

4. CONTAINMENT

This chapter describes the containment configuration and test requirements for the 10-160B Cask. Both normal conditions of transport and hypothetical accident conditions are discussed.

4.1 Containment Boundary

4.1.1 Containment Vessel

The package containment vessel is defined as the inner shell of the shielded transport cask and the primary and secondary lids together with the associated o-ring seals and lid closure bolts. The inner shell of the cask, or containment vessel, consists of a right circular cylinder of 68 inches inner diameter and 77 inches inside height (nominal dimensions). The shell is fabricated of an outer shell of 2-inch thick steel plate, a 1 7/8 inch layer of lead, and an inner shell of 1 1/8 – inch thick steel. The cylindrical shell is attached at the base to a circular end plate construction with full penetration welds. The primary lid is attached to the cask body with 24, 1 3/4 inch 8 UN bolts. A secondary lid covers the 31 inch opening in the primary lid and is attached to the primary lid using 12, 1 3/4 inch 8 UN bolts. See Section 4.1.4 for closure details.

4.1.2 Containment Penetrations

There are two penetrations of the containment vessel. These are (1) an optional drain line, and (2) an optional cask vent port located in the secondary lid. The optional drain line is located at the cask base and consists of a 1/2 inch diameter hole drilled into the stainless steel cask bottom. The optional vent port penetrates the secondary lid into the main cask cavity. Both the vent and drain are sealed at the base of the exterior opening with an elastomer Parker Stat-o-Seal and a cap screw. The exterior openings are plugged by self-sealing Teflon-coated hex socket plugs.

4.1.3 Welds

The containment vessel is fabricated from steel using full penetration welds.

4.1.4 Closure and Seals

The primary lid closure consists of a two layer steel plate construction, stepped to fit over and within the top edge of the cylindrical body. The lid is supported at the perimeter of the cylindrical body by a 3.00-inch thick plate (bolt ring) welded to the top of the inner and outer cylindrical body walls. The lid confines two (2) solid, high temperature elastomer o-rings (Parker or equivalent) in machined grooves. Groove dimensions prevent over-compression of the o-rings by the lid closure bolt preload forces and

hypothetical accident preload forces. The primary lid is attached to the cask body by 24 bolts. The primary lid is fitted with a secondary lid of similar construction attached with 12 bolts. The secondary lid is also sealed with two (2) solid, high temperature elastomer o-rings (Parker or equivalent) in machined grooves. Only the inner o-ring of each lid is part of the containment boundary.

The optional vent penetration, test ports, and drain penetrations are sealed as described in Section 4.1.2. The seal plugs in these penetrations are lockwired prior to each shipment. Table 4.1 gives the torque values for bolts and cap screws.

Table 4.1
Bolt and Cap Screw Torque Requirements

Location	Size	Torque Values +/- 10% (Lubricated)	
		In-lb	Ft-lb
Test Ports (2)	1/2 NPT	144	12
Primary Lid	1-3/4 inch, 8 UN	3600	300
Second Lid	1-3/4 inch, 8 UN	3600	300
Vent Port*	1/2 - 20 UNF	240	20
Drain Port*	1/2 - 20 UNF	240	20

*Optional - These ports may not be installed on cask.

4.2 Containment Requirements for Normal Conditions of Transport

4.2.1 Leak Test Requirements

The 10-160B cask is designed, fabricated, and leak tested to preclude a release of radioactive material in excess of the limits prescribed in NRC Regulatory Guide 7.4, paragraph C and 10CFR71.51(a)(1). The limits on leakage during normal conditions of transport are defined by 10CFR71.51(a)(1).

The leak test procedure must be able to detect leaks of 2.57×10^{-6} ref-cm³/sec (based on dry air at 25°C with a pressure differential of one atmosphere) to assure compliance with 10CFR71.51(a)(1). A description of the calculational procedure used to determine this value follows.

10CFR71.51(a)(1) states the containment requirements for normal conditions of transport as:

...no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A₂ per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging;

ANSI N14.5-1997 (Reference 4) states that the permissible leak rate shall be determined by equation 1 (below):

$$\text{(Equation 1)} \quad L = \frac{R}{C}$$

where:

L = permissible volumetric leak rate for the medium

R = package containment requirement (Ci/sec)

C = activity per unit volume of the medium that could escape from the containment system

In Section 3.4.4, it is noted that the saturated water vapor in equilibrium at 188 degrees-F and 12.2 psig could exist within the internal shipping containers (liners or drains). It is assumed that these conditions exist within the cask cavity. The containment must limit the leakage of this water vapor to that prescribed in ANSI N14.5. It is very conservative to assume that the concentration of nuclides in the free liquid is equal to that of the solids which comprise the vast majority of material being transported in the cask. This value is determined below:

$$C = \frac{\text{Total Curie Content of Vapor}}{\text{Minimum Void Volume in Cask Cavity}}$$

- Cask curie content = 3000 x A₂ or less
- Free water is limited to restriction of one-percent of solid volume
- Hence the curie content = 0.01 x 3000 A₂
- The minimum void volume occurs when the largest liner is shipped

$$\text{(Equation 2)} \quad V (\text{cask cavity}) = \frac{\pi}{4} \times 67.25^2 \times 75.75 = 269,064 \text{ in}^3$$

The largest liner will have at least ¾ inch of radial clearance and a 1½ inch of height difference, giving a volume,

$$\begin{aligned}
 \text{(Equation 3)} \quad V (\text{liner}) &= \frac{\pi}{4} \times (67.25 - 2 \times 0.75)^2 \times (75.75 - 1.5) \text{ in}^3 \\
 &= 252,103 \text{ in}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{Void Volume} &= 269,064 - 252,103 = 16,961 \text{ in}^3 \\
 &= 16,961 \text{ in}^3 \times 16.4 \text{ cm}^3/\text{in}^3 \\
 &= 278,161 \text{ cm}^3
 \end{aligned}$$

Hence,

$$\text{(Equation 4)} \quad C = \frac{30 A_2 \text{ Ci}}{278,161 \text{ cm}^3} = 1.08 \times 10^{-4} A_2 \text{ Ci/cm}^3$$

And,

$$\begin{aligned}
 \text{(Equation 5)} \quad L_n &= \frac{R_n}{C} = \frac{2.78 \times 10^{-10} A_2 \text{ Ci/sec}}{1.08 \times 10^{-4} A_2 \text{ Ci/cm}^3} \quad \text{Eqn. 3, Ref. 4} \\
 &= 2.57 \times 10^{-6} \text{ cm}^3/\text{sec}
 \end{aligned}$$

A leak rate at standard conditions will be calculated which is equivalent to a volumetric leak rate of $2.57 \times 10^{-6} \text{ cm}^3/\text{sec}$.

