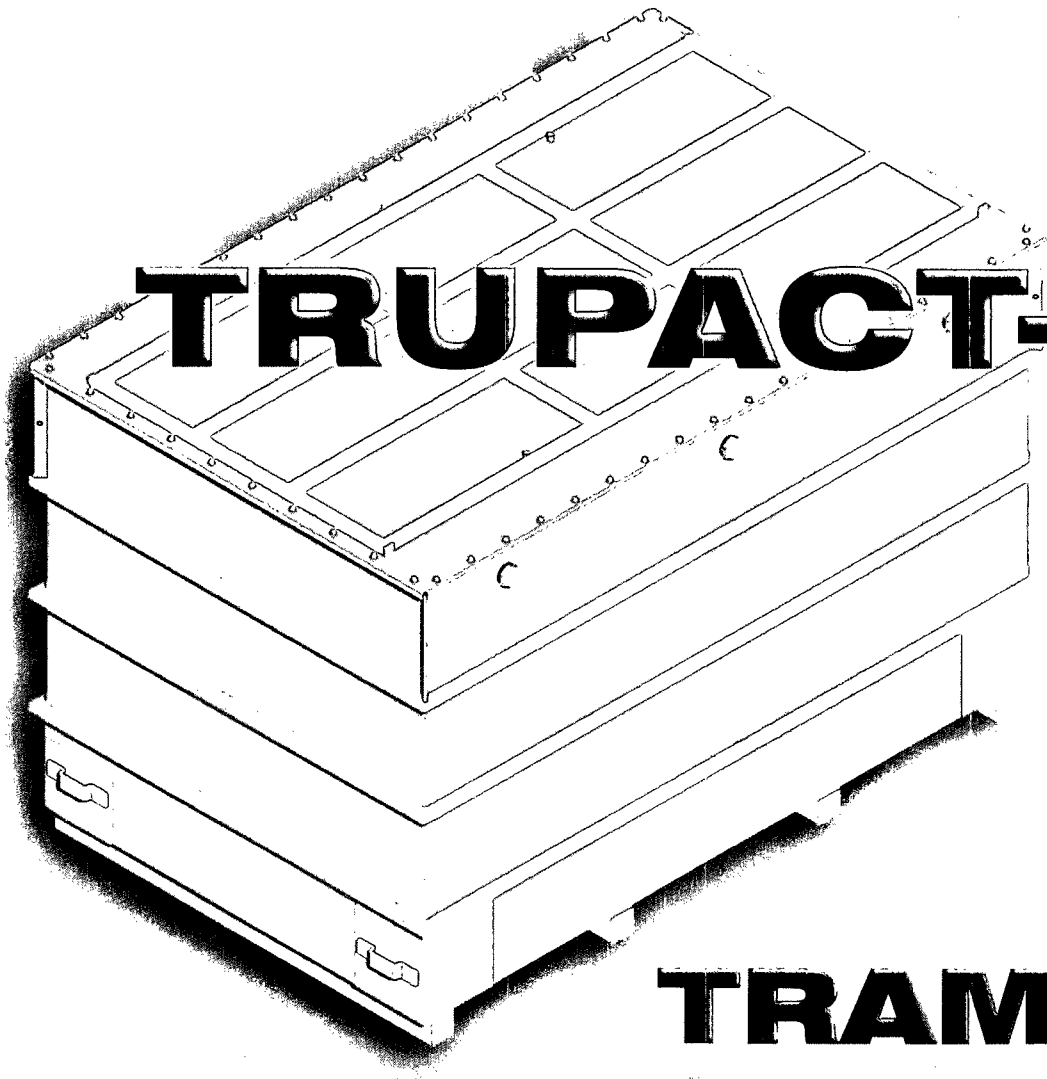
TRUPACT-III



TRAMPAC

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LIST OF ABBREVIATIONS AND ACRONYMS

AFGC	allowable flammable gas concentration
ALARA	as-low-as-reasonably-achievable
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CBFO	Carlsbad Field Office
CFR	Code of Federal Regulations
CH	contact-handled
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FGE	fissile gram equivalent
FGGR	flammable gas generation rate
GC	gas chromatography
ID	identification
MLEL	mixture lower explosive limit
MNOP	maximum normal operating pressure
mrem/hour	millirem per hour
MS	mass spectrometry
NCT	normal conditions of transport
NDE	nondestructive examination
NRC	U.S. Nuclear Regulatory Commission
PTCD	Payload Transportation Certification Document
QA	quality assurance
SLB2	Standard Large Box 2
STP	standard temperature and pressure
TRAMPAC	TRU Waste Authorized Methods for Payload Control
TRU	transuranic
TRUPACT-III TRAMPAC	TRUPACT-III Authorized Methods for Payload Control
VOC	volatile organic compound(s)
WIPP	Waste Isolation Pilot Plant

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1.0 INTRODUCTION

The TRUPACT-III Authorized Methods for Payload Control (TRUPACT-III TRAMPAC) is the governing document for shipments in the TRUPACT-III packaging. All users of the TRUPACT-III shall comply with all payload requirements outlined in this document, using one or more of the methods described.

1.1 Background

Several U.S. Department of Energy (DOE) sites have contact-handled (CH) transuranic (TRU) waste inventories that were packaged in large boxes. These boxes, which are too large to be accommodated by the packagings currently licensed for CH-TRU waste shipment (i.e., TRUPACT-II and HalfPACT), are considered "oversized." Approximately 24 percent (by volume) of the entire DOE CH-TRU waste inventory is estimated to currently exist in oversized boxes. This estimate corresponds to more than 13,000 boxes. The DOE sites with the majority of this inventory are the Idaho National Laboratory, the Hanford Site, the Los Alamos National Laboratory, and the Savannah River Site.

The largest rectangular box that potentially could be transported in a TRUPACT-II is approximately 4- x 4- x 5.5-feet. The oversized inventory in storage at the DOE sites is in boxes that are nominally 4- x 4- x 7-feet or larger. The TRUPACT-III packaging has been designed and developed primarily for the transportation of these large boxes. In addition to existing large boxes, it is anticipated that ongoing or planned site activities will result in the generation of new large boxes (e.g., decontamination and decommissioning of site facilities). The TRUPACT-III packaging is considered a cost-effective and safe alternative to designing, building, and operating repackaging and size-reduction facilities at each of the sites to repackage the oversized waste inventory into smaller containers for transportation in the TRUPACT-II packaging. The use of the TRUPACT-III for the shipment of oversized boxes that meet the requirements of this document is consistent with *as-low-as-reasonably-achievable* (ALARA) considerations associated with waste packaging and transportation plans that will decrease worker exposure by reducing the amount of waste that must be repackaged or size reduced.

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1.2 Scope

The TRUPACT-III TRAMPAC defines the authorized contents for the TRUPACT-III packaging.

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1.3 Purpose

The purposes of the TRUPACT-III TRAMPAC are to:

- Define the requirements for a payload to be transported in the TRUPACT-III packaging
- Describe the compliance methodology that shall be used to evaluate and prepare the payload for transport in a TRUPACT-III packaging.

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1.4 Requirements

Requirements are established to ensure compliance of the payload with the transportation parameters of the TRUPACT-III packaging. The TRUPACT-III TRAMPAC defines payload requirements under the following categories:

- Container and Physical Properties (Chapter 2.0)
- Nuclear Properties (Chapter 3.0)
- Chemical Properties (Chapter 4.0)
- Gas Generation Properties (Chapter 5.0)
- Payload Assembly Criteria (Chapter 6.0).

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1.5 Methods of Compliance

This document describes allowable methods to be used for determining compliance with each payload requirement and the controls imposed on the use of each method. Each generator or storage site shall select and implement a single 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 delineated in a programmatic or waste-specific data TRU Waste Authorized Methods for Payload Control (TRAMPAC).

Each shipper shall document and demonstrate compliance with the TRUPACT-III TRAMPAC by one of the following methods:

- A programmatic TRAMPAC, which defines the process in which payload compliance is met, will be prepared by the shipper and approved by the DOE Carlsbad Field Office (CBFO). Implementing procedures of the TRAMPAC will be reviewed by the DOE-CBFO for completeness and compliance as part of the audit process.
- A waste-specific data TRAMPAC will be prepared by the shipper and approved by the DOE-CBFO. The waste data are evaluated against the requirements in this document.

A summary of the methods of compliance that shall be used for TRUPACT-III payload control is provided in the following sections.

1.5.1 Records and Database Information (Knowledge of Process)

Information obtained from existing site records and/or databases or knowledge of process may be used to qualify waste for transport.

1.5.2 Administrative and Procurement Controls

Site-specific administrative and procurement controls may be used to show that the payload container specifications are met and/or that payload container contents are monitored and controlled (e.g., to show that filters procured from vendors meet the requirements of this document or that prohibited waste forms were excluded from the generating facility).

1.5.3 Visual Inspection

Visual inspection may be used to evaluate compliance with specific requirements (e.g., visual inspection of payload container type and marking). Visual inspection is typically used to verify external characteristics of the payload container.

1.5.4 Visual Examination

Visual examination at the time of waste generation and/or packaging may be used to qualify waste for transport. For example, site/equipment-specific procedures at a waste generating area may require visual examination of the physical form of the waste by the operator and the removal of all prohibited waste forms prior to placement in the payload container.

1.5.5 Nondestructive Examination

Nondestructive examination (NDE) techniques, such as radiography, may be used to qualify waste for transport after the payload container is closed (e.g., to nondestructively examine the physical form of the waste and to verify the absence of prohibited waste forms). Site/equipment-specific quality assurance and quality control procedures shall ensure that NDE system operator(s) are properly trained and qualified.

1.5.6 Measurement

Direct measurement or evaluation based on analysis using the direct measurement shall be used, as needed, to qualify waste (e.g., direct measurement of the weight, analysis of assay data to determine decay heat, or survey measurements to determine surface dose rate).

1.5.7 Sampling Programs

Sampling programs comprised of the statistical application of other methods identified in Section 1.5 may be used to qualify waste for transport.

1.6 TRUPACT-III Content Codes Document

The TRUPACT-III Content Codes document[1] is a catalog of TRUPACT-III authorized contents and a description of the methods used to demonstrate compliance with the TRUPACT-III TRAMPAC.

1.6.1 Required Elements

Each content code within the TRUPACT-III Content Codes document must contain the following elements:

CONTENT CODE: Identifies the TRUPACT-III as the shipping package (i.e., the prefix "T3") and includes the two-letter site abbreviation that designates the generator of the waste, the three-digit code that designates the waste, and alpha or numeric differentiators (e.g., to designate differences in packaging configurations). Content code identifiers are defined in the TRUPACT-III Content Codes document[1].

CONTENT DESCRIPTION: Identifies the physical form of the waste.

GENERATING SITE: Provides the location of waste generation.

WASTE DESCRIPTION: Provides basic information regarding the nature and/or main components of the waste.

GENERATING SOURCE(S): Lists processes and/or buildings at each site that generate the waste in each content code.

WASTE FORM: Provides more detailed information on the waste contents, how the waste is processed, and/or specific information about the chemistry of constituents.

WASTE PACKAGING: Describes, in detail, techniques necessary for waste packaging in a given content code. This includes a description of the waste confinement layers; the number of layers of confinement used in packaging waste; and the mechanism for bag, can, or container closure.

METHODS FOR ISOTOPIC DETERMINATION: Describes the types of radioactive measurement techniques or other methods used to obtain fissile material content and decay heat values for a particular content code.

RESIDUAL LIQUIDS: Describes the procedures used to ensure that the limit imposed on residual liquids (<1% by volume) is met for each content code.

EXPLOSIVES/COMPRESSED GASES: Identifies the methods used to preclude the presence of explosives and compressed gases.

PYROPHORICS: Describes the controls in place to ensure that nonradioactive pyrophoric materials in the waste are excluded, reacted to render nonreactive, or are immobilized prior to placement in waste. Describes the controls in place to ensure that the ≤1% (weight) limit on radioactive pyrophoric materials in the waste is met.

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[1] U.S. Department of Energy (DOE), *TRUPACT-III Content Codes*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

CORROSIVES: Describes the controls in place to ensure that corrosive materials in the waste either are not present or are neutralized or immobilized prior to placement in a container.

CHEMICAL COMPATIBILITY: Describes the controls in place to ensure chemical compatibility for the waste contents and the TRUPACT-III packaging. All chemicals/materials in the waste for a specific content code are restricted to the list of allowable chemicals/materials (Table 4.3.2-1) and the 5% limit on total materials not listed in Table 4.3.2-1 as specified in Section 4.3, *Chemical Composition.*

CHEMICAL LIST: Lists the chemicals/materials that may be present in the content code in quantities greater than 1% (weight) (used in the chemical compatibility evaluation) and less than or equal to 1% (weight) and, additionally, identifies the predominant chemicals/materials or relevant quantities (% weight) of specific materials (used in the G value determination).

G VALUE: Defines the G value (gas generation potential) for the content code based on the chemical/materials present in the waste.

ADDITIONAL CRITERIA: Provides details on how the waste qualifies for shipment by meeting additional transport requirements (e.g., venting containers).

MAXIMUM ALLOWABLE FLAMMABLE GAS GENERATION RATES: Specifies the flammable gas generation rate (FGGR) limits for the content code.

MAXIMUM ALLOWABLE DECAY HEAT LIMITS: Specifies the decay heat limits for the content code. Decay heat limits based on dose-dependent G values are also specified, as applicable.

1.6.2 Use and Approval

All containers must have a content code approved by the Waste Isolation Pilot Plant (WIPP) CH-TRU Payload Engineer to be eligible for shipment. Any site requiring the transportation of CH-TRU waste in the TRUPACT-III that is not described in an approved content code must request the revision or addition of a content code by submitting a request in writing to the WIPP CH-TRU Payload Engineer.

The WIPP CH-TRU Payload Engineer has the authority to approve a content code request only if compliance with the transportation requirements of the TRUPACT-III TRAMPAC can be demonstrated. Any submittal not meeting the requirements of the TRUPACT-III TRAMPAC shall not be approved for inclusion in the TRUPACT-III Content Codes document[1] or be used as the basis for a shipment in the TRUPACT-III. The WIPP CH-TRU Payload Engineer does not have the authority to change the transportation requirements for the TRUPACT-III as specified in the TRUPACT-III TRAMPAC without approval from the U.S. Nuclear Regulatory Commission (NRC).

The process for requesting a content code addition or revision is as follows:

1. The site prepares in writing a request containing sufficient information to satisfy all of the necessary elements identified in Section 1.6.1, *Required Elements.* If the request is for a content code revision, only the revised elements require preparation and documentation. The site shall ensure that the information submitted in the form of a content code addition or revision accurately describes the waste and waste generating processes based on site knowledge.

2. The site submits the request (e.g., draft content code or revised content code elements) in writing to the WIPP CH-TRU Payload Engineer for review.
3. The WIPP CH-TRU Payload Engineer shall review the submittal for completeness and satisfactory demonstration of compliance with all transportation requirements of the TRUPACT-III TRAMPAC. As part of this review, the WIPP CH-TRU Payload Engineer's responsibilities may include a review to ensure that each of the previously identified elements (Section 1.6.1, *Required Elements*) is complete, compliance with the list of allowable chemicals/materials pursuant to Section 4.3, *Chemical Composition*, is evaluated, and confinement layer release rates are appropriately applied in the calculation of FGGR limits pursuant to the methodology referenced in Section 5.1, Flammable (Gas/VOC) Concentration Limits. The WIPP CH-TRU Payload Engineer shall not approve any submittal that does not demonstrate compliance with every transportation requirement for the TRUPACT-III.
4. Upon completion of the review, the WIPP CH-TRU Payload Engineer shall send formal written notification to the site indicating the status of the request. If the request is denied, the WIPP CH-TRU Payload Engineer shall indicate in the notification the reason why the request was not accepted and shall identify which elements of the submittal are incomplete or out of compliance.
5. If the request is approved, a site may begin using the new or revised content code once official notification is received from the WIPP CH-TRU Payload Engineer. Sites may not use proposed content code additions or revisions to make shipments in the TRUPACT-III prior to receipt of notification from the WIPP CH-TRU Payload Engineer.
6. The WIPP CH-TRU Payload Engineer shall record all approved content code additions or revisions in the TRUPACT-III Content Codes document[1]. The current revision of the TRUPACT-III Content Codes document[1] shall be available to sites.

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1.7 Compliance Responsibilities

1.7.1 Transportation Certification Official

The site Transportation Certification Official is responsible for administratively verifying the compliance of payloads with all TRUPACT-III TRAMPAC requirements. The site Transportation Certification Official shall approve every payload for transport by signature on the transportation certification documents.

1.7.2 DOE-CBFO

The DOE-CBFO is responsible for the performance of compliance audits, which are conducted prior to the first shipment and periodically thereafter to evaluate TRUPACT-III payload compliance. Audit activities include document reviews and interviews of site operators on a job-function basis relative to meeting the applicable criteria. Where specific technical ability is required (e.g., for isotopic inventory and assay data), technical experts are included on the audit team. The DOE-CBFO will grant or deny waste transportation authorization based on objective evidence of the audit and the recommendation of the audit team's report. Compliance audits are not required at sites that document compliance by preparing waste-specific data TRAMPAC documents that are reviewed and approved by the DOE-CBFO.

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2.0 CONTAINER AND PHYSICAL PROPERTIES

2.1 Authorized Payload Container

2.1.1 Requirements

The only authorized payload container for the TRUPACT-III is the Standard Large Box 2 (SLB2). The TRUPACT-III will accommodate one SLB2. The SLB2 is a specialized payload container with a top-loading and a bottom-loading option for use within the TRUPACT-III packaging. The SLB2 and any ancillary handling equipment (i.e., roller floor and loading pallet) transported within the TRUPACT-III shall comply with the specifications in Section 2.8, *Specification for Authorized Payloads*.

2.1.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Visual inspection to the specifications of Section 2.8
- Administrative and procurement controls demonstrating that payload containers have been procured to the specifications of Section 2.8.

In addition to meeting the specifications of Section 2.8, *Specification for Authorized Payloads*, at the time of procurement, the integrity of the payload container shall be visually inspected prior to transport to ensure that the payload container is in good and unimpaired condition (e.g., no significant rusting and is of sound structural integrity). Compliance shall be documented in accordance with site-specific procedures prior to shipment.

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2.2 Container/Assembly Weight

2.2.1 Requirements

Each payload container, payload assembly, and loaded TRUPACT-III shall comply with the maximum weight limits summarized in Table 2.2.1-1 and Table 2.2.1-2.

Table 2.2.1-1 – Payload Container Maximum Gross Weight Limit

Authorized Payload Container	Maximum Gross Weight per Payload Container (pounds)
SLB2	10,500

Table 2.2.1-2 – Payload Assembly and Loaded TRUPACT-III Maximum Gross Weight Limits

Authorized Payload Configuration	Maximum Weight per Payload Assembly (Contents) (pounds)	Maximum Gross Weight per Loaded TRUPACT-III (Package) (pounds)
One SLB2	11,409	55,116

The maximum weight limit for the payload assembly includes the weight of the loaded payload container and any removable ancillary handling equipment (i.e., roller floor and loading pallet). Actual payload assembly weights may be further limited by the "as-built" TRUPACT-III weights and U.S. Department of Transportation requirements for a loaded transport vehicle.

Payload containers, payload assemblies, and loaded TRUPACT-III packages shall be acceptable for transport only if the weights plus the measurement errors are less than or equal to the maximum weights specified in Table 2.2.1-1 and Table 2.2.1-2.

2.2.2 Methods of Compliance and Verification

Compliance shall be by measurement. Weights of the well-defined payload pallet and/or roller floor may be analytically established. The weight of each payload container shall be determined using a calibrated scale. The scale calibrations shall be in accordance with the National Institute of Standards and Technology Handbook 44[1], or an equivalent standard. The weight of the roller floor and loading pallet shall be added to the sum of the weight of the individual payload container for the evaluation of compliance with the maximum weight per payload assembly of 11,409 pounds. The weight and measurement error of the payload container shall be recorded in

[1] National Institute of Standards and Technology, *Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices*, NIST Handbook 44, National Institute of Standards and Technology, Office of Weights and Measures, Washington, D.C.

the Payload Transportation Certification Document (PTCD) (see Section 6.2.1, *Procedure for Certification of Individual Payload Containers*).

2.3 Container Marking

2.3.1 Requirements

Each payload container shall be labeled with a unique identification number.

2.3.2 Methods of Compliance and Verification

Compliance shall be through visual inspection of each payload container, and the unique container identification number/label shall be recorded on the PTCD (see Section 6.2.1, *Procedure for Certification of Individual Payload Containers*).

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2.4 Filter Vents

2.4.1 Requirements

Each payload container to be transported in the TRUPACT-III shall have one or more filter vents meeting the minimum specifications of Table 2.4.1-1 and this section. The release rates of hydrogen for any inner containers and other inner confinement layers shall be accounted for as described in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements.*

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

The filter vent housing and element for the payload container shall have an operating temperature range from –40°C to +70°C (-40°F to +158°F). The filter vent threads shall be compatible with the bung in the container.

Table 2.4.1-1 – Minimum Filter Vent Specifications

Payload Container Type	Minimum Filter Vent Specification		
	Total Flow Rate (ml/min of air, STP, at 1 inch of water)①	Efficiency (percent)	Total Hydrogen Diffusivity (mol/s/mol fraction at 25°C)②,③
SLB2	35	>99.9	9.90E-4

① Filters tested at a different pressure gradient shall have a proportional flow rate (e.g., 35 ml/min at 1 inch of water = 1,000 ml/min at 1 psi).

② Total hydrogen diffusivity may be achieved through the use of multiple filter vents.

③ Filters exceeding these specifications may be used to decrease the resistance to hydrogen release in accordance with the logic outlined in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements.*

ml/min = Milliliter(s) per minute
mol/s/mol fraction = Moles per second per mole fraction
STP = Standard temperature and pressure

2.4.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Administrative and procurement controls demonstrating that filter vents have been procured to the specifications of Section 2.4.1, *Requirements*
- Visual inspection to the specifications of Section 2.4.1
- Sampling by measurement of filter characteristics to the specifications of Section 2.4.1.

If sampling by measurement is selected as the compliance method, the test methods used to determine the compliance of filter vents with the minimum performance-based requirements specified in Table 2.4.1-1 and this section shall be directed by procedures under a quality assurance (QA) program.

2.5 Residual Liquids

2.5.1 Requirements

The total volume of residual liquid in a payload container shall be less than 1 percent (volume) of the payload container.

2.5.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Review of records and database information, which may include knowledge of process
- Radiography
- Visual examination
- Sampling program.

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2.6 Sharp or Heavy Objects

2.6.1 Requirements

Sharp or heavy objects in the payload container shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload container packaging these items.

2.6.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Review of records and database information, which may include knowledge of process
- Radiography
- Visual examination
- Sampling program.

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2.7 Sealed Containers

2.7.1 Requirements

Sealed containers that are greater than 4 liters (nominal) are prohibited except for solid inorganic waste packaged in a metal container; solid inorganic waste in metal cans does not generate any flammable gas (see Appendix 3.2 of the CH-TRU Payload Appendices[1]).

2.7.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Review of records and database information, which may include knowledge of process
- Radiography
- Visual examination
- Sampling program.

[1] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

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2.8 Specification for Authorized Payloads

2.8.1 Specification for Authorized Payload Container

The SLB2 is authorized for transport in the TRUPACT-III (Figure 2.8.1-1). The TRUPACT-III will accommodate one SLB2. The SLB2 is a specialized payload container with a top-loading and a bottom-loading option for use within the TRUPACT-III packaging. The SLB2 has been specifically designed for efficient loading of the TRUPACT-III. The SLB2 is sized to accommodate the packaging of existing 4- x 4- x 7- and 5- x 5- x 8-foot boxes as well as other containers of smaller sizes. Table 2.8.1-1 presents the nominal external dimensions for the SLB2. The SLB2 shall employ the use of square tubing as external bumpers located to align, where applicable, with the TRUPACT-III payload cavity guide bars.

