SAFETY ANALYSIS REPORT

FOR

CHEM-NUCLEAR SYSTEMS

MODEL CNS 8-120B

TYPE B RADWASTE SHIPPING CASK

REVISION 3

MAY 1999

CHEM-NUCLEAR SYSTEMS
CORPORATE HEADQUARTERS
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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).

4.5.1 Introduction

The purpose of this calculation is to determine the allowable leak rate using the R-12 halogen gas and R-134a that may be used to perform the annual verification leak tests on the CNS 8-120B 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 4.5 have been verified by hand calculations.

This calculation uses formulas presented in ANSI N14.5 - 1997 (Ref. 4).

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.

First, using the Standard Allowable Leak Rate from Section 4.3.2 of the SAR, determine the maximum possible diameter hole in the cask o-ring that would permit this leak rate at standard conditions.

$L_{std} = 2.09 10^{6} \cdot std \cdot \frac{cm^3}{sec}$ Section 4.3.2 of 8-120B SAR

Where, for air at standard conditions:

$T \equiv 298 \cdot K$

$P_u \equiv 1.0 \cdot atm$ Upstream test pressure

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First, using the Standard Allowable Leak Rate from Section 4.3.2 of the SAR, determine the maximum possible diameter hole in the cask o-ring that would permit this leak rate at standard conditions.

$L_{std} = 2.09 \cdot 10^{-6} \cdot std \cdot \frac{cm^3}{sec}$ Section 4.3.2 of 8-120B SAR

Where, for air at standard conditions:

$T \equiv 298 \cdot K$

$P_u \equiv 1.0 \cdot atm$ Upstream test pressure

$P_d = .01 \cdot atm$ Downstream test pressure

$P_a = .505 \cdot atm$ Average test pressure

$M_{air} = 29 \cdot \frac{gm}{mole}$ Molecular weight of air

$\mu_{air} = 0.0185 cP$ Viscosity of air

The diameter of the o-rings on the CNS 8-120B are 0.275 in. Assume a, which is the length of the hole in the o-ring is 25% of the o-ring diameter; then:

$O_{ring} = .275 \cdot in$ Diameter of the o-ring

$a = 25 \cdot \% \cdot O_{ring}$

$a = 0.175 \cdot cm$

From ANSI N14.5 - 1997:

$$F_c(D) = \frac{2.49 \cdot 10^6 \cdot D^4 \cdot cP \cdot std}{a \cdot \mu_{air} \cdot sec \cdot atm}$$ Eqn. B3 - ANSI N14.5

$$F_m(D) = \frac{3.81 \cdot 10^3 \cdot D^3 \cdot \sqrt{\frac{T}{M_{air}}} \cdot cm \cdot gm^{0.5}}{a \cdot P_a \cdot K^{0.5} \cdot mole^{0.5} \cdot sec}$$ Eqn. B4 - ANSI N14.5

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

Solve this equation iteratively for D. Therefore, the maximum possible diameter of hole in the O-ring is that would permit a leakage rate of L_{std} is:

$D_{max} = 2.355 \cdot 10^{-4} \cdot c$

Next, 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.

$P_{mix} = 2.7 \cdot atm$

$P_{air} = 1.0 \cdot atm$

$P_{R12} = 1.7 \cdot atm$

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

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

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

$M_{mix} = \frac{M_{R12} \cdot P_{R12} + M_{air} P_{air}}{P_{mix}}$ Eqn. B10 - ANSI N14.5

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

$\mu_{mix} = \frac{\mu_{air} \cdot P_{air} + \mu_{R12} \cdot P_{R1}}{P_{mix}}$ Eqn. B11 - ANSI N14.5

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

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:

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

Substitute these properties for the air/R12 mixture and the maximum diameter hole (D_{max}) into equations Eqn. B2, B3, and B5 from ANSI N14.5:

$F_c = \frac{2.49 \cdot 10^6 \cdot D_{max}^4 \cdot cP \cdot std}{a \cdot \mu_{mix} \cdot sec \cdot atm} \quad \Rightarrow \quad F_c = 2.992 \cdot 10^{-6} \cdot \frac{cm^3}{sec \cdot atm}$