Equations B.3, B.4, and B.5 are used to determine the diameter of hole that would give a leak rate of $2.57 \times 10^{-6} \text{ cm}^3/\text{sec}$.

$$L_u = (F_c + F_m)(P_u - P_d) \left(\frac{P_a}{P_u} \right) \quad \text{Eqn. B.5, Reference 4}$$

$$F_m = \frac{3.81 \times 10^3 D^3 \sqrt{\frac{T}{M}}}{a P_a} \quad \text{Eqn. B.4, Reference 4}$$

$$F_c = \frac{2.49 \times 10^6 D^4}{a \mu} \quad \text{Eqn. B.3, Reference 4}$$

where:

L_u = upstream leakage rate, cm^3/sec

$$\mu_{\text{air}} = 0.0185 \text{ cP}$$

$$T = 188^\circ\text{F} = 360^\circ\text{K} \quad \text{Section 3.4.4}$$

$$P_u = 12.2 \text{ psig} = 1.83 \text{ atm}$$

$$P_d = 1.0 \text{ atm}$$

$$P_a = (1.83 + 1.0)/2 = 1.42 \text{ atm}$$

$$M_{\text{water}} = 18 \text{ g/gmole}$$

a = length of hole; assume 0.6 cm

The molecular weight of air is 29 g/gmole; using the molecular weight of water here is conservative.

Substituting into Eqns. B.3, B.4, and B.5:

$$F_c = 1.98 \times 10^8 D^4$$

$$F_m = 1.48 \times 10^4 D^3$$

$$2.57 \times 10^{-6} = (1.98 \times 10^8 D^4 + 1.48 \times 10^4 D^3)(2.05 - 1.0) \left(\frac{1.53}{2.05} \right) \quad \text{Solve for } D$$

$$D = 3.54 \times 10^{-4} \text{ cm}$$

Next, using Equation B.5 from Reference 4, determine the flow of air at standard conditions through a hole of this size. Where:

$$a = 0.6 \text{ cm}$$

$$M_{\text{air}} = 29 \text{ g/gmole}$$

$$\mu_{\text{air}} = 0.0185 \text{ cP}$$

$$P_u = 1.0 \text{ atm}$$

$$P_d = 0.01 \text{ atm}$$

$$P_a = (1.0 + 0.01)/2 = 0.505 \text{ atm}$$

$$T = 298^\circ\text{K}$$

Substituting into B.5:

$$L_{std} = 2.45 \times 10^{-6} \frac{\text{ref} - \text{cm}^3}{\text{sec}}$$

4.2.2 Pressurization of the Containment Vessel

Section 2.4.4 summarizes normal condition temperatures and pressures within the containment vessel. These pressures and associated temperatures are used to evaluate the integrity of the 10-160B package. None of these conditions reduce the effectiveness of the package containment.

4.2.3 Coolant Containment

Not applicable; there are no coolants in the 10-160B package.

4.2.4 Coolant Loss

Not applicable; there are no coolants in the 10-160B package.

4.3 Containment Requirements for Hypothetical Accident Conditions

4.3.1 Leak Test Requirements

Section 2.7 demonstrates that the 10-160B cask will maintain its containment capability throughout the hypothetical accident conditions. Fission gas products will not be carried within the cask so there can be no release of fission gases. The 10-160B cask is designed, fabricated, and leak tested to preclude a release of radioactive material in excess of the limits prescribed in NRC Regulatory Guide 7.4, paragraph C and 10CFR71.51(a)(2). The limits on leakage during normal conditions of transport are defined by 10CFR71.51(a)(2).

The leak test procedure which assures compliance with leakage during normal conditions of transport will also be sufficient to assure compliance during hypothetical accident conditions. A description follows of the calculational procedure which demonstrates that the maximum leakage requirement during normal conditions of transport is more stringent than the maximum leakage requirement during the hypothetical accident.

10CFR71.51(a)(2) states the containment requirements for the hypothetical accident conditions as:

... no escape of krypton-85 exceeding $10 A_2$ in 1 week, no escape of other radioactive material exceeding a total amount A_2 in 1 week, and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in) from the external surface of the package.

Since the cask does not carry fission products or radioactive gases, only the A_2 per week requirement is limiting. A release of A_2 in one week is equivalent to the activity release rate, R_a , given by equation 9.

(Equation 9)
$$R_a = (A_2 / \text{week})(1 \text{ week} / 168 \text{ hr})$$

$$= 5.952 \times 10^{-3} A_2 / \text{hr}$$

In Section 3.5.4, it is noted that the saturated water vapor in equilibrium at 250 degrees-F and 34.7 psig could exist within the internal shipping containers (liners or drains). It is assumed that these conditions exist within the cask cavity. The containment must limit the leakage of this water vapor to that prescribed in ANSI N14.5. It is very conservative to assume that the concentration of nuclides in the free liquid is equal to that of the solids which comprise the vast majority of material being transported in the cask. This value is determined below:

$$C = \frac{\text{Total Curie Content of Vapor}}{\text{Minimum Void Volume in Cask Cavity}}$$

- Cask curie content = 3000 x A₂ or less
- Free water is limited to restriction of one-percent of solid volume
- Hence the curie content = 0.01 x 3000 A₂
- The minimum void volume occurs when the largest liner is shipped

(Equation 10)
$$V(\text{cask cavity}) = \frac{\pi}{4} \times 67.25 \times 75.75 = 269,064$$

The largest liner will have at least ¾ inch of radial clearance and a 1½ inch of height difference, giving a volume

$$\begin{aligned}
 \text{(Equation 11)} \quad V(\text{liner}) &= \frac{\pi}{4} \times (67.25 - 2 \times 0.75)^2 \times (75.75 - 1.5) \text{ in}^3 \\
 &= 252,103 \text{ in}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{Void Volume} &= 269,064 - 252,103 = 16,961 \\
 &= 16,961 \text{ in}^3 \times 16.4 \text{ cm}^3/\text{in}^3 \\
 &= 278,161 \text{ cm}^3
 \end{aligned}$$

Hence,

$$\text{(Equation 12)} \quad C = \frac{30A_2 \text{ Ci}}{278,161 \text{ cm}^3} = 1.08 \times 10^{-4} A_2 \text{ Ci/cm}^3$$

The corresponding volumetric leak rate, L, is calculated by substituting C given by equation 12 and R_a given by equation 9 into equation 1. Equation 13 results from these substitutions.

$$\begin{aligned}
 \text{(Equation 13)} \quad L_a &= \frac{5.952 \times 10^{-3} A_2 \text{ Ci/hr}}{1.08 \times 10^{-4} A_2 \text{ Ci/cm}^3} \frac{1 \text{ hr}}{3600 \text{ sec}} \\
 &= 1.53 \times 10^{-2} \text{ cm}^3/\text{sec}
 \end{aligned}$$

The allowable leak rate during the hypothetical accident is larger than during the normal conditions of transport, $2.45 \times 10^{-6} \text{ ref-cm}^3/\text{sec}$. Thus, the leak rate for normal conditions of transport is limiting and will determine the maximum permissible leak rate during tests.

4.4 Determination of Test Conditions for Preshipment Leak Test

4.4.1 Test Method

The preshipment leak test is performed using the Gas Pressure Drop Method as shown in A.5.1, Table A-1 of ANSI N14.5-1997. The Gas Pressure Drop test is conducted on the 10-160B by pressurizing the annulus between the O-rings on the primary and secondary lids with dry air or nitrogen. If vent and drain ports are installed, these are tested by pressurizing the ports with dry air or nitrogen.

As required by ANSI N14.5, the test is conducted by holding the test pressure on the component being tested for a prescribed period of time (calculated below) and monitoring for any detectable drop in pressure. ANSI N14.5 – 1997 states (Reference 4, Table 1) that the acceptance criteria for the preshipment leak test is a leakage rate that is either less than the reference air leakage rate, L_R , or no detected leakage when tested to a sensitivity of 1×10^{-3} ref-cm³/sec. This section will show that the requirement of ANSI N14.5 is met by testing to a sensitivity of 1×10^{-3} ref-cm³/sec when performing the Gas Pressure Drop test for 15 minutes (10 minutes for vent or drain lines).