Table 2.8.1-1 – Payload Container Dimensions

Authorized Payload Container	Nominal External Dimensions (inches)		
	Width	Height	Length
SLB2	69	73	108

Table 2.8.1-2 presents the payload container construction materials. Table 2.8.1-3 specifies the weights associated with the SLB2 that are applicable to shipment within the TRUPACT-III. Each SLB2 must be filtered to meet the specifications of Section 2.4, *Filter Vents*

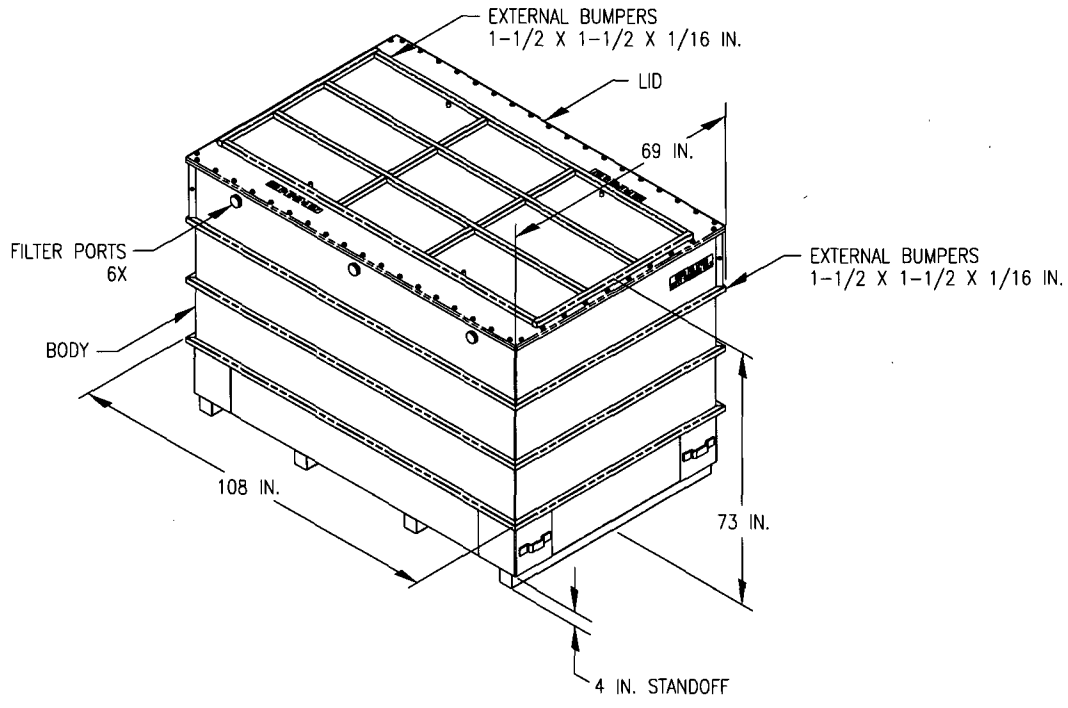
Table 2.8.1-2 – Payload Container Materials of Construction

SLB2 Component	Material
Body and lid	Steel
Gasket	Elastomeric

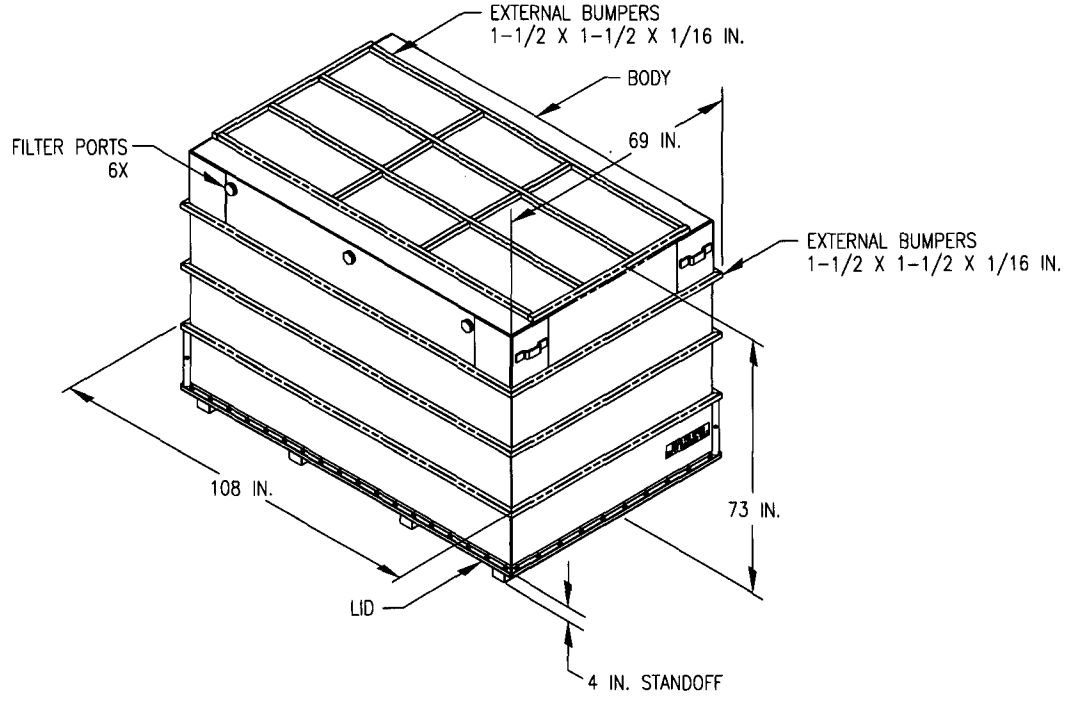
Table 2.8.1-3 – Payload Container Weights

Authorized Payload Container	Weight (pounds)	
	Approximate Empty	Maximum Gross
SLB2	2,700	10,500

The SLB2 may be directly loaded with waste or used to package various individual containers. Table 2.8.1-4 identifies the material content forms authorized for transport within this payload container.



Top-Loading Configuration



Bottom-Loading Configuration

Figure 2.8.1-1 – Schematic of SLB2

Table 2.8.1-4 – Payload Container Material Content Forms Authorized for Transport

Form Number	Description
1	Direct Load: Solids, any particle size (e.g., fine powder or inorganic particulates)
2	Direct Load: Solids, large particle size (e.g., sand, concrete, or debris)
3	Direct Load: Solids, large objects (e.g., metal cans, such as drums, containing waste)
4	Direct Load: Large, bulky dense objects with sharp and obtrusive members or components with dispersible Form 1 and 2 (e.g., steel or concrete boxes, steel plate, electric motors, steel pipe, or concrete blocks) ①

① Blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload container.

2.8.2 Specification for Authorized Ancillary Handling Equipment

A roller floor (Figure 2.8.2-1) and loading pallet (Figure 2.8.2-2) are used to assemble a TRUPACT-III payload. Table 2.8.2-1 presents the nominal external dimensions for the ancillary handling equipment. The loading pallet may include additional bumpers or guides to facilitate alignment with the TRUPACT-III payload cavity during loading and unloading.

Table 2.8.2-1 – Ancillary Handling Equipment Dimensions

Component	Nominal External Dimensions (inches)		
	Width	Height	Length
Roller Floor①	70	3	106.7
Loading Pallet	70	½②	108

① Dimensions when rollers are retracted during transportation.

② Distance that the base of the SLB2 will be raised from the top surface of the roller floor when supported on the pallet.

Table 2.8.2-2 presents the ancillary handling equipment construction materials. Table 2.8.2-3 specifies the weights associated with the ancillary handling equipment.

Table 2.8.2-2 – Ancillary Handling Equipment Primary Materials of Construction

Component	Material
Roller Floor	Aluminum
Loading Pallet	Steel and/or aluminum

Table 2.8.2-3 – Ancillary Handling Equipment Weights

Component	Nominal Weight (pounds)
Roller Floor	660
Loading Pallet	250

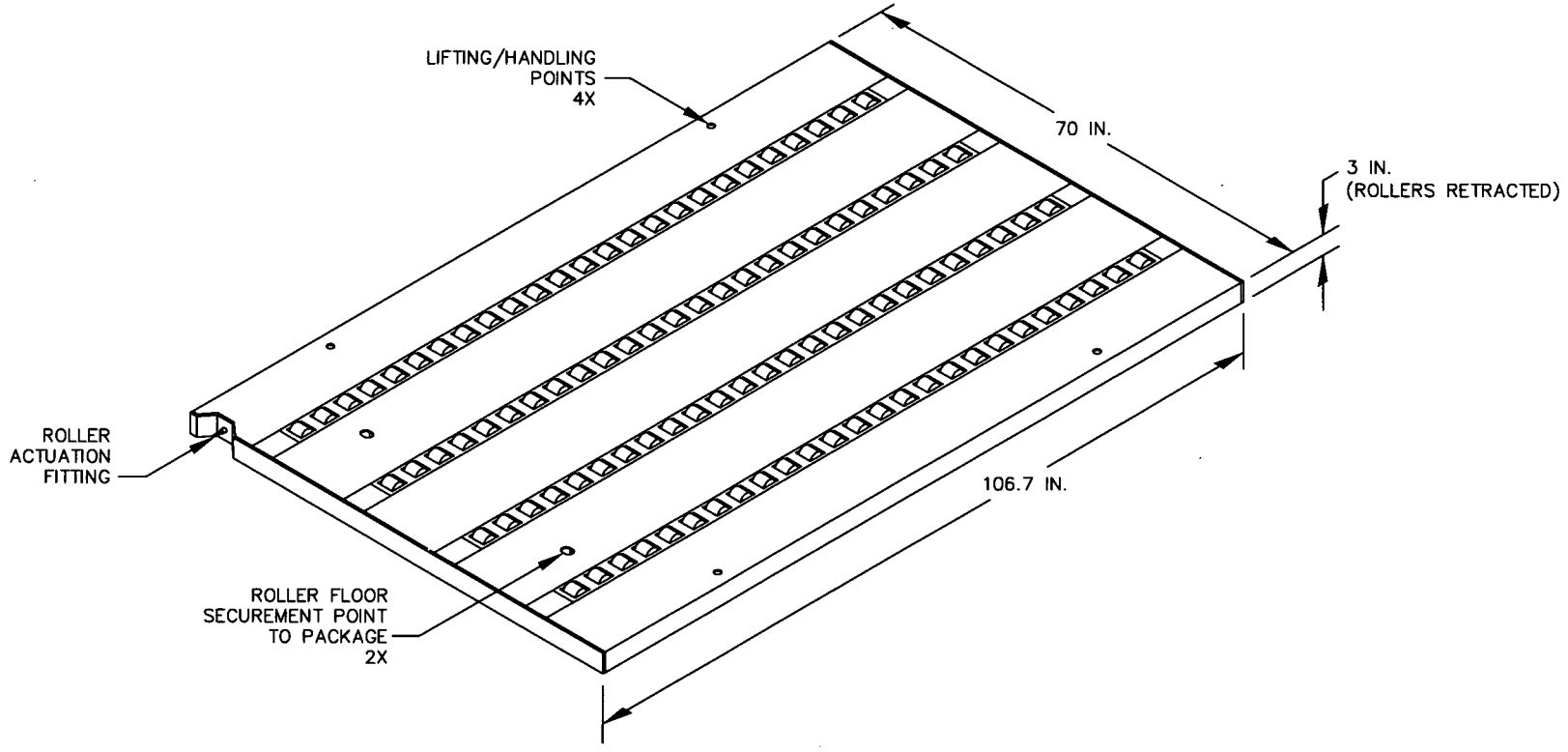


Figure 2.8.2-1 – TRUPACT-III Roller Floor

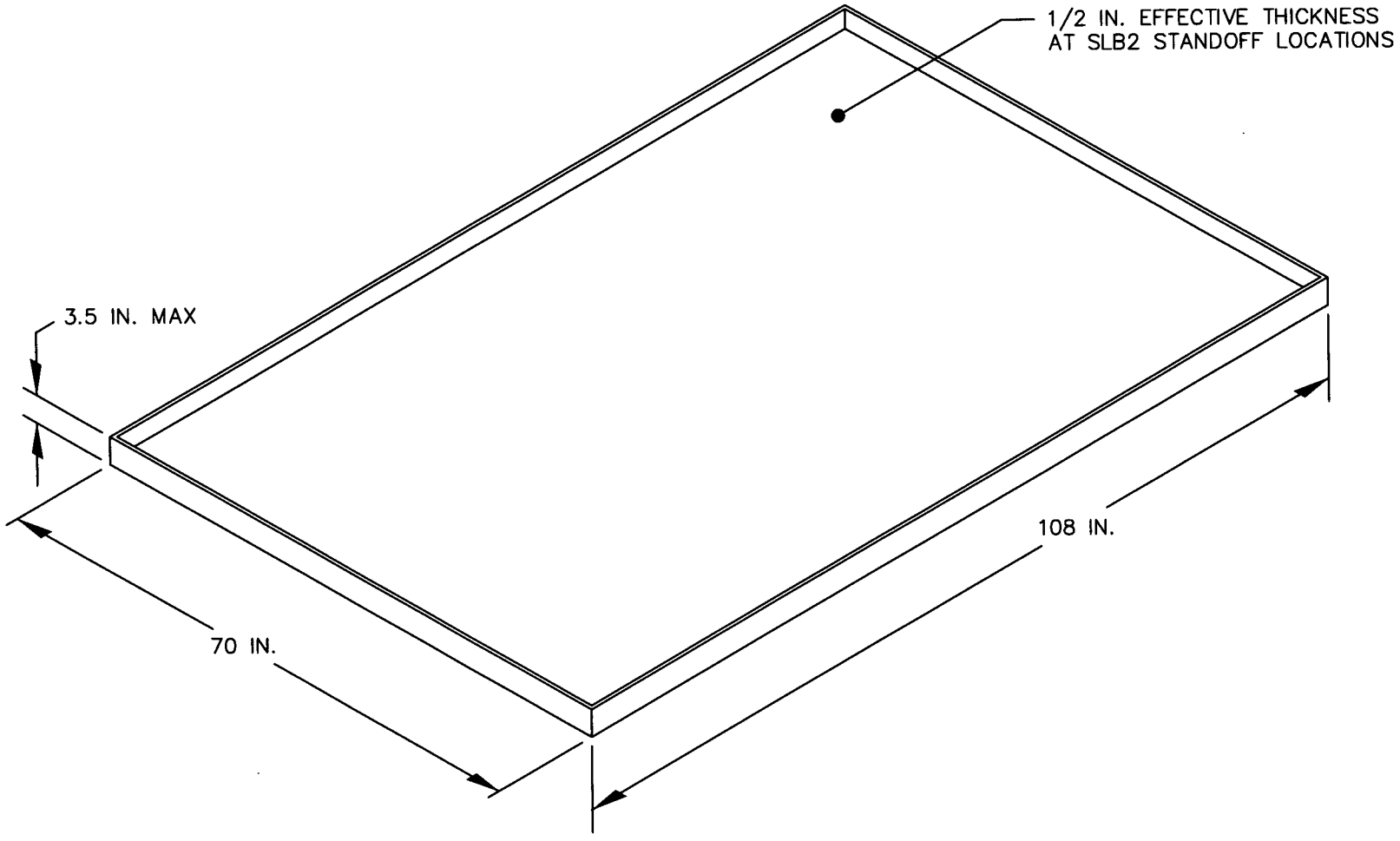


Figure 2.8.2-2 – TRUPACT-III Loading Pallet

3.0 NUCLEAR PROPERTIES

The nuclear properties requirements outlined in this section require a knowledge of isotopic composition and quantity of fissile material. The four major product material isotopic compositions are:

1. Weapons-grade plutonium (primarily Pu-239)
2. Fuel-grade plutonium (primarily Pu-239)
3. Heat-source plutonium (primarily Pu-238)
4. Other TRU isotopes.

Site process areas usually only handle product materials of specific isotopic composition (e.g., weapons-grade plutonium has the following composition: 93.83% Pu-239, 5.82% Pu-240, 0.34% Pu-241, 0.02% Pu-242, 0.01% Pu-238). Therefore, the isotopic composition in the waste from specific process areas remains constant since product isotopic composition is closely controlled to meet production isotopic specification requirements.

3.1 Nuclear Criticality

3.1.1 Requirements

A TRUPACT-III payload shall not contain greater than 1 percent by weight beryllium and/or beryllium oxide.

A TRUPACT-III payload shall not contain machine-compacted waste.

A payload shall be acceptable for transport only if the Pu-239 fissile gram equivalent (FGE) plus two times the error (i.e., two standard deviations) is less than or equal to 500 grams per TRUPACT-III package.

The fissile material limit per TRUPACT-III package may be increased if the payload is documented to contain Pu-240 as specified in Table 3.1.1-1. The minimum Pu-240 content for the payload shall be determined after the subtraction of two times the error (i.e., two standard deviations).

Table 3.1.1-1 – Fissile Material Limits per TRUPACT-III Package with Credit for Pu-240 Poisoning

Minimum Pu-240 Content in TRUPACT-III Payload (grams)	Fissile Material Limit per TRUPACT-III Package (Pu-239 FGE)
0	500
5	515
15	535
25	555

3.1.2 Methods of Compliance and Verification

Compliance with the FGE requirements involves the following steps:

- Determination of the isotopic composition
- Determination of the quantity of radionuclides
- Calculation of the FGE and compliance evaluation.

Each of these steps is discussed in detail below.

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, from analysis of the waste, or from existing records. The isotopic composition of the waste need not be determined by direct analysis or measurement of the waste unless process information is not available.

The following are two examples of analytical methods for determining isotopic composition:

- Mass spectrometry (MS)
- Gamma ray pulse height analysis.

Depending on the mixture of radionuclides present in the waste, one or both of the methods may be required. These assay methods are described in Appendix 5.2 of the CH-TRU Payload Appendices.[1]

MS is a primary method for determining the radioisotopic composition in product material (e.g., plutonium isotopic composition). The isotopic analyses shall be performed in accordance with the following American Society for Testing and Materials (ASTM) MS methods: ASTM C 696[2], ASTM C 697[3], and ASTM C 759[4], or equivalent methods.

Gamma ray pulse height analysis or MS is used to determine the isotopic composition for gamma-emitting radionuclides. Gamma ray pulse height analysis shall be performed in accordance with ASTM C 1030[5], or an equivalent method.

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[1] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

[2] American Society for Testing and Materials (ASTM), *Standard Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Uranium Dioxide Powders and Pellets*, ASTM C 696, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

[3] American Society for Testing and Materials (ASTM), *Standard Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Plutonium Dioxide Powders and Pellets*, ASTM C 697, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

[4] American Society for Testing and Materials (ASTM), *Standard Test Methods for Chemical, Mass Spectrometric, Spectrochemical, Nuclear, and Radiochemical Analysis of Nuclear-Grade Plutonium Nitrate Solutions*, ASTM C 759, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

[5] American Society for Testing and Materials (ASTM), *Standard Test Method for Determination of Plutonium Isotopic Composition by Gamma-Ray Spectrometry*, ASTM C 1030, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

Quantity of Radionuclides

The quantity of the radionuclides in each payload container shall be estimated by either a direct measurement or records 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, and/or 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 and the total quantity of Pu-239 FGE. 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.

The following are five examples of assay methods for quantifying radionuclides in TRU waste:

- Passive gamma (hyper-pure germanium, germanium, lithium-drifted germanium, sodium iodide: transmission-corrected and noncorrected)
- Radiochemical assay (alpha and gamma spectroscopy)
- Passive neutron coincidence counting assay
- Passive-active neutron assay
- Calorimetry.

These assay methods are described in Appendix 5.2 of the CH-TRU Payload Appendices.[1]

General assay requirements that apply to all sites are as follows:

- Each site shall select and use the assay method(s) of its choice, provided the method(s) is/are approved by the DOE-CBFO under the programmatic or waste-specific data TRAMPAC (see Section 1.5, *Methods of Compliance*) and the prescribed controls are implemented.
- The site's waste content code descriptions shall list the specific assay method(s) and its/their application(s).
- Site/equipment-specific operating and QA procedures or the waste-specific data package shall describe the assay method(s) and the controls imposed on the assay operations. The controls include performing calibration and background measurements. The calibration and background measurements shall fall within the stated acceptable ranges before assays are performed.
- Site/equipment-specific QA plans and procedures or the QA associated with the waste-specific data package shall include oversight of assay methods and controls.
- Each site shall provide a specialized training program for assay operators.

Calculation of the Pu-239 FGE and Compliance Evaluation

The American National Standards Institute (ANSI)/American Nuclear Society (ANS) (ANSI/ANS-8.1[6]) establishes U-233, U-235, and Pu-239 subcritical mass limits for aqueous mixtures that might not be uniform and are independent of compound. Subcritical mass limits for other actinide isotopes are given in ANSI/ANS-8.15[7]. The bases for these limits are similar, and the same mass limit for Pu-239 is given in both standards. The ratio of these mass limits provides the basis for the Pu-239 FGE conversion factors given in Table 3.1.2-1.

FGE conversion factors for other fissile or fissionable isotopes, including special actinide elements, shall be obtained using the ANSI/ANS 8.1[6] and 8.15[7] methods described above, or equivalent method.

The FGE of the SLB2 shall be calculated by summing the product of the quantity (in grams) of each radionuclide and its respective FGE conversion factor provided in Table 3.1.2-1. The FGE value plus two times the error (i.e., two standard deviations) shall be less than or equal to the applicable limit for the SLB2.

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[6] American National Standards Institute/American Nuclear Society (ANSI/ANS), 1998, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, ANSI/ANS-8.1, American National Standards Institute/American Nuclear Society, Washington, D.C.

[7] American National Standards Institute/American Nuclear Society (ANSI/ANS), 1981, *Nuclear Criticality Control of Special Actinide Elements*, ANSI/ANS-8.15, American National Standards Institute/American Nuclear Society, Washington, D.C.

