Washington TRU Solutions LLC

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June 5, 2006

Ms. J. S. Caverly, Project Manager
Licensing Section
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
U. S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

Subject: RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION FOR REVIEW OF AN APPLICATION FOR REVISION 4 OF THE RH-TRU 72-B SHIPPING PACKAGE (DOCKET NO. 71-9212, TAC NO. L23913)

References
1. Letter from P. C. Gregory to M. Rahimi dated October 14, 2005, subject: Revision 4 of the RH-TRU 72-B Shipping Package Application, Docket No. 71-9212
2. Letter from J. S. Caverly to P. C. Gregory dated April 27, 2006, subject: Request for Additional Information for Review of an Application for Revision 4 of the RH-TRU 72-B Shipping Package (Docket 71-9212)

Dear Ms. Caverly:

Washington TRU Solutions LLC, on behalf of the U.S. Department of Energy (DOE), hereby submits an amendment to Revision 4 of the application for a Certificate of Compliance for the RH-TRU 72-B Shipping Package, U.S. Nuclear Regulatory Commission (NRC) Docket No. 71-9212 (Reference 1). The amendment is in response to the NRC's Request for Additional Information (RAI) (Reference 2). Other editorial or typographical corrections have been made to the application as noted at the end of Attachment B. This letter includes the following attachments:

- Attachment A – Enclosures to Letter
- Attachment B – Responses to Request for Additional Information
- Attachment C – Revised Documents.

Technical changes necessary to specifically address the RAI are indicated by red-lining in the margin of the revised documents ("|") and are summarized in Attachment B. All technical changes made to the documents in the original submittal of the Revision 4 application (Reference 1) also continue to be indicated by red-lining in the margin of the documents ("|").

As noted in previous application submittals, an NRC/DOE agreement exists to waive applicable review fees.

If you have any questions regarding this submittal, please contact Mr. R. A. Johnson of my staff at (360) 438-6145 or me at (505) 234-7469.

Sincerely,

Todd Sellmer
for

P. C. Gregory, Manager
Packaging

RAJ:clm

Attachments

cc: M. A. Italiano, CBFO

ATTACHMENT A

ENCLOSURES TO LETTER

Attachment B	Responses to Request for Additional Information
Attachment B-1	Mathematical Justification for Revised RH-TRU 72-B IV and RH-TRU Canister Void Volumes
Attachment B-2	Determination of Minimum Sample Size for Statistical Sampling of Remote-Handled Transuranic (RH-TRU) Waste
Attachment C	Revised Documents (two hard copies and seven CDs in Adobe PDF format)

- RH-TRU 72-B SAR, Revision 4
- RH-TRAMPAC, Revision 0
- RH-TRU Payload Appendices, Revision 0

ATTACHMENT B

RESPONSES TO REQUEST FOR ADDITIONAL INFORMATION

RH-TRU 72-B SAFETY ANALYSIS REPORT

CHAPTER 1.0 – GENERAL INFORMATION

1-1 Revise the SAR text so that the Inner Vessel (IV) is properly identified as an optional containment boundary. In many instances (for example: 4th paragraph on page 1.1-2, 2nd paragraph on page 1.2-1) the IV is identified as providing an inner containment boundary.

This statement is incorrect in the face of the current amendment application, where the leakage rate testing of the Inner Vessel is proposed as optional.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. To clarify, the RH-TRU 72-B IV is designed, and each IV that is produced is constructed and configured in a manner, such that a leaktight containment boundary is initially established at time of manufacture. This is demonstrated for each IV that is manufactured by performance of the leakage rate tests discussed in Section 8.1.3, *Fabrication Leakage Rate Tests,* of the RH-TRU 72-B SAR. Similarly, at the time of annual maintenance, each IV is again shown to be leaktight via performance of the leakage rate tests of Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*, of the RH-TRU 72-B SAR. At the time of shipment, if an optional preshipment leakage rate test (per Section 7.4.1, *Preshipment Leakage Rate Test*, of the RH-TRU 72-B SAR), or alternatively, a maintenance/periodic leakage rate test (per Section 8.2.2), is successfully performed on the IV, a leaktight IV can also be claimed during shipment. Of importance, even if the preshipment leakage rate test is not performed on the IV containment seals at the time of shipment, it is expected that a leaktight containment will still exist (i.e., the IV is configured in the same manner, with all O-ring seals in place, whether or not the optional preshipment leakage rate test is to be performed).

Given the above, from a design, manufacturing, and maintenance perspective, as well as from a consideration of what is likely to exist during transport, it is considered appropriate to classify all IV components intended to provide a containment function as containment boundary components, even if the optional IV preshipment leakage rate test is not performed. This was the logic used to initially develop Revision 4 of the RH-TRU 72-B SAR. However, it is acknowledged that in the absence of an IV preshipment leakage rate test, a leaktight secondary containment cannot be guaranteed during transport. Chapter 1.0, *General Information*, and Chapter 4.0, *Containment*, of the RH-TRU 72-B SAR have therefore been revised to clearly reflect this situation. Other chapters of the RH-TRU 72-B SAR have not, however, been revised. Rather, in those other chapters, components associated with establishing a leaktight condition of the IV are still referred to as containment components because they are intended and expected to perform that function whether or not the IV preshipment leakage rate test is performed.

CHAPTER 2.0 – STRUCTURAL AND MATERIALS

2-1 Justify the inconsistency on the boundary conditions assumed between the upper and lower plates subjected to puncture bar acceleration of 29.5 g. This information is located in Section 2.7.3.3 – End Puncture, page 2.7-28.

For the top closure lid, the maximum stress was calculated to be 61,666 psi giving rise to a safety margin of +0.1, assuming the lid is simply supported at its edge. However, for the bottom closure plate, different boundary conditions of fixed edge are assumed, resulting in a maximum stress of 63,446 psi or safety margin of +0.07.

On the other hand, if the simply supported boundary conditions are also assumed for the bottom closure plate, consistent with the boundary conditions set for the top, the staff calculated the maximum bending stress at the center of the plate to be 88,799 psi, exceeding the allowable stress intensity for Type F304 stainless steel at 160F (67,700 psi) by a factor of 31%.

This information is necessary to determine compliance with 10 CFR 71.41(a) and 10 CFR 71.73(c)(3).

Response:

Comment incorporated. The reason for assuming simple supports for the top closure lid and fixed edges for the bottom closure plate was an attempt to recognize the difference between the bolted configuration of the top closure and the continuously welded configuration of the bottom closure to two relatively thick shells located at its outer edge. Whereas the simple support assumption is clearly conservative for either end, both ends will actually fall somewhere between simply supported and rigidly fixed. By inspection, it was considered that the bolted top end configuration would tend to approach simply supported, so simple supports were conservatively assumed there. Conversely, for the bottom end, use of simple supports appeared to be overly conservative as it was expected that the response would approach that of a fixed edge configuration. Given RAI 2-1, and acknowledging the potentially non-conservative fixed edge assumption, a new finite element analysis (FEA) model was created to more accurately establish the state of stress in the bottom closure. Details of that FEA evaluation have been added as a new Appendix 2.10.1.6, *Outer Cask Bottom Stresses Due to Puncture,* of the RH-TRU 72-B SAR. Per that appendix, a maximum membrane-plus-bending stress intensity at the inside center of the closure plate of 66,760 psi is established. With an allowable limit of 67,700 psi, the previously reported margin is reduced from +0.07 to +0.01. Although this margin is relatively small, conservatisms still exist within the new FEA model. For instance, any bending resistance provided by the 1.5-inch thick IV bottom closure plate and/or the 0.5-inch thick impact limiter plate immediately adjacent to the outer cask (OC) closure plate has been ignored as has any beneficial load spreading associated with the presence of crushed foam and the 0.5-inch impact limiter plate between the top of the puncture bar and the OC bottom plate. Further, the radial locations of loads coming into the OC closure plate from the payload, canister, and IV have been placed at the outermost radial locations possible.

Section 2.7.3.3, *End Puncture*, of the RH-TRU 72-B SAR has been revised to reference the new Appendix 2.10.1.6 and summarize the stress results contained therein.

2-2 Provide information to justify the torque coefficient K = 0.2 for chrome plated bolts. This information is located in Section 2.10.6.2 – Analysis Methodology, page 2.10.6-3.

The choice of K value used for calculating the bolt stresses is very sensitive to the outcome as can be witnessed in the Tables 2.10.6-1 to 2.10.6-8. For example, using K = 0.13, the stress intensity of the bolt is calculated as 56,702 psi for the case of 90 degree drop, whereas if K = 0.2 the stress intensity drops to 40,667 psi. It has been established that K = 0.11 -0.15 for Cd plated bolts. However, there is no reference information or data provided to support using the K value of 0.2 for the Chrome plated bolts.

This information is necessary to determine compliance with 10 CFR 71.31(a)(1).

Response:

Comment incorporated. The bolt stress analyses in the RH-TRU 72-B SAR consider extreme torque coefficients ranging from a minimum of 0.13 to a maximum of 0.20. This range was selected to cover a wide variety of bolt conditions, platings, and/or lubrications. As referenced in Appendix 2.10.6, *Closure Bolt Stress Evaluations*, of the RH-TRU 72-B SAR, the 0.13 value is representative of cadmium plated fasteners. As established in other references, chrome plating has a much lesser influence on torque coefficient. For example, per http://raskcycle.com/techtip/webdoc14.html, whereas cadmium plating reduces the torque coefficient by 25%, chrome plating has no effect. Given this, a torque coefficient of 0.173 can be reasonably set for chrome-plated fasteners (i.e., 75% of 0.173 = 0.13).

Given the above, a footnote has been added to Paragraph c of Section 2.10.6.2, *Analysis Methodology*, of the RH-TRU 72-B SAR relative to the torque coefficient of 0.20 used for non-cadmium plated bolts. That footnote reads as follows: "A torque coefficient of 0.20 is also considered in order to bound a wide variety of bolt conditions, platings and/or lubrications. Specific to the chrome plating option identified in Drawing Note 31, per http://raskcycle.com/techtip/webdoc14.html, cadmium plating reduces the torque coefficient by 25% more than does chrome plating. Using this relationship and a torque coefficient of 0.13 for cadmium plating results in a value of 0.173 for chrome plating, which falls within the analysis-assumed range of 0.13 to 0.20."

CHAPTER 3.0 – THERMAL

3-1 Revise the allowable temperature limits for the butyl O-ring presented in the 2nd paragraph of Section 3.3, since they do not agree with the provided reference. Similarly, revise the values shown on Table 3.1-1. Verify that, throughout the application, material temperature allowable limits are consistent.

The Safety Analysis Report for the TRUPACT-II Shipping Package, Revision 21, which is referenced in the current application, indicates the butyl rubber sealing material having a working range of -65ºF to 225ºF, and a short duration (8 hours or less) upper limit of 400ºF. Also, on page 3.5-4 of the RH-TRU 72-B application, an upper operating limit of 250ºF for the butyl O-ring seals is mentioned.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. In response to RAIs 3-1 and 4-2, the operating temperature range for butyl O-ring seals, as established by several references, was thoroughly reviewed. All RH-TRU 72B SAR sections that make reference to the operating temperature range were also subsequently reviewed and have

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been revised to consistently use the reference data. A brief discussion of the available reference data and how it is now integrated into the RH-TRU 72-B SAR is provided below. Section 3.3, *Technical Specifications of Components*, Section 3.5.6, *Evaluation of Package Performance for the Hypothetical Accident Thermal Conditions*, and Section 4.3, *Containment Requirements for the Hypothetical Accident Conditions*, and Tables 3.1-1 and 3.1-2 of the RH-TRU 72-B SAR have been appropriately revised.

Four reference documents provide data associated with the operating range of the butyl material used for the TRUPACT-II, HalfPACT, and RH-TRU 72-B package O-rings. As a generic reference for butyl, the 1991 edition of the Parker O-ring Handbook, Figure A3-5, identifies a normal recommended temperature range of -65 ºF to 250 ºF. This range generally corresponds to long-term functional service as indicated on page A3-34 of Parker. In addition, Rainier Rubber issues information on its company standard compounds, of which RR-0405-70 butyl is one. Per their web site, http://www.rainierrubber.com/compounds.htm, a normal operating temperature range of -65 ºF to 225 ºF is identified. The slightly more conservative Rainier Rubber data establishing the high end of the range has now been adopted for use in the RH-TRU 72-B SAR as the long-term high-temperature limit. Short-term excursions above 225 ºF, associated with the hypothetical accident condition (HAC) thermal event, can also be accommodated, but require data beyond the general information available from Parker or Rainier Rubber. One set of data is as provided in Section 2.10.2, *Elastomer O-ring Seal Performance Tests*, of the TRUPACT-II SAR. Per that appendix, the butyl material was shown to establish a leaktight condition at -40 ºF, remain leaktight at -20 ºF when subjected to movement of the adjacent seal surfaces such as could occur during HAC free drop conditions, continue to hold a hard vacuum when heated to 400 ºF for eight hours (simulating the HAC thermal excursion), and remain leaktight when subsequently re-cooled to -20 ºF, which is the minimum applicable post fire ambient temperature. Notably, the TRUPACT-II related testing considered O-ring seal compressions as low as 15%. With a minimum O-ring seal compression for a prototypic TRUPACT-II packaging of 17.0% (see last sentence of Section 2.10.2.5, *Example O-ring Seal Compression Calculation*, of TRUPACT-II SAR), the conclusion for TRUPACT-II was that seals would remain leaktight for extended periods over a temperature range of -40 ºF to 225 ºF, with short-term (up to eight hours) excursions to 400 ºF.

For the RH-TRU 72-B, minimum O-ring seal compressions of 15% and 14% are identified in Section 4.3, *Containment Requirements for the Hypothetical Accident Conditions*, respectively, for production unit IVs and OCs. Since these compressions fall at or slightly below the 15% compression addressed in the

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TRUPACT-II O-ring seal testing, additional test data at reduced compression values is needed. Such data is available from Appendix 2.10.6 of the Radioisotope Thermoelectric Generator (RTG) Transportation System Safety Analysis Report for Packaging, WHC-SD-RTG-SARP-001. As documented therein, at 10% compression, the butyl material was again shown to establish a leaktight condition at -40 ºF, to hold a hard vacuum when heated to 380 ºF for 24 hours (simulating the HAC thermal excursion), to continue to hold a hard vacuum at 350 ºF for an additional 144 hours, and remain leaktight when subsequently re-cooled to -20 ºF. To ensure leaktight conditions will exist for the 14% minimum compression possible for the RH-TRU 72-B OC containment O-ring seal, the RTG data is adopted instead of the TRUPACT-II data.

In summary, the conclusion for RH-TRU 72-B is that seals will remain leaktight for extended periods over a temperature range of -40 ºF to 225 ºF, with short-term (up to 24 hours) excursions to 380 ºF. The RH-TRU 72-B SAR has been revised to consistently reflect these clarified temperature limits.

3-2 Clarify footnote 2 on page 3.2-2, where a justification for using a value of 0.3 for the emissivity of the outer surfaces makes reference to a 0.5 value. Provide references for all emissivity values proposed on Table 3.2-3.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. The 0.5 value referenced in footnote 2 on page 3.2-2 is a typographical error; the footnote has been revised to reference the correct value of 0.3. The thermal analysis assumes that, as a design option, the exterior surfaces of the outer cask and the impact limiters could be painted. As such, a range of surface emissivities appropriate for either coated or uncoated surfaces are considered in order to establish the conservative approach for analysis. An emissivity value of 0.3 represents uncoated, “as-received” Type 304 stainless steel with a slight degree of oxidation. Since coated surfaces will yield higher surface emissivities and, thus, lower package temperatures under NCT conditions, the lower value of 0.3 is used in the NCT evaluations in order to provide a bounding temperature prediction for either coated or uncoated packages.

References for all emissivity values have been added to Table 3.2-3 of Section 3.2, *Summary of Thermal Properties of Materials*, of the RH-TRU 72-B SAR. The list of references has been extended to provide additional justification

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for the values assumed. The values provided for the assumed surface emissivity (ε) and solar absorptivity (α) of the trunnions, thermal shield, and impact limiter shell in the previously approved Revision 3 of the RH-TRU 72-B SAR were transposed. This error has been corrected in Table 3.2-3.

3-3 Clarify how external barometric pressure changes can influence the internal pressure developed inside the IV, as stated on page 3.4-3. Provide a physical explanation for subtracting 11.2 psi from the design pressure of 150 psig, as shown on page 3.4-5.

In Section 3.4.4.3, the approach (using a pressure limit of 138.8 psig instead of 150 psig) for justifying the 23.5 watts decay heat for waste material "NewPaper" is definitely conservative (a higher pressure limit would allow a higher decay heat value) but seems to lack any physical meaning. On page 2.6-7, the reduced external pressure condition (per 10 CFR 71.71(c)(3)) of 3.5 psia is considered negligible from a structural perspective; however, this low pressure value is somehow associated with an internal pressure of 11.2 psig.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Assuming that a 14.7 psia barometric pressure exists at the time of closure of the IV and OC, and that a subsequent reduction of barometric pressure from 14.7 to 3.5 psia occurs, the net effect is equivalent to an 11.2 psig increase in internal pressure. This is the physical basis for equating the 3.5-psia reduced external pressure to an 11.2-psig internal pressure increase, as is done in Section 2.6.3, *Reduced External Pressure,* of the RH-TRU 72-B SAR. The applicability of this load case is per NRC Regulatory Guide 7.8, Table 1, which indicates that maximum internal pressure is to be combined with reduced external pressure. For conservatism, when evaluating the structural response of the RH-TRU 72-B OC, it has been assumed that the IV is unable to contain its internal pressure and therefore communicates directly with and internally pressurizes the OC. Similarly, when evaluating the structural response of the IV, it has been conservatively assumed that the OC does not retain pressure such that a reduced external pressure will directly affect the IV (with an effect equivalent to increasing the internal pressure by 11.2 psig as discussed above). By addressing a 150-psig net internal pressure in Section 2.6.1.3.2, *Stresses Due to Maximum Pressures*, of the RH-TRU 72-B SAR for both inner and outer vessels and a 138.8-psig maximum internal pressure build-up in the IV during a 60-day shipping period in Section 3.4.4.3, *Maximum Pressure for Normal Conditions of*

Transport, of the RH-TRU 72-B SAR, the effect of a 3.5-psia reduced external pressure is conservatively covered.

