71-9204

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13 April, 2001
E&L-071-01

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

Dear Ms. Osgood:

Subj: Safety Analysis Report for the CNS 10-160B, C of C 9204, Rev. 16

Enclosed is a supplement to our application, dated 5 January 2001, for the revision to the Safety Analysis Report (SAR) for the CNS 10-160B, Certificate of Compliance (CofC) No. 9204. As we discussed, we identified some additional needed changes to the SAR to reflect various revisions in regulations and to clarify the leak testing requirements and methodology. The additional changes to the SAR include the following:

- Revision to the description of the vent and drain port in Chapter 4,
- Revision to the containment leak rate calculations of Chapter 4 to better implement the recommendations of ANSI N14.5,
- Revision to Chapters 7 & 8 modifying the method of performing the pre-shipment leak test, and
- Several updated regulation references.

All changes are indicated by a revision bar in the margin.

The following items are attached to this letter:

1. Replacement pages for Attachment 1 of our January 5 submittal:
    - Chapter 4, pages 4-1 through 4-28
2. Replacement pages for those in Revision 16 of the SAR
    - Chapter 7, pages 7-3, 7-5, 7-6, and 7-7
    - Chapter 8, pages 8-2 and 8-7

Should you or members of your staff have any questions about the application, please contact me at (803)758-1898.

Sincerely,

Mark Whittaker, CHP
Senior Analyst – Engineering & Licensing

NMSS01 Public

Replacement pages for Attachment 1 of our January 5 submittal

4-1 – 4-28

*Please replace previously submitted pages with the attached pages

# 4. CONTAINMENT

This chapter describes the containment configuration and test requirements for the CNS 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 ¾ 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, 1¾ 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 ½ 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 silicone Parker Stat-o-Seals 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 silicone 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 silicone 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 CNS 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 $3.25\times10^{-6}$ ref-cm$^3$/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 $10^{-6}$ $A_2$ 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):

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

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 168 degrees-F and 8.4 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 $A_2$ or less
- Free water is limited to restriction of one-percent of solid volume
- Hence the curie content = 0.01 x 3000 $A_2$
- The minimum void volume occurs when the largest liner is shipped

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

The largest liner will have at least ¾ inch of radial clearance and a 1½ inch of height difference, giving a volume, (Equation 3) $$V\,(\text{liner}) = \frac{\pi}{4} \times (67.25 - 2 \times 0.75)^2 \times (75.75 - 1.5)\ \text{in}^3$$

$$= 252{,}103\ \text{in}^3$$

Void Volume $= 269{,}064 - 252{,}103 = 16{,}961\ \text{in}^3$

$= 16{,}961\ \text{in}^3 \times 16.4\ \text{cm}^3/\text{in}^3$

$= 278{,}161\ \text{cm}^3$

Hence,

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

And,

(Equation 5) $$Ln = \frac{Rn}{C} = \frac{2.78 \times 10^{-10}\ A_2\ \text{Ci/sec}}{1.08 \times 10^{-4}\ A_2\ \text{Ci/cm}^3}$$ Eqn. 3, Ref. 4

$$= 2.57 \times 10^{-6}\ \text{cm}^3/\text{sec}$$

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

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

$$Lu = (Fc + Fm)(Pu - Pd)\left(\frac{Pa}{Pu}\right)$$ Eqn. B.5, Reference 4

$$Fm = \frac{3.81 \times 10^3 D^3 \sqrt{\frac{T}{M}}}{a\,Pa}$$ Eqn. B.4, Reference 4

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

where:

$L_u$ = upstream leakage rate, $cm^3/sec$

$\mu_{air}$ = 0.0185cP

T = 168°F = 349°K    Section 3.4.4

$P_u$ = 8.4 psig = 1.57 atm

$P_d$ = 1.0 atm

$P_a$ = (1.57 + 1.0)/2 = 1.28 atm

$M_{water}$ = 18 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:

$$Fc = \frac{2.49x10^6 D^4}{(0.6)(0.0185)} = 2.24 \times 10^8 D^4$$

$$Fm = \frac{3.81x10^3 D^3 \sqrt{\frac{349}{18}}}{(0.6)(1.28)} = 2.18 \times 10^4 D^3$$

$$2.57x10^{-6} = (2.24x10^8 D^4 + 2.18x10^4 D^3)(1.57 - 1.0)\left(\frac{1.28}{1.57}\right) \qquad \text{Solve for D}$$

D = 3.74 x $10^{-4}$ 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 cm

$M_{air}$ = 29 g/gmole

$\mu_{air}$ = 0.0185 cP

$P_u$ = 1.0 atm

$P_d$ = 0.01 atm

$P_a$ = (1.0 + 0.01)/2 = 0.505 atm

T = 298°K

$$Fc = \frac{(2.49x10^6)(3.74x10^{-4})^4}{(0.6)(0.0185)} = 4.38 \times 10^{-6} \frac{cm^3}{atm - sec}$$

$$F_m = \frac{(3.81x10^3)(3.74x10^{-4})^3\sqrt{\frac{298}{29}}}{(0.60)(0.505)} = 2.11 \, x \, 10^{-6} = \frac{cm^3}{atm - sec}$$

Substituting into B.5:

$$L_{std} = (4.38x10^{-6} + 2.11x10^{-6})(1.0 - 0.01)\left(\frac{0.505}{1.0}\right) = 3.25 \, x \, 10^{-6} \, \frac{ref - cm^3}{sec}$$

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 CNS 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 CNS 10-160B package.