Table 3.1.2-1 – Pu-239 Fissile Gram Equivalent, Decay Heat, and Specific Activity of Selected Radionuclides

NUCLIDE		SPECIFIC ATOMIC NUMBER	Pu-239 FGE[①②]	DECAY HEAT[③] (W/g)	SPECIFIC ACTIVITY[④] (Ci/g)
H	3	1	0.00E+00	3.28E-01	9.76E+03
Be	10	4	0.00E+00	2.68E-05	2.24E-02
C	14	6	0.00E+00	1.32E-03	4.51E+00
Na	22	11	0.00E+00	8.94E+01	6.32E+03
P	32	15	0.00E+00	1.19E+03	2.89E+05
P	33	15	0.00E+00	2.33E+02	1.58E+05
S	35	16	0.00E+00	1.23E+01	4.26E+04
Ca	45	20	0.00E+00	8.12E+00	1.78E+04
Sc	46	21	0.00E+00	4.25E+02	3.38E+04
V	49	23	0.00E+00	2.06E-01	8.08E+03
Cr	51	24	0.00E+00	1.95E+01	9.24E+04
Mn	54	25	0.00E+00	3.88E+01	7.82E+03
Fe	55	26	0.00E+00	8.49E-02	2.44E+03
Fe	59	26	0.00E+00	3.80E+02	4.92E+04
Co	57	27	0.00E+00	7.29E+00	8.55E+03
Co	58	27	0.00E+00	1.91E+02	3.18E+04
Co	60	27	0.00E+00	1.76E+01	1.14E+03
Ni	59	28	0.00E+00	3.22E-06	8.08E-02
Ni	63	28	0.00E+00	6.05E-03	5.98E+01
Cu	64	29	0.00E+00	7.21E+03	3.89E+06
Zn	65	30	0.00E+00	2.89E+01	8.24E+03
As	73	33	0.00E+00	1.02E+01	2.25E+04
Se	79	34	0.00E+00	2.18E-05	6.97E-02
Kr	85	36	0.00E+00	5.94E-01	3.97E+02
Rb	86	37	0.00E+00	3.71E+02	8.22E+04
Rb	87	37	0.00E+00	7.32E-11	8.75E-08
Sr	89	38	0.00E+00	1.01E+02	2.94E+04
Sr	90	38	0.00E+00	1.60E-01	1.38E+02
Y	88	39	0.00E+00	2.24E+02	1.41E+04
Y	90	39	0.00E+00	3.01E+03	5.44E+05
Y	90m	39	0.00E+00	4.40E+04	1.09E+07
Y	91	39	0.00E+00	8.83E+01	2.45E+04
Zr	88	40	0.00E+00	4.46E+01	1.80E+04
Zr	90	40	0.00E+00	N/A[⑤]	N/A[⑤]
Zr	90m	40	0.00E+00	2.13E+09	1.55E+11

NUCLIDE		SPECIFIC ATOMIC NUMBER	Pu-239 FGE[①②]	DECAY HEAT[③] (W/g)	SPECIFIC ACTIVITY[④] (Ci/g)
Zr	93	40	0.00E+00	7.29E-07	2.51E-03
Zr	95	40	0.00E+00	1.10E+02	2.17E+04
Nb	93m	41	0.00E+00	5.01E-02	2.83E+02
Nb	94	41	0.00E+00	1.91E-03	1.87E-01
Nb	95	41	0.00E+00	1.87E+02	3.91E+04
Nb	95m	41	0.00E+00	6.11E+02	3.81E+05
Tc	99	43	0.00E+00	8.49E-06	1.70E-02
Tc	99m	43	0.00E+00	4.31E+03	5.27E+06
Ru	103	44	0.00E+00	1.05E+02	3.26E+04
Ru	106	44	0.00E+00	2.00E-01	3.38E+03
Rh	103m	45	0.00E+00	7.55E+03	3.25E+07
Rh	106	45	0.00E+00	6.74E+07	3.56E+09
Pd	107	46	0.00E+00	2.83E-08	5.14E-04
Ag	108	47	0.00E+00	2.74E+06	7.35E+08
Ag	108m	47	0.00E+00	2.53E-01	2.61E+01
Ag	109m	47	0.00E+00	1.32E+06	2.61E+09
Ag	110	47	0.00E+00	3.01E+07	4.17E+09
Ag	110m	47	0.00E+00	7.99E+01	4.80E+03
Cd	109	48	0.00E+00	1.68E+00	2.61E+03
Cd	113m	48	0.00E+00	2.34E-01	2.17E+02
Cd	115m	48	0.00E+00	9.59E+01	2.55E+04
In	114	49	0.00E+00	6.32E+06	1.38E+09
In	114m	49	0.00E+00	3.23E+01	2.31E+04
In	115m	49	0.00E+00	1.26E+04	6.34E+06
Sn	119m	50	0.00E+00	2.38E+00	4.48E+03
Sn	121m	50	0.00E+00	1.44E-02	5.91E+01
Sn	123	50	0.00E+00	2.58E+01	8.22E+03
Sn	126	50	0.00E+00	3.06E-05	2.84E-02
Sb	124	51	0.00E+00	2.32E+02	1.75E+04
Sb	125	51	0.00E+00	3.27E+00	1.04E+03
Sb	126	51	0.00E+00	1.54E+03	8.36E+04
Sb	126m	51	0.00E+00	1.01E+06	7.85E+07
Te	123	52	0.00E+00	6.50E-17	4.85E-12
Te	123m	52	0.00E+00	1.31E+01	8.87E+03
Te	125m	52	0.00E+00	1.57E+01	1.80E+04
Te	127	52	0.00E+00	3.59E+03	2.64E+06
Te	127m	52	0.00E+00	5.21E+00	9.43E+03
Te	129	52	0.00E+00	7.48E+04	2.09E+07

NUCLIDE		SPECIFIC ATOMIC NUMBER	Pu-239 FGE[1][2]	DECAY HEAT[3] (W/g)	SPECIFIC ACTIVITY[4] (Ci/g)
Te	129m	52	0.00E+00	5.42E+01	3.01E+04
I	125	53	0.00E+00	6.38E+00	1.76E+04
I	129	53	0.00E+00	9.34E-08	1.79E-04
I	131	53	0.00E+00	4.23E+02	1.25E+05
Cs	134	55	0.00E+00	1.33E+01	1.31E+03
Cs	135	55	0.00E+00	3.82E-07	1.15E-03
Cs	137	55	0.00E+00	9.74E-02	8.80E+01
Ba	133	56	0.00E+00	6.82E-01	2.53E+02
Ba	137	56	0.00E+00	N/A[5]	N/A[5]
Ba	137m	56	0.00E+00	2.12E+06	5.38E+08
Ce	141	58	0.00E+00	4.19E+01	2.88E+04
Ce	142	58	0.00E+00	0.00E+00	2.40E-08
Ce	144	58	0.00E+00	2.14E+00	3.22E+03
Pr	143	59	0.00E+00	1.26E+02	6.73E+04
Pr	144	59	0.00E+00	5.54E+05	7.56E+07
Pr	144m	59	0.00E+00	6.22E+04	1.81E+08
Pm	146	61	0.00E+00	2.22E+00	4.43E+02
Pm	147	61	0.00E+00	3.44E-01	9.38E+02
Pm	148	61	0.00E+00	1.26E+03	1.64E+05
Pm	148m	61	0.00E+00	2.73E+02	2.14E+04
Sm	146	62	0.00E+00	3.47E-07	2.38E-05
Sm	147	62	0.00E+00	3.04E-10	2.30E-08
Sm	151	62	0.00E+00	3.10E-03	2.66E+01
Eu	150	63	0.00E+00	5.95E-01	6.46E+01
Eu	152	63	0.00E+00	1.35E+00	1.78E+02
Eu	154	63	0.00E+00	2.39E+00	2.67E+02
Eu	155	63	0.00E+00	3.42E-01	4.70E+02
Gd	152	64	0.00E+00	2.77E-13	2.18E-11
Gd	153	64	0.00E+00	2.96E+00	3.53E+03
Tb	160	65	0.00E+00	9.24E+01	1.13E+04
Ho	166m	67	0.00E+00	1.99E-02	1.80E+00
Tm	168	69	0.00E+00	8.39E+01	8.44E+03
Ta	182	73	0.00E+00	5.60E+01	6.31E+03
Au	198	79	0.00E+00	1.51E+03	2.45E+05
Tl	207	81	0.00E+00	5.58E+05	1.90E+08
Tl	208	81	0.00E+00	6.93E+06	2.95E+08
Tl	209	81	0.00E+00	8.58E+06	4.16E+08
Pb	209	82	0.00E+00	5.32E+03	4.54E+06

NUCLIDE		SPECIFIC ATOMIC NUMBER	Pu-239 FGE[1][2]	DECAY HEAT[3] (W/g)	SPECIFIC ACTIVITY[4] (Ci/g)
Pb	210	82	0.00E+00	1.96E-02	7.72E+01
Pb	211	82	0.00E+00	7.61E+04	2.47E+07
Pb	212	82	0.00E+00	2.64E+03	1.39E+06
Pb	214	82	0.00E+00	1.49E+05	3.28E+07
Bi	207	83	0.00E+00	5.34E-01	5.48E+01
Bi	210	83	0.00E+00	2.86E+02	1.24E+05
Bi	211	83	0.00E+00	1.64E+07	4.18E+08
Bi	212	83	0.00E+00	2.42E+05	1.47E+07
Bi	213	83	0.00E+00	7.64E+04	1.93E+07
Bi	214	83	0.00E+00	7.25E+05	4.41E+07
Po	209	84	0.00E+00	4.94E+00	1.68E+01
Po	210	84	0.00E+00	1.45E+02	4.54E+03
Po	211	84	0.00E+00	4.58E+09	1.04E+11
Po	212	84	0.00E+00	9.24E+15	1.77E+17
Po	213	84	0.00E+00	6.26E+14	1.26E+16
Po	214	84	0.00E+00	1.46E+13	3.21E+14
Po	215	84	0.00E+00	1.29E+12	2.95E+13
Po	216	84	0.00E+00	1.40E+10	3.48E+11
Po	218	84	0.00E+00	9.90E+06	2.78E+08
At	211	85	0.00E+00	3.05E+04	2.06E+06
At	217	85	0.00E+00	6.74E+10	1.61E+12
Rn	219	86	0.00E+00	5.30E+08	1.30E+10
Rn	220	86	0.00E+00	3.44E+07	9.22E+08
Rn	222	86	0.00E+00	5.01E+03	1.54E+05
Fr	221	87	0.00E+00	6.71E+06	1.77E+08
Fr	223	87	0.00E+00	1.10E+05	3.87E+07
Ra	223	88	0.00E+00	1.83E+03	5.18E+04
Ra	224	88	0.00E+00	5.37E+03	1.59E+05
Ra	225	88	0.00E+00	2.78E+01	3.92E+04
Ra	226	88	0.00E+00	2.88E-02	1.00E+00
Ra	228	88	0.00E+00	2.76E-02	2.76E+02
Ac	225	89	0.00E+00	1.99E+03	5.80E+04
Ac	227	89	0.00E+00	3.68E-02	7.32E+01
Ac	228	89	0.00E+00	1.80E+04	2.24E+06
Th	227	90	0.00E+00	1.11E+03	3.07E+04
Th	228	90	0.00E+00	2.71E+01	8.29E+02
Th	229	90	0.00E+00	6.17E-03	2.13E-01
Th	230	90	0.00E+00	5.75E-04	2.04E-02

NUCLIDE		SPECIFIC ATOMIC NUMBER	Pu-239 FGE[①②]	DECAY HEAT[③] (W/g)	SPECIFIC ACTIVITY[④] (Ci/g)
Th	231	90	0.00E+00	6.43E+02	5.32E+05
Th	232	90	0.00E+00	2.68E-09	1.11E-07
Th	234	90	0.00E+00	3.45E+00	2.32E+04
Pa	231	91	0.00E+00	1.46E-03	4.78E-02
Pa	233	91	0.00E+00	4.90E+01	2.08E+04
Pa	234	91	0.00E+00	2.40E+04	2.00E+06
Pa	234m	91	0.00E+00	3.40E+06	6.87E+08
U	232	92	0.00E+00	6.93E-01	2.16E+01
U	233	92	9.00E-01	2.84E-04	9.76E-03
U	234	92	0.00E+00	1.82E-04	6.32E-03
U	235	92	6.43E-01	6.04E-08	2.19E-06
U	236	92	0.00E+00	1.78E-06	6.54E-05
U	237	92	0.00E+00	1.64E+02	8.25E+04
U	238	92	0.00E+00	8.62E-09	3.40E-07
U	239	92	0.00E+00	1.69E+05	3.35E+07
U	240	92	0.00E+00	1.17E+03	9.26E+05
Np	237	93	1.50E-02	2.09E-05	7.13E-04
Np	238	93	0.00E+00	1.49E+03	2.59E+05
Np	239	93	0.00E+00	5.87E+02	2.32E+05
Np	240	93	0.00E+00	8.52E+04	1.27E+07
Np	240m	93	0.00E+00	9.98E+05	1.08E+08
Pu	236	94	0.00E+00	1.87E+01	5.37E+02
Pu	238	94	1.13E-01	5.73E-01	1.73E+01
Pu	239	94	1.00E+00	1.95E-03	6.29E-02
Pu	240	94	2.25E-02	7.16E-03	2.30E-01
Pu	241	94	2.25E+00	3.31E-03	1.04E+02
Pu	242	94	7.50E-03	1.17E-04	3.97E-03
Pu	243	94	0.00E+00	5.38E+03	2.60E+06
Pu	244	94	0.00E+00	5.22E-07	1.79E-05
Am	241	95	1.87E-02	1.16E-01	3.47E+00
Am	242	95	0.00E+00	9.38E+02	8.08E+05
Am	242m	95	3.46E+01	4.32E-03	9.83E+00
Am	243	95	1.29E-02	6.49E-03	2.02E-01
Am	245	95	0.00E+00	2.12E+04	6.24E+06
Cm	240	96	0.00E+00	7.48E+02	2.01E+04
Cm	242	96	0.00E+00	1.23E+02	3.35E+03
Cm	243	96	5.00E+00	1.90E+00	5.22E+01
Cm	244	96	9.00E-02	2.86E+00	8.18E+01

NUCLIDE		SPECIFIC ATOMIC NUMBER	Pu-239 FGE[①②]	DECAY HEAT[③] (W/g)	SPECIFIC ACTIVITY[④] (Ci/g)
Cm	245	96	1.50E+01	5.77E-03	1.74E-01
Cm	246	96	0.00E+00	1.02E-02	3.11E-01
Cm	247	96	5.00E-01	2.98E-06	9.38E-05
Cm	248	96	0.00E+00	5.53E-04	4.30E-03
Cm	250	96	0.00E+00	1.59E-01	2.10E-01
Bk	247	97	0.00E+00	3.69E-02	1.06E+00
Bk	249	97	0.00E+00	3.24E-01	1.66E+03
Bk	250	97	0.00E+00	3.34E+04	3.90E+06
Cf	249	98	4.50E+01	1.54E-01	4.14E+00
Cf	250	98	0.00E+00	4.12E+00	1.11E+02
Cf	251	98	9.00E+01	5.89E-02	1.60E+00
Cf	252	98	0.00E+00	4.06E+01	5.44E+02
Cf	254	98	0.00E+00	9.10E-01	8.50E+03
Es	252	99	0.00E+00	4.37E+01	1.11E+03
Es	253	99	0.00E+00	9.91E+02	2.52E+04
Es	254	99	0.00E+00	7.35E+01	1.88E+03
Es	254m	99	0.00E+00	1.69E+03	3.14E+05

[①] American National Standards Institute/American Nuclear Society (ANSI/ANS), 1981, "Nuclear Criticality Control of Special Actinide Elements," ANSI/ANS-8.15-1981, American National Standards Institute/American Nuclear Society, Washington, D.C.

[②] American National Standards Institute/American Nuclear Society (ANSI/ANS), 1998, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-1998, American National Standards Institute/American Nuclear Society, Washington, D.C.

[③] International Commission on Radiological Protection, 1983. International Commission on Radiological Protection, 1983, "Radionuclide Transformations: Energy and Intensity of Emissions," Annals of the International Commission on Radiological Protection-38, Volumes 11-13, Pergamon Press, Oxford.

[④] Walker, F.W., Kiravac, G.J., and Rourke, F.M., 1983, Chart of the Nuclides, 13th Edition, Knolls Atomic Power Laboratories, Schenectady, NY.

[⑤] These isotopes are stable and thus have decay heats and specific activities of zero.

Ci/g = Curies per gram.
W/g = Watts per gram.

3.2 Radiation Dose Rates

3.2.1 Requirements

The external radiation dose rate of an individual payload container shall be less than or equal to 200 millirem/hour (mrem/hour) at the surface.

The external radiation dose rates of the TRUPACT-III shall be less than or equal to 200 mrem/hour) at the surface and less than or equal to 10 mrem/hour at 2 meters.

Additional payload container shielding, beyond that identified in Section 2.8, *Specification for Authorized Payloads*, as an integral component of the payload container, shall not be used to meet the above requirements. However, payload containers that meet the above radiation dose rate requirements without shielding may be shielded to levels that are ALARA.

3.2.2 Methods of Compliance and Verification

The payload container surface dose rate shall be measured and compliance recorded on the PTCD (see Section 6.2.1, *Procedure for Certification of Individual Payload Containers*). Measurements shall be made with instruments traceable to a national standard. The dose rate for the TRUPACT-III at the surface and at 2 meters shall be measured and compliance determined and documented in accordance with site procedures.

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3.3 Activity Limits

3.3.1 Requirements

As described in Section 2.7.7, *Deep Water Immersion*, of the TRUPACT-III Safety Analysis Report[1], a payload shall be acceptable for transport only if the activity plus error (i.e., one standard deviation) is less than or equal to 10^5 A_2. A_2 values are defined in 10 CFR 71[2].

3.3.2 Methods of Compliance and Verification

Compliance with the activity requirements is similar to the compliance methodology described in Section 3.1.2, *Methods of Compliance and Verification*. The activity of the payload shall be calculated from the isotopic composition and quantity of radionuclides comprising the payload. The total payload activity plus error (i.e., one standard deviation) shall be used to determine compliance with the 10^5 A_2 payload activity limit.

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[1] Packaging Technology, Inc., *Safety Analysis Report for the TRUPACT-III Shipping Package*, current revision, USNRC Docket No. 71-9305, Packaging Technology, Inc., Tacoma, Washington

[2] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Materials*, 01-01-07 Edition.

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4.0 CHEMICAL PROPERTIES

4.1 Pyrophoric Materials

As defined by 10 CFR §61.2:

> A pyrophoric solid is any solid material, other than one classed as an explosive, which under normal conditions is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation, handling, or disposal hazard. Included are spontaneously combustible and water-reactive materials.[1]

Examples of pyrophoric radionuclides are metallic plutonium and americium. Examples of nonradioactive pyrophorics, or materials/wastes that may cause a pyrophoric-type event, are organic peroxides, sodium metal, and chlorates.

All waste generating sites administratively control the procurement, distribution, use, and disposal of nonradioactive pyrophoric materials. In general, pyrophoric materials are not permitted in TRU waste process areas. The quantity of pyrophoric materials that does enter any process is strictly limited and controlled by site safety considerations.

4.1.1 Requirements

Radioactive pyrophoric materials shall be present only in small residual amounts (≤1 percent [weight]) in payload containers. Radioactive pyrophorics in concentrations greater than 1 percent by weight and all nonradioactive pyrophorics shall be reacted (or oxidized) and/or otherwise rendered nonreactive prior to placement in the payload container.

4.1.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Review of records and database information, which may include knowledge of process
- Administrative and procurement controls.

[1] U.S. Nuclear Regulatory Commission (NRC), *Pyrophoric definition*, Code of Federal Regulations Title 10, Section 61.2, U.S. Nuclear Regulatory Commission, Washington, D.C.

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4.2 Explosives, Corrosives, and Compressed Gases

As defined by 49 CFR §173.50:

> ...an explosive means any substance or article, including a device, which is designed to function by explosion (i.e., an extremely rapid release of gas and heat) or which, by chemical reaction within itself, is able to function in a similar manner even if not designed to function by explosion, unless the substance or article is otherwise classed under the provisions of [49 CFR 173, Subpart C]. The term includes a pyrotechnic substance or article, unless the substance or article is otherwise classed under the provisions of [49 CFR 173, Subpart C].[1]

Examples of explosives are ammunition, dynamite, black powder, detonators, nitroglycerine, urea nitrate, and picric acid.

As defined by 40 CFR §261.22:

> (a) A solid waste exhibits the characteristic of corrosivity if a representative sample of the waste has...the following propert[y]:
>
> (1) It is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5.
>
> (b) A solid waste that exhibits the characteristic of corrosivity has the EPA Hazardous Waste Number of D002.[2]

The physical form of the waste and waste generating procedures at the sites ensure that the waste is in a nonreactive form. All waste generating sites control the procurement, distribution, use, and disposal of explosives. Most sites have lists of restricted materials that include explosives. Typically, the TRU waste generating and storage sites do not allow explosives in the same facility as TRU waste. In addition, sampling programs for pH of inorganic sludges have shown that the sludges consistently meet the limitation on corrosives.[3]

4.2.1 Requirements

Explosives, corrosives, and compressed gases (pressurized containers) are prohibited from the payload.

Used (i.e., empty) aerosol cans are allowed as they do not impact the package internal pressure or flammability. Verification that any aerosol cans present in retrievably stored waste are empty shall be by radiography and/or process knowledge and shall be documented in site-specific compliance documents. Any aerosol cans that are not empty are prohibited.

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[1] U.S. Department of Transportation (DOT), *An Explosive; definition*, Code of Federal Regulations Title 49, Section 173.50, U.S. Department of Transportation, Washington, D.C.

[2] U.S. Environmental Protection Agency (EPA), *Characteristic of corrosivity*, Code of Federal Regulations Title 40, Section 261.22, U.S. Environmental Protection Agency, Washington, D.C.

[3] U.S. Department of Energy (DOE), *CH-TRU Waste Content Codes (CH-TRUCON)*, current revision, DOE/WIPP-3194, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

4.2.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Visual examination of the waste
- Administrative and procurement controls
- Radiography
- Sampling program
- Review of records and database information, which may include knowledge of process.

4.3 Chemical Composition

The chemical constituents allowed in the waste are restricted so that a conservative bounding G value may be established for the gas generation potential of the waste. Wastes to be shipped in the TRUPACT-III must comply with the list of allowable materials in Table 4.3.2-1.

4.3.1 Requirements

Chemical constituents in a payload shall conform to the list of allowable materials in Table 4.3.2-1. The total quantity of chemicals/materials not listed in Table 4.3.2-1 in any payload container is restricted to less than 5 weight percent total. These materials, if present, are, in general, present as trace chemicals/materials (materials that occur individually in the waste in quantities less than 1 weight percent).

4.3.2 Methods of Compliance and Verification

Compliance shall be by one, or a combination, of the following methods:

- Review of records and database information, which may include knowledge of process
- Administrative and procurement controls
- Sampling program.

Content codes approved by the WIPP CH-TRU Payload Engineer comply with the chemical composition requirements. Any proposed change in process technology at a generator site for a given content code must be evaluated for compliance with the list of allowable materials in Table 4.3.2-1. All changes in the chemical characteristics of the waste shall be recorded, and the date of the new process, description of the process, and list of new chemicals submitted to the WIPP CH-TRU Payload Engineer. The WIPP CH-TRU Payload Engineer may allow transport of the waste under the approved content code if none of the restrictions are violated as a result of the change. The NRC shall be notified of any change not covered by the authorized contents as defined by this document through an amendment to the TRUPACT-III TRAMPAC. All changes exceeding currently authorized contents shall be submitted to the NRC for review and approval prior to incorporation into a chemical list or content code.

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Table 4.3.2-1 – Allowable Materials for TRUPACT-III Payloads①

Absorbent polymers, organic
Absorbents/adsorbents (e.g., Celite®, diatomaceous earth, diatomite, Florco®, Oil-Dri®, perlite, vermiculite)
Acids (inorganic and organic) – neutralized/solidified
Alumina cement
Aquaset® products (for aqueous solutions)
Aqueous sludges
Aqueous solutions/water
Asbestos
Ash (e.g., ash bottoms, fly ash, soot)
Asphalt
Bakelite® ②
Batteries, dry (e.g., flashlight)
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)
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
Heel (e.g., ash heel; soot heel; firebrick heel; sand, slag, and crucible heel)
Insulation (inorganic and organic)
Leaded rubber (e.g., gloves, aprons, sheet material)
Leather
Magnesia cement (e.g., Ramcote® cement)
Magnesium alloy
Metal hydroxides
Metal oxides (e.g., slag)
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)

Other inorganic materials
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, 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)
Waxes, commercial brands

Notes:

① Other chemicals or materials not identified in this table are allowed provided that they meet the requirements of Section 4.3.1. All materials in the final waste form must be inert (nonreactive), be in a nonreactive form, or have been rendered nonreactive.

② Bakelite is a trademark for materials that can be composed of several different polymers, including polyethylene, polypropylene, epoxy, phenolic, polystyrene, phenoxy, perylene, polysufone, ethylene copolymers, ABS, acrylics, and vinyl resins and compounds.

4.4 Chemical Compatibility

The list of allowable materials in Table 4.3.2-1 restricts the chemical composition of the payload. The basis for evaluating chemical compatibility is the U.S. Environmental Protection Agency (EPA) document "A Method for Determining the Compatibility of Hazardous Wastes" (EPA-600/2-80-076).[1] This method provides a systematic means of analyzing the chemical compatibility for 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.[1] As described in Appendix 6.1 of the CH-TRU Payload Appendices[2], the EPA method classifies individual chemical compounds into chemical groups and identifies the potential adverse reactions resulting from incompatible combinations of the groups.

4.4.1 Requirements

Chemical compatibility shall be ensured for the following three conditions:

- Chemical compatibility of the waste form with the payload container
- Chemical compatibility of the waste form with the TRUPACT-III packaging
- Chemical compatibility of the waste form with the TRUPACT-III O-ring seals.

4.4.2 Methods of Compliance and Verification

Compatibility of all authorized wastes has been demonstrated for transport in the TRUPACT-III using the chemicals listed in Table 4.3.2-1. The Section 4.3, *Chemical Composition*, restrictions imposed on the chemical constituents of the content codes approved by the WIPP CH-TRU Payload Engineer ensure compliance with the compatibility requirements (see also Appendices 6.1, 6.2, 6.3, and 6.4 of the CH-TRU Payload Appendices).[2] The chemical list for each content code is formally documented by the site.

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

[2] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

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5.0 GAS GENERATION PROPERTIES

Gas generation, concentrations, and pressures during transport of CH-TRU wastes in a TRUPACT-III payload are restricted as follows:

- For any package containing water and/or organic substances that could radiolytically generate combustible gases, determination must be made by tests and measurements or by analysis of a representative package such that the following criterion is met over a period of time that is twice the expected shipment time (defined in Appendix 7.1.2, *Shipping Period – General Case*, and Appendix 7.1.3, *Shipping Period – Controlled Shipments*): The hydrogen generated must be limited to a molar quantity that would be no more than 5% by volume of the innermost layer of confinement (or equivalent limits for other inflammable gases) if present at standard temperature and pressure (STP) (i.e., no more than 0.063 gram-moles/cubic foot at 14.7 psia and 32°F).
- The gases generated in the payload and released into the cavity shall be controlled to maintain the pressure within the TRUPACT-III containment vessel below the acceptable design pressure of 25 psig.