The calculations in 4.4.2 and 4.4.3 below are performed assuming dry air is the test gas, although as indicated in the above paragraph and in Chapter 8, nitrogen may be used as well. If nitrogen is the test gas used, the calculations for the required charge time in 4.4.2 and 4.4.3 below are conservative. Since air is primarily nitrogen, the physical properties of the two gases are very close. However, because the molecular weight and viscosity of nitrogen are slightly less than air's, the pressure drop experienced during the required charge time using nitrogen as the test gas will be slightly greater than for air.

	molecular wt	Viscosity (cP)	(Ref. 8)
air	29.0	.0185	
nitrogen	28.01	.0173	

4.4.2 Determining Required Charge Time for Gas Pressure Drop Test

The preshipment leak test is performed by charging the annulus of the O-rings (of the vent and drain port) with air and holding the pressure for the prescribed time. Any pressure drop larger than the minimum detectable increment on the pressure measuring instrument shall be corrected. In this section the minimum hold time is determined.

The annulus between the O-rings is pressurized with air. The annulus is centered between O-rings and is 1/8" deep and 1/8" wide with a minimum inner diameter of 68-15/16". The minimum volume of the annulus is 55 cm³.

The required hold time for the Gas Pressure Drop test is determined using Equation 15 below, which is Equation B.14 of ANSI N14.5-1997. The same hold time determined below will be used for both the primary and secondary lids. Since the volume of the secondary lid annulus is approximately 28 cm³, the test sensitivity will be greater than the primary lid's.

(Equation 15)
$$L_R = \frac{V T_s}{3600 \text{ HP}_s} \left[\frac{P_1}{T_1} - \frac{P_2}{T_2} \right]$$
 Eqn B.14, Reference 4

where:

L_R = atm-cm³/sec of air at standard conditions

V = gas volume in the test annulus cm³

T_s = reference absolute temperature, 298°K

H = test duration, hours

P_1 = gas pressure in test item at start of test, atm, abs

P_2 = gas pressure in test item at end of test, atm, abs

P_s = standard pressure = 1 atm

T_1 = gas temperature in test item at start of test, °K

T_2 = gas temperature in test item at end of test, °K

4.4.3 Required Hold Time at the Test Pressure

As discussed in Section 4.4.1 above, the maximum sensitivity for the preshipment leak test as prescribed in ANSI N14.5-1997 is 10⁻³ ref-cm³/sec. Further, ANSI N14.5-1997 states that in cases where the test sensitivity has been established and the Gas Pressure Drop test is used, the maximum permitted leak rate is:

$L \leq S/2$ Equation B-17, Reference 4

Therefore the maximum permitted leak rate for the preshipment leak test is 5 x 10⁻⁴ ref-cm³/sec. Substituting this in Eqn. B-17 above, determine the required hold time, where:

$V = 55 \text{ cm}^3$

$T_s = T_1 = T_2 = 298^\circ\text{K}$

$P_1 - P_2 = \text{pressure instrument sensitivity} = 0.1 \text{ psig}$

$$5 \times 10^{-4} = \frac{(55 \text{ cm}^3)(298^\circ \text{K})}{3600(H \text{ hr})(1 \text{ atm})} \left(\frac{0.007 \text{ atm}}{298^\circ \text{K}} \right)$$

Solve for H:

$H = 0.214 \text{ hr} = 12.8 \text{ min.}$

For conservatism, the test will be conducted for 15 minutes.

4.5 Periodic Verification Leak Rate Determination Using R-12 Test Gas

This section contains calculations to determine the periodic verification test measurement that is equivalent to the maximum permissible leak rate as determined using ANSI N14.5-1997 (Reference 4).

The purpose of this calculation is to determine the allowable leak rate using the R-12 halogen gas that may be used to perform the annual verification leak tests on the 10-160B cask.

4.5.1 Introduction

The text of this document is prepared using Mathcad, Version 6.0, software. Most conventions used in the text are the same as normal practice. A benefit of the Mathcad code is that it automatically carries all units with the variables used in the calculations. The code also allows output of variables in any form of the fundamental units (length, mass, time, etc.), allowing for automatic conversions between unit systems without the need for conversion factors. All Mathcad calculations in this Section 4.5 have been verified by hand calculations.

This calculation uses formulas presented in ANSI N14.5 - 1997.

4.5.2 Detector Sensitivity Calculation – Test Conditions

This section determines the sensitivity necessary for a leak test performed with R-12 halogen gas. This test is performed using a halogen leak detector. A leak standard, traceable to NIST, is used to calibrate the leak detector to detect the maximum allowable test leak rates specified in Figure 4.3. The test is performed as follows: The annulus between the o-ring seals of the 10-160B primary and secondary lids will be evacuated to a minimum vacuum of 20”Hg, and then be pressurized to a minimum pressure of 25 psig with R-12 halogen gas. In section 4.2.1, it was determined that the maximum possible diameter hole in the cask O-ring (D_{\max}) that would permit the standard leak rate ($L_{\text{std}} = 2.45 \times 10^{-6}$) is:

The maximum possible diameter of hole in the O-ring is:

$$D_{\max} = 3.54 \times 10^{-4} \text{ cm} \quad \text{From Section 4.2.1}$$

$$L_{\text{std}}(D) = (F_c(D) + F_m(D) \cdot (P_u - P_d) \cdot \frac{P_a}{P_d}) \quad \text{Eqn. B5 – ANSI N14.5 - 1997}$$

Determine the equivalent air/R12 mixture (L_{mix}) that would leak from D_{max} during a leak test. Assume the O-ring void is first evacuated to 20"Hg vacuum (9.92"Hg abs) and then pressurized to 25 psig (2.7 atm) with an air/R12 mixture.

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

$$P_{\text{air}} := 9.92 \cdot \text{in_Hg}$$

$$P_{\text{air}} = 0.33 \text{atm}$$

$$P_{\text{R12}} := P_{\text{mix}} - P_{\text{air}}$$

$$P_{\text{R12}} = 2.37 \text{atm} \quad P_d := 1.0 \cdot \text{atm}$$

$$P_a := \frac{P_{\text{mix}} + P_{\text{air}}}{2} \Rightarrow P_a = 1.85 \text{atm}$$

$$M_{\text{R12}} := 121 \cdot \frac{\text{gm}}{\text{mole}} \quad \text{ANSI N14.5 – 1997}$$

$$\mu_{\text{R12}} := 0.0124 \cdot \text{cP} \quad \text{ANSI N14.5 – 1997}$$

$$M_{\text{mix}} := \frac{M_{\text{R12}} \cdot P_{\text{R12}} + M_{\text{air}} \cdot P_{\text{air}}}{P_{\text{mix}}} \quad \text{Eqn. B7 - ANSI N14.5}$$

$$\Rightarrow M_{\text{mix}} = 109.7 \frac{\text{gm}}{\text{mole}}$$

$$\mu_{\text{mix}} := \frac{\mu_{\text{air}} \cdot P_{\text{air}} + \mu_{\text{R12}} \cdot P_{\text{R12}}}{P_{\text{mix}}} \quad \text{Eqn. B8 – ANSI N14.5 - 1997}$$