4.2.4 Coolant Loss

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

## 4.3 Containment Requirements for Hypothetical Accident Conditions

4.3.1 Leak Test Requirements

Section 2.7 demonstrates that the CNS 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 CNS 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)
$$Ra = (A2\,/\text{week})(1\ \text{week}/168\ \text{hr}) = 5.952 \times 10^{-3}\ A2\,/\,\text{hr}$$

In Section 3.5.4, it is noted that the saturated water vapor in equilibrium at 243 degrees-F and 31.2 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 $A_2$ or less
- Free water is limited to restriction of one-percent of solid volume
- Hence the curie content = 0.01 x 3000 $A_2$
- 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,

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

Void Volume $= 269{,}064 - 252{,}103 = 16{,}961$

$= 16{,}961\ \text{in}^3 \times 16.4\ \text{cm}^3/\text{in}^3$

$= 278{,}161\ \text{cm}^3$

Hence,

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

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.

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

The allowable leak rate during the hypothetical accident is larger than during the normal conditions of transport, $3.25 \times 10^{-6}$ ref-cm$^3$/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 CNS 10-160B by pressurizing the annulus between the O-rings on the primary and secondary lids with air. If vent and drain ports are installed, these are tested by pressurizing the ports with air.

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 $1\times10^{-3}$ ref-cm$^3$/sec. This section will show that the requirement of ANSI N14.5 is met by testing to a sensitivity of $1\times10^{-3}$ ref-cm$^3$/sec when performing the Gas Pressure Drop test for 15 minutes (10 minutes for vent or drain lines).

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 cm$^3$.

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 cm$^3$, the test sensitivity will be greater than the primary lid's.

(Equation 15) $$LR = \frac{V\,Ts}{3600\,HPs}\left[\frac{P1}{T1} - \frac{P2}{T2}\right]$$ Eqn B.14, Reference 4

where:

$L_R$ = atm-cm$^3$/sec of air at standard conditions

V = gas volume in the test annulus cm$^3$

$T_s$ = 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-cm$^3$/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-cm$^3$/sec. Substituting this in Eqn. B-17 above, determine the required hold time, where:

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

$T_s = T_1 = T_2 = 298°K$

$P_1 - P_2$ = pressure instrument sensitivity = 0.1 psig

$$5x10^{-4} = \frac{(55\,\text{cm}^3)(298^o\,K)}{3600(H\ hr)(1\,\text{atm})}\left(\frac{0.007\,\text{atm}}{298°\,K}\right)$$

Solve for H:

H = 0.214 hr = 12.8 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 CNS 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 is 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 General Electric Model H-25 leak detector, along with a Yokogawa Model LS-20 leak standard containing R-12 halogen gas. The leak standard is used to calibrate the leak detector to alarm at the maximum allowable test leak rate. The test is performed by filling the region between the O-rings with 25 psig of R-12 halogen gas.

$L_{std} := 3.25\,10^{-6} \cdot ref \cdot \frac{cm^3}{sec}$ Section 4.2.1 of 10-160B SAR

Where, for air at standard conditions:

$P_a := .505 \cdot atm$

$T := 298 \cdot K$

$P_u := 1.0 \cdot atm$

$M_{air} := 29 \cdot \frac{gm}{mole}$

$P_d := .01 \cdot atm$

$\mu_{air} := 0.0185 \cdot cP$

Assume a, which is the length of the hole in the o-ring, is

From 4.2.1

$a := 0.6 \cdot cm$

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

$D_{max} := 3.74 \cdot 10^{-4} \cdot cm$ From Section 4.2.1

$$L_{std}(D) = (F_c(D) + F_m(D) \bullet (P_u - P_d) \bullet \frac{P_a}{P_d}$$ 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 pressurized to 25 psig (2.7 atm) with an air/R12 mixture.

