71-9204

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26 October 2005
E&L-098-05

Meraj Rahimi
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards, NMSS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Rahimi:

Subject: Amendment Request for the CNS 10-160B Certificate No. 9204

Duratek respectfully submits the enclosed amendment request for the CNS 10-160B cask SAR and C of C. We request that you approve our proposed Revision 20 to the SAR and revise the Certificate to reflect the following changes:

1. Revision of Appendix 4.10.2
   Duratek is revising Appendix 4.10.2 of the SAR, in several places, to specify that the shipping period is that given in the previously approved Attachment C rather than specify a 60-day period. Attachment C allows use of a shipping period of either 60 days or an NRC approved site-specific period. A second change allows demonstrating compliance with the 5% hydrogen limit using a payload-specific mixing analysis.

2. Revision of Appendix 4.10.2.1
   Duratek is revising Appendix 4.10.2.1 to include a site specific controlled shipping period and use that shipping period in the calculation of decay heat limits. Also, the contents of one shipment, i.e., shipment #12, are analyzed to show that this shipment meets the 5% hydrogen limit.

The changes have been noted with margin bars identifying the location of changes and deleted language is shown with "strikeout".

The US Department of Energy is completing the Battelle Columbus Laboratories Decommissioning Project (BCLDP) for decontaminating and decommissioning the Battelle site in West Jefferson, Ohio. Cleanup and demolition activities at the site have generated remote handled (RH-TRU) waste that must be transferred to another facility. The RH-TRU must be transferred by December 2005 so that final decontamination can proceed according to the site closure schedule. As noted in the attached letter sent on behalf of DOE (Attachment 3), DOE is requesting that this submittal be acted on as soon as possible. Due to the urgency of DOE's need to use the CNS 10-160B for the BCLDP waste, we request the highest possible priority for review of this submittal.

There are three attachments to this letter, including the SAR revision pages themselves. Each attachment is listed below:

Attachment 1	Revised Appendix 4.10.2; please replace the current Appendix 4.10.2 with the pages in this attachment.
Attachment 2	Revised Appendix 4.10.2.1; please replace the current Appendix 4.10.2.1 with the pages in this attachment.
Attachment 3	DOE letter on priority for review

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 Licensing

Attachments: As stated

NMSS01

ATTACHMENT 1

Appendix 4.10.2

TRU Waste Payload Control

1.0 INTRODUCTION

The purpose of this appendix is to identify the requirements for the control of remote handled transuranic (RH-TRU) and contact-handled transuranic (CH-TRU) waste, as defined by the U.S. Department of Energy (DOE) (Reference 12.1), as payload for transport in the CNS 10-160B cask.

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

- Restrictions on the physical and chemical form of CH-TRU and 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~~ the transport period. (As a conservative analysis, the maximum pressure calculations are performed for a period of one year. Attachment C discusses the transport period.)
- Restrictions on the amount of potentially flammable gases that might be present or generated in the payload during ~~a 60-day~~ the transport period.
- Restrictions on the layers of confinement for RH-TRU and CH-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 loaded cask.

The methods for determining or measuring each restricted parameter, the factors influencing the parameter values, and the methods used by each shipping site for demonstrating compliance, are provided in the site-specific sub tier appendices.

This appendix also includes the following as attachments:

- Description of the use of dose-dependent G values for TRU wastes (Attachment A)
- Chemical compatibility analysis for the TRU waste content codes (Attachment B).
- Shipping period for TRU waste in the CNS 10-160B cask (Attachment C)

2.0 PURPOSE

2.1 Payload Parameters

The purpose of this appendix is to describe the payload requirements for RH-TRU and CH-TRU waste for transport in the CNS 10-160B cask. Detailed descriptions of the site compliance methods associated with these requirements shall be provided in the site-specific sub tier appendices. Any and all assumptions used in the site compliance methods will be specified in the site-specific sub tier appendices.

Sub tier appendices will be added, as necessary, to incorporate additional site-specific waste content codes that may be identified in the future. These appendices shall be submitted to the U.S. Nuclear Regulatory Commission (NRC) for review and approval, with shipments under additional codes authorized only after NRC approval.

Section 2.2 describes some typical methods of compliance available to show compliance with the individual payload parameter requirements. Section 3.0 describes the relationship between payload parameters and the classification of RH-TRU and CH-TRU materials into CNS 10-160B cask payload content codes. Sections 4.0 through 11.0 discuss each payload parameter requirements for the CNS 10-160B cask.

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.

2.2 Methods of Compliance

This section describes some typical methods that may be used to determine compliance with each payload parameter requirement and the controls imposed on the use of each method. Each shipping site shall select and implement a single compliance method, or a combination of methods, to ensure that the payload is compliant with each requirement and is qualified for shipment. These methods shall be documented in the site-specific sub tier appendices associated with this appendix.

A summary of typical methods of compliance that may be used for the 10-160B cask payload control is provided in the following sections.

2.2.1 Visual Examination

Visual examination at the time of waste generation may be used to qualify waste for transport. The operator(s) of a waste generating area shall visually examine the physical form of the waste according to site/equipment-specific procedures and remove all prohibited waste forms prior to its placement in the payload container. Observation of the waste generation process by an independent operator may be used as an independent verification of the compliance of the waste prior to closure of the payload container.

2.2.2 Visual Inspection

Visual inspection may be used to evaluate compliance with specific restrictions (e.g., visual inspection of payload container type, number of filters, etc.).

2.2.3 Radiography

Radiography may be used as an independent verification to qualify waste for transport. Radiography may be used to nondestructively examine the physical form of the waste, and to verify the absence of prohibited waste forms, after the payload container is closed.

2.2.4 Process Knowledge (Records and Database Information)

Process knowledge (PK) (also referred to as acceptable knowledge for the purposes of this document) refers to applying knowledge of the waste in light of the materials or processes used to generate the waste. PK is detailed information on the waste obtained from existing published or documented waste analysis data or studies conducted on wastes generated by processes similar to that which generated the waste. PK may include information on the physical, chemical, and radiological properties of the materials associated with the waste generation process(es), the fate of those materials during and subsequent to the process, and associated administrative controls. PK commonly includes detailed information on the waste obtained from existing waste analysis data, review of waste generating process(es), or detailed information relative to the properties of the waste that are known due to site-specific or process-specific factors (e.g., material accountability and tracking systems or waste management databases may supply information on waste isotopic composition or quantity of radionuclides, among other waste attributes). PK sources may include information collected by one or more of the compliance methods described in Sections 2.2.1 through 2.2.7.

Information obtained from existing site records and/or databases or knowledge of process may be used as a basis for reporting the absence of prohibited waste forms within waste containers. PK may also be used to show compliance with the physical and chemical form requirements and the payload container and contents requirements.

2.2.5 Administrative and Procurement Controls

Site-specific administrative and procurement controls may be used to show that the payload container contents are monitored and controlled, and to demonstrate the absence of prohibited items within waste containers.

2.2.6 Sampling Programs

Sampling programs may be used as an independent verification of compliance.

2.2.7 Measurement

Direct measurement or evaluation based on analysis using the direct measurement may be used to qualify waste (e.g., direct measurement of the weight or analysis of assay data to determine decay heat).

3.0 TRU WASTE PAYLOAD FOR CNS 10-160B CASK

RH-TRU and CH-TRU waste is classified into content codes, which give a description of the RH-TRU and CH-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 and CH-TRU waste to be shipped from each site are provided in the site-specific sub tier appendices to this appendix. Each content code provides a listing of all the payload parameters, their corresponding limits and restrictions, and the methods used by the site to meet these limits.

4.0 PHYSICAL FORM REQUIREMENTS

The physical form of waste comprising the CNS 10-160B cask payload is restricted to solid or solidified materials in secondary containers. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. A secondary container is any container placed inside the primary

container, the CNS 10-160B cask. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers greater than four liters in volume that do not have a known, measured, or calculated hydrogen release rate or resistance are prohibited.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

The chemical constituents allowed in a given content code determine the chemical properties of the waste. 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).

6.0 CHEMICAL COMPATIBILITY

Each content code has an associated chemical list based on PK information. Chemical constituents in a payload container assigned to a given content code shall conform to these chemical lists (included in each site-specific sub tier appendix). Chemicals or materials that are not listed are allowed in trace amounts (quantities less than one weight percent) in a payload container provided that the total quantity of trace chemicals or materials is restricted to less than five weight percent.

Chemical compatibility of the waste within itself and with the packaging shall ensure that chemical processes would not occur that might pose a threat to safe transport of the payload in the 10-160B Cask. The basis for evaluating the chemical compatibility shall be the U.S. Environmental Protection Agency (EPA) document, "A Method for Determining the Compatibility of Hazardous Wastes" (Reference 12.2). This method provides a systematic means of analyzing the chemical compatibility of specific combinations of chemical compounds and materials. Any incompatibilities between the payload and the packaging shall be evaluated separately if not covered by the EPA method.

As described in Attachment B to this appendix, the EPA method classifies individual chemical compounds, identified in the list of allowable chemicals and materials, into chemical groups and identifies the potential adverse reactions resulting from incompatible combinations of the groups. Attachment B presents the methodology and results for the chemical compatibility analyses performed on the list of allowable chemicals and materials associated with the TRU waste content codes expected to be shipped in the 10-160B Cask.

Chemicals and materials included on the content code chemical lists (in concentrations greater than one weight percent) shall be a subset of the list of allowable materials identified in Table B-1 of Attachment B to this appendix to demonstrate compliance with the compatibility requirement. The results of the compatibility analyses show that these content codes can be transported without any incompatibilities.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

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~~ the shipping period (see Attachment C).

- 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).

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.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

Thirty-gallon and 55-gallon secondary containers may be used as payload containers in the CNS 10-160B. The available volume of the cask cavity limits the number of payload containers that may be shipped at one time. In the case of 55-gallon drums, a maximum number of ten drums can be loaded into the 10-160B cask. Payload containers must have at least one filter vent. 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. Typically, for purposes of radiological safety, TRU waste in the payload container may be packaged in one or more layers of confinement (plastic bags). Bags are closed with a twist and tape, fold and tape or heat-sealed closure. Heat-sealed bags may have a filter vent or be unvented.

Any drum or rigid polymer liner present inside a payload container shall have a filter vent or an opening that is equivalent to or larger than a 0.3-inch diameter hole before the container is transported in the CNS 10-160B.

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 71.15 (10 CFR 71.15) are not exceeded. Plutonium content must not exceed 0.74 TBq (20 curies) per cask.

Compliance with the isotopic characterization and fissile content requirements involves the following steps:

- Determination of isotopic composition
- Determination of the quantity of radionuclides
- Calculation of the fissile mass and comparison with 10 CFR 71.15 limits
- Calculation of plutonium content and comparison with 20 curie limit.

9.1.1 Isotopic Composition

The isotopic composition of the waste may be determined from direct measurements taken on the product material during the processing or post-process certification at each site, analysis of the waste, or from existing records and PK. The isotopic composition of the waste need not be determined by direct analysis or measurement of the waste unless PK is not available.

9.1.2 Quantity of Radionuclides

The quantity of the radionuclides in each payload container shall be estimated by either PK or direct measurement of the individual payload container, a summation of assay results from individual packages in a payload container, or a direct measurement on a representative sample of a waste stream (such as solidified inorganics). An assay refers to one of several radiation measurement techniques that determine the quantity of nuclear material in TRU wastes. Assay instruments detect and quantify the primary radiation (alpha, gamma, neutron) emanating from specific radionuclides, or a secondary radiation emitted from neutron interrogation techniques. The measured quantity of radiation is then used to calculate the quantity of other radionuclides. That calculation requires knowledge of the isotopic composition of the waste. Combinations of gamma spectroscopy and neutron measurements are often needed to calculate the quantity of nonfissile radionuclides.

9.1.3 Calculation of Fissile Mass

The calculation of the fissile mass shall be performed to meet the requirements of 10 CFR 71.15.

9.1.4 Calculation of Plutonium Curies

The total plutonium (all plutonium isotopes) activity (curies) for each payload container shall be determined as described above and summed for the entire payload to demonstrate compliance with the 20 curie limit.

10.0 DECAY HEAT AND HYDROGEN GAS GENERATION RATES

10.1 Requirements

The hydrogen gas concentration shall not exceed five percent by volume in all void volumes within the CNS 10-160B cask payload during ~~a 60-day~~ the shipping period (see Attachment C). ~~–~~Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided 1) the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit, or 2) through a demonstration using a payload-specific mixing analysis/calculation, the individual payload containers within a payload can be shown to have decay heats and/or hydrogen gas generation rates below payload-specific limits determined to assure the 5% flammable gas concentration limit is met.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

As stated in Section 7, chemical, biological, and thermal gas generation mechanisms are expected to be insignificant in the CNS 10-160B cask. In addition, potentially flammable VOCs are restricted to 500 ppm in the headspace of the CNS 10-160B cask secondary containers (Section 5). 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~~ the shipping period (see Attachment C).

Each content code shall have 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. 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. The maximum allowable hydrogen generation rates and decay heat limits for each site-specific content code shall be determined and reported in the site-specific payload compliance appendix (sub tier to this appendix). The modeling methodology for determining the hydrogen gas generation rate limit and the decay heat limit shall be presented in each site-specific payload compliance appendix. Conservative assumptions may be used in site-specific subtier appendices to introduce an additional margin of safety.

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 cask IV available for gas accumulation.
- Operating temperature and pressure for the payload in the 10-160B cask IV during the shipping period.
- Duration of the shipping period (see Attachment C).
- 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) (see Attachment A for description of dose-dependent G values and the Matrix Depletion Program).

10.3 Determination of Maximum Allowable Hydrogen Generation Rate

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:
Packaging configurations are content code specific and will be documented in the sub-tier appendices. The bags, any rigid container with an opening or filter vent, and the drum filter vent all provide some resistance to the release of hydrogen from the container.

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 60-day~~ the 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 system temperature increases and decreases as the result of diurnal and seasonal variations in the environment (i.e, weather, solar radiation). Heat released from the radioactive components in the waste can also contribute to thermal input in the system.

The input parameters that can be described as a function of temperature are the release rate across the different confinement layers in the payload containers and the hydrogen G values for the waste streams. The resistance to the release of hydrogen is a function of temperature as documented in Appendix 6.9 of the CH-TRU Payload Appendices (Reference 12.3). The resistance generally decreases with increasing temperature and increases with decreasing temperature. The release rates across each confinement layer shall be defined at a specified temperature. The specified temperature shall be defined in terms of the expected operating temperature range. Since the release rates decrease with decreasing temperature, the use of the minimum expected operating temperature to calculate the lowest release rate will provide the maximum margin of safety when calculating the hydrogen gas generation rate or decay heat limit. Theoretically, the G value for a waste stream increases with increasing temperature (Reference 12.3). The G values at room temperature (i.e., 70°F) will be adjusted to the maximum expected operating temperature using the Arrhenius equation, unless it is demonstrated that the G values for the waste streams are not a function of temperature. The G values adjusted to reflect the maximum expected operating temperature would provide the maximum margin of safety in the calculated hydrogen gas generation rate or decay heat limits.

These are the important input parameters for determining the maximum allowable hydrogen generation rate limit. 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

At steady state, the flow rate of hydrogen across each of the confinement layers is equal to the same value and to the hydrogen generation rate. The maximum hydrogen concentration in a payload container with filter vents is reached at steady state. That is, a filter vented container with a hydrogen generation source has increasing concentrations of hydrogen with time until steady state conditions are reached. For the purpose of these calculations, it has been assumed that all payload containers are at steady state at the start of transport.

Once the drums are sealed inside the CNS 10-160B cask IV, concentrations of hydrogen in the different layers increase due to the accumulation of hydrogen in the IV cavity. Some of the hydrogen generated during the transport period would accumulate in the payload containers, with the remainder being released into the cavity. For the purpose of these calculations, the mole fraction of hydrogen in a bag layer is set equal to the steady state value plus the mole fraction of hydrogen that has accumulated in the cavity. The IV cavity mole fraction of hydrogen is obtained by assuming that all of the hydrogen generated is released into the IV cavity. The maximum hydrogen concentration in the innermost layer is then limited to less than or equal to five (5) volume percent at the end of the shipping period by suitably choosing the gas generation rates. The maximum number of moles of hydrogen which can accumulate in the IV cavity is:

$$N_{gen} = (CG)(n_{gen})(t)$$

Where:

N_{gen} = total moles of hydrogen generated
CG = hydrogen gas generation rate per innermost layer of confinement (moles/sec)

n_{gen} = number of hydrogen generators (payload containers) in the CNS 10-160B cask
t = shipping period duration, s

The maximum mole fraction of hydrogen in the CNS 10-160B IV cavity is then equal to:

$X_{fh} = (N_{gen}/N_{tg}) = \{N_{gen}/[P(V_{void})/RT]\}$

Where:

X_{fh} = maximum mole fraction of hydrogen in the CNS 10-160B IV cavity
N_{tg} = total moles of gas inside the CNS 10-160B IV cavity
P = pressure inside the CNS 10-160B, assumed to be constant at 1 atm (760 mm Hg), because the amount of gas generated is much less than the total amount of air originally in the cavity
V_{void} = void volume inside the CNS 10-160B IV cavity (liters)
R = gas constant = 62.361 mm Hg-liter/mole-K
T = absolute temperature of air in the CNS 10-160B IV cavity at the time of closure = 70°F = 294K

The gas generation rate per innermost confinement layer that will yield a maximum hydrogen concentration of five (5) volume percent is then computed as the following:

$X_{inner} = X_{fh} + (CG)(R_{eff})$

Where:

X_{inner} = mole fraction of hydrogen in innermost confinement layer (a value of 0.05 has been used for this parameter since this is the maximum permissible concentration)
R_{eff} = the effective resistance to the release of hydrogen (sec/mole)

The effective resistance is computed by summing the individual confinement layer resistances. The resistance of a layer is equal to the reciprocal of the release rate from that layer. After substituting the first two equations into the third for X_{inner} and solving for the gas generation rate the following results:

$CG = (X_{inner})/\{R_{eff} + [(t)(n_{gen})/N_{tg}]\}$

where all terms are as defined previously.

10.4 Determination of Maximum Allowable Decay Limits for Content Codes

The maximum allowable decay heat limit for the CH-TRU waste content codes will be calculated assuming 100% deposition of the emitted energy into the waste within the drum. Specifically, the decay heat limit is calculated from the hydrogen gas generation rate and effective G-Value through the following expression:

$Q = [(CG)(N_A)/(G_{eff}\ \text{molecules/100eV})][1.602 \times 10^{-19}\ \text{watt-sec/eV}]$

Where:

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

Q	=	decay heat per innermost confinement layer (watts)
N_A	=	Avogadro's number = 6.023×10^{23} molecules/mole
G_{eff}	=	G (hydrogen gas) = effective G value for flammable gas (molecules of hydrogen formed/100 electron volts [eV] emitted energy).

The maximum allowable decay heat limits for the RH-TRU waste content codes will be determined using the RadCalc Software (Reference 12.4). The current version of RadCalc 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 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 (Reference 12.5). 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 (Reference 12.6) 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 that 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:

$$D_{total}(t) = \sum_{i=1}^{NR} \Gamma A C_i / \&_i \, (0.82E_i^{\forall} + E_i^{\exists} + E_i^{\ni} + E_i^{x})[1 - \exp(-\&_i t)]$$

where,

$D_{total}(t)$	=	Total cumulative absorbed dose at time, t (rad)
A	=	A proportionality constant equal to 1.84×10^{10} rad gram MeV^{-1} yr^{-1} Ci^{-1}
C_i	=	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
$E_i^{\forall}$	=	$\forall$ energy in MeV of the "i"th radionuclide extracted from Flaherty et al. (Reference 12.11)
$E_i^{\exists}$	=	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. (Reference 12.7).
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. (Reference 12.7).
Eiϋ	=	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:

$$E_i^{\ni} = \Gamma_j \, n_{ij} \, f_{ij} \, E_{ij}^{\ni}$$

where,

Γj	=	the summation of the fractions of the gamma ray energies absorbed for all gamma emissions of the "i"th nuclide.
n_{ij}	=	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.
$E_{ij}^{\ni}$	=	the energy in MeV, of the "j"th gamma ray of the "i"th nuclide.

RadCalc uses curve fits obtained from Flaherty et al. (Reference 12.7) and recalculated using the Monte Carlo N-Particle (MCNP) transport code (Reference 12.8) for ten containers, for obtaining the absorbed gamma dose.

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

10.4.1.3 G Value Data

G values for TRU waste are content specific. G values are determined based on the bounding materials present in the payload. The G values at room temperature (i.e., 70°F) will be adjusted to the maximum

expected operating temperature using the Arrhenius equation (unless data shows that the G values are temperature independent) in order to introduce a greater margin of safety in the calculated hydrogen gas generation rate or decay heat limits. The use of temperature-dependent and or dose-dependent G values for authorized content codes is discussed in the individual site-specific sub tier appendices. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of this Appendix.