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

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

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

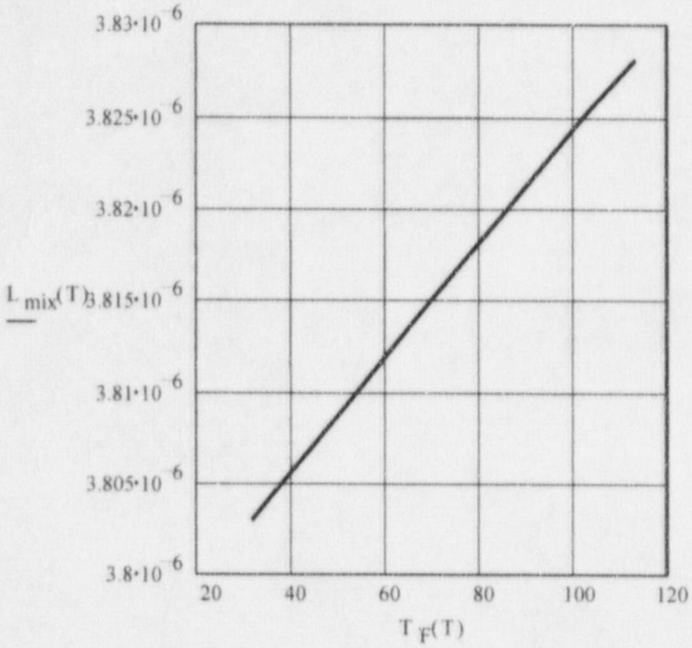

Fig.4.1 - Allowable R-12/Air Mixture Test Leakage, cm^3/sec, versus test temperature, deg.F

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.

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

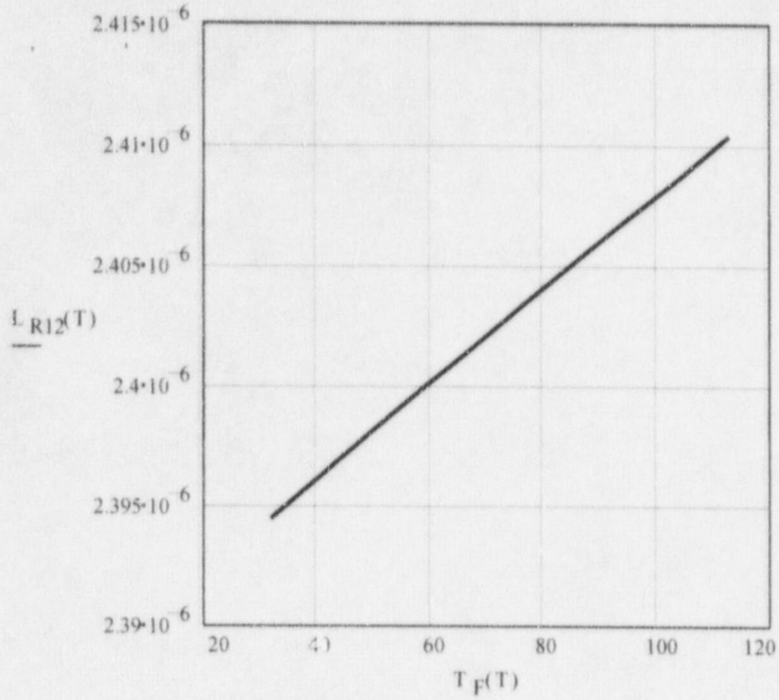

Fig.4.2 - Allowable R-12 test leakage, cm^3/sec versus test temperature, deg.F

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

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

where,

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

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.

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

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

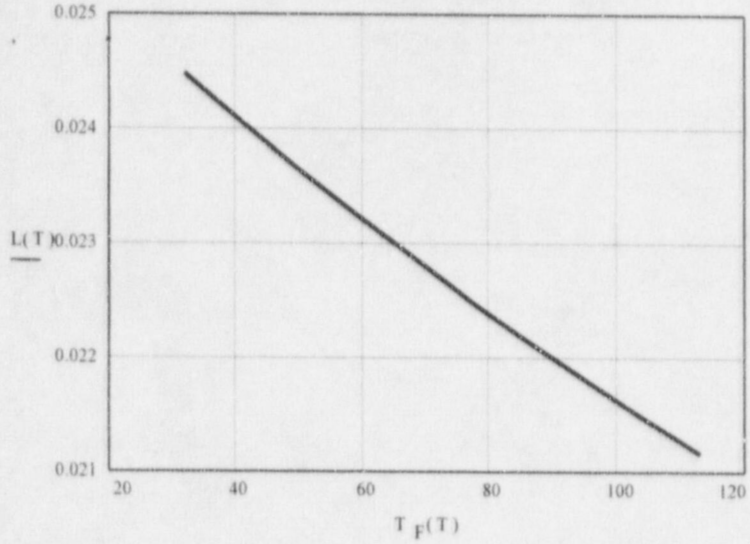

Fig.4.3 - Allowable R-12 test leakage, oz/yr, versus test temperature, deg.F

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:

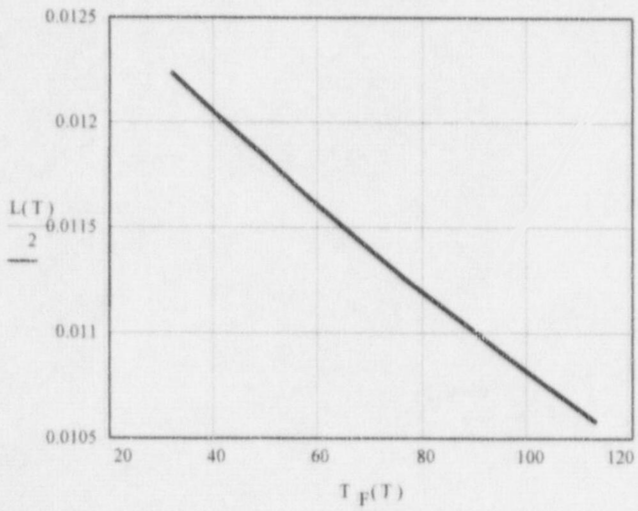

Fig.4.4 - Allowable R-12 test leakage sensitivity, oz/yr, versus test temperature, deg.F

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 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 4).

4.6.1 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 8-120B cask. This halogen gas is now in widespread use as a replacement gas for R-12 in many industrial applications. Properties for R134a are attached in Appendix 4.1.

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

4.6.2 Detector Sensitivity Calculation - Test Conditions

The test is performed by filling the region between the o-rings with 25 psig of R-134a halogen gas. In Section 4.5.2, 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} = 2.09×10^{-6} std cm^3/sec) is:

$$D_{max} = 2.355 \cdot 10^{-4} \cdot c$$

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.

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

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

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

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

The properties of R134a are:

$M_{R134a} = 102 \cdot \frac{gm}{mole}$ Appendix 4.1

$\mu_{R134a} = 0.012 \cdot cP$ Appendix 4.1

$M_{mix} = \frac{M_{R134a} \cdot P_{R134a} + M_{air} \cdot P_{air}}{P_{mix}}$ Eqn. B10 - ANSI N14.5

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

$\mu_{mix} = \frac{\mu_{air} \cdot P_{air} + \mu_{R134a} \cdot P_{R134a}}{P_{mix}}$ Eqn. B11 - ANSI N14.5

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

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:

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

Substitute these properties for the air/R134a mixture and the maximum diameter hole (D_{max}) into equations Eqn. B2, B3, and B4 from ANSI N14.5:

$F_c = \frac{2.49 \cdot 10^6 \cdot D_{max}^4 \cdot cP \cdot std}{a \cdot \mu_{mix} \cdot sec \cdot atm}$ $\Rightarrow$ $F_c = 3.044 \cdot 10^{-6} \cdot \frac{cm^3}{sec \cdot atm}$

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

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

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

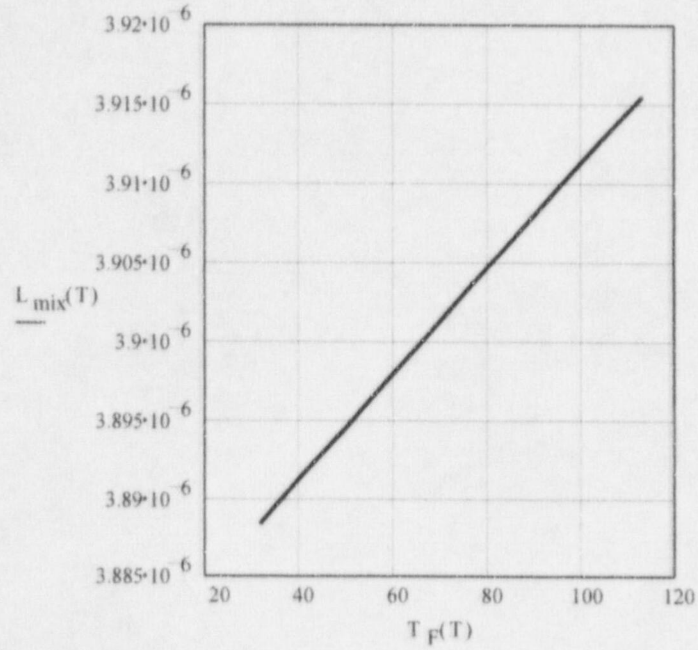

Fig.4.5 - Allowable R-134a/Air Mixture Test Leakage, cm^3/sec, versus test temperature, deg.F

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.

