ENERCON FEDERAL SERVICES, INC.	CALCULATION COVER SHEET	CALC. NO. RTL-001-CN-CALC-0101 REV. 1 PAGE NO. 1 of 22

Title:	Containment Evaluation for the RT-100	**Client:** Robatel Technologies **Project:** RT-100 Transport Package

Item	Cover Sheet Items	Yes	No
1	Does this calculation contain any open assumptions that require confirmation? (If **YES**, Identify the assumptions) ________	☐	☒
2	Does this calculation serve as an "Alternate Calculation"? (If **YES**, Identify the design verified calculation.) **Design Verified Calculation No.** ________	☐	☒
3	Does this calculation Supersede an existing Calculation? (If **YES**, identify the superseded calculation.) **Superseded Calculation No.** ________	☐	☒

Scope of Revision:

O-ring groove width (assumption 5) was changed from 1.1 cm to 0.49 cm to reflect updated drawings. This altered the standard leakage rates of the cask. These leakage rates were recalculated and updated. Added references for drawings used in Figures 7.1 and 7.2. Added reference for assumption 5. Updated table of contents, list of figures, and list of tables to reflect this addition of references. Renumbered references throughout text to reflect updated references list. Updated equations to reflect new o-ring groove width. Revised section 7.6 to include a calculation of the leak rate acceptance criteria using helium as a fill gas for fabrication, periodic, and maintenance tests. Changed standard viscosity for helium, and updated associated leakage rate to reflect this change.

Revision Impact on Results:

Increased standard leakage rate for air from 5.952E-06 [ref-cm^3/sec] to 6.154E-06 [ref-cm^3/sec] and from 7.679E-06 [ref-cm^3/sec] to 7.848E-06 [ref-cm^3/sec].

Study Calculation ☐	**Final Calculation** ☐
Safety-Related ☒	**Non-Safety Related** ☐

(Print Name and Sign)

Originator: Amy Varallo	Amy Varallo	**Date:** 10/07/12
Design Verifier: Alan Wells	Alan H Wells PhD	**Date:** 10/7/12
Approver: Curt Lindner		**Date:** 10/7/12

CALCULATION REVISION STATUS

REVISION	DATE	DESCRIPTION
0		Initial Issue
1	10/02/12	O-ring groove width (assumption 5) was changed from 1.1 cm to 0.49 cm to reflect updated drawings. This altered the standard leakage rates of the cask. These leakage rates were recalculated and updated. Added references for drawings used in Figures 7.1 and 7.2. Added reference for assumption 5. Updated table of contents, list of figures, and list of tables to reflect this addition of references. Renumbered references throughout text to reflect updated references list. Updated equations to reflect new o-ring groove width. Revised section 7.6 to include a calculation of the leak rate acceptance criteria using helium as a fill gas for fabrication, periodic, and maintenance tests.

PAGE REVISION STATUS

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APPENDIX REVISION STATUS

APPENDIX NO.	PAGE NO.	REVISION NO.	APPENDIX NO.	PAGE NO.	REVISION NO.

ENERCON FEDERAL SERVICES, INC.	CALCULATION DESIGN VERIFICATION CHECKLIST	CALC. NO. RTL-001-CN-CALC-0101 REV. 1 PAGE NO. 3 of 22

Item	CHECKLIST ITEMS	Yes	No	N/A
1	**Design Inputs** - Were the design inputs correctly selected, referenced (latest revision), consistent with the design basis, and incorporated in the calculation?	X		
2	**Assumptions** - Were the assumptions reasonable and adequately described, justified and/or verified, and documented?	X		
3	**Quality Assurance** - Were the appropriate QA classification and requirements assigned to the calculation?	X		
4	**Codes, Standards, and Regulatory Requirements** - Were the applicable codes, standards, and regulatory requirements, including issue and addenda, properly identified and their requirements satisfied?	X		
5	**Construction and Operating Experience** - Have applicable construction and operating experience been considered?	X		
6	**Interfaces** - Have the design-interface requirements been satisfied, including interactions with other calculations?	X		
7	**Methods** - Was the calculation methodology appropriate and properly applied to satisfy the calculation objective?	X		
8	**Design Outputs** - Was the conclusion of the calculation clearly stated, did it correspond directly with the objectives, and are the results reasonable compared to the inputs?	X		
9	**Radiation Exposure** - Has the calculation properly considered radiation exposure to the public and plant personnel?	X		
10	**Acceptance Criteria** - Are the acceptance criteria incorporated in the calculation sufficient to allow verification that the design requirements have been satisfactorily accomplished?	X		
11	**Computer Software** - Is a computer program or software used, and if so, are the requirements of CSP 3.02 met?			X

COMMENTS:

	(Print Name and Sign)	
Design Verifier:	Alan Wells Alan H Wells PhD	**Date:** 10/7/12
Others:		**Date:**

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1. Purpose and Scope

The purpose of this calculation is to provide an analysis that demonstrates compliance with the permitted activity release limits specified in 10CFR71 [1] for the Robatel Technologies RT-100 cask. Satisfaction of the containment criteria, expressed in this analysis as the design basis leakage rate, ensures that the package will not exceed the allowable radionuclide release rate. Leakage rates are determined using NUREG/CR-6487, *Containment Analysis for Type B Packages Used to Transport Various Contents* [2] and the NRC's Regulatory Guide 7.4, *Leakage Tests on Packages for Shipment of Radioactive Materials* [3] as guides. These calculations must also be in accordance with the requirements of ANSI N14.5 [4].