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

$P_{air} := 1.0 \cdot at$

$P_{R12} := 1.7 \cdot atm$

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

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

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

$$M_{mix} := \frac{M_{R12} P_{R12} + M_{air} P_{air}}{P_{mix}}$$ Eqn. B7 ANSI N14.5 - 1997

$\Rightarrow$ $M_{mix} = 86.93 \cdot \frac{gm}{mole}$

$$\mu_{\mu\iota\xi} := \frac{\mu_{\alpha\iota\rho} \cdot \Pi_{\alpha\iota\rho} + \mu_{P12} \cdot \Pi_{P12}}{\Pi_{\mu\iota\xi}}$$ Eqn. B8 ANSI N14.5 - 1997

$\Rightarrow$ $\mu_{mix} = 0.015 \cdot cP$

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

$T := 273 \cdot K, 278 \cdot K .. 318 \cdot$ Temperature range for test: $32^oF$ to $113^oF$

$$F_c := \frac{2.49 \cdot 10^6 \cdot D_{max}^4 \cdot cP \cdot std}{a \cdot \mu_{mix} \cdot sec \cdot atm} \quad \Rightarrow \quad F_c = 5.539 \cdot 10^{-6} \cdot \frac{cm^3}{sec \cdot atm}$$

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

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

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

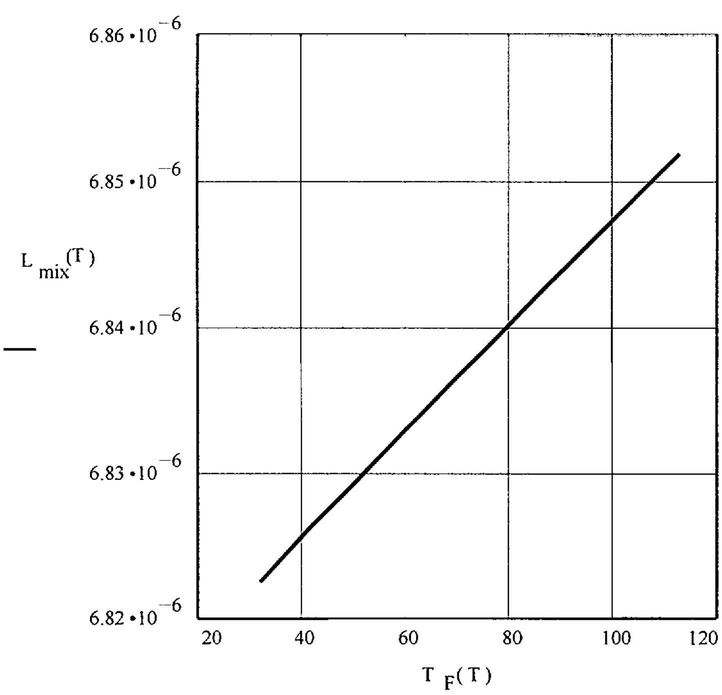


Fig.4.1 - Allowable R-12 Gas/Air Mixture Test Leakage, $cm^3$/sec, versus test temperature, deg.F

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.

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

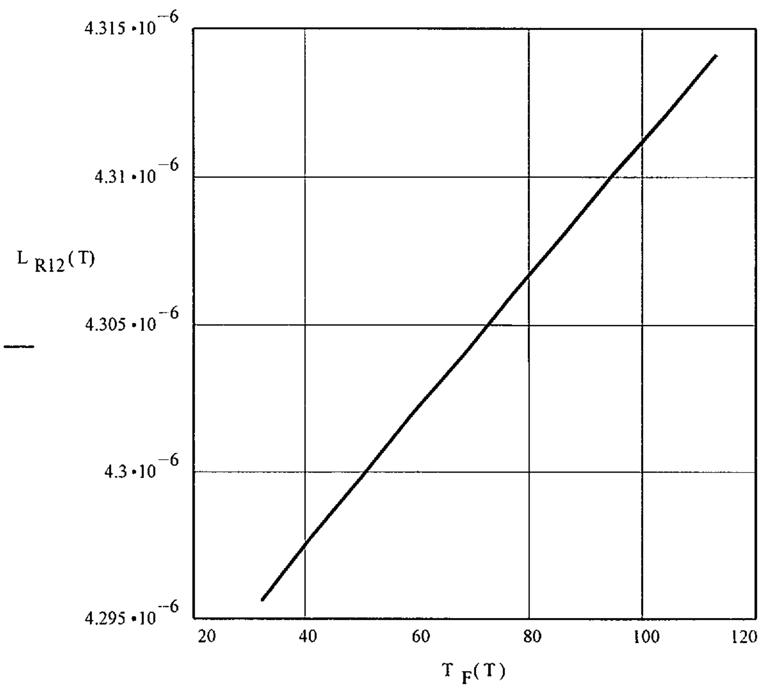


Fig.4.2 - Allowable R-12 test leakage, $cm^3$/sec versus test temperature, deg.F

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

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

where,

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

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.