Of note, the same approach is used in evaluating the TRUPACT-II package, where Section 3.4.4.3, *Maximum Normal Operating Pressure*, of the TRUPACT-II SAR considers a 50-psig maximum internal pressure build-up in the IV during a 60-day shipping period and the corresponding structural evaluations of the inner and outer vessels consider internal pressures that are 11.2 psig greater (see Section 2.6.1.3, *Stress Calculations*, of the TRUPACT-II SAR, where 61.2 psig analyses are performed for both inner and outer vessels).

3-4 Justify the use of 493 liters as the total void volume in the NCT maximum pressure calculations for both NewMet and NewPaper waste materials when, on page 3.4-7, the canister and IV void volumes (190.5 + 493 = 683.5 liters) are identified as the only volumes available in calculating pressures under NCT. Provide mathematical justification for both 190.5 and 493 liters values. Discuss the reason for calculating pressure inside the package IV (and not inside the OC) when, in fact, this application suggests optional pre-shipment leakage testing of the IV closure.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. The use of 493 liters (in lieu of 493 + 190.5 = 683.5 liters) in the calculations presented in Section 3.4.4.3, *Maximum Pressure for Normal Conditions of Transport*, of the RH-TRU 72-B SAR, as introduced in Revision 0 and carried through subsequent revisions of the RH-TRU 72-B SAR, conservatively neglected the void space internal to the canister. As a result of RAI 3-4 and upon further review, the IV and canister void volumes have been revised. Attachment B-1 provides the mathematical justification for revised IV and RH-TRU canister void volume values, which are applicable to both fixed and removable lid canister types. The revised IV void volume with RH-TRU canister is 450 liters, and the RH-TRU canister void volume with three 55-gallon drums is 240 liters, for a total available void volume of 450 + 240 = 690 liters. The 240-liter void volume value for an RH-TRU canister with three 55-gallon drums is also conservatively satisfied for direct-load RH-TRU canister configurations due to inherent porosity in the direct-load contents (e.g., an RH-TRU canister internal volume between 904 and 942 liters will provide approximately 240 liters of void space even if completely filled with direct-load particulate contents in a face-centered cubic tightly-packed configuration). However, the MNOP calculations have been revised to conservatively use only the IV void volume of 450 liters. This is consistent with the flammable gas generation methodology described in Appendix 2.5, *Compliance Methodology for Gas Generation Requirements*, of the RH-TRU Payload Appendices, which specifies (in Table 2.5-2) a conservative default void volume of 1 liter for direct-loaded RH-TRU canisters without void volume characterization information.

The IV geometry was selected for the pressure calculation in lieu of the OC geometry because the IV geometry gives the most limiting void volume. It is acknowledged that the pre-shipment leakage rate testing of the IV is optional, but due to the fact that the use of IV O-rings is not optional, the most conservative void volume and associated pressure calculation is based on the geometry of the IV (also see response to RAI 1-1).

Affected sections of the RH-TRU 72-B SAR, the RH-TRAMPAC, and the RH-TRU Payload Appendices have correspondingly been revised to incorporate the revised void volume values established in Attachment B-1 (i.e., Sections 3.4.4.3, *Maximum Pressure for Normal Conditions of Transport*, and 3.5.4.1, *Temperature Control*, and Table 3.4-5 of the RH-TRU 72-B SAR, Section 5.3, *Pressure Limit*, of the RH-TRAMPAC, and Appendix 2.5, *Compliance Methodology for Gas Generation Requirements*, of the RH-TRU Payload Appendices).

3-5 Clarify the statement in the first paragraph on page 3.4-8: “for decay heats greater than 23.5 watts, compliance with the applicable hydrogen gas generation limit ensures compliance with the pressure limit.” Modify the application appropriately.

This subject is further discussed in Section 5.3 of the RH-TRAMPAC document. However, a generalization is being made based on a specific result from content code ID 325B (calculations shown in Section 2.5.5 of the RH-TRU Appendices document). Had another content code been chosen and with fewer restrictions (confinement layers) for the flowing of gases, the ratio between the FGGRs would be smaller. The generalization that is being proposed is not acceptable because it ignores the intrinsic details of any given content code. For example in the extreme case of a content code waste with no internal barriers for the movement of radiolytic gas, a rather large FGGR would be determined based on the 5% hydrogen molar fraction limit, since the available internal volume is large. In this case, the FGGR (and the corresponding decay heat limit) based on a pressure limit approach should take precedence.

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10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. The text in Section 5.3, *Pressure Limit*, of the RH-TRAMPAC has been clarified to show that the statement referenced in RAI 3-5 is based not on Content Code ID 325B, but on a hypothetical content code with no layers of confinement and with the maximum possible flammable gas generation rate limit (i.e., calculated by assuming that the entire internal volume of the IV [1,460 liters as determined in Attachment B-1] is available). As clarified in the response to RAI TP5-1, the referenced statement is applicable to all solid inorganic, solid organic, and solidified inorganic waste. Solidified organic waste, for which this logic is not applicable, is not expected in RH-TRU waste.

3-6 Provide a physical explanation for the thermal shield not reaching temperature values much closer to the 800ºC (1472ºF) fully engulfing fire environment. Provide the time-dependent temperature behavior for other nodes (besides node 571) situated on the thermal shield. If an error is found with the thermal modeling, revise the application accordingly.

Figures 3.5-3 and 3.5-8 show the temperature for node 571 barely above 1200ºF, even at the end of the 30 minutes fire. This is hardly credible, especially because of the thermal shield design: 10 gauge stainless steel sheet spaced outward from the outer shell by a 12 gauge wire wrap on a 3-inch pitch space. This steel sheet is somewhat isolated from the rest of the package body and, due to its small thermal inertia, should have quickly responded to the fire, with its temperature reaching values very close to the fire itself.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

The noted temperature response during the HAC fire event is correct and typical for applications with thermal shields. The time-dependent temperature behavior of the other thermal nodes representing the thermal shield (i.e., Nodes 370, 470, 670, and 770; see Figures 3.6.1-1 and 3.6.1-2 of Appendix 3.6.1, *Thermal Model Details*, of the RH-TRU 72-B SAR) exhibit a similar temperature response. While the thermal shield may appear to be thermally isolated from the cask, the thermal connection is significant under the elevated temperature environment of the HAC fire because the level of the radiation exchange increases with the absolute temperature to the fourth power. To perform its function, a thermal shield needs to be relatively thermally *isolated* from the cask, but not thermally *disconnected*. The fact that shortly after the start of the HAC fire event the thermal shield differs in temperature by only 275 ºF from the fire, but nearly 1,000 ºF from the cask demonstrates that the thermal shield is functioning as intended.

The temperature of the thermal shield at each time step in the fire transient is determined by an energy balance between the heat transfer mechanisms connecting the thermal shield with the ambient and the heat transfer mechanisms connecting the shield with the cask outer surface. From the general principles of heat transfer and conservation of energy, the following is known over each time interval of the HAC fire transient:

heat conducted into shield + heat generated within shield = heat conducted out of shield + change in energy stored within shield

Because the thermal shield does not generate heat, the above relationship simplifies to:

heat conducted into shield = heat conducted out of shield + change in energy stored within shield

Expressing each of the remaining items in this energy balance in mathematical terms yields the following equations:

1. Heat conducted into shield = $h_c\left(T_{ambient} - T_{shield}\right) + \sigma F\left((0.9)T^4_{ambient} - T^4_{shield}\right)$

2. Heat conducted out of the shield = $\left(\frac{k}{gap}\right)\left(T_{shield} - T_{cask}\right) + \sigma F\left(T^4_{shield} - T^4_{cask}\right)$

3. Heat stored in shield = (mass)(c_p)ΔT per unit time

where h_c is the convective heat transfer rate between the thermal shield and the ambient (Btu/hr-ft^2-ºF), $T_{ambient}$ is the temperature of the ambient environment (ºR), T_{shield} is the temperature of the thermal shield (ºR), σ is the Stefan-Botzmann constant (1.714(10)$^{-9}$ Btu/hr-ft^2-ºF^4), F is the shape factor modulus that accounts for the emissivity and relative geometries of the surfaces involved, k is the effective thermal conductivity through the air and wire wrap separating the

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thermal shield from the cask body (Btu/hr-ft-ºF), "gap" is the width of gap between the thermal shield and the cask body (ft), T_{cask} is the temperature of the surface of the cask body (ºR), "mass" is the mass of the thermal shield on a unit area basis (lb/ft^2), c_p is the specific heat of the thermal shield material (Btu/lb-ºF), and ΔT is the temperature change within the thermal shield (ºF/hr).

Given the relatively small thermal inertia of the thermal shield, the energy balance essentially reduces to:

$$\text{heat conducted into shield} = \text{heat conducted out of shield}$$

Because the heat conducted into the shield is a function of temperature difference between the ambient environment and the thermal shield (see Equation 1, above), a zero or near-zero temperature difference between the thermal shield and the ambient would also mean there is zero or near-zero heat input to the shield and, by extension of the relationship above, into the cask body. Therefore, based on the conservation of energy, if the thermal shield quickly reaches the HAC fire temperature, the heat input into the cask during the fire must also quickly go to essentially zero if the conservation of energy is maintained. Obviously, a zero heat flow into the cask is not correct, therefore, the thermal shield cannot be equal or nearly equal in temperature to the HAC fire.

Examining this phenomenon from another direction, consider the situation where the thermal shield temperature is nearly equal to that of the fire. At that point, there is relatively little heat input into the thermal shield from the fire because of the low temperature difference. However, because the temperature difference between the cask and the thermal shield would be large, the heat flow from the thermal shield into the cask would be much greater (especially since the radiation heat exchange is driven by the absolute temperature to the fourth power). Based on the conservation of energy, the only way this difference in heat flows can be balanced out is if energy stored within the thermal shield is removed (i.e., the thermal shield drops in temperature). However, given the low thermal inertia of the thermal shield, even a small reduction in internal energy would require a relatively large temperature decrease. As the thermal shield drops in temperature, the heat input from the fire grows because the temperature difference grows. Conversely, the heat flow into the cask drops because the temperature difference between the thermal shield and the cask becomes smaller. A balance point is reached wherein the combination of the temperature difference and the combined effective thermal conductance on both sides of the thermal shield are essentially equal. Then as the cask rises in temperature, so will the thermal shield until, given a very long fire event, steady-state conditions are reached and the thermal shield temperature will be nearly equal to the fire temperature.

This is exactly the type of temperature response exhibited in Figure 3.5-3 and Figure 3.5-8. At the onset of the HAC fire, the temperature of thermal shield (Node 571) quickly rises to approximately 1,200 ºF, and then increases slowly during the remainder of the fire event. This result occurs because a 275 ºF ΔT between the thermal shield and the flame (assuming a flame temperature of 1,475 ºF with an effective emissivity of 0.9) produces approximately the same level of heat transfer as a 1,000 ºF ΔT between the thermal shield and the cask. For example, at the 0.1 hour point in the transient event, illustrated in Figure 3.5-3, the heat transfer to and from the thermal shield on a per-square-foot basis is as follows:

Using Equation 1 above, heat transfer into the thermal shield is:

$$h_c(1{,}475 - 1{,}200) + \sigma F\left((0.9)(1{,}475 + 460)^4 - (1{,}200 + 460)^4\right) = 7{,}576 \text{ Btu/hr - ft}^2$$

where, from the thermal model, $h_c \approx 2.5$ Btu/hr-ft^2-ºF, σ = 1.714(10)$^{-9}$ Btu/hr-ft^2-ºF^4, and F ≈ 0.8.

Using Equation 2 above, heat transfer out of the thermal shield is:

$$\left(\frac{k}{gap}\right)(1{,}200 - 200) + \sigma F\left((1{,}200 + 460)^4 - (200 + 460)^4\right) = 7{,}478 \text{ Btu/hr - ft}^2$$

where, from the thermal model, k/gap ≈ 3.24 Btu/hr-ft^2-ºF, σ = 1.714(10)$^{-9}$ Btu/hr ft^2-ºF^4, and F ≈ 0.334.

As seen from even this rough calculation, the flow of heat into and out of the thermal shield balances to within 100 Btu/hr-ft^2, or to within approximately 1%. Repeating the above calculations for the conditions at the end of the HAC fire (i.e., the thermal shield ≈ 1,230 ºF and the cask ≈ 595 ºF) yields a heat balance within approximately 10%. In both cases, the mismatch in heat flow is attributed to a combination of the energy used to heat up the thermal shield, energy transferred in the axial direction, and the simplicity of 1-D hand calculations versus a 2-D computer model. Further, these calculations are based on the peak temperature data presented in the figures, which do not necessarily occur at the same locations on the cask. In addition, the sensitivity of the thermal shield temperature is such that an increase in the thermal shield temperature by 17 ºF (i.e., from 1,230 ºF to 1,247 ºF) in the 1-D hand calculation would yield an energy match at the end of the HAC fire.

Therefore, the existence of the predicted temperature difference between the thermal shield and the ambient, even at the end of the HAC fire, is credible and demonstrates the advantage of using a thermal shield to protect a cask body from short-term HAC fire events. To achieve higher thermal shield temperatures would require the thermal shield to be thermally disconnected from the underlying cask body (i.e., as in an isolated, thin plate). While this action would raise the thermal shield temperatures closer to the HAC fire temperature, it would also mean lower energy input to the cask and, thus, lower peak cask temperatures.

CHAPTER 4.0 – CONTAINMENT

4-1 Clarify whether the choice of using pre-shipment or maintenance/periodic leakage rate testing means that all containment seal boundaries (in the Inner Vessel and the Outer Cask) are to be tested under the same procedure. Modify the application (Chapters 4 and 7) appropriately.

The application is not clear about the possibility of using pre-shipment leakage rate test criteria for some of the seal ports and maintenance leakage rate test criteria for others.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. As stated in Section 4.1.3.1.2, *Maintenance Leakage Rate Tests*, of the RH-TRU 72-B SAR, these leakage rate tests are performed on the package annually and, additionally, upon repair of an O-ring sealing surface and/or replacement of a containment O-ring seal, a gas sampling port closure bolt, or a backfill port closure bolt (IV only). The maintenance leakage rate tests demonstrate the tested component to be “leaktight”, i.e., 1×10^{-7} reference cubic centimeters per second (ref-cm^3/s), air, or less, per ANSI N14.5-1997.

As stated in Section 4.1.3.1.3, *Preshipment Leakage Rate Test*, of the RH-TRU 72-B SAR, these tests are performed prior to shipment of a loaded package. As further described in Section 7.4.1, *Preshipment Leakage Rate Test*, of the RH-TRU 72-B SAR, this test is essentially a “go/no-go” test conducted at a sensitivity of 1×10^{-3} ref-cm^3/s, air. The preshipment leakage rate tests demonstrate proper assembly prior to shipment, but do not quantitatively measure actual leakage rate; thus, an acceptable configuration of the package is demonstrated upon successfully meeting the acceptance criteria. Should a containment O-ring seal fail and/or damage to a sealing surface or component prevent the system from passing the preshipment leakage rate test, the default procedure is to correct the problem, then perform the appropriate maintenance leakage rate test from Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*, of the RH-TRU 72-B SAR on the replaced and/or repaired component.

At the time of a shipment, each containment seal of the OC (lid seal and gas sampling port seal) and optionally, of the IV (lid seal, gas sampling port seal and backfill port seal), is subjected to either a preshipment, gas pressure rise leakage rate test or a maintenance/periodic leakage rate test. The use of either leakage rate test procedure is acceptable for preshipment containment sealing component verification. Although the intent is to normally utilize the gas pressure rise leakage rate test approach described in Section 7.4.1.3, *Performing the Gas Pressure Rise Leakage Rate Test*, of the RH-TRU 72-B SAR for all containment seals at the time of shipment, the choice of which test to perform on an individual containment seal can vary between OC and IV as well as between the various containment seals on a given OC or IV. Section 4.1.3.1.3, *Preshipment Leakage Rate Test*, Steps 7.1.2.15 and 7.1.2.21 of Section 7.1.2, *Loading the RH-TRU 72-B Package*, Section 7.4.1.4, *Optional Preshipment Leakage Rate Test*, and Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*, of the RH-TRU 72-B SAR have been revised to clarify that at the time of shipment, each containment seal can be tested via either test method. Again, if any containment seal component is repaired or replaced, the maintenance/periodic leakage rate test must be performed on that sealing component.

4-2 Revise the SAR to clarify the discrepancy between the test conditions for Rainier Rubber Butyl Compound RR0405-70 and the stated operating temperatures in the text of Section 4.3, “Containment Requirements for the Hypothetical Accident Conditions.”

Section 4.3 of the SAR states that butyl rubber O-ring testing on a previously approved package “demonstrated that compressions as low as 10% will still result in a ‘leaktight’ seal at both hot (at and above 350ºF) and cold (-40ºF) conditions.” Footnote 3 on the same page states that the test O-rings were “stabilized at -20ºF and shown, via helium leak testing, to be leaktight.” The SAR should show that the O-ring material is capable of providing containment capabilities at the minimum regulatory temperatures (see RAI 3-1).

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This information is necessary to show that the package meets the containment requirements for normal conditions of transport specified in 10 CFR 71.51(a)(1).

Response:

Comment incorporated. Please see the response to RAI 3-1. Specific to the RAI 4-2 question relative to stabilizing and demonstrating leaktight capability at -20 ºF, it is noted that this stabilization took place after the high temperature excursion used to simulate the HAC thermal event. As discussed in the response to RAI 3-1, the applicable post-fire steady state temperature is -20 ºF. Footnote 3 of Section 4.3, *Containment Requirements for the Hypothetical Accident Conditions*, of the RH-TRU 72-B SAR has been revised to add text stating that, preceding the high temperature excursion, the test O-ring seals were first chilled to -40 ºF and shown to be leaktight at 10% compression.