The RT-100 cask's maximum allowable leakage rate ensures that the requirements of 10CFR71.51 are met. The containment boundary for the RT-100 cask consists of the inner cask shell, the inner bottom plate, the upper flange, the primary lid and inner o-ring, the secondary lid and inner o-ring, and the vent port cover plate and associated o-ring.

The maximum leakage rates for normal and accident conditions of transport are determined in this analysis. These rates are then correlated to test conditions for the RT-100 cask. In order to calculate the maximum leakage rates for normal conditions of transport, the temperature is determined for normal and accident conditions. The internal pressure is calculated based on the provided internal temperature for either normal or accident conditions, and the standard temperature and pressure conditions of 298K (25°C, 76.7°F) and 1-atm are utilized.

2. Summary and Conclusion

Using the most restrictive allowable leakage rate determined in this calculation as the test criterion for the containment system ensures that the package will not exceed the regulatory dictated allowable radionuclide release rates. This allowable leakage rate is bounding for powdered solids with specific activity not exceeding 20.35 A_2/g.

Table 2.1 Allowable Standard Leakage Rates

	Allowable Leakage Rate [ref-cm^3/sec]	Sensitivity [ref-cm^3/sec]
Air	6.154E-06	3.077E-06
Helium	7.848E-06	3.924E-06

3. References

1. 10CFR71, "Packaging and Transport of Radioactive Material," 2010.

2. NUREG/CR-6487, UCRL-ID-124822, *Containment Analysis for Type B Packages Used to Transport Various Contents*, B.L. Anderson et al., Lawrence Livermore National Laboratory, November 1996.
3. NRC's Regulatory Guide 7.4, *Leakage Tests on Packages for Shipment of Radioactive Materials*.
4. ANSI N14.5-1997, "American National Standard for Radioactive Material Leakage Tests on Packages for Shipment."
5. RT100-PE-1001-2, Rev. E, RT-100 General Assembly, Sheet 2.
6. "Particle-size distribution and packing fraction of geometric random packings." H. J. H. Brouwers, Physical Review E 74, 031309, 2006.
7. DOE Handbook, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, "Volume I - Analysis of Experimental Data," U.S. Department of Energy, Washington, D.C., 1994.
8. RTL-001-CALC-TH-0102, Rev. 0, "RT-100 Cask Maximum Normal Operating Pressure Calculation."
9. RTL-001-CALC-TH-0202, Rev. 0, "RT-100 Cask Hypothetical Accident Condition Maximum Pressure Calculation."

4. Assumptions

The following assumptions are employed in determining the allowable leakage rates:

1. Any residual activity on the interior surface of the cask due to previous use is negligible.
2. The temperature for the leakage rate for normal conditions is assumed to be the maximum cavity temperature at normal conditions. The pressure is calculated based on a ratio of standard temperature and pressure.
3. The temperature for the leakage rate for accident conditions is assumed to be the maximum cavity temperature under accident conditions. The pressure is calculated based on a ratio of standard temperature and pressure.
4. The flow is unchoked for all analyses because the unchoked flow correlations better approximate the true measured flow rate for the leakage rates associated with transportation packages. Per NUREG/CR-6487 Section 2.2.5, page 6, "it was found that the continuum and molecular flow equation provided good agreement with the experimental results for flow rates less than about 1 atm·cm^3/s." Since the gas flow rate of interest for this radioactive material transportation container is less than 1 atm·cm^3/s, the unchoked correlations are chosen.
5. The o-ring contact surface or seating width with the smallest diameter will determine the allowable leakage rates of the cask. This width can be assumed as the groove width for the o-ring in the vent port cover plate (0.49-cm) [5, Section H-H, Detail 1] since it is smaller than the o-

rings in the primary and secondary lids, and this is the value which will be used as the capillary length.

6. The maximum allowable activity is $3000A_2$.

7. The calculated leakage rate for each transport condition assumes a 25% void volume in the storage cavity. This value is chosen due to its conservative nature, since the random close packing fraction for uniform spheres is 0.64 [6]. The resin beads in this cask are assumed to be uniform spheres.

8. The nuclear material being transported is Category II material. This yields the value for aerosol density, 1×10^{-6} g/cm^3, found in NUREG/CR-6487, page 12, Section 3.3. Since the RT-100 cavity void volume is 1.15×10^6 cm^3 (see Table 5.3 below), the total aerosol mass in the 25% void region of the cask is 1.15 grams.

9. The activity per unit volume of the medium that could escape from the containment system under accident conditions (C_A) is equal to that under normal conditions (C_N).