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

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

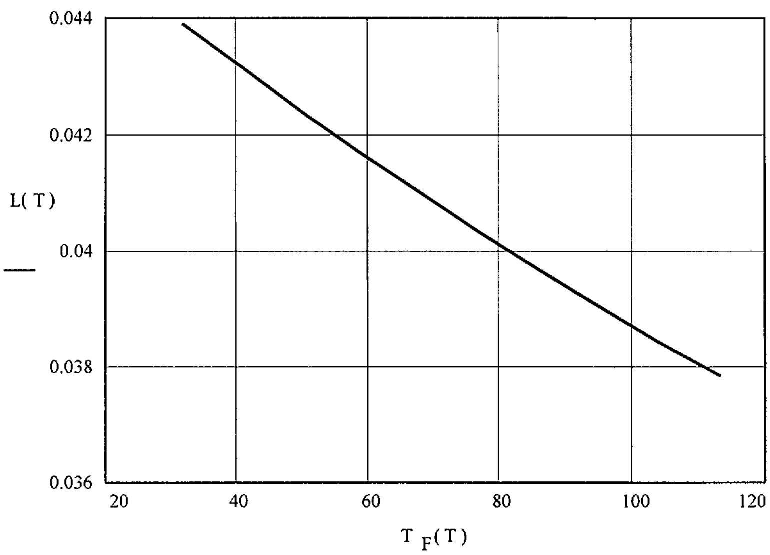


Fig.4.3 - Allowable R-12 test leakage, oz/yr, versus test temperature, deg.F

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:

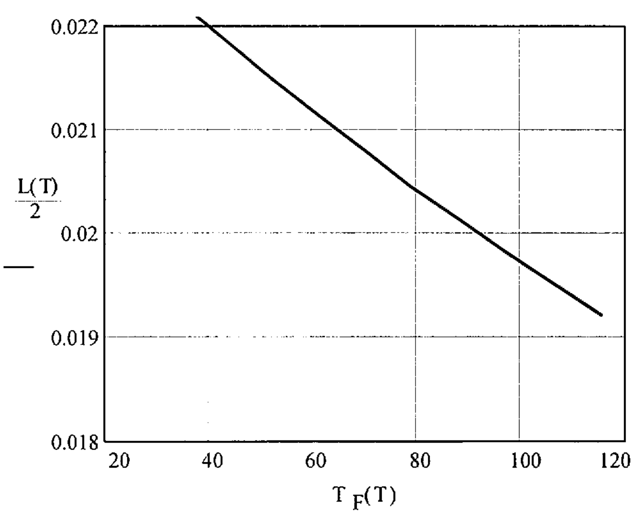


Fig.4.4 - Allowable R-12 test leakage sensitivity, oz/yr, versus test temperature, deg.F

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 CNS 10-160B cask.

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 4.6 have been verified by hand calculations.

### 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 ($L_{std} = 3.25 \times 10^{-6}$ ref- $cm^3$/sec) is:

$$D_{max} := 3.74 \cdot 10^{4} \cdot cm$$

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.

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

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

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

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

$P_a = 1.85 \cdot atm$

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

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

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

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

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

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

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:

$:= 273 \cdot K, 278 \cdot K .. 318 \cdot K$ Temperature range for test: 32°F to approx. 113°F

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

$\Rightarrow$ $F_c = 4.203 \cdot 10^6 \cdot \frac{cm^3}{sec \cdot atm}$

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

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

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

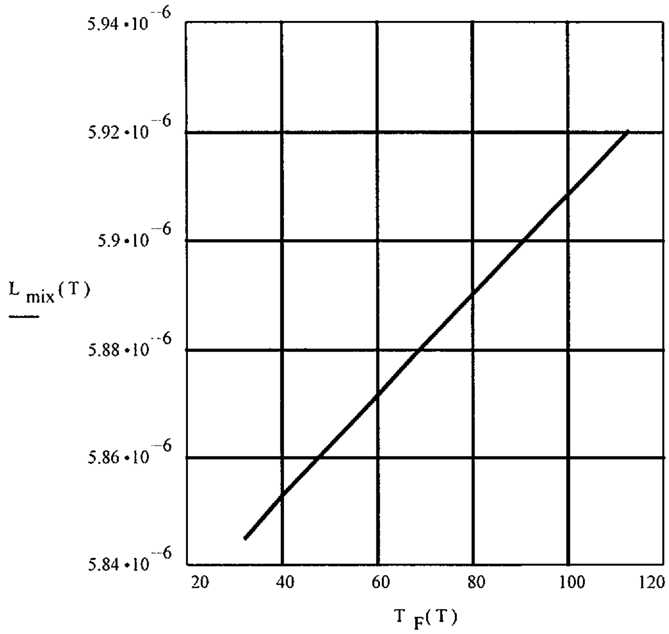


Fig.4.5 - Allowable He/Air Mixture Test Leakage, $cm^3$/sec, versus test temperature, deg.F

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.