10.4.2 Input Parameters

The input parameters for the RadCalc software can be placed in three groups: (1) container data, (2) waste data, and (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.

10.4.2.2 Waste 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, cm^3
Waste Mass – mass of the waste, g
G Value – G value of the waste, molecules per 100 eV

Liquids and gas wastes are prohibited in the CNS 10-160B cask. The volume of the waste is determined based on the maximum number of 55-gallon drums that can be placed in the 10-160B cask. The waste volume in one drum is assumed to be 217 liters per drum (the external volume of a 55-gallon waste drum) and 2170 liters for 10 drums of waste in the cask. The waste volume is used by RadCalc, along with the waste mass, to determine the volume of hydrogen generated in the cask. The mass of the waste is calculated based on the assumed bulk density of the waste. The volume of hydrogen generated is a function of container waste density and geometry (Reference 12.7). The most conservative estimate of the volume of hydrogen (greatest volume) would occur at the highest possible bulk density of the waste. Appropriate density values for the RH-TRU content codes are discussed in the individual site-specific sub-tier appendices.

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 (Attachment C). 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 that will result in the maximum 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.

10.5 Methodology for Compliance with Payload Assembly Requirements

Prior to shipping, the Transportation Certification Official at the shipping site (TCO) shall ensure that the CNS 10-160B Cask payload consists of payload containers belonging to the same or equivalent content code. In the event that payload containers of different content codes with different bounding G values and resistances are assembled together in the CNS 10-160B Cask, the TCO shall ensure that the decay heat and hydrogen gas generation rate for all payload containers within the payload are less than or equal to the limits associated with the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

11.0 WEIGHT

The weight limit for the contents of the loaded cask is 14,500 pounds.

12.0 REFERENCES

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Attachment A

Use of Dose-Dependent G Values for TRU Wastes

A.1.0 BACKGROUND

This attachment describes controlled studies and experiments that quantify the reduction in the rate of hydrogen gas generation (G value) over time based on the total dose received by the target matrix. Over time and with constant exposure to radiation, hydrogen is removed from the hydrogenous waste or packaging material (the matrix), thus decreasing the number of hydrogen bonds available for further radiolytic breakdown (the matrix is depleted). Therefore, when the alpha-generating source is dispersed in the target matrix, it will affect only that portion of the target material that is present in a small spherical volume surrounding the source particle. As the amount of available hydrogen is reduced over time, the effective G value decreases with increasing dose toward a value that is defined as the "dose-dependent G value." This phenomenon of matrix depletion has been studied and observed in previous studies (see Appendix 3.3 of the CH-TRU Payload Appendices [Reference A.7.1]). A formal study was recently undertaken to quantify dose-dependent G values under strictly controlled conditions and evaluate their applicability to transuranic (TRU) wastes (Reference A.7.2). This appendix summarizes the results of this study and derives dose-dependent G values for TRU waste materials, as applicable.

A.2.0 OVERVIEW OF THE MATRIX DEPLETION PROGRAM

The Matrix Depletion Program (MDP), established as a joint venture by the U.S. Department of Energy (DOE) National TRU Waste Program and the DOE Mixed Waste Focus Area, is comprised of the following elements:

1. Laboratory experiments for the assessment of effective G values as a function of dose for matrices expected in contact-handled (CH)-TRU wastes (polyethylene, polyvinyl chloride, cellulose, etc.), as well as an assessment of the impact of other variables (isotope, temperature, etc.) on the dose-dependent G values.

2. Measurements of effective G values and hydrogen concentrations in real waste and comparisons with dose-dependent G values.

3. Analysis to calculate effective G values from fundamental nuclear and molecular mechanisms.

A total of 60 one-liter test cylinders containing the simulated TRU waste materials were used, with two replicates for each test. Solid waste matrices (plastics and cellulose) were prepared by sprinkling the radioactive isotope powders over the matrix, folding the matrix over the contaminated surfaces, securing them, and placing them in test cylinders. Solidified waste matrices (cement) were mixed with a solution of dissolved plutonium oxide, water, and sodium hydroxide to adjust the pH. The test cylinders were connected to measurement devices that facilitated sampling of generated gases and quantifying the gas generation over time. The entire test apparatus was controlled by a personal computer through LABVIEW software.

All activities of the MDP were performed under a documented quality assurance (QA) program that specified the performance-based QA/quality control requirements for all aspects of the program (Reference A.7.3). The experiments under the MDP were designed using an U.S. Environmental Protection Agency established procedure to formulate data quality objectives. QA objectives for the MDP were defined in terms of precision, accuracy, representativeness, completeness, and comparability. All data were validated and verified pursuant to the performance objectives of the program. The MDP was run for a duration of approximately three years.

A.3.0 RESULTS AND CONCLUSIONS FROM THE MDP

Results from the MDP are described in detail in the MDP final report (Reference A.7.2) and are summarized in Table A-1 in terms of the dose-dependent G values for each matrix tested.

For all matrices, these dose-dependent G values were achieved within a maximum dose of 0.006 watt*year (product of watts times years). For example, for a waste container with a watt loading of 0.1 watt, the dose-dependent G value shown in Table A-1 would be reached after 0.06 years or 22 days. The lower the watt loading, the longer it would take for the watt*year criteria to be satisfied and the dose-dependent G value to be applicable.

Table A-1. Experimental Dose-Dependent G Values

Matrix	Current Waste Material Type G Value	Number of Observations	Mean	Standard Deviation	95% Upper Tolerance Limit
Cement	1.3	202	0.25	0.18	0.58
Dry Cellulose	3.4	302	0.27	0.18	0.59
Polyethylene	3.4	186	0.23	0.22	0.64
Polyvinyl Chloride	3.4	99	0.14	0.19	0.50
Wet Cellulose	3.4	276	0.44	0.36	1.09

Source: Reference A.7.1.

The following conclusions can be drawn from the results of the MDP:

- Increasing dose (product of the decay heat loading and elapsed time) decreases the effective G value for hydrogen due to depletion of the matrix in the vicinity of the alpha-emitting radioactive source particle. The lower G value, called the "dose-dependent G value," is applicable after a dose of 0.006 watt*years.
- As with initial G values, the dose-dependent G values are a function of the waste matrix.
- Dose-dependent G values for wet cellulosics were higher than those for dry cellulosics because of the presence of water.
- The dose-dependent G values were independent of temperature based on testing performed at room temperature and at 140°F.
- Experiments performed with different particle sizes show that while initial G values could be higher for smaller particle sizes, the dose-dependent G values for all particle sizes tested are bounded by the values shown in Table A-1.
- Previous experiments that included agitation of cylinders similar to those used in the MDP indicated that agitation did not affect dose-dependent G values (See Section A.4.0).
- Isotopic composition did not have a significant impact on the dose-dependent G values based on experiments performed with two different isotopes of Pu (^{238}Pu and ^{239}Pu).

Data from actual CH-TRU waste containers at the Rocky Flats Environmental Technology Site and the Idaho National Engineering and Environmental Laboratory show that even when compared to the mean dose-dependent G values from the matrix depletion experiments, G values from real waste containers are lower. Theoretical analysis, using nuclear and molecular level mechanisms, also shows that hydrogen generation from radiolysis and matrix depletion is consistent with the experimental results from the MDP.

A.4.0 EFFECTS OF AGITATION ON DOSE-DEPENDENT G VALUES

The effects of agitation on dose-dependent G values have been evaluated by previous studies at both the laboratory-scale and drum-scale levels, and agitation has been found to have no impact on dose-dependent gas generation rates. Agitation could occur under transportation conditions but, as shown below, does not cause redistribution of the radionuclides to a nondepleted portion of the waste matrix and therefore does not cause an increase in the dose-dependent G values as shown in this section.

The earliest study of the effects of agitation on gas generation rates was performed by Zerwekh at the Los Alamos National Laboratory (LANL) in the late 1970s (Reference A.7.4). Zerwekh prepared an experimental array of 300-cm^3 stainless steel pressure cylinders, each loaded with 52.5 grams of a single or a combination of TRU waste matrix materials. Materials tested included cellulosics, polyethylene (PE) (low-density) bags, PE (high-density) drum liner material, and other typical TRU waste material. Net gas G values as a function of elapsed time were derived for each of the test cylinders and showed the characteristic decrease in G value with dose. Thorough mechanical shaking of two of the cylinders on two different occasions did not affect the rate of gas generation (Reference A.7.4).

In a second study, researchers at LANL retrieved six drums of ^{238}Pu contaminated waste from storage to study gas generation (Reference A.7.5). The wastes were contained in 30-gallon drums and consisted of either mixed cellulosic wastes or mixed combustible wastes. The drums ranged in age from four to ten years. Two of the drums containing mixed combustible wastes were tumbled end over end in a drum tumbler for four hours (Reference A.7.5). The researchers also reported G values for three drums of newly generated waste that were previously characterized. All six retrieved drums had measured G values that were lower than those measured for newly generated drums. The researchers concluded that the retrieved drums' effective hydrogen G values corroborate the matrix depletion observed for the laboratory-scale experiments in Reference A.7.4. Also, because of the vigorous nature of the agitation experienced by two of the four-year-old drums, the researchers concluded that radionuclide redistribution does not occur under transportation conditions (Reference A.7.5).

More recently, experiments on alpha radiolysis were conducted at LANL by Smith et al. (Reference A.7.6) to determine radionuclide loading limits for safe on-site storage of containers at LANL. Simulated TRU waste matrices in the form of cellulose (cheesecloth and computer paper) and PE (bottle and bag material forms) were contaminated with pre-weighed amounts of $^{238}PuO_2$ powder. The first PE experiment (referred to as PE test cylinder 1) used a PE bottle to allow any potential later redistribution of the radionuclide particles to fresh matrix surfaces. The radionuclide powder was poured into the bottle, which was sealed and gently rolled to allow contamination of the sides of the bottle. The bottle was returned to an upright position and the lid was punctured with an approximately 0.5-inch diameter hole to allow free movement of generated gas from the bottle to the test canister. It was noted that the $^{238}PuO_2$ powder adhered to the walls of the bottle and very little, if any, collected at the bottom. The remaining five test sample matrices were prepared by uniformly sprinkling the powder across a letter-sized sheet of the waste matrix, folding the sheet in toward the center from each end, and finally rolling each sheet into a cylindrical shape of about 2 by 4 inches. The six test matrices were placed inside six cylindrical, 2.06 liter stainless steel sealed canisters. Gas samples were extracted periodically and analyzed by mass spectrometry.

The first test canister for each waste material was subjected to vigorous dropping, rolling several times, and shaking on day 188 to simulate drum handling and transportation that could result in redistribution of the $^{238}PuO_2$ to fresh nondepleted portions of the waste matrix. Any agitation effects were expected to be most pronounced for the test canister containing the PE bottle in PE test cylinder 1, because some aggregation of the powder at the bottom of the bottle was expected. However, no change in the effective hydrogen G value was observed for either the cellulose or PE test canisters.

In summary, three separate studies have investigated the ability of agitation to redistribute radionuclide particles to nondepleted surfaces of TRU waste matrices. All three studies conclusively showed that the dose-dependent G values are not impacted by agitation during transportation. Application of dose-dependent effective G values is discussed in Section A.5.0.

A.5.0 APPLICATION OF DOSE-DEPENDENT G VALUES TO CH- and RH-TRU WASTES

Application to CH-TRU dose-dependent G values, based on the results of the MDP, are applicable to solid organic and solid inorganic CH-TRU waste material types. Solidified organic and inorganic solid wastes will be governed by the initial G values under all conditions because the solidified, aqueous nature of these waste forms, in theory, precludes observation of matrix depletion (as the matrix near the Pu is depleted, water can move to replace the depleted matrix). The watt*year criteria used to apply dose-dependent G values is twice the highest value recorded in the experiments. The dose-dependent G values chosen for the TRU waste materials are the 95% upper tolerance limit values shown in Table A-1. The application of dose-dependent G values to the waste types is as follows:

- Solid Inorganic Waste: Dose-dependent G value (H_2) for containers meeting a watt*year criteria of 0.012 is governed by assuming polyethylene as the packaging material, with a G value (H_2) of 0.64.

- Solid Organic Waste: Dose-dependent G value for containers meeting a watt*year criteria of 0.012 is governed by wet cellulosic materials in the waste, with a G value (H_2) of 1.09.

As can be seen from Table A-1, the above dose-dependent G values represent conservative values that are more than two times the mean value from the experiments.

The phenomenon of matrix depletion primarily stems from the nature of the waste matrix and the type of penetrating radiation; thus, if the waste matrix and radiation type are properly accounted for, G value results obtained for CH-TRU waste can be applicable to RH-TRU waste as well.

With respect to waste matrix, both CH- and RH-TRU waste are characterized by a large percentage of the materials shown in Table A-1. Thus, the required level of conservatism will be attained by assuming that the waste is comprised of the matrix with the greatest associated G value.

With respect to radiation type, both CH- and RH-TRU waste are characterized by large amounts of alpha and beta emitters; the primary difference between the two waste forms is the noticeable presence of gamma emitters in RH-TRU waste. Thus, while the G value for CH-TRU waste is dependent primarily on the emitted decay heat (since most or all of the alpha and beta radiation is absorbed by the waste matrix and contributes to hydrogen gas generation), the G value for RH-TRU waste is dependent on the actual fraction of the decay heat that is absorbed by the waste matrix.

Since the results of the MDP are applicable only to alpha and beta radiation, while gamma radiation effects were not quantified, G values for RH-TRU waste can be separated into those for alpha, beta, and gamma radiation and treated accordingly. Thus, RH-TRU waste G values for alpha and beta radiation can be treated as being dose-dependent and the lower "dose-dependent G value" used after a dose of

0.012 watt*years (twice the highest value recorded in the experiments), while G values for gamma radiation can conservatively be treated as not being dose-dependent and the initial G value used.

A.6.0 COMPLIANCE WITH WATT*YEAR CRITERIA

For RH-TRU waste, content codes using dose-dependent G values to obtain maximum allowable decay heat limits are required to comply with the watt*year criteria of 0.012 watt*years. Demonstration of compliance with the 0.012 watt*year criteria is carried out as follows:

1. Determine maximum allowable decay heat (Q) using the a and ß dose-dependent G values and non-dose-dependent G values for ? radiation.

2. Determine decay heat limit that excludes the gamma radiation contribution (Q_{allow}) as a function of the maximum allowable hydrogen gas generation rate (Cg) and bounding G value for the content code as:

$$Q_{allow} = \frac{Cg * N_A * 1.602(10)^{-19} \ watt\text{-}sec/eV}{G}$$

where,

Cg = Maximum allowable hydrogen gas generation rate limit obtained using the methodology described in site-specific sub tier appendices.

G = Bounding G value (molecules of hydrogen formed/100 electron volts [eV] emitted energy)

N_A = Avogadro's number (6.023×10^{23} molecules/mole).

3. Determine the Q_{allow}/Q ratio, which represents the minimum fraction of the total container decay heat that excludes the gamma radiation contribution.

4. Calculate the decay heat value for a container ($Q_{watt*yr}$) for watt*year compliance as:

$$Q_{watt*yr} = \frac{Q_{allow}}{Q} * Q_{actual}$$

where, Q_{actual}, is the actual decay heat value for the container.

5. The watt*year for the payload is calculated as $Q_{watt*yr}$ times the elapsed time, and this valueis compared to the 0.012 watt*year limit. The elapsed time is the time elapsed between the time of generation of the payload and the time of sealing of the payload.

A.7.0 REFERENCES

A.7.1. U.S. Department of Energy (DOE), "Safety Analysis Report for the TRUPACT-II Shipping Package," and associated Contact Handled Transuranic Waste Authorized Methods for Payload Control (CH-TRAMPAC) and CH-TRU Payload Appendices, Current Revisions, U.S. Department of Energy Carlsbad Field Office, Carlsbad, New Mexico.

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Attachment B

Chemical Compatibility of TRU Waste Content Codes

B.1.0 INTRODUCTION

This attachment describes the method used for demonstrating chemical compatibility in a given payload container, within a given waste stream/content code, and among content codes for the CNS-10-160B Cask payload. The chemical compatibility analyses cover normal conditions of transport as well as hypothetical accident conditions.

B.2.0 METHODOLOGY FOR CHEMICAL COMPATIBILITY ANALYSES

The chemical compatibility analysis was performed using the methods described in the EPA document "A Method for Determining the Compatibility of Hazardous Wastes" (Reference B.3.1).

Waste streams/content codes are classified as potentially chemically "incompatible" if the potential exists for any of the following reactions:

- explosion
- heat generation
- gas generation (flammable gases)
- pressure build up (nonflammable gases)
- toxic by-product generation
- fire
- violent polymerization
- solubilization of toxic substances.

Note: Solubilization of toxic substances and toxic byproduct generation are not directly a concern for transportation of waste in the CNS 10-160B Cask payload but have been included for completeness.

Each generator and storage site has produced a comprehensive list of chemicals present in an approved content code. These chemical components are determined by examining the process technology, and by comprehensive analyses of the process knowledge. Under this system, all chemical inputs into the system are accounted for, even though all of these components may not be a final part of the waste. For example, generator sites might include both acids and bases in their lists, even though the two groups have been neutralized prior to placement in a payload container.

A list of chemicals/materials that may be present in TRU waste in concentrations greater than or equal to 1 percent by weight was compiled based on process knowledge from the potential waste shipping sites, as shown in Table B-1. The chemical compatibility analyses for the CNS 10-160B Cask payload are then based on this table.

Although Table B-1 only identifies chemicals/materials in TRU waste in concentrations greater than or equal to 1 percent by weight, interactions involving compounds present in trace quantities (<1 percent by weight) do not pose an incompatibility problem for the following reasons:

- Most trace chemicals reported by the sites are in concentrations well below the trace limit of 1 weight percent.

- The trace chemicals are usually dispersed in the waste, which further dilutes concentrations of these materials.

- Total trace chemicals within a payload container are limited to less than 5 weight percent.

Table B-1
Table of Allowable Materials for TRU Waste[a]

Absorbent polymers, organic
Absorbents/adsorbents (e.g., Celite®, diatomaceous earth, diatomite, Florco®, Oil-Dri®, perlite, vermiculite)
Acids (inorganic and organic)
Alcohols (e.g., butanol, ethanol, isopropanol, methanol)
Alumina cement
Aquaset® products (for aqueous solutions)
Aqueous sludges or solutions
Asbestos
Ash (e.g., ash bottoms, fly ash, soot)
Asphalt
Bakelite® b
Batteries, dry (e.g., flashlight)
Caustics
Cellulose (e.g., Benelex®, cotton Conwed®, paper, rags, rayon, wood)
Cellulose acetate butyrate
Cellulose propionate
Ceramics (e.g., molds and crucibles)
Chlorinated polyether
Clays (e.g., bentonite)
Concrete
Detergent, solid (e.g., emulsifiers, surfactants)
Envirostone® (no organic emulsifiers allowed)
Esters (e.g., ethyl acetate, polyethylene glycol ester)
Ethers (e.g., ethyl ether)
Fiberglass (inorganic and organic)
Filter media (inorganic and organic)
Firebrick
Glass (e.g., borosilicate glass, labware, leaded glass, Raschig rings)
Graphite (e.g., molds and crucibles)
Greases, commercial brands
Grit
Halogenated organics (e.g., bromoform; carbon tetrachloride; chlorobenzene; chloroform; 1,1-dichloroethane; 1,2-dichloroethane; 1,1-dichloroethylene; cis-1,2-dichloroethylene; methylene chloride; 1,1,2,2-tetrachloroethane; tetrachloroethylene; 1,1,1-trichloroethane; 1,1,2-trichloroethane; trichloroethylene; 1,1,2-trichloro-1,2,2-trifluoroethane)
Heel (e.g., ash heel; soot heel; firebrick heel; sand, slag, and crucible heel)
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)
Hydrocarbons, aromatic (e.g., benzene; ethyl benzene; toluene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; xylene)
Insulation (inorganic and organic)
Ketones (e.g., acetone, methyl ethyl ketone, methyl isobutyl ketone)
Leaded rubber (e.g., gloves, aprons, sheet material)
Leather
Magnesia cement (e.g., Ramcote® cement)
Magnesium alloy
Metal hydroxides
Metal oxides (e.g., slag)

Table B-1
Table of Allowable Materials for TRU Waste[a]
(Continued)

Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)
Nitrates (e.g., ammonium nitrate, sodium nitrate)
Oil (e.g., petroleum, mineral)
Organophosphates (e.g., tributyl phosphate, dibutyl phosphate, monobutyl phosphite)
Paint, dry (e.g., floor/wall paint, ALARA)
Petroset® products (for aqueous solutions)
Plastics [e.g., polycarbonate, polyethylene, polymethyl methacrylate (Plexiglas®, Lucite®), polysulfone, polytetrafluoroethylene (Teflon®), polyvinyl acetate, polyvinyl chloride (PVC), polyvinylidene chloride (saran)]
Polyamides (nylon)
Polychlorotrifluoroethylene (e.g., Kel-F®)
Polyesters (e.g., Dacron®, Mylar®)
Polyethylene glycol (e.g., Carbowax®)
Polyimides
Polyphenyl methacrylate
Polypropylene (e.g., Ful-Flo® filters)
Polyurethane
Polyvinyl alcohol
Portland cement
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)
Rubber, natural or synthetic [e.g., chlorosulfonated polyethylene (Hypalon®), ethylene-propylene rubber, EPDM, polybutadiene, polychloroprene (neoprene), polyisobutylene, polyisoprene, polystyrene, rubber hydrochloride (pliofilm®)]
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)
Sand/soil (inorganic and organic)
Trioctyl phosphine oxide
Water
Waxes, commercial brands
Other inorganic materials

[a]Other chemicals or materials not identified in this table are allowed provided that they meet the requirements for trace constituents (less than one weight percent of the payload container individually; less than five weight percent of the payload container combined). All materials in the final waste form must be inert (nonreactive), be in a nonreactive form, or have been rendered nonreactive.