10. The specific activity = 3000 A_2/1.15 grams = 2609 A_2/gram*(ARF)*(RF) = 2609 A_2/gram*(.0078) = 20.35 A_2/gram, where:

    ARF is the Airborne Release Fraction, or the coefficient used to estimate the amount of a radioactive material that can be suspended in air and made available for airborne transport under a specific set of induced physical stresses [7]. The value of ARF for this calculation is 0.0078, taken from Table 5-5, pages 5-18 of Reference 7, "Measured ARFs and RF from Burning of Contaminated Polystyrene." For conservatism, the value of 0.0078 is the maximum measured value.

    RF is the Respirable Fraction, which has a value of 0.90 for the release selected from Table 5-5 of Reference [7]. This value is conservatively set to 1.0 for this containment calculation.

    These values provide a bounding value for the fraction of escapable and respirable particles, and this value is then multiplied by the maximum theoretical specific activity. Thus, a specific activity of 20.35 A_2/gram represents the worst-case scenario for an airborne release—that is, if the resin particles are combusted and released through the leakage hole in the cask. This yields a conservative value for the cask leakage rate, since it is unlikely that combustion will be the form of airborne release in a sealed cask.

5. Design Inputs

5.1 Description of Containment System

5.1.1 Containment Vessel

The package containment system is defined as the inner shell of the shielded transport cask, together with the associated lid, o-ring seals, and lid closure bolts. The inner shell of the cask or containment vessel consists of a right circular cylinder of 1730 mm inner diameter and 1960 mm inside height. The shell is fabricated of stainless steel. At the base, the cylindrical shell is attached to a circular end plate with full penetration welds. The primary lid is attached to the cask body with thirty-two (32) equally spaced M48 hex head bolts. A secondary lid covers an opening in the primary lid and is attached to the primary lid using eighteen (18) equally spaced M36 hex head bolts. See Section 5.1.4 for closure details.

5.1.2 Containment Penetration

There are three penetrations of the containment vessel. These are (1) the primary lid with the containment boundary of the primary lid's inner o-ring; (2) the secondary lid with the containment boundary of the secondary lid's inner o-ring; and (3) the cask vent port located in the primary lid. The vent port penetrates the primary lid into the main cask cavity. The vent penetration contains a Staubli connector and is sealed with the vent port cover plate and associated elastomeric o-ring. The primary and secondary lids are sealed with elastomeric o-rings.

5.1.3 Welds and Seals

The containment vessel is fabricated using full penetration groove welds. Seals are described in Sections 5.1.2 and 5.1.4.

5.1.4 Closure

The primary lid closure consists of a partially recessed, 211 mm-thick stainless steel plate. The lid is supported at the perimeter of the cylindrical body by a thick plate (upper forging) which is welded to the top of the inner and outer cylindrical shells. The lid is attached to the cask body by thirty-two (32) equally spaced M48 hex head bolts. Two (2) solid, elastomeric o-rings are retained in machined grooves at the lid perimeter. Groove dimensions prevent over-compression of the o-rings by the closure bolt pre-load forces and hypothetical accident impact forces. The cask is fitted with a secondary lid of similar construction attached to the primary lid with eighteen (18) equally spaced M36 hex head bolts. The secondary lid is also sealed with two (2) solid, elastomeric o-rings in machined grooves.

The vent penetration is sealed with a Staubli connector and associated o-ring, which is used beneath the heads of the hex head cap screws. Table 5.1 gives the torque values for the cap screws.

Table 5.1 Bolt and Cap Screw Torque Requirements

Location	Size	Lubrication	Torque Values (N-m)
Primary Lid	M48	N/A	1320 (± 560)
		Fel-Pro 5000 (paste)	660 (± 280)
Secondary Lid	M36	N/A	550 (± 230)
		Fel-Pro 5000 (paste)	275 (± 115)

5.2 Cavity Volume, Conditions and Contents

The cavity dimensions are displayed below:

Table 5.2 Cask Cavity Dimensions

	Inches	Centimeters
L_{cavity}	77.2	196
D_{cavity}	68.1	173

Thus, the volume of the cylindrical cavity is:

$$V_{cavity} = (\pi \cdot D_{cavity}^{2} \cdot L_{cavity})/4$$

A conservative estimate for the void fraction of the cavity is 25%, so the actual corrected free-volume of the cavity is ($0.25*V_{cavity}$).

Table 5.3 Cask Cavity Volume

Total Cavity Volume [cm^3]	4.60E+06
Free Void Volume [cm^3]	1.15E+06

The temperatures under normal and accident conditions used in this analysis are determined based on the maximum internal cavity temperatures for normal and accident situations. The standard leakage rate is the leakage rate of dry air when it is leaking from 1-atm (upstream pressure) to 0.1-atm (downstream pressure) at 298K.

Table 5.4 Parameters for Normal Transport and Accident Conditions

Parameter	Normal Conditions[8]	Accident Conditions[9]	Standard Conditions
P_u [atm]	3.38	6.8	1
P_d [atm]	1	1	0.1
P_a [atm]	2.19	3.9	0.55
T [°F]	176 (353 K)	302 (423 K)	76.7 (298 K)
M [g/mol]	29 (air), 4 (He)	29 (air), 4 (He)	29 (air), 4 (He)
μ [cP]	0.0209 (air), 0.0223 (He)	0.0239 (air), 0.0253 (He)	0.0185 (air), 0.0198 (He)
a [cm]	0.49	0.49	0.49

6. Methodology

The leakage rates for normal and accident conditions of transport at operating conditions and the allowable leakage rate at test conditions for the RT-100 cask containing powdered solid radioactive material are determined using the methodology described in NUREG/CR-6487 [2]. To calculate the leakage rates for each transportation condition, the following are determined:

- the source term concentration for the releasable material,
- the releasable activity, and
- the allowable leakage rates at transport (operating) conditions.