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

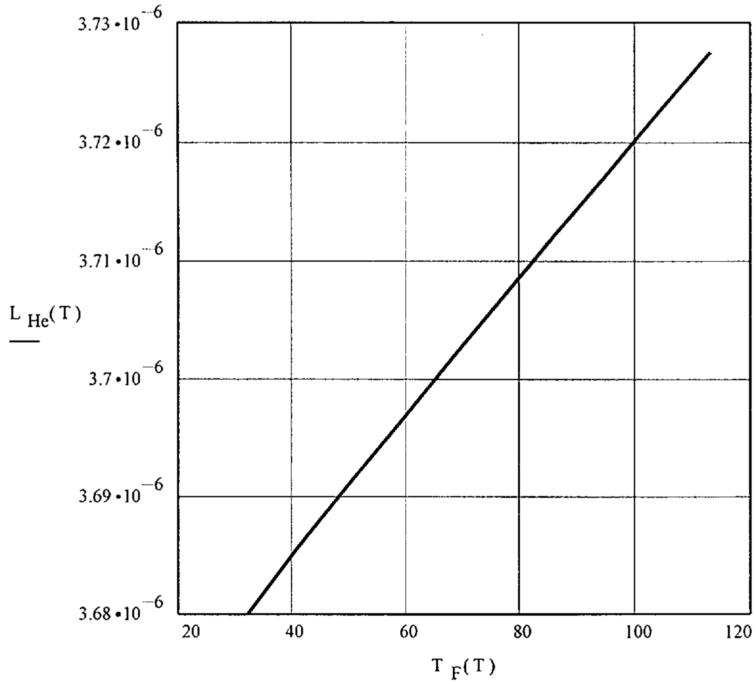


Fig.4.6 - Allowable Helium test leakage, $cm^3$/sec versus test temperature, deg.F

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

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

where,

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

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.

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

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

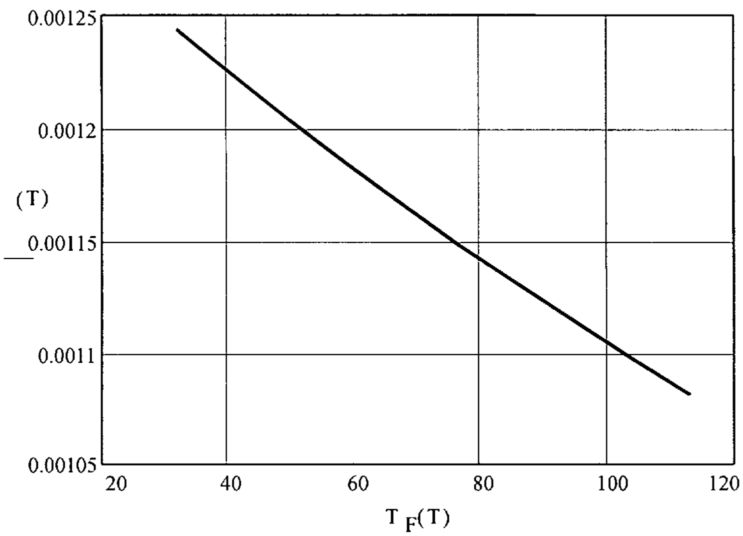


Fig.4.7 - Allowable helium test leakage, oz/yr, versus test temperature, deg.F

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:

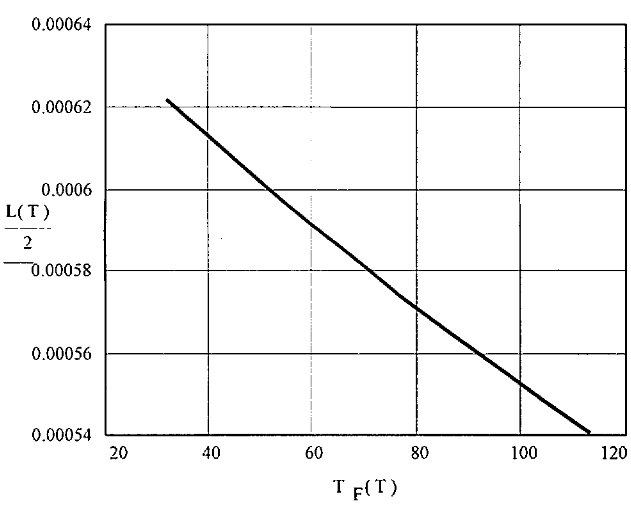


Fig.4.8 - Allowable helium test leakage sensitivity, oz/yr, versus test temperature, deg.F

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 CNS 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.

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 4.7 have been verified by hand calculations.

### 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 General Electric Model H-25 leak detector, along with a Yokogawa Model LS-20 leak standard containing R-134a halogen gas. The leak standard is used to calibrate the leak detector to alarm at the maximum allowable test leak rate. The test is performed by filling the region between the o-rings with 25 psig of 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 ($L_{std} = 3.25 \times 10^{-6}$) is:

$$D_{max} := 3.74 \cdot 10^{-4} \cdot cm$$

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 pressurized to 25 psig (2.7 atm) with an air/R134a mixture.