CHAPTER 7.0 – OPERATING PROCEDURES

7-1 Specify and justify which ports shall be used for pre-shipment leakage rate testing for both the Outer Cask and the Inner Vessel. Modify the SAR so that a vent port is clearly identified as being the same as the gas sampling port.

Section 7.4.1.2, step 1, is confusing about the appropriateness of using different ports for the pre-shipment leakage tests, including the fact that the expression "vent port" is rarely used throughout the SAR. The previous version (Revision 3) of the RH-TRU 72-B application seemed to indicate that there were 3 tests to be performed in the Inner Vessel (IV) and 2 tests in the Outer Cask (OC).

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. The OC contains two distinct ports: (1) the seal test port, and (2) the gas sampling port. The IV contains three distinct ports: (1) the seal test port, (2) the gas sampling port, and (3) the backfill port.

The "seal test port" communicates with the space between the two main O-ring seals on the OC, and the space between the upper and middle main O-ring seals on the IV. The "backfill port" communicates with the space between the middle and lower main O-ring seals on the IV, and is used for injecting helium for subsequent helium leakage rate testing of the main containment (middle) O-ring seal. The terms "gas sampling port" and "vent port" refer to identical penetrations through the containment boundary. For consistency, Section 1.2.1.4,

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(Continued)

Receptacles, Valves, Testing and Sampling Ports; Section 7.3.1, *Shipment of the Package as LSA Material*; and Section 7.4.1.2, *Determining the Test Volume and Test Time*, of Appendix 7.4.1, *Preshipment Leakage Rate Test*, of the RH-TRU 72-B SAR have been revised to use the correct term “gas sampling port” (instead of “vent port”) and to clarify references to the other ports.

Leakage rate tests are performed using both ports on the OC. The seal test port is used to test the main seals; the seal test port plug itself, however, is not leakage rate tested because the port is outside the containment boundary. The gas sampling port plug is leakage rate tested because the port penetrates the containment boundary.

Leakage rate tests are performed using all three ports on the IV. The seal test port is used to test the main seals; the seal test port plug itself, however, is not leakage rate tested because the port is outside the containment boundary. Both the gas sampling port plug and backfill port plug are leakage rate tested because these ports penetrate the containment boundary.

The preshipment leakage rate test procedure delineated in Appendix 7.4.1 of the RH-TRU 72-B SAR provides a generic step-by-step process for leakage rate testing each of the aforementioned OC and IV ports. For clarity, Step 1 of Section 7.4.1.2 of Appendix 7.4.1 has been revised to specify the ports to be tested.

7-2 Provide physical and mathematical details about the procedures for Determining the Test Volume and Test Time (Section 7.4.1.2) and Performing the Gas Pressure Rise Leakage Rate Test (Section 7.4.1.3). Explain the temporal and thermal-hydraulics requirements that would characterize a stable system as specified in Steps 6 and 7 of Section 7.4.1.2. Justify the evacuation criteria of 0.76 torr or the sensitivity on the digital readout, whichever is less, specified in Step 5 of Section 7.4.1.2.

The proposed procedure is very different from the one previously approved (Revision 3 of the RH-TRU 72-B application, dated August 2001) and does not resemble anything presented or discussed in the ANSI N14.5-1997 Standard. No detail is given about what characterizes a stable system, how long (time) should pass before the stability is verified, or whether temperature changes are to be observed and accounted for.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

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Response:

Performing a pressure rise preshipment leakage rate test reasonably fast (i.e., less than 10 minutes, ideally) while preventing the test results from indicating a false-positive-failure is difficult, usually due to unacceptably high levels of off-gassing from inter-system contaminants. Thus, a successful leak detector requires ultra-clean piping and components, and stable instrumentation with sufficient sensitivity.

A large amount of leak detector testing has been performed to overcome these difficulties in a practical manner. In general, we found that evacuating the system to 1/1000th of an atmosphere (0.76 torr) was sufficient to flash the volatile materials within most contaminants to vapor where they would be subsequently evacuated from the system. As such, 0.76 torr became a reasonable maximum value for the lower limit. Should a leak detector's pressure transducer have a greater sensitivity and the system's pressure can be further reduced, then the benefit is a reduced test time while still ensuring valid results; hence, the reason for allowing a pressure lower than 0.76 torr in Step 5 of Section 7.4.1.2, *Determining the Test Volume and Test Time,* of the RH-TRU 72-B SAR.

The calculational basis for the preshipment pressure rise leakage rate test is taken from Annex B.12 of ANSI N14.5-1997, with the leakage rate, L_R, as follows:

$$L_R = \frac{VT_s}{3600HP_s}\left(\frac{P_2}{T_2} - \frac{P_1}{T_1}\right) \text{ref-cm}^3\text{/s}$$

where V is the gas test volume (cm^3), T_s is the standard temperature (25 ºC; 298 K), H is the test duration (hours), P_s is the standard pressure (1 atm, absolute; 14.7 psia; 760 torr), P_1 is the pressure (atm, absolute) at test start, T_1 is the temperature (K) at test start, P_2 is the pressure (atm, absolute) at test finish, and T_2 is the temperature (K) at test finish. (Note that 1 ref-cm^3/s is equivalent to 1 cm^3/s at 25 ºC and 1 atm.)

Assume the test temperatures, T_1 and T_2, are equivalent to T_s, and the test duration is short enough that temperature changes are negligible. Also, assuming the test duration, S, is in seconds instead of hours (thereby eliminating "3600" in the denominator), and the allowable leakage rate, L_R, is 1.0×10^{-3} cm^3/s, air, at 1 atm (760 torr), then the above equation becomes:

$$L_R = \frac{V(298\,K)}{S(760\text{ torr})}\left(\frac{P_2}{298\,K} - \frac{P_1}{298\,K}\right) = 1.0 \times 10^{-3}\text{ cm}^3/\text{s}$$

that simplifies to:

$$\frac{V}{S(760\text{ torr})}\left(P_2 - P_1\right) = 1.0 \times 10^{-3}\text{ cm}^3/\text{s}$$

Finally, rearranging the above equation in terms of the test duration, S, results in the following:

$$S = \frac{V}{(760\text{ torr})(1.0 \times 10^{-3}\text{ cm}^3/\text{s})}\left(P_2 - P_1\right) = V(1.32)\Delta P\ \text{ seconds}$$

This is the same equation given in Step 9 of Section 7.4.1.2, *Determining the Test Volume and Test Time*, of Appendix 7.4.1 of the RH-TRU 72-B SAR, where S is the test duration (seconds), V is the test volume (cm^3), and ΔP is the difference between the start and finish test volume pressures (torr).

The determination of the test volume, as given in the equation in Step 8 of Section 7.4.1.2 of Appendix 7.4.1, is made by assuming air at atmospheric pressure is vented into the system to be tested. The "calibrated" volume is then isolated from the system to be tested. The system is evacuated to a pressure of 0.76 torr, or less, and then isolated from the vacuum pump. Opening the isolation valve between the system and the "calibrated" volume (at atmospheric pressure) results in a rise in the system pressure until an equilibrium pressure is achieved. The final pressure can be then used to determine the total volume of the tested system (which, in turn, is used to determine the required test time, S, in the above equation). This process follows the procedure given in Steps 3 through 7 of Section 7.4.1.2 of Appendix 7.4.1.

The derivation of the equation in Step 8 of Section 7.4.1.2 of Appendix 7.4.1 for determining the test volume uses the Ideal Gas Law, as follows:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Assuming the initial and final temperatures are constant (because the duration of testing is short), the above equation becomes:

$$P_1V_1 = P_2V_2$$

From Step 3 of Section 7.4.1.2 of Appendix 7.4.1, P_{atm} is the pressure within calibration volume V_c. From Step 6 of Section 7.4.1.2 of Appendix 7.4.1, P_{test} is the pressure within evacuated test volume, V_t. Finally, from Step 7 of Section 7.4.1.2 of Appendix 7.4.1, when atmospheric pressure air is released into the evacuated test volume, P_{total} is the pressure within both calibration and test volumes, V_c and V_t. Thus,

$$P_{atm}V_c + P_{test}V_t = P_{total}(V_c + V_t)$$

Simplifying the above equations results in the equation given in Step 8 of Section 7.4.1.2 of Appendix 7.4.1:

$$V_t = V_c\left(\frac{P_{atm} - P_{total}}{P_{total} - P_{test}}\right)$$

A "stable" system merely means the pressure reading is taken after sufficient time has passed such that pressure fluctuations from suddenly opening (or closing) valves are minimized when read with a highly sensitive pressure transducer. This definition is subjectively based on the system's physical characteristics.

The application for Revision 4 of the RH-TRU 72-B SAR included revisions from the previously approved Revision 3 to ensure that Appendix 7.4.1, *Preshipment Leakage Rate Test*, of the RH-TRU 72-B SAR is identical to corresponding, currently approved appendices in the TRUPACT-II and HalfPACT SARs.

CHAPTER 8.0 – ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8-1 Clarify whether the Inner Vessel and Outer Casks are hydrostatically tested to 150% of their MNOP values. If this is the case, revise the application so that the hydrostatic tests are performed <u>after</u> the fabrication leakage rate tests ($\leq 1 \times 10^{-7}$ ref-cm^3/s air).

Section A.3.5 of the ANSI N14.5-1997 states that "for leaks smaller than 10^{-6} ref-cm^3/s, wetting of the test item before leakage rate test should be avoided." Some of the leak paths may become clogged by liquid if the hydrostatic test is conducted prior to the leakage rate test.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. Section 8.1, *Acceptance Tests*, of the RH-TRU 72-B SAR specifies fabrication acceptance of the containment boundaries in the following sequence: (1) structural and pressure testing, (2) non-destructive examination of containment vessel welds, and (3) fabrication leakage rate tests. This intentional testing sequence ensures that any micro-cracks that may occur, being too small to be detected by a subsequent visual and/or liquid penetrant examination, are discovered via fabrication leakage rate testing. Should leakage rate testing precede structural or pressure testing, containment integrity could be compromised.

Section 8.1.2.2, *Inner Vessel and Outer Cask Pressure Testing*, of the RH-TRU 72-B SAR is intentionally non-specific, allowing either pneumatic or hydrostatic pressure testing of the containment vessels. As stated in Section 8.1.2.2, both the OC and IV shall be "…pressure tested to 150% of the maximum normal operating pressure (MNOP) to verify structural integrity. The MNOP of the IV and OC is equal to the 150 psig design pressure. Thus, each containment vessel shall be tested to 150 × 1.5 = 225 psig," as required by 10 CFR §71.85(b). The acceptability of hydrostatically testing the containment boundaries prior to fabrication leakage rate testing is discussed in the following paragraphs.

Fabrication leakage rate testing is performed using a helium mass spectrometer leak detector (MSLD) to ensure the containment boundary exhibits a leakage rate not exceeding 1×10^{-7} ref-cm^3/s, air, per the requirements delineated in Chapter 4.0, *Containment*, of the RH-TRU 72-B SAR. When a pressurized envelope method of helium leakage rate testing is performed, the vessel's interior is evacuated into the millitorr (i.e., 10^{-3} torr) range to allow the MSLD to operate. Such a low pressure assures that all free-standing water will be completely flashed to vapor, leaving none in the system to possibly block leakage paths. When an evacuated envelope method of helium leakage rate testing is performed, the vessel's interior is evacuated to a 90% vacuum or better to allow a sufficient concentration of helium inside the vessel for accurate helium leakage rate testing. Also, as found in thermodynamic steam tables, all free-standing water will be completely flashed to vapor at temperatures of 45 ºF or greater, leaving none in the system to possibly block leakage paths.

Annex A.3.5, *Wetting of the Test Item*, of ANSI N14.5-1997 allows for thorough drying of the test item prior to performing testing for leaks smaller than

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10^{-6} ref-cm^3/s. The vacuum pumps incorporated into both methods of helium leak testing used for the fabrication leakage rate testing along with the level of vacuum required for these processes act as a vacuum drying system for the test item.

For completeness, Section 8.1.3.1.1, *Testing the IV Structure Integrity – Evacuated Envelope Method*, of the RH-TRU 72-B SAR has been revised to require fabrication leakage rate testing *at 45 ºF or greater* to ensure all free-standing water is reduced to vapor, thereby eliminating the possibility of clogging a potential leak path.

8-2 Revise the application so that the calibration of the leak detector (as described in steps 8.1.3.0.2 and 8.2.2.0.2) takes into account the whole leak detecting system to be used during the tests.

The length of pipes as well as pipe fittings may affect the outcome of a measuring effort.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

<u>**Response**</u>**:**

Comment incorporated. Sections 8.1.3.0.2 and 8.2.2.0.2 have been revised to require that the guidelines of Section 8.4, *Sensitivity*, and Annex A.5.3.4, *Test Method and Considerations*, of ANSI N14.5-1997 be followed for establishing the system response (dwell time) using a calibrated standard leak.

8-3 Clarify how the 60-seconds flame retardancy test and the 90-seconds intumescence test support the use of the polyurethane foam material as a thermal barrier during the 30-minute regulatory fire.

These acceptance tests seem far removed from the expected behavior of the foam during a 30-minute regulatory fire. Note that during the intumescence test, any remaining flame is to be gently extinguished after the sample is removed from the furnace. This is in disagreement with 10 CFR 71.73(*c*)(4), which explicitly says that "any combustion of materials of construction must be allowed to proceed until it terminates naturally."

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

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(Continued)

Response:

The general chemical composition of the polyurethane foam used in the RH-TRU 72-B impact limiters is the same as that of the foam used in the TRUPACT-II and HalfPACT (e.g., see Sections 8.1.4.1.1.1, *Polyurethane Foam Chemical Composition*, of the RH-TRU 72-B, TRUPACT-II, and HalfPACT SARs). Although nominal density of the RH-TRU 72-B foam (11.5 pcf) is somewhat greater than for the TRUPACT-II and HalfPACT (8.25 pcf), general behavior will be the same. Relative to performance in the HAC, full-scale prototypes of the TRUPACT-II and HalfPACT were extensively tested, specifically including free drop, puncture, and fire testing. Working together, the flame retardancy and intumescent characteristics of the foam were shown to be sufficient to mitigate the effects of the HAC thermal (fire) event on the TRUPACT-II and HalfPACT (i.e., exposed foam continued to burn only briefly [maximum of approximately 1 hour] after cessation of the 30-minute fire and areas of cracked/damaged foam resulting from preceding free drop and puncture tests were seen to “self heal” or intumesce during the fire, thus blocking further erosion of foam in the damaged areas and effectively insulating thermally sensitive package components from the fire). Similar behavior will be exhibited by the foam used in the RH-TRU 72-B package impact limiters.

To ensure that the as-installed foam used in production unit TRUPACT-IIs, HalfPACTs, and RH-TRU 72-Bs will all perform similarly and properly if subjected to HAC thermal events, foam samples taken from each batch of foam used in these packages are tested for both flame retardancy and intumescence. Notably, the tests performed are identical for all three packages (e.g., see Section 8.1.4.1.2.2.1, *Flame Retardancy*, and Section 8.1.4.1.2.2.2, *Intumescence*, of the RH-TRU 72-B, TRUPACT-II, and HalfPACT SARs). The 60-second flame retardancy test discussed therein is based on the Federal Aviation Regulation (FAR) §25.853 Flame Resistance Test, which was selected from available industry standard test methods as being the most reasonable and practical test that could be performed to ensure proper flame retardancy. The 90-second intumescence test was developed by General Plastics Manufacturing Company, a primary supplier of polyurethane foam to the nuclear industry, specifically for use in qualifying foam used in radioactive material shipping packages such as the RH-TRU 72-B and TRUPACT-II. Of note, the intumescence test was originally developed in conjunction with Sandia National Laboratories during their development of the Safe Secure Transporter (SST).

The concern stated in RAI 8-3 with gently extinguishing any remaining flame at the end of the intumescence test being inconsistent with 10 CFR §71.73(c)(4) is addressed by noting the flame retardancy test (Section 8.1.4.1.2.2.1, *Flame*

Retardancy, of the RH-TRU 72-B SAR) is based on natural termination of combustion, whereas the intumescence test addresses the self healing nature of the foam. Both properties are important for proper foam performance. Gently extinguishing the intumescence test sample after the foam has been shown to properly intumesce is considered to be of no significance.

RH-TRU PAYLOAD APPENDICES

APPENDIX 2.5

2.5-1 Clarify the differences between Table 2.5-1 in the RH-TRU Payload Appendices and Table 2.4-1 in the RH-TRAMPAC document. Modify the application appropriately.

The two tables do not address the same confinement layers.

10 CFR 71.7 states that the application must be complete and accurate in all material respects.

Response:

Comment incorporated. The RH-TRAMPAC and the RH-TRU Payload Appendices have been revised so that Table 2.4-1 of Section 2.4, *Filter Vents*, of the RH-TRAMPAC presents only the minimum filter specifications for the RH-TRU canister and Table 2.5-1 of Appendix 2.5, *Compliance Methodology for Gas Generation Requirements*, of the RH-TRU Payload Appendices presents the release rates of hydrogen through common confinement layers used in gas generation calculations (inner confinement layers and RH-TRU canister). Table 2.4-1, *Minimum Filter Vent Specifications*, of Section 2.4.1, *Requirements*, of the RH-TRAMPAC has been revised to delete the filter specifications for the inner containers (i.e., can, liner, and drum), which are duplicated by Table 2.5-1, *Release Rates of Hydrogen through Common Confinement Layers*, of Appendix 2.5 of the RH-TRU Payload Appendices. Section 2.4 of the RH-TRAMPAC has been revised to clarify the content of Table 2.4-1 as RH-TRU canister filters only and to add a reference to Appendix 2.5 of the RH-TRU Payload Appendices for hydrogen release rates for inner containers and other inner confinement layers. Table 2.5-1 of Appendix 2.5 of the RH-TRU Payload Appendices has been revised to add the minimum fixed lid canister release rate of 1.48E-5 mole/sec/mol fraction and a reference to Section 2.4 of the RH-TRAMPAC for this value. Section 2.5.3.1, *Input Parameters*, of Appendix 2.5 of the RH-TRU Payload Appendices has been revised to clarify that Table 2.5-1 presents the release rates for common confinement layers and that release rates of any other inner bags, cans, liners, or drums must be shown to be equivalent to one of the confinement layers listed in Table 2.5-1.

