SAFETY ANALYSIS REPORT

FOR
CHEM-NUCLEAR SYSTEMS, INC.

MODEL CNS 8-120B

TYPE B RADWASTE SHIPPING CASK

REVISION 1
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Chem-Nuclear Systems, Inc.
140 Stoneridge Drive
Columbia, SC 29210

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4.6 Periodic Verification Leak Rate Determination using R-134a Test Gas

This section contains calculations to determine the periodic verfication test measurement that is equivalent to the maximum permissable leak rate as determined using ANSI N14.5-1987 methodology.

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. The gas is recognized by ANSI N14.5-1987, which provides the necessary data and basis for the following calculations for the R-134a gas.

The text of the calculations in this section is prepared using Mathcad, Version 4.0, software. Most conventions used in this 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, which allows for easy identification of calculational errors. 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 calculations in this section have been verified using hand calculations.

Another convention used in this document worthy of note is the conventions used in the graphical output. The variables used for the X and Y axes in the graph are in all cases divided by the units that they are presented in. This forces the Mathcad software to use the desired units, rather than the default fundamental units. The numbers along the axes are to be read in these units. In the mass leak calculations for the R-134a gas, the graphical output is in 10^{-2} oz/yr. This point should be remembered, and all data read in the appropriate units.

4.6.2 Maximum Permissible Leak Rates at Standard Conditions

This section presents a summary of the ANSI N14.5-1987 allowable leak rate calculations which have been calculated in previous sections of this Chapter. The equation numbers from ANSI N14.5-1987 are listed beside the equation when applicable. The allowable leak rate can be calculated using the following formula:

$$L_N = \frac{R_N}{C_N}$$ (Eq 1 - ANSI N14.5-1987)

Where:

L_N is the normal condition leak rate

R_N is the 10 CFR 71.51(a)(1) allowable release rate

C_N is the volumetric radiactive material concentration in the cask

Before calculating the leak rate, the values of R and C must be determined. The allowable release rate, R, is defined in 10 CFR 71.51(a)(1) as 10^{-6} A_2 per hour. The 8-120B cask is allowed to contain up to 2000 A_2, per the requirements of 10 CFR 170.31(c)(11). Additionally, free water is assumed to be limited to 1% of the solid volume. Assuming that the activity in the water is the only that is available for release, we have 20 A_2 available for release, as calculated previously in Section 4.2.1 of the SAR. The value of C is defined as this curie content, divided by the void volume of the cask containment, as presented below.

$$R_N := 10^{-6} \cdot \frac{A_2}{hr} \qquad C_N := \frac{20 \cdot A_2}{V_{cavity}}$$

The void volume of the cavity is defined in Section 4.2.1 to be 300,000 cm^3. Therefore, the radioactive material concentration can be calculated as follows:

$$V_{cavity} = 300000 \cdot cm^3 \quad \text{and} \quad C_N = 6.67 \cdot 10^{-5} \cdot \frac{A_2}{cm^3}$$

Therefore:

$$L_N = 4.17 \cdot 10^{-6} \cdot \frac{cm^3}{sec}$$

This leak rate is the allowable for the cask under normal operating conditions. In Section 3.4.4, these conditions are assumed to be the partial pressure of the saturated water vapor at 171°F, with a total containment pressure of 8.95 psig. This leak rate can then be converted to an air leak rate at standard temperature and pressure conditions.

For the normal conditions of transport, the upstream pressure is 8.95 psig, or 1.6 atm, and the downstream pressure is atmospheric, or 1 atm. According to ANSI N14.5-1987, the standard conditions upstream and downstream pressures are 1.0 atm and 0.01 atm, respectively. The standard leak rate is calculated as follows:

$$L_{std} := L_N \cdot \frac{N_y}{N_x} \cdot \frac{\left(P_{us}^2 - P_{ds}^2\right)}{\left(P_u^2 - P_d^2\right)} \quad \text{(Eq B2 - ANSI N14.5-1987 - Derived)}$$

where:

$P_u := 1.6 \cdot atm$ (Normal Transport upstream pressure)

$P_d := 1.0 \cdot atm$ (Normal Transport downstream pressure)

$P_{us} := 1.0 \cdot atm$ (Standard Conditions upstream pressure)

$P_{ds} := 0.01 \cdot atm$ (Standard Conditions downstream pressure)

$N_y := 0.014 \cdot cP$ (Viscosity of Saturated Water Vapor at Normal Transport Conditions)