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

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

$$P_{R134a} := 1.7 \cdot atm$$

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

$$P_a = 1.85 \cdot atm$$

The properties of R134a are given in the attached literature (Appendix 4.1):

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

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

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

$$\Rightarrow \quad M_{mix} = 74.96 \cdot \frac{gm}{mole}$$

$$\mu_{\mu\iota\xi} := \frac{\mu_{\alpha\iota\rho} \cdot \Pi_{\alpha\iota\rho} + \mu_{P134\alpha} \cdot \Pi_{P134\alpha}}{\Pi_{\mu\iota\xi}} \qquad \text{Eqn. B8 - ANSI N14.5}$$

$$\Rightarrow \quad \mu_{mix} = 0.014 cP$$

Next, 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:

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

Substitute these properties for the air/R134a mixture and the maximum diameter hole ($D_{max}$) into equations B.3, B.4, and B.5 from ANSI N14.5:

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

$$\Rightarrow \quad F_c = 5.636 \cdot 10^{-6} \cdot \frac{cm^{3}}{sec \cdot atm}$$

$$F_m(T) = \frac{3.81\cdot 10^{3}\cdot D_{ma}^{3}\cdot\sqrt{\frac{T}{M_{mi}}}\cdot cmgm^{0.5}}{a\cdot P_a\cdot K^{0.5}\cdot mole^{0.5}\cdot sec}$$

$$L_{mix}(T) = \left(F_c - F_m(T)\right)\cdot\left(P_{mix} - P_{air}\right)\cdot\frac{P_a}{P_{mi}}$$

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

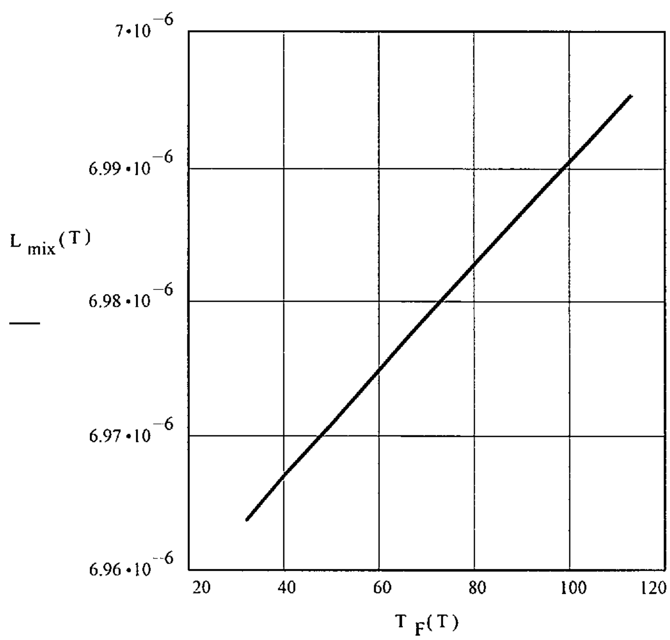


Fig.4.9 - Allowable R134a/Air Mixture Test Leakage, $m^3$/sec, versus test temperature, deg.F

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.

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

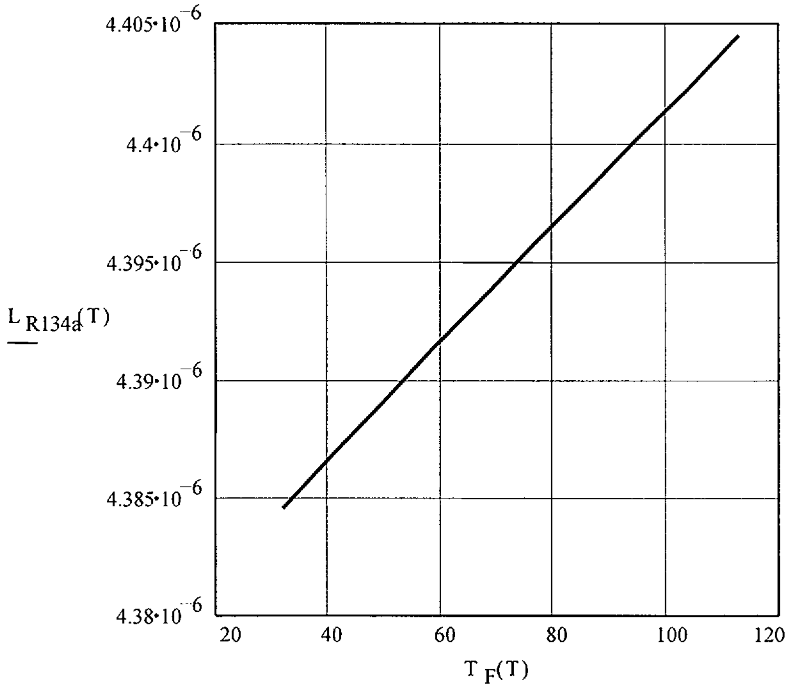


Fig.4.10 - Allowable R-134a test leakage, $cm^3$/sec versus test temperature, deg.F