2.5-2 Justify the use of 333K (= 140°F) as an upper bound temperature value for calculating decay heat limits, as proposed in Section 2.5.4. Modify RH-TRAMPAC, if appropriate.

From the Tables 3.4-3 and [*3.4-4*] in the SAR, one can see that average payload temperatures can reach much higher values. One would recommend that, at the end of the iterative process to determine the decay heat limit for a given content code, the assumed content temperature be verified against the resulting decay heat value. There may be situations where the conservatism behind the assumed high temperature value is being violated.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. The 333K temperature value was used given the relatively low decay heat limits expected to be applicable. In response to RAI 2.5-2, the methodology for calculating decay heat limits has been revised as follows:

Based on the values presented in Table 3.4-3 and Table 3.4-4 of the RH-TRU 72-B SAR, the average payload temperatures (T_{ap} in °F) are approximately linear functions of the decay heat (Q in watts). Thus, the average payload temperature will vary for each content code. The relationships are defined by the following linear equations:

Paper Waste
$T_{ap} = 1.08288\ Q + 123.593$

Metallic Waste
$T_{ap} = 0.18123\ Q + 124.436$

The calculation of the decay heat limits for content codes has been revised to be based on performing an iterative process until the applicable relationship is satisfied. Section 2.5.4.1, *Input Parameters*, of Appendix 2.5, *Compliance Methodology for Gas Generation Requirements*, of the RH-TRU Payload Appendices has been revised to add this iterative process. The calculations of the FGGR and decay heat limits for the example Content Code ID 325B in

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Section 2.5.5, *Example Flammable Gas Generation Rate Limit Calculation*, and Section 2.5.6, *Example Decay Heat Limit Calculation*, of Appendix 2.5 show the application of this process and demonstrate that the resulting decay heat limit and corresponding temperature satisfy the applicable relationship.

2.5-3 Revise/clarify the calculations shown in Section 2.5.5 and 2.5.6 to justify the choice of the PVC pouches as the Innermost Confinement Boundary.

As clearly stated in Section 2.7.1 of the RH-TRAMPAC document, sealed containers that are greater than 4 liters are prohibited except for metal containers packaging solid inorganic waste. One would then assume that the metal cans (5-gallon, 7.5-gallon, or 10-gallon) mentioned for content code ID 325B must have some sort of venting and, if so, must be considered as confinement boundaries that are interior to the PVC pouches. The 9700 cm^2 area calculated for the PVC pouch does not include the contribution of either the top or bottom of the assumed cylinder. The FGGR limit per canister value of 9.352 shown in Table 2.5-8 can not be reproduced. The values presented in Table 2.5-10 were derived through the use of the Arrhenius equation (Equation 34) when, in fact, dose-dependent G's for alpha and beta radiations are not temperature-dependent, as stated in Attachment A to Appendix 2.2.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. As correctly noted, sealed containers greater than 4 liters are prohibited. Boundaries that restrict, but do not prohibit, the release of hydrogen gas across the boundary must be considered as confinement boundaries. 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. Section 2.5.3.1, *Input Parameters*, of Appendix 2.5, *Compliance Methodology for Gas Generation Requirements*, of the RH-TRU Payload Appendices has been revised to clarify this definition of "confinement layer." In the Content Code ID 325B example, the metal cans are not considered confinement layers because the lid of each can does not have a gasket and there are holes drilled in the can sides to accommodate the placement of a lifting cable attachment. The absence of a lid closure gasket and the presence of two holes in each can allow for the free release of hydrogen. Section 2.5.5.2, *ID 325B Content Description and Waste Packaging Configuration*, and Section 2.5.7, *Content Code ID 325B*, of

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(Continued)

Appendix 2.5, *Compliance Methodology for Gas Generation Requirements*, of the RH-TRU Payload Appendices have been revised to add text clarifying the description of the metal cans in Content Code ID 325B.

The permeable surface area for either PVC pouch (inner or outer) used in the hydrogen release rate calculation is 9,700 cm^2. This is a conservative (smaller permeable surface area results in lower hydrogen release rate) value assigned to both PVC pouches. As noted in Section 2.5.5.4, *Confinement Layer Flammable Gas Release Rates*, of Appendix 2.5 of the RH-TRU Payload Appendices (page 2.5-19), the 9,700 cm^2 value includes the top and side surface areas of a cylinder having a diameter of 40.6 cm and a height of 66.0 cm (the dimensions of the smaller inner PVC pouch). This value conservatively does not include the area of the bottom of the cylinder.

The FGGR limit per canister value of 9.352 cm^3/hour at STP [0°C and 1 atm] in Table 2.5-8, *Flammable Gas Generation Rate Limits for Content Code ID 325B*, of Appendix 2.5 of the RH-TRU Payload Appendices was incorrectly calculated with an error in the conversion. The conversion error for the FGGR limit per canister has been corrected, and the values in Table 2.5-8 of Appendix 2.5 have been recalculated to use the revised void volume values (see response to RAI 3-4).

Section 2.2.2, *Bounding G Values for Waste Materials*, of Appendix 2.2, *G Values for RH-TRU Waste*, and Section 2.5.6.3, *Effective G Values for Content Code ID 325B*, of Appendix 2.5 of the RH-TRU Payload Appendices have been revised to reflect the fact that the dose-dependent G values for alpha and beta radiations are not temperature dependent, consistent with Attachment A, *Use of Dose-Dependent G Values for RH-TRU Waste*, of Appendix 2.2.

2.5-4 Quantify the degree of conservatism associated with the proposed RADCALC procedure for establishing decay heat limit for a given content code. Clarify the degree of precision with which the isotopic composition is known/estimated. Discuss how variations among drums of the same content code are accounted for when establishing bounding values for isotopic composition. Discuss the appropriateness and conservatism behind the gamma deposition model, specified through a container geometry option and a waste density input value. Discuss and quantify how the input variables uncertainties and the input options affect the overall RADCALC results and how this is taken into consideration in the proposed methodology for determining decay heat limits. Discuss and quantify benchmark efforts that have been conducted to verify the applicability of the RADCALC code for waste scenarios similar to what is being proposed.

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The combined uncertainties (input and options) in the use of RADCALC may adversely play against the conservative assumptions previously described in the methodology for establishing decay heat load limits. The precision of RADCALC calculations must also be accounted for.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Isotopic Composition

The isotopic composition is determined in accordance with the Waste Isolation Pilot Plant (WIPP) Certification Program protocols. The RH-TRU Waste Characterization Program Implementation Plan (WCPIP) (DOE, 2003) specifies the data quality objectives and quality assurance objectives associated with the RH-TRU waste characterization process. For RH-TRU waste, isotopic composition may be determined using a dose-to-curie conversion or radioassay in conjunction with adequate acceptable knowledge (AK) information. "Dose-to-curie" describes the process of deriving the curie content of RH-TRU waste containers based on a dose rate measurement taken with calibrated instrumentation. For each method, the WCPIP specifies quality assurance objectives of precision, accuracy, representativeness, completeness, and comparability. The implementation of each method requires the determination of total measurement uncertainty (TMU), which reflects the cumulative uncertainties associated with the quality assurance objectives and individual components of the selected characterization method [e.g., uncertainties associated with equipment calibrations, assumed isotopic distribution (AK), calculations, and bias]. The method used to calculate the TMU must be documented and technically justified, and compliance with this WIPP Certification Program requirement is evaluated by the U.S. Department of Energy (DOE) Carlsbad Field Office in reviews of the TMU documentation package for each characterization method. As required by Section 5.1.4, *Decay Heat Limits*, of the RH-TRAMPAC, the resulting error (i.e., one standard deviation) is added to the actual decay heat value prior to the evaluation of compliance with the decay heat limit calculated for the content code.

AK compiled on a waste-stream basis forms the foundation for the characterization of an RH-TRU waste stream. AK includes the radiological characteristics of the waste, which may consist of the results of measurements, radionuclide inventory records, safeguards information, modeling studies, and other assessments used to determine the radionuclide characteristics of the waste stream. As described in the WCPIP, the resulting AK Summary Report must address the expected variability in radionuclide concentrations among the containers in the waste stream in order to relate waste stream characteristics to individual containers for reporting and tracking. Because the limits specified for a single content code are based on a given radionuclide composition, all containers assigned to the content code must be represented by the specified radionuclide composition. The development of multiple content codes each with unique radiological properties provides a system for accounting for any variations among containers in a waste stream when establishing bounding values for isotopic composition.

Conservatism behind the Gamma Deposition Model
As specified in the Radcalc User's Manual (DTS, 2005), for hydrogen gas generation calculations, complete (100%) absorption of alpha and beta radiation by the waste is assumed. For gamma radiation, a gamma deposition model is assumed. Gamma absorption curves are models that take gamma-ray energy and waste density as inputs and return an absorption percentage. The models are package specific and are derived from numerous MCNP runs over a range of gamma energies and waste densities.

The gamma deposition/absorption model selected to represent the RH-TRU canister assumes a 6-foot diameter by 6-foot tall cylinder (6x6) with an internal volume of approximately 4,600 liters. The RH-TRU canister has a nominal outside diameter of 26 inches and a nominal overall height of 120.5 inches, with an internal volume between 904 and 942 liters, approximately one fourth the volume of the 6x6 cylinder. As shown in Appendix B of the Radcalc Technical Manual (DFS, 2002), the gamma absorption fraction is proportional to the container volume (higher volume yields higher absorption fraction). The 6x6 cylinder gamma deposition/absorption model is the largest volume and most conservative model available within Radcalc, other than 100% gamma absorption, and will overestimate the gamma absorption that occurs within the RH-TRU canister.

The waste density/void volume values are typically conservatively assigned (overestimating the actual waste density/underestimating the actual void volumes), thereby overestimating the gamma absorption. A list of input parameters to Radcalc for hydrogen gas generation calculation and a description of conservativism follows.

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Input Parameter	Conservativism
Waste density/void volume	Bounding value (based on most dense contents out of inventory)
Selected gamma absorption curve model	Conservatively chosen model with highest gamma absorption fraction
G values	Bounding values from Appendix 2.2 of RH-TRU Payload Appendices
Time period of decay	Bounding value based on latest (most recent) waste generation date
Seal time	Bounding shipping period. 10 or 60 days – dependent on applicable shipping period

Because conservative or bounding values are used, along with conservative gamma absorption curves, the resulting hydrogen gas generation calculations and subsequent decay heat limits will be conservative estimates.

Section 2.5.6.5, *Container and Waste Data*, of Appendix 2.5 of the RH-TRU Payload Appendices has been revised to determine waste density based on the heaviest drum in the inventory without subtracting the weight of the drum itself or the inner containers.

Applicability of Radcalc
The Radcalc program has been specifically designed to automate selected packaging and transportation determinations for shipment of radioactive materials. Radcalc capabilities include the following:

- Classifies radioactive material packages based on selected U.S. Department of Transportation definitions and methodologies outlined in 49 CFR, Subchapter C, “Hazardous Material Regulations”
- Performs classifications and calculations in accordance with selected methods prescribed by the DOE, NRC, U.S. Environmental Protection Agency, and International Conference of Radiological Protection
- Calculates the decay heat and activity of radionuclides and their daughter products at a future date using a radioactive decay algorithm and a decay library of 1,867 isotopes
- Calculates the radiolytic generation of hydrogen gas and the pressurization of the package due to gas accumulation.

Radcalc is a tool intended to assist personnel involved in shipping radioactive materials. (DTS, 2005)

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Only two components of Radcalc are used in support of the transportation of RH-TRU waste in the RH-TRU 72-B – radioactive decay calculations and hydrogen gas generation calculations.

The decay algorithm uses a data library containing 1,867 isotopes, 1,610 of them radioactive. This data library contains half-lives, atomic masses, decay energies, and discrete photons. The library includes complete information for all isotopes listed in 49 CFR Subpart C, including all decay daughters and stable isotope endpoints. Many other isotopes of primarily scientific interest are also included in the database. The Radcalc nuclear database is based on a combination of the Fusion Evaluated Nuclear Data Library (FENDL) (IAEA, 1988) and the Joint Evaluated File (JEF) (OECD, 1993). The Radcalc atomic mass database is based on “The NUBASE Evaluation of Nuclear and Decay Properties” (Audi, *et al.*, 1997).

As indicated above, the hydrogen gas generation calculations are based on an assumed 100% alpha and beta radiation absorption and a conservative gamma absorption model for a cylinder with a volume more than four times larger than the RH-TRU canister.

As indicated in Section 2.4 of the Radcalc User’s Manual (DTS, 2005), Duratek Technical Services (DTS) developed and maintains Radcalc on behalf of the DOE National Transportation Program. All work performed in the development of Radcalc Version 4.0 was under a DOE-approved quality assurance program based on the following:

- 18 Basic Requirements prescribed in 10 CFR 71, “Packaging and Transportation of Radioactive Materials,” Subpart H, “Quality Assurance”
- 10 CFR 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste,” Subpart G, “Quality Assurance”
- 10 Criterion prescribed in 10 CFR 830, “Nuclear Safety Management,” and 830.122, “Quality assurance criteria”
- DOE Order 414.1A, Quality Assurance (DOE, 1999)
- 18 Basic and Supplementary Requirements of American Society of Mechanical Engineers (ASME) NQA-1-1994, Quality Assurance Requirements for Nuclear Facility Applications, Part II, “Basic and Supplementary Requirements,” Subpart 2.7, “Quality Assurance Requirements for Computer Software for Nuclear Facility Applications” (ASME, 1994)

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Radcalc performs all calculations in Institute of Electrical and Electronics Engineers standard, 8-byte double precision, which roughly correlates to 15 significant digits. Radcalc does not round the results of calculations at any point.

In order to ensure the use of the most current version of the Radcalc software, the references to the Radcalc User's Manual, Technical Manual, and Database Manual in Section 5.1.4, *Decay Heat Limits*, of the RH-TRAMPAC and in Appendix 2.5, *Compliance Methodology for Gas Generation Requirements*, of the RH-TRU Payload Appendices have been revised to refer to the "current version" of the documents.

References for Response to RAI 2.5-4:

American Society of Mechanical Engineers (ASME), 1994, "Quality Assurance Program Requirements for Nuclear Facilities," American Society of Mechanical Engineers, New York, New York.

Audi, G, O. Bersillon, J. Blachot, A.H. Wapstra, 1997, "The NUBASE Evaluation of Nuclear and Decay Properties," *Nuclear Physics A*, Vol. 624, pp. 1-124.

Duratek Technical Services (DTS), 2005, "Radcalc Volume 1: User's Manual," DTS-SQA-009.1, Rev. 0, Duratek Technical Services, Richland, Washington (http://www.radcalc.energy.gov).

Duratek Federal Services (DFS), 2002, "Radcalc 3.0 Volume II: Technical Manual," DFSNW-RPT-042, Rev. 0, Duratek Federal Services, Northwest Operations, Richland, Washington (http://www.radcalc.energy.gov).

International Atomic Energy Agency, (IAEA), 1988, "Fusion Evaluated Nuclear Data Library (FENDL)," Version 2.0, Nuclear Data Services, International Atomic Energy Agency, Vienna, Austria.

Organization for Economic Cooperation and Development (OECD), 1993, "Joint Evaluated File (JEF)," Version 2.2, Nuclear Energy Agency, Organization for Economic Cooperation and Development.

U.S. Department of Energy (DOE), 2003, "Remote-Handled TRU Waste Characterization Program Implementation Plan," Revision 0D, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

U.S. Department of Energy (DOE), 1999, Order 414.1A, "Quality Assurance," U.S. Department of Energy, Washington, D.C.

2.5-5 Discuss the possibility of different content code drums being stored together, prior to shipping, or being loaded into the RH-TRU 72-B cask. Clarify whether RADCALC can correctly handle a heterogeneous loading. Discuss the reason for not accounting for gas generation due to the interaction between gamma radiation and the materials used for pouches and liners. Provide a conservative approach and modify RH-TRAMPAC, if appropriate.

The calculations that were presented rely on the drums being of the same code content, prior to and during transportation. The determination of steady-state flammable gas concentrations is based on the homogeneous loading assumption. The mixing of different code content drums is not as straight forward since, due to the gamma-radiation, there is the possibility of inducing gas generation in the neighboring drums. For example, a high-radiation but non-hydrogen-bearing waste drum could induce hydrogen gas in a low-radiation but high-hydrogen-bearing waste drum right next to it. Without the knowledge of this "spatial" effect, one could erroneously conclude that the second drum was OK for shipping.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

<u>Response</u>:

It is possible for different content code drums to be stored together at a generator/shipping site prior to being prepared from shipment. However, any impacts of potential associated gas generation are mitigated as follows:

- The contribution of gamma radiation to total decay heat is typically expected to be relatively small (less than 20% of the total decay heat is from gamma radiation) (Khericha, *et al.*, 2003). An even smaller percentage actually causes hydrogen gas generation due to the higher energy of the gamma radiation that tends to pass through the lower density organic waste forms without generating hydrogen.

- Because the volume of the 6x6 cylinder selected to represent the RH-TRU canister in Radcalc is much larger than the RH-TRU canister, the estimate of gas generation during shipping is extremely conservative. This provides an allowance for any potential gas generation impacts from storing containers of different content codes together.

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- In decay heat calculations, the G values used are associated with the bounding materials in the waste. In reality, some of the energy would be absorbed by waste materials with no or low gas generation potential.

The only allowable method for different content code drums to be loaded into the same RH-TRU canister is through the "limited mixing" scenario described in Section 6.2.1, *Procedure for Certification of Individual RH-TRU Canisters*, of the RH-TRAMPAC. Only one canister is shipped per RH-TRU 72-B, and no other mixing methodologies are allowed. As stated in Section 6.2.1 of the RH-TRAMPAC, under the limited mixing scenario:

> "Inner containers of different waste types with different bounding G values and resistances may be packaged together in an RH-TRU canister provided the decay heat limit and FGGR limit for all inner containers are conservatively assumed to be the same as that of the inner container with the lowest decay heat limit and FGGR limit specified by the applicable content code. The RH-TRU canister shall be assigned the content code with the most restrictive limits."