The corresponding leakage hole diameters are calculated using the equations for continuum and molecular flow. Then, using these leak hole diameters, the corresponding allowable leakage rates at test conditions are calculated. Parameters are utilized in a way ensuring conservatism in the final leakage rates for the conditions considered.

6.1 Allowable Radionuclide Release Rates

The containment criterion for the RT-100 cask under normal conditions of transport is given in 10CFR71.51(a)(1). This criterion requires that the package have a radioactive release rate less than 1E-06A_2 in one hour, where A_2 is the effective A_2 for the total source term in the packaging. Additionally, 10CFR71.51(a)(2) directs that for accident conditions, the quantity of radioactivity that may be released in one week is equal to A_2 (effective A_2 for the total source term).

NUREG/CR-6487 [2] and ANSI N14.5-1997 [4] provide Equation 6.1 (normal transport conditions) and Equation 6.2 (accident conditions) for computation of the allowable release rates.

Equation 6.1

$$R_N = L_N C_N \leq A_2 \times 2.78\text{E-}10/\text{second}$$

where:

R_N is the release rate for normal transport [Ci/s],
L_N is the volumetric gas leakage rate [cm^3/s],
C_N is the total source term activity concentration under normal transport conditions [Ci/cm^3], and
A_2 is the appropriate effective A_2 value [Ci].

Equation 6.2

$$R_A = L_A C_A \leq A_2 \times 1.65\text{E-}06/\text{second}$$

where:

R_A is the release rate for accident conditions [Ci/s],
L_A is the volumetric gas leakage rate [cm^3/s],
C_A is the total source term activity concentration under accident conditions [Ci/cm^3], and
A_2 is the appropriate effective A_2 value [Ci].

6.2 Allowable Leakage Rates at Normal and Accident Conditions

The allowable upstream leakage rates at normal and accident conditions are determined by dividing the allowable release rates by the appropriate source term activity concentrations as shown in Equation 6.3.

Equation 6.3

$$L_N = \frac{R_N}{C_N} \text{ or } L_A = \frac{R_A}{C_A}$$

where:

L_N or L_A is the allowable leakage rate at the upstream pressure for normal (N) or accident (A) conditions [cm^3/s],

R_N or R_A is the allowable release rate for normal (N) or accident (A) conditions [Ci/s], and

C_N or C_A is the total source term activity concentration for normal (N) or accident (A) conditions [Ci/cm^3].

For this analysis, C_N and C_A are defined as follows in Equation 6.4.

Equation 6.4

$$C_N \text{ or } C_A = S_A \cdot \rho$$

where:

C_N or C_A is the total source term activity concentration for normal (N) or accident (A) conditions [Ci/cm^3],

S_A is the specific activity of releasable material in the cask [A_2/g], and

ρ is equal to the aerosol density of the material determined from Table 5.4 [g/cm^3].

The allowable leakage rates determined using Equation 6.3 are the allowable leakage rates at the upstream pressures, which are then used to determine the allowable leakage rates at average pressures using the ratio presented in Equation 6.5.

Equation 6.5

$$L_{@P_a} = L_{@P_u} \frac{P_u}{P_a}$$

where:

$L_{@Pa}$ is the allowable leakage rate at the average pressure [cm^3/s] for normal or accident conditions,

$L_{@Pu}$ is the allowable leakage rate at the upstream pressure [cm^3/s] for normal or accident conditions,

P_u is the upstream pressure [atm],

P_d is the downstream pressure [atm], and

P_a is the average pressure; $P_a = (P_u + P_d)/2$ [atm].

6.3 Allowable Leakage Rates at Test Conditions

The methodology provided below details the conversion of the allowable leakage rate at either normal or accident conditions to an allowable leakage rate at test conditions.

For conservatism, unchoked flow correlations are used as they better approximate the true measured flow rate for the leakage rates associated with transportation packages. Using the equations for molecular and continuum flow provided in NUREG/CR-6487 [2], the corresponding leak hole diameters are calculated for the RT-100 cask for each transport condition by solving Equation 6.6 for *D*, the leak hole diameter. The capillary length required for Equation 6.6 for the containment system is conservatively chosen as the o-ring groove width in the primary lid, which is 0.49 cm.