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

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

where,

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

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

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

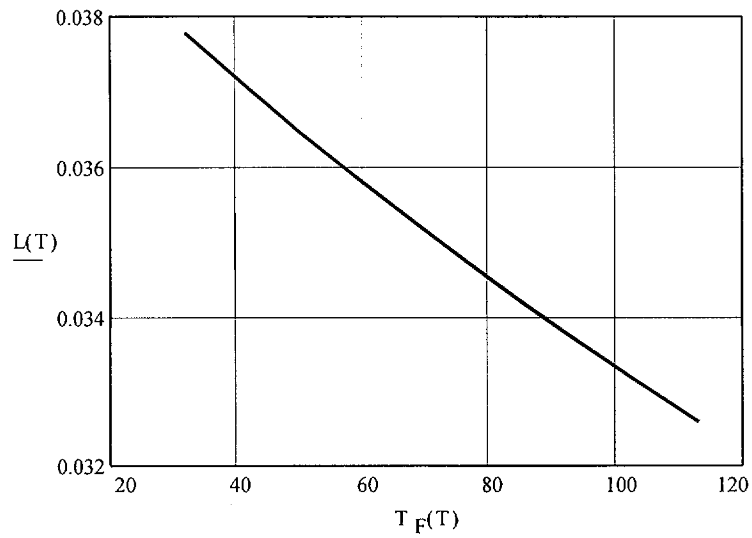


Fig.4.11 - Allowable R134a test leakage, oz/yr, versus test temperature, deg.F

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:

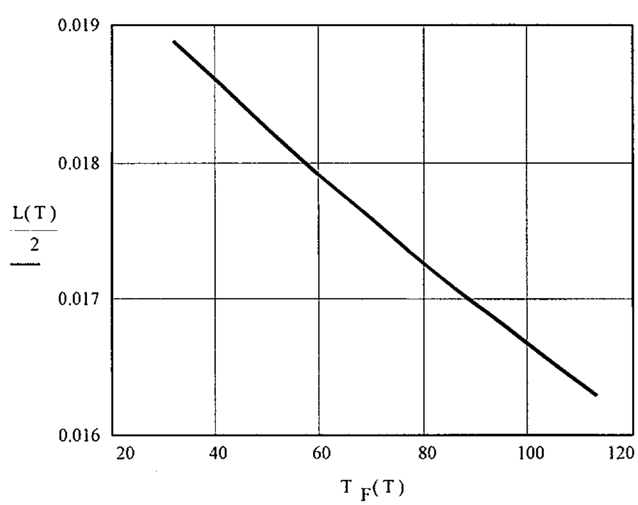


Fig.4.12 - Allowable R134a test leakage sensitivity, oz/yr, versus test temperature, deg.F

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%.

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 0063 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 References

1. Hansen Couplings, The Hansen Manufacturing Company, Cleveland, Ohio.

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.

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Replacement pages for those in Revision 16 of the SAR
Chapter 7, pages 7-3, 7-5, 7-6, and 7-7
Chapter 8, pages 8-2 and 8-7

*Please replace current revision pages with the attached pages

OPERATIONS TO PREVENT DAMAGES TO SEAL SURFACES OR THE LID

7.1.4 Visually inspect accessible areas of the cask interior for damage, loose materials, or moisture. Clean and inspect seal surfaces. Replace seals when defects or damage is noted which may preclude proper sealing.

**NOTE** **RADIOACTIVELY CONTAMINATED LIQUIDS MAY BE PUMPED OUT, REMOVED BY USE OF AN ABSORBENT MATERIAL, OR VIA DRAIN LINE. REMOVAL OF ANY MATERIAL FLOW INSIDE THE CASK SHALL BE PERFORMED UNDER THE SUPERVISION OF QUALIFIED HEALTH PHYSICS (HP) PERSONNEL WITH THE NECESSARY HP MONITORING AND RADIOLOGICAL HEALTH SAFETY PRECAUTIONS AND SAFEGUARDS.**

**NOTE** **WHEN SEALS ARE REPLACED (INCLUDING SEALS ON THE OPTIONAL VENT AND DRAIN PORTS), LEAK TESTING IS REQUIRED AS SPECIFIED IN SECTION 8.2.2.2.**

7.1.5 Check the torques on the cavity vent and drain line cap screws to determine that the cap screws are properly installed using O-rings. This step is not required if the cask does not have the optional vent and drain lines, or if the tamper seals on the vent or drain lines have not been removed. Torque the cap screws to 20 ± 2 ft-lbs.

7.1.6 Place radwaste material, disposable liners, drums, or other containers into cask and install shoring or bracing, if necessary to restrict movement of contents during transport.

7.1.7 Clean and inspect lid seal surfaces.

7.1.10.3 Reconnect cask to trailer using tie-down equipment.

7.1.11 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed.

7.1.12 Attach and hand tighten ratchet binders between upper and lower impact limiters.

7.1.13 Cover lift lugs as required.

7.1.14 Install anti-tamper seals to the designated ratchet binder.

7.1.15 Replace center plate on the upper impact limiter.

7.1.16 Inspect package for proper placards and labeling.

7.1.17 Complete required shipping documentation.

7.1.18 Prior to shipment of a loaded package the following shall be confirmed:

(a) That the licensee who expects to receive the package containing materials in excess of Type A quantities specified in 10 CFR 20.1906(b) meets and follows the requirements of 10 CFR 20.1906 as applicable.