Any mixing of inner containers within the canister requires that all inner containers are assigned the most conservative FGGR and decay heat limits. Under these constraints, all containers within the canister are limited by the decay heat limit and FGGR limit of the container belonging to the content code with the most restrictive limits. The decay heat limit and FGGR limit for the RH-TRU canister are based on the inner container with the most restrictive limits. For example, for an RH-TRU canister packaging three 55-gallon drums, the canister decay heat and FGGR limits are three times the decay heat and FGGR limits for the drum belonging to the content code with the most restrictive limits. If an inner container with a lower gas generation potential is mixed with containers with higher gas generation potentials meeting the limits, the total gas generation potential within the RH-TRU canister will be less than the canister limit due to the reduced potential of the one container. Radcalc is not being used to model heterogeneous loading. The only mixing methodology allowed is the "limited mixing" scenario described in Section 6.2.1, *Procedure for Certification of Individual RH-TRU Canisters*, of the RH-TRAMPAC. The response to RAI 2.5-6 discusses the interaction between gamma radiation and the packaging materials.

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References for Response to RAI 2.5-5:

Khericha, S.T., R.N. Bhatt, and K.J. Liekhus, 2003, "Methodology to Predict Hydrogen Concentration in RH-TRU Waste Drums," INEEL/EXT-02-01250, Idaho National Engineering and Environmental Laboratory, Bechtel BWXT Idaho LLC, Idaho Falls, Idaho

2.5-6 Discuss the reason for not accounting for gas generation due to the interaction between gamma radiation and the materials used for pouches and liners for a given content code waste. Clarify whether there were material restrictions (i.e., low G values for liner materials) when the waste was being generated. Provide a conservative approach and modify RH-TRAMPAC, if appropriate.

Gamma radiation will not be fully deposited within the waste itself. The radiation that escapes will interact with the surrounding material, including hydrogen-bearing components such as PVC pouches, or fiber liners. The calculations that were presented rely on the gas being generated within the waste matter only.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

The use of bounding G values accounts for any gas generation from the irradiation of the packaging materials such as PVC pouches and liners. For example, if inorganic material is packaged in a plastic pouch, potential gas generation from irradiation of the plastic is used as the G value. The bounding G value is based on the assumption that both the waste and packaging materials (i.e., PVC pouches and fiber liners) have the bounding hydrogen G value. In addition, the flammable gas generation rate limit is determined by assuming all generation is occurring within the innermost confinement layer. This is a bounding assumption, as the generated gas must be transported across the most layers of resistance.

APPENDIX 3.1

3.1-1 Provide a reference for Equation 4 in Section 3.1.4 and discuss its proper statistical applicability. Clarify the terms in this equation. Specify a minimum value for N (true population size) below which the proposed sampling technique is not applicable. Explain how n_0 is specified/determined, based on a non-infinite population. Clarify how any bias in the container selection will be avoided.

Sampling techniques are in general not applicable to small populations, unless a larger margin of error is applied. Known or unknown variances in the process of generating waste containers, even if belonging to the same content code, may also invalidate the proposed statistical approach. Depending on the waste stream process and the period of time the containers were generated (months, years), it is possible for progressive modifications to have taken place.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. Attachment B-2 provides a reference for and a detailed discussion of the statistical applicability of Equation 4 and clarifies the equation terms, including a minimum value for N and how n_0 is determined for a non-infinite population. Section 3.1.4, *Analytical Requirements for Test Methods*, of Appendix 3.1, *Gas Generation Test Plan for Remote-Handled Transuranic (RH-TRU) Waste Containers*, of the RH-TRU Payload Appendices has been revised to clarify the definition of the terms and the applicability of Equation 4 and to cite the reference provided in Attachment B-2 as the source of Equation 4. Section 3.1.4 of Appendix 3.1 of the RH-TRU Payload Appendices also has been revised to add text that requires the equation results to be used with the Bootstrap (Resampling) technique.

As required by Section 3.1.4 of Appendix 3.1 of the RH-TRU Payload Appendices, the containers selected for evaluation must be representative of the population with techniques such as random or stratified sampling used to avoid bias in container selection. This requires the container selection to be indiscriminate in terms of any differences in the waste properties that relate to gas generation, without any inherent bias. As correctly noted by RAI 3.1-1, not all containers assigned to a single content code may have consistent gas generation properties. Therefore, Section 3.1.4 of Appendix 3.1 of the RH-TRU Payload Appendices has been revised to clarify that a site must document the basis for defining a population of containers with consistent gas generation properties. For example, containers identified by process knowledge or other characterization to have consistent gas generation properties may be grouped into one population. The justification for grouping necessarily includes the examination of waste generation activities and packaging dates to ensure consistency of the processes over the applicable time period. If modifications have taken place over time in the generation of containers assigned to a single content code, all containers cannot be grouped into one population and must instead be grouped into multiple subpopulations each with consistent gas generation properties.

APPENDIX 4.6

4.6-1 Revise the text in Section 4.6.4, so that the proper Table in the SAR is identified. Clarify whether the 164 watts limit is being derived from the paper waste Table 3.4-3 or the metallic waste Table 3.4-4. Justify the use of average payload temperatures to support the proposed decay heat limit.

The referenced Table 3.4.4-1 does not exist. Two hypothetical and bounding content codes are addressed in Section 3.4: NewMet (inorganic waste) and NewPaper (organic waste). As a result of Inner Vessel pressure limitations, the decay heat load limit for the organic waste is established as 23.5 watts. This value is far more limiting than the proposed 164 watts.

10 CFR 71.33 states that the application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package.

Response:

Comment incorporated. Section 4.6.4, *Conclusions*, of Appendix 4.6, *Thermal Stability of Payload Materials at Transport Temperatures*, of the RH-TRU Payload Appendices has been revised to correct the references to the tables and sections of the RH-TRU 72-B SAR. The 164-watt value was extrapolated from Figure 3.4-1 of the RH-TRU 72-B SAR for paper waste (corresponding to a temperature of 302ºF [150ºC]). However, as paper waste is further restricted to the 50-watt limit based on the thermal analysis described in Section 3.4.4, *Maximum Internal Pressure*, of the RH-TRU 72-B SAR, the text in Section 4.6.4 of Appendix 4.6 of the RH-TRU Payload Appendices has been simplified to compare temperatures rather than extrapolated wattages. Section 4.6.4 of Appendix 4.6 of the RH-TRU Payload Appendices has been revised to clarify the discussion on the thermal stability of payload materials at expected temperatures for normal conditions of transport and the negligible impact thermal degradation has on gas generation and pressure increase within the RH-TRU 72-B.

The revised (see response to RAI 3-4) theoretical analysis presented in Section 3.4.4.3, *Maximum Pressure for Normal Conditions of Transport*, of the RH-TRU 72-B SAR shows that all organic payloads less than or equal to 21.70 watts will comply with the design pressure limit. Also see responses to RAI 3-5 and RAI TP5-1, which show that organic waste exceeding 21.70 watts will comply with the design pressure limit if the applicable hydrogen gas generation rate limit is met.

RH-TRAMPAC (TP)

TP3-1 Revise Chapter 3.0 of the RH-TRAMPAC, "Nuclear Properties Requirements," to justify adding only one standard deviation to the measured values when determining ^{239}Pu FGE and ^{235}U FEM, and subtracting only one standard deviation from the measured value when determining ^{240}Pu content. Alternatively, revise Chapter 3.0 of the RH-TRAMPAC to require two times the measurement error to be considered.

Chapter 3.0 of the previously approved CH-TRAMPAC requires the addition of two times the measurement error when determining ^{239}Pu FGE, and the subtraction of two times the measurement error when determining ^{240}Pu content. The RH-TRAMPAC should either be consistent with the CH-TRAMPAC requirements, or discuss why a less conservative determination of nuclear properties is appropriate for the RH-TRU 72-B.

This information is needed to ensure that the applicant has identified the specific contents of the package according to §71.33(b).

Response:

Comment incorporated. Consistent with Section 3.1.1, *Requirements*, of the CH-TRAMPAC, Section 6.2.1, *Procedure for Certification of Individual RH-TRU Canisters*, and Table 6.2-1, *Payload Transportation Certification Document (PTCD)*, of the RH-TRAMPAC have been revised to require two times the error to be considered in the evaluation of compliance with ^{239}Pu FGE and ^{235}U FEM limits and in the determination of ^{240}Pu content.

In addition, Section 6.2.1 and Table 6.2-1 of the RH-TRAMPAC have been revised to correct the text describing the sum of partial fractions calculation required to demonstrate compliance with the HAC radiation dose rate limits. The revised text is consistent with the accurate description provided in Section 3.2, *Radiation Dose Rates*, of the RH-TRAMPAC.

TP5-1 Clarify the 7.02×10^{-7} g-mol/sec FGGR value mentioned in the second paragraph of Section 5.3

This value cannot be found in Appendix 2.5 of the RH-TRU Payload Appendices, as stated.

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10 CFR 71.7 states that the application must be complete and accurate in all material respects.

Response:

Comment incorporated. The FGGR value mentioned in Section 5.3, *Pressure Limit*, of the RH-TRAMPAC is for a purely hypothetical content code that maximizes the FGGR limit. Section 5.3 of the RH-TRAMPAC has been revised to use the revised void volumes (see response to RAI 3-4) and to show a simple derivation of a maximum hypothetical FGGR limit, which replaces the previous 7.02×10^{-7} g-mol/sec FGGR value. This example uses a content code with no internal barriers and with the entire IV volume available (as determined in Attachment B-1). Section 5.3 of the RH-TRAMPAC has also been revised to clarify that the logic by which compliance with the FGGR limit ensures compliance with the total gas generation rate limit is applicable to solidified inorganic, solid inorganic, and solid organic RH-TRU content codes. Solidified organic waste, for which this logic is not applicable, is not expected in RH-TRU waste.

OTHER CHANGES

The following changes have also been made to correct minor editorial and typographical errors:

- Table 5.1-1, *Summary of HAC Activity Limits*, of the RH-TRU 72-B SAR has been revised to correct pagination issues that caused the presentation of individual radionuclide limits to be out of order. The revised table orders the presentation of radionuclides alphabetically and of isotopes by atomic number.

- Section 4.3.1, *Requirements*, of the RH-TRAMPAC has been revised to clarify that the 5% (weight) restriction on the total quantity of trace chemicals/materials applies to those constituents in the waste that are not listed in Table 4.3-1, *Table of Allowable Materials for RH-TRU Waste*, of Section 4.3, *Chemical Composition*, of the RH-TRAMPAC.

ATTACHMENT B-1

Mathematical Justification for Revised RH-TRU 72-B IV and RH-TRU Canister Void Volumes

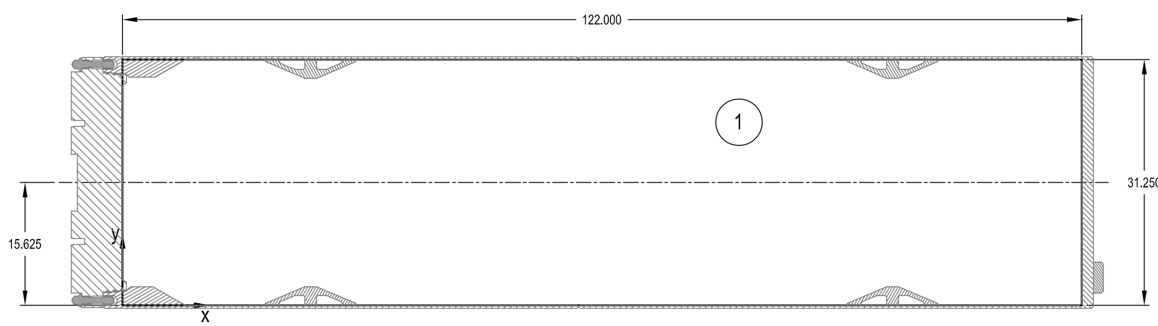
Abstract:

This calculation package determines the internal volume of the RH-TRU 72-B Inner Vessel, the external and internal volume of the RH Payload Canister (both fixed and removable lid designs), the Inner Vessel void volume when equipped with both the fixed lid and removable lid RH Payload Canister, and the RH Payload Canister void volume when equipped with three 55-gallon drums. Due to RH Payload Canister design options and possible use of the fixed or removable lid RH Payload Canister in the RH-TRU 72-B Inner Vessel, a single bounding set of void volume values are determined as follows:

Void Volume in Inner Vessel with Canister = 450 L
Void Volume in Canister with 3, 55-gal drums = 240 L

RH-TRU 72-B Inner Vessel Void Volume Calculations:

The internal volume of the Inner Vessel is calculated by subtracting the volume of geometric features which protrude into the bounding evelope volume of the vessel. The volumes of revolution are calculated by integrating the differential volume of revolution utilizing the method of discs and/or washers. The following provides the envelope geometry of the vessel and the interior protruding geometric features which are evaluated individually to determine the net resulting interior volume of the Inner Vessel.



$a := 0$

$b := 122.000$

$R := 15.625$

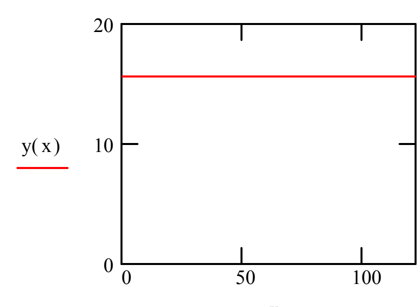
$y(x) := 15.625$

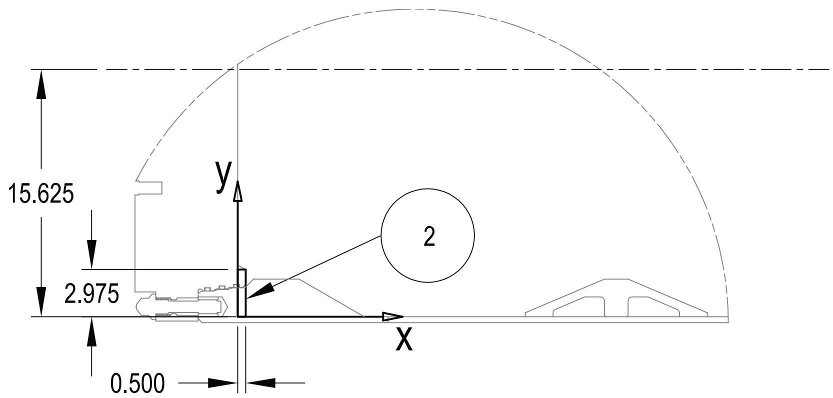
$r(x) := R - y(x)$

$$V_1 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_1 = 9.357 \cdot 10^4$

$x .. a, b$





$a := 0$

$b := 0.500$

$R := 15.625$

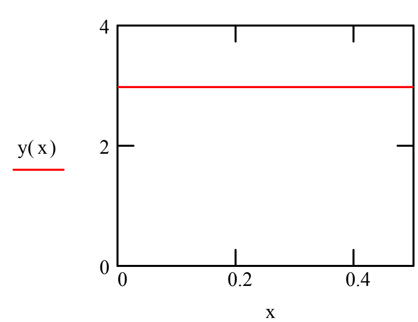
$y(x) := 2.975$

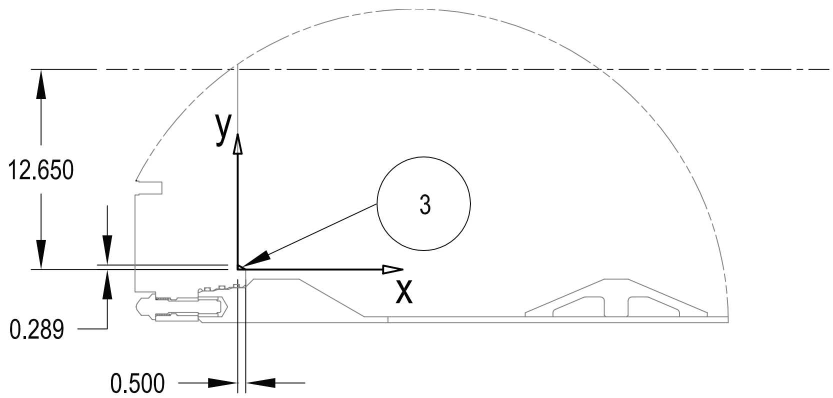
$r(x) := R - y(x)$

$$V_2 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_2 = 132.132$

$x .. a, b$





$a := 0$

$b := 0.500$

$R := 12.650$

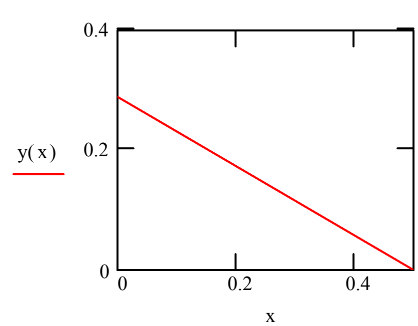
$$y(x) := \frac{-0.289}{b} \cdot x + 0.289$$