[b]Bakelite is a trademark for materials that can be composed of several different polymers, including polyethylene, polypropylene, epoxy, phenolic, polystyrene, phenoxy, perylene, polysulfone, ethylene copolymers, ABS, acrylics, and vinyl resins and compounds.

- Trace chemicals that might be incompatible with materials/chemicals in concentrations greater than or equal to 1 percent by weight would have reacted during the waste generating process prior to placement in payload containers.

- The waste is either solidified and immobilized (solidified materials) or present in bulk form as a solid (solid materials). In almost all cases, any possible reactions take place before the waste is generated in its final form.

Potential incompatibilities between the allowable materials/compounds listed in Table B-1 have been analyzed for the CNS 10-160B payload. The analysis assigned EPA chemical reactivity group numbers and names to each allowable material. The reactivity group numbers were assigned based on information provided in Reference B.3.1. If the allowable material (or chemical) is a non-reactive inorganic material (not covered under the EPA reactivity group numbers), it was assigned a reactivity group number of "0" to reflect a complete analysis for all allowable materials (materials assigned a reactivity group number of "0" do not present a compatibility concern). The compiled list of allowable materials and assigned reactivity group numbers is provided in Attachment 1.0.

The list of allowable materials and assigned reactivity group numbers was sorted by reactivity group number and then condensed to form a list of the represented reactivity groups (Attachment 2.0).

Using the list of represented reactivity groups, a hazardous waste compatibility chart was generated. The chart, which is provided in Attachment 3.0, is a reduced version of the hazardous waste compatibility chart presented in Reference B.3.1. The chart summarizes the potential types of reactions possible between each of the reactivity groups represented in the list of allowable materials. The reaction codes and consequences of the reactions are specified for each combination of two reactivity groups.

Using the waste compatibility chart, a list of potential chemical incompatibilities in the TRU waste was generated. The list, which is presented in Attachment 4.0, also presents assessments of whether or not the reaction associated with each of the potential chemical incompatibilities will or will not occur. The results of the assessments indicated that no chemical incompatibilities will occur. Therefore, by precluding all potential incompatibilities, the chemicals/materials identified in Table B-1 are determined to be compatible for the CNS 10-160B Cask payload.

Chemical lists provided for site-specific TRU waste content codes identified for shipment in the CNS 10-160B Cask are a subset of Table B-1. Chemical incompatibilities therefore do not exist in and across these content codes. Only content codes with chemical lists that have been evaluated by this process and determined to be compatible shall be approved for shipment in the CNS 10-160B Cask.

B.3.0 REFERENCES

B.3.1 Hatayama, H. K., Chen, J.J., de Vera, E.R., Stephens, R.D., Storm, D.L., "A Method for Determining the Compatibility of Hazardous Wastes," EPA-600/2-80-076, EPA, Cincinnati, Ohio, 1980.

Attachment 1.0

Lists of Allowable Materials and
Associated Reactivity Groups

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number[c]
Absorbent polymers, organic	Combustible and flammable materials, miscellaneous	101
Absorbents/adsorbents (e.g., Celite®, diatomaceous earth, diatomite, Florco®, Oil-Dri®, perlite, vermiculite)	Other solidification materials and absorbents/adsorbents	0
Acids, inorganic	Acids, Mineral, Non-oxidizing	1
Acids, inorganic	Acids, Mineral, Oxidizing	2
Acids, organic	Acids, organic	3
Alcohols (e.g., butanol, ethanol, isopropanol, methanol)	Alcohols and Glycols	4
Alumina cement	Water reactive substance	107
Aquaset® products (for aqueous solutions)	Other solidification materials and absorbents/adsorbents	0
Aqueous sludges or solutions	Other solidification materials and absorbents/adsorbents	0
Asbestos	Other Inorganics (non-reactive)	0
Ash (e.g., ash bottoms, fly ash, soot)	Other Inorganics (non-reactive)	0
Asphalt	Combustible and flammable materials, miscellaneous	101
Bakelite®	Combustible and flammable materials, miscellaneous	101
Batteries, dry (e.g., flashlight)	Metals, alkali and alkaline earth, elemental and alloys	21
Caustics	Caustics	10
Cellulose (e.g., Benelex®, cotton Conwed®, paper, rags, rayon, wood)	Combustible and flammable materials, miscellaneous	101
Cellulose acetate butyrate	Polymerizable compounds	103
Cellulose propionate	Polymerizable compounds	103
Ceramics (e.g., molds and crucibles)	Other Inorganics (non-reactive)	0
Chlorinated polyether	Ethers	14
Clays (e.g., bentonite)	Other Inorganics (non-reactive)	0
Concrete	Other solidification materials and absorbents/adsorbents	0
Detergent, solid (e.g., emulsifiers, surfactants)	Esters	13
Detergent, solid (e.g., emulsifiers, surfactants)	Hydrocarbons, aromatic	16
Detergent, solid (e.g., emulsifiers, surfactants)	Hydrocarbons, aliphatic, unsaturated	28
Detergent, solid (e.g., emulsifiers, surfactants)	Organophosphates, phosphothioates, and phosphodithioates	32
Envirostone® (no organic emulsifiers allowed)	Other solidification materials and absorbents/adsorbents	0
Esters (e.g., ethyl acetate, polyethylene glycol ester)	Esters	13
Ethers (e.g., ethyl ether)	Ethers	14
Fiberglass, inorganic	Other Inorganics (non-reactive)	0
Fiberglass, organic	Combustible and flammable materials, miscellaneous	101
Filter media, inorganic	Other Inorganics (non-reactive)	0
Filter media, organic	Combustible and flammable materials, miscellaneous	101
Firebrick	Other Inorganics (non-reactive)	0

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number[c]
Glass (e.g., borosilicate glass, labware, leaded glass, Raschig rings)	Other Inorganics (non-reactive)	0
Graphite (e.g., molds and crucibles)	Other Inorganics (non-reactive)	0
Greases, commercial brands	Combustible and flammable materials, miscellaneous	101
Grit	Other Inorganics (non-reactive)	0
Halogenated organics (e.g., bromoform; carbon tetrachloride; chlorobenzene; chloroform; 1,1-dichloroethane; 1,2-dichloroethane; 1,1-dichloroethylene; cis-1,2-dichloroethylene; methylene chloride; 1,1,2,2-tetrachloroethane; tetrachloroethylene; 1,1,1-trichloroethane; 1,1,2-trichloroethane; trichloroethylene; 1,1,2-trichloro-1,2,2-trifluoroethane)	Halogenated Organics	17
Heel (e.g., ash heel; soot heel; firebrick heel; sand, slag, and crucible heel)	Other Inorganics (non-reactive)	0
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, unsaturated	28
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, saturated	29
Hydrocarbons, aromatic (e.g., benzene; ethyl benzene; toluene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; xylene)	Hydrocarbons, aromatic	16
Insulation, inorganic	Other Inorganics (non-reactive)	0
Insulation, organic	Combustible and flammable materials, miscellaneous	101
Ketones (e.g., acetone, methyl ethyl ketone, methyl isobutyl ketone)	Ketones	19
Leaded rubber (e.g., gloves, aprons, sheet material)	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23
Leaded rubber (e.g., gloves, aprons, sheet material)	Metals and metal compounds, toxic	24
Leaded rubber (e.g., gloves, aprons, sheet material)	Combustible and flammable materials, miscellaneous	101
Leather	Combustible and flammable materials, miscellaneous	101
Magnesia cement (e.g., Ramcote® cement)	Water reactive substance	107
Magnesium alloy	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23
Metal hydroxides	Other Inorganics (non-reactive)	0
Metal oxides (e.g., slag)	Other Inorganics (non-reactive)	0
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, alkali and alkaline earth, elemental	21
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental and alloy in the form of powders, vapors, or sponges	22
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number[c]
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals and metal compounds, toxic	24
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Reducing agents, strong	105
Nitrates (e.g., ammonium nitrate, sodium nitrate)	Oxidizing Agents, Strong	104
Oil (e.g., petroleum, mineral)	Combustible and flammable materials, miscellaneous	101
Organophosphates (e.g., tributyl phosphate, dibutyl phosphate, monobutyl phosphite)	Organophosphates, phosphothioates, and phosphodithioates	32
Paint, dry (e.g., floor/wall paint, ALARA)	Combustible and flammable materials, miscellaneous	101
Petroset® products (for aqueous solutions)	Other solidification materials and absorbents/adsorbents	0
Plastics [e.g., polycarbonate, polyethylene, polymethyl methacrylate (Plexiglas®, Lucite®), polysulfone, polytetrafluoroethylene (Teflon®), polyvinyl acetate, polyvinyl chloride (PVC), polyvinylidene chloride (saran)]	Combustible and flammable materials, miscellaneous	101
Polyamides (nylon)	Amides	6
Polyamides (nylon)	Combustible and flammable materials, miscellaneous	101
Polychlorotrifluoroethylene (e.g., Kel-F®)	Combustible and flammable materials, miscellaneous	101
Polyesters (e.g., Dacron®, Mylar®)	Esters	13
Polyesters (e.g., Dacron®, Mylar®)	Combustible and flammable materials, miscellaneous	101
Polyethylene glycol (e.g., Carbowax®)	Alcohols and Glycols	4
Polyethylene glycol (e.g., Carbowax®)	Combustible and flammable materials, miscellaneous	101
Polyimides	Hydrocarbons, aromatic	16
Polyphenyl methacrylate	Combustible and flammable materials, miscellaneous	101
Polypropylene (e.g., Ful-Flo® filters)	Combustible and flammable materials, miscellaneous	101
Polyurethane	Combustible and flammable materials, miscellaneous	101
Polyvinyl alcohol	Alcohols and Glycols	4
Portland cement	Caustics	10
Portland cement	Water reactive substance	107
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Aldehydes	5
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Phenols and Creosols	31
Rubber, natural or synthetic [e.g., chlorosulfonated polyethylene (Hypalon®), ethylene-propylene rubber, EPDM, polybutadiene, polychloroprene (neoprene), polyisobutylene, polyisoprene, polystyrene, rubber hydrochloride (pliofilm®)]	Combustible and flammable materials, miscellaneous	101

Lists of Allowable Materials and Associated Reactivity Groups		
	Reactivity Group[b]	
Allowable Chemical/Material[a]	Name	Number[c]
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)	Other Inorganics (non-reactive)	0
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)	Fluorides, inorganic	15
Sand/soil, inorganic	Other Inorganics (non-reactive)	0
Sand/soil, organic	Combustible and flammable materials, miscellaneous	101
Trioctyl phosphine oxide	Organophosphates, phosphothioates, and phosphodithioates	32
Water	Water and Mixtures containing water	106
Waxes, commercial brands	Combustible and flammable materials, miscellaneous	101
Other inorganic materials	Other Inorganics (non-reactive)	0

[a]Chemicals in ***bold italic*** have been assigned to more than one reactivity group.
[b]Reactivity group from Hatayama, H.K., J. J. Chen, E.R. deVera, 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.
[c]Non-reactive inorganic materials or chemicals are assigned a reactivity group number of "0."

Attachment 2.0

Lists of Unique Reactivity Group Numbers in Lists of Allowable Materials

List of Unique Reactivity Group Numbers in Lists of Allowable Materials

Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number
Absorbents/adsorbents (e.g., Celite®, diatomaceous earth, diatomite, Florco®, Oil-Dri®, perlite, vermiculite)	Other solidification materials and absorbents/adsorbents	0
Acids, inorganic	Acids, Mineral, Non-oxidizing	1
Acids, inorganic	Acids, Mineral, Oxidizing	2
Acids, solid, organic	Acids, Organic	3
Polyethylene glycol (e.g., Carbowax®)	Alcohols and Glycols	4
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Aldehydes	5
Polyamides (nylon)	Amides	6
Portland cement	Caustics	10
Esters (e.g., ethyl acetate, polyethylene glycol ester)	Esters	13
Ethers (e.g., ethyl ether)	Ethers	14
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)	Fluorides, inorganic	15
Hydrocarbons, aromatic (e.g., benzene; ethyl benzene; toluene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; xylene)	Hydrocarbons, aromatic	16
Halogenated organics (e.g., bromoform; carbon tetrachloride; chlorobenzene; chloroform; 1,1-dichloroethane; 1,2-dichloroethane; 1,1-dichloroethylene; cis-1,2-dichloroethylene; methylene chloride; 1,1,2,2-tetrachloroethane; tetrachloroethylene; 1,1,1-trichloroethane; 1,1,2-trichloroethane; trichloroethylene; 1,1,2-trichloro-1,2,2-trifluoroethane)	Halogenated Organics	17
Ketones (e.g., acetone, methyl ethyl ketone, methyl isobutyl ketone)	Ketones	19
Batteries, dry (e.g., flashlight)	Metals, alkali and alkaline earth, elemental and alloys	21
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental and alloy in the form of powders, vapors, or sponges	22
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23
Leaded rubber (e.g., gloves, aprons, sheet material)	Metals and metal compounds, toxic	24
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, unsaturated	28
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, saturated	29
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Phenols and Creosols	31
Organophosphates (e.g., tributyl phosphate, dibutyl phosphate, monobutyl phosphite)	Organophosphates, phosphothioates, and phosphodithioates	32

List of Unique Reactivity Group Numbers in Lists of Allowable Materials

Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number
Asphalt	Combustible and flammable materials, miscellaneous	101
Cellulose acetate butyrate	Polymerizable compounds	103
Nitrates (e.g., ammonium nitrate, sodium nitrate)	Oxidizing Agents, Strong	104
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Reducing agents, strong	105
Aqueous solutions/water	Water and Mixtures containing water	106
Portland cement	Water reactive substances	107

[a]Chemicals in ***bold italic*** have been assigned to more than one reactivity group.
[b]Reactivity group from Hatayama, H.K., J.J. Chen, E.R. deVera, 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.

Attachment 3.0

Waste Chemical Compatibility Chart

Hazardous Waste Chemical Compatibility Chart

Group No.	Reactivity Group Name	1	2	3	4	5	6	10	13	14	15	16	17	19	21	22	23	24	28	29	31	32	101	103	104	105	106	107
1	Acids, Mineral, Non-Oxidizing																											
2	Acids, Mineral, Oxidizing																											
3	Acids, Organic		G, H																									
4	Alcohols and Glycols	H	H, F	H, P																								
5	Aldehydes	H, P	H, F	H, P																								
6	Amides	H	H, GT																									
10	Caustics	H	H	H		H																						
13	Esters	H	H, F					H																				
14	Ethers	H	H, F																									
15	Fluorides, Inorganic	GT	GT	GT																								
16	Hydrocarbons, Aromatic		H, F																									
17	Halogenated Organics	H, GT	H, GT, P					H, GF																				
19	Ketones	H	H, F					H																				
21	Metals, Alkali and Alkaline Earth, Elemental	GF, H, F	GF, H, F	GF, H, F	GF, H, F	GF, H, F	GF, H	GF, H	GF, H																			
22	Metals, Other Elemental Alloys as Powders, Vapors, or Sponges	GF, H, F	GF, H, F	GF				GF, H					H, E															
23	Metals, Other Elemental Alloys as Sheets, Rods, Moldings, Etc.	GF, H, F	GF, H, F										H, F															
24	Metals and Metal Compounds, Toxic	S	S	S			S	S																				
28	Hydrocarbons, Aliphatic, Unsaturated	H	H, F			H										H, E												
29	Hydrocarbons, Aliphatic, Saturated		H, F																									
31	Phenols and Cresols	H	H, F												GF, H													
32	Organophosphates, Phosphothioates, Phosphodithioates	GT, H	GT, H					H, E							H													
101	Combustible and Flammable Materials, Miscellaneous	H, G	GT, H, F												H, G, F													
103	Polymerizable Compounds	P, H	P, H	P, H				P, H							P, H	P, H	P, H	P, H			P, H							
104	Oxidizing Agents, Strong	GT, H		GT, H	H, F	H, F	GT, H, F		H, F	H, F		H, F	GT, H	H, F	H, F, E	H, F, E	H, F		H, F	H, F	H, F	GT, H, F	H, G, F	GT, H, F	104			
105	Reducing Agents, Strong	GF, H	GT, H, F	GF, H	GF, H, F	GF, H, F	GF, H		H, F				H, E	GF, H								GF, H	GF, GT	GF, H	GF, H, P	H, F, E	105		
106	Water and Mixtures Containing Water	H	H												GF, H	GF, H		S									GF, GT	106	
107	Water Reactive Substances	E	X	T	R	E	M		A	C	T	I	V	I	D	O		N	M	I	I	I							107
Reactivity Group No.		1	2	3	4	5	6	10	13	14	15	16	17	19	21	22	23	24	28	29	31	32	101	103	104	105	106	107

Reactivity Code	Consequence
E	Explosion
F	Fire
G	Innocuous and Non-Flammable Gas Generation
GF	Flammable Gas Generation
GT	Toxic Gas Generation
H	Heat Generation
P	Violent Polymerization
S	Solubilization of Toxic Substance