Equation 6.6

$$L_{@Pa} = \left[\frac{2.49\times10^{6}\,D^{4}}{a\cdot\mu} + \frac{3.81\times10^{3}D^{3}\sqrt{\frac{T}{M}}}{a\cdot P_{a}}\right]\times[P_{u} - P_{d}]$$

where:

$L_{@Pa}$ is the allowable leakage rate at the average pressure for normal and accident conditions [cm^3/s],
a is the capillary length [0.49 cm],
T is the temperature for normal or accident conditions [K],
M is the gas molecular weight [g/mol] = 29.0 for air, 4.0 for He from ANSI N14.5, Table B1,
μ is the dynamic viscosity for helium or air [cP],
P_u is the upstream pressure [atm],
P_d is the downstream pressure [atm],
P_a is the average pressure; $P_a = (P_u + P_d)/2$ for normal or accident conditions [atm], and
D is the capillary diameter [cm].

The leak hole diameter is determined using the parameters for normal and accident conditions of transport presented in Table 5.4.

Using these leak hole diameters and the temperature and pressures for test conditions, Equation 6.6 is solved for the leakage rates at the average pressure and test conditions. These calculations are performed for normal and accident conditions. The most restrictive allowable leakage rate calculated at test conditions is then used as the acceptance leakage rate.

6.4 Leak Test Sensitivity

The sensitivity (S) for the leakage test procedures is established by ANSI N14.5-1997 [4] as shown in Equation 6.7.

Equation 6.7

$$S = \tfrac{1}{2}\cdot \textit{Leakage Rate}$$

7. Calculations

Microsoft Excel is used in conjunction with Wolfram Alpha's implicit equation solving tool as the calculation method for this analysis. All calculations are completed in Microsoft Excel Workbooks. For normal and accident conditions, *RT-100 Containment Calculation-Air.xlsx* and *RT-100 Containment Calculation-He.xlsx* are used.

The *All Assumptions* worksheet in both files provides necessary design inputs and assumption parameters used in calculation of the acceptable leakage rates.

The *Equations- Normal Cond.* and *Equations- Accident Cond.* worksheets are used to determine the allowable leakage rates at the average pressure for normal and accident conditions. These two worksheets are set up with the values provided in Table 5.4.

For the calculation of the reference helium leak rate for test acceptance criteria, the Microsoft Excel workbook *Helium test rate.xls* is used.

7.1 Normal Conditions of Transport, Air

Under normal conditions of transport, the leakage rate at upstream pressure is determined by Equation 6.3:

$$L_N = \frac{R_N}{C_N} = \frac{2.78\times10^{-10}}{2.03\times10^{-5}} = 1.37\text{E-05 [cm}^3\text{/sec]}$$

This is the maximum permitted volumetric leakage rate under normal conditions of transport for powdered solids. The reference leakage rate under normal conditions corresponding to this volumetric leakage rate is then determined using Equation 6.6:

$$1.37\text{E-05} = \left[\frac{2.49\times10^6 D_{max}^4}{0.49\cdot0.0209} + \frac{3.81\times10^3 D_{max}^3\sqrt{\frac{353}{29}}}{0.49\cdot2.19}\right]\times[3.38-1]\times\frac{3.38}{2.19}$$

Solve for the D_{max} using an implicit equation solver which yields the upstream pressure leakage rate at normal conditions:

D_{max} = 4.25E-04 [cm]

Based on this value of D_{max}, calculate the reference leakage rate under standard conditions:

$$L_{ref} = \left[\frac{2.49\times10^6(4.25\text{E-04})^4}{0.49\cdot0.0185} + \frac{3.81\times10^3(4.25\text{E-04})^3\sqrt{\frac{298}{29}}}{0.49\cdot0.55}\right]\times[1-0.1]\times\frac{1}{.055}$$

L_{ref} = 6.154E-06 [cm^3/sec]

7.2 Hypothetical Accident Conditions, Air

Under accident conditions, the leakage rate at upstream pressure is determined by Equation 6.3:

$$L_A = \frac{R_A}{C_A} = \frac{1.65\times10^{-6}}{2.03\times10^{-5}} = 8.11\text{E-02 [cm}^3\text{/sec]}$$

This is the maximum permitted volumetric leakage rate under accident conditions for powdered solids. The reference leakage rate under accident conditions corresponding to this volumetric leakage rate is then determined using Equation 6.6:

$$8.11E\text{-}02 = \left[\frac{2.49\times10^{6}\,D_{max}^{\ 4}}{0.49\cdot0.0239} + \frac{3.81\times10^{3}D_{max}^{\ 3}\sqrt{\frac{423}{29}}}{0.49\cdot3.90}\right]\times[6.8-1]\times\frac{6.8}{3.9}$$

Solve for the D_{max} using an implicit equation solver which yields the upstream pressure leakage rate at accident conditions:

D_{max} = 3.26E-03 [cm]

Based on this value of D_{max}, calculate the reference leakage rate under standard conditions:

$$L_{ref} = \left[\frac{2.49\times10^{6}\,(3.26E\text{-}03)^{4}}{0.49\cdot0.0185} + \frac{3.81\times10^{3}(3.26E\text{-}03)^{3}\sqrt{\frac{298}{29}}}{0.49\cdot0.55}\right]\times[1-0.1]\times\frac{1}{0.55}$$

L_{ref} = 1.619E-02 [cm^3/sec]

7.3 Normal Conditions of Transport, Helium

Under normal conditions of transport, the leakage rate at upstream pressure is determined by Equation 6.3:

$$L_N = \frac{R_N}{C_N} = \frac{2.78\times10^{-10}}{2.03\times10^{-5}} = 1.37E\text{-}05\ [cm^3/sec]$$