(b) That trailer placarding and cask labeling meet DOT specifications (49 CRF 172).

(c) That all radiation and surface contamination levels are within the limits of the applicable federal regulations.

(d) That all anti-tamper seals are properly installed.

## 7.2 Procedure for Unloading Package

In addition to the following sequence of events for unloading a package, packages containing quantities of radioactive material in excess of Type A quantities specified in 10 CFR 20.1906(b) shall be received, monitored, and handled by the licensee receiving the package in accordance with the requirements of 10 CFR 20.1906 as applicable.

7.2.1 Move the unopened package to an appropriate level unloading area.

7.2.2 Perform an external examination of the unopened package. Record any significant observations.

7.2.3 Remove anti-tamper seals.

7.2.4 Loosen and disconnect ratchet binders from the upper overpack assembly.

7.2.5 Remove upper overpack assembly using caution not to damage the cask or overpack assembly.

7.2.6 If cask must be removed from trailer, refer to Step 7.1.1.

7.2.7 (Optional if vent port installed). Vent cask cavity removing plugs from the vent line.

7.2.8 Loosen and remove the twenty-four (24) 1¾" – 8 UN primary lid bolts.

7.2.9 Using suitable lifting equipment, lift lid from cask using care during handling operations to prevent damage to cask and lid seal surfaces.

**NOTE: THE CABLES USED FOR LIFTING THE LID MUST HAVE A TRUE ANGLE WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 45°.**

7.2.10 Remove contents to disposal area.

**NOTE: RADIOACTIVELY CONTAMINATED LIQUIDS MAY BE PUMPED OUT, REMOVED BY USE OF AN ABSORBENT MATERIAL, OR VIA DRAIN LINE. REMOVAL OF ANY MATERIAL FROM INSIDE THE CASK SHALL BE PERFORMED UNDER THE SUPERVISION OF QUALIFIED HEALTH PHYSICS (HP) PERSONNEL WITH THE NECESSARY HP MONITORING AND RADIOLOGICAL HEALTH SAFETY PRECAUTIONS AND SAFEGUARDS.**

7.2.11 Assemble package in accordance with loading procedure (7.1.7 through 7.1.17).

## 7.3 Preparation of Empty Packages for Transport

The Model CNS-10-160B cask requires no special transport preparation when empty. Loading and unloading procedures outlined in this chapter shall be followed as applicable for empty packages. The requirements of 49 CFR 173.428 shall be complied with.

### 8.1.3 Leak Tests

This test shall be performed prior to acceptance and operation of a newly fabricated package in accordance with ASTM E-427 using a General Electric Model H-25 Leak Detector, or a helium leak detector if helium is the test gas used. Calibration of the Model H-25 leak detector shall be made in conjunction with a General Electric Model LS-20 calibrated leak standard. The setting corresponding to the approved leak test rate will be used (see Section 4.0). The annulus between the O-ring seals of the 10-160B primary and secondary lids will be pressurized to 25 psig with pure dichlorodifluoromethane (R-12), 1,1,1,2 - tetrafluoroethane(R-134a), or helium. The detector probe shall be moved along the interior surface of the inner seals according to the specifications of ASTM E-427.

If installed, the vent and drain lines will be tested by pressurizing the inlet (cavity) side of the lines and checking for leaks at the outlet side of the cap screw.

Sensitivity at the test conditions is equivalent to the prescribed procedure sensitivity for leak-tightness of $1 \times 10^{-6}$ atm-cm$^3$/sec based on dry air at standard conditions as defined in ANSI N14.5-1987 (See Section 4.5, 4.6, or 4.7 for the determination of the test conditions). Any condition which results in leakage in excess of this value shall be corrected.

8.2.2.2 Assembly Verification Leak Test

This test is required before each shipment of Type B material quantities. The test will verify that the containment system has been assembled properly.

The test will be performed by pressurizing the annulus between the O-ring seals of either the primary or the secondary lid or the inlet to the vent and drain lines (if applicable) with air.

NOTE: PRESHIPMENT LEAKAGE RATE TESTING IS REQUIRED ONLY FOR THE CONTAINMENT BOUNDARY AREAS THAT HAVE BEEN OPENED DURING THE UNLOAD-LOADING CYCLE.

The test shall be performed using a pressure gauge, readable without estimation and calibrated to a maximum error of 1% of full scale.

The test pressure shall be applied for at least 15 minutes (10 minutes for vent or drain ports). A drop in pressure of greater than the minimum detectable amount shall be cause for test failure. The maximum sensitivity of the gauge shall be 0.1 psig.

Sensitivity at the test conditions is equivalent to the prescribed procedure sensitivity of $10^{-3}$ ref-cm$^3$/sec based on dry air at standard conditions as defined in ANSI