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

Attachment 4.0

Potential Chemical Incompatibilities

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
1	4	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	5	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	5	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	6	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	10	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; Bases/caustic materials are neutralized and solidified/immobilized prior to shipping
1	13	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	14	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	15	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	17	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	17	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	19	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	21	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	21	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	21	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	22	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	22	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	22	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	23	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	23	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	23	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	24	Solubilization of Toxic Substances	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.
1	28	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
1	31	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	32	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	32	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	101	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	101	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	103	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	103	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	104	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
1	104	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
1	105	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
1	105	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
1	106	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume
1	107	Highly Reactive	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
2	3	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	3	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	4	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	4	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
2	5	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	5	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	6	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	6	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	10	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; Bases/caustic materials are neutralized and solidified/immobilized prior to shipping
2	13	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	13	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	14	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	14	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	15	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	16	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	16	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	17	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	17	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	17	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	19	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	19	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	21	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	21	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	21	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	22	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	22	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	22	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
2	23	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	23	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	23	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	24	Solubilization of Toxic Substances	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.
2	28	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	28	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	29	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	29	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	31	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	31	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	32	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	32	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	101	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	101	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	101	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	103	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	103	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	105	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
2	105	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
2	105	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
2	106	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
2	107	Highly Reactive	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
3	4	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	4	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	5	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	5	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	10	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; Bases/caustic materials are neutralized and solidified/immobilized prior to shipping
3	15	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	21	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	21	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	21	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	22	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	24	Solubilization of Toxic Substances	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.
3	103	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	103	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	104	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
3	104	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
3	105	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
3	105	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
3	107	Highly Reactive	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
4	21	Flammable Gas Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping
4	21	Heat Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping
4	21	Fire	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping
4	104	Heat Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
4	104	Fire	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
4	105	Heat Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
4	105	Flammable Gas Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
4	105	Fire	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
4	107	Highly Reactive	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
5	10	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; bases/caustic materials are neutralized and solidified/immobilized prior to shipping
5	21	Flammable Gas Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
5	21	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping
5	21	Fire	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping
5	28	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping
5	104	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
5	104	Fire	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
5	105	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
5	105	Flammable Gas Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
5	105	Fire	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
5	107	Highly Reactive	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
6	17	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping
6	17	Toxic Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping
6	21	Flammable Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping
6	21	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping
6	24	Solubilization of Toxic Substances	Reaction will not occur – Amides are solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.
6	104	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
6	104	Fire	Reaction will not occur – Amides are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
6	104	Toxic Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
6	105	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
6	105	Flammable Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
6	107	Highly Reactive	Reaction will not occur – Amides are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
10	13	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	17	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	19	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	21	Flammable Gas Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	21	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	22	Flammable Gas Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	22	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	23	Flammable Gas Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	23	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	24	Solubilization of Toxic Substances	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping; Additionally, any solubilization of toxic substances will not affect transportation of wastes.
10	32	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	32	Explosion	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	103	Violent Polymerization	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	103	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
10	107	Highly Reactive	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
13	21	Flammable Gas Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping
13	21	Heat Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping
13	104	Heat Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
13	104	Fire	Reaction will not occur – Esters are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
13	105	Heat Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
13	105	Fire	Reaction will not occur – Esters are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
13	107	Highly Reactive	Reaction will not occur – Esters are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
14	104	Heat Generation	Reaction will not occur – Ethers are solidified / immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.
14	104	Fire	Reaction will not occur – Ethers are solidified / immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.
14	107	Highly Reactive	Reaction will not occur – Ethers are solidified / immobilized prior to shipping. Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result	
Group A	Group B	(A x B)	Explanation of Potential Incompatibility
15	107	Highly Reactive	Reaction will not occur – Salts are reacted during use and processing; Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
16	104	Heat Generation	Reaction will not occur – Aromatic hydrocarbons are solidified/immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.
16	104	Fire	Reaction will not occur – Aromatic hydrocarbons are solidified/immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.
16	107	Highly Reactive	Reaction will not occur – Aromatic hydrocarbons are solidified/immobilized prior to shipping. Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
17	21	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	21	Explosion	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	22	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	22	Explosion	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	23	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	23	Fire	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	104	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
17	104	Toxic Gas Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
17	105	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
17	105	Explosion	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result	
Group A	Group B	(A x B)	Explanation of Potential Incompatibility
17	107	Highly Reactive	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
19	21	Flammable Gas Generation	Reaction will not occur – Ketones are solidified/immobilized prior to shipping
19	21	Heat Generation	Reaction will not occur – Ketones are solidified/immobilized prior to shipping
19	104	Heat Generation	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
19	104	Fire	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
19	105	Flammable Gas Generation	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
19	105	Heat Generation	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
19	107	Highly Reactive	Reaction will not occur – Ketones are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
21	31	Flammable Gas Generation	Reaction will not occur – Phenols and Creosols are solidified/immobilized prior to shipping; metals are typically in oxide form
21	31	Heat Generation	Reaction will not occur – Phenols and Creosols are solidified/immobilized prior to shipping; metals are typically in oxide form
21	32	Heat Generation	Reaction will not occur – Organophosphates are solidified/immobilized prior to shipping; metals are typically in oxide form
21	101	Heat Generation	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; metals are typically in oxide form
21	101	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; metals are typically in oxide form

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
21	101	Fire	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; metals are typically in oxide form
21	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; metals are typically in oxide form
21	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; metals are typically in oxide form
21	104	Heat Generation	Reaction will not occur –Oxidizing agents are reacted prior to being placed in the waste/shipped; metals are typically in oxide form
21	104	Fire	Reaction will not occur –Oxidizing agents are reacted prior to being placed in the waste/shipped; metals are typically in oxide form
21	104	Explosion	Reaction will not occur –Oxidizing agents are reacted prior to being placed in the waste/shipped; metals are typically in oxide form
21	106	Flammable Gas Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; metals are typically in oxide form.
21	106	Heat Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; metals are typically in oxide form.
21	107	Highly Reactive	Reaction will not occur – Metals are typically in oxide form; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
22	28	Heat Generation	Reaction will not occur – Unsaturated aliphatic hydrocarbons are solidified/immobilized prior to shipping
22	28	Explosion	Reaction will not occur – Unsaturated aliphatic hydrocarbons are solidified/immobilized prior to shipping
22	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
22	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
22	104	Heat Generation	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
22	104	Fire	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
22	104	Explosion	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
22	106	Flammable Gas Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; water reactive metals are reacted prior to shipping
22	106	Heat Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; water reactive metals are reacted prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
22	107	Highly Reactive	Reaction will not occur –Water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
23	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
23	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
23	104	Heat Generation	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
23	104	Fire	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
23	107	Highly Reactive	Reaction will not occur –Water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
24	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
24	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
24	106	Solubilization of Toxic Substances	Reaction will not occur – Free liquid content is limited to less than 1% of waste volume; Additionally, any solubilization of toxic substances will not affect transportation of wastes.
24	107	Highly Reactive	Reaction will not occur – Water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
28	104	Heat Generation	Reaction will not occur – Unsaturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
28	104	Fire	Reaction will not occur – Unsaturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
28	107	Highly Reactive	Reaction will not occur – Unsaturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
29	104	Heat Generation	Reaction will not occur – Saturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
29	104	Fire	Reaction will not occur – Saturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
29	107	Highly Reactive	Reaction will not occur – Saturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
31	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; phenols and creosols are immobilized/solidified prior to shipping
31	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; phenols and creosols are immobilized/solidified prior to shipping
31	104	Heat Generation	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
31	104	Fire	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
31	105	Flammable Gas Generation	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
31	105	Heat Generation	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
31	107	Highly Reactive	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
32	104	Heat Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
32	104	Fire	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
32	104	Toxic Gas Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
32	105	Toxic Gas Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
32	105	Flammable Gas Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
32	105	Heat Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
32	107	Highly Reactive	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
101	104	Heat Generation	Reaction will not occur – Combustible materials are dry; oxidizing agents are reacted prior to being placed in the waste/shipped
101	104	Fire	Reaction will not occur – Combustible materials are dry; oxidizing agents are reacted prior to being placed in the waste/shipped
101	104	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Combustible materials are dry; oxidizing agents are reacted prior to being placed in the waste/shipped
101	105	Flammable Gas Generation	Reaction will not occur – Combustible materials are dry; reducing agents are reacted prior to being placed in the waste/shipped
101	105	Heat Generation	Reaction will not occur – Combustible materials are dry; reducing agents are reacted prior to being placed in the waste/shipped
101	107	Highly Reactive	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
103	104	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
103	104	Fire	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
103	104	Toxic Gas Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
103	105	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
103	105	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
103	105	Flammable Gas Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
103	107	Highly Reactive	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
104	105	Heat Generation	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; reducing agents are reacted prior to being placed in the waste/shipped
104	105	Fire	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; reducing agents are reacted prior to being placed in the waste/shipped
104	105	Explosion	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; reducing agents are reacted prior to being placed in the waste/shipped
104	107	Highly Reactive	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
105	106	Flammable Gas Generation	Reaction will not occur – Reducing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume
105	106	Toxic Gas Generation	Reaction will not occur – Reducing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
105	107	Highly Reactive	Reaction will not occur – Reducing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
106	107	Highly Reactive	Reaction will not occur – Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.

Attachment C

Shipping Period for TRU Waste in the 10-160B Cask

C.1.0 INTRODUCTION

This Attachment presents the basis for the shipping period for TRU wastes from the time of cask closure until cask opening. This shipping period is used in the analysis of the gas generation in the 10-160B cask.

The 10-160B cask may be used to ship TRU waste from generator sites to the Waste Isolation Pilot Plant (WIPP) for disposal or between sites (e.g., from the Battelle West Jefferson, OH site to the U.S. Department of Energy [DOE] Hanford, WA site) for interim storage. While the shipments are in transit, a satellite tracking system will be operational to monitor progress and provide direct communication between the driver and the transport dispatcher.

C.2.0 EXPECTED SHIPPING PERIOD

The expected shipping period is the amount of time from the sealing of the cask at the loading facility until the opening of the cask at the unloading facility. It consists of: the time from cask sealing to the release of the transport unit from the loading facility, the expected transit time, and the time from arrival at the unloading facility until the cask is opened. For assessing the expected shipping period, it will be assumed that there are no delays.

C.2.1 Loading

The loading process from cask sealing to unit release includes health physics surveys, installing the upper impact limiter, and vehicle inspections. The time from cask sealing until the unit is released for travel has been accomplished in less than four (4) hours. To be conservative, a one-day (24 hour) duration will be assumed.

C.2.2 Transit

The longest route of prospective intersite shipments is from Savannah River, SC to Hanford, approximately 2800 miles. Shipments to WIPP are encompassed by this distance. All TRU shipments will be made with two drivers. Using two drivers, on an appropriate rotational schedule, the truck can travel for twenty-four (24) hours per day for up to seven days. Assuming an average speed of 45 mph, which includes time for vehicle inspections, fueling, meals, and driver relief, the duration of a 2800 mile trip is expected to be 62 hours. Again, to be conservative, the transit duration will be assumed to be three days (72 hours).

C.2.3 Unloading

The unloading process includes receipt survey and security checks, positioning of the trailer in the TRU waste unloading area, removal of the cask from the trailer to a transfer cart, positioning of the cask in the cask unloading room, and removal of the lid. This process has been accomplished in less than eight (8) hours. Again, to be conservative, the unloading duration will be assumed to be one day (24 hours).

C.2.4 Total

The total expected shipping period, with no delays, is less than 75 hours. For the purpose of this analysis, a conservative period of 5 days (120 hours) will be assumed.

C.3.0 SHIPPING DELAYS

The maximum shipping time will be assumed to be the sum of the expected shipping time and the time for delays which could extend the shipping time. These delays are: loading delays; transit delays due to weather or road closures, shipping vehicle accidents, mechanical delays, or driver illness; and unloading delays. Each of these delays are assessed below.

C.3.1 Loading Delays

There are a number of situations that could extend the time between cask sealing and truck release. These include: loading preceding a holiday weekend, problems with a leak test, and handling equipment failure. Both the leak test problem and the handling equipment failure should be resolvable by replacing or obtaining temporary equipment. Each of these situations is unlikely to cause more than a two day delay. The holiday weekend could cause a delay of three days, i.e., from Friday afternoon until Tuesday. It is very unlikely that more than two of the three loading delays could occur on the same shipment, so a total of five days seems a reasonably conservative assessment for a loading delay.

C.3.2 Transit Delays

Transit delays due to weather, e.g., a road closed due to snow, are unlikely to cause a delay of more than five days. A road closure due to a vehicle accident or a roadway or bridge failure would result in re-routing which could add up to two days to the transit time. A transit time delay due to weather or road closure will be assumed to be five days.

Transit delays due to an accident with the truck could cause a lengthy delay. Response time for notification and to take immediate corrective action is assumed to be one day. (The use of the on-board satellite communication system will facilitate an early response.) Accident mitigation may require transferring the cask to a different trailer using cranes and other heavy equipment. Mitigation is assumed to take five days for a total accident delay of six days.

Mechanical problems with the truck or trailer could also cause multi-day delays. Significant failures may require a replacement tractor or trailer. An appropriate response to a mechanical failure is assumed to take four days.

Driver illness could also cause transit delays. If a driver it too ill to continue, a replacement driver will be brought in. A two day delay is assessed for bringing in a replacement driver.

C.3.3 Unloading Delay

An unloading delay will occur if the truck arrives just before a holiday weekend. This could result in a four day delay. Additionally, a delay due to unloading equipment failure could occur. Repair of such equipment should not require more than four days. The unloading delay will be conservatively assumed to be five days. If an unanticipated situation occurs that would result in a much longer delay, the cask can be vented.

C.3.4 Total Delay

The total delay, i.e., the sum of the delay times for each of the delay types, is 27 days. This assumes that each type of delay occurs on the same shipment.

C.4.0 MAXIMUM SHIPPING PERIOD

The maximum shipping period, as the sum of the expected shipping period and the total delay, is 32 days. This period assumes that each of the possible shipping delays occurs on the same shipment, a very unlikely occurrence. Further, for additional conservatism, the assumed maximum will be nearly doubled to 60 days. Thus, a 60 day shipping period will be the maximum used in analysis of gas generation in the sealed cask. A shorter, site-specific shipping period may be developed and included in the site-specific sub tier appendix, which contains the waste content codes for the site, that is submitted to the NRC for approval. This site-specific shipping period may be used in the gas generation analysis for the site's waste.

ATTACHMENT 2

Appendix 4.10.2.1

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

1.0 INTRODUCTION

This appendix presents the methods of preparation and characterization to qualify remote-handled (RH) transuranic (TRU) and contact-handled (CH) TRU waste, as defined by the U.S. Department of Energy (DOE) (Reference 12.1), as payload for transport in the CNS 10-160B cask and to demonstrate that the TRU waste forms at Battelle Columbus Laboratories (BCL), described in this appendix, comply with the payload requirements. The methods for determining 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 121A, BC 121B, 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)
- 10-day Controlled Shipment (Attachment C)
- Special Requirements for Shipment Number 12 (Attachment D).

2.0 PURPOSE

The purpose of this appendix is to describe the methods that shall be used to prepare and characterize the RH-TRU and CH-TRU waste belonging to BCL prior to transport in the CNS 10-160B cask. This appendix is based on the format and requirements for TRU waste identified in Appendix 4.10.2 of the CNS 10-160B Safety Analysis Report (SAR). It incorporates acceptable methods applicable to the content codes listed in Table 3-1 of this appendix.

Section 3.0 describes the TRU waste payload. Sections 4.0 through 11.0 discuss each payload parameter and the BCL methods for demonstrating compliance with the CNS 10-160B cask payload requirements.

3.0 TRU WASTE PAYLOAD FOR CNS 10-160B CASK

TRU waste is classified into content codes, which give a description of the RH-TRU and CH-TRU waste materials 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 and CH-TRU waste from BCL are provided in Attachment A and are listed in Table 3-1.

Table 3-1. BCL Content Codes

Content Code	Waste Form Description
BC 121A, BC 121B	CH-TRU Solid Organic Waste (D&D operations)
BC 312A	RH-TRU Solidified Organic Waste (R&D operations)
BC 314A	RH-TRU Cemented Inorganic Process Solids (R&D operations)
BC 321A	RH-TRU Solid Organic Waste (D&D operations)
BC 321B	RH-TRU Solid Organic Waste (Pool filters and resins)
BC 322A	RH-TRU 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 (i.e., the BCL Decommissioning Project (BCLDP) TRU Waste Certification Program (WCP)). TRU waste generated from the BCL will comply with all transportation requirements using the following methods:

- Formally documented acceptable knowledge (AK)/process knowledge of the processes generating the waste
- Visual examination (VE), including 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 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. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers greater than four liters in size are prohibited.

4.2 Methods of Compliance and Verification

All TRU waste from the BCLDP is newly packaged under procedures and plans that ensure compliance with transportation and other governing regulations. Pursuant to these procedures, compliance with the physical form requirements is ensured by documented AK and VE.

The BCL uses VE to verify the physical waste form descriptions documented as AK. As waste items are sorted, the BCL VE expert evaluates each waste item for consistency with the AK process description for the waste stream being packaged and determines and documents the physical form and description, and material type(s) and composition (percentage) of the item. The BCL AK expert independently reviews determinations made by the VE expert with respect to waste item assignments to waste streams as defined by the AK process descriptions during the AK confirmation process. AK discrepancy reports are generated with associated corrective actions, as necessary. The BCL also uses VE to ensure absence of prohibited items. As waste items are sorted, the BCL VE expert evaluates each waste item. As identified, any prohibited item is segregated for mitigation or other disposition and is not loaded into a waste container for shipment.

In addition to the generation of inventory loading records for each waste container, the VE documentation includes video/audio records. Video documentation of TRU waste packaging shall be

performed at all times when TRU waste is being sorted and packaged under TC-OP-01.4 in the BCL hot cells using two cameras and two videocassette recorders. A microphone feed is provided to verify and verbally note the identification of the waste stream and the container. This process duplicates the information recorded in hardcopy form on the waste container loading record. When TRU waste packages are in the cell, but packaging is not being performed, motion/light sensitive recording equipment shall be left running, with a videocassette in place, to document any movement in the packaging area. This will be used to verify that all packaging was recorded and that no packaging was performed without the proper VE documentation.

The BCLDP TRU WCP will use AK and VE to verify that the liquid content of the payload container complies with the requirements. Packaging personnel shall restrict the presence of free liquids to the extent that is reasonably achievable by pouring, pumping, or aspirating. Free liquids encountered during packaging shall be absorbed. Any liquid in nontransparent inner containers, including pumps or mechanical equipment that may contain an oil reservoir that is not solidified, will be handled by assuming that the container is filled with liquid and the volume will be added to the total liquid documented for the payload container in evaluating compliance with the 1% (volume) limit on free liquids.

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 packaging operations include the practice of size reduction and the use of a 0.015-inch thick steel liner in the 55-gallon drums. Following size reduction, items with the potential to puncture the liner and drum are blocked, braced, or suitably packaged to ensure container integrity. Waste may alternatively be repackaged into 55-gallon drums lined with a rigid polyethylene liner.

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. Sealed containers greater than 4 liters identified during the sorting process will be segregated for disposition and shall not be packaged for shipment.

As described in TC-AP-01.1, TRU Waste Data Package Generation, compliance with each of the restrictions on physical form shall be recorded in the payload container data package.

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.

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 (e.g., organic peroxides, sodium metal, and chlorides) shall be segregated and not be packaged into payload containers. Radioactive pyrophoric material (e.g., metallic plutonium and americium), if present in the waste stream, shall be limited to less than 1 weight percent 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 VE, as described in Section 4.2, during waste generation and packaging to verify the absence of nonradioactive pyrophoric materials and compliance with the restriction on radioactive pyrophoric material (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 and compliance with the restriction on radioactive pyrophoric material 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 VE, as described in Section 4.2, 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. The BCL wastes 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 minimizes the introduction of potentially flammable VOCs into the drums), and the lack of a source for potentially flammable VOCs.

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 weight percent) in a payload container provided that the total quantity of trace chemicals/materials is restricted to less than 5 weight percent.
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

Attachment B of Appendix 4.10.2 of the CNS 10-160B SAR presents the methodology and results for the chemical compatibility analyses performed for the list of allowable chemicals/materials associated with the TRU waste content codes expected to be shipped in the CNS 10-160B cask. The results of these chemical compatibility analyses show that these content codes can be transported without any incompatibilities.

The chemicals present in the BCL content codes conform to the list of allowable materials in Attachment B of Appendix 4.10.2 of the CNS 10-160B SAR and thereby meet the chemical compatibility requirements. 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~~ the shipping period (see Attachment C of Appendix 4.10.2 of the CNS 10-160B SAR).

- 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

Compliance with the CNS 10-160B cask design pressure limit for each BCL 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	$G_{eff}(RT)$[a]	Void Volume (Liters)	Activation Energy (kcal/mole)	Decay Heat Limit per Cask (Watts)	G_{eff}[b]	P_{max}[c] (psig)
BC 121A	8.1	1938	2.1	2.26	14.19	31.13
BC 121B	8.1	1938	2.1	2.26	14.19	31.13
BC 312A[d]	--	--	--	--	--	--
BC 314A	0.72	1938	0	~~7.23~~11.43[e]	0.72	~~12.02~~14.17
BC 321A	8.1	1938	2.1	~~1.96~~2.26[e]	14.19	~~28.10~~31.13
BC 321B	8.1/2.1[fe]	1938	2.1	~~2.03~~4.17[e]	4.65	~~15.03~~22.10
BC 322A	0.024	1938	0	~~217~~342.8[e]	0.024	~~12.02~~14.17

[a] G value for net gas (molecules per 100 eV) at room temperature (70°F).
[b] Effective 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.
[c] Maximum pressure.
[d] This code consists of solidified organics; compliance with pressure limits will be shown by testing.
[e] Decay heat limit per cask from 10-day controlled shipment. This is the maximum decay heat for this content code.
[fe] BC 321B reports 12% cellulosics and 80% resins (remainder being inorganic material) and is reflected in the calculation of the temperature-corrected G_{eff}.

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 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.

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.

Table 8-1. Minimum Filter Vent Specifications				
	Filter Specification			
Container/Filter Type	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 Filter	1	35	99.5	3.70E-6
Drum Liner Filter	1	35	NA[b]	3.70E-6

[a] Filters 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).
[b] Filters 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 rigid polyethylene liner, if present, in a payload container shall be punctured with a 1-inch diameter hole before the container is transported in the CNS 10-160B.

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 and liners, if present, shall be visually inspected to ensure that they have been fitted with the required number of filter vents or required hole diameter 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 TBq (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 DD-98-04, Waste Characterization, Classification and Shipping Support Technical Basis Document, and 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 BCL West Jefferson North facility in low isotopic enrichments (Reference 12.2). 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 content codes for the BCL TRU wastes described in this section. Attachment D describes the special methodology used to assure compliance with hydrogen gas concentration requirements for BCL Shipment Number 12.