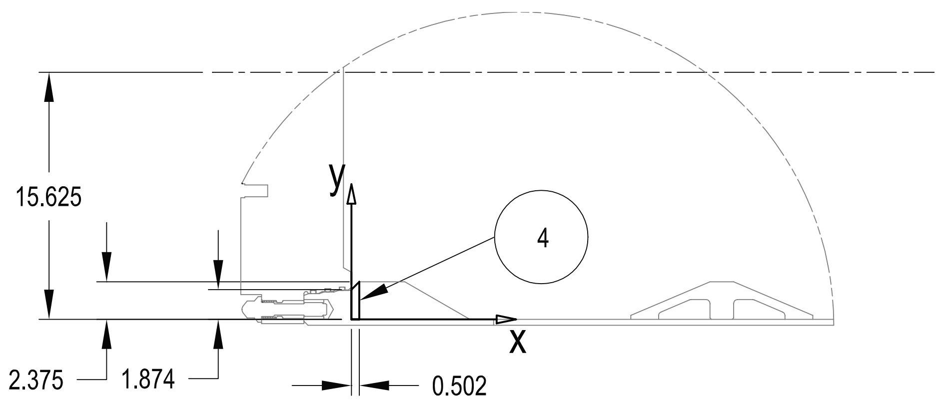
$$r(x) := R - y(x)$$

$$V_3 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$$V_3 = 5.699$$

$x .. a, b$





$a := 0$

$b := 0.502$

$R := 15.625$

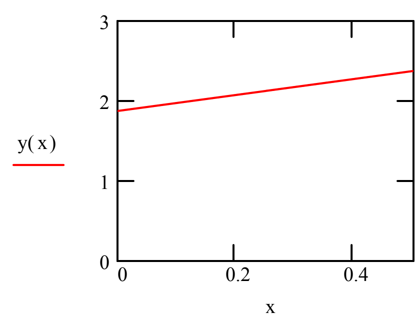
$$y(x) := \frac{(2.375 - 1.874)}{b} \cdot x + 1.874$$

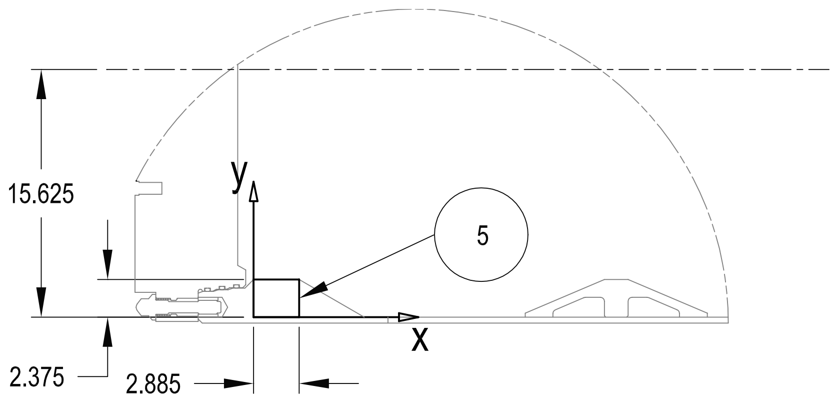
$$r(x) := R - y(x)$$

$$V_4 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_4 = 97.552$

$x .. a, b$





$a := 0$

$b := 2.885$

$R := 15.625$

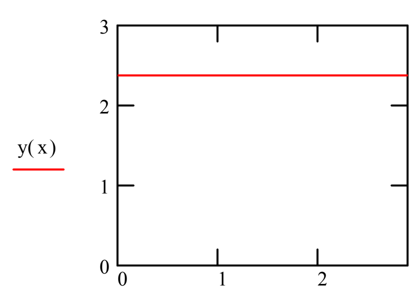
$y(x) := 2.375$

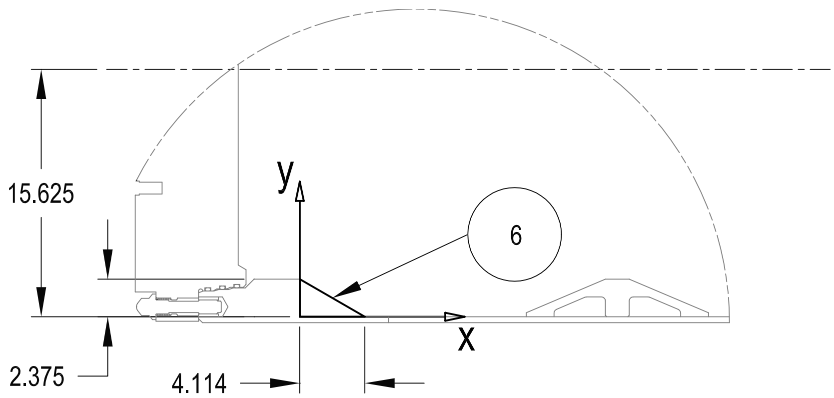
$r(x) := R - y(x)$

$$V_5 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_5 = 621.557$

$x .. a, b$





$a := 0$

$b := 4.114$

$R := 15.625$

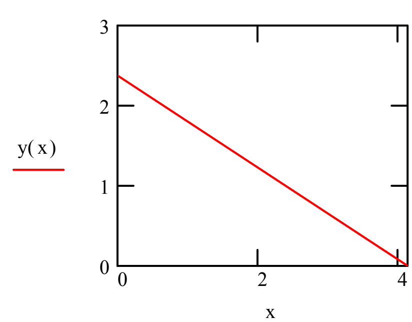
$y(x) := \frac{-2.375}{b} \cdot x + 2.375$

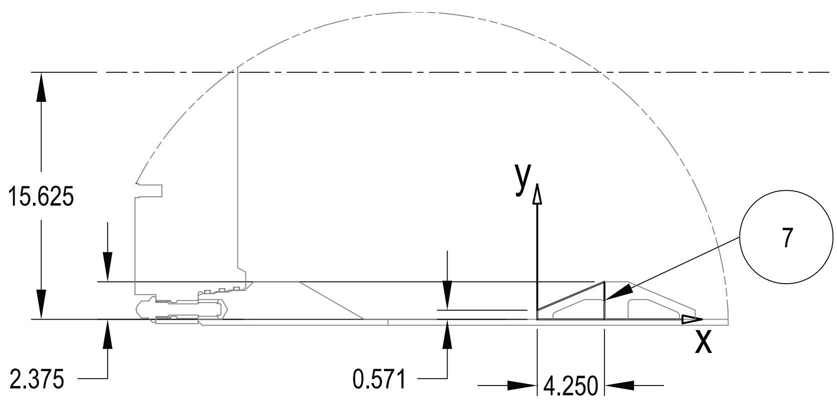
$r(x) := R - y(x)$

$$V_6 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_6 = 455.32$

$x .. a, b$





$a := 0$

$b := 4.250$

$R := 15.625$

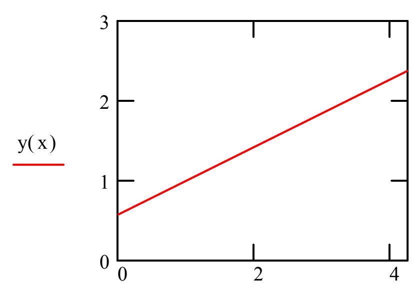
$$y(x) := \frac{(2.375 - 0.571)}{b} \cdot x + 0.571$$

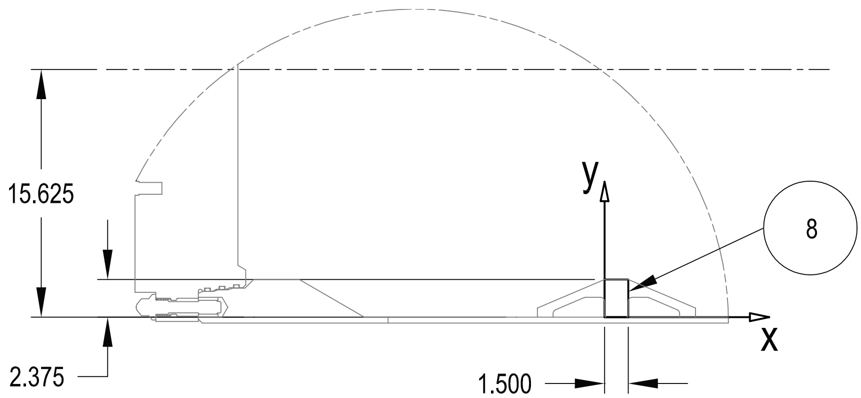
$r(x) := R - y(x)$

$$V_7 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_7 = 582.008$

$x .. a, b$





$a := 0$

$b := 1.500$

$R := 15.625$

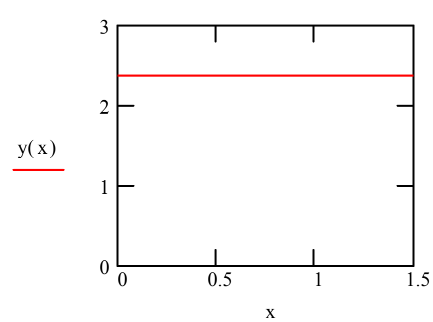
$y(x) := 2.375$

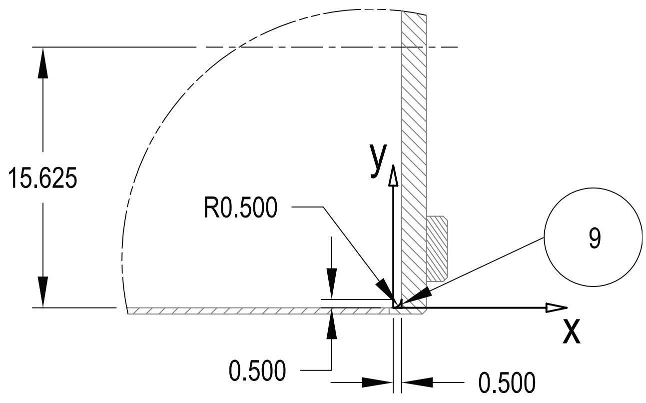
$r(x) := R - y(x)$

$$V_8 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_8 = 323.167$

$x .. a, b$





$a := 0$

$b := 0.500$

$R := 15.625$

$RR := 0.500$

$h := 0.000$

$k := 0.500$

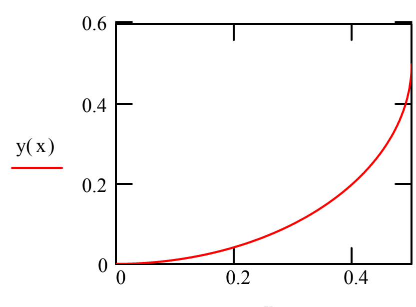
$$y(x) := k - \left(-x^2 + 2 \cdot x \cdot h - h^2 + RR^2\right)^{\left(\frac{1}{2}\right)}$$

$$r(x) := R - y(x)$$

$$V_9 := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_9 = 5.229$

$x .. a, b$



With the optional use of angle iron guide rails between the upper flange and the lower canister locating ring, the internal volume of the Inner Vessel is as follows:

$$V_{guiderail} := (2.5 \cdot in \cdot 0.25 \cdot in + 2.00 \cdot in \cdot 0.25 \cdot in) \cdot 93 \cdot in$$

$$V_{guiderail} = 1.714 \, L$$

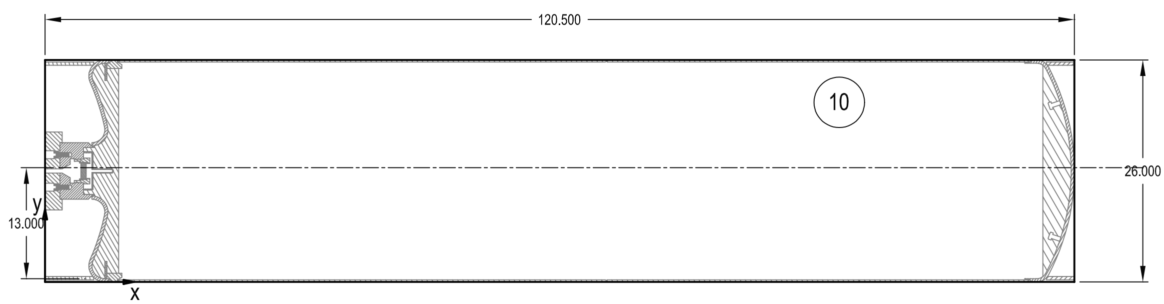
$$V_{IV} := \left(V_1 - V_2 - V_3 - V_4 - V_5 - V_6 - 4 \cdot V_7 - 2 \cdot V_8 - V_9\right) \cdot in^3 - 2 \cdot V_{guiderail}$$

$$V_{IV} = 1.460 \cdot 10^3 \, L$$

RH-TRU 72-B Payload Canister External Volume Calculations:

The external volume of the RH payload canister is determined by subtracting from the bounding envelope volume of the canister the volume of void space provided by the lack of geometric features internal to the bounding envelope. The volumes of revolution are calculated by integrating the differential volume of revolution utilizing the method of discs and/or washers. The following provides the envelope geometry of the canister and the geometry of void space internal to the envelope volume which are evaluated individually to determine the net resulting external volume of the payload canister.

Fixed Lid Canister with Reverse-Dished Lid and Torispherical Bottom



$a := 0$

$b := 120.500$

$R := 13.000$

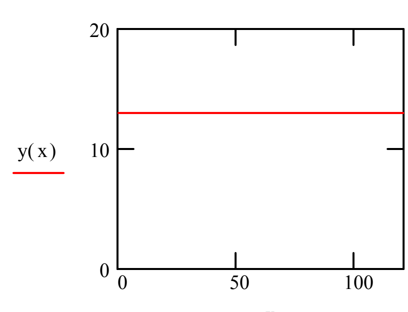
$y(x) := 13.000$

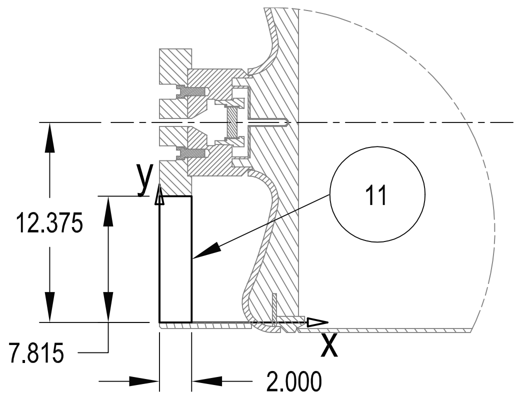
$r(x) := R - y(x)$

$$V_{10} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$$V_{10} = 6.398 \cdot 10^4$$

$x .. a, b$





$a := 0$

$b := 2.000$

$R := 12.375$

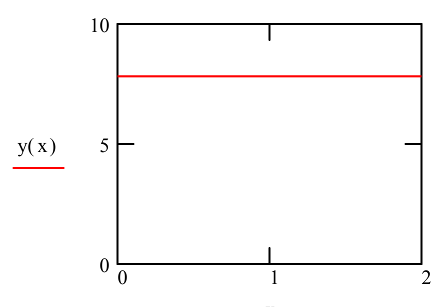
$y(x) := 7.815$

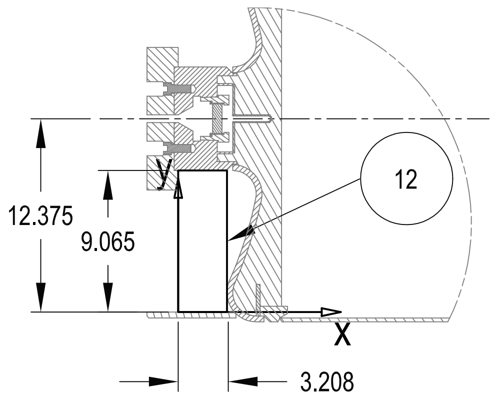
$r(x) := R - y(x)$

$$V_{11} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{11} = 831.561$

$x .. a, b$





$a := 0$

$b := 3.208$

$R := 12.375$

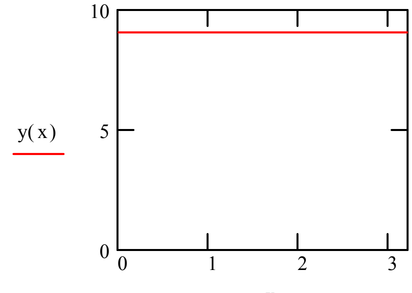
$y(x) := 9.065$

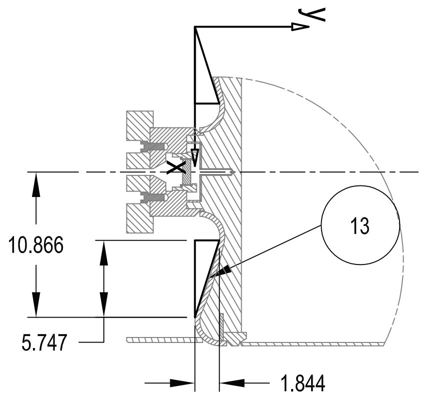
$r(x) := R - y(x)$

$$V_{12} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{12} = 1.433 \cdot 10^3$

$x .. a, b$





$a := 0$

$b := 5.747$

$R := 10.866$

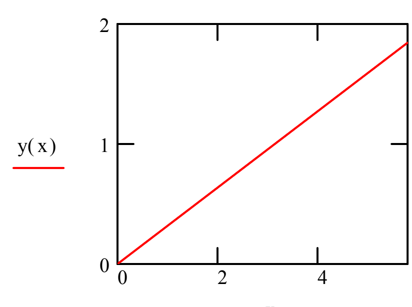
$y(x) := \frac{1.844}{b} \cdot x$

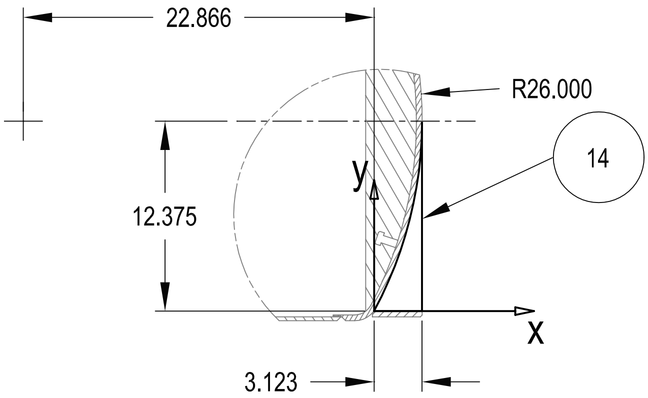
$r(x) := R - x$

$$V_{13} := \int_a^b 2\,\pi \cdot (r(x) \cdot y(x))\,dx$$

$V_{13} = 234.205$

$x .. a, b$





$a := 0$

$b := 3.123$

$R := 12.375$

$RR := 26.000$

$h := -22.866$

$k := 12.375$

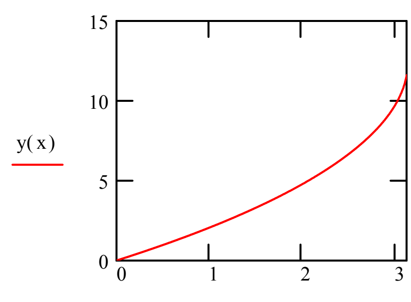
$$y(x) := k - \left(-x^2 + 2 \cdot x \cdot h - h^2 + RR^2\right)^{\left(\frac{1}{2}\right)}$$

$$r(x) := R - y(x)$$

$$V_{14} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$$V_{14} = 732.466$$

x .. a, b



Therefore, the external volume of the Fixed Lid Canister (with reverse-dished head and torispherical bottom) and the void volume inside of the Inner Vessel when loaded with a Fixed Lid Canister are as follows:

$$V_{FLC\_external} := (V_{10} - V_{11} - V_{12} - V_{13} - V_{14}) \cdot in^3$$

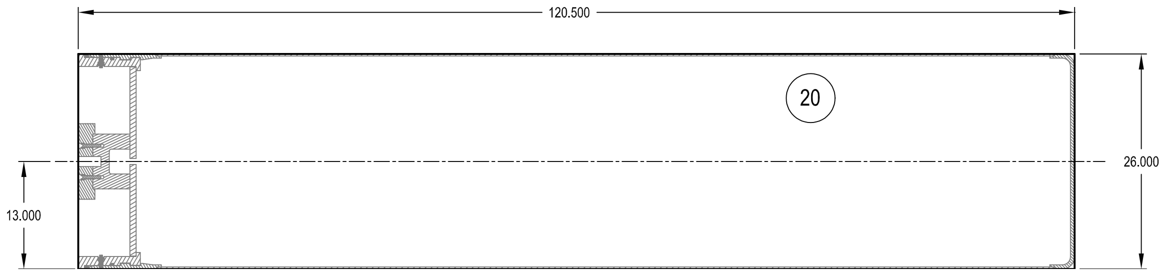
$$V_{FLC\_external} = 995.445 \cdot L$$

$$V_{IVFLC\_void} := V_{IV} - V_{FLC\_external}$$

$$V_{IVFLC\_void} = 464.179 \cdot L$$

Note that the external volume of the Fixed Lid Canister with a flat lid plate and flat bottom head option would be greater than that with the reverse dished and torispherical head option (i.e., is non-conservative from a IV void volume calculational perspective). The flat lid plate and flat head options for the Fixed Lid Canister closely approximate and are bounded by the Removable Lid Canister external volume calculations provided below.