$N_x := 0.0185 \cdot cP$ (Viscosity of Air at Standard Conditions)

This equation as presented is derived from equation B2 in ANSI N14.5-1987, and can be found in this form in the 1977 version of ANSI N14.5. The F_m component of equation B2 mentioned above is assumed to be essentially zero, and the constant factors, hole diameter and hole length, cancel out when ratioing the normal transport and standard conditions values, resulting in the equation above. Substituting the values above, we can solve for the standard leak rate.

$$L_{std} = 2.02 \cdot 10^{-6} \cdot std \frac{cm^3}{sec}$$

The preceeding calculation is only valid if the flow is not choked. This can be determined by comparing the ratio of downstream to upstream pressures to the critical pressure ratio for water vapor. The critical pressure ratio is calculated as follows:

$$r_c := \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \quad \text{(Eq B6 - ANSI N14.5-1987)}$$

where:

$k = 1.33$ (Specific Heat Ratio for Water Vapor, Reference 3, page 836)

$r_c = 0.54$

Now, the downstream to upstream pressure ratio can be calculated:

$$\frac{P_d}{P_u} = 0.625 > 0.54$$

Therefore, the flow is not choked, and the use of the equation is valid.

4.6.3 Detector Sensitivity Calculation - Test Conditions

This section determines the sensitivity necessary for a leak test performed with R-134a halogen gas. The test is performed by CNSI using a General Electric Model H-25B 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. The properties of the R-134a gas and the test conditions are as follows:

$P_{R134a} = 25\ \text{psi}$ $P_{air} = 1\ \text{atm}$

$P_u = P_{R134a} + P_{air}$ (Upstream Test Pressure)

$P_d = 1\ \text{atm}$ (Downstream Test Pressure)

Before proceding, a choked flow calculation must be made to determine if the flow during the test would be choked. Using the methodology of Section 4.6.2 above, the pressure ratio for the test is calculated as follows:

$$\frac{P_d}{P_u} = 0.37$$

According to Table B1 of ANSI N14.5-1987, the critical pressure ratio for R-134a is 0.585. Therefore, the pressure ratio is less than the critical pressure ratio, and the flow is choked. Equation B2, used to correlate to standard conditions above, is for non-choked conditions and cannot be used for this calculation. Instead, equation B13 of ANSI N14.5-1987 can be used to correlate the allowable leak rate at test conditions to the standard leak rate for choked flow conditions.

where:

$k = 1.33$ (Specific Heat Ratio for Water Vapor, Reference 3, page 836)

$r_c = 0.54$

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$P_{R134a} := 25 \cdot psi$ $\quad P_{air} := 1 \cdot atm$

$P_u := P_{R134a} + P_{air}$ (Upstream Test Pressure)

$P_d := 1 \cdot atm$ (Downstream Test Pressure)

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Before performing this calculation, we must determine the material properties of the R-134a and air mixture. Using equations B9, B10, and B11 in ANSI N14.5-1987 and the partial pressures of air and R-134a gas, we can determine the pressure, molecular weight, and viscosity of the gas mixture.

$P_{mix} := P_{R134a} + P_{air}$ (R-134a and Air pressures as calculated above)

$M_{air} := 29 \cdot \frac{gm}{mole}$ (ANSI N14.5-1987)

$k_{air} := 1.4$ (ANSI N14.5-1987)

$M_{R134a} := 146 \cdot \frac{gm}{mole}$ (ANSI N14.5-1987)

$k_{R134a} := 1.1$ (ANSI N14.5-1987)

$$M_{mix} := \frac{M_{R134a} \cdot P_{R134a} + M_{air} \cdot P_{air}}{P_{mix}} \qquad M_{mix} = 102.7 \cdot \frac{gm}{mole}$$

$$k_{mix} := \frac{k_{R134a} \cdot P_{R134a} + k_{air} \cdot P_{air}}{P_{mix}} \qquad k_{mix} = 1.21$$

The maximum allowable leak rate for the mixture, and for R-134a specifically, can now be determined using the values calculated above, and equation B13 from ANSI N14.5-1987.