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 ~~a 60-day~~the shipping period (Attachment C of this appendix to the CNS 10-160B SAR). A CNS 10-160B cask payload must be assembled of payload containers belonging to the same content code. Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided 1) the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit, or 2) through a demonstration using a payload-specific mixing analysis/calculation, the individual payload containers within a payload can be shown to have decay heats and/or hydrogen gas generation rates below payload-specific limits determined to assure the 5% flammable gas concentration limit is met.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

As stated in Appendix 4.10.2 of the CNS 10-160B SAR, chemical, biological, and thermal gas generation mechanisms are insignificant in the CNS 10-160B cask. In addition, as shown in Section 5.1 of Appendix 4.10.2 of the CNS 10-160B SAR, 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~~ the maximum shipping period (see Attachment C of Appendix 4.10.2 of the CNS 10-160B SAR).

Attachment A provides the TRU waste content codes for the BCL 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 TRU content codes for BCL wastes are listed in Table 10-1A for the 60-day shipping period (see Attachment C of the Appendix 4.10.2 of the CNS 10-160B SAR) and Table 10-1B for the 10-day controlled shipment shipping period (see Attachment C of this appendix). (Ssee Attachment A of Appendix 4.10.2 of the CNS 10-160B SAR for a description of the Matrix Depletion Program and dose-dependent G values).

10.3 Determination of Maximum Allowable Hydrogen Generation Rates for Content Codes

The maximum allowable hydrogen generation rates were determined using the modeling methodology described in Appendix 4.10.2 of the CNS 10-160B SAR and the following input parameters.

Waste Packaging Configuration and Release Rates: Each content code has a unique packaging configuration that is completely defined. The waste described by content codes BC 312A, BC 314A, BC 321A, and BC 322A will be placed directly into a 55-gallon drum lined with a steel liner. The waste described by content code BC 321B will also be placed directly into a 55-gallon drum that may be lined with a steel liner or a polyethylene liner. The waste described by content codes BC 121A and BC 121B will be placed into a 55-gallon drum that may be lined with a polyethylene 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. Note that, if used, the polyethylene liner in content codes BC 121A and BC 121B is punctured with a 1-inch diameter hole. For BC 321B if a rigid polyethylene liner is used the release rate associated with liner lid hole is conservatively assumed to be the same as that of the steel liner filter. These are based on release rates obtained for filters (Reference 12.3) 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 Volume in the CNS 10-160B IV: The cask will have a payload of 10 drums and a drum carriage. The interior volume of the cask, V_{cask}, is 4438 liters. The volume occupied by the drum carriage, $V_{carriage}$, is 143.2 liters. The external volume of a single drum, V_{drum}, is 235.7 liters. The void volume within the cask is calculated as:

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

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

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

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 60-day~~ the shipping period (Attachment C of Appendix 4.10.2 of the CNS 10-160B SAR) would be negligible compared to the quantity of air initially present at the time of sealing the CNS 10-160B cask.

Table 10-1A Maximum Allowable Hydrogen Generation Rates and Decay Heat Limits 60-Day Shipping Period						
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 (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose > 0.012 watt*year)
BC 121A	3.944E-8	3.944E-7	0.081	0.81	0.238	2.26[a]
BC 121B	4.745E-8	4.745E-7	0.101	1.01	0.298	2.26[a]
BC 312A	3.429E-8	3.429E-7	[b] —	[b] —	[b] —	[b] —
BC 314A	3.429E-8	3.429E-7	0.723	7.23	0.723	7.23
BC 321A	3.429E-8	3.429E-7	0.096	0.96	0.196	1.96
BC 321B	3.429E-8	3.429E-7	0.181	1.81	0.203	2.03
BC 322A	3.429E-8	3.429E-8	21.7	~~217~~100[c]	21.7	~~217~~100[c]

[a] Constrained by total decay heat that will comply with design pressure limit (see Table 7-1).
[b] No decay heat limit or activity limit due to unknown G value.
[c] Constrained by package limit of 100 watts.

Table 10-1B Maximum Allowable Hydrogen Generation Rates and Decay Heat Limits 10-Day Controlled Shipment Shipping Period						
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 (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose > 0.012 watt*year)
BC 121A	6.848E-08	6.848E-07	0.164	1.64	0.482	2.26[a]
BC 121B	9.691E-08	9.691E-07	0.277	2.26[a]	0.814	2.26[a]
BC 312A	5.431E-08	5.431E-07	[b] —	[b] —	[b] —	[b] —
BC 314A	5.431E-08	5.431E-07	1.142	11.42	1.142	11.42
BC 321A	5.431E-08	5.431E-07	0.197	1.97	0.402	2.26[a]
BC 321B	5.431E-08	5.431E-07	0.371	3.71	0.417	4.17
BC 322A	5.431E-08	5.431E-07	34.27	100[c]	34.27	100[c]

[a] Constrained by total decay heat that will comply with design pressure limit (see Table 7-1).
[b] No decay heat limit or activity limit due to unknown G value.
[c] Constrained by package limit of 100 watts.

Table 10-2. Release Rates of Hydrogen

Content Code	Confinement Layer	Release Rate (mol/sec/mol fraction)	
		T = 233K	T = 348.6K
BC 121A	Polyethylene Liner	5.20×10^{-4}	5.66×10^{-4}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 121B	Liner bag	4.67×10^{-6}	4.67×10^{-6} [a]
	Polyethylene liner	5.20×10^{-4}	5.66×10^{-4}
	Drum filter	2.46×10^{-6}	4.98×10^{-6}
BC 312A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 314A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 321A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 321B	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 322A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}

[a] This is the minimum measured value and is applicable to all temperatures.

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. Release rates increase with increasing temperature (Reference 12.4). 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.

10.4 Determination of Maximum Allowable Decay Limits

The maximum allowable decay heat limits for the CH-TRU and RH-TRU waste content codes for BCL were calculated using the methodologies described in Appendix 4.10.2 of the CNS 10-160B SAR and the content code-specific G values and waste data described below.

10.4.1 G Value Data

G values for 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 10-160B cask (168°F) using the Arrhenius equation. The maximum operating temperature yields the lowest decay heat limits for the operating temperature range of the CNS 10-160B cask.

Table 10-3 summarizes the bounding G values for hydrogen and the activation energies for the G values for these different content codes at the temperature that provides the minimum decay heat limit. Materials determining these bounding G values are also listed in Table 10-3. These G values are further discussed by content code below.

Dose-dependent G values for the authorized content codes are provided in Table 10-4 at the temperature that provides the minimum decay heat limit (i.e., 348.6K, the maximum operating temperature). The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.10.2 of the CNS 10-160B SAR.

BC 121A and BC 121B

These content codes represent solid organic debris consisting of various combustible and non-combustible items. The material present in this waste with the highest G value at the maximum operating temperature of the CNS 10-160B cask (168°F) is cellulosics and is therefore considered as the bounding material. The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/ 100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.10.2 of the CNS 10-160B SAR. The G values at 70°F are adjusted to the maximum operating temperature of the CNS 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the CNS 10-160B cask (168°F), the bounding hydrogen G values for cellulosics are 5.61 molecules/100 eV (dose = 0.012 watt*year) and 1.91 molecules/100 eV (dose > 0.012 watt*year).

Table 10-3. Summary of Bounding G Values (Dose = 0.012 watt*year)

Content Code	Waste Material	Maximum Hydrogen Gas G value at 70°F (molecules/ 100 eV)	Bounding Hydrogen Gas G Value (molecules/100 eV)			Activation Energy (kcal/mole)
			a-radiation	ß-radiation	?-radiation	
BC 121A	Cellulose	3.2	5.61			2.1
BC 121B	Cellulose	3.2	5.61			2.1
BC 312A	Oils/Alcohol	-	-	-	-	-
BC 314A	30% Water	0.48	0.48	0.48	0.48	0
BC 321A	Cellulose	3.2	4.60	5.61	5.61	2.1
BC 321B	12% Cellulose + 80% Resins	1.74	2.51	3.06	3.06	2.1
BC 322A	1% Water	0.016	0.016	0.016	0.016	0

Table 10-4. Summary of Bounding G Values (Dose > 0.012 watt*year)

Content Code	Waste Material	Maximum Hydrogen Gas G value at 70°F (molecules/ 100 eV)	Bounding Hydrogen Gas G Value (molecules/100 eV)			Activation Energy (kcal/mole)
			a-radiation	ß-radiation	?-radiation	
BC 121A	Cellulose	1.09	1.91			2.1
BC 121B	Cellulose	1.09	1.91			2.1
BC 312A	Oils/Alcohol	-	-	-	-	-
BC 314A	30% Water	0.48	0.48	0.48	0.48	0
BC 321A	Cellulose	1.09	1.57	1.91	5.61	2.1
BC 321B	12% Cellulose + 80% Resins	1.74	2.15	2.62	3.06	2.1
BC 322A	1% Water	0.016	0.016	0.016	0.016	0

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 solidified cement slugs. 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 all temperatures because the activation energy is 0 kcal/mole). There is no dose dependent G value for this content code per Attachment A of Appendix 4.10.2 of the CNS 10-160B SAR.

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. The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.10.2 of the CNS 10-160B SAR. The G values at 70°F are adjusted to the maximum operating temperature of the CNS 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the CNS 10-160B cask (168°F), the bounding hydrogen G values for cellulosics are 5.61 molecules/100 eV (dose = 0.012 watt*year) and 1.91 molecules/100 eV (dose > 0.012 watt*year).

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. G values for this content code at the maximum operating temperature (348.6K) are listed in Tables 10-3 and 10-4.

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 all temperatures because the activation energy is 0 kcal/mole). There is no dose dependent G value for this content code per Attachment A of Appendix 4.10.2 of the CNS 10-160B SAR.

10.4.2 Waste 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, cm^3
- Waste Mass – mass of the waste, g
- G Value – G value of the waste, molecules per 100 eV

Liquids and gas wastes are prohibited in the CNS 10-160B cask. The volume of the waste is assumed to be 217 liters per drum (the external volume of the waste drum) and 2170 liters for 10 drums in the cask. The waste volume is used by RadCalc, along with the waste mass, to determine the volume of hydrogen generated in the cask. The mass of the waste is calculated based on the assumed bulk density of the waste. The volume of hydrogen generated is directly proportional to the mass of the waste, as discussed in Reference 12.5. The most conservative estimate of the volume of hydrogen (greatest volume) would occur at the highest possible bulk density of the waste. The waste bulk densities for content codes BC 321A and BC 321B are conservatively assumed to be 0.55 g/cm^3 and 0.36 g/cm^3, respectively. A conservative bounding waste bulk density of 1.5 g/cm^3, obtained from Reference 12.6, is used for content codes BC 314A and BC 322A, consisting of cement and metal scrap as bounding materials, respectively. Representative waste drum data for these content codes provide waste bulk densities well below the 1.5 g/cm^3 bounding bulk density used to calculate the decay heat limits. This mass of waste is calculated based on the total volume of the 10 waste drums (2170 liters).

10.4.3 Determining Decay Heats

Methods for demonstrating compliance of the BCL TRU waste with the decay heat and hydrogen gas generation rate limits are shown in Attachment B.

10.5 Methodology for Compliance with Payload Assembly Requirements

The TCO shall ensure that the CNS 10-160B cask payload consists of payload containers belonging to the same content code. In the event that payload containers of different content codes with different bounding G values and resistances are assembled together in the CNS 10-160B cask, the TCO shall ensure that the decay heat and hydrogen gas generation rate for all payload containers within the payload are less than or equal to the limits associated with the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

11.0 WEIGHT

11.1 Requirements

The weight limit for the contents of 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 and evaluate compliance with the maximum loaded cask weight limit.

12.0 REFERENCES

12.1 U.S. Department of Energy (DOE), 2002, "Contact Handled-Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant," Rev. 0, *DOE/WIPP-02-3122*, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

12.2 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

12.3 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.

12.4 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.

12.5 Flaherty, J.E., A. Fujita, C.P. Deltete, and G.J. Quinn, 1986, "A Calculational Technique to Predict Combustible Gas Generation in Sealed Radioactive Waste Containers," *GEND 041*, EG&G Idaho, Inc., Idaho Falls, Idaho.

12.6 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.

Attachment A

Transuranic Content Codes and Chemical Lists
for Battelle Columbus Laboratories

CONTENT CODE: BC 121

CONTENT DESCRIPTION: Solid Organic Waste – CH-TRU Waste

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible items, and solidified organic and inorganic liquid wastes.

GENERATING SOURCES: This waste is generated from activities supporting the decontamination and decommissioning of Building JN-4 under the Battelle Columbus Laboratories Decommissioning Project (BCLDP).

WASTE FORM: The waste includes combustible items such as cloth and paper products, plastic, cardboard, rubber, wood, tubing, hoses, gloves, and filter waste (e.g., filters and filter housings). The waste includes noncombustible items such as crushed metal cans, scrap metal, piping, paint chips, hand tools, nuts, bolts, nails, Plexiglas, glass, and crucibles. The waste also includes solidified liquids, soil or dirt, and equipment such as vacuum cleaners.

WASTE PACKAGING: For content code BC 121A the waste is contained with one drum liner bag that is then placed inside a rigid polyethylene drum liner, which if present, is punctured with a 1-inch-diameter hole. Ten drums will then be placed into the CNS 10-160B cask. For content code BC 121B waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum may be lined with a rigid polyethylene liner punctured with a 1-inch diameter hole. 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 repackaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Liquid waste will be solidified using Floor Dry. 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 (e.g., aerosol cans) shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics (e.g., sodium potassium) 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 and the rigid liner, if present, is vented with 1.0-inch minimum diameter hole.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limits are ~~summarized~~listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period~~the table below~~.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limits are ~~summarized~~listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period~~the table below~~.

~~**Maximum Allowable Hydrogen Gas Generation Rates and Decay Heat 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 (Dose<=0.012 watt*year)~~	~~Maximum Allowable Decay Heat Limit, Watts/Cask (Dose<=0.012 watt*yr)~~	~~Maximum Allowable Decay Heat Limit, Watts/Drum (Dose>0.012 watt*year)~~	~~Maximum Allowable Decay Heat Limit, Watts/Cask (Dose>0.012 watt*year)~~
~~BC-121A~~	~~3.944E-8~~	~~3.944E-7~~	~~0.081~~	~~0.81~~	~~0.238~~	~~2.26~~
~~BC-121B~~	~~4.745E-8~~	~~4.745E-7~~	~~0.101~~	~~1.01~~	~~0.298~~	~~2.26~~

BATTELLE COLUMBUS LABORATORIES CONTENT CODES BC 121A AND BC 121B
SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CARDBOARD
CELLULOSICS
CLOTH
CONCRETE
DIATOMACEOUS EARTH (FLOOR DRY)
DIRT
EQUIPMENT (including vacuum cleaner, motors, and dosimeter system)
FILTERS
GLASS
HYDRAULIC OIL, GLYCOLS, OILS, AND ALCOHOLS (including butanol, ethanol, and methanol)
METALS (including mercury, brass, lead shielding, lead shot, silver, stainless steel, aluminum, iron, copper beryllium, and zirconium)
OTHER INORGANICS
PAINT CHIPS (including barium, cadmium, chromium, and lead)
PAPER
PLASTER-OF-PARIS
PLASTIC
PLEXIGLAS
RADSORB
RUBBER
SOIL
WOOD

MATERIALS AND CHEMICALS <1%

ACIDS AND ACID SOLUTIONS
METALS (including lithium and sodium [reacted; dissolved in butyl alcohol])
SOLVENTS (including acetone, benzene, ethyl alcohol, butyl alcohol, methyl alcohol, ethyl benzene, toulene, hexane, methyl ethyl ketone, trichloroethylene, Marine Strip [contains methylene chloride])
WATER

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.

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 limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 3.429E-08 moles per second per drum and 3.429E-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
VERMICULITE
RADSORB
AQUA-SET/PETRO-SET

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 water 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 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 limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per CNS 10-160B cask~~.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 0.723 watts per drum and 7.23 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)
CEMENT 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., 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 limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per CNS 10-160B cask~~.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 0.096 watts per drum and 0.96 watts per CNS 10-160B cask if dose #0.012 watt*yr and 0.196 watts per drum and 1.96 watts per CNS 10-160B cask if dose >0.012 watt*yr~~.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 321A
SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

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

MATERIALS AND CHEMICALS <1%

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

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 may be lined with a steel or polyethylene 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, and the steel or polyethylene liner, if present, is either punctured or 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 limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per CNS 10-160B cask~~.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 0.181 watts per drum and 1.81 watts per CNS 10-160B cask if dose #0.012 watt*yr and 0.203 watts per drum and 2.03 watts per CNS 10-160B cask if dose >0.012 watt*yr~~.

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
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 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 limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period ~~is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per CNS 10-160B cask~~.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limits are listed in Table 10-1A for the 60-day shipping period and Table 10-1B for the 10-day controlled shipment shipping period. ~~is 21.7 watts per drum and 217 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

MATERIALS AND CHEMICALS <1%

CARBON TETRACHLORIDE
1,1,1-TRICHLOROETHANE
TRICHLOROETHYLENE

Attachment B

Methodology for Determination of Decay Heats and Hydrogen Gas Generation Rates for Content Codes for Battelle Columbus Laboratories

1.0 INTRODUCTION

All Battelle Columbus Laboratories Decommissioning Project (BCLDP) transuranic (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 methods used in conjunction with acceptable knowledge by the BCLDP.

The overall methodology for the determination of the radioassay properties is described in DD-98-04, Waste Characterization, Classification, and Shipping Support Technical Basis Document and is summarized in Figure 1. Under the methodology, the isotopic content for an identified TRU waste stream is determined by a combination of (1) representative waste stream sample analyses, (2) conservative application of the Oak Ridge Isotope Generation and Depletion (ORIGEN2) code values for isotopes expected to be present, but not represented by the sample analyses, and (3) assessment of cesium (Cs)-137 content of a payload container based on external radiation field measurements and calculation of TRU isotopic content using a ratio of radionuclides based on known Cs-137 content. The determinations are verified on an approved, periodic basis by sample submission to the BCLDP Radioanalytical Laboratory for gamma and/or alpha spectroscopy. The results of the implementation of the DD-98-04 methodology provide the data inputs to the Microsoft Access database~~computer program (spreadsheet)~~ used by the TRU Waste Transportation Certification Official to determine the parameters of interest for each payload container (including fissile grams equivalent and decay heat).

Since the gamma rays emitted by radionuclides can be readily detected and quantified by common measurement techniques, i.e., as a dose rate, emitted gamma are used to model the quantity of isotopes present in a standard waste stream. Verifying samples are analyzed for both gamma and alpha emitters. Because isotopes other than gamma emitters are known to be present, laboratory measurements of the isotopic distribution are combined with a computer-generated distribution of account for required isotopes, e.g., per U.S. Department of Transportation requirements. The measured isotopic distribution is based on laboratory analysis (alpha and gamma spectroscopy) of air, smear and material samples taken from throughout the accessible work areas of Building JN-1. Using the measured distribution as a base, the remaining isotopes are scaled according to the distribution generated by the ORIGEN2 computer code, which models the production and decay of fission and activation products of commercial nuclear power plant fuel. Commercial fuel best characterizes the overwhelming majority of the isotopes present, by isotope and relative ratio.

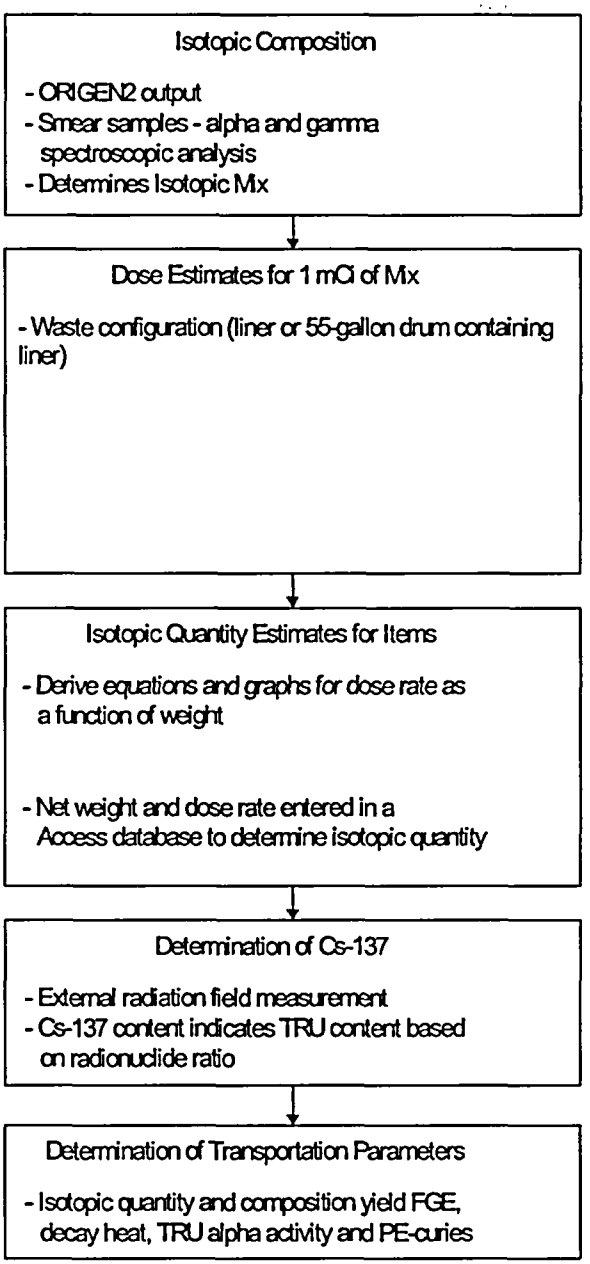

Figure 1
BCLDP Methodology for Determination
of Radioassay Properties for TRU Waste

The "JN standard isotopic mixture" used in the model is representative of the composition of the majority of radioactive waste generate in all areas of the BCL facility, except the pool. Waste from the

pool is separately characterized based on sample results. In addition to the pool waste, other waste streams may be encountered that do not match the JN standard isotopic mix (e.g., sludges). In such cases, the newly characterized waste will be characterized based on specific analytical results (alpha and gamma spectroscopy).

A given quantity of the JN standard isotopic mixture is used as the radioactive material source with the MicroShield ~~QAD~~ computer shielding code to generate external gamma ray ~~interaction~~ exposure rates for various package and form weights. These interaction rates are used to generate ~~interaction~~ exposure rates-to-weight conversion equations for each package and waste form. The equations are incorporated into a Microsoft Access database ~~spreadsheets~~ so that activity content~~, in millicuries,~~ for individual packages ~~and waste forms~~ can be calculated. ~~Spreadsheets are also used to calculate TRU interaction rate levels, and plots of these values as a function of net container weight are provided for each container type to simplify field sorting and packaging.~~

Required MicroShield~~QAD~~ inputs include source and package dimensions including any shielding materials, and quantities of individual isotopes that make up the source (i.e., JN standard isotopic mixture). MicroShield~~QAD~~ calculations are performed for a range of representative weights for each package. Specific package models include a liner and a 55-gallon drum containing a liner. ~~field sort waste bag, metal case, IP-2 147 cubic feet box, standard D box, 55 gallon drum, and standard B-25 box models.~~ The final packaging configuration for BCL TRU waste is the 55-gallon drum containing a liner.

Waste matrices are modeled as ~~either cellulose or~~ iron. ~~The cellulose matrix represents the varied composition of the bag and D box models, which are composed of plastics, wood, cloth, etc., and are similar to cellulose in their electronic configuration. The iron matrix is used for the B-25 box and 55-gallon drum models, which include a range of more dense materials, including concrete. The choice of waste matrices is conservative as the physical properties of cellulose and iron relative to radiological parameters are well characterized.~~ It is important to note that the representative weights for 55-gallon drums containing waste typically~~, for example,~~ correspond to a density much less than the density of iron (7.86 g/cm^3), on the close order of less than 1.0 g/cm^3.

As detailed in DD-98-04, estimated uncertainties associated with the container weight, Cs-137 activity based on measurement of decay gammas emanating from the container, and estimation of inventories of other radionuclides and total transuranics based on measured or predicted ratios to Cs-137 activity have been factored into the determinations of an upper bounding uncertainty for the methodology.

The application of the ORIGEN2 code in the proposed BCLDP TRU Waste Certification Program methodology for determining radioassay properties for 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. The following subsection provides details on the application of the ORIGEN2 code for determining the radioassay properties.

Application of ORIGEN2 Code

The ORIGEN2 code (RSIC Code Package CCC-371) is used in the DD-98-04 methodology. Characterization of the JN standard isotopic distribution depended upon whether available data existed to permit estimation of the normalized activity ratio (to Cs-137 activity) for the isotopes of interest. Where sufficient data were available, a lognormal fit was used. Where insufficient data was available, the results of a series of ORIGEN2 software analyses were employed.

For Am-241, Cm-244, Co-60, Cs-134, Eu-154, Np-237, Pu-238, Pu-239/-240, Sb–125, Sr-90, U-234, and U-238, as many as 69 samples from the anticipated waste stream were available. A two-parameter (μ, σ)

lognormal distribution was fitted to these data. The mean parameter (μ) estimated for each studied isotope represented its assumed normalized activity ratio (to Cs-137) in the standard isotopic distribution. The estimated spread parameter (σ) was used in considering the total uncertainty associated with the waste characterization.

For the isotopes of interest, the computer code ORIGEN2 was used to estimate their normalized activity ratio (to Cs-137). Specifically, values were assumed for enrichments, burn-up, and decay consistent with the processed used to generate the waste stream being classified. These values were then applied as parameters within the ORIGEN2 software, producing estimates of the activities of the various isotopes of interest.

Professional judgement consensus center, low, and high values were identified for each of these three parameters: enrichment, burn up, and decay. Taken together, these three values were meant to represent the central tendency and distribution (i.e., practical range) of the enrichment, burn up, and decay of potential waste streams. A deliberate choice was made to underestimate the decay time so as to make the resultant values conservative.

Twenty-seven iterations of ORIGEN2 software code would be required to consider each combination of these three values for each of three parameters (i.e., $3^3 = 27$). Additional code runs would be necessary, moreover, to provide some measure of the uncertainty associated with the application of ORIGEN2 in estimating the normalized activity ratios of the remaining isotopes of interest. Latin Hypercube sampling is an alternative approach, allowing for effective integration of computer code but with fewer runs. In order to apply these values in the context of a Latin Hypercube design, an assumed distribution is required for each parameter considered in the design. Because the low and high values for each parameter were not symmetric in relation to the center value, a skewed distribution was selected. The lognormal represents a skewed distribution that can be readily applied without additional mathematical complication. The log-transformed center value was assumed to represent the distribution's log mean, and its log standard deviation was derived by averaging the deviations of the log-transformed low and high values from the log mean. Specifically, the average deviation was assumed to represent 1.645 (i.e., the 0.95 quantile of a standard normal distribution) times the log-standard deviation. Doing so is equivalent to assuming the low and high values represent, on average, a range from the 5^{th} to the 95^{th} percentile of the distribution.

In using the ORIGEN2 software code to characterize the normalized activity ratios for the isotopes without available data, the Latin Hypercube employed in the DD-98-04 methodology assumed that values for enrichment, burn up, and decay and software together represent a 'black-box' estimation of normalized activity ratios. Using this approach, a series of replicate designs is applied. The mean result from each replicate design is considered when estimating the mean and variance in normalized activity.

Four replicates of a five-sample Latin Hypercube design were developed thereby providing 20 analysis runs. The distribution of each parameter was divided into five partitions of equal probability. Latin Hypercube sampling, then, insures that a random value of each partition is included in each of the five replicated designs, while minimizing the total number of required analysis runs.

The mean result across the 20 ORIGEN2 runs (or equivalently, the mean of the mean results determined for the four replicated designs) estimated for each studied isotope represents its assumed normalized activity ratio (to Cs-137) in the standard isotopic distribution. Though ORIGEN2 reports activities for all the isotopes of interest, only the results for those isotopes without sufficient available sample data are retained. The ORIGEN2 results and those based on available data are comparable. The estimated variance in mean result across the four replicate designs—a measure of the uncertainty associated with

using the ORIGEN2 software to characterize isotope activity—is used in considering the total uncertainty associated with the waste characterization.

3.0 OBJECTIVES OF THE GAS GENERATION TESTING

The maximum allowable hydrogen gas generation rates for the 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:

$$C_g = X_H \times L_{CF}$$

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).

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

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

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 C

10-Day Controlled-Shipment

1.0 Introduction

This attachment presents the shipping period determination for shipments designated as controlled shipments. For these shipments, the CNS 10-160B cask is loaded at the shipping site, transported from the shipping site to the receiving site, and vented within a maximum of 10 days from the closure (or sealing) of the inner vessel (IV). The basis for the 10-day shipping period is defined in this attachment. The use of a 10-day controlled shipment is an option available for Battelle Columbus Laboratories Decommissioning Project (BCLDP) waste. The shipping site shall impose administrative controls to ensure compliance with the conditions described herein. If the shipment is made without use of the controlled shipment option, the shipping period defined in Attachment C of Appendix 4.10.2, i.e., 60 days, shall be used.

2.0 Approach

The shipping period is defined to begin with closure (or sealing) of the IV during loading at the shipping facility and end with venting of the IV during unloading at the receiving facility. Conservative time estimates for the following activities were used in determining the shipping period for controlled shipments:

- Loading time
- Transport time
- Unloading time.

2.1 Loading Time

The loading time begins with the sealing of the IV and ends with the departure of the shipment of the package from the site. Activities to be completed during the loading time include leak testing and handling of the loaded package(s). As directed by site procedures for controlled shipments, these activities must be completed within 24 hours. If these activities are delayed beyond 24 hours, the package(s) must be vented and the closure process repeated.

2.2 Transport Time

The transport time begins with the departure of the shipment from the shipping site and ends with the arrival of the shipment at the receiving site. The transport time is dependent upon the distance between the shipping and receiving sites and capabilities for efficient response to potential transport time delays. As shown in Table C-1, at an average speed of 40 miles per hour (mph) the longest travel time from a shipping site to a receiving site is 57.1 hours (corresponding to the 2283-mile distance from BCL to Hanford). Controlled shipments shall be made only when the shipping distance between shipping site and receiving site is less than or equal to 2283 miles. This average speed takes into account stops for vehicle inspections every two hours, fueling, meals, driver relief, and state vehicle inspections.

Table C-1. Normal Transit Times										
			Transit Time in Hours (Miles per Hour)				Transit Time in Days (Miles per Hour)			
From	To	Distance (Miles)	40	45	50	55	40	45	50	55
BCL	ANL	345	8.6	7.7	6.9	6.3	0.4	0.3	0.3	0.3
BCL	Hanford	2283	57.1	50.7	45.7	41.5	2.4	2.1	1.9	1.7
BCL	INL	1869	46.7	41.5	37.4	34.0	1.9	1.7	1.6	1.4
BCL	LANL	1472	36.8	32.7	29.4	26.8	1.5	1.4	1.2	1.1
BCL	ORNL	358	9.0	8.0	7.2	6.5	0.4	0.3	0.3	0.3
BCL	SRS	620	15.5	13.8	12.4	11.3	0.6	0.6	0.5	0.5
BCL	WIPP	1910	47.8	42.4	38.2	34.7	1.9	1.8	1.6	1.4
ANL	WIPP	1727	43.2	38.4	34.5	31.4	1.7	1.6	1.4	1.3
Hanford	WIPP	1808	45.2	40.2	36.2	32.9	1.8	1.7	1.5	1.4
INL	WIPP	1392	34.8	30.9	27.8	25.3	1.4	1.3	1.2	1.1
LANL	WIPP	342	8.6	7.6	6.8	6.2	0.3	0.3	0.3	0.3
ORNL	WIPP	1440	36.0	32.0	28.8	26.2	1.4	1.3	1.2	1.1
SRS	WIPP	1540	38.5	34.2	30.8	28.0	1.5	1.4	1.3	1.2

The potential factors that could delay the normal transport time are as follows:

- Adverse weather
- Vehicle accidents
- Mechanical problems with the truck
- Driver illness.

Administrative controls in place at the shipping site prohibit the initiation of a controlled shipment at times when adverse weather exists or is forecasted. Any transport time delays associated with adverse weather are expected to be minimal and are, therefore, adequately covered by the margin of safety included in this analysis (see Section 3.0).

Prompt emergency response, truck maintenance, and driver or equipment replacement during the transport of controlled shipments is ensured by the application of additional resources. U.S. Department of Energy (DOE) transuranic (TRU) waste shipment administrative controls require the designation of a shipment as a "controlled shipment" prior to initiation of the shipment from the site. This designation provides a trigger that requires additional resources to be available in order to provide accelerated response to avoid any significant delay during the transport time. This controlled shipment protocol is in addition to the routine use of the TRANSCOM system employed by DOE TRU waste transporters, which provides continuous tracking of the shipment during transport from the shipping site to the receiving site.

Vehicle accidents have the potential for the longest transport time delays due to the time required to respond and perform required corrective actions. However, additional time may be required for notification and response of other appropriate authorities such as Radiological Assistance

Teams (if required). Deployment of other appropriate authorities such as Radiological Assistance Teams (if required) from the shipping facility, from the receiving facility, from the Waste Isolation Pilot Plant (WIPP), or other intermediate site, whichever is closer, would take no more than 1 day to reach an accident scene. Prompt mitigation of any accident is ensured by the application of DOE TRU waste transportation protocol for controlled shipments. Due to the additional resources available during controlled shipments, up to 2 days is considered appropriate for completing accident corrective actions. This time includes deployment of a backup truck and trailer, retrieving and transferring the package(s) to the backup vehicle, and performing any necessary surveys and/or inspections to confirm the shipment is prepared for continued transport.

Truck maintenance associated with common mechanical problems could result in transport time delays. The majority of routine mechanical problems (flat tires, belt or hose failures, etc.) can be rectified in a matter of hours. A worst-case mechanical problem would result in the need for a replacement truck, which is included in the time estimated for vehicle accident mitigation as described above.

The last remaining potential scenario for delaying the transport time is driver illness. The additional resources available for controlled shipments ensure prompt replacement of an ill driver. The time required to replace a driver is conservatively estimated as 1 day.
As a result of DOE TRU waste transportation protocols applied to shipments designated as controlled shipments, a 5-day transport time accounts for any unexpected impact to the expected transport time.

2.3 Unloading Time

The unloading time begins with the arrival of the shipment at the receiving site and ends with the venting of the IV. Operational procedures shall be in place at the receiving site to ensure that processing and unloading procedures for controlled shipments are initiated within 24 hours of shipment arrival regardless of holidays or other scheduled facility closure periods. Section 4.0 below outlines administrative controls imposed to ensure venting of the IV within 24 hours of shipment arrival.

3.0 Summary

Based on a loading time of 24 hours, an estimated transport time of less than 60 hours, and an unloading time of 24 hours, the normal expected shipping period for controlled shipments is 4 to 5 days. Using a conservatively estimated transport time of 5 days, the maximum expected shipping period for controlled shipments is 7 days. The additional contingency of a 3-day margin of safety results in a maximum shipping period of 10 days. Table C-2 provides a summary of the activities comprising the shipping period.

Table C-2 – Shipping Period Analysis Summary		
Activity	**Normal Expected Time (days)**	**Maximum Time Used in Analysis (days)**
Loading Time	<1	1
Transport Time	1-3	5
Unloading Time	<1	1
Margin of Safety	–	3
Shipment Time	3-5	10

This analysis justifies using a 10-day period as the basis for determining compliance with gas generation requirements under rigorous operational controls during loading, transport, and unloading as specified in this attachment.

4.0 Administrative Controls

Compliance with the 10-day shipping period is administratively controlled in accordance with the conditions of this attachment and through the following steps. The steps must be completed by the shipping site Transportation Certification Official, or designee, and designated receiving site operations personnel, as applicable.

Loading Time

The loading time begins with the closure of the IV and ends with the departure of the shipment from the shipping site. The loading time is limited to a maximum of 24 hours. The following steps must be completed to ensure compliance with the 24-hour loading time:

1. Record date and time on the Shipping Site Control Checklist for Controlled Shipments shown in Table C-3 below. Table C-3 may be reformatted for site use provided that the same information is recorded.

2. Note date and time that the shipment containing the loaded package is ready to depart the shipping site. Record date and time on the Shipping Site Control Checklist for Controlled Shipments (Table C-3).

3. Review dates and times recorded in Steps 1 and 2 to calculate total loading time. If total loading time is less than or equal to 24 hours, proceed to Step 4. If total Loading Time exceeds 24 hours, the package must be vented and the closure process must be repeated. Return to Step 1 above.

4. Indicate compliance with the 24-hour loading time by signature on the Site Control Checklist for Controlled Shipments (Table C-3).

Unloading Time

The unloading time begins with the arrival of the shipment at the receiving site and ends with the venting of the package. The maximum unloading time is 24 hours. The following steps must be completed to document compliance:

5. Note date and time that the package arrives at the receiving site. Record date and time on the Receiving Site Control Checklist for Controlled Shipments shown in Table C-4. Table C-4 may be reformatted for site use provided that the same information is recorded.

6. Using the date and time recorded in Step 5, ensure that the package is vented within 24 hours of the arrival of the shipment at the receiving site. Record date and time of venting to show compliance.

7. Indicate compliance with the 24-hour unloading time by signature on the Receiving Site Control Checklist for Controlled Shipments (Table C-4).

Table C-3 – Shipping Site Control Checklist for Controlled Shipments

Shipment No. _____ Packaging No._____

To be completed by Site Transportation Certification Officer, or designee, for each package designated as a controlled shipment:

Step Number	Activity	Recorded Date	Recorded Time	Completion of Activity (Indicate by checkmark [√])
1	Record date and time of IV closure			
2	Record date and time the shipment containing the loaded package is ready to depart from the shipping site destined for receiving site			
3	Calculate and record total Loading Time [Limit = 24 hours]	[redacted]		
	• *Total Loading Time ≤1 day, proceed to Step 4.* • *Total Loading Time > 1 day, STOP. Vent package and repeat closure process.*			
4	I certify that the above data is accurate and compliant with the Loading Time limit of 24 hours, as specified in Attachment C of Appendix 4.10.2.1 of the CNS 10-160B SAR. _____ / _____ TRANSPORTATION CERTIFICATION OFFICIAL (OR DESIGNEE) DATE			

Note: Controlled shipments (10 days) shall be made in accordance with the conditions specified in Attachment C of Appendix 4.10.2.1 of the CNS 10-160B SAR. This table may be reformatted for site use provided that the same information is recorded.

Table C-4 - Receiving Site Control Checklist for Controlled Shipments

Shipment No. _____ Packaging No._____

To be completed by designated receiving site operations personnel for each package designated as a controlled shipment:

Step Number	Activity	Recorded Date	Recorded Time	Completion of Activity (Indicate by checkmark [√])
5	Record date and time that the package arrives at receiving site			
6	Vent package within 24 hours of date and time recorded above and record vent date and time			
7	I certify that the above data is accurate and compliant with the Unloading Time limit of 24 hours, as specified in Attachment C of Appendix 4.10.2.1 of the CNS 10-160B SAR. _____ / _____ RECEIVING SITE OPERATIONS PERSONNEL DATE			

Note: Controlled shipments (10 days) shall be made in accordance with the conditions specified in Attachment C of Appendix 4.10.2.1 of the CNS 10-160B SAR. This table may be reformatted for site use provided that the same information is recorded.

Attachment D

Special Requirements for Shipment Number 12

1.0 INTRODUCTION

Shipment number 12 is comprised of a payload of ten drums. Six drums are Content Code BC 321A, two drums are Content Code 321B, 1 drum is Content Code BC 314A, and 1 drum is Content Code is BC 322A. The drums of Content Code BC 321A and BC 321B have decay heats plus error such that each of these drums is below the decay heat limit of Content Code BC 321A, which has the most restrictive decay heat limit.. The one drum of Content Code BC 314A and the one drum of Content Code BC 322A meet their respective content code decay heat limits, but exceed the decay heat limit of Content Code BC 321A. The purpose of the attachment is to demonstrate that for shipment number 12, all drums in the payload to be transported in the CNS 10-160B cask shall comply with the 5% (by volume) limit on hydrogen concentration during transport and that gases generated in the payload and released into the Inner Vessel (IV) cavity will 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). The demonstration is based on calculating bounding hydrogen and net gas generation rates for each container to show that the allowable rates are not exceeded during a 10-day controlled shipping period.

2.0 COMPLIANCE EVALUATION METHODOLOGY

The compliance evaluation methodology is based on bounding calculations employing the Radcalc code (Reference 9.1) to calculate the maximum hydrogen gas generation and net gas generation rates for each drum in order to demonstrate that the rates are below the appropriate rate limits. This attachment defines all the assumptions, input parameters and steps of the compliance evaluation methodology. The remainder of this attachment is organized according to the following summary of the methodology.

- Quantification of the isotopic composition of each drum in the payload of shipment number 12 (see Section 3.0).

- Calculation of the drum decay heat plus error for each drum on the assumed compliance date of October 31, 2005. These calculations were performed using the Radcalc code to perform the decay and in-growth calculations for the elapsed time between isotopic survey date and compliance date and the Curies to Watts conversion (see Section 4.0).

- Definition of bounding hydrogen G values (see Section 5.0).

- Calculation of the bounding radiolytic hydrogen gas generation rates on the compliance date due to a-radiation and ß-radiation for each drum. These calculations were performed by executing the Radcalc code (with one input file for each drum) with bounding hydrogen G values for a-radiation and ß-radiation (see Section 6.0).

- Calculation of the total activity of each isotope in the payload by summing the isotope activity present in each of the ten drums. Calculation of the bounding radiolytic hydrogen gas generation rate on the compliance date due to ?-radiation for each distinct Content Code-specific ?-radiation hydrogen G value. These calculations were performed by executing the Radcalc code (with one input file for each distinct ?-radiation hydrogen G value). Because there is one distinct bounding ?-radiation hydrogen G value for each of the four Content Codes represented in the shipment number 12, four executions of the Radcalc code were required. The resulting rate for each execution is based on the total isotopic activity from the ten drums. Thus, the Radcalc calculated hydrogen generation rate was divided by 10 for each of the four executions to arrive at the Content Code-specific ?-radiation radiolytic contribution (see Section 6.0)

- Calculation of the bounding total radiolytic hydrogen gas generation rate for each drum by summing the rates for a-radiation plus ß-radiation with the bounding ?-radiation rate. The total hydrogen gas generation rate for each drum was compared to the appropriate allowable hydrogen gas generation rate for that content code (see Section 6.0).

- Multiplication of the bounding hydrogen gas generation rate for each drum by the ratio of the Content Code-specific net gas G value to hydrogen gas G value to derive a bounding net gas generation rate for each drum. This is followed by aggregation of the individual drum net gas generation rates to calculate the maximum pressure increase in the IV during a 365-day period and comparison to the 31.2 psig packaging design limit.

3.0 ISOTOPIC CHARACTERIZATION

The overall methodology for the determination of the radioassay properties is described in DD-98-04, Waste Characterization, Classification and Shipping Support Technical Basis Document, and 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 isotopic characterization in terms of activity in Curies by isotope for each of the ten drums in shipment number 12 is summarized in Tables D-1 and D-2. Each activity value includes the error associated with the quantification technique.

Table D-1
Initial Radioactivity in Drums BC0034, BC0038, BC0095, BC0160, and BC0167.

Isotope	Drum BC0034 Activity (Ci)	Drum BC0038 Activity (Ci)	Drum BC0095 Activity (Ci)	Drum BC0160 Activity (Ci)	Drum BC0167 Activity (Ci)
Be-10	1.271E-09	6.997E-11	2.025E-11	1.148E-11	4.067E-12
C-14	3.186E-04	1.754E-05	5.076E-06	2.878E-06	1.020E-06
Si-32	1.051E-11	5.788E-13	1.675E-13	9.498E-14	3.364E-14
Cl-36	3.184E-06	1.753E-07	5.073E-08	2.877E-08	1.019E-08
K-40	1.261E-12	6.941E-14	2.009E-14	1.139E-14	4.035E-15
Ni-59	1.249E-04	6.878E-06	1.990E-06	1.129E-06	3.998E-07
Co-60	5.272E+00	2.902E-01	8.399E-02	4.763E-02	1.687E-02
Ni-63	1.541E-02	8.482E-04	2.455E-04	1.392E-04	4.930E-05
Se-79	1.011E-04	5.565E-06	1.611E-06	9.133E-07	3.235E-07
Sr-90	1.118E+01	6.152E-01	1.780E-01	1.010E-01	3.576E-02
Mo-93	1.786E-07	9.833E-09	2.846E-09	1.614E-09	5.716E-10
Nb-93m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Zr-93	4.724E-04	2.600E-05	7.525E-06	4.267E-06	1.512E-06
Nb-94	3.857E-08	2.123E-09	6.145E-10	3.485E-10	1.234E-10
Tc-99	3.208E-03	1.766E-04	5.111E-05	2.898E-05	1.027E-05
Ru-106	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pd-107	3.152E-05	1.735E-06	5.022E-07	2.848E-07	1.009E-07
Ag-108m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cd-109	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ag-110m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cd-113m	6.923E-03	3.811E-04	1.103E-04	6.255E-05	2.215E-05
Sn-119m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sn-121m	1.648E-04	9.074E-06	2.626E-06	1.489E-06	5.274E-07
Sb-125	7.802E-02	4.295E-03	1.243E-03	7.048E-04	2.497E-04
Te-125m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sb-126	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sn-126	2.054E-04	1.131E-05	3.272E-06	1.855E-06	6.572E-07
Te-127m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-129	8.100E-06	4.459E-07	1.290E-07	7.318E-08	2.592E-08

Table D-1
Initial Radioactivity in Drums BC0034, BC0038, BC0095, BC0160, and BC0167.

Isotope	Drum BC0034 Activity (Ci)	Drum BC0038 Activity (Ci)	Drum BC0095 Activity (Ci)	Drum BC0160 Activity (Ci)	Drum BC0167 Activity (Ci)
Ba-133	1.059E-28	5.832E-30	1.688E-30	9.571E-31	3.390E-31
Cs-134	7.004E-02	3.856E-03	1.116E-03	6.328E-04	2.241E-04
Cs-135	8.489E-05	4.673E-06	1.352E-06	7.669E-07	2.716E-07
Cs-137	1.703E+01	9.374E-01	2.713E-01	1.538E-01	5.449E-02
Ce-144	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pm-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sm-147	1.114E-09	6.132E-11	1.775E-11	1.006E-11	3.565E-12
Eu-150	2.873E-09	1.581E-10	4.577E-11	2.595E-11	9.193E-12
Sm-151	8.070E-02	4.442E-03	1.286E-03	7.290E-04	2.582E-04
Eu-152	6.388E-04	3.517E-05	1.018E-05	5.771E-06	2.044E-06
Gd-152	1.004E-16	5.526E-18	1.599E-18	9.070E-19	3.213E-19
Gd-153	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Eu-154	2.627E-01	1.446E-02	4.186E-03	2.374E-03	8.408E-04
Eu-155	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Tm-170	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Re-187	4.954E-12	2.727E-13	7.892E-14	4.475E-14	1.585E-14
Pb-210	5.484E-11	3.019E-12	8.737E-13	4.954E-13	1.755E-13
Po-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ra-226	2.544E-10	1.401E-11	4.053E-12	2.298E-12	8.141E-13
Ac-227	1.884E-09	1.037E-10	3.001E-11	1.702E-11	6.028E-12
Ra-228	3.397E-14	1.870E-15	5.412E-16	3.069E-16	1.087E-16
Th-228	7.832E-06	4.312E-07	1.248E-07	7.076E-08	2.506E-08
Th-229	5.095E-11	2.805E-12	8.118E-13	4.603E-13	1.631E-13
Th-230	5.227E-08	2.877E-09	8.327E-10	4.722E-10	1.673E-10
Pa-231	4.881E-09	2.687E-10	7.776E-11	4.409E-11	1.562E-11
Th-232	5.722E-14	3.150E-15	9.115E-16	5.169E-16	1.831E-16
U-232	7.868E-06	4.331E-07	1.253E-07	7.108E-08	2.518E-08
U-233	9.155E-09	5.040E-10	1.459E-10	8.271E-11	2.930E-11
Th-234	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
U-234	2.941E-04	1.619E-05	4.686E-06	2.657E-06	9.411E-07
U-235	4.296E-06	2.365E-07	6.845E-08	3.881E-08	1.375E-08
U-236	5.696E-05	3.136E-06	9.075E-07	5.146E-07	1.823E-07
Np-237	7.691E-05	4.234E-06	1.225E-06	6.948E-07	2.461E-07
Pu-238	8.221E-01	4.526E-02	1.310E-02	7.427E-03	2.631E-03
U-238	8.342E-05	4.592E-06	1.329E-06	7.537E-07	2.670E-07
Pu-239	1.056E-01	5.813E-03	1.682E-03	9.539E-04	3.379E-04
Pu-240	1.722E-01	9.477E-03	2.743E-03	1.555E-03	5.509E-04
Am-241	8.534E-01	4.698E-02	1.360E-02	7.710E-03	2.731E-03
Pu-241	1.385E+01	7.623E-01	2.206E-01	1.251E-01	4.431E-02
Am-242m	1.704E-03	9.382E-05	2.715E-05	1.540E-05	5.454E-06
Cm-242	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Table D-1
Initial Radioactivity in Drums BC0034, BC0038, BC0095, BC0160, and BC0167.

Isotope	Drum BC0034 Activity (Ci)	Drum BC0038 Activity (Ci)	Drum BC0095 Activity (Ci)	Drum BC0160 Activity (Ci)	Drum BC0167 Activity (Ci)
Pu-242	5.151E-04	2.836E-05	8.206E-06	4.653E-06	1.648E-06
Am-243	6.378E-03	3.511E-04	1.016E-04	5.762E-05	2.041E-05
Cm-243	4.475E-03	2.464E-04	7.130E-05	4.043E-05	1.432E-05
Cm-244	6.873E-01	3.783E-02	1.095E-02	6.209E-03	2.199E-03
Pu-244	2.200E-10	1.211E-11	3.505E-12	1.988E-12	7.041E-13
Cm-245	1.093E-04	6.019E-06	1.742E-06	9.877E-07	3.499E-07
Cm-246	3.744E-05	2.061E-06	5.966E-07	3.383E-07	1.198E-07
Cm-247	1.742E-10	9.591E-12	2.776E-12	1.574E-12	5.575E-13
Cm-248	7.161E-10	3.942E-11	1.141E-11	6.469E-12	2.291E-12
Cf-249	1.023E-08	5.632E-10	1.630E-10	9.243E-11	3.274E-11
Cf-250	2.401E-08	1.322E-09	3.825E-10	2.169E-10	7.684E-11
Cm-250	1.648E-16	9.071E-18	2.625E-18	1.489E-18	5.273E-19
Cf-251	4.055E-10	2.232E-11	6.459E-12	3.663E-12	1.297E-12

Table D-2
Initial Radioactivity in Drums BC0138, BC0130, BC0127, BC0124, and BC0148.

Isotope	Drum BC0138 Activity (Ci)	Drum BC0130 Activity (Ci)	Drum BC0127 Activity (Ci)	Drum BC0124 Activity (Ci)	Drum BC0148 Activity (Ci)
Be-10	1.688E-10	1.608E-11	4.176E-12	1.646E-11	3.453E-08
C-14	4.232E-05	4.030E-06	1.047E-06	4.126E-06	1.388E-06
Si-32	1.397E-12	1.330E-13	3.454E-14	1.362E-13	0.000E+00
Cl-36	4.230E-07	4.028E-08	1.046E-08	4.124E-08	0.000E+00
K-40	1.675E-13	1.595E-14	4.143E-15	1.633E-14	0.000E+00
Ni-59	1.660E-05	1.580E-06	4.105E-07	1.618E-06	0.000E+00
Co-60	7.003E-01	6.668E-02	1.732E-02	6.828E-02	0.000E+00
Ni-63	2.047E-03	1.949E-04	5.062E-05	1.995E-04	0.000E+00
Se-79	1.343E-05	1.279E-06	3.321E-07	1.309E-06	4.846E-03
Sr-90	1.484E+00	1.414E-01	3.672E-02	1.447E-01	4.409E+02
Mo-93	2.373E-08	2.259E-09	5.868E-10	2.313E-09	0.000E+00
Nb-93m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.603E-02
Zr-93	6.274E-05	5.975E-06	1.552E-06	6.117E-06	2.153E-02
Nb-94	5.123E-09	4.879E-10	1.267E-10	4.995E-10	1.642E-06
Tc-99	4.261E-04	4.058E-05	1.054E-05	4.155E-05	1.567E-01
Ru-106	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.831E-05

Table D-2
Initial Radioactivity in Drums BC0138, BC0130, BC0127, BC0124, and BC0148.

Isotope	Drum BC0138 Activity (Ci)	Drum BC0130 Activity (Ci)	Drum BC0127 Activity (Ci)	Drum BC0124 Activity (Ci)	Drum BC0148 Activity (Ci)
Pd-107	4.187E-06	3.987E-07	1.036E-07	4.082E-07	1.320E-03
Ag-108m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.886E-07
Cd-109	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.617E-12
Ag-110m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.098E-11
Cd-113m	9.196E-04	8.757E-05	2.275E-05	8.966E-05	1.647E-01
Sn-119m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.626E-13
Sn-121m	2.189E-05	2.085E-06	5.415E-07	2.135E-06	1.631E-03
Sb-125	1.036E-02	9.868E-04	2.563E-04	1.010E-03	1.301E-01
Te-125m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.175E-02
Sb-126	2.728E-05	2.598E-06	6.747E-07	2.660E-06	1.265E-03
Sn-126	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.035E-03
Te-127m	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.883E-27
I-129	1.076E-06	1.025E-07	2.661E-08	1.049E-07	3.726E-04
Ba-133	1.407E-29	1.340E-30	3.481E-31	1.372E-30	0.000E+00
Cs-134	9.304E-03	8.859E-04	2.301E-04	9.071E-04	1.296E-01
Cs-135	1.128E-05	1.074E-06	2.789E-07	1.099E-06	4.307E-03
Cs-137	2.262E+00	2.154E-01	5.594E-02	2.205E-01	8.147E+02
Ce-144	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.235E-07
Pm-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.153E-01
Sm-147	1.480E-10	1.409E-11	3.660E-12	1.443E-11	5.425E-08
Eu-150	3.816E-10	3.634E-11	9.438E-12	3.720E-11	6.803E-08
Sm-151	1.072E-02	1.021E-03	2.651E-04	1.045E-03	3.633E+00
Eu-152	8.485E-05	8.080E-06	2.099E-06	8.273E-06	1.566E-02
Gd-152	1.334E-17	1.270E-18	3.298E-19	1.300E-18	0.000E+00
Gd-153	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.565E-15
Eu-154	3.490E-02	3.323E-03	8.632E-04	3.403E-03	8.996E+00
Eu-155	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.261E+00
Tm-170	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.542E-29
Re-187	6.580E-13	6.266E-14	1.628E-14	6.416E-14	0.000E+00
Pb-210	7.285E-12	6.937E-13	1.802E-13	7.102E-13	9.912E-13
Po-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.175E-13
Ra-226	3.379E-11	3.218E-12	8.358E-13	3.295E-12	5.183E-12
Ac-227	2.502E-10	2.382E-11	6.188E-12	2.439E-11	7.227E-12
Ra-228	4.512E-15	4.297E-16	1.116E-16	4.399E-16	0.000E+00
Th-228	1.040E-06	9.907E-08	2.573E-08	1.014E-07	0.000E+00
Th-229	6.768E-12	6.445E-13	1.674E-13	6.599E-13	5.127E-10
Th-230	6.943E-09	6.611E-10	1.717E-10	6.769E-10	1.121E-09
Pa-231	6.483E-10	6.173E-11	1.603E-11	6.321E-11	2.570E-11
Th-232	7.600E-15	7.237E-16	1.880E-16	7.410E-16	0.000E+00
U-232	1.045E-06	9.952E-08	2.585E-08	1.019E-07	0.000E+00
U-233	1.216E-09	1.158E-10	3.008E-11	1.186E-10	4.932E-07

Table D-2
Initial Radioactivity in Drums BC0138, BC0130, BC0127, BC0124, and BC0148.

Isotope	Drum BC0138 Activity (Ci)	Drum BC0130 Activity (Ci)	Drum BC0127 Activity (Ci)	Drum BC0124 Activity (Ci)	Drum BC0148 Activity (Ci)
Th-234	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.474E-06
U-234	3.907E-05	3.720E-06	9.662E-07	3.809E-06	6.147E-06
U-235	5.707E-07	5.434E-08	1.412E-08	5.564E-08	5.518E-08
U-236	7.566E-06	7.205E-07	1.871E-07	7.377E-07	1.194E-06
Np-237	1.022E-05	9.728E-07	2.527E-07	9.960E-07	5.099E-03
Pu-238	1.092E-01	1.040E-02	2.701E-03	1.065E-02	1.694E-02
U-238	1.108E-05	1.055E-06	2.741E-07	1.080E-06	1.474E-06
Pu-239	1.403E-02	1.336E-03	3.469E-04	1.367E-03	1.449E-03
Pu-240	2.287E-02	2.177E-03	5.656E-04	2.229E-03	1.777E-02
Am-241	1.134E-01	1.079E-02	2.804E-03	1.105E-02	5.689E+00
Pu-241	1.839E+00	1.751E-01	4.549E-02	1.793E-01	1.999E-01
Am-242m	2.264E-04	2.156E-05	5.599E-06	2.207E-05	4.904E-02
Cm-242	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.044E-02
Pu-242	6.842E-05	6.515E-06	1.692E-06	6.671E-06	1.101E-05
Am-243	8.472E-04	8.067E-05	2.095E-05	8.260E-05	7.928E-02
Cm-243	5.944E-04	5.660E-05	1.470E-05	5.796E-05	4.458E-02
Cm-244	9.129E-02	8.693E-03	2.258E-03	8.901E-03	4.167E+00
Pu-244	2.923E-11	2.783E-12	7.229E-13	2.849E-12	0.000E+00
Cm-245	1.452E-05	1.383E-06	3.592E-07	1.416E-06	8.880E-04
Cm-246	4.974E-06	4.736E-07	1.230E-07	4.849E-07	1.831E-04
Cm-247	2.314E-11	2.204E-12	5.724E-13	2.256E-12	0.000E+00
Cm-248	9.512E-11	9.057E-12	2.353E-12	9.273E-12	0.000E+00
Cf-249	1.359E-09	1.294E-10	3.361E-11	1.325E-10	0.000E+00
Cf-250	3.190E-09	3.037E-10	7.889E-11	3.110E-10	0.000E+00
Cm-250	2.189E-17	2.084E-18	5.414E-19	2.134E-18	0.000E+00
Cf-251	5.386E-11	5.128E-12	1.332E-12	5.251E-12	0.000E+00

4.0 DRUM DECAY HEATS

The Radcalc code, Version 4.0, (Reference 9.1) was used to calculate the decay heat plus error for each drum in shipment number 12 at the time of an assumed compliance evaluation date of October 31, 2005. The code requires that the activity be entered for each isotope. The Radcalc code will calculate the initial decay heat generation based solely on the radionuclide activities entered. If a time to decay source is specified, Radcalc will also perform decay and in-growth calculations to provide the rate of heat generation in Watts at the end of this decay time. The dates of isotopic survey characterization and the elapsed time in days to the assumed compliance

date of October 31, 2005 are listed for the 10 drums in shipment number 12 in Table D-3. The Radcalc calculated decay heat plus error values for each drum on October 31, 2005 are summarized in Table D-4 based on the initial isotopic activities listed in Tables D-1 and D-2 and the elapsed times listed in Table D-3.

Table D-3
Elapsed Time Between Isotopic Survey and Compliance Evaluation Date

Drum Identifier	Content Code	Isotopic Survey Date	Compliance Evaluation Date	Elapsed Time (days)
BC0127	BC 321A	9/10/2002	10/31/2005	1147
BC0124	BC 321A	9/9/2002	10/31/2005	1148
BC0160	BC 321A	2/24/2003	10/31/2005	980
BC0130	BC 321A	9/13/2002	10/31/2005	1144
BC0167	BC 321A	3/14/2003	10/31/2005	962
BC0138	BC 321A	9/16/2002	10/31/2005	1141
BC0034	BC 314A	9/11/2002	10/31/2005	1146
BC0095	BC 321B	8/29/2002	10/31/2005	1159
BC0038	BC 321B	8/29/2002	10/31/2005	1159
BC0148	BC 322A	11/27/2002	10/31/2005	1069

Table D-4
Decay Heat Plus Error for Drums in Shipment Number 12 on October 31, 2005

Drum Identifier	Decay Heat + Error (Watt) on Compliance Evaluation Date
BC0127	9.514E-04
BC0124	3.750E-03
BC0160	2.664E-03
BC0130	3.664E-03
BC0167	6.028E-03
BC0138	3.849E-02
BC0034	2.896E-01
BC0095	4.608E-03
BC0038	1.592E-02
BC0148	6.812E+00

5.0 BOUNDING HYDROGEN G VALUES

The decay heats plus error for drums of Content Codes BC 321A and BC 321B are relatively low. Some of the containers satisfy the 0.012 Watt*yr criteria methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program discussed in Attachment A of Appendix 4.10.2 of the CNS 10-160B SAR. However, for calculating maximum hydrogen gas generation rates, each drum will be assumed to have not satisfied the dose-dependent criterion. Thus, the hydrogen G value data of Table 10-3 of Appendix 4.10.2.1 of the CNS 10-160B SAR will be used. Values in Table 10-3 summarize the bounding G values for hydrogen and the activation energies for the G values for the different content codes. The ß-radiation and ?-radiation G values at the minimum and maximum operating temperatures of the CNS 10-160B cask are summarized in Table D-5. The a-radiation hydrogen G values for Content Codes BC 321A and BC 321 are 82% of the ß-radiation and ?-radiation values listed in Table D-5 as only 82% of the alpha decay energy escapes from particles of PuO_2 when the particle size distribution is taken into account (see Table 10-3 of Appendix 4.10.2.1). For drums of Content Codes BC 321 A and BC 321B, maximum G values occur at the maximum operating temperature of the CNS 10-160B cask. The a-radiation hydrogen G values for Content Codes BC 314A and BC 322A are the same as those listed for ß-radiation and ?-radiation and are independent of temperature as water is the bounding material.

Table D-5
Bounding Hydrogen G Value for ß-radiation and ?-radiation by Content Code

Content Code	Temperature (K)	Bounding Hydrogen G Value (molecules/100 eV) for ß-radiation and ?-radiation
BC 321A	233	2.87
	348.6	5.61
BC 321B	233	0.68
	348.6	3.06
BC 314A	233	0.48
	348.6	0.48
BC 322A	233	0.016
	348.6	0.016

The bounding hydrogen G values by radiation type and by drum are summarized in Table D-6.

Table D-6
Bounding Hydrogen Gas G Values by a-, ß-, and ?- By Radiation Type and By Drum

Drum Identifier	Content Code	Bounding Hydrogen Gas G Value (molecules/100 eV)		
		a-radiation	ß-radiation	?-radiation
BC0127	BC 321A	4.60	5.61	5.61
BC0124	BC 321A	4.60	5.61	5.61
BC0160	BC 321A	4.60	5.61	5.61
BC0130	BC 321A	4.60	5.61	5.61
BC0167	BC 321A	4.60	5.61	5.61
BC0138	BC 321A	4.60	5.61	5.61
BC0034	BC 314A	0.48	0.48	0.48
BC0095	BC 321B	2.51	3.06	3.06
BC0038	BC 321B	2.51	3.06	3.06
BC0148	BC 322A	0.016	0.016	0.016

6.0 CALCULATION OF MAXIMUM HYDROGEN GAS GENERATION RATES

A bounding radiolytic hydrogen gas generation rate due to a-radiation and ß-radiation was calculated for each drum using the Radcalc code. One Radcalc input file was created for each drum using the drum specific data documented in Sections 3.0, 4.0, and 5.0 of this attachment. The ?-radiation G value was set to zero in each case as the ?-radiation radiolysis contribution was calculated through a separate analysis as discussed below. The Radcalc code was executed with each input file and the code-calculated a-radiation and ß-radiation radiolysis rate for each drum is listed in the third column of Table D-8 in units of cubic centimeters (cc) per hour (hr) at standard temperature and pressure (STP) (defined in Radcalc as 0 °C and 101.325 kPa or 1 atm).

Because of the nature of gamma-rays, the potential for ?-radiation from one drum to cause radiolytic gas generation in another drum of the payload is accounted for as follows. The total initial activity of each isotope in the payload was calculated by summing the isotope activity present in each of the ten drums. The resulting total initial activities by isotope are summarized in Table D-7. As indicated in Table D-3, the initial activities are based on different isotopic survey dates. A common initial date is needed for purposes of the ?-radiation calculations. Activities were maximized on the assumed compliance date of October 31, 2005 by using the latest isotopic

survey date (i.e., March 14, 2003 for drum BC0167) corresponding to a minimum elapsed time of 962 days for the ?-radiation calculations.

Table D-7. Total Initial Activities of 10-Drums in Shipment Number 12	
Isotope	**Total Initial Activity of 10 Drums (Ci)**
Be-10	3.611E-08
C-14	3.980E-04
Si-32	1.309E-11
Cl-36	3.964E-06
K-40	1.570E-12
Ni-59	1.555E-04
Co-60	6.563E+00
Ni-63	1.918E-02
Se-79	4.972E-03
Sr-90	4.548E+02
Mo-93	2.224E-07
Nb-93m	1.603E-02
Zr-93	2.212E-02
Nb-94	1.690E-06
Tc-99	1.607E-01
Ru-106	1.831E-05
Pd-107	1.359E-03
Ag-108m	2.886E-07
Cd-109	1.617E-12
Ag-110m	1.098E-11
Cd-113m	1.733E-01
Sn-119m	3.626E-13
Sn-121m	1.836E-03
Sb-125	2.272E-01
Te-125m	3.175E-02
Sb-126	1.299E-03
Sn-126	9.258E-03
Te-127m	1.883E-27
I-129	3.827E-04
Ba-133	1.319E-28
Cs-134	2.168E-01
Cs-135	4.413E-03
Cs-137	8.359E+02
Ce-144	1.235E-07
Pm-147	8.153E-01
Sm-147	5.564E-08
Eu-150	7.161E-08
Sm-151	3.734E+00
Eu-152	1.645E-02
Gd-152	1.250E-16
Gd-153	9.565E-15

Table D-7. Total Initial Activities of 10-Drums in Shipment Number 12	
Isotope	**Total Initial Activity of 10 Drums (Ci)**
Eu-154	9.323E+00
Eu-155	1.261E+00
Tm-170	9.542E-29
Re-187	6.167E-12
Pb-210	6.927E-11
Po-210	9.175E-13
Ra-226	3.219E-10
Ac-227	2.352E-09
Ra-228	4.229E-14
Th-228	9.751E-06
Th-229	5.762E-10
Th-230	6.619E-08
Pa-231	6.102E-09
Th-232	7.123E-14
U-232	9.795E-06
U-233	5.046E-07
Th-234	1.474E-06
U-234	3.723E-04
U-235	5.404E-06
U-236	7.211E-05
Np-237	5.195E-03
Pu-238	1.040E+00
U-238	1.053E-04
Pu-239	1.329E-01
Pu-240	2.321E-01
Am-241	6.752E+00
Pu-241	1.744E+01
Am-242m	5.116E-02
Cm-242	4.044E-02
Pu-242	6.523E-04
Am-243	8.722E-02
Cm-243	5.015E-02
Cm-244	5.023E+00
Pu-244	2.739E-10
Cm-245	1.024E-03
Cm-246	2.297E-04
Cm-247	2.169E-10
Cm-248	8.915E-10
Cf-249	1.274E-08
Cf-250	2.989E-08
Cm-250	2.051E-16
Cf-251	5.048E-10
Total	1.344E+03

The Radcalc code provides for the user to specify a source factor. The source factor multiplies all

the activities in the source by the constant source factor. A source factor of 0.5 was used in all Radcalc ?-radiation calculations. This is deemed to be a bounding value that will overestimate the ?-radiation gas generation contribution in each drum because the actual source factor will be considerably less for the following reasons.

1) Each of the ten drums has a 1-inch shield liner containing the RH waste that is placed inside a filtered 55-gallon drum. Based on the isotopes and activities present on the compliance date, the only gamma-ray energy of significance is the maximum 0.662 MeV photon from Cs-137, which comprises 62% of the initial total activity in the ten drums. The other major radionuclide Sr-90, which comprises 34% of the initial total activity in the ten drums, is a beta emitter. Thus, the drum with the majority (>95%) of the total activity (i.e., Drum BC0148) also contains a 1-inch thick steel (i.e., mostly iron) shield in addition to being the most dense drum. The attenuation of the 1-inch thick steel shield for the highest activity drum is calculated as follows.

The minimum reduction in intensity of the gamma radiation is calculated from (Reference 9.2) as:

$$\frac{I}{I_0} = B\, e^{-\mu x}$$

where,

I_0	=	Intensity of photons at source
I	=	Intensity of photons at a distance (i.e. thickness) x of the shielding material
B	=	Build up factor
μ	=	Mass attenuation coefficient x density of material (0.0738 cm^2/g interpolated from Reference 9.4 for a 0.662 MeV photon x 7.86 g/cm^3 for iron density) or 0.58 cm^{-1}
x	=	Thickness of shielding material (1 inch = 2.54 cm)

Thus, the $e^{-\mu x}$ term is equal to 0.23.

The point source build up factor, B, for a μx factor of (0.0738 cm^2/g x 7.86 g/cm^3 x 2.54 cm) or 1.47 was interpolated from Reference 9.3 to be 2.45.

Thus, the overall intensity reduction of the 0.662 MeV Cs-137 gamma photon is calculated as:

$$\frac{I}{I_0} = B\, e^{-\mu x}$$

$$\frac{I}{I_0} = 2.45 * 0.23 = 0.56 \; or \; 56\%$$

Thus, the 1-inch shield in the highest activity drum will reduce the ?-irradiation of the other drums by at least 44% without accounting for the attenuation offered by the other steel drum liners.

2) The payload is comprised of two 5-packs of drums. Each five pack is comprised of drums that are arranged in a circular geometric arrangement. Based on geometry arguments, less than 50% of the gamma rays emanating from the waste will be able to irradiate other waste drums. Thus, the combination of the 1-inch steel shielding and geometric considerations indicate that a more realistic source reduction factor of 0.56 x 0.5 or 0.28 would be justified. However, for purposes of bounding the ?-radiation gas generation rate, and as stated earlier a source reduction factor of 0.5 was used for all ?-radiation calculations.

3) The Radcalc user is able to select the gamma absorption curve based on the package size and shape analyzed. The gamma absorption curve is a method to estimate the fraction of the decay energy in the form of gamma rays that is absorbed inside the waste package. The gamma rays absorbed within the waste package are assumed to contribute to hydrogen gas production, while gamma rays that leave the package do not.

Gamma absorption curves are models that take gamma ray energy and waste density as arguments and return an absorption percentage. The models are package specific, and were derived from numerous MCNP code runs over a range of gamma energies and waste densities. For purposes of bounding the ?-radiation gas generation rate contribution in each drum, the 100% Gamma Absorption Curve was used for all ?-radiation calculations. Thus, attenuation of the gamma energies by the waste, containers, and steel liners is not considered as an additional margin of safety in the ?-radiation calculations.

4) As in the case of bounding G values for a- and ß-radiation, bounding ?-radiation G values were used such that all of the waste in a drum is assumed to be comprised of only the bounding waste material. In reality, as indicated on the chemical lists in Attachment A of Appendix 4.10.2.1 of the CNS 10-160B SAR, the BCLDP drums contain substantial quantities of inert (i.e.,

non gas-generating) inorganic materials (e.g., glass, metal, diatomaceous earth, and soil).

The ?-radiation gas generation rate contribution for each drum was calculated as described in the following. One Radcalc input file was created for each distinct ?-radiation G value (i.e. 5.61, 3.06, 0.48, and 0.016 molecules/100 eV). Initial isotopic activities listed in Table D-7 were used in each case with 962 days as the elapsed time to decay the source. A source factor of 0.5 was specified for each of the four input files as discussed earlier. The 100% Gamma Absorption Curve was selected for each of the four cases. The a-radiation and ß-radiation G values were each set to zero as the rate contribution for those radiations were calculated previously. The Radcalc code was executed with each of the four input files. The hydrogen generation rate calculated by the Radcalc code in each case is for a payload of ten drums. Thus, the rate was divided by 10 in each case to arrive at a Content Code-specific ?-radiation radiolytic contribution on a per drum basis. For example, with a ?-radiation G value of 5.61 molecules/100 eV, the Radcalc code calculated a hydrogen gas generation rate of 65.14 cc/hr at STP for the payload. This rate was divided by 10 to arrive at a rate of 6.514 cc/hr at STP for each drum of Content Code BC 321A. Similarly, for the ?-radiation G value of 3.06 molecules/100 eV, the payload gas generation rate was calculated to be 35.53 cc/hr at STP and 3.553 cc/hr was assigned as the rate for each of the two Content Code BC 321B drums. The ?-radiation rate contributions for each drum are summarized in column four of Table D-8.

The total radiolytic hydrogen gas generation rate for each drum was calculated by summing the rates for a-radiation plus ß-radiation (column 3 of Table D-8) with the bounding ?-radiation rate (column 4 of Table D-8). The total volumetric gas generation rate in cc/hr at STP for each drum is listed in column 5 of Table D-8. The total volumetric gas generation rate was converted into a molar gas generation rate using the ideal gas law as listed for each drum in column 6 of Table D-8. The total hydrogen gas generation rate for each drum was compared to the appropriate allowable hydrogen rate for that content code. In each case, the bounding rate is less than the allowable rate limit. Thus, each drum in the payload of shipment number 12 has been demonstrated to comply with the 5% (by volume) limit on hydrogen during a 10-day controlled shipment.

Table D-8
Bounding Hydrogen Gas Generation Rates and Gas Generation Rate Limits by Drum

Drum Identifier	Content Code	Alpha + Beta H_2 Gas Generation Rate (GGR) (cc/hr at STP)	Gamma H_2 GGR (cc/hr at STP)	Alpha + Beta + Gamma H_2 GGR (cc/hr at STP)	Alpha + Beta + Gamma H_2 GGR (mol/s)	10-Day Controlled Shipment H_2 GGR Limit (mol/s)
BC0127	BC 321A	2.570E-02	6.514E+00	6.540E+00	8.105E-08	9.820E-08[a]
BC0124	BC 321A	1.013E-01	6.514E+00	6.615E+00	8.199E-08	9.820E-08[a]
BC0160	BC 321A	7.124E-02	6.514E+00	6.585E+00	8.161E-08	9.820E-08[a]
BC0130	BC 321A	9.897E-02	6.514E+00	6.613E+00	8.196E-08	9.820E-08[a]
BC0167	BC 321A	1.611E-01	6.514E+00	6.675E+00	8.273E-08	9.820E-08[a]
BC0138	BC 321A	1.040E+00	6.514E+00	7.554E+00	9.362E-08	9.820E-08[a]
BC0034	BC 314A	7.324E-01	5.574E-01	1.290E+00	1.598E-08	5.431E-08[b]
BC0095	BC 321B	6.796E-02	3.553E+00	3.621E+00	4.488E-08	9.820E-08[a]
BC0038	BC 321B	2.348E-01	3.553E+00	3.788E+00	4.694E-08	9.820E-08[a]
BC0148	BC 322A	5.609E-01	1.858E-02	5.795E-01	7.182E-09	5.431E-08[b]
Totals		3.094E+00	4.677E+01	4.986E+01	6.179E-07	8.942E-07

[a] Value corresponds to the allowable rate limit at the maximum operating temperature and maximum G values.

[b] Value corresponds to the allowable rate limit at the minimum operating temperature as the G value is constant with temperature.

7.0 CALCULATION OF NET GAS GENERATION RATES

Table 7-1 of Appendix 4.10.2.1 of the CNS 10-160B SAR lists the maximum net gas generation G values by content code. Hydrogen G values by drum were listed earlier in Table D-6 of this attachment, while calculated bounding hydrogen gas generation rates by drum are documented in Table D-8. The net gas generation rate for each drum was calculated through the following relationship:

$$Net\ Gas\ Generation\ Rate = \frac{G(net)}{G(hydrogen)}\ x\ Hydrogen\ Gas\ Generation\ Rate$$

The results of the calculations are summarized in Table D-9.

Table D-9. Net Gas Generation Rates by Drum.					
Drum Identifier	**Content Code**	**H_2 Gas Generation Rate (mol/s)**	**G (H2) (molecules/ 100 eV)**	**G (net) (molecules/ 100 eV)**	**Net Gas Generation Rate (mol/s)**
BC0127	BC 321A	8.105E-08	5.61	14.19	2.050E-07
BC0124	BC 321A	8.199E-08	5.61	14.19	2.074E-07
BC0160	BC 321A	8.161E-08	5.61	14.19	2.064E-07
BC0130	BC 321A	8.196E-08	5.61	14.19	2.073E-07
BC0167	BC 321A	8.273E-08	5.61	14.19	2.092E-07
BC0138	BC 321A	9.362E-08	5.61	14.19	2.368E-07
BC0034	BC 314A	1.598E-08	0.48	0.72	2.398E-08
BC0095	BC 321B	4.488E-08	3.06	4.65	6.819E-08
BC0038	BC 321B	4.694E-08	3.06	4.65	7.134E-08
BC0148	BC 322A	7.182E-09	0.016	0.024	1.077E-08
Totals		6.179E-07			1.446E-06

The net radiolytic gas generation rate, ng, is 1.446E-06 moles/sec by summing the individual drum net gas generation rates.

The total liters of radiolytic gases generated at STP (1 atm and 0 °C), VR, at the end of 365 shipping days would be:

VR = ng x 365 days x 86,400 sec/day x 22.4 L/mole

VR = (1.446E-06 moles/sec) (365 days) (86,400 sec/day) (22.4 L/mole)

VR = 1021.5 liters at STP.

The generated volume of radiolytic gases is heated to the maximum operating temperature of the CNS 10-160B cask of 168 °F.

The corresponding volume occupied is:

Vrg = (1021.5 liters) x [(460 °R + 168 °F) / (460 °R + 32 °F)]

Vrg = 1303.9 liters at 168 °F.

This gas contributes a pressure of:

Prg = (1303.9 liters) / (1938 liters of total void volume)

Prg = 0.6728 atm (9.89 psia) at 168 °F.

The initial pressure of gas present in the cask void is 14.7 psia at 70 °F. This gas is also heated to 168 °F. The increased pressure associated with this increase in temperature is:

Phu = (14.7 psia) x [(460 °R + 168 °F) / (460 °R + 70 °F)]

Phu = 17.42 psia.

The water vapor pressure, Pwv, from the steam tables at 168 °F is 5.60 psia. The maximum gas pressure in the cask at the end of 365 days for shipment number 12, Pmax, is the sum of the three pressure components less an assumed atmospheric pressure, Pa, of 14.7 psia, or:

Pmax = Prg + Phu + Pwv - Pa (4)
= 9.89 psia + 17.42 psia + 5.60 psia - 14.7 psia
= 18.21 psig.

Thus, the pressure increase during a period of 365 days is below the design pressure limit of 31.2 psig for shipment number 12.

8.0 SUMMARY AND CONCLUSIONS

Shipment number 12 from BCLDP consists of 10 55-gallon waste drums from 4 different content codes (BC 321A, BC 321B, BC 314A, and BC 322A). To allow for the shipment of this mixture of content codes, the above analysis was performed. The results of the analysis demonstrate that for shipment number 12, consisting of the drums listed in Table D-8, all drums in the payload to be transported in the CNS 10-160B cask shall comply with the 5% (by volume) limit on hydrogen concentration during a 10-day controlled shipment transport and that gases generated in the payload and released into the Inner Vessel (IV) cavity maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch gauge (psig).

9.0 REFERENCES

9.1 Duratek Technical Services and Josephson Engineering Services 2005, "RadCalc Volume I: User's Manual RadCalc 4.0", DTS-SQA-009.1, Rev. 0, April 2005, Duratek Technical Services and Josephson Engineering Services, Richland, Washington.

9.2 Glasstone, S. and A. Sesonske, 1981, Nuclear Reactor Engineering, Third Edition, Van Nostrand Reinhold Company, New York, NY.

9.3 Radiological Health Handbook. 1970. Compiled and edited by the Bureau of Radiological Health and The Training Institute, Environmental Control Administration. Washington, D. C.: Government Printing Office.

ATTACHMENT 3

U.S. Department of Energy

Ohio Field Office
Columbus Closure Project
1425 Plain City-Georgesville Road, SR 142
P.O. Box 200
West Jefferson, OH 43162

Closure Project

October 5, 2005

Mr. Meraj Rahimi
NMSS/SFPO MS/06F18
U.S. Nuclear Regulatory Commission
One White Flint North
16555 Rockville Pike
Rockville, MD 20852-2738

Dear Mr. Rahimi

SUBJECT: PRIORITY REQUEST FOR REVIEW OF SAR AMENDMENT FOR THE CNS 10-160B SHIPPING CASK (C of C No. 9204)

The U.S. Department of Energy requests that the NRC give priority to its review of a requested change to the Safety Analysis Report (SAR) for the CNS 10-160B Type B cask submitted by Duratek, Inc., the cask license holder. The requested change to the Battelle-specific appendix of the SAR is needed in order to ship remote-handled TRU waste from the Battelle West Jefferson site. The decommissioning completion schedule for the site in the NRC-approved Decommissioning Plan is December 31, 2005. Removal of the TRU waste currently stored at the site is a critical milestone to meeting that schedule.

If you have any questions, please contact me at 513-200-9677 or Mr. Tom Baillieul at 614-879-6941 X312.

Sincerely,

John M. Sattler
Director
Columbus Closure Project

TAB/tab/C05-054

cc:
P. Weaver, Battelle
M. Whittaker, Duratek