Removable Lid Canister



$a := 0$

$b := 120.500$

$R := 13.000$

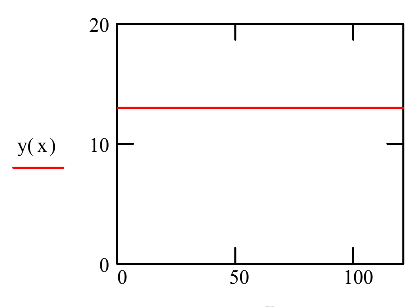
$y(x) := 13.000$

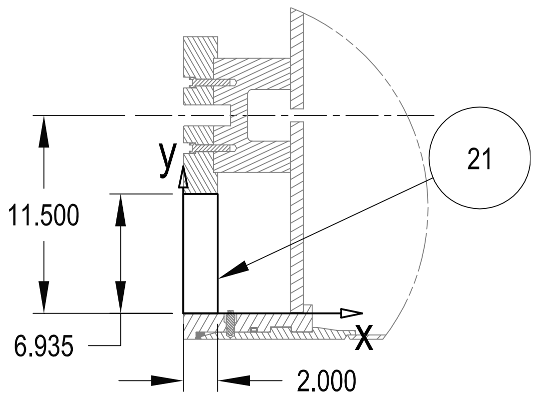
$r(x) := R - y(x)$

$$V_{20} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{20} = 6.398 \cdot 10^4$

$x .. a, b$





$a := 0$

$b := 2.000$

$R := 11.500$

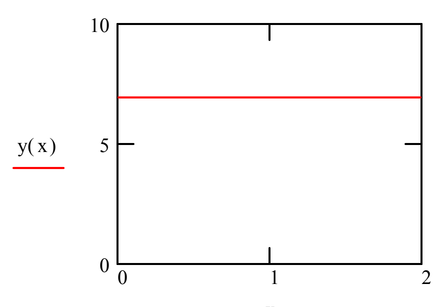
$y(x) := 6.935$

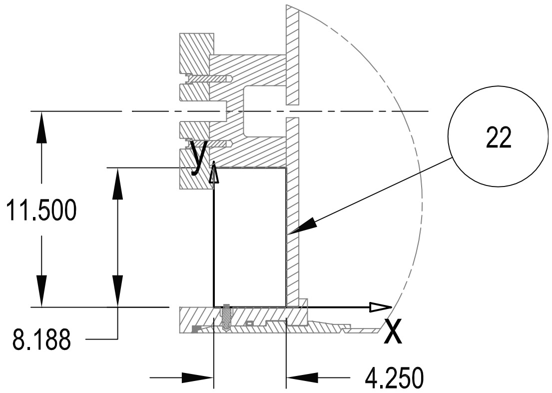
$r(x) := R - y(x)$

$$V_{21} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{21} = 700.015$

$x .. a, b$





$a := 0$

$b := 4.250$

$R := 11.500$

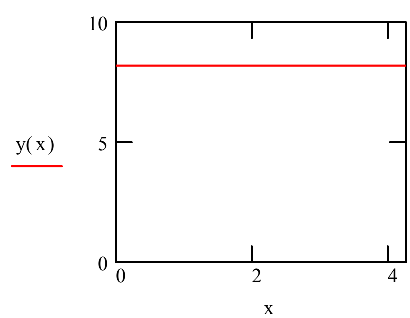
$y(x) := 8.188$

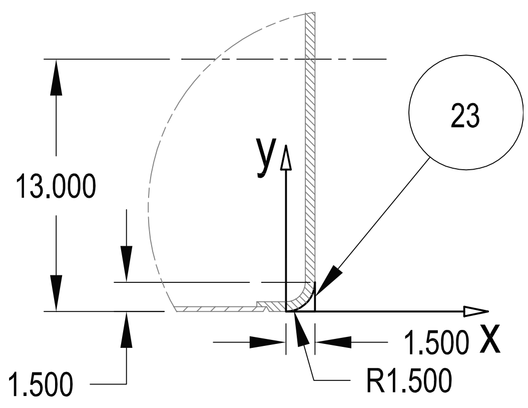
$r(x) := R - y(x)$

$$V_{22} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$$V_{22} = 1.619 \cdot 10^3$$

$x .. a, b$





$a := 0$

$b := 1.500$

$R := 13.000$

$RR := 1.500$

$h := 0.000$

$k := 1.500$

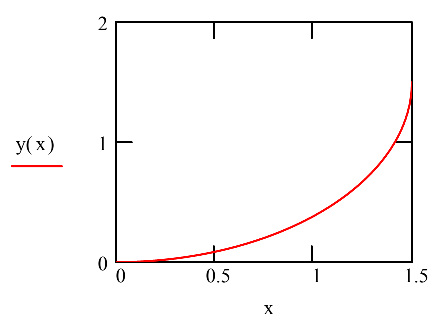
$$y(x) := k - \left(-x^2 + 2 \cdot x \cdot h - h^2 + RR^2\right)^{\left(\frac{1}{2}\right)}$$

$$r(x) := R - y(x)$$

$$V_{23} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$$V_{23} = 38.424$$

$x .. a, b$



Therefore, the external volume of the Removable Lid Canister and the void volume inside of the Inner Vessel when loaded with a Removable Lid Canister are as follows:

$$V_{RLC\_external} := \left(V_{20} - V_{21} - V_{22} - V_{23}\right) \cdot in^3$$

$$V_{RLC\_external} = 1.010 \cdot 10^3 \circ L$$

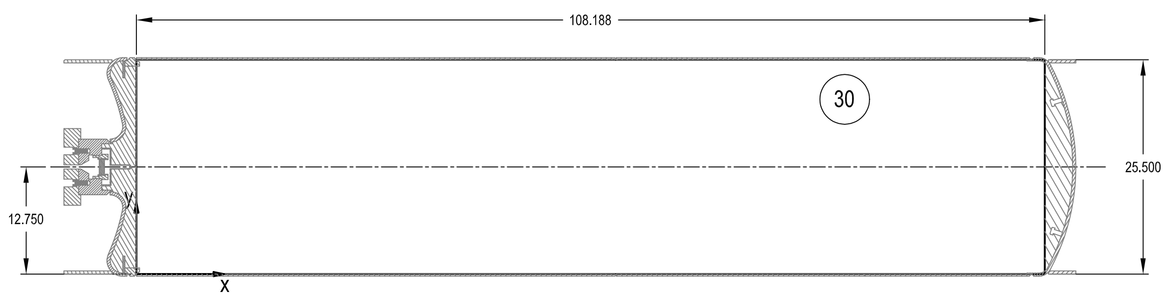
$$V_{IVRLC\_void} := V_{IV} - V_{RLC\_external}$$

$$V_{IVRLC\_void} = 449.866 \circ L$$

<u>RH-TRU 72-B Payload Canister Internal Volume Calculations</u>:

The internal volume of the Payload Canister is calculated by subtracting the volume of geometric features which protrude into the bounding evelope volume of the vessel. The volumes of revolution are calculated by integrating the differential volume of revolution utilizing the method of discs and/or washers. The following provides the envelope geometry of the payload canister and the interior protruding geometric features which are evaluated individually to determine the net resulting interior volume of the Payload Canister.

Fixed Lid Canister with Reverse-Dished Lid and Torispherical Bottom and Optional Bottom Shield Plug Installed



$a := 0$

$b := 108.188$

$R := 12.750$

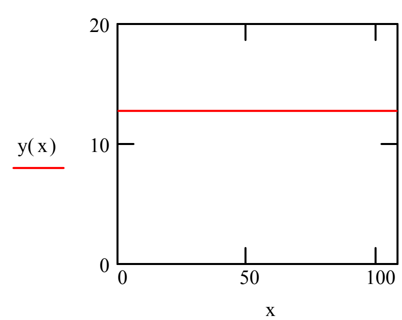
$y(x) := 12.750$

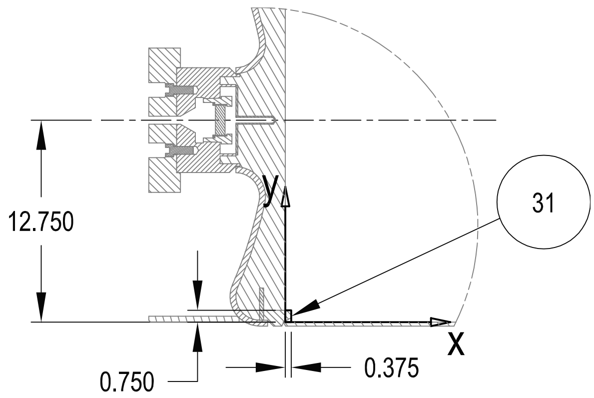
$r(x) := R - y(x)$

$$V_{30} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{30} = 5.525 \cdot 10^4$

$x .. a, b$





$a := 0$

$b := 0.375$

$R := 12.750$

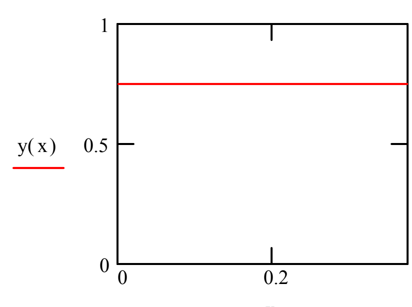
$y(x) := 0.750$

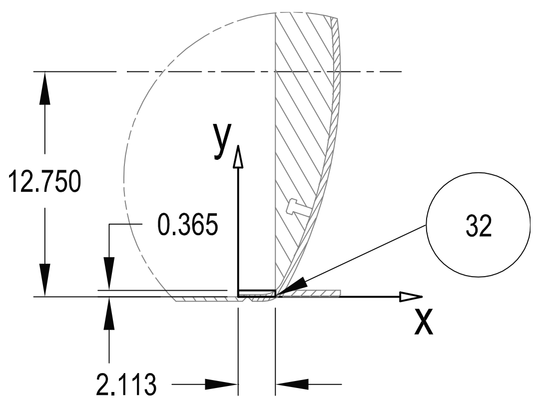
$r(x) := R - y(x)$

$$V_{31} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{31} = 21.868$

$x .. a, b$





$a := 0$

$b := 2.113$

$R := 12.750$

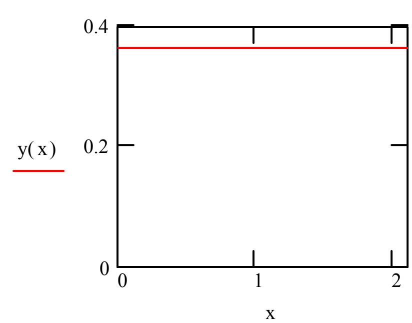
$y(x) := 0.365$

$r(x) := R - y(x)$

$$V_{32} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{32} = 60.901$

$x .. a, b$



With the optional use of the bottom shield plug, the internal volume of the Fixed Lid Canister with reverse-dished lid plate and torispherical bottom head is as follows:

$$V_{FLC\_internal} := \left(V_{30} - V_{31} - V_{32}\right) \cdot in^3$$

$$V_{FLC\_internal} = 904.064 \circ L$$

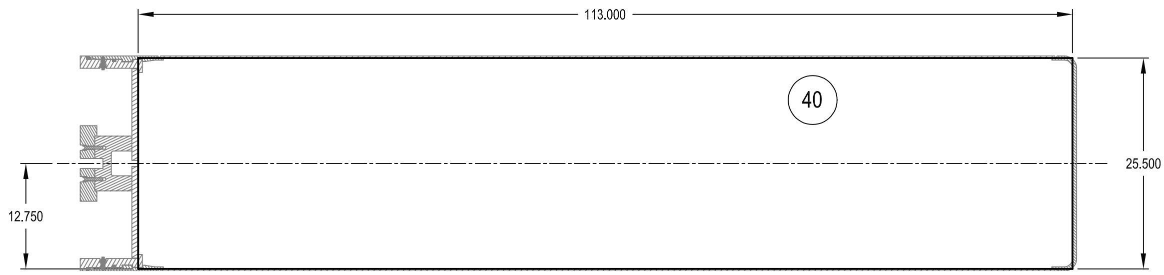
Loaded with three 55-gallon drums with an external volume of 220 liters (ref Section 3.4.4.2 of the TRUPACT-II SAR), the Fixed Lid Canister has a net internal void volume when loaded with 55-gallon drums as follows:

$$V_{FLCDrum\_void} := V_{FLC\_internal} - 3 \cdot (220 \cdot L)$$

$$V_{FLCDrum\_void} = 244.064 \circ L$$

Note that the internal volume of the Fixed Lid Canister with a flat lid plate and flat bottom head option would be greater than that with the reverse dished and torispherical head option (i.e., is non-conservative from a canister internal void volume calculational perspective). The flat lid plate and flat head options for the Fixed Lid Canister closely approximate the Removable Lid Canister internal volume calculations provided below.

Removable Lid Canister



$a := 0$

$b := 113.000$

$R := 12.750$

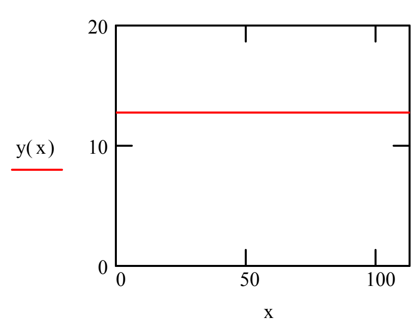
$y(x) := 12.750$

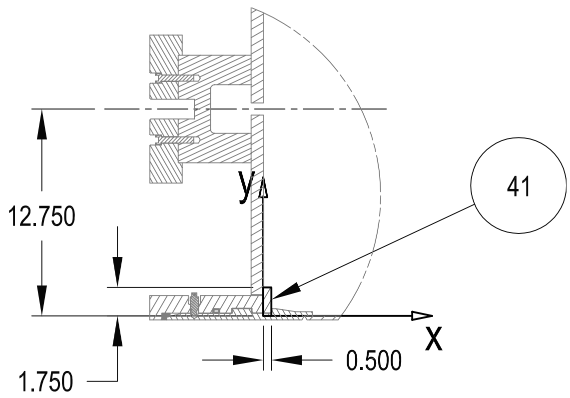
$r(x) := R - y(x)$

$$V_{40} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{40} = 5.771 \cdot 10^4$