$$\Rightarrow \mu_{\text{mix}} = 0.0131 \text{cP}$$

Determine L_{mix} as a function of temperature. Assume the viscosities of air and R12 do not change significantly over the range of temperatures evaluated:

$$T := 273 \cdot \text{K}, 278 \cdot \text{K}.. 318 \cdot \text{K} \quad \text{Temperature range for test: } 32^\circ\text{F to } 113^\circ\text{F}$$

$$F_c := \frac{2.49 \cdot 10^6 \cdot D_{\max}^4 \cdot c \cdot P_{\text{std}}}{a \cdot \mu_{\text{mix}} \cdot \text{sec} \cdot \text{atm}}$$

then,

$$F_c = 4.84 \times 10^{-6} \frac{\text{cm}^3}{\text{atmsec}}$$

$$F_m(T) := \frac{3.81 \cdot 10^3 \cdot D_{\max}^3 \cdot \sqrt{\frac{T}{M_{\text{mix}}}} \cdot \text{cm} \cdot \text{gm}^{0.5}}{a \cdot P_a \cdot K^{0.5} \cdot \text{mole}^{0.5} \cdot \text{sec}}$$

$$L_{\text{mix}}(T) := (F_c + F_m(T)) \cdot (P_{\text{mix}} - P_{\text{air}}) \cdot \frac{P_a}{P_{\text{mix}}}$$

The R-12 component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the R-12 partial pressure to the total pressure of the mix, as follows.

$$L_{\text{R12}}(T) := L_{\text{mix}}(T) \cdot \frac{P_{\text{R12}}}{P_{\text{mix}}}$$

Determine the equivalent mass flow rate for L_{R12} in oz/yr:

$$N(T) := \frac{P_{\text{R12}} \cdot V}{R_0 \cdot T} \quad \text{Ideal Gas Law}$$

where,

$$R_0 := \frac{82.05 \text{ cm}^3 \cdot \text{atm}}{\text{mole} \cdot \text{K}}$$

This data can then be used to convert the volumetric leak rate for R-12 calculated above to a mass leak rate. By dividing N by V , the number of moles per unit volume can be multiplied by the molecular weight of the gas and the maximum allowable volumetric leak rate to determine the maximum allowable mass leak rate, as a function of test temperature as shown in the graph below. The conversion from grams per second to ounces per year is also shown below.

$$L(T) := L_{\text{R12}}(T) \cdot \frac{N(T)}{V} \cdot M_{\text{R12}} \cdot \frac{\text{yr}}{\text{oz}}$$

$$\frac{\text{gm}}{\text{sec}} = 1.113 \times 10^6 \frac{\text{oz}}{\text{yr}} \quad \text{Conversion of gm/sec to oz/yr}$$

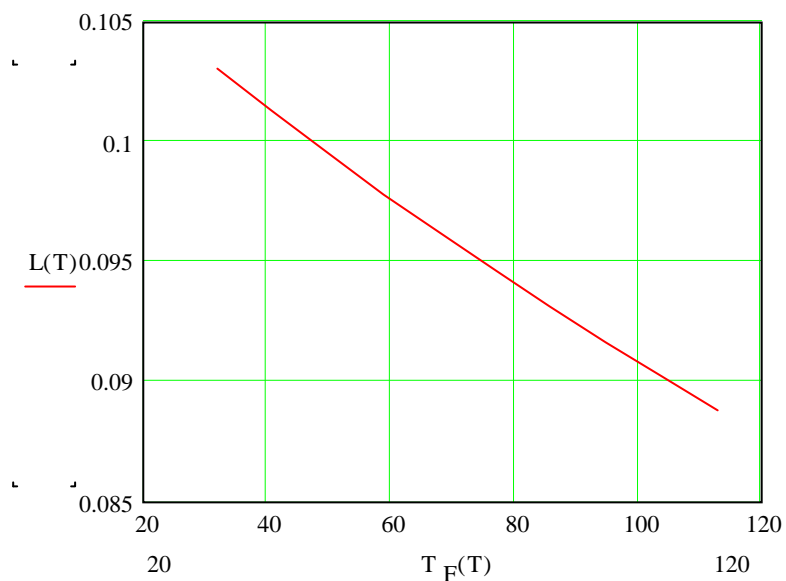


Fig.4.1 - Allowable R-12 test leakage, oz/yr, versus test temperature, deg.F

The graph above can be used to determine the allowable leak rate based on the temperature at the time of the test. According to ANSI N14.5 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity in oz/yr is presented below:

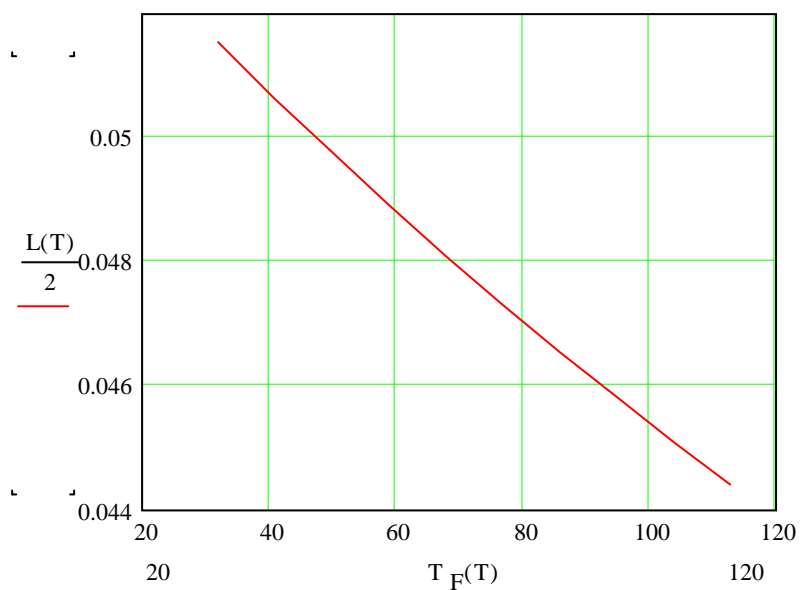


Fig.4.2 - Allowable R-12 test leakage sensitivity, oz/yr, versus test temperature, deg.F

The values presented in Figure 4.4 should be used to determine the sensitivity to calibrate the leak detector prior to the test.

4.6 Periodic Verification Leak Rate Determination Using Helium Test Gas

This section contains calculations to determine the periodic verification test measurement that is equivalent to the maximum permissible leak rate as determined using ANSI N14.5-1997 (Reference 4).

4.6.1 Introduction

The purpose of this calculation is to determine the allowable leak rate using the Helium gas that may be used to perform the annual verification leak tests on the 10-160B cask.