The design limit for the TRUPACT-III is 80 watts. Specific requirements associated with the restrictions on gas generation during transport of a payload are described in detail below.

5.1 Flammable (Gas/VOC) Concentration Limits

5.1.1 Requirements

As discussed in Appendices 6.1, 6.5, and 6.6 of the CH-TRU Payload Appendices[1], chemical, biological, and thermal mechanisms of gas generation are insignificant, and the primary mechanism for potential flammable gas generation in TRU wastes is radiolysis. TRU wastes to be transported in the TRUPACT-III are restricted so that no flammable mixtures can occur in any layer of confinement during shipment. While the predominant flammable gas of concern is hydrogen, the presence of flammable volatile organic compounds (VOCs) is limited along with hydrogen to ensure the absence of flammable (gas/VOC) mixtures in the TRUPACT-III payload.

5.1.2 Methods of Compliance and Verification

Compliance with the 5% (by volume) limit on the hydrogen concentration can be demonstrated by one of two methods:

- **Compliance with FGGR Limit:** The 5% (by volume) restriction on hydrogen concentration may be converted into a limit on the allowable FGGR per container. If it can be shown for a given container that this limit can be met, the hydrogen concentration will remain at or below 5% under transportation conditions. A generalized procedure for determining the FGGR of a container is provided in Appendix 7.1.4, *Determination of*

[1] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

Flammable Gas Generation Rates. FGGR limits for each content code are specified in the TRUPACT-III Content Codes document.[2]

- **Compliance with Decay Heat Limit**: The 5% (by volume) restriction on hydrogen concentration may be converted into a limit on the allowable decay heat per container. If it can be shown for a given container that this limit can be met, the hydrogen concentration will remain at or below 5% under transportation conditions. Procedures for determining the decay heat value for a container are described in Section 3.0, *NUCLEAR PROPERTIES*. Decay heat limits for each content code are specified in the TRUPACT-III Content Codes document.[2]

Compliance with flammable (gas/VOC) concentration limits may be demonstrated through the evaluation of compliance with either a decay heat or FGGR limit per container specified in approved content codes. If a container meets either the applicable decay heat limit or the FGGR limit, compliance with the flammable (gas/VOC) limits is ensured. The compliance methodology for flammable (gas/VOC) concentration limits is described in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements*. As there is only a single SLB2 in a TRUPACT-III, the limits per SLB2 are also the limits for the TRUPACT-III package. The WIPP CH-TRU Payload Engineer shall use the methodology described in Appendix 7.1.1 to determine the flammable (gas/VOC) concentration limits for all payload containers. The implementation of the methodology described in Appendix 7.1.1 is detailed below.

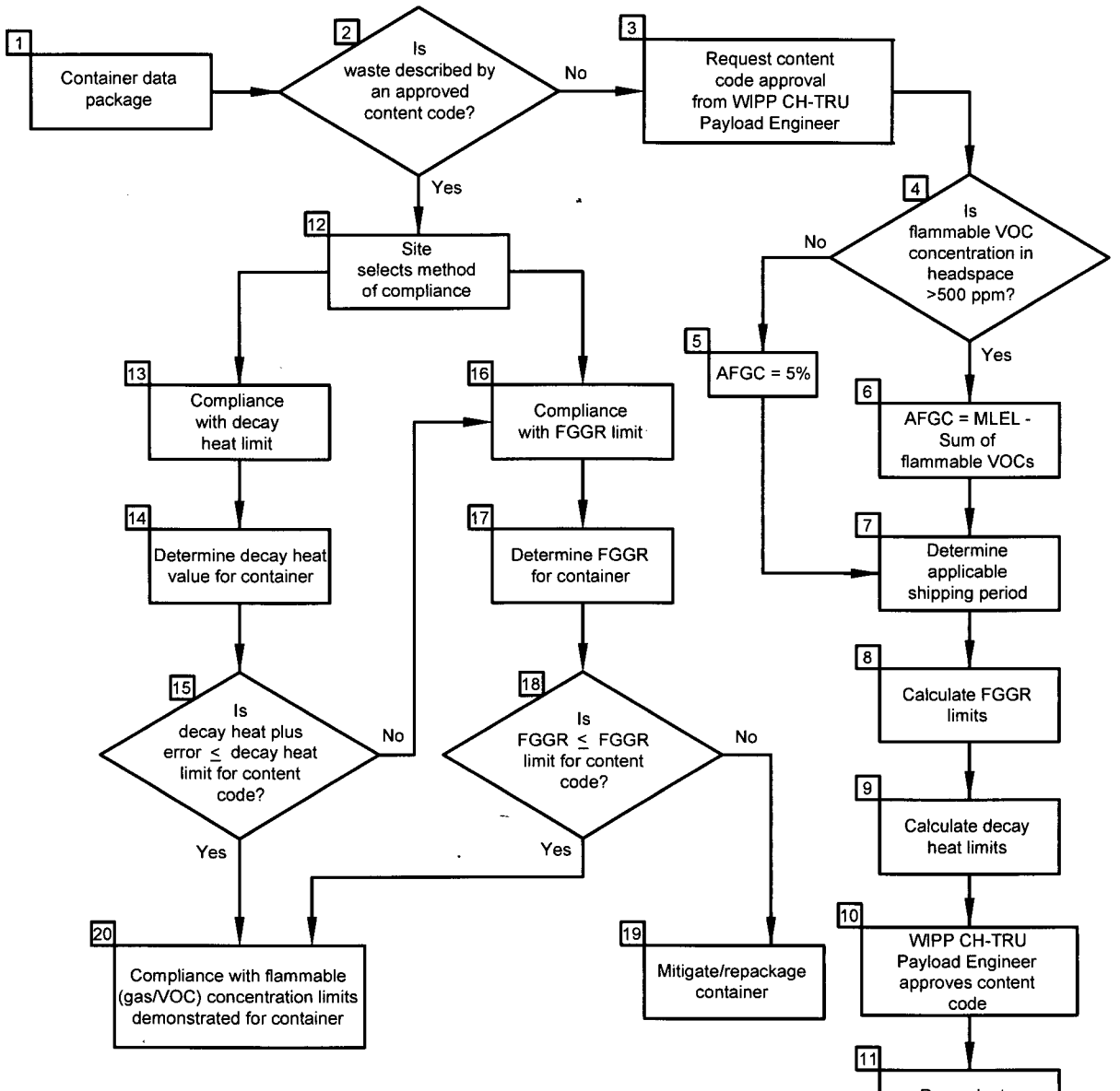
Compliance with Flammable (Gas/VOC) Concentration Limits

As shown in Figure 5.1.2-1, compliance with the limit on hydrogen concentration can be demonstrated by meeting either the FGGR limit or decay heat limit:

- If the actual FGGR for a container (as determined through the methodology of Appendix 7.1.4, *Determination of Flammable Gas Generation Rates*) is less than the FGGR limit specified by the content code for the container, the flammable (gas/VOC) concentration limit will be met.
- If the decay heat value plus error for a container (determined as described in Section 3.1, *Nuclear Criticality*) is less than the decay heat limit specified by the content code for the container, the flammable (gas/VOC) concentration limit will be met.

The derivation of flammable (gas/VOC) concentration limits is detailed in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements*.

[2] U.S. Department of Energy, *TRUPACT-III Content Codes*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.



AFGC = Allowable Flammable Gas Concentration
CH-TRU = Contact-Handled Transuranic
FGGR = Flammable Gas Generation Rate
MLEL = Mixture Lower Explosive Limit
ppm = Parts Per Million
VOC = Volatile Organic Compound

Figure 5.1.2-1 – Methodology for Compliance with Flammable (Gas/VOC) Concentration Limits

Figure 5.1.2-1 presents the logic for performing the compliance evaluation for flammable (gas/VOC) concentration limits, which consists of the following steps:

Step 1, Container data package – The starting point for compliance evaluation is the container data package, which includes all data associated with the container. These data are gathered from one or more of the methods of payload compliance listed and defined in Section 1.5, *Methods of Compliance* (i.e., records and database information, administrative and procurement controls, visual inspection, visual examination, NDE, measurement, and sampling programs).

Step 2, Is waste described by an approved content code? – Each SLB2 must have a content code approved by the WIPP CH-TRU Payload Engineer to be eligible for shipment. If the container is accurately described by an approved content code, the container shall be assigned to the content code and the compliance evaluation shall proceed to **Step 12, Site selects method of compliance.** If the container is not described by an approved content code, proceed to **Step 3, Request content code approval from WIPP CH-TRU Payload Engineer.**

Step 3, Request content code approval from WIPP CH-TRU Payload Engineer – The site must request the revision or addition of a content code by submitting a request in writing to the WIPP CH-TRU Payload Engineer as described in Section 1.6.2, *Use and Approval.* Data necessary to complete each of the required content code elements specified in Section 1.6.1, *Required Elements*, must be provided by the site as part of this request. Under the direction of the WIPP CH-TRU Payload Engineer, the request will be reviewed for completeness and satisfactory demonstration of compliance with all transportation requirements of the TRUPACT-III TRAMPAC. The process of requesting content code approval proceeds to **Step 4, Is flammable VOC concentration in headspace >500 ppm?**

Step 4, Is flammable VOC concentration in headspace >500 ppm? – The concentration of flammable VOCs present in the headspace of a container may be determined as described in Section 5.1.3, *Flammable VOCs.* If it can be determined based on available data that no flammable VOCs are present in the container, or if it can be established that the total flammable VOC concentration in the container headspace is less than or equal to 500 ppm (i.e., VOC contribution to flammability is expected to be negligible), proceed to **Step 5, Allowable Flammable Gas Concentration is 5%.** If the concentration of flammable VOCs in the container cannot be established to be less than or equal to 500 ppm, proceed to **Step 6, Allowable Flammable Gas Concentration is Mixture Lower Explosive Limit minus sum of flammable VOCs.**

Step 5, Allowable Flammable Gas Concentration is 5% – For containers with flammable VOC concentrations less than or equal to 500 ppm in the headspace, the allowable flammable gas concentration (AFGC) is equal to 5% hydrogen. Proceed to **Step 7, Determine applicable shipping period.**

Step 6, Allowable Flammable Gas Concentration is Mixture Lower Explosive Limit minus sum of flammable VOCs – For containers with flammable VOC concentrations greater than 500 ppm in the headspace, the AFGC must be adjusted (reduced from 5% hydrogen) to account for the total flammable VOC concentration. As described in Section 5.1.3, *Flammable VOCs*, a specific mixture lower explosive limit (MLEL) shall be calculated for the container. The reduced AFGC is then calculated as the MLEL minus the sum of flammable VOCs in the

innermost layer of confinement. Following the calculation of the reduced AFGC, proceed to **Step 7, Determine applicable shipping period.**

Step 7, Determine applicable shipping period – The conditions specified in Appendix 7.1.3, *Shipping Period – Controlled Shipments*, must be met for use of the 10-day Controlled Shipment shipping period. For other shipments (not Controlled Shipments), a 60-day shipping period (Appendix 7.1.2, *Shipping Period – General Case*) shall be applied. The requirements for the use of the Controlled Shipment (10 days) shipping period shall be met by administrative and procedural controls as specified in Appendix 7.1.3 and Section 6.2.3, *Shipments Designated as Controlled Shipments*. Following the selection of either the 10- or 60-day shipping period, proceed to **Step 8, Calculate FGGR limits.**

Step 8, Calculate FGGR limits – As described in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements*, the FGGR limits for the content code shall be calculated. Following the calculation of the FGGR limits, proceed to **Step 9, Calculate decay heat limits.**

Step 9, Calculate decay heat limits – As described in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements*, the decay heat limits for the content code shall be calculated. Following the calculation of the decay heat limits, proceed to **Step 10, WIPP CH-TRU Payload Engineer approves content code.**

Step 10, WIPP CH-TRU Payload Engineer approves content code – If compliance with all other transportation requirements of the TRUPACT-III TRAMPAC has been demonstrated, the WIPP CH-TRU Payload Engineer shall approve the content code and send formal written notification to the site indicating the approval of the request. Upon receipt of official notification of content code approval from the WIPP CH-TRU Payload Engineer, the compliance evaluation shall proceed to **Step 11, Re-evaluate container.**

Step 11, Re-evaluate container – The container shall be re-evaluated beginning with **Step 2, Is waste described by an approved content code?**

Step 12, Site selects method of compliance – Compliance with flammable (gas/VOC) limits may be demonstrated through the evaluation of compliance with either the decay heat limit or FGGR limit per container specified in approved content codes. If compliance will be demonstrated by meeting the decay heat limit, the evaluation shall proceed to **Step 13, Compliance with decay heat limit.** If compliance will be demonstrated by meeting the FGGR limit, the evaluation shall proceed to **Step 16, Compliance with FGGR limit.**

Step 13, Compliance with decay heat limit – The compliance evaluation using the decay heat limit specified in the assigned content code shall proceed to **Step 14, Determine decay heat value for container.**

Step 14, Determine decay heat value for container – The site shall determine the decay heat value for the container as described in Section 3.1, *Nuclear Criticality*. Following the determination of the decay heat value for the container, the compliance evaluation shall proceed to **Step 15, Is decay heat plus error ≤ decay heat limit for content code?**

Step 15, Is decay heat plus error ≤ decay heat limit for content code? – Compliance with the applicable decay heat limit specified by the assigned content code is evaluated. If the container exceeds the decay heat limit, the compliance evaluation shall proceed to **Step 16, Compliance**

with FGGR limit. If the container meets the decay heat limit, the flammable (gas/VOC) limits are met and the compliance evaluation is complete (see **Step 20, Compliance with flammable (gas/VOC) concentration limits demonstrated for container**).

Step 16, Compliance with FGGR limit – The compliance evaluation using the FGGR limit specified in the assigned content code shall proceed to **Step 17, Determine FGGR for container**.

Step 17, Determine FGGR for container – The site shall determine the FGGR value for the container as described in Appendix 7.1.4, *Determination of Flammable Gas Generation Rates.* Following the determination of the FGGR value for the container, the compliance evaluation shall proceed to **Step 18, Is FGGR ≤ FGGR limit for content code?**

Step 18, Is FGGR ≤ FGGR limit for content code? – Compliance with the applicable FGGR limit specified by the assigned content code is evaluated. If the container exceeds the FGGR limit, the compliance evaluation shall proceed to **Step 19, Mitigate/repackage container**. If the container meets the FGGR limit, the flammable (gas/VOC) limits are met and the compliance evaluation is complete (see **Step 20, Compliance with flammable (gas/VOC) concentration limits demonstrated for container**).

Step 19, Mitigate/repackage container – If the container cannot be shown to meet the applicable decay heat limit or FGGR limit, the container is not eligible for shipment and must be segregated for repackaging, treatment, or other mitigation measures. Following the completion of mitigation measures, the compliance evaluation shall proceed to **Step 1, Container data package**.

Step 20, Compliance with flammable (gas/VOC) concentration limits demonstrated for container – All containers reaching this step meet the flammable (gas/VOC) limits and are eligible for shipment if all other transportation requirements are satisfied.

5.1.3 Flammable VOCs

For a given container, one of the following must be established in order to evaluate compliance with flammable (gas/VOC) limits (a list of flammable VOCs is provided in Table 5.1.3-1).

- No flammable VOCs are present,
- Total flammable VOC concentration in the container headspace is less than or equal to 500 ppm, or
- Estimated concentration of flammable VOCs in the container headspace if greater than 500 ppm.

Table 5.1.3-1 – Flammable VOCs

Acetone
Benzene
1-Butanol
Chlorobenzene
Cyclohexane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
cis-1,2-Dichloroethene
Ethyl benzene
Ethyl ether
Methanol
Methyl ethyl ketone
Methyl isobutyl ketone
Toluene
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene
Xylenes

The following methods may be used to estimate the total flammable VOC concentration in the container headspace. An upper bounding concentration of flammable VOCs may be applied to the waste using these methods:

- Establish that no flammable VOCs are present, or establish the concentration of flammable VOCs in the waste (or container headspace) using records and database information. This may include taking credit for repackaging and/or segregation activities during waste generation.
- Using spot detection methods, establish the absence or the concentration of flammable VOCs (e.g., during waste generation, characterization, or packaging). Examples of spot detection methods include the use of flame ionization detectors, trace gas analyzers, and portable VOC monitors.
- Determine the concentration of potentially flammable VOCs by measuring the container headspace. Measurement of the container headspace may be performed on a statistical basis under a sampling program.

If the headspace concentration of potentially flammable VOCs is determined to be less than or equal to 500 ppm, the container is evaluated against flammable (gas/VOC) concentration limits calculated using an AFGC of 5% hydrogen.

If the concentration of potentially flammable VOCs is determined to be greater than 500 ppm in the headspace, the AFGC must be adjusted (i.e., reduced from the value of 5% volume) to account for the total concentration of flammable VOCs. The adjusted AFGC value is then used to calculate the FGGR limit and decay heat limit for the content code using the methodology in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements.* The methodology for calculating the adjusted AFGC value is as follows:

Calculate the MLEL within the innermost confinement layer by the flammable group method described in Appendix 3.10 of the CH-TRU Payload Appendices[1] using the following equation:

$$MLEL = \frac{100\%}{\sum (f_i \, GCF_i)}$$

where,

MLEL = Mixture lower explosive limit (volume percent)

f_i = Fraction of flammable gas *i* in mixture on an air-free and nonflammable VOC free basis (i.e., the concentration of flammable compound *i* divided by the sum of the concentrations of flammable VOCs and hydrogen)

GCF_i = Group contribution factor for compound *i*. The group contribution factor values for various compounds are listed in Appendix 3.10 of the CH-TRU Payload Appendices[1].

Calculate the content-code-specific AFGC as the difference between the MLEL and the sum of the flammable VOCs within the innermost confinement layer. This AFGC is used to determine the FGGR limit and decay heat limit for the content code.

5.2 Aspiration and Venting

If containers have been stored in an unvented condition, they shall be aspirated to ensure equilibration of any gases that may have accumulated in the closed container prior to transport.

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5.3 Compliance with Design Pressure and Total Gas Generation Limits

The maximum pressure within the TRUPACT-III package under normal conditions of transport (NCT) is calculated based on bounding values. As shown in Appendices 6.1, 6.5, and 6.6 of the CH-TRU Payload Appendices[1], gas generation due to chemical, biological, and thermal mechanisms is insignificant during transport, and radiolysis is the primary mechanism for potential flammable and net (total) gas generation. The major factors affecting the internal pressure are radiolytic gas generation, thermal expansion of gases, and the vapor pressure of water within the TRUPACT-III containment vessel.

Calculation of maximum pressure in the TRUPACT-III containment vessel considers immediate release of gases from the SLB2 and any inner containers to the TRUPACT-III containment vessel. The TRUPACT-III containment vessel and interior void volumes are assumed to be filled with gas at 70°F (294 K) and 14.7 psia when the package is closed for transport. It is conservatively assumed that the void volume in the TRUPACT-III containment vessel outside the SLB2 container of 2,354 liters (Appendix 7.1.5, *Determination of Void Volumes for TRUPACT-III Payload*) is the only volume available in calculating pressures under NCT (no credit is taken for available void volume within the SLB2 payload container and any inner containers). Sufficient water is assumed to be present for saturated water vapor at any temperature. The pressure increase due to water vapor is obtained using the Bolton[2] equation for the saturation vapor pressure of water vapor as a function of temperature.

The maximum pressure inside the TRUPACT-III is calculated for the maximum shipping period of 60 days. The use of a 60-day shipping period in the calculation of maximum normal operating pressure (MNOP) is consistent with 10 CFR §71.41(c)[3]. As specified in 10 CFR §71.41(c), this section shows that the "...controls proposed to be exercised by the shipper are demonstrated to be adequate to provide equivalent safety of the shipment." The use of this shipping period is consistent with the analysis presented in Appendix 7.1.2, *Shipping Period – General Case*, which shows that the maximum normal shipping period will be less than 60 days by a large margin of safety. As described in Appendix 7.1.2, routine monitoring of shipments includes the use of the TRANSCOM system at the WIPP, which provides continuous tracking of shipments from the shipping site to its destination.

The method used to calculate the maximum pressure is provided below. The number of moles per second of total gas generated by radiolysis is calculated from the following equation:

Equation 1

$$n_g = G_{eff(T)} * W * C$$

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[1] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

[2] Bolton, D., 1980, "The Computation of Equivalent Potential Temperature," *Monthly Weather Review*, No. 108, pp. 1046-1053.

[3] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Materials*, 01-01-07 Edition.

where,

n_g = Rate of radiolytic gas generation (moles/second)

$G_{eff(T)}$ = Temperature-corrected effective G-value [the total number of molecules of gas generated per 100 eV of energy emitted (molecules/100 eV) at the temperature of the target material]

W = Total decay heat (watts)

C = Conversion constant for the units used = 1.04×10^{-5} (moles)(eV)/(molecule)(watt-second).

The effective G values are discussed in Appendix 3.2 of the CH-TRU Payload Appendices[1] and Appendix 7.1.6, *Determination of Bounding Dose-Dependent Net Gas G Value for TRUPACT-III Payload.* As discussed in Appendix 3.2 of the CH-TRU Payload Appendices[1], the effective G values provided at room temperature (T_{RT}) are a function of temperature based on the activation energy (E_a) for the material. They are increased, as a result of increased bulk average payload (i.e., contents) temperature, using the corresponding activation energy values obtained from Appendix 3.2 of the CH-TRU Payload Appendices[1]. The total increase in pressure for a 60-day shipping period for a bounding solid organic waste material is summarized below.

From Appendix 3.2 of the CH-TRU Payload Appendices[1] the maximum effective total (net) gas G value at room temperature is 8.4 molecules/100 eV when dose is $\leq$0.012 watt*year, and the activation energy is 2.1 kcal/g mole for combustible wastes. From Appendix 7.1.6, *Determination of Bounding Dose-Dependent Net Gas G Value for TRUPACT-III Payload*, the maximum effective total (net) gas G value at room temperature is 1.5 molecules/100 eV when dose is >0.012 watt*year. An activation energy of 2.1 kcal/g mole is also used for this case.

Bounding TRUPACT-III payload temperatures are documented in Section 3.0, *Thermal Evaluation*, of the TRUPACT-III Safety Analysis Report[4] at three different payload decay heats (20 watts, 40 watts, and 80 watts). Temperatures required to calculate pressure increases include the bulk average payload temperature (T_{ap}), the bulk average void volume (gas) temperature (T_{avv}), and the minimum TRUPACT-III inner wall temperature ($T_{minwall}$). The T_{ap} is used to correct the effective G value as discussed in Section 5.3.1, *Applicable G Values*. The T_{avv} is used to correct for the thermal expansion (i.e., heat-up) of gases. The water vapor pressure contribution is calculated based on the temperature of the coolest or condensing surface on the inner wall of the TRUPACT-III, $T_{minwall}$. All three of these temperatures are approximately linear functions of the decay heat in watts. Thus, the temperatures will vary for each content code. The relationships are represented by the following regression equations where all three temperatures are in units of °C and Q is payload decay heat in watts:

$$T_{ap} = 0.52214\ Q + 48.70$$

$$T_{avv} = 0.18286\ Q + 48.40$$

$$T_{minwall} = 0.05107\ Q + 46.35.$$

[4] Packaging Technology, Inc., *Safety Analysis Report for the TRUPACT-III Shipping Package*, current revision, USNRC Docket No. 71-9305, Packaging Technology, Inc., Tacoma, Washington

The calculation of decay heat limits for content codes is based on an iterative process until the previous three regression equations are met. As discussed in Section 5.3.1, there may be two sets of G values for each content code, depending on whether the 0.012 watt*year dose criterion has been satisfied. Thus, there may be two payload decay heat limits for each content code corresponding to the two G values. Because of the dependence of T_{ap}, T_{avv}, and $T_{minwall}$ on the payload decay heat, there also may be two values for each of these three temperatures for each content code. As shown in Table 5.3.3-1 (at the end of this section), as a result of the iterative process a payload decay heat of 19.30 watts corresponds to the design pressure limit (25 psig) when dose $\leq$ 0.012 watt*year, and a payload decay heat of 77.35 watts corresponds to the design pressure limit (25 psig) when dose > 0.012 watt*year.