$x .. a, b$





$a := 0$

$b := 0.500$

$R := 12.750$

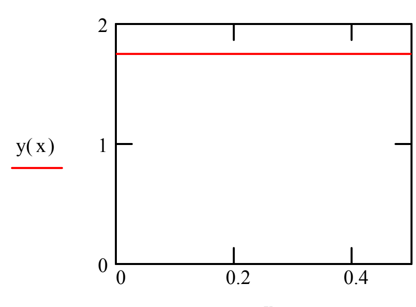
$y(x) := 1.750$

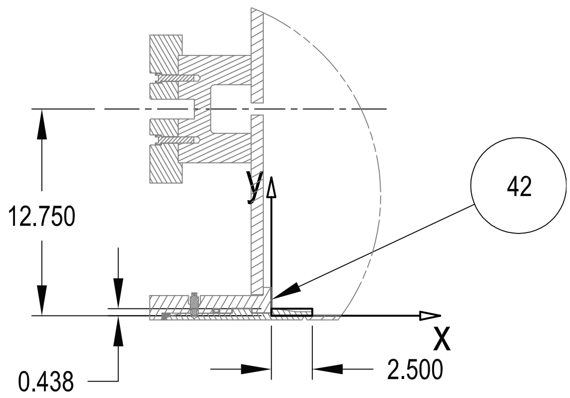
$r(x) := R - y(x)$

$$V_{41} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{41} = 65.286$

$x := a, b$





$a := 0$

$b := 2.500$

$R := 12.750$

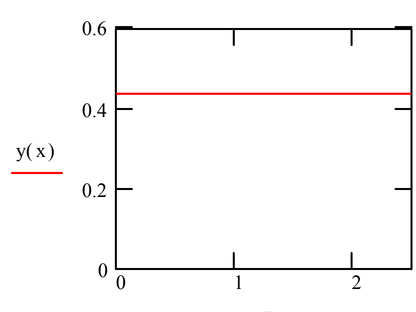
$y(x) := 0.438$

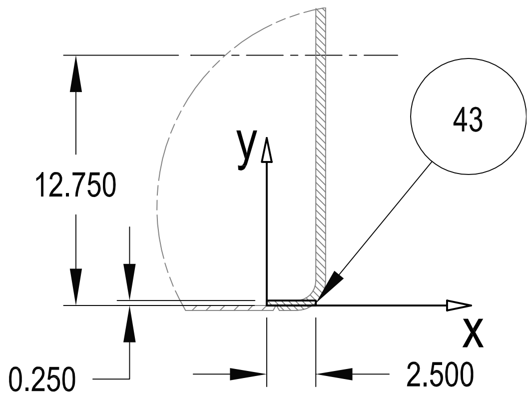
$r(x) := R - y(x)$

$$V_{42} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{42} = 86.214$

$x := a, b$





$a := 0$

$b := 2.500$

$R := 12.750$

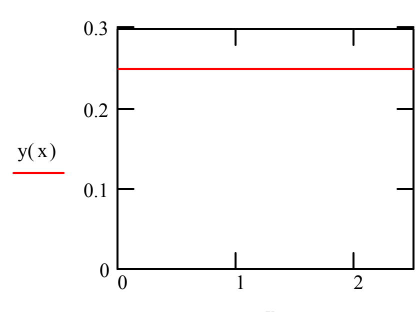
$y(x) := 0.250$

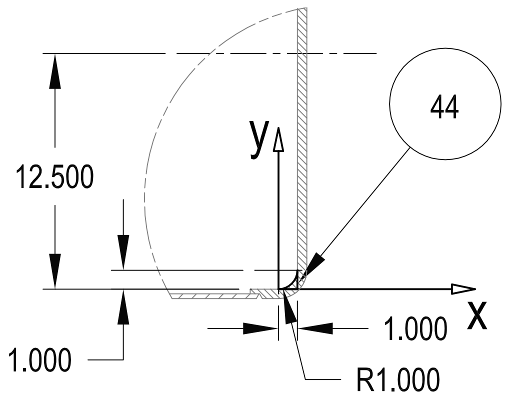
$r(x) := R - y(x)$

$$V_{43} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$V_{43} = 49.578$

$x .. a, b$





$a := 0$

$b := 1.000$

$R := 12.500$

$RR := 1.000$

$h := 0.000$

$k := 1.000$

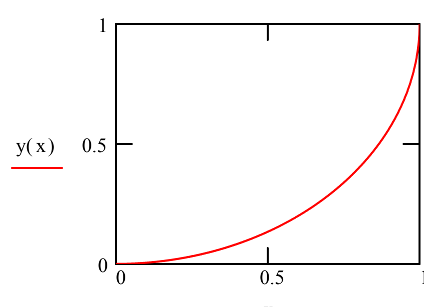
$$y(x) := k - \left(-x^2 + 2 \cdot x \cdot h - h^2 + RR^2\right)^{\left(\frac{1}{2}\right)}$$

$$r(x) := R - y(x)$$

$$V_{44} := \int_a^b \pi \cdot \left(R^2 - r(x)^2\right) dx$$

$$V_{44} = 16.554$$

$x .. a, b$



With the optional use of the body rail pipes, the internal volume of the Fixed Lid Canister with reverse-dished lid plate and torispherical bottom head is as follows:

$$V_{railpipe} := \left(\frac{\pi}{4}\right)\cdot(0.44\cdot in)^2\cdot 36.00\cdot in$$

$$V_{railpipe} = 0.09\,L$$

$$V_{RLC\_internal} := \left(V_{40} - V_{41} - V_{42} - V_{43} - V_{44}\right)\cdot in^3 - 2\cdot V_{railpipe}$$

$$V_{RLC\_internal} = 941.947\,L$$

Loaded with three 55-gallon drums with an external volume of 220 liters (ref Section 3.4.4.2 of the TRUPACT-II SAR), the Removable Lid Canister has a net internal void volume when loaded with 55-gallon drums as follows:

$$V_{RLCDrum\_void} := V_{RLC\_internal} - 3\cdot(220\cdot L)$$

$$V_{RLCDrum\_void} = 281.947\,L$$

Summary of Calculations:

Internal Volume of Inner Vessel: $V_{IV} = 1460 \cdot L$

External Volume of Fixed Lid Canister: $V_{FLC\_external} = 995 \cdot L$

Void Volume in Inner Vessel with Fixed Lid Canister: $V_{IVFLC\_void} = 464 \cdot L$

Internal Volume of Fixed Lid Canister: $V_{FLC\_internal} = 904 \cdot L$

Void Volume in Fixed Lid Canister with 3, 55-gal drums: $V_{FLCDrum\_void} = 244 \cdot L$

External Volume of Removable Lid Canister: $V_{RLC\_external} = 1010 \cdot L$

Void Volume in Inner Vessel with Removable Lid Canister: $V_{IVRLC\_void} = 450 \cdot L$

Internal Volume of Removable Lid Canister: $V_{RLC\_internal} = 942 \cdot L$

Void Volume in Removable Lid Canister with 3, 55-gal drums: $V_{RLCDrum\_void} = 282 \cdot L$

External Volume of 55-gal drum (from TRUPACT-II SAR): $V_{55gal} := 220 \cdot L$

Conclusions:

To envelope both canister designs, the following bounding void volume values are to be utilized in gas generation and/or pressure calculations:

Void Volume in Inner Vessel with Canister = 450 L
Void Volume in Canister with 3, 55-gal drums = 240 L

References:

1. X-106-500-SNP, Rev. 4, RH-TRU 72-B Packaging SAR Drawing
2. 165-F-011, Rev. A, RH-TRU 72-B Cask Welded Lid Canister Assembly
3. 165-F-007, Rev. F, RH-TRU 72-B Cask Removable Lid Canister Assembly

ATTACHMENT B-2

Determination of Minimum Sample Size for Statistical Sampling of Remote-Handled Transuranic (RH-TRU) Waste

To: CCP Records Custodian
From: T. R. Gatliffe, Washington TRU Solutions LLC
Date: May 31, 2006
Subj: Determination of Minimum Sample Size for Statistical Sampling of Remote-Handled Transuranic (RH-TRU) Waste

This document presents the development and discussion of minimum required sample size determination for statistical sampling of RH-TRU waste to support calculation of a 95% upper tolerance limit for flammable gas generation rates with 95% confidence.

Background

An Upper Tolerance Limit (UTL) for a given population is a value defined so as to provide an upper limit for $\beta \times 100\%$ of the population (i.e., $\beta \times 100\%$ of all future observations), where $0 < \beta < 1$. Thus, the quantity $\beta \times 100$ represents the quantile rank for the value within the population. When an Upper Tolerance Limit is estimated from a representative sample from the population, some level of confidence, $(1-\alpha) \times 100\%$, is associated with the estimate. For example, if $\beta = 0.95$ and $\alpha = 0.05$, the resulting Upper Tolerance Limit would be a value for which we would have $(1-0.05) \times 100\% = 95\%$ confidence that at least $0.95 \times 100\% = 95\%$ of the population is less than that value. This tolerance limit would be called a "95/95 UTL" or sometimes a "95^{th} UTL" or "UTL_{95}". This type of tolerance limit is known in statistics as a β-content upper tolerance limit with confidence level $(1-\alpha) \times 100\%$ (Guttman, 1970).[1]

Upper Tolerance Limit Calculation

Millard and Neerchal (2001)[2] discuss the use of tolerance limits to demonstrate compliance to a fixed standard for measured concentration values following normal, lognormal, and Poisson distributions and a non-parametric approach with relatively low power. However, the first three require detailed knowledge of the underlying population distribution and the assumption that the distribution is non-mixed while the last involves computation of quantiles for the beta distribution to model the population. A simpler and more easily implemented approach is based in the *Bootstrap* (or *Resampling*) technique in which multiple sample sets (usually several hundred or more) of size *n* are drawn, with replacement, from an initial representative sample of size *n*, the statistic of interest is computed for each sample, and empirical probability and cumulative density functions are derived to more precisely estimate the statistic of interest. The Bootstrap is a non-parametric technique in the sense that the population distribution function is modeled by the initial sample data and the only assumption is that the sample is representative of the population (Davison and Hinkley, 1997).[3]

The production of an upper tolerance limit estimate is conceptually and practicably very simple with the Bootstrap technique. For example, if one desired to estimate the upper 90% tolerance limit with 95% confidence for a population represented by an existing sample set of size 120, one could simply construct many (1,000 for this example) new sample sets by randomly

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[1] Guttman, I. (1970). *Statistical Tolerance Regions: Classical and Bayesian.* Hafner Publishing Co., Darien, CT, 150 pp.

[2] Millard, S. P. and Neerchal, N. K. (2001). *Environmental Statistics with S-Plus. Applied Envrionmental Statistics Series.* CRC Press LLC, Boca Raton, FL, 830 pp.

[3] Davison, A. C. and Hinkley, D. V. (1997). *Bootstrap Methods and their Application. Cambridge Series in Statistical and Probabilistic Mathematics.* Cambridge University Press, Cambridge, UK, 582 pp.

drawing, with replacement, 120 observations from the original sample data set. "Drawing with replacement" implies that as each individual observation is selected, it is returned to the candidate data pool before the next individual selection is made. Thus, every member of the original sample data set has an equal likelihood of selection for each individual data point in the new sample set. At this point there will be 1,000 new realizations of sample data sets of size 120. Each of these new sample sets can be examined to determine the 90th percentile of the sample as an estimate of the 90th percentile of the population. The 1,000 estimates would then be ordered and the 50th largest estimate chosen. This value then is the value for which there is only a 5% probability that 90th percentile of any sample of size 120 is expected to exceed. Thus, one may have 95% confidence that the 90th percentile is no greater than that value, assuming the original sample is representative of the underlying population and the sample size is large enough to yield adequate precision in specifying the percentile of interest.

Minimum Required Sample Size Determination

The problem of ensuring adequate precision dictates the minimum sample size for the original representative sample. If the limit being sought is a β-content upper tolerance limit, then the sample size should be large enough to provide high confidence that the (β×100)th percentile is captured and narrowly constrained within the sample. One way to do this is to choose a sample size so as to ensure that at least (β-*d*)×100% of the individual observations will fall below the (β×100)th percentile and at least (1-β-*d*)×100% of the individual observations will fall above the (β×100)th percentile of the population, where *d* is the desired degree of precision. This may be achieved by considering the case of an indicator variable *X* where *X*=1 if an observation falls above the (β×100)th percentile and *X*=0 if the observation is less. In this case *X* is distributed as Bernoulli with parameter *p* and *Y* = ΣX is distributed as binomial with parameters *n* and *p* for an infinite population and as hypergeometric with parameters *N, n,* and *pN* for a finite population of size *N*, where *p* = 1-β and *n* = sample size.

As documented in the *PASS 2005® Power and Sample Size* statistical software program[4], to estimate *p* while controlling the absolute error, *d*, with a given probability, 1-α, for an infinite population, you iteratively solve to find the minimum *n* to satisfy Equation [1].

$$\Pr\left(\left|\frac{Y}{n}-p\right|<d\right)=\Pr\left(y_1\le Y\le y_2\right)=\sum_{y=y_1}^{y_2}\binom{n}{y}p^n\left(1-p\right)^{n-y}\ge 1-\alpha \qquad [1]$$

When the population is of finite size (*N*), the preceding relation must be transformed to use the hypergeometric distribution in place of the binomial form shown. Direct calculation using the hypergeometric is somewhat complex and relatively difficult. However, a normal approximation to the hypergeometric distribution may be used and *PASS 2005®* software calculations are based on Equation [2].[4]

$$z_{1-\alpha/2}=\frac{d}{\sqrt{\frac{p\left(1-p\right)\left(N-n\right)}{nN}}} \qquad [2]$$

Using this equation to determine the required minimum sample size to produce a 95% confidence interval equal to the sample proportion plus or minus *d* = 0.03 when the estimated

[4] Hintze, J. (2004). *NCSS and PASS.* Number Cruncher Statistical Systems, Kaysville, UT. UTL: www.ncss.com.

proportion is 0.95 for a finite population sizes of both *N* = 1,000,000 and *N* = 100,000 yields a minimum required sample size of *n* = 203. This value may be considered the asymptotic upper limit for sample size for the stated conditions. Conditions requiring lesser confidence and/or a larger precision band would yield smaller limiting values for *n*. However, the stated conditions are reasonable and applicable in establishing a base sample for use in the Bootstrap UTL techniques.

As shown in Table 1, minimum required sample sizes for a range of representative population sizes from *N*=20 to *N*=1,000,000 were determined using the approach described above through the *PASS 2005®* program. The specific program output is included as an enclosure. For ease in determining the required sample size when the *PASS 2005®* program might not be readily available, it was found that the minimum sample size number could also be equivalently determined from the following commonly used finite population correction formula for binomial results (rounding the result up to the next higher whole number):

$$n' = \frac{n_0}{1+\frac{n_0-1}{N}} = \frac{203}{1+\frac{202}{N}} = \frac{203\times N}{N+202} \qquad [3]$$

The equivalence of this estimation formula is illustrated in Table 1 with the parallel columns labeled ***n*** (from the *PASS 2005®* program output), ***n'*** (from Equation [3]), ***n''*** (the whole number value corresponding to n'), and ***Δ*** (the difference: n'' – n). As can be seen, the minimum sample size determined using the finite population correction formula always rounds either exactly to the n-formula value from Equation [2] or conservatively to one unit larger.

N	***n***	***n'***	***n''***	***Δ***
1000000	203	202.96	203	0
100000	203	202.59	203	0
75000	203	202.45	203	0
50000	202	202.18	203	1
25000	202	201.37	202	0
15000	201	200.30	201	0
10000	199	198.98	199	0
7500	198	197.68	198	0
5000	195	195.12	196	1
2500	188	187.82	188	0
1500	179	178.91	179	0
1000	169	168.89	169	0

N	***n***	***n'***	***n''***	***Δ***
750	160	159.93	160	0
500	145	144.59	145	0
250	112	112.28	113	1
150	87	86.51	87	0
100	67	67.22	68	1
75	55	54.96	55	0
50	41	40.28	41	0
40	34	33.55	34	0
30	27	26.25	27	0
25	23	22.36	23	0
20	19	18.29	19	0

Table 1. Minimum Sample Size (n) for Use in Bootstrap UTL_{95} Computation for Various Population Sizes (N) and Comparison to the Simplified Sample-Size Formula.

Conclusion

Equation 3 is applicable in determining a minimum sample size, n', for use with the Bootstrap technique to calculate UTL values for a population of size N. The applicable n_0 value for Equation 3 is 203. This equation is applicable from a minimum population size of 20. Once the minimum required sample size has been determined and the requisite sample data set collected (and representiveness established), the Bootstrap technique can be used to establish a 0.95-content upper tolerance limit with confidence level 95% using the procedure described above. The recommended resampling size is a minimum of 2,000 replications up to a maximum of 10,000. Although the computing power available in desktop resampling software requires only a few seconds for the larger value, little or no additional precision is gained from much larger collection numbers.

cc: M. Devarakonda
J. Biedscheid
E. L. D'Amico
S. Peterman

PASS 2005® Software Output

Confidence Interval of A Proportion

Numeric Results

Precision	C.C. Confidence Coefficient	n Sample Size	p Baseline Proportion	N Population Size
0.03	0.95017	203	0.95	1,000,000
0.03	0.95038	203	0.95	100,000
0.03	0.95004	202	0.95	50,000
0.03	0.95051	202	0.95	25,000
0.03	0.95055	201	0.95	15,000
0.03	0.95017	199	0.95	10,000
0.03	0.95035	198	0.95	7,500
0.03	0.95010	195	0.95	5,000
0.03	0.95031	188	0.95	2,500
0.03	0.95029	179	0.95	1,500
0.03	0.95035	169	0.95	1,000
0.03	0.95036	160	0.95	750
0.03	0.95083	145	0.95	500
0.03	0.95009	112	0.95	250
0.03	0.95242	87	0.95	150
0.03	0.95016	67	0.95	100
0.03	0.95194	55	0.95	75
0.03	0.96224	41	0.95	50
0.03	0.96177	34	0.95	40
0.03	0.97629	27	0.95	30
0.03	0.98040	23	0.95	25
0.03	0.99271	19	0.95	20

Report Definitions

Precision is the plus and minus value used to create the confidence interval.
Confidence Coefficient, C.C., is probability value associated with the confidence interval.
Sample Size, n, is the size of the sample drawn from the population.
Baseline Proportion, p, is the estimated baseline proportion.

Summary Statements for Numeric Results can be read for each row above as:

"A sample size of (n) from a population of (N) produces a 95% confidence interval equal to the sample proportion plus or minus 0.03 when the estimated proportion is 0.95."

For example:

A sample size of 203 from a population of 100,000 produces a 95% confidence interval equal to the sample proportion plus or minus 0.03 when the estimated proportion is 0.95.

Similarly,

A sample size of 41 from a population of 50 produces a 96% confidence interval equal to the sample proportion plus or minus 0.03 when the estimated proportion is 0.95.

References

Desu, M. M. and Raghavarao, D. 1990. Sample Size Methodology. Academic Press. New York.

Machin, D., Campbell, M., Fayers, P., and Pinol, A. 1997. Sample Size Tables for Clinical Studies, 2nd Edition. Blackwell Science. Malden, MA.

Hahn, G. J. and Meeker, W.Q. 1991. Statistical Intervals. John Wiley & Sons. New York.

ATTACHMENT C

REVISED DOCUMENTS

(two hard copies and seven CDs in Adobe PDF format)

- RH-TRU 72-B SAR, Revision 4
- RH-TRAMPAC, Revision 0
- RH-TRU Payload Appendices, Revision 0