4.6.2 Detector Sensitivity – Test Conditions

In Section 4.2.1, it was determined that the maximum possible diameter hole in the cask O-ring (D_{\max}) that would permit the standard leak rate ($L_{\text{std}} = 2.45 \times 10^{-6}$ ref- cm^3/sec) is:

$$D_{\max} = 3.54 \times 10^{-4} \text{ cm} \quad \text{From Section 4.2.1}$$

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

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

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

$$P_{\text{He}} := 1.7 \cdot \text{atm}$$

$$P_a := \frac{P_{\text{mix}} + P_{\text{air}}}{2}$$

$$P_a = 1.85 \cdot \text{atm}$$

$$M_{\text{He}} := 4.0 \cdot \frac{\text{gm}}{\text{mole}} \quad \text{ANSI N14.5 - 1997}$$

$$\mu_{\text{He}} := 0.0198 \cdot \text{cP} \quad \text{ANSI N14.5 - 1997}$$

$$M_{\text{mix}} := \frac{M_{\text{He}} P_{\text{He}} + M_{\text{air}} P_{\text{air}}}{P_{\text{mix}}} \quad \text{Eqn. B7 - ANSI N14.5}$$

$$\Rightarrow M_{\text{mix}} = 13.26 \cdot \frac{\text{gm}}{\text{mole}}$$

$$\mu_{\text{mix}} := \frac{\mu_{\text{air}} \cdot P_{\text{air}} + \mu_{\text{He}} \cdot P_{\text{He}}}{P_{\text{mix}}} \quad \text{Eqn. B8 - ANSI N14.5}$$

$$\Rightarrow \mu_{\text{mix}} = 0.019 \cdot \text{cP}$$

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

$$T := 273 \cdot \text{K}, 278 \cdot \text{K}.. 318 \cdot \text{K} \quad \text{Temperature range for test: } 32^\circ\text{F to approx. } 113^\circ\text{F}$$

$$F_c := \frac{2.49 \cdot 10^6 \cdot D_{\text{max}}^4 \cdot \text{cP} \cdot \text{std}}{a \cdot \mu_{\text{mix}} \cdot \text{sec} \cdot \text{atm}}$$

$$F_m(T) := \frac{3.81 \cdot 10^3 \cdot D_{\text{max}}^3 \cdot \sqrt{\frac{T}{M_{\text{mix}}}} \cdot \text{cm} \cdot \text{gm}^{0.5}}{a \cdot P_a \cdot \text{K}^{0.5} \cdot \text{mole}^{0.5} \cdot \text{sec}}$$

$$L_{\text{mix}}(T) := (F_c + F_m(T)) \cdot (P_{\text{mix}} - P_{\text{air}}) \cdot \frac{P_a}{P_{\text{mix}}}$$

$$T_F(T) := \left[(T \cdot F - 273 \cdot \text{K}) \cdot \frac{9}{5 \cdot \text{K}} + 32 \right]$$

The Helium component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the Helium partial pressure to the total pressure of the mix, as follows.

$$L_{\text{He}}(T) := L_{\text{mi}}(T) \cdot \frac{P_{\text{He}}}{P_{\text{mi}}}$$

Determine the equivalent mass flow rate for L_{He} in oz/yr:

$$N(T) := \frac{P_{He} \cdot V}{R_o \cdot T} \quad \text{Ideal Gas Law}$$

where,

$$R_o := \frac{82.05 \text{ cm}^3 \cdot \text{atm}}{\text{mole} \cdot \text{K}}$$

This data can then be used to convert the volumetric leak rate for Helium calculated above to a mass leak rate. By dividing N by V , the number of moles per unit volume can be multiplied by the molecular weight of the gas and the maximum allowable volumetric leak rate to determine the maximum allowable mass leak rate, as a function of test temperature as shown in the graph below. The conversion from grams per second to ounces per year is also shown below.

$$L(T) := L_{He}(T) \cdot \frac{N(T)}{V} \cdot M_{He} \cdot \frac{\text{yr}}{\text{oz}}$$

$$\frac{\text{gm}}{\text{sec}} = 1.113 \cdot 10^6 \cdot \frac{\text{oz}}{\text{yr}} \quad \text{Conversion of gm/sec to oz/yr}$$

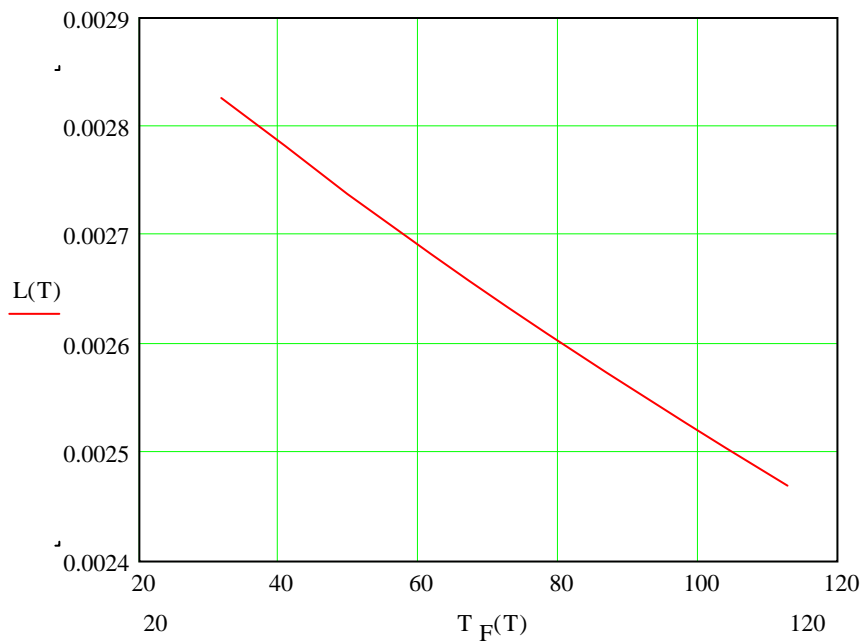


Fig.4.3 - Allowable helium test leakage, oz/yr, versus test temperature, deg.F

The graph above can be used to determine the allowable leak rate based on the temperature at the time of the test. According to ANSI N14.5 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity in oz/yr is presented below:

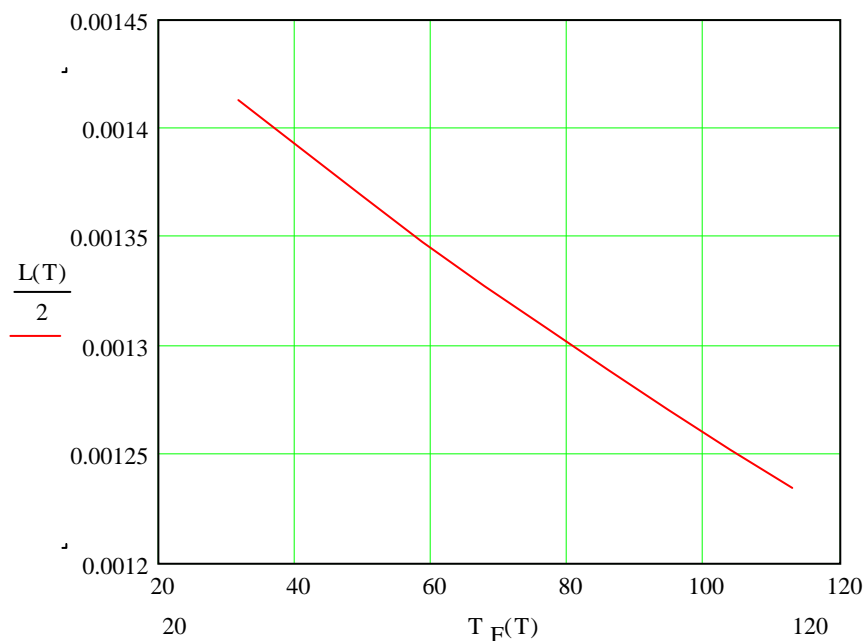


Fig.4.4 - Allowable helium test leakage sensitivity, oz/yr, versus test temperature, deg.F

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

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

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

4.7.1 Introduction

The purpose of this calculation is to determine the allowable leak rate using the R-134a halogen gas that will be used as an alternative to perform the annual verification leak tests on the 10-160B cask. This halogen gas is now in widespread use as a replacement gas for R-12 in many industrial applications. Properties for R134a are included in Appendix 4.1.