This is the maximum permitted volumetric leakage rate under normal conditions of transport for powdered solids. The reference leakage rate under normal conditions corresponding to this volumetric leakage rate is then determined using Equation 6.6:

$$1.37E\text{-}05 = \left[\frac{2.49\times10^{6}\,D_{max}^{\ 4}}{0.49\cdot0.0223} + \frac{3.81\times10^{3}D_{max}^{\ 3}\sqrt{\frac{353}{4}}}{0.49\cdot2.19}\right]\times[3.38-1]\times\frac{3.38}{2.19}$$

Solve for the D_{max} using an implicit equation solver which yields the upstream pressure leakage rate at normal conditions:

D_{max} = 4.11E-04 [cm]

Based on this value of D_{max}, calculate the reference leakage rate under standard conditions:

$$L_{ref} = \left[\frac{2.49\times10^{6}(4.11E\text{-}04)^{4}}{0.49\cdot0.0198} + \frac{3.81\times10^{3}(4.11E\text{-}04)^{3}\sqrt{\frac{298}{4}}}{0.49\cdot0.55}\right]\times[1-0.1]\times\frac{1}{.055}$$

L_{ref} = 7.848E-06 [cm^3/sec]

7.4 Hypothetical Accident Conditions, Helium

Under accident conditions, the leakage rate at upstream pressure is determined by Equation 6.3:

$$L_A = \frac{R_A}{C_A} = \frac{1.65\times10^{-6}}{2.03\times10^{-5}} = 8.11E\text{-}02\ [cm^3/sec]$$

This is the maximum permitted volumetric leakage rate under accident conditions for powdered solids. The reference leakage rate under accident conditions corresponding to this volumetric leakage rate is then determined using Equation 6.6:

$$8.11E\text{-}02 = \left[\frac{2.49\times10^{6}D_{max}^{4}}{0.49\cdot0.0253} + \frac{3.81\times10^{3}D_{max}^{3}\sqrt{\frac{423}{4}}}{0.49\cdot6.8}\right]\times[6.8-1]\times\frac{6.8}{3.9}$$

Solve for the D_{max} using an implicit equation solver which yields the upstream pressure leakage rate at accident conditions:

D_{max} = 3.29E-03 [cm]

Based on this value of D_{max}, calculate the reference leakage rate under standard conditions:

$$L_{ref} = \left[\frac{2.49\times10^{6}(3.29E\text{-}03)^{4}}{0.49\cdot0.0198} + \frac{3.81\times10^{3}(3.29E\text{-}03)^{3}\sqrt{\frac{298}{4}}}{0.49\cdot0.55}\right]\times[1-0.1]\times\frac{1}{0.55}$$

L_{ref} = 1.207E-02 [cm^3/sec]

7.5 Summary of Calculated Leakage Rates

The allowable leakage rates at the upstream pressure are determined from the release rates using Equation 6.3. The allowable leakage rates for air are presented in Table 7.1, and the allowable leakage rates for helium are presented in Table 7.2.

Table 7.1 Allowable Leakage Rates for Air

	L_X Allowable Leakage Rate [cm^3/s]
Normal Conditions	1.37E-05
Accident Conditions	8.11E-02

Table 7.2 Allowable Leakage Rates for Helium

	L_X Allowable Leakage Rate [cm^3/s]
Normal Conditions	1.37E-05
Accident Conditions	8.11E-02

The allowable leakage rates at the upstream pressure are then converted to the leakage rate at the average pressure using the method described previously. The resulting standard leakage rates are presented in Table 7.3 for air and Table 7.4 for helium. In addition, Tables 7.3 and 7.4 also present the sensitivities for the leakage test procedures for air and helium, respectively, which are calculated from Equation 6.7.

Table 7.3 Standard Leakage Rates for Air

Standard Leakage Rate [ref-cm3/sec]		Sensitivity [ref-cm3/sec]	
Normal	Accident	Normal	Accident
6.154E-06	1.619E-02	3.077E-06	8.093E-03

Table 7.4 Standard Leakage Rates for Helium

Standard Leakage Rate [ref-cm3/sec]		Sensitivity [ref-cm3/sec]	
Normal	Accident	Normal	Accident
7.848E-06	1.207E-02	3.924E-06	6.034E-03

7.6 Containment Boundary Test Requirements for Maintenance, Fabrication, Periodic and Pre-Shipment

The following leakage tests are conducted on the RT-100 package as required by ANSI N14.5:

Table 7.5 Leakage Tests of the RT-100 Package

Test	Frequency	Test Gas	Acceptance Criteria

Maintenance	After maintenance, repair (such as weld repair), or replacement of components of the containment system	Helium	$\leq L_{He}^*$
Fabrication	Prior to the first use of the RT-100		
Periodic	Within 12 months prior to each shipment		
Pre-Shipment	Before each shipment, after the contents are loaded and the package is closed	Nitrogen or air (optional)	Sensitivity $\leq 10^{-3}$ ref-cm^3/sec

*Adjusted for the individual properties of the test gas; sensitivity is $\leq L_{He}/2$

As shown in Table 7.5, the Maintenance, Fabrication, and Periodic leakage tests may be performed using helium as the tracer gas. The acceptance criterion for these tests is the reference air leakage rate, L_{He}, which is calculated below.