5.3.1 Applicable G Values

The temperature-corrected effective G value, $G_{eff(T_{ap})}$, is calculated using the Arrhenius equation (see Appendix 3.1 of the CH-TRU Payload Appendices[1]):

Equation 2

$$G_{eff(T_{ap})} = G_{eff(RT)} \exp\left[(E_a / R)\{(T_{ap} - T_{RT})/(T_{ap} * T_{RT})\}\right]$$

where,

$G_{eff(RT)}$= Effective net gas G value at room temperature (8.4 molecules/100 eV)

E_a = Activation energy (2.1 kcal/mole)

R = Gas constant (1.99×10^{-3} kcal/mole K)

T_{RT} = Room temperature 294 K (21°C)

T_{ap} = Bulk average payload temperature:
331.9 K (58.8°C) for dose ≤0.012 watt*year
362.2 K (89.1°C) for dose >0.012 watt*year.

Substitution of the variables in Equation 2 results in the following expressions for the net gas G value at the two possible bulk average payload temperatures:

Dose ≤0.012 Watt*Year

G(331.9 K) = 8.4 molecules/100 eV exp[(2.1 kcal/mole/1.99×10^{-3} kcal/mole K) {(331.9 K – 294 K) / (331.9 K x 294 K)}]

G(331.9 K) = 12.66 molecules/100 eV.

Dose >0.012 Watt*Year

G(362.2 K) = 1.5 molecules/100 eV exp[(2.1 kcal/mole/1.99×10^{-3} kcal/mole K) {(362.2 K – 294 K) / (362.2 K x 294 K)}]

G(362.2 K) = 2.95 molecules/100 eV.

5.3.2 Total Gas Generation Analysis

Using these temperature-corrected effective G values, the radiolytic gas generation rate from Equation 1 is calculated as follows:

Dose ≤0.012 Watt*Year

n_g = (12.66 molecules/100 eV) x (19.30 watts) x 1.04 x 10^{-5} (moles)(eV)/ [(molecule)(watt-second)]

= 2.541 x 10^{-5} moles/second.

The total liters of radiolytic gases generated at STP at the end of 60 days would be:

V_R = (2.541 x 10^{-5} mole/second) x (60 days) x (86,400 seconds/day) x (22.4 liters/mole)

= 2,951 liters at STP.

The generated volume of radiolytic gases is heated to the bulk average void volume gas temperature of 52°C (325.1 K). The corresponding volume occupied is:

= (2,951 liters at STP) x (325.1 K / 273.15 K) = 3,511 liters at 52°C (325.1 K).

This gas contributes a pressure of:

P_{rg} = 3,511 liters / 2,354 liters total void volume = 1.492 atm (21.9 psia) at 52°C (325.1 K).

The initial pressure of gas present inside the TRUPACT-III at 294 K is 14.7 psia. This gas is also heated to 52°C (325.1 K). The increased pressure associated with this increase in temperature is:

P_{hu} = (14.7 psia) x (325.1 K / 294 K) = 16.3 psia.

The water vapor pressure is based on the temperature of the coolest, or condensing, surface on the inner wall of the container, $T_{minwall}$, of 47.3°C (320.5 K). The water vapor pressure, P_{wv}, from the Bolton[2] equation is 1.6 psia.

Thus, the maximum pressure inside the TRUPACT-III at the end of 60 days is:

P_{max} = $P_{rg} + P_{hu} + P_{wv} - P_{atm} = 21.9 + 16.3 + 1.6 - 14.7 = 25$ psig.

Dose >0.012 Watt*Year

n_g = (2.95 molecules/100 eV) x (77.35 watts) x 1.04 x 10^{-5} (moles)(eV)/ [(molecule)(watt-second)]

= 2.373 x 10^{-5} moles/second.

The total liters of radiolytic gases generated at STP at the end of 60 days would be:

V_R = (2.373 x 10^{-5} mole/second) x (60 days) x (86,400 seconds/day) x (22.4 liters/mole)

= 2,755 liters at STP.

The generated volume of radiolytic gases is heated to the bulk average void volume gas temperature of 62.6°C (335.7 K). The corresponding volume occupied is:

= (2,755 liters at STP) x (335.7 K / 273.15 K) = 3,386 liters at 62.6°C (335.7 K).

This gas contributes a pressure of:

P_{rg} = 3,386 liters / 2,354 liters total void volume = 1.438 atm (21.1 psia) at 62.6°C (335.7 K).

The initial pressure of gas present inside the TRUPACT-III at 294 K is 14.7 psia. This gas is also heated to 62.6°C (335.7 K). The increased pressure associated with this increase in temperature is:

P_{hu} = (14.7 psia) x (335.7 K / 294 K) = 16.8 psia.

The water vapor pressure is based on the temperature of the coolest, or condensing, surface on the inner wall of the container, $T_{minwall}$, of 50.3°C (323.5 K). The water vapor pressure, P_{wv}, from the Bolton[2] equation is 1.8 psia.

Thus, the maximum pressure inside the TRUPACT-III at the end of 60 days is:

$P_{max} = P_{rg} + P_{hu} + P_{wv} - P_{atm} = 21.1 + 16.8 + 1.8 - 14.7 = 25$ psig.

5.3.3 Bounding Analysis

The methodology for calculating the FGGR limit is provided in Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements*. The FGGR limit will be maximized if the waste is directly loaded in the SLB2 with only the SLB2 filters offering resistance to the release of hydrogen. Based on the effective resistance values presented in Appendix 7.1.1, the effective resistance of the SLB2 filters at 294 K is 1,034 second/mole. This effective resistance value will be used to calculate the payload decay heat limit based on compliance with the 5% restriction on hydrogen.

The void volume in the TRUPACT-III containment vessel outside the SLB2, V_{void}, is 2,354 liters (Appendix 7.1.5, *Determination of Void Volumes for TRUPACT-III Payload*). The total moles of gas inside the TRUPACT-III containment vessel with an SLB2 is calculated through the Ideal Gas Law as:

$N_{tg} = P V_{void} / (RT)$

= (760 mm Hg) (2,354 liters) / [(62.361 mm Hg-liter/mole-K)(294 K)]

= 97.58 moles

The FGGR limit for the payload is calculated through the equation provided in Appendix 7.1.1 as:

FGGR limit $= (X_{inner})/\{R_{eff} + [t/N_{tg}]\}$

= (0.05)/{1,034 second/mole + [(60 days)(86,400 second/day)/(97.58 moles)]}

= 9.232×10^{-7} mole/second.

The decay heat limit for the payload (Q) is then calculated through the following equation (Equation (5) of Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements*):

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

where,

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

G_{eff} = Effective flammable gas G value (molecules of flammable gas formed / 100 eV emitted energy).

$= [9.232 \times 10^{-7}\ \text{mole/second}][6.023 \times 10^{23}\ \text{molecules/mole}] \times [1.602 \times 10^{-19}\ \text{watt-second/eV}]/[1.09\ \text{molecules}/100\ \text{eV}]$

$= 8.17$ watts.

Therefore, in the case where dose is >0.012 watt*year, the ratio of the decay heat limit based on compliance with the design pressure limit to the decay heat limit based on compliance with 5% hydrogen limit is 77.35 watts / 8.17 watt or 9.47. In the case where dose is ≤0.012 watt*year, the decay heat limit based on flammable gas is $[9.232 \times 10^{-7}$ mole/second] $[6.023 \times 10^{23}$ molecules/ mole] x $[1.602 \times 10^{-19}$ watt-second/eV] / 3.4 molecules/100 eV = 2.62 watts. The ratio of the decay heat limit based on compliance with the design pressure limit to the decay heat limit based on compliance with the 5% hydrogen limit is 19.30 / 2.62 = 7.37. Based on this analysis, the payload will reach the 5% hydrogen limit before it reaches the 25-psig design pressure limit. Because radiolysis is the primary mechanism for gas generation of both flammable and total gas, compliance with the FGGR limit will always ensure compliance with the total gas generation rate limit for all combustible wastes.

Table 5.3.3-1 – Bounding Temperatures for Net (Total) Gas Generation Calculations

Payload Configuration	Void Vol. Outside SLB2 (L)	Decay Heat Payload (W)	Bulk Average Payload Temp. (T_{ap}) (K)	T_{avv} (K)	$T_{minwall}$ (°C)	Eff G Value for Total Gas at 21.11°C (molecules/ 100 eV)	Activation Energy (kcal/mol)	G Value Total Gas (temperature corrected) (molecules/ 100 eV)	Ng Radiolytic Total Gas Gen. (mol/sec)	Vr (L) at STP	Vrg (L)	Prg (atm)	Prg (psia)	Phu (psia)	Pwv (psia)	Pmax (psig)
One SLB2	2,354	19.30	331.9	325.1	47.3	8.40	2.1	12.66	2.541E-05	2,951	3,511	1.492	21.9	16.3	1.6	25.0
One SLB2	2,354	77.35	362.2	335.7	50.3	1.50	2.1	2.95	2.373E-05	2,755	3,386	1.438	21.1	16.8	1.8	25.0

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6.0 PAYLOAD ASSEMBLY CRITERIA

This section presents an overview of the control procedures that shall be used by the sites in order to assemble a payload qualified for transport in the TRUPACT-III. The parameters described in previous sections shall be evaluated for selection of the payload. The SLB2 identification (ID) number shall uniquely identify the SLB2. Each SLB2 shall be assigned an approved content code. Wherever applicable, the parameters shall be checked against the limits after addition of the measurement error, as detailed in previous sections. If any of the limits are not met by the SLB2, it shall be rejected from transport (subject to mitigation or repackaging), marked, and segregated.

6.1 Requirements

The TRUPACT-III payload shall be authorized for shipment by the site Transportation Certification Official by completing and signing the PTCD.

The shipping records shall be maintained by the shipper for a minimum period of three years after the shipment is made.

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6.2 Methods of Compliance and Verification

6.2.1 Procedure for Certification of Individual Payload Containers

Generating and storage sites shall qualify an SLB2 for transport in the TRUPACT-III by verifying that the container meets the parameter requirements/limits specified by this document and summarized in Table 6.2.3-1 – *Payload Transportation Certification Document (PTCD)* (at the end of this section). The information in Table 6.2.3-1 must be completed for each SLB2. Table 6.2.3-1 may be reformatted for site use. All parameters noted on the form must be included in modified versions. Data on the parameters shall be obtained by methods outlined in this document. Table 6.2.3-1 shall be completed as follows (section numbers in parentheses refer to sections in the TRUPACT-III TRAMPAC that provide requirement information for the transportation parameter described).

Identification Parameters

- SLB2 ID # (Section 2.3): The site-specific ID number is unique to each container of waste and provides a means for tracking data records and package history. These records on the properties of the container are referred to as the data package. The container ID number assigned to the container appears on a label affixed to the payload container and can be read for visual verification or for electronic retrieval (i.e., bar codes). This ID number may be used to track data necessary for payload container compliance determinations.
- Certification Site: This is the location at which transportation certification takes place.
- Container Designated for Controlled Shipment? (Section 5.1.2): Indicate if the container is designated for controlled shipment in accordance with the controls specified in Appendix 7.1.3, *Shipping Period – Controlled Shipments*. If the container is designated for controlled shipment, Table 6.2.3-2 – *Shipping Site Control Checklist for Controlled Shipments*, must also be completed as described in Section 6.2.3, *Shipments Designated as Controlled Shipments*.
- Content Code (Section 1.6): The site Transportation Certification Official shall ensure that the proper content code is assigned to the SLB2.
- Payload Container Specifications are Met (Section 2.8.1): Compliance with the payload container specifications of Section 2.8.1, *Specification for Authorized Payload Container*, shall be ensured.
- Filter Specifications of Section 2.4 are Met: Compliance with the filter specifications in Section 2.4, *Filter Vents*, shall be ensured.

Transportation Parameters

Compliance information for the transportation parameters shall be obtained from the data package for the container. The following criteria shall be met:

Criteria:

- Residual liquids are <1% of the payload container volume. (Section 2.5)

- Sharp/heavy objects are blocked/braced/suitably packaged (Section 2.6). This requirement is met if blocking, bracing, or packaging is ensured within the payload container or if sharp/heavy objects are not present.
- Radioactive pyrophorics are ≤1% (weight). (Section 4.1)
- Nonradioactive pyrophorics are not present or have been reacted. (Section 4.1)
- Explosives are not present. (Section 4.2)
- Corrosives are not present. (Section 4.2)
- Pressurized containers and compressed gases are not present. (Section 4.2)
- Sealed containers >4 liters (nominal) are not present (except for solid inorganic waste packaged in metal). (Section 2.7)
- Beryllium and/or beryllium oxide are ≤1% of waste weight. (Section 3.1)
- Machine-compacted waste is not present. (Section 3.1)
- Flammable VOCs are ≤500 ppm in the container headspace. (Section 5.1.3) [Note: If flammable VOCs are >500 ppm, the Flammability Assessment Methodology Program has been used (Appendix 3.10 of the CH-TRU Payload Appendices[1]) and the assigned content code reflects the resulting flammable (gas/VOC) concentration limits.]

- Weight Limit (Section 2.2): The loaded weight of each SLB2 is obtained from its data package. The SLB2 weight plus error shall be compared to the maximum allowable weight limit of 10,500 pounds.
- Fissile Mass Limit (Section 3.1): The Pu-239 FGE of the payload container shall be recorded. The Pu-239 FGE plus two times the error (i.e., two standard deviations) of the payload container shall be compared to the applicable FGE limit per payload.
- Package Design Decay Heat Limit (Section 5.0): The decay heat of the payload container shall be determined as described in Section 3.1, *Nuclear Criticality*. The decay heat plus error (i.e., one standard deviation) shall be compared to the package design decay heat limit of 80 watts.
- Flammable (Gas/VOC) Concentration Limits (Section 5.1): Compliance with the 5% limit on hydrogen concentration shall be by one of two methods:
  - Compliance with FGGR Limit: If this method is used, the FGGR for the payload container shall be determined according to the procedures described in Appendix 7.1.4, *Determination of Flammable Gas Generation Rates*. This FGGR shall be compared to the FGGR limit specified in the assigned content code.
  - Compliance with Decay Heat Limit: If this method is used, the decay heat of the payload container shall be determined as described in Section 3.1, *Nuclear Criticality*.

[1] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

The decay heat plus error (i.e., one standard deviation) shall be compared to the decay heat limit specified in the assigned content code.

- Activity Limit (Section 3.3): The total payload container activity shall be less than or equal to 10^5 A_2 curies.
- Radiation Dose Rate Limit (Section 3.2): The measured radiation dose rate at the surface of the payload container shall be ≤200 mrem/hour.

If the above requirements are met, proceed to Section 6.2.2, *Procedure for Certification of a TRUPACT-III Package.*

6.2.2 Procedure for Certification of a TRUPACT-III Package

Compliance with the SLB2 requirements ensures compliance with the TRUPACT-III package requirements, except for the weight and dose rate measurements for the loaded package. No additional controls, other than certifying the SLB2 and meeting the weight and dose rate requirements of Section 2.2, *Container/Assembly Weight*, and Section 3.2, *Radiation Dose Rates*, are needed for certifying the package for shipment. Compliance with the dose rate limits for the loaded package shall be documented in accordance with site-specific procedures.

- TRUPACT-III Body ID No.: Record the ID number shown on the TRUPACT-III body.
- Shipment No.: Record the shipment number of the trailer.
- Date TRUPACT-III Closed: The date that the TRUPACT-III is closed (i.e., closure lid installed) shall be recorded.
- Time TRUPACT-III Closed: For containers designated for controlled shipment only, the time that the TRUPACT-III is closed (i.e., closure lid installed) shall be recorded. For containers not designated for controlled shipment, the time that the TRUPACT-III is closed need not be recorded (e.g., enter "NA" for time).
- Weight of Payload Loading Pallet and Roller Floor (Section 2.2): The total weight of the pallet and roller floor is recorded. If the weight is determined through a single measurement of the payload assembly, indicate the weight of the pallet and roller floor is not applicable (e.g., "NA").
- Total Weight (Section 2.2): The sum of the payload container weight plus the weight of the pallet and roller floor shall be recorded.
- Total Weight Plus Error Less Than or Equal to Payload Assembly Limit (Section 2.2): The payload container weight plus the weight of the pallet and roller floor plus the weight error shall be less than or equal to 11,409 pounds.
- Transportation Certification Official: The site Transportation Certification Official shall verify that all of the requirements for the above transportation parameters are met as stated in this document. The site Transportation Certification Official shall sign and date the PTCD upon verifying that the TRUPACT-III TRAMPAC transportation requirements are met, thereby authorizing the payload for shipment. If the requirements are not met, the payload is rejected (nonconformance disposition) and not qualified for shipment under this document.

6.2.3 Shipments Designated as Controlled Shipments

Compliance with the 10-day shipping period is administratively controlled in accordance with the conditions of Appendix 7.1.3, *Shipping Period – Controlled Shipments*, and through the following steps. These steps must be completed by the site Transportation Certification Official, or designee, and the designated receiving site operations personnel, as applicable.

Loading Time

The loading time begins with the closure of the TRUPACT-III containment vessel and ends with the departure of the shipment from the 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:

6.2.3.1 Review PTCD to determine date and time that the TRUPACT-III containment vessel closure was completed. Record date and time on Table 6.2.3-2 – *Shipping Site Control Checklist for Controlled Shipments*. Table 6.2.3-2 may be reformatted for site use provided that the same information is recorded.

6.2.3.2 Note date and time that the shipment containing the loaded package is scheduled to depart the site. Record date and time on Table 6.2.3-2.

6.2.3.3 Review dates and times recorded in Steps 6.2.3.1 and 6.2.3.2 to calculate total loading time. If total loading time is less than or equal to 24 hours, proceed to Step 6.2.3.4. If total Loading Time exceeds 24 hours, the package must be vented for a period at least as long as the period the TRUPACT-III containment vessel was sealed and the closure process must be repeated. Return to Step 6.2.3.1 above.

6.2.3.4 Indicate compliance with the 24-hour loading time by signature on Table 6.2.3-2.

Transport and Unloading Time

The transport and unloading time begins with the departure of the shipment from the shipping site and ends with the venting of the package at the receiving site. The maximum transport and unloading time is 9 days. The following steps must be completed to document compliance:

6.2.3.5 Review Table 6.2.3-2 to determine the date and time that the package was scheduled to depart from the shipping site. Record this date and time on Table 6.2.3-3 – *Receiving Site Control Checklist for Controlled Shipments*. Table 6.2.3-3 may be reformatted for site use provided that the same information is recorded.

6.2.3.6 Using the date and time recorded in Step 6.2.3.5, ensure that the package is vented within 9 days of the departure of the shipment from the shipping site by implementing the site unloading procedures specific to controlled shipments. Record the date and time to show compliance.

6.2.3.7 Indicate compliance with the 9-day transport and unloading time by signature on Table 6.2.3-3.

Table 6.2.3-1 – Payload Transportation Certification Document (PTCD)

IDENTIFICATION PARAMETERS

SLB2 ID #: _____ Certification Site: _____

Container Designated for Controlled Shipment?① o Yes o No

Content Code: _____

Payload container specifications are met.

Filter specifications of Section 2.4 are met.

TRANSPORTATION PARAMETERS

Criteria:

- Residual liquids are <1% of payload container volume
- Sharp/heavy objects are blocked/braced/suitably packaged
- Radioactive pyrophorics are ≤1% (weight)
- Nonradioactive pyrophorics are not present or have been reacted
- Explosives are not present
- Corrosives are not present
- Pressurized containers and compressed gases are not present
- Sealed containers >4 liters (nominal) are not present (except for solid inorganic waste packaged in metal)
- Beryllium and/or beryllium oxide are ≤1% of waste weight
- Machine-compacted waste is not present.
- Flammable VOCs are ≤500 ppm in the container headspace
  - If not, the Flammability Assessment Methodology Program has been used to calculate flammable (gas/VOC) concentration limits

Weight Limit:			
Value (pounds)	Error	Value + 1X Error (pounds)	Limit (pounds)
			10,500

Fissile Mass Limit:			
Value (Pu-239 FGE)	Error	Value (Pu-239 FGE) + 2X Error	Limit
			_____ Pu-239 FGE

Package Design Decay Heat Limit:			
Value (watts)	Error	Value + 1X Error (watts)	Limit (watts)
			80

Flammable (Gas/VOC) Concentration Limits: ②

Compliance with FGGR Limit: ②

FGGR Value (mole/second)	FGGR Limit (mole/second)

Compliance with Decay Heat Limit: ②

Decay Heat Value (watt)	Error	Value + 1X Error (watt)	Decay Heat Limit (watt)

Activity Limit: Activity less than or equal to 10^5 A_2 curies

Radiation Dose Rate Limit: ③ Payload container surface radiation dose rate is ≤200 mrem/hour

TRUPACT-III PACKAGE

TRUPACT-III Body ID No. _____

Shipment No.: _____

Date TRUPACT-III Closed: _____ Time TRUPACT-III Closed: _____ ④

Weight of Payload Loading Pallet and Roller Floor: _____ pounds

Total Weight: _____ pounds Total Weight plus Error ≤ 11,409 pounds

APPROVED FOR SHIPMENT

I certify that the above TRUPACT-III packaging and contents meet the requirements for transport.

_____

Transportation Certification Official

_____

Date

① If the payload container is designated for controlled shipment, Table 6.2.3-2 must also be completed for the shipment of this payload container as specified in Section 6.2.3, *Shipments Designated as Controlled Shipments*.

② Compliance with the flammable (gas/VOC) concentration limits shall be documented for either the FGGR limit or the decay heat limit.

③ In addition, compliance with the dose rate requirements for the TRUPACT-III package (Section 3.2, *Radiation Dose Rates*) shall be by survey of the loaded package.

④ Only required for payload containers designated for controlled shipment (10-day shipping period).

Table 6.2.3-2 – Shipping Site Control Checklist for Controlled Shipments

Shipment No. _____ Packaging No._____

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

TRUPACT-III TRAMPAC Section No.	Activity	Recorded Date	Recorded Time	Completion of Activity (Indicate by checkmark [√])
6.2.3.1	Record date and time of TRUPACT-III closure			
6.2.3.2	Record date and time the shipment containing the loaded package is scheduled to depart from the site			
6.2.3.3	Calculate and record total **Loading Time** [Limit = 24 hours]			
	Total Loading Time ≤1 day, proceed to No. 6.2.3.4. *Total Loading Time >1 day,* ***STOP****. Vent package and repeat closure process.*			
6.2.3.4	I certify that the above data is accurate and compliant with the Loading Time limit of 24 hours, as specified in Section 6.2.3 of the TRUPACT-III TRAMPAC. _____ / _____ TRANSPORTATION CERTIFICATION OFFICIAL (OR DESIGNEE) DATE			

Note: Controlled shipments (10 days) shall be made in accordance with the conditions specified in Appendix 7.1.3, *Shipping Period – Controlled Shipments*, and Section 6.2.3, *Shipments Designated as Controlled Shipments*. This table may be reformatted for site use provided that the same information is recorded.

Table 6.2.3-3 – 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:

TRUPACT-III TRAMPAC Section No.	Activity	Recorded Date	Recorded Time	Completion of Activity (Indicate by checkmark [√])
6.2.3.5	Record date and time that the package was scheduled to depart from the shipping site			
6.2.3.6	Vent package within 9 days of date and time recorded above and record vent date and time			
6.2.3.7	I certify that the above data is accurate and compliant with the Transport and Unloading Time limit of 9 days, as specified in Section 6.2.3 of the TRUPACT-III TRAMPAC. _____ / _____ RECEIVING SITE OPERATIONS PERSONNEL DATE			

Note: Controlled shipments (10 days) shall be made in accordance with the conditions specified in Appendix 7.1.3, *Shipping Period – Controlled Shipments*, and Section 6.2.3, *Shipments Designated as Controlled Shipments*. This table may be reformatted for site use provided that the same information is recorded.