4.7.2 Detector Sensitivity Calculation - Test Conditions

This section determines the sensitivity necessary for a leak test performed with R-134a halogen gas. This test is performed using a halogen leak detector. A leak standard, traceable to NIST, is used to calibrate the leak detector to detect the maximum allowable test leak rates specified in Figure 4.11. The test is performed as follows: The annulus between the o-ring seals of the 10-160B primary and secondary lids will be evacuated to a minimum vacuum of 20"Hg, and then be pressurized to a minimum pressure of 25 psig with R-134a halogen gas. In section 4.2.1, it was determined that the maximum possible diameter hole in the cask O-ring (D_{\max}) that would permit the standard leak rate ($L_{\text{std}} = 2.45 \times 10^{-6}$) is:

$$D_{\max} = 3.54 \times 10^{-4} \text{ cm}$$

Next, determine the equivalent air/R134a mixture (L_{mix}) that would leak from D_{\max} during a leak test. Assume the O-ring void is first evacuated to 20"Hg vacuum (9.92"Hg absolute) and then pressurized to 25 psig (2.7 atm) with an air/R134a mixture.

$$P_{\text{mix}} := 2.7 \text{ atm}$$

$$P_{\text{air}} := 9.92 \text{ in}_\text{Hg}$$

$$P_{\text{air}} = 0.33 \text{ atm}$$

$$P_{\text{R134a}} := P_{\text{mix}} - P_{\text{air}}$$

$$P_{\text{R134a}} = 2.37 \text{ atm} \quad P_{\text{d}} := 1.0 \text{ atm}$$

$$P_{\text{a}} := \frac{P_{\text{mix}} + P_{\text{air}}}{2}$$

$$P_{\text{a}} = 1.85 \text{ atm}$$

The properties of R134a are given in the attached literature:

$$M_{R134a} := 102 \frac{\text{gm}}{\text{mole}}$$

$$\mu_{R134a} := 0.012 \text{ cP}$$

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

$$\Rightarrow M_{\text{mix}} = 93.04 \frac{\text{gm}}{\text{mole}}$$

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

$$\Rightarrow \mu_{\text{mix}} = 0.013 \text{ cP}$$

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

$$T := 273 \text{ K}, 278 \text{ K}.. 318 \text{ K} \quad \text{Temperature range for test: } 32^{\circ}\text{F to } 113^{\circ}\text{F}$$

$$F_c := \frac{2.49 \cdot 10^6 \cdot D_{\text{max}}^4 \cdot \text{cP} \cdot \text{ref}}{a \cdot \mu_{\text{mix}} \cdot \text{sec} \cdot \text{atm}}$$

$$F_m(T) := \frac{3.81 \cdot 10^3 \cdot D_{\text{max}}^3 \cdot \sqrt{\frac{T}{M_{\text{mix}}}} \cdot \text{cm} \cdot \text{gm}^{0.5}}{a \cdot P_a \cdot \text{K}^{0.5} \cdot \text{mole}^{0.5} \cdot \text{sec}}$$

$$L_{\text{mix}}(T) := (F_c + F_m(T)) \cdot (P_{\text{mix}} - P_{\text{air}}) \cdot \frac{P_a}{P_{\text{mix}}}$$

$$T_F(T) := \left[(T \cdot F - 273 \text{ K}) \cdot \frac{9}{5 \cdot \text{K}} + 32 \right]$$

The R-134a component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the R-134a partial pressure to the total pressure of the mix, as follows.

$$L_{R134a}(T) := L_{mix}(T) \cdot \frac{P_{R134a}}{P_{mix}}$$

Determine the equivalent mass flow rate for L_{R134a} in oz/yr, the measurement used by the detector:

$$N(T) := \frac{P_{R134a} \cdot V}{R_o \cdot T} \quad \text{Ideal Gas Law}$$

where,

$$R_o := \frac{82.05 \text{ cm}^3 \cdot \text{atm}}{\text{mole} \cdot \text{K}} \quad \text{Universal Gas Constant}$$

This data can then be used to convert the volumetric leak rate for R-134a calculated above to a mass leak rate. By dividing N by V, the number of moles per unit volume can be multiplied by the molecular weight of the gas and the maximum allowable volumetric leak rate to determine the maximum allowable mass leak rate, as a function of test temperature as shown in the graph below. The conversion from grams per second to ounces per year is also shown below.

$$L(T) := L_{R134a}(T) \cdot \frac{N(T)}{V} \cdot M_{R134a} \cdot \frac{\text{yr}}{\text{oz}}$$

$$\frac{\text{gm}}{\text{sec}} = 1.113 \times 10^6 \frac{\text{oz}}{\text{yr}} \quad \text{Conversion of gm/sec to oz/yr}$$

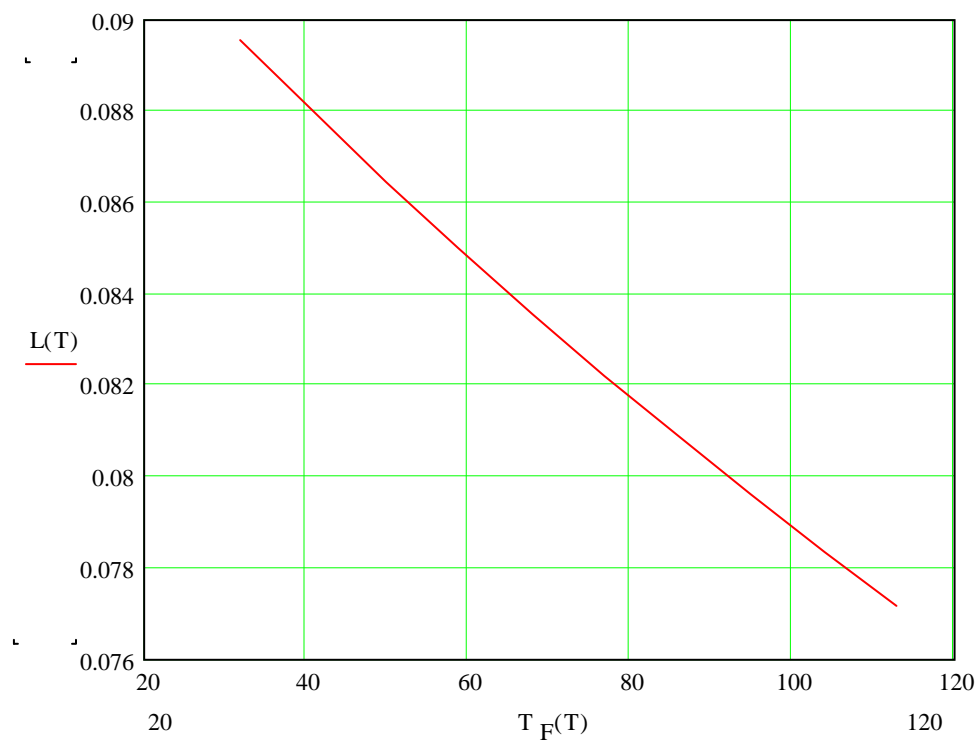


Fig.4.5 - Allowable R134a test leakage, oz/yr, versus test temperature, deg.F

The graph above can be used to determine the allowable leak rate based on the temperature at the time of the test. According to ANSI N14.5 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity in oz/yr is presented below:

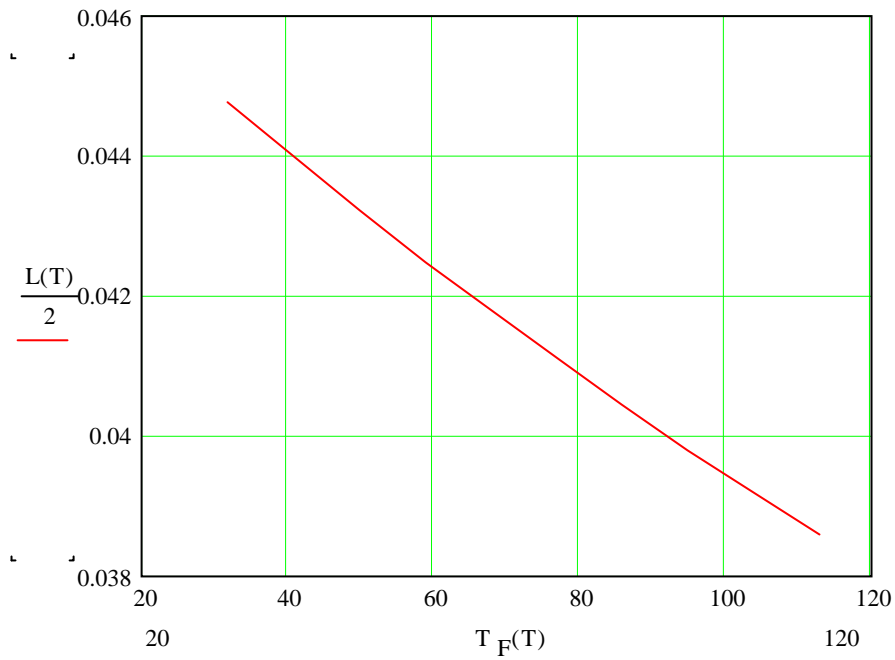


Fig.4.6 - Allowable R134a test leakage sensitivity, oz/yr, versus test temperature, deg.F

The values presented in Figure 4.12 should be used to determine the sensitivity to calibrate the leak detector prior to the test.

4.8 Combustible Gas Generation Safety Assurance

Assurance of safe shipment of vessels which may generate combustible gas is based on meeting the following criteria over the shipment period.

- i) The quantity of hydrogen generated must be limited to a molar quantity that would be no more than 5% by volume at STP (or equivalent limits for other inflammable gases) of the secondary container gas void (i.e., no more than 0.063 gram moles/cubic foot, or
- ii) The secondary container and the cask cavity (if required) must be inerted with a diluent to assure the oxygen, including that radiolytically generated, shall be limited to 5% by volume in those portions of the package which could have hydrogen greater than 5%. This criterion does not apply to TRU wastes, which shall be governed by the requirements of Appendix 4.10.2.

Criterion (i) essentially stipulates that the quantity of hydrogen shall be limited to 5% of the secondary container gas void at STP. This 5% hydrogen gas volume at standard conditions is equivalent to a hydrogen partial pressure of 0.735 psi or 0.063 gram moles/cubic foot. By actual experiment (Ref. 6), the produce an approximate 2.3 psi incremental pressure increase above a nominally atmospheric initial pressure. This is because 0.063 gram moles of hydrogen per cubic foot provides such a small source that the peak pressure rise resulting from ignition of this source is slight. (The pressure rise is independent of the total volume under test, i.e. the 0.063 gram moles per cubic foot relationship to a 2.3 psi pressure rise is valid for one or many cubic feet of specimen volume). Methodology for demonstrating compliance with the 5% hydrogen concentration limit for TRU waste is described in Appendix 4.10.2, Transuranic (TRU) Waste Compliance Methodology for Hydrogen Gas Generation. This incremental pressure rise is an inconsequential load on the cask structure.

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

4.9 Periodic Verification Leak Rate Determination for Leaktight Status

4.9.1 Introduction

The purpose of this section is to describe the method for performing a periodic leak test to demonstrate meeting the leaktight criterion per ANSI N14.5-1997. This test method is only applicable to a 10-160B cask with butyl rubber o-rings and ethylene propylene seals.

4.9.2 Test Conditions

The test is performed with a mass spectrometer leak detector. The test is conducted on the 10-160B by evacuating the cask cavity to at least 90% vacuum then pressurizing the cask cavity with helium (+1 psig, -0 psig). The annulus between the o-rings is evacuated until the vacuum is sufficient to operate the helium mass spectrometer leak detector and the helium concentration in the annulus is monitored. The acceptance criterion is 1.0×10^{-7} atm-cm³/sec of air (leaktight). The detector sensitivity must be less than or equal to 5.0×10^{-8} atm-cm³/sec. Similar tests are performed on the vent and drain ports, if so equipped.

4.11 References

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2. Mark's Standard Handbook for Mechanical Engineers, Theodore Baumeister, et. al., Eighth Edition, McGraw-Hill Book Company, New York, 1979.
3. Basic Engineering Thermodynamics, M. W. Zemansky and H. C. Van Ness, McGraw-Hill Book Company, New York, 1966.
4. American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials, American National Standards Institute, Inc., New York, ANSI N14.5-1997, 1998.
5. CRC Handbook of Chemistry and Physics, Robert C. Weast and Melvin J. Astle, eds., 62nd Edition, CRC Press, Inc., Boca Ration, Florida, 1981.
6. Flame and Detonation Initiation Area Propagation in Various Hydrogen - Air Mixtures With and Without Water Spray, L. W. Carlson, et. al., Atomic International Division of Rockwell International, Canoga Park, California, May 11, 1973.
7. Combustion, Flames and Explosions of Gases, B. Lewis and G. von Elbe, Academic Press, New York, 1961, Second Edition, Appendix B.
8. Nondestructive Testing Handbook, 2nd Ed., Vol. One, American National Standards Institute, Inc., New York, 1982.