$T := 273 \cdot K, 278 \cdot K .. 318 \cdot K$ (Allowable temp. range for test: 32°F to ¯110°F)

$T_{conv}(T) := \left[(T - 273 \cdot K) \cdot \frac{9}{5 \cdot K} + 32 \right] \cdot F$ (Conversion from Kelvin to Fahrenheit)

$$L_{mix}(T) := \frac{L_{std}}{\sqrt{\left[\frac{0.583}{\left(\frac{k_{mix}}{k_{mix}+1} \right)} \right] \cdot \left(\frac{M_{mix}}{29 \cdot \frac{gm}{mole}} \right) \cdot \left[\frac{298 \cdot K}{(T)} \right]} \cdot \left(\frac{1 \cdot atm}{P_{mix}} \right) \cdot \frac{0.634}{\left(\frac{2}{k_{mix}+1} \right)^{\left(\frac{1}{k_{mix}-1} \right)}}}$$

(Eq B13 - ANSI N14.5-1987)

The value of the allowable leak rate of the mixture as a function of the test temperature can now be plotted:

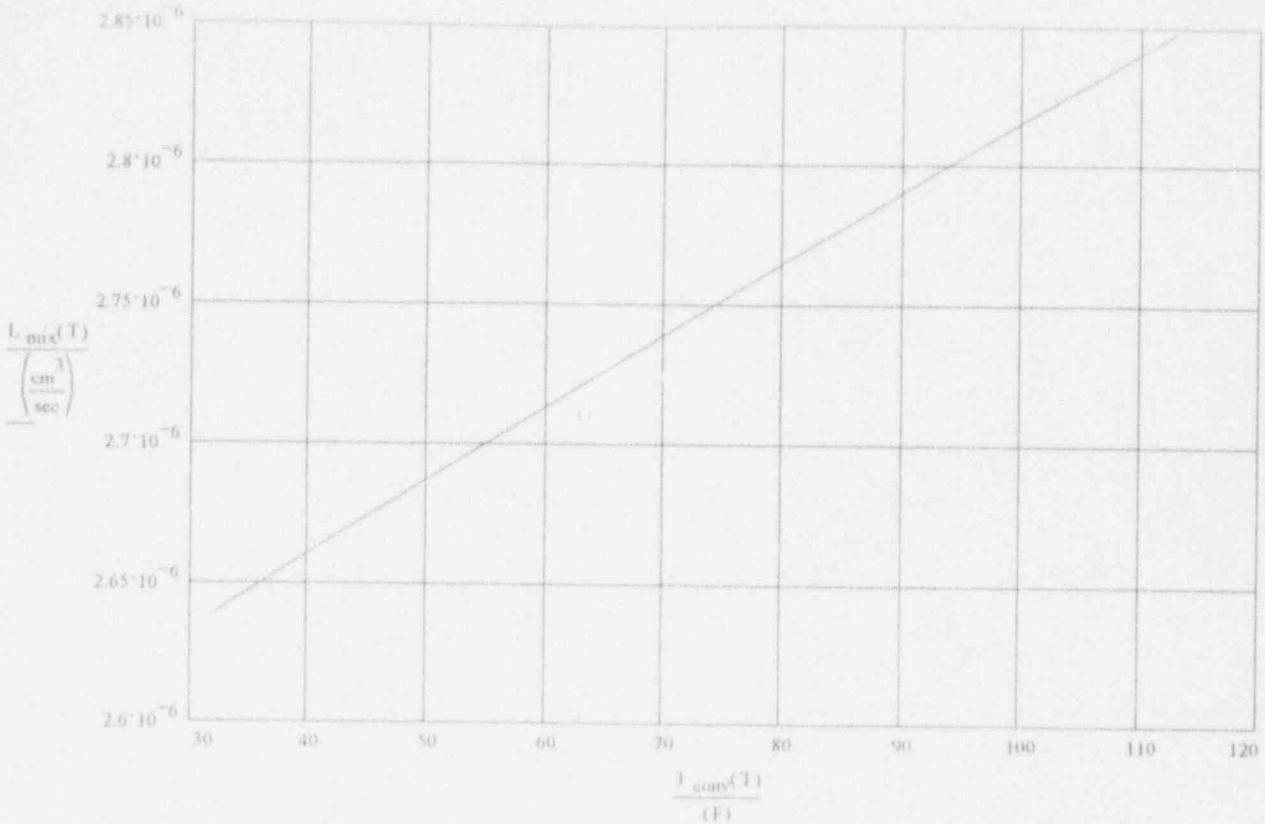

Figure 4.1 - Allowable Gas/Air Mixture Test Leakage, cm^3/sec, versus Test temperature, deg F

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.

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

Now, the allowable leak rate for R-134a can be graphed as before:

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