7.0 APPENDICES

7.1 TRUPACT-III TRAMPAC Appendices

7.1.1 Compliance Methodology for Gas Generation Requirements

7.1.2 Shipping Period – General Case

7.1.3 Shipping Period – Controlled Shipments

7.1.4 Determination of Flammable Gas Generation Rates

7.1.5 Determination of Void Volumes for TRUPACT-III Payload

7.1.6 Determination of Bounding Dose-Dependent Net Gas G Value for TRUPACT-III Payload

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7.1.1 Compliance Methodology for Gas Generation Requirements

7.1.1.1 Summary

The hydrogen concentration must be maintained at or below 5% by volume within any confinement layer and the TRUPACT-III containment vessel during transport of the waste materials. This appendix describes the logic and methodology used to evaluate compliance with this requirement for waste to be shipped in the TRUPACT-III. This methodology shall be implemented in the determination of flammable (gas/VOC) concentration limits for each content code under the direction of the WIPP CH-TRU Payload Engineer.

Compliance with the 5% (by volume) limit on the hydrogen concentration can be demonstrated by one of two methods:

- **Compliance with FGGR Limit:** The 5% (by volume) restriction on hydrogen concentration may be converted into a limit on the allowable FGGR per SLB2. If it can be shown for a given SLB2 that this limit can be met, the hydrogen concentration will remain at or below 5% under transportation conditions. A generalized procedure for determining the FGGR of a SLB2 is provided in Appendix 7.1.4, *Determination of Flammable Gas Generation Rates*. FGGR limits for each content code are specified in the TRUPACT-III Content Codes document.[1]
- **Compliance with Decay Heat Limit:** The 5% (by volume) restriction on hydrogen concentration may be converted into a limit on the allowable decay heat per SLB2. If it can be shown for a given SLB2 that this limit can be met, the hydrogen concentration will remain at or below 5% under transportation conditions. Procedures for determining the decay heat value for a SLB2 are described in Section 3.1, *Nuclear Criticality*. Decay heat limits for each content code are specified in the TRUPACT-III Content Codes document.[1]

For each content code, the limit on the hydrogen concentration can be met either by complying with the FGGR limit or the decay heat limit. Parameters that govern the FGGR limit and decay heat limit are summarized below:

FGGR Limit Parameters

- 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 TRUPACT-III containment vessel available for gas accumulation
- Operating pressure and temperature for the payload in the TRUPACT-III packaging during the shipping period
- Duration of the shipping period.

[1] U.S. Department of Energy (DOE), *TRUPACT-III Content Codes*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

Decay Heat Limit Parameters (in addition to the FGGR limit parameters)

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

7.1.1.2 Methodology for Determining Compliance with Gas Generation Requirements

Figure 7.1.1-1 is a flowchart showing the methodology used to demonstrate compliance with the 5% (by volume) limit on hydrogen concentration in the TRUPACT-III package. As discussed in Appendices 6.1, 6.5, and 6.6 of the CH-TRU Payload Appendices[2], chemical, biological, and thermal mechanisms of gas generation are insignificant, and the primary mechanism for potential flammable gas generation in TRU waste is radiolysis. The 5% hydrogen concentration limit can be converted into limits on FGGR and decay heat. As shown in Figure 7.1.1-1, if potentially flammable VOCs exceed 500 ppm, the 5% hydrogen concentration restriction is replaced by a reduced AFGC that is then converted into similarly reduced limits on FGGR and decay heat in accordance with the methodology documented in Section 5.1.3, *Flammable VOCs.*

As shown in Figure 7.1.1-1, compliance with the limit on flammable (gas/VOC) concentration can be demonstrated by meeting either the FGGR limit or decay heat limit:

- If the FGGR for a SLB2 (as determined through the methodology of Appendix 7.1.4, *Determination of Flammable Gas Generation Rates*) is less than the FGGR limit specified by the content code for the SLB2, the flammable (gas/VOC) concentration limit will be met. The determination of the FGGR limits for a content code is discussed in Section 7.1.1.3, *Determination of FGGR Limits for Content Codes.*
- If the decay heat value plus error for a SLB2 (determined as described in Section 3.1, *Nuclear Criticality*) is less than the decay heat limit specified by the content code for the SLB2, the flammable (gas/VOC) concentration limit will be met. The determination of the decay heat limits for a content code is discussed in Section 7.1.1.4, *Determination of Decay Heat Limits for Content Codes.*

7.1.1.3 Determination of FGGR Limits for Content Codes

7.1.1.3.1 Input Parameters

The parameters needing quantification include the following:

Waste Packaging Configuration and Release Rates

Each content code has a unique packaging configuration with confinement layers that are completely defined. A confinement layer is any boundary that restricts, but does not prohibit, the release of hydrogen gas across the boundary. Release rates of hydrogen through typical confinement layers used for waste packaging have been quantified and are summarized in Table 7.1.1-1. Packaging configurations that allow free release of hydrogen (e.g., punctured plastic bags, bags open at the end, pieces of plastic sheeting wrapped around the waste for handling, or metal cans with closures that allow free hydrogen release) are not considered confinement layers.

[2] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad, New Mexico.

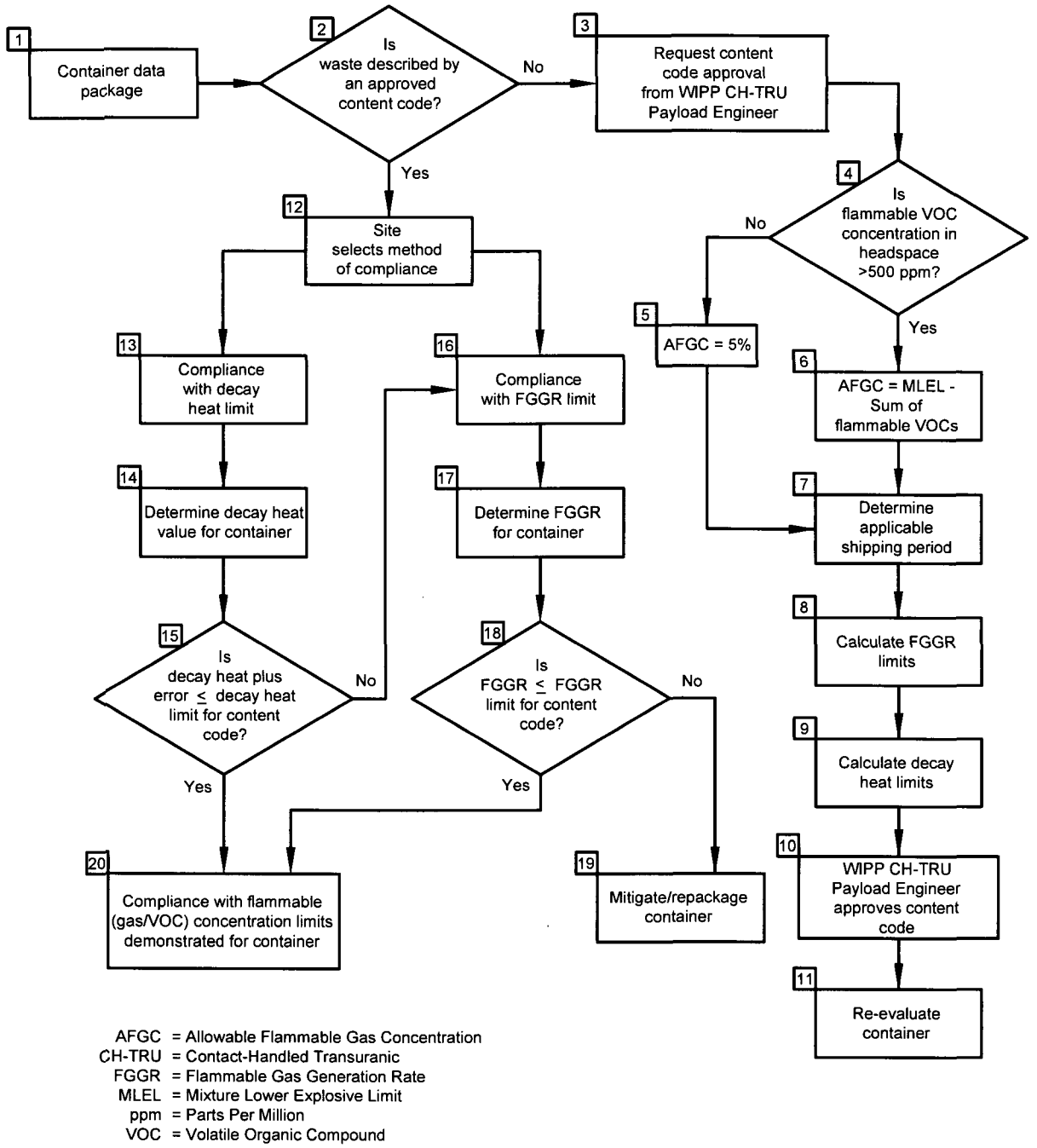


Figure 7.1.1-1 – Methodology for Compliance with Flammable (Gas/VOC) Concentration Limits

Table 7.1.1-1 – Release Rates of Hydrogen Through Common Confinement Layers

Confinement Layer	Release Rate (mole/sec/mol fraction) at 298 K (25°C)
Filtered confinement layer (e.g., metal can)	1.90E-6
	3.70E-6
High-Diffusivity Confinement Layer Filters (HDCF)	
HDCF (2X)	7.40E-6
HDCF (5X)	1.85E-5
HDCF (25X)	9.25E-5
HDCF (100X)	3.70E-4
Filtered bag	1.075E-5
High-Diffusivity Bag Filter (HDBF)	
HDBF (2X)	2.150E-5
HDBF (5X)	5.375E-5
HDBF (25X)	2.688E-4
HDBF (100X)	1.075E-3
Twist-and-tape inner bag	5.60E-7
Twist-and-tape drum liner bag	4.67E-6
Fold-and-tape SWB liner bag	7.96E-6
Heat-sealed bag	$RR = \frac{\rho A_p P_g}{x_p} \frac{mole}{22{,}400\,cm^3(STP)}$ where, RR = Release rate of hydrogen, mole/sec/mol fraction H_2 ρ = Hydrogen permeability, cm^3 (STP) cm^{-1} (cm Hg)$^{-1}$ s^{-1} [3.6E-10 for polyvinylchloride and 8.6E-10 for polyethylene] A_p = Permeable surface area, cm^2 P_g = Gas pressure, 76 cm Hg x_p = Bag thickness, cm
SLB2	9.90E-4①

① Release rate meets the minimum filter specification of Section 2.4, *Filter Vents*.

Any other type of confinement layer (other than those with release rates listed in Table 7.1.1-1) shall be shown, by testing or analysis, to be equivalent to one of the confinement layers in Table 7.1.1-1 for purposes of minimum hydrogen release. "Equivalency" may be established by demonstration of a hydrogen release rate greater than or equal to one of the values specified in Table 7.1.1-1. In determining FGGR limits for content codes, the WIPP CH-TRU Payload Engineer shall use the release rates specified in Table 7.1.1-1 as the default values for confinement layers. Content code-specific release rates determined to be equivalent to those listed in Table 7.1.1-1 shall be documented by the site and approved by the WIPP CH-TRU Payload Engineer as described in Section 1.6.2, *Use and Approval.*

Void Volumes in TRUPACT-III Containment Vessel

The TRUPACT-III containment vessel void volume of 2,354 liters (Appendix 7.1.5, *Determination of Void Volumes for TRUPACT-III Payload*) is calculated as the difference between an empty TRUPACT-III and the sum of the external volume of the SLB2 and the volume occupied by ancillary handling equipment.

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 was considered, resulting in a greater FGGR limit. Furthermore, the amount of hydrogen gas generated during the shipping period would be negligible compared to the quantity of air initially present at the time of closing the TRUPACT-III package.

Temperature

The input parameter affected by temperature is the release rates through different confinement layers. An ambient temperature of 70°F (21°C, 294 K) is used to derive gas generation limits for the TRUPACT-III, as ambient temperature yields the most restrictive limits for CH-TRU waste as shown in Appendix 6.9 of the CH-TRU Payload Appendices[2]. Ambient temperature also corresponds to the temperature at which the TRUPACT-III containment vessel will be loaded with the payload.

Shipping Period

The conditions specified in Appendix 7.1.3, *Shipping Period – Controlled Shipments*, must be met for use of the controlled shipping period (10 days). For other shipments (not controlled shipments), a 60-day shipping period is applicable as described in Appendix 7.1.2, *Shipping Period – General Case.*

7.1.1.3.2 Mathematical Analysis

At steady state, the flow rates of hydrogen across each of the confinement layers are equal and equal the hydrogen generation rate. The maximum hydrogen concentration in a vented SLB2 is reached at steady state (i.e., a vented SLB2 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 inner containers within the SLB2 and the SLB2 containment vessel itself are at steady state at the start of transport. Furthermore, it is

conservatively assumed that all the gas generation occurs within the innermost confinement layer of the container with the highest resistance to the release of hydrogen.

Once the SLB2 is loaded and the TRUPACT-III is closed, concentrations of hydrogen in the different confinement layers increase due to the accumulation of hydrogen in the TRUPACT-III containment vessel void. Some of the hydrogen generated during the transport period will accumulate inside the SLB2 cavity and inner containers, with the remainder being released into the TRUPACT-III containment vessel. For the purpose of these calculations, the mole fraction of hydrogen within a confinement layer is set equal to the steady state value plus the mole fraction of hydrogen that has accumulated in the TRUPACT-III containment vessel. The TRUPACT-III containment vessel mole fraction of hydrogen is obtained by assuming that all of the hydrogen generated is released into the TRUPACT-III containment vessel. The maximum hydrogen concentration in the innermost confinement layer is then limited to less than or equal to 5% (volume) at the end of the shipping period. This is a pseudo-steady state methodology consistent with the TRUPACT-II and HalfPACT methodology (Appendix 2.3 of the CH-TRU Payload Appendices[2]) and yields conservative FGGR and decay heat limits.

The maximum number of moles of hydrogen that can accumulate in the TRUPACT-III containment vessel is:

Equation 1

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

where,

N_{gen} = Total moles of hydrogen generated

CG = Hydrogen gas generation rate within the innermost confinement layer of the highest resistance inner container (mole/sec)

t = Shipping period duration (e.g., 60 days).

The maximum mole fraction of hydrogen in the TRUPACT-III containment vessel is then equal to:

Equation 2

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

where,

X_{fh} = Maximum mole fraction of hydrogen in the TRUPACT-III containment vessel

N_{tg} = Total moles of gas inside the TRUPACT-III containment vessel, which has a void volume of 2,354 liters

P = Pressure inside the TRUPACT-III, 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 TRUPACT-III containment vessel

V_{void} = Void volume inside the TRUPACT-III containment vessel with an SLB2 (2,354 liters)

R = Gas constant = 62.361 mm Hg-liter/mole-K

T = Absolute temperature of air in the TRUPACT-III containment vessel at the time of closure = 70°F = 294 K.

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

Equation 3

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

where,

X_{inner} = Mole fraction of hydrogen in innermost confinement layer (a value of 0.05 has been used for this parameter as this is the maximum permissible concentration)

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

The effective resistance is calculated by summing the individual confinement layer resistances. The resistance of a layer is equal to the reciprocal of the release rate from that layer.

Substituting Equations 1 and 2 into Equation 3 and solving for CG yields the FGGR limit as follows:

Equation 4

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

7.1.1.4 Determination of Decay Heat Limits for Content Codes

7.1.1.4.1 Input Parameters

The calculation of the decay heat limit requires knowledge of the FGGR limit. Therefore, the input parameters required to calculate the FGGR limit are also required to calculate decay heat limit. In addition, the following parameters are needed:

G Value

The G value is a measure of the amount of gas generated from a waste material per unit (100 eV) of radioactive material present. Bounding G values of hydrogen for the different waste materials found in CH-TRU waste are presented in Appendix 3.1 of the CH-TRU Payload Appendices.[2]

As described in Attachment A of Appendix 3.2 of the CH-TRU Payload Appendices[2], for alpha energy, 82.0% of the total energy is available for absorption by the waste material (except for waste containing contamination in solution, in which case 100% of the total energy is available).[2] With time and constant exposure to radiation, hydrogen is removed from hydrogenous waste materials, thus decreasing the number of hydrogen bonds available for further radiolytic breakdown. For these waste materials, as the amount of available hydrogen is reduced with time, the G value decreases with increasing dose toward a value that is defined as the "dose-dependent G value" for hydrogen. The methodology associated with the determination of flammable gas dose-dependent G values is discussed in Appendix 3.3 of the CH-TRU Payload Appendices[2]. As noted in Appendix 3.3 of the CH-TRU Payload Appendices, a dose criterion of >0.012 watt*year

for a given payload container is required for use of dose-dependent G values for hydrogen. Also as noted in Appendix 3.3 of the CH-TRU Payload Appendices, dose-dependent G values are not applicable to solidified aqueous waste materials.

Table 7.1.1-2 summarizes the maximum G values for flammable gas (with and without dose-dependence) for the bounding waste materials that radiolytically generate gas and may be present in CH-TRU waste. CH-TRU wastes that can be classified as solidified inorganics, solid inorganics, or solid organics based on the chemicals and materials present in the waste in quantities greater than 1% (weight) and the list of allowable materials specified in Table 4.3.2-1, *Allowable Materials for TRUPACT-III Payloads*, are bound by the G values summarized in Table 7.1.1-2. For solid organic materials other than those listed in Table 7.1.1-2, a bounding G value from Table 7.1.1-2 (e.g., polyethylene) is applicable provided that the material is allowed by Table 4.3.2-1 and is not a solidified organic material. Inorganic and nonhydrogenous materials do not generate hydrogen and have a G value of zero. Waste materials that have no potential to generate radiolytic gas include metals, glass, salts, ceramics, and other inorganics, which are often present in substantial quantities within CH-TRU waste payload containers.

Table 7.1.1-2 – Summary of Effective Flammable Gas G Values for Bounding Materials in CH-TRU Waste

Waste Material	Flammable Gas G Value at 70°F (molecules/100 eV) (≤0.012 watt*year) ①	Flammable Gas G Value at 70°F (molecules/100 eV) (>0.012 watt*year)
Water	1.6x ②	1.6x ②
Polyethylene	3.4	0.64
Polyvinyl Chloride	0.57	0.50
Cellulose	2.62	1.09
Organic Resins	1.4	1.09
Other Polymers	3.4	1.09

① Per Appendix 3.2 of the CH-TRU Payload Appendices[2], G values based on 82% of the energy escaping from particles of PuO_2.

② x is the mass fraction of water in the waste.

The WIPP CH-TRU Payload Engineer shall determine the effective G value for a content code using the chemical composition information provided by the site. The waste-specific G value is calculated as the sum of the products of the flammable gas G values for the applicable materials and the percentages by weight present in the waste. For example, for a container packaging primarily inorganic waste with no more than 20 percent bounding organic material meeting the >0.012 watt*year criterion, the waste-specific effective G value is 1.09(0.20) + 0(0.80) = 0.218.

7.1.1.4.2 Mathematical Analysis

The maximum allowable decay heat limit for an SLB2 is calculated from the FGGR limit (i.e., CG) and the effective flammable gas G value through the following expression:

Equation 5

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

where,

Q = Decay heat limit per SLB2 (watts)

CG = FGGR limit per SLB2 (mole/sec)

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

G_{eff} = Effective flammable gas G value for the waste matrix (molecules of hydrogen formed/100 eV emitted energy).

As described in Section 7.1.1.4.1, *Input Parameters*, SLB2s may be evaluated for compliance with decay heat limits determined using dose-dependent G values if compliance with the criterion of >0.012 watt*year can be demonstrated. A specific example for the determination of FGGR and decay heat limits is provided below.

The example calculation is for an SLB2 directly loaded with inorganic waste with no more than 20% bounding organic material. The SLB2 has six filters with a total hydrogen diffusivity value of 9.90E-4 moles/second/mole fraction. The applicable shipping period is 60 days. Flammable VOCs are less than 500 ppm in the payload.

From Equation 4, the FGGR limit can be calculated as:

$$CG = \frac{X_{inner}}{R_{eff} + t/N_{tg}}$$

where,

$X_{inner} = 0.05$ (as flammable VOCs are ≤500 ppm, the 5% hydrogen limit is applicable)

$$R_{eff} = \frac{1}{9.90\text{E}-4} = 1010.1 \text{ seconds/mole}$$

The effective release rate at the ambient temperature of 21°C (294 K) may be calculated using the temperature-dependent relationships defined in Appendix 6.9, *Temperature Dependence of Hydrogen Gas Generation and Release Rates*, of the CH-TRU Payload Appendices[2].

R_{eff} at 294K = $(298 \text{ K} / 294 \text{ K})^{1.75}$ x 1010.1 seconds/mole

= 1034 seconds/mole

t = 60 days = 5.184E+06 seconds

N_{tg} = moles inside the TRUPACT-III containment vessel

$$= \frac{PV_v}{RT} = \frac{760 \text{ mm Hg} * 2{,}354 \text{ liters}}{62.361 \text{ mm Hg} - \text{Liter/mole K} * 294\text{K}}$$

= 97.58 moles.

Therefore,

$$CG = \frac{0.05}{1034 + \frac{5.184E+06}{97.58}} = 9.232E-07 \text{ moles/second}$$

From Equation 5, the decay heat limit can be calculated as:

$$Q = \frac{(CG)(N_A)(1.602E-19 \text{ watt} - \text{sec/eV})}{G_{eff} \text{ molecules/100 eV}}$$

where,

G_{eff} (dose $\leq$0.012 watt*year) = 3.4 * 0.2 + 0 * 0.8 = 0.68

G_{eff} (dose >0.012 watt*year)) = 1.09 * 0.2 + 0 * 0.8 = 0.218

Therefore,

Q (dose $\leq$0.012 watt*year) = $\frac{9.232E-07 * 6.023E+23 * 1.602E-19}{0.68/100}$

= 13.1 watts

Q (dose >0.012 watt*year) = $\frac{9.232E-07 * 6.023E+23 * 1.602E-19}{0.218/100}$

= 40.9 watts

In summary, the following gas generation limits are applicable to this example content code:

FGGR limit = 9.232E-07 moles/sec

Decay heat limit (dose $\leq$0.012 watt*year) = 13.1 watts

Decay heat limit (dose >0.012 watt*year) = 40.9 watts

7.1.2 Shipping Period — General Case

7.1.2.1 Introduction

The purpose of this appendix is to develop, on a conservative basis, the time for the shipping period (from closure of the TRUPACT-III containment vessel until venting during removal of the closure lid) that should be considered for the analysis of gas generation in the TRUPACT-III package.

7.1.2.2 Background

TRUPACT-III shipments will be made by a fleet of trucks, each capable of transporting a single TRUPACT-III package, or by rail. The analysis in this appendix is presented for the case of shipments by truck. Shipments by rail shall meet the 60-day total maximum shipping period requirement for truck shipments. Using administrative controls, a 10-day shipping period is applicable for shipments to WIPP as presented in Appendix 7.1.3, *Shipping Period – Controlled Shipments*.

Each TRUPACT-III package is loaded on a specially designed trailer that travels over public highways on specified routes. Because of the large number of trips and because of the agreements for notification to the states through which these shipments will pass on their way to the WIPP or other receiving site, a state-of-the-art satellite tracking system will be employed to monitor the progress and position of each shipment. This monitoring capability will be available to authorities in the affected states as well as to the transportation management staff at the WIPP site and other receiving sites.

7.1.2.3 Approach

The approach to be taken in establishing the shipping period will be to develop a normal or expected shipment time based on the planned loading, transport, and unloading times. Then, a maximum shipment time will be based on adding to the normal shipment time delays caused by a number of factors. This maximum shipment time will assume that all possible delays occur. The probability of each of these delays occurring is small. The joint probability of all of these delays occurring would be extremely small. Thus, the development of a maximum shipment time based on the sum of extended delays for each of the factors is considered to have a large margin of error. In the event that a particular shipment is experiencing a delay resulting in an abnormal shipment time, close monitoring of the delay by WIPP will ensure minimal delay in the schedule.

7.1.2.3.1 Normal or Expected Shipment Time

The normal transport time is the sum of the times associated with loading the TRUPACT-III package, the normal transit time, and the unloading of the package. The loading time is the time interval from closing (sealing) the TRUPACT-III containment vessel until the truck leaves the waste shipper's facility. The transit time is the time interval beginning with departure from the shipper's facility and ending with the arrival at the WIPP site or other receiving site. The unloading time is that time interval beginning with the arrival at the receiving site and ending

with the venting during removal of the TRUPACT-III closure lid. This total time defines the expected shipment time.