4.10 Appendices

Appendix 4.10.1

Properties of R-134a



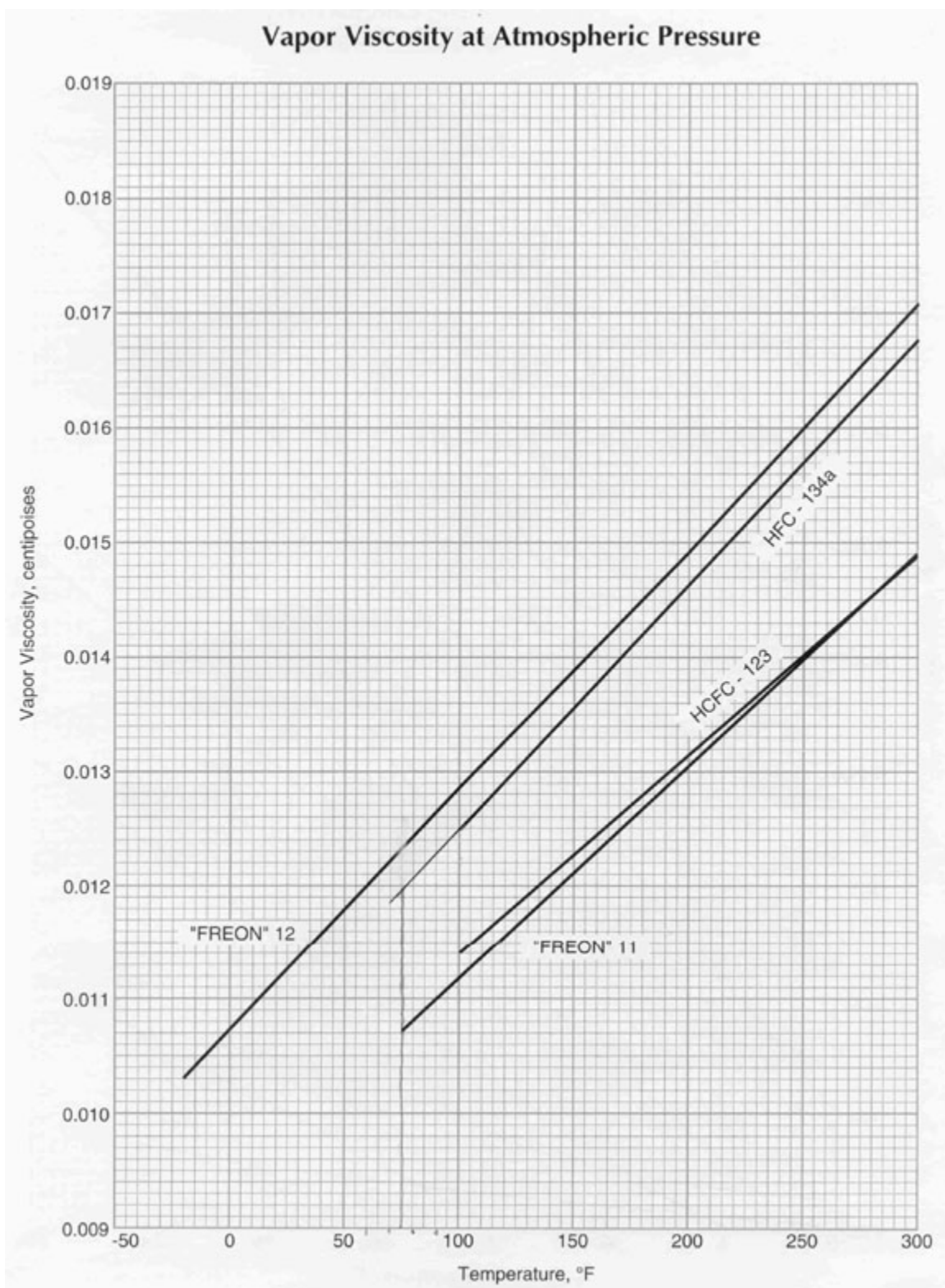
Suva®
refrigerants

P134a

DuPont HFC-134a

Properties, Uses, Storage, and Handling

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





SUVA®

REFRIGERANTS

ART - 1

PRODUCT INFORMATION

Transport Properties of SUVA® Refrigerants:

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

Viscosity
Thermal Conductivity
and
Heat Capacity
for the
Liquid and Vapor

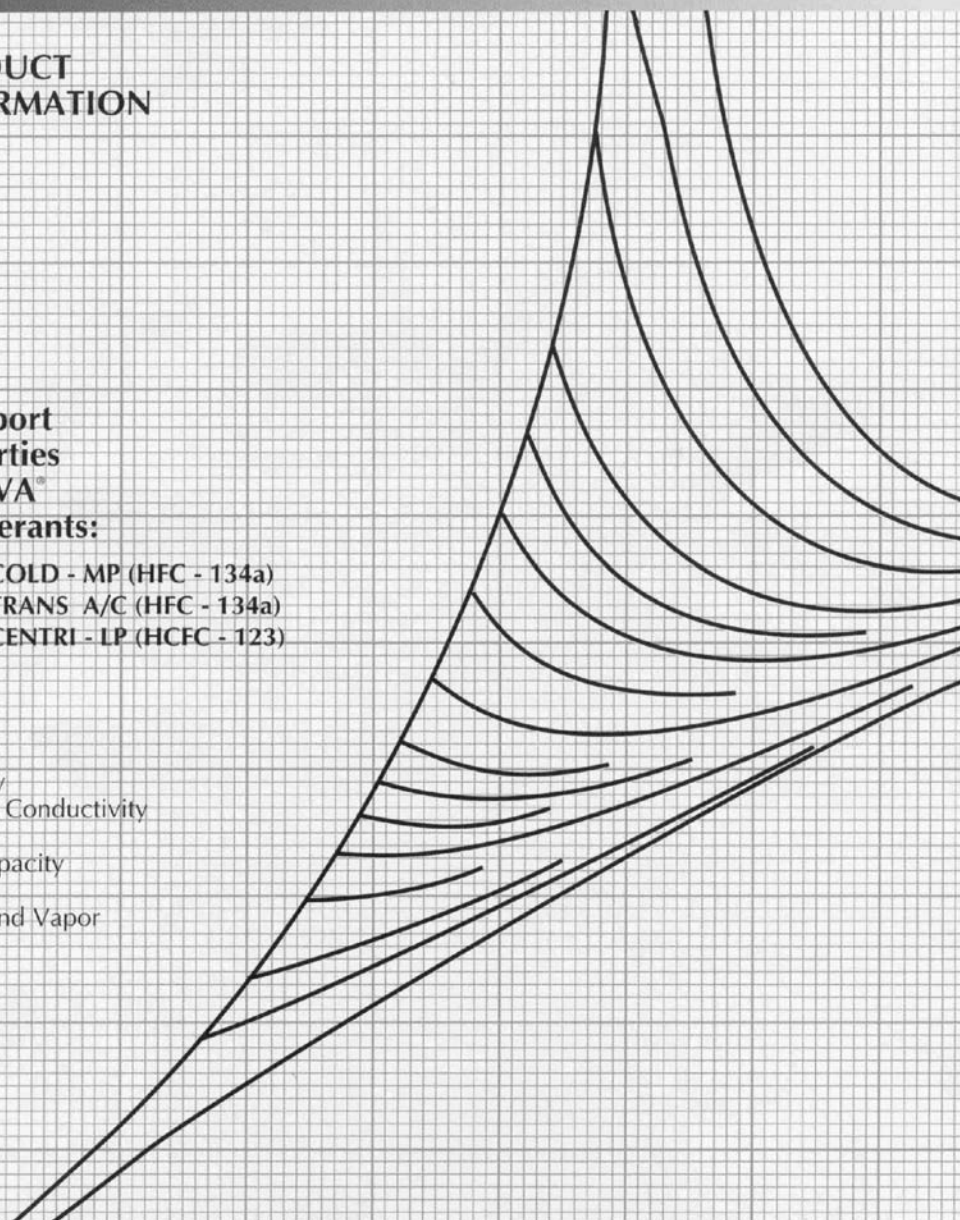


Table 2
Physical Properties of HFC-134a

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

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

Note: kPa is absolute pressure.

Appendix 4.10.2

Transuranic (TRU) Waste Compliance Methodology for Hydrogen Gas Generation