7.6.1 Determination of Equivalent Reference Leakage Rate for Helium Gas

This section determines the allowable leakage rate using the helium gas which may be used to perform the annual verification leakage tests summarized in Table 7.5 above. This calculation uses formulas presented in ANSI N14.5 [4].

It is known that the reference air leakage rate, L_R, is 6.154×10^{-6} ref-cm^3/sec as calculated previously. The maximum diameter hole through the O-ring corresponding to this leakage rate, D_{max1}, is 4.25×10^{-4} cm. So,

$L_R = 6.154 \times 10^{-6}$ ref-cm^3/sec $\qquad D_{max1} = D_{max} = 4.25\times 10^{-4}$ cm

The equivalent air/helium mixture that would leak from D_{max} during a leak test as described in Table 7.5 is determined. Assume the cask void is evacuated to 0.3 atm and then pressurized to 1.1 atm with an air/helium mixture.

$P_{void} = P_{air} = 0.3$ atm

$P_{mix} = 1.1$ atm

$P_{He} = P_{mix} - P_{air} = 0.8$ atm

The downstream pressure, P_d, under standard conditions is 0.01 atm.

$P_a = 0.5 \times (P_{mix} + P_d) \rightarrow P_a = 0.555$ atm

From ANSI N14.5- 1997 Table B.1:

$M_{He} = 4.0$ g/mol $\qquad M_{air} = 29.0$ g/mol

$\mu_{He} = 0.0198$ cP $\qquad \mu_{air} = 0.0185$ cP

The mass of the mixture of air/helium gases is then determined:

$$M_{mix} = \frac{M_{He}P_{He} + M_{air}P_{air}}{P_{mix}} \rightarrow M_{mix} = 10.82 \text{ g/mol}$$ Equation B.7- ANSI N14.5

$$\mu_{mix} = \frac{\mu_{He}P_{He} + \mu_{air}P_{air}}{P_{mix}} \rightarrow \mu_{mix} = 0.0194 \text{ cP}$$ Equation B.8- ANSI N14.5

Determine L_{mix} as a function of temperature. Assume that the viscosities of air and helium do not change significantly over the range of temperatures evaluated.

Temperature range for test = T = 273-328 K, or equivalently 32°F to 130°F.

$$F_c(D_{max}) = \frac{2.49 \cdot 10^6 \cdot (D_{max})^4}{a \cdot \mu_{mix}}$$ Equation B.3 from ANSI N14.5-1997

$$F_m(T) = \frac{3.81 \cdot 10^3 \cdot (D_{max})^3 \sqrt{\frac{T}{M_{mix}}}}{a \cdot P_a}$$ Equation B.4 from ANSI N14.5-1997

$$L_{mix}(T) = (F_c + F_m(T)) \cdot (P_{mix} - P_d) \cdot \frac{P_a}{P_{mix}}$$ Equation B.5 from ANSI N14.5-1997

Convert the test temperature to Fahrenheit: $T_F(T) = [(T - 273) \cdot \frac{9}{5} + 32]$ °F