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

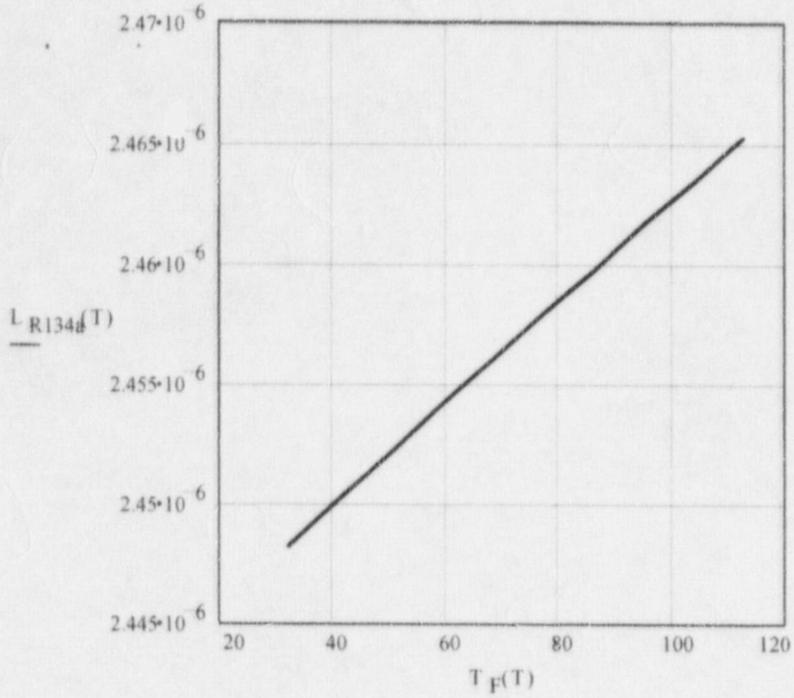

Fig.4.6 - Allowable R-134a test leakage, cm^3/sec versus test temperature, deg.F

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

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

where,

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

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.

$$L(T) = L_{R134a}(T) \cdot \frac{N(T)}{V} \cdot \text{[illegible]}_{134a} \frac{yr}{oz}$$

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

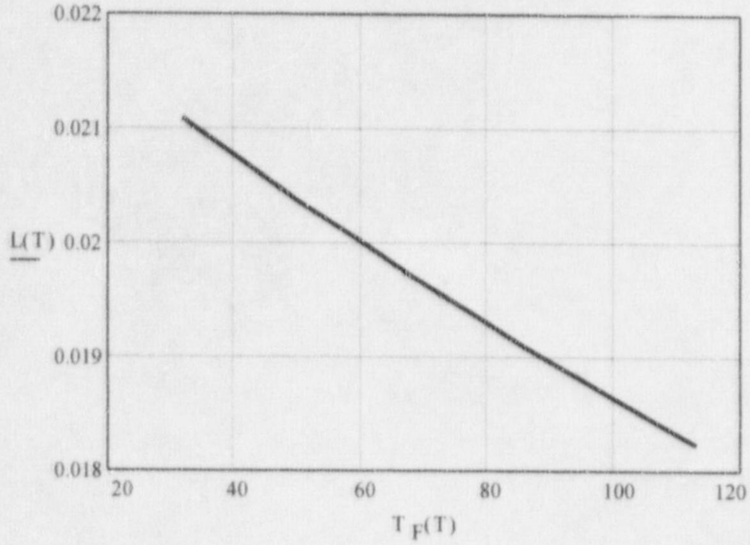

Fig.4.7 - Allowable test leakage, oz/yr, versus test temperature, deg.F

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:

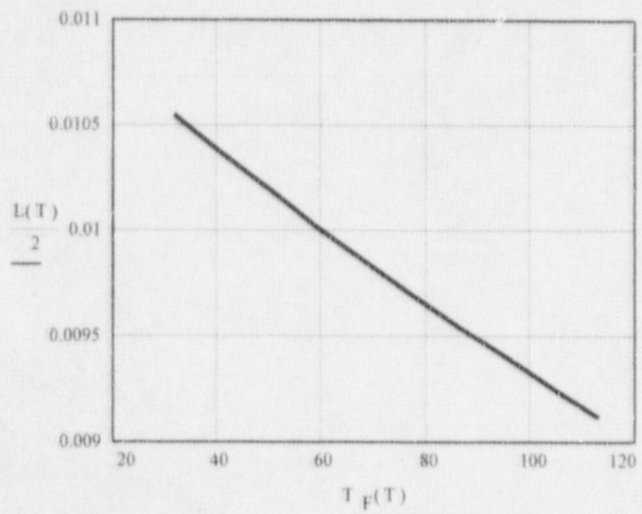

Fig.4.8 - Allowable test leakage sensitivity, oz/yr, versus test temperature, deg.F

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 References

1. Weast, Robert C. and Astle, Melvin J., Handbook of Chemistry and Physics, 63rd Edition, CRC Press, 1982.

2. Van Wylan, Gordon J. and Sonntag, Richard E., Fundamentals of Classical Thermodynamics. Second Edition, John Wiley and Sons, Inc., 1973.

3. Thomas, Lindon C., Heat Transfer - Professional Version, Prentice-Hall, Inc., 1993.

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, 1997.