7.1.2.3.2 Off-Normal or Maximum Shipment Time

The maximum shipment time includes those delays that could extend the shipment time. These delays are:

- Delays in loading or releasing the truck at the shipper's facility.
- Delays in transit caused by adverse weather conditions leading to road closures, or road closures due to accidents involving other vehicles.
- Accidents involving the shipment vehicle. These delays would include the time required for notification of appropriate authorities (including the DOE Emergency Response Team) and the time to take corrective action. This corrective action may involve transfer of the TRUPACT-III package to a back-up truck, which would require the services of heavy equipment.
- Delays in transit caused by mechanical problems with the truck. This factor would include such things as tire problems, broken belts and hoses, and any other such minor problems.
- Delays caused by one or both of the drivers becoming ill.
- Delays in unloading the TRUPACT-III package at the WIPP site or other receiving site. These could potentially be caused by factors such as truck arrival at the start of a long holiday weekend or equipment problems at the receiving site.

7.1.2.4 Discussion

7.1.2.4.1 Normal or Expected Shipment Time

As stated previously, the normal or expected shipment time is that time interval beginning with the sealing of the TRUPACT-III containment vessel at the shipper's facility and ending with the venting during removal of the TRUPACT-III closure lid.

TRUPACT-III Package Loading

The package is designed so that it can be loaded within a few hours. The loading operation is facilitated by design features and contents handling methods aimed at a quick turnaround during either loading or unloading. For example, a roller floor is provided on the floor of the packaging to allow for loading the payload on a rolling payload pallet. The contents are handled in the horizontal position and are rolled into the packaging. All steps in the loading process (e.g., from attaching the lifting fixture to the crane until the lift fixture lift links are disconnected from the overpack cover following loading) can be accomplished in a few hours. Thus, the time associated with loading the TRUPACT-III package for shipment is expected to be less than eight hours. However, to be conservative, one day (24 hours) is allotted for this activity.

Transit Time

Specific routes have been selected for transport of waste between the DOE facilities and from each of the DOE facilities to the WIPP site. The distances from the primary DOE facilities with large box inventory to the WIPP site are given in Table 7.1.2-1.

Table 7.1.2-1 – Normal Transit Times

To WIPP From	Distance (Miles)	Transit Time in Hours (Miles per Hour)				Transit Time in Days (Miles per Hour)			
		40	45	50	55	40	45	50	55
Hanford	1808	45.2	40.2	36.2	32.9	1.8	1.7	1.5	1.4
INL	1392	34.8	30.9	27.8	25.3	1.4	1.3	1.2	1.1
Knolls-NFS	1573	39.3	35.0	31.5	28.6	1.6	1.5	1.3	1.2
LANL	342	8.6	7.6	6.8	6.2	0.3	0.3	0.3	0.3
LLNL	1463	36.6	32.5	29.3	26.6	1.5	1.4	1.2	1.1
NTS	1177	29.4	26.2	23.5	21.4	1.2	1.1	1.0	0.9
ORNL	1440	36.0	32.0	28.8	26.2	1.4	1.3	1.2	1.1
SNL	326	8.2	7.2	6.5	5.9	0.3	0.3	0.3	0.2
SRS	1540	38.5	34.2	30.8	28.0	1.5	1.4	1.3	1.2
WVDP	2391	59.8	53.1	47.8	43.5	2.4	2.2	2.0	1.8

These shipments will be made by trucks having two drivers. Regulations governing maximum driving and on-duty times are given in 49 CFR 395, "Hours of Service of Drivers."[1]

These regulations permit a driver to drive not more than ten (10) hours following eight (8) consecutive hours off duty or to be in the on-duty status not more than fifteen (15) hours. If the fifteen hours on-duty status is reached, a driver must be out of the vehicle in an off-duty status for eight (8) hours. Drivers using sleeper berth equipment may cumulate the eight (8) hours off duty (for the ten [10] hour on-duty status) resting in the sleeper in two separate periods (each period must be at least two [2] hours) totaling eight (8) hours. Drivers cannot be on duty more than seventy (70) hours in eight consecutive days. By using the two drivers and a rotational on-duty/off-duty system of approximately five (5) hours, the vehicle can be maintained operational for twenty-four (24) hours per day for seven days.

Experience at the Idaho National Laboratory has shown that shipments of this type can achieve an average speed of 45 mph. This average speed includes stops for vehicle inspections every two hours, fueling, meals, driver relief, and state vehicle inspections.

The normal transit times to WIPP range from 0.3 day for shipments from the Los Alamos National Laboratory to 2.2 days for shipments from the West Valley Demonstration Project as shown in Table 7.1.2-1. For the purpose of conservatism three days (72 hours) is assumed for a maximum normal transit time.

[1] Title 49, Code of Federal Regulations, Section 395 (49 CFR 395), "Hours of Service of Drivers."

Unloading

Normal unloading will be accomplished in less than a day. Once the truck has undergone the health physics survey and security checks, the tractor is disconnected, and a trailer jockey is connected to the trailer. The trailer and package are cleaned, and the trailer is moved to the unloading area. The TRUPACT-III is removed from the trailer and placed into the unloading area. The overpack cover is removed to allow access to the closure lid. The closure lid is removed after the containment vessel has been vented through a facility gas-handling system, and other procedural steps are then taken.

The normal unloading of a trailer will be accomplished in less than one day. The unloading time is, thus, conservatively assigned a value of one day (24 hours).

Total Normal or Expected Shipment Time

The total normal or expected shipment time is three to five days depending on the origin of the waste. Normal loading time is one day, transit time is one to three days, and unloading time is one day.

7.1.2.4.2 Off-Normal or Maximum Shipping Time

Loading Delays

There are a number of factors that could extend the time interval between the sealing of the TRUPACT-III closure lid and the truck leaving the shipper's facility:

- Loading could begin on a day preceding a holiday weekend
- Difficulty testing the containment O-ring seals
- Handling equipment failure.

In the most severe sequence, loading could begin on a day preceding a long (holiday) weekend. If, for example, loading began on a Friday afternoon preceding a three-day weekend, loading would not be completed until the following Tuesday. This would result in a four-day loading period.

The containment O-ring seals may fail the leak test, which would generally call for some maintenance. The worst case would probably be a failure in the leak test equipment that could take up to two days to correct.

The crane or the lifting fixture could also fail, forcing a delay in any further loading until corrected. This could also take two days.

It would be very unlikely for more than two of these scenarios to happen simultaneously, so a total of six days is deemed to be a reasonable maximum time to account for delays associated with loading. If there were conditions that could cause long, unanticipated delays, the TRUPACT-III package can be vented at the shipper's facility.

Transit Time Delays

There are several factors that could extend the maximum normal transit time of three days. Adverse weather conditions could lead to delays and road closures. A telephone survey of states in the waste shipment corridor states was conducted to ascertain a reasonable time to assume for weather delays. Table 7.1.2-2 provides the results of this survey. One can conclude from this survey that weather conditions may close a major highway for two to five days. Long-term interruptions in normal traffic caused by bridge outages, etc., would result in rerouting traffic to alternate routes. Accidents involving other vehicles could also cause delays and road closures of up to a day. It is concluded that a total transit delay of five (5) days is reasonable to assume for weather delays or road closures.

Accidents involving the shipment vehicle itself could cause lengthy delays. These delays would include the accident response time for notifying appropriate authorities (including Radiological Assistance Teams, if required) and the time to take corrective action or to mitigate the accident. One day is conservatively assumed for the response to the accident. (In addition to normal accident response protocol, monitoring of the satellite tracking system would also facilitate an early response to accidents.) Corrective action may involve retrieving the TRUPACT-III package from a damaged trailer (including the possibility that the truck could be over an embankment) and transferring it to a back-up truck. Special equipment such as cranes may be required to carry out these operations. An accident mitigation time of five days will be assumed. This time includes the time for delivery of a back-up truck, and the time to move in special heavy equipment and rig special lifting fixtures to retrieve and transfer the package to the back-up vehicle.

Delays in transit could be caused by routine mechanical problems with the truck. These problems could include tire failures, broken belts and hoses, electrical failures, and similar minor problems, or more significant problems necessitating bringing a back-up truck into service. It is conservatively assumed that appropriate responses to mechanical failures of the truck can be made in four days.

Lastly, one or both of the drivers could become ill during the trip, necessitating the possibility that one driver must do all the driving or relief drivers would have to be sent to where the truck is parked. If one driver has to do all the driving, the transit time would be doubled (i.e., add three days). If relief drivers are required, a two-day delay will occur to allow for travel time of the replacement driver(s).

Table 7.1.2-2 – Survey of Weather Related Delays on Interstate Highways of the TRU Waste Shipment Corridor Sites

State/City	Office Contacted	Date Contacted	Type of Weather Related Delays	Highway
1. Alabama/Montgomery	State DOT	2/4/88	24 hrs. max.	All
2. Arizona/Phoenix	Dept. of Public Safety	2/4/88	8 hrs. maximum for any type of emergency.	All
3. Arkansas/Little Rock	State DOT Construction of Maintenance	2/17/88	1/2 day maximum.	All
4. California/Sacramento	State DOT Highway Dept.	2/18/88	2 days due to snow every 2 to 3 years. Few minutes to 2 to 3 weeks due to flood. 2 weeks due to earthquake. Detours provided.	I-5 I-15 Route 14
5. Colorado/Denver	State DOT	2/5/88	12 hrs. maximum.	
6. Georgia/Atlanta	State DOT Maintenance	2/2/88	No information available.	
7. Idaho/Boise	State DOT	2/4/88	3 to 4 hrs. due to blizzard.	
8. Illinois/Springfield	State DOT	2/7/88	10 days because a bridge pier slipped. (Trucks were off the road for 14 days). Detours provided.	Northbound I-90, I-94
9. Indiana/Indianapolis	Dept. of Highway Operations	2/5/88	2 days due to snowstorm or blizzard/wind.	I-65
10. Kentucky/Frankfort	State DOT Highway Maintenance	2/5/88	8 hrs. maximum.	
11. Louisiana/Baton Rouge	State DOT Office of Highway Traffic and Planning	2/3/88	No information available.	
12. Mississippi/Jackson	State DOT Highway Dept.	2/17/88	None.	
13. Missouri/Jefferson City	Highway Patrol	2/4/88	1/2 to 1 day due to flooding. 1 to 1-1/2 days with detours provided.	I-70
14. Nevada/Carson City	State DOT Maintenance Div.	2/4/88	4 to 8 hrs. due to snow.	I-80
15. New Mexico/Santa Fe	State DOT	2/9/88	Closed periodically due to snow and/or wind but for a very short period of time.	Interstate
16. Ohio/Columbus	State DOT	2/5/88	8 hrs. maximum.	All
17. Oklahoma/Oklahoma City	State DOT	2/5/88	1 month due to a bridge was washed out on Cimmaron River.	I-35
18. Oregon/Salem	State DOT	2/4/88	8 hrs. maximum. Generally, usage of highway stopped for trucks/oversized vehicles for up to 8 hours for icy conditions	Interstate
19. South Carolina/ Columbia	State DOT State Dept. of Health and Control	2/3/88	No information but generally 8 hrs. maximum.	

State/City	Office Contacted	Date Contacted	Type of Weather Related Delays	Highway
20. Pennsylvania/ Harrisburg	State DOT	2/22/91	No information but generally 1 day maximum	Interstate
21. Tennessee/Nashville	State DOT	2/3/88	96 hours due to rain. 72 Hours due to rain/high water level.	State Route 54 N in Haywood County State Route 188
22. Texas/Austin	State DOT	2/16/88	2 to 3 hours due to flooding. 8 hours maximum due to snow.	I-20
23. Utah/Salt Lake City	State DOT Traffic Engr.	2/4/88	4 to 5 hours due to blizzard.	I-15
24. Washington/Olympia	State DOT	2/4/88	2 days due to avalanche.	I-90
25. West Virginia/ Charleston	State DOT	2/19/91	1 day maximum	I-70
26. Wyoming/Cheyenne	State DOT Motor Vehicle Safety	2/4/88	4 to 5 days predominantly due to weather.	I-80

Unloading Delays

Delays in unloading the TRUPACT-III package at the WIPP site or other receiving site could be caused by a number of factors: A truck could arrive at the receiving site late on a Friday preceding a three-day weekend, and the normal processing and unloading would not be completed until the following Tuesday, causing a delay in unloading of approximately 5 days. There could be equipment problems at the receiving site that could cause delays in unloading the package. Venting and handling equipment could break down. A total unloading time of four days will be assumed if unloading begins just before a regular weekend or five days for a holiday weekend. This is a reasonable maximum time to account for delays associated with unloading because the package can be vented at the receiving site (using workers overtime) if an unanticipated chain of delays were to occur.

Total Off-Normal or Maximum Shipment Time

The total off-normal or maximum shipment time is summarized in Table 7.1.2-3. A maximum shipment time of 31 days is projected assuming the worst-case scenario of all off-normal occurrences happening in the same shipment.

Table 7.1.2-3 – Shipment Time Summary

Activity	Time (Days)
Normal Shipment Time	
Loading	1
Transit Time	1-3
Unloading	1
Maximum Normal Shipment Time	3-5
Off-Normal Shipment Time①	
Loading	6
Transit Time	
• Normal (maximum)	3
• Weather delays and road closures	5
• Accident response	1
• Accident Mitigation	5
• Truck maintenance problems	4
• Driver illness	2
Unloading	5
Maximum Off-Normal Shipment Time	31

① Adding all the times for relatively low-probability, independent delays provides a conservative value for the maximum off-normal transit time.

7.1.2.5 Summary and Conclusions

The total normal or expected shipment time from the DOE facilities to the WIPP site or other receiving site will be three to five days. The maximum or off-normal shipment time that has been postulated to occur as a consequence of a series of accidents or other off-normal events and delays is 31 days. This maximum shipment time is six times the maximum normal expected shipment time. This justifies using a 31-day period for the basis of determining potential buildup of flammable concentrations in the TRUPACT-III package under the specified normal conditions with the absence of venting or operational controls during transport. However, to add an additional margin of safety, the shipping period used for the analysis of gas generation in the TRUPACT-III package is nearly double the maximum off-normal shipment time, or 60 days, which is more than an order of magnitude longer than the maximum normal shipment time.

7.1.3 Shipping Period – Controlled Shipments

7.1.3.1 Introduction

This appendix presents the shipping period determination for shipments designated as controlled shipments. For these shipments, the TRUPACT-III packaging is loaded at the site, transported from the site to the WIPP or other receiving site, and vented within a maximum of 10 days from the closure (or sealing) of the TRUPACT-III containment vessel. The basis for the 10-day shipping period is defined in this appendix. The use of a 10-day controlled shipment is an option available to sites that elect to impose administrative controls to ensure compliance with the conditions described herein.

7.1.3.2 Approach

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

- Loading time
- Transport time
- Unloading time.

7.1.3.2.1 Loading Time

The loading time begins with the sealing of the TRUPACT-III containment vessel 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. 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 in accordance with the administrative controls described in Section 6.2.3, *Shipments Designated as Controlled Shipments.*

7.1.3.2.2 Transport Time

The transport time begins with the departure of the shipment from the site and ends with the arrival of the shipment at the receiving site. The transport time is dependent upon the distance between the two sites and capabilities for efficient response to potential transport time delays. As shown in Table 7.1.3-1, at an average speed of 40 mph, the longest travel time from a site to WIPP is 59.8 hours (corresponding to the 2,391-mile distance from the West Valley Demonstration Project to WIPP). Controlled shipments shall be made only when the shipping distance between the two sites is bound by that shown for the West Valley Demonstration Project to WIPP in Table 7.1.3-1. This average speed takes into account stops for vehicle inspections every two hours, fueling, meals, driver relief, and state vehicle inspections.

Table 7.1.3-1 – Normal Transit Times

To WIPP From	Distance (Miles)	Transit Time in Hours (Miles per Hour)				Transit Time in Days (Miles per Hour)			
		40	45	50	55	40	45	50	55
Hanford	1808	45.2	40.2	36.2	32.9	1.8	1.7	1.5	1.4
INL	1392	34.8	30.9	27.8	25.3	1.4	1.3	1.2	1.1
Knolls NFS	1573	39.3	35.0	31.5	28.6	1.6	1.5	1.3	1.2
LANL	342	8.6	7.6	6.8	6.2	0.3	0.3	0.3	0.3
LLNL	1463	36.6	32.5	29.3	26.6	1.5	1.4	1.2	1.1
NTS	1177	29.4	26.2	23.5	21.4	1.2	1.1	1.0	0.9
ORNL	1440	36.0	32.0	28.8	26.2	1.4	1.3	1.2	1.1
SNL	326	8.2	7.2	6.5	5.9	0.3	0.3	0.3	0.2
SRS	1540	38.5	34.2	30.8	28.0	1.5	1.4	1.3	1.2
WVDP	2391	59.8	53.1	47.8	43.5	2.4	2.2	2.0	1.8

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 7.1.3.3, *Summary and Conclusions*).

Prompt emergency response, truck maintenance, and driver or equipment replacement during the transport of controlled shipments is ensured by the application of additional resources. Administrative controls applied to all CH-TRU waste shipments regardless of destination 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 at WIPP, which provides continuous tracking of the shipment during transport regardless of its destination (i.e., to WIPP or other 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. Based on the training programs provided to local emergency response personnel along the transport routes, accident response time would be minimal (less than one hour). 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 from WIPP, the shipping facility, 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 WIPP site 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 WIPP protocols applied to shipments designated as controlled shipments, a 5-day transport time accounts for any unexpected impact to the expected transport time.

7.1.3.2.3 Unloading Time

The unloading time begins with the arrival of the shipment at the receiving site and ends with the venting of the TRUPACT-III containment vessel. Normal unloading will be accomplished in less than one day (24 hours). Section 6.2.3, *Shipments Designated as Controlled Shipments*, outlines administrative controls imposed to ensure venting of the TRUPACT-III containment vessel within 9 days of shipment departure from the shipping site.

7.1.3.3 Summary and Conclusions

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 7.1.3-2 provides a summary of the activities comprising the shipping period.

Table 7.1.3-2 – Shipping Period Analysis Summary

Activity	Normal Expected Time (days)	Maximum Time Used in Analysis (days)
Loading Time	<1	1
Transport Time	<2.5	5
Unloading Time	<1	1
Margin of Safety	–	3
Shipment Time	4-5	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 appendix.

Sample shipping time data based on over 4,500 shipments of CH-TRU waste to WIPP are shown in Table 7.1.3-3. As shown, all shipments have been made in well under 10 days even without the use of administrative controls specified in this appendix. The controlled shipments completed under the conditions specified in this appendix will readily comply with the 10-day shipping period.

Only shipments designated as controlled shipments and, therefore, subject to the protocol described in this appendix and the administrative controls specified in Section 6.2.3, *Shipments Designated as Controlled Shipments*, for loading and unloading are eligible for evaluation using the 10-day shipping period.

Table 7.1.3-3 – Sample Shipping Time Data

To WIPP From	Total Number of Shipments as of 06-13-06	Average Shipping Time (hours)①	% of Time Shipments are Completed within Average Time	Shipping Time Delays	
				Duration of Maximum Delay	Explanation
ANL-E	13	38	100%	N/A	N/A
ANL-W	1	34	100%	N/A	N/A
Hanford	282	45	82%	5 days	Repairs at generator site on loading equipment
INL	1,721	36	80%	5 days	Weather delay; delay occurred en route; shipment was returned to INL and delayed prior to second departure
LANL	207	9	94%	1 day	Delay occurred at LANL as the result of generator site issues prior to shipment departure
LLNL	18	33	99%	1 hour	Delay in route
NTS	48	30	99%	9 hours	Delay in departure
RFETS	2,045	18	96%	2 days	Weather delay; delay occurred at RFETS prior to shipment departure and en route following departure
SRS	675	32	86%	3.7 days	Weather delay; delay occurred at SRS prior to shipment departure

① Average shipping times are estimated based on average speeds of 50 miles per hour and include time associated with safety inspections, fuel and food stops, and driver breaks.

N/A = Not applicable.

7.1.4 Determination of Flammable Gas Generation Rates

7.1.4.1 Objectives of the Gas Generation Testing

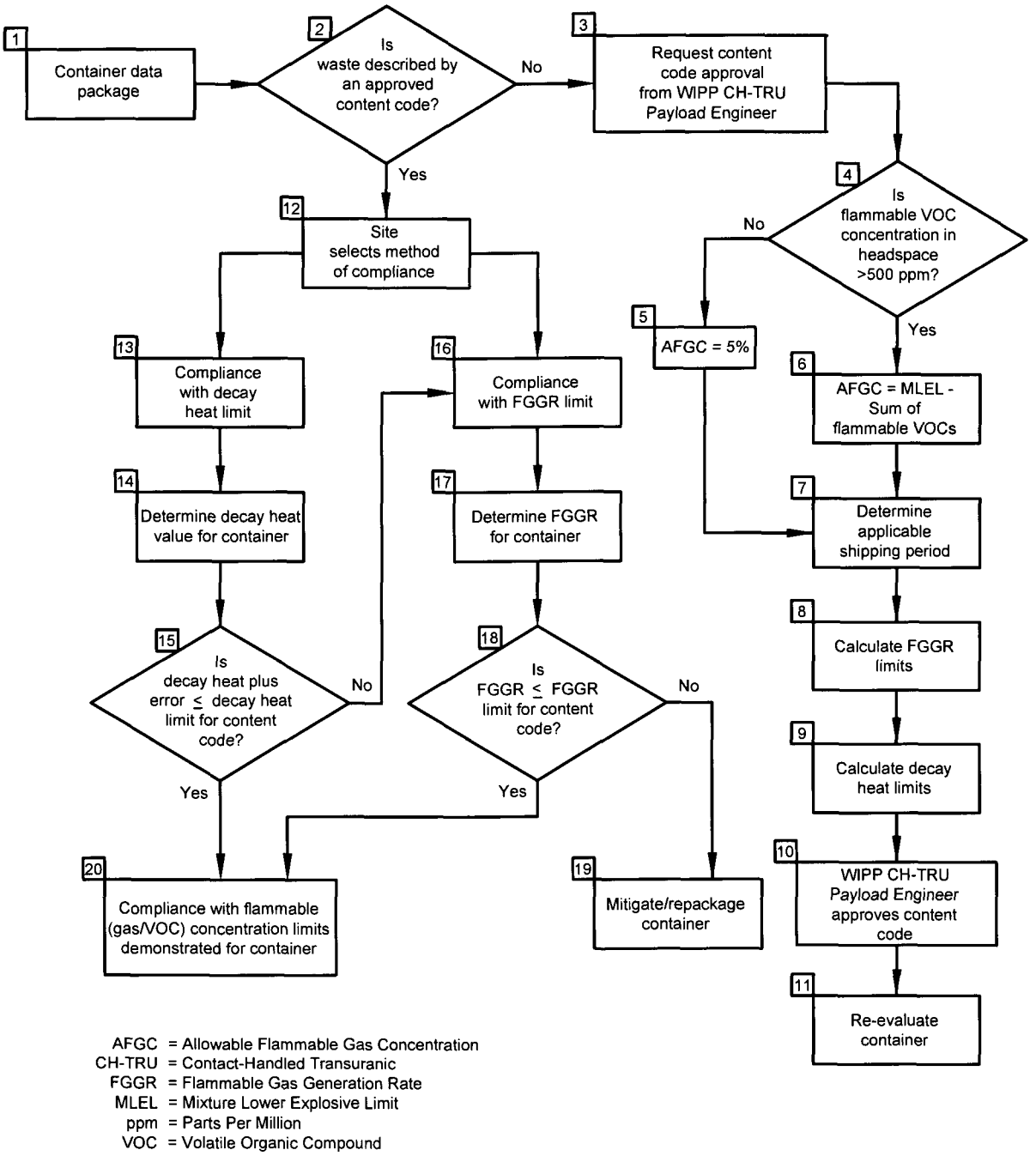
All waste to be transported in the TRUPACT-III packaging shall comply with the 5% (by volume) limit on hydrogen concentration during transport. Appendix 7.1.1, *Compliance Methodology for Gas Generation Requirements*, presents the compliance methodology for meeting this limit. The 5% (by volume) limit on the hydrogen concentration may be converted to limits on the FGGR and decay heat for each content code. If it can be shown for a given waste container that one of these limits can be met, the hydrogen concentration will remain at or below 5% under transportation conditions. FGGR and decay heat limits determined in accordance with Appendix 7.1.1 are specified in content codes approved by the WIPP CH-TRU Payload Engineer.

As shown in Figure 7.1.4-1, the 5% limit on hydrogen concentration and the associated FGGR limit and decay heat limit specified in a given content code are adjusted down when the container headspace concentration of flammable VOCs is greater than 500 ppm. In this case, the limit on hydrogen concentration is less than 5% to account for the concentration of flammable VOCs. The resulting reduced AFGC is converted to reduced limits on FGGR and decay heat for the content code.

Once a container is assigned to an approved content code and the "Compliance with FGGR limit" method is selected, the FGGR for the container must be determined (see Figure 7.1.4-1). The generalized procedure for determining the FGGR of a container by measuring/testing is provided in this appendix. The FGGR for the container can then be compared to the FGGR limit specified for the assigned content code.

7.1.4.2 Gas Generation Test Methodology

The following sections describe how compliance with the FGGR limit will be implemented for solid and solidified waste forms. Implementation of the requirements of this appendix shall be documented in site-specific procedures under a documented QA program approved by the DOE-CBFO.



AFGC = Allowable Flammable Gas Concentration
CH-TRU = Contact-Handled Transuranic
FGGR = Flammable Gas Generation Rate
MLEL = Mixture Lower Explosive Limit
ppm = Parts Per Million
VOC = Volatile Organic Compound

Figure 7.1.4-1 – Methodology for Compliance with Flammable (Gas/VOC) Concentration Limits

7.1.4.2.1 Demonstration of Compliance with FGGR Limit for Solid Waste Forms

For solid waste forms, the container headspace will be sampled and analyzed to determine the concentration of hydrogen. Sampling lines that communicate with the container headspace will be installed. Samples of the headspace gas will be withdrawn and analyzed using gas chromatography and/or MS. The analytical results will be used to calculate the FGGR. The measured FGGR will be compared to the appropriate FGGR limit for the assigned content code.

At steady-state conditions (applicable to the majority of SLB2s that are generated and/or stored in a vented condition over extended time periods before shipment), 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 container headspace is used to calculate the FGGR.

The FGGR of the container is calculated from the measured hydrogen gas concentration using the following relationship:

Equation 1

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

where,

C_g = FGGR (mole/second)

X_H = Measured concentration of hydrogen gas in the container headspace (mole fraction)

L_{CF} = Diffusion characteristic of the container filter (mole/second/mole fraction).

The FGGR shall be compared to the FGGR limit specified in the assigned content code. The container shall be qualified for shipment only if the limit is met.

Closed systems where a container is enclosed in a gas generation testing vessel can be used to perform gas generation testing. In this case, the headspace of the gas generation testing vessel can be monitored for gas generation with periodic sampling. Gas concentrations in the enclosure will increase in time and can be related to gas generation rates of hydrogen.

7.1.4.2.2 Demonstration of Compliance with FGGR Limit for Solidified Waste Forms

The methods described in Section 7.1.4.2.1, *Demonstration of Compliance with FGGR Limit for Solid Waste Forms*, (for solid waste forms) may be used to determine compliance with FGGR limits for solidified waste forms in addition to the methodology described below.

To determine the FGGR for a container of solidified waste, a small sample of the waste form can be analyzed for its gas generation properties. The FGGR for the container can then be determined based on the mass of waste in the container. 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 FGGR for the sample:

Equation 2

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

where,

$C_{g,sample}$	=	FGGR for sample (mole/second)
X	=	Mole fraction hydrogen in the test chamber
P	=	Absolute ambient pressure (atm)
$V_{chamber}$	=	Volume of the test chamber (liters)
R	=	Gas law constant (0.08206 atm liter $mole^{-1}$ K^{-1})
T	=	Absolute ambient temperature (K)
Δt	=	Elapsed time (second).

The FGGR for the container will be calculated using the following relationship:

Equation 3

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

where,

$C_{g,container}$	=	FGGR for container (mole/second)
$m_{container}$	=	Mass of waste in container (g)
m_{sample}	=	Mass of sample (g).

7.1.4.3 Data Needs and Interpretation

This section documents the data needs for the testing described in Section 7.1.4.2.1, *Demonstration of Compliance with FGGR Limit for Solid Waste Forms*, and Section 7.1.4.2.2, *Demonstration of Compliance with FGGR Limit for Solidified Waste Forms*. For any sampling and analysis done as part of these procedures, the following information should be documented:

1. Content Code - This is the content code for the waste being tested, which provides a short description of the waste.
2. Container ID - The test container should be given an identification code, which should be recorded for each test.
3. Ambient Conditions - The temperature and pressure conditions should be recorded during the test period.
4. Duration of Testing - Testing should be continued until enough analytical data is available to calculate the FGGR.
5. Sampling - Gas samples shall be collected in documented air-tight containers with proper chain-of-custody forms for transmittal to the analytical laboratory.

6. Analytical Methods - Instruments and methods used for measuring gas concentrations should conform to standard analytical methods (e.g., GC or GC/MS). Instruments shall be calibrated with certified gas standards. Calibration data, including instrument error and precision, should be available for all testing done.
7. Data Reduction - Any formulae or mathematical analysis used to reduce the data obtained to derive the FGGR should be documented, checked, and approved by a qualified individual. Proper QA procedures should be followed and documented for any data reduction.
8. Interpretation of Results - The interpretation of results with respect to the test criteria should be documented by the test supervisor.

7.1.4.4 Analytical Requirements for Test Methods

The minimum data requirements for the test methods described in Section 7.1.4.2.1, *Demonstration of Compliance with FGGR Limit for Solid Waste Forms*, and Section 7.1.4.2.2, *Demonstration of Compliance with FGGR Limit for Solidified Waste Forms*, are as follows:

- If a sample of the waste is tested (Section 7.1.4.2.2), the results should be reproducible with respect to the hydrogen generation potential of the waste.
- If the headspace hydrogen concentration of a container is the primary variable measured (Section 7.1.4.2.1), a sufficient number of data points should be obtained in order to determine a hydrogen generation rate. Data points should be obtained until the FGGR is shown to remain constant or decrease, or until the testing period equals or exceeds the time of the shipping period.
- If multiple containers assigned to a single content code require evaluation for FGGR limit compliance, a statistical subpopulation of these containers may be evaluated. Not all containers assigned to a single content code may have consistent gas generation properties. Therefore, the basis for defining a population of containers with consistent gas generation properties must be documented.

Containers selected from the defined population for evaluation (i.e., the subpopulation) must be representative of the population with techniques such as random or stratified sampling used to avoid bias in container selection. The required subpopulation size may be calculated using the following equation (a form of the finite population correction formula for binomial distribution results)[1]:

Equation 4

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}} = \frac{n_0 * N}{N + n_0 - 1}$$

[1] Gatliffe, T., May 2006, "Determination of Minimum Sample Size for Statistical Sampling of Remote-Handled Transuranic (RH-TRU) Waste," Washington TRU Solutions LLC, Carlsbad, New Mexico.

where,

n_0 = 203, a conservative (upper limit) subpopulation size for ensuring the 95th percentile can be established with a ±0.03 precision level and 95% confidence for a finite population

n = Required subpopulation size

N = Size of represented population.

A 95% upper threshold limit of the FGGR shall be calculated for each subpopulation using the Bootstrap (Resampling) technique.[1]

As shown by the equation, the minimum number of required containers in the subpopulation depends on the represented population size. When used with Bootstrap (Resampling) technique with replication size of 1,000 or more, the equation is valid for a represented minimum population size of 20. However, for waste populations, a minimum population size of 50 is specified (given the large percentage of containers that have to be sampled in smaller populations). Because the Bootstrap technique is independent of the population distribution form, the only requirement for the subpopulation is that it be representative of the population. Equation 4 above ensures that the proportion of the population represented in the subpopulation increases as the population size decreases. As such, potential local distributional anomalies in smaller populations should be adequately represented in the selected subpopulation.

7.1.5 Determination of Void Volumes for TRUPACT-III Payload

This appendix documents the determination of the following TRUPACT-III package void volumes:

- Empty TRUPACT-III containment vessel
- Empty SLB2
- TRUPACT-III containment vessel when loaded with one SLB2.

7.1.5.1 Void Volume Calculation for Empty TRUPACT-III Containment Vessel

The internal dimensions of the TRUPACT-III containment vessel are as follows:

Height = 2,000 mm (200 cm)

Length = 2,790 mm (279 cm)

Width = 1,840 mm (184 cm).

The internal volume (in liters) of the TRUPACT-III containment vessel excluding the volumes occupied by the interior protruding features and the ancillary handling equipment is:

$$H * L * W = (200\text{cm})(279\text{cm})(184\text{cm})\left(\frac{1\text{ liter}}{1{,}000\text{cm}^3}\right) = 10{,}267\text{ liters}$$

The interior protruding features of the TRUPACT-III containment vessel consist of the end strips, the lid shear lip, the debris shield, and eight full cavity length 1-inch by 3-inch guide rails. The external volumes associated with these interior protruding features are as follows:

$Vol_{endstrip} = 4$ liters

$Vol_{other} = 59$ liters

Therefore, the internal volume of the TRUPACT-III containment vessel accounting for the total volume occupied by the interior protruding features is:

10,267 liters – 63 liters = 10,204 liters

The ancillary handling equipment consists of the roller floor, pallet, and rails/guide channels. The external volumes associated with the ancillary handling equipment are as follows:

$Vol_{roller} = 108$ liters

$Vol_{pallet} = 68$ liters

$Vol_{rail} = 9$ liters

The total volume occupied by the ancillary handling equipment is:

$Vol_{roller} + Vol_{pallet} + Vol_{rail} = 185$ liters

Thus, the internal volume of the TRUPACT-III containment vessel taking into account the ancillary handling equipment is:

$$IVol_{TIII} = 10{,}204 \text{ liters} - Vol_{roller} - Vol_{pallet} - Vol_{rail} = 10{,}019 \text{ liters}$$

7.1.5.2 Void Volume Calculation for Empty SLB2

The internal dimensions of the SLB2 are as follows:

Height = 66.5 in. (168.910 cm)

Length = 104.25 in. (264.795 cm)

Width = 65.25 in. (165.735 cm).

The internal volume (in liters) of the empty SLB2 excluding the volumes associated with the six body vertical stiffeners and the interior protruding portions of the body flange and labyrinth members is:

$$H * L * W = (168.910\text{cm})(264.795\text{cm})(165.735)\left(\frac{1 \text{ liter}}{1{,}000\text{cm}^3}\right) = 7{,}413 \text{ liters}$$

The external volumes associated with the six body vertical stiffeners and the interior protruding portions of the body flange and labyrinth members are as follows:

$$Vol_{vertstiffeners} = (6)(27\text{in}^3) = 162\text{in}^3\left(\frac{16.4\text{cm}^3}{\text{in}^3}\right)\left(\frac{1 \text{ liter}}{1{,}000\text{cm}^3}\right) = 3 \text{ liters}$$

$$Vol_{iflangelabyr} = 966\text{in}^3\left(\frac{16.4\text{cm}^3}{\text{in}^3}\right)\left(\frac{1 \text{ liter}}{1{,}000\text{cm}^3}\right) = 16 \text{ liters}$$

The internal volume of the empty SLB2 taking into account the volumes of the six body vertical stiffeners and the body flange and labyrinth members is:

$$IVol_{SLB2} = 7{,}413 \text{ liters} - Vol_{vertstiffeners} - Vol_{iflangelabyr} = 7{,}394 \text{ liters}$$

7.1.5.3 Void Volume Calculation for TRUPACT-III Containment Vessel When Loaded with One SLB2

The external volume of the SLB2 is calculated as follows:

Internal free volume of SLB2 = 7,394 liters

Additional volume corresponding to the weight of the steel SLB2 materials of construction is calculated as:

$$\frac{\text{weight}}{\text{density}} = \frac{2{,}700\text{lb}}{0.284\text{lb} \cdot (\text{in}^3)^{-1}} = 9.507\text{in}^3\left(\frac{16.4\text{cm}^3}{\text{in}^3}\right)\left(\frac{1 \text{ liter}}{1{,}000\text{cm}^3}\right) = 156 \text{ liters}$$

The volumes occupied by the skid members, body and lid bumpers, and labyrinth region are as follows:

$$Vol_{bodyskid} = 60 \text{ liters}$$

$$Vol_{bumper} = 51 \text{ liters}$$

$$Vol_{oflangelabyr} = 4 \text{ liters}$$

Additional volume occupied by skid members, body and lid bumpers, and labyrinth region is calculated as:

$$Vol_{bodyskid} + Vol_{bumper} + Vol_{oflangelabyr} = 60 \text{ liters} + 51 \text{ liters} + 4 \text{ liters} = 115 \text{ liters}$$

Therefore, the external volume of the SLB2 is:

$$7{,}394 \text{ liters} + 156 \text{ liters} + 115 \text{ liters} = 7{,}665 \text{ liters}$$

Thus, the internal volume of the TRUPACT-III containment vessel when loaded with one SLB2 is:

$$IVol_{TIIIw/SLB2} = 10{,}019 \text{ liters} - 7{,}665 \text{ liters} = 2{,}354 \text{ liters}$$

7.1.5.4 Summary of Calculations

The TRUPACT-III package void volumes are as follows:

Empty TRUPACT-III containment vessel = 10,019 liters

Empty SLB2 = 7,394 liters

TRUPACT-III containment vessel when loaded with one SLB2 = 2,354 liters.

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7.1.6 Determination of Bounding Dose-Dependent Net Gas G Value for TRUPACT-III Payload

7.1.6.1 Introduction

Based on analyses presented in Appendices 6.1, 6.5, and 6.6 of the CH-TRU Payload Appendices[1], the primary mechanism for potential gas generation in CH-TRU wastes is radiolysis. The gas generation potential of a waste material, or "G value," is defined as the number of molecules of gas generated per 100 eV of energy absorbed. For a container with contents of a given waste type, net gas G values may be used in establishing the contribution of radiolytic gas generation to the MNOP in the TRUPACT-III during shipment and in evaluating compliance with the design pressure limit. A bounding effective net gas G value of 8.4 for solid organic materials is established in Appendix 3.2 of the CH-TRU Payload Appendices[1] based on cellulose (G value of 10.2 with 82% of the energy released from plutonium particles for a effective net gas G value of 10.2 x 0.82 = 8.4).

7.1.6.2 Purpose and Scope

Appendix 3.3 of the CH-TRU Payload Appendices[1] establishes dose-dependent G values for flammable gas (for containers meeting a criterion of >0.012 watt*year) based on documented evidence from a formal testing program that showed that flammable gas G values decreased with increasing dose. While evidence pointed to the same phenomenon for net gas G values, Appendix 3.3 of the CH-TRU Payload Appendices did not establish dose-dependent net gas G values. The purpose of this appendix is to establish dose-dependent effective net gas G values that are applicable to CH-TRU waste payloads to be shipped in the TRUPACT-III packaging that have met a specified dose criterion.

7.1.6.3 Review of Previous Experimental Studies

Appendix 3.1 of the CH-TRU Payload Appendices[1] contains a review of published experimental studies for the radiolysis of cellulose, which is summarized in Tables 3.1-30 and 3.1-31 of that appendix. The highest initial net gas G value from the studies, 10.2 from Ershov[2], was based on gamma irradiation of sulfite cellulose and was selected for use as the bounding net gas G value for CH-TRU waste. The Ershov study[2] did not report any data pertaining to the potential impact of dose on G value. Other radiolysis experiments representative of CH-TRU wastes also presented in Appendix 3.1 of the CH-TRU Payload Appendices[1] show a much lower initial net gas G value and dose-dependent depletion of the effective net gas G value. While the conditions in the Ershov study[2] are not consistent with other radiolysis experiments representative of CH-TRU waste materials, the previously established value is conservatively used as the bounding effective net gas G value without dose-dependence. These experiments are summarized below.

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[1] U.S. Department of Energy (DOE), *CH-TRU Payload Appendices*, current revision, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

[2] B. G. Ershov, *et al.*, *Mechanism of the Radiation Chemical Conversions of Cellulose*, translated from Khimiya Vysokikh Energii 20, pp. 142-147, 1986.

Zerwekh[3] conducted gas generation experiments in test cylinders and sampled actual drums of TRU waste for gas generation over time. Data from drum sampling showed a decrease in the concentrations of the generated gases over the same time durations as in the experiments, and the maximum drum concentrations reached by any particular gaseous component were significantly lower than those observed on the laboratory scale, indicating the laboratory scale data provides bounding results for gas generation in TRU waste drums.

Zerwekh[3] performed alpha radiolysis experiments on both dry and wet mixtures of cellulosic materials. The dry mixture consisted of paper wipes, paper tissues, embossed paper towel with polyethylene backing, cheesecloth, and cotton laboratory smock material. The net gas G value for dry cellulosic materials decreased from a high of approximately 1.5 within the first few days of the experiment to approximately 1.4 after a period of 125 days at an absorbed dose of approximately 0.012 watt*year (the criterion currently used for dose-dependent flammable gas G values for applicable CH-TRU wastes as established by Appendix 3.3 of the CH-TRU Payload Appendices[1]), to approximately 0.5 after a period of 1,000 days at an absorbed dose of approximately 0.095 watt*year (Figure 22 of Zerwekh[3]).

The wet cellulosic waste consisted of wet cheesecloth that had been soaked in water prior to use. The net gas G values for the wet cellulosic materials decreased from a high of approximately 1.7 within the first few days of the experiment to approximately 1.5 after a period of 125 days at an absorbed dose of approximately 0.012 watt*year, to approximately 1.3 after a period of 1,000 days at an absorbed dose of approximately 0.095 watt*year (Figure 28 of Zerwekh[3]).

Kazanjian[4] measured gas consumption and generation from Pu-238 alpha irradiation of both wet and dry Kimwipes® (paper tissues commonly used in laboratories). The G values decreased as the dose increased. The net gas G value decreased from ~1.1 initially to ~0.5 at 6.0E23 eV (0.003 watt*year) for dry Kimwipes®, and from ~0.6 initially to ~0.3 at an absorbed dose of 4.5E23 eV (0.0023 watt*year) for wet Kimwipes®. All G values were significantly lower for wet Kimwipes® compared to the values for dry Kimwipes®. This is attributed to some of the alpha decay energy being absorbed by water rather than by the cellulose. The net gas G values for both wet and dry Kimwipes® decreased to half of the initial values while still in the initial dose range (i.e., ≤ 0.012 watt*year).

Bibler[5] conducted alpha radiolysis experiments using a 5-M nitric acid Cm-244 solution, which was absorbed by paper tissue that was dried and folded to surround the Cm-244 deposit. A net gas G value of 1.9 was measured during the first five hours of one experiment, with the first measurement taken at an absorbed dose of ~4E19 eV (~2.03E-7 watt*year). The net gas G value decreased to a value of 0.6 at an absorbed dose of 2.5E23 eV (0.0013 watt*year). Three different concentrations of Cm-244, with up to a factor of 4 difference, were used in the experiments, and all observations showed decreasing net gas G values with increasing absorbed

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[3] A. Zerwekh, *Gas Generation from Radiolytic Attack of TRU-Contaminated Hydrogeneous Waste*, Los Alamos National Laboratory, LA-7674-MS, June 1979.

[4] A. R. Kazanjian, *Radiolytic Gas Generation in Plutonium Contaminated Waste Materials*, Rockwell International, Rocky Flats Plant, RFP-2469, October 1976.

[5] N. E. Bibler, *Radiolytic Gas Production During Long-Term Storage of Nuclear Wastes*, E. I. DuPont de Nemours and Company, Savannah River Laboratory, DP-MS-76-51, American Chemical Society Meeting (preprint), October 27-29, 1976.

dose. In these experiments, the net gas G value decreased to less than one-third of the initial value at approximately 10% of the dose-dependent threshold of ≤0.012 watt*year.

Kosiewicz[6] used paper typically used in radioactive material research laboratories at the time, representing forms of paper that would eventually be disposed of as TRU waste. Gas generation was measured by pressure change, and G(gas) was calculated. G values were plotted as functions of energy deposited, or total accumulated dose, for experiments conducted in both air and argon atmospheres. Kosiewicz[6] measured a peak net gas G value of 1.9 at a very low absorbed dose. At a total accumulated dose of approximately 7E23 eV (~0.004 watt*year) the net gas G values reported were 1.5 for an air atmosphere and 1.44 for an argon atmosphere. The net gas G value decreased to half its initial value after an absorbed dose of ~2.5E24 eV (~0.013 watt*year).

In summary, investigations of radiolytic gas generation have repeatedly demonstrated that net gas production is a function of dose and decreases with increasing dose. As noted earlier, the initial net effective G values of other studies are well below the bounding value of 8.4 established in Appendix 3.2 of the CH-TRU Payload Appendices based on Ershov[2].

7.1.6.4 Dose-Dependent Effective Net Gas G Value Determination from Matrix Depletion Studies

Smith, *et al.*[7] studied matrix depletion and the dose dependence of G values in materials representative of CH-TRU waste materials. Results were presented for six test canisters, three containing cellulose (in the form of cheesecloth and computer paper) and three containing polyethylene (in the form of bottle and plastic bag pieces). All were contaminated with Pu-238 in known quantities and activities.

Experimental durations were 795 days (test canisters 1c and 1f), 945 days (test canisters 1e and 1b), and 1,085 days (test canisters 1a and 1d), and samples were withdrawn at frequencies determined to reflect the expected rate of gas generation and accumulated dose. The samples were analyzed by MS and the mole percent data obtained for hydrogen were used to calculate the cumulative effective G value for hydrogen (hydrogen G value) generation for each sampling point. Mole percent concentrations of methane, carbon dioxide, carbon monoxide, oxygen, and nitrogen were also collected at each sampling event.

Using the equations given in Appendix A of Smith, *et al.*[7], and the given data for mole percent of methane, carbon monoxide, and carbon dioxide, the net gas G values for each sampling period were calculated. The dose-dependent net gas G values from these calculations for the six test canisters are presented in Table 7.1.6-1. As in the Matrix Depletion Program studies (INEEL, 1999[8]; and Appendix 3.3 of CH-TRU Payload Appendices[1]) for flammable gas G values, absorbed dose levels greater than 0.006 watt*year, half the 0.012 watt*year value, are considered

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[6] S. T. Kosiewicz, *Gas Generation from Organic Transuranic Wastes. I. Alpha Radiolysis at Atmospheric Pressure*, Nuclear Technology 54, pp. 92-99, 1981.

[7] Smith, M.C., E.L. Callis, J.H. Cappis, E.M. Foltyn, R.S. Marshall, and J. Espinoza, 1997, *Alpha Radiolytic Gas Generation: Determination of Effective G Values*, Benchmark Environmental Corporation, Albuquerque, New Mexico.

[8] Idaho National Engineering and Environmental Laboratory, 1999, *TRUPACT-II Matrix Depletion Program Final Report*, INEL/EXT-98-00987, Rev. 1, Idaho national engineering and Environmental Laboratory, Idaho Falls, Idaho,.

depleted for net gas G values (i.e., the boundary level between initial dose and dose-dependent) as an added margin of safety.

Table 7.1.6-1 – Calculated Bounding Net Gas G Values from Smith, *et al.*

Test Canister	Material	Dose-Dependent Bounding Net Gas G Value①
1a	Cellulose	1.14
1b	Cellulose	1.47
1c	Cellulose	1.14
1d	Polyethylene	0.75
1e	Polyethylene	1.28
1f	Polyethylene	0.75

① Dose level >0.006 watt*year.

As shown in Table 7.1.6-1, the maximum dose-dependent bounding effective net gas G value is 1.47. This value is consistent with that observed in other experiments discussed in Section 7.1.6.3, *Review of Previous Experimental Studies*, which show a maximum depleted value of 1.5 (Zerwekh[3]).

7.1.6.5 Conclusion

The dose-dependent effective net gas G value for solid organic waste is bound by a value of 1.5 at a dose >0.006 watt*year and can be used for TRUPACT-III payload materials that have met a dose criteria of >0.012 watt*year (as noted above, the dose criteria of 0.006 is doubled to provide a margin of safety and to be consistent with the dose criteria established for flammable gas G values). The effective net gas G value of 8.4 (previously established by Appendix 3.2 of the CH-TRU Payload Appendices[1]) is retained for solid organic waste if the dose criterion of >0.012 watt*year is not met.