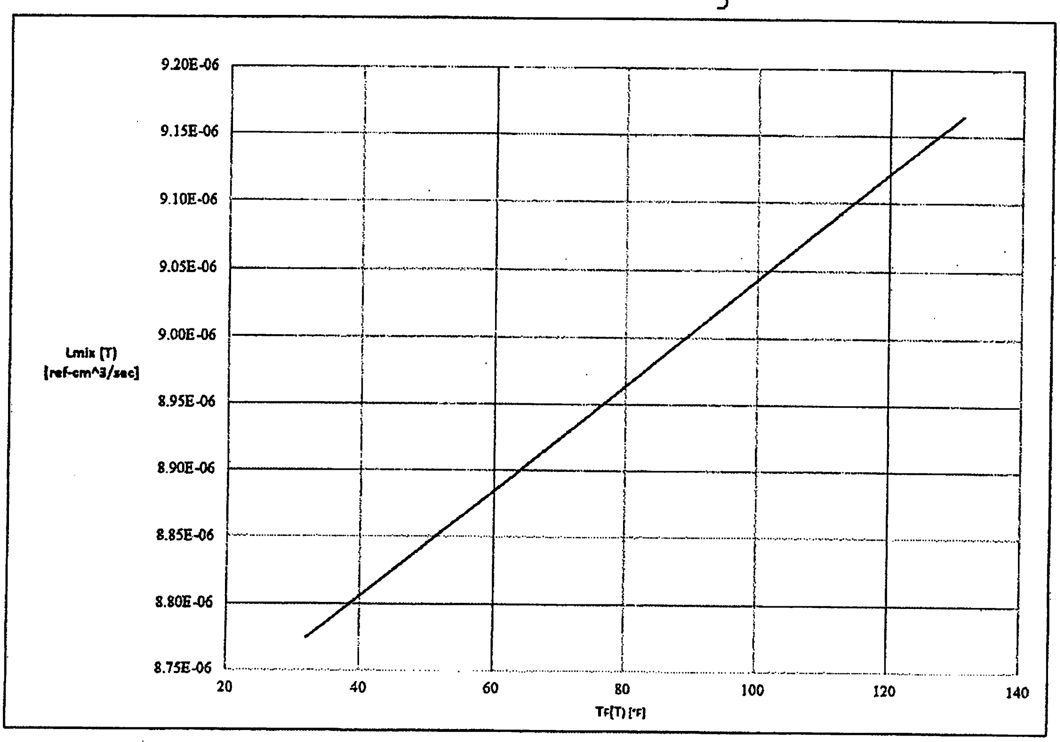

Figure 7.1 Allowable air/helium mixture test leakage rate, cm^3/sec versus air temperature, °F

The helium component of this leak rate is determined by multiplying the leak rate of the mixture by the ratio of the helium partial pressure to the total mix pressure.

$$L_{He}(T) = L_{mix}(T) \cdot \frac{P_{He}}{P_{mix}}$$

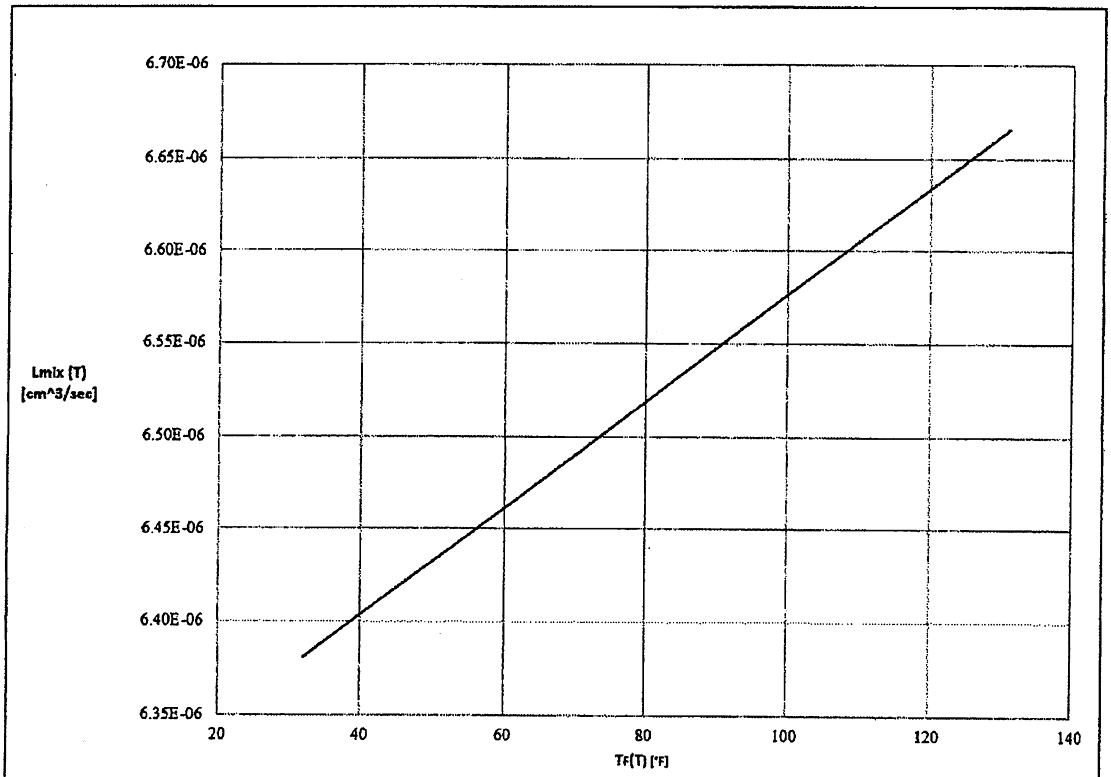

Figure 7.2 Allowable helium test leakage rate, cm^3/sec versus air temperature, °F

Figure 7.2 should be used to determine the allowable leak rate, L_{He}, for the maintenance, fabrication, and periodic leak tests of the RT-100 package.

The Fabrication leakage tests are performed on the entire containment boundary including the closure lid, the vent port, the cask inner shell and base plate, and the associated weldment.

The Maintenance and Periodic leakage tests are performed on the closure lid and the vent port. They are generally performed as follows:

Proprietary Information

Figure Withheld Under 10 CFR 2.390

Figure 7.3 Periodic Leak Test of Closure Lid[5, Section F-F]

The void space in the cavity is pressurized with a test gas using the vent port in the lid. Some of the volume of the cavity may be temporarily filled to reduce the volume of test gas required to conduct the test. Using the test port in the lid, the inner (containment boundary) o-ring is then checked for leaks.

Proprietary Information

Figure Withheld Under 10 CFR 2.390

Figure 7.4 Periodic Leak Test of Vent Port[5, Section H-H]

The void space in the cavity is pressurized with a test gas using the drain port. Some of the volume of the cavity may be temporarily filled to reduce the volume of test gas required to conduct the test. The inner (containment boundary) vent port cover plate o-ring is then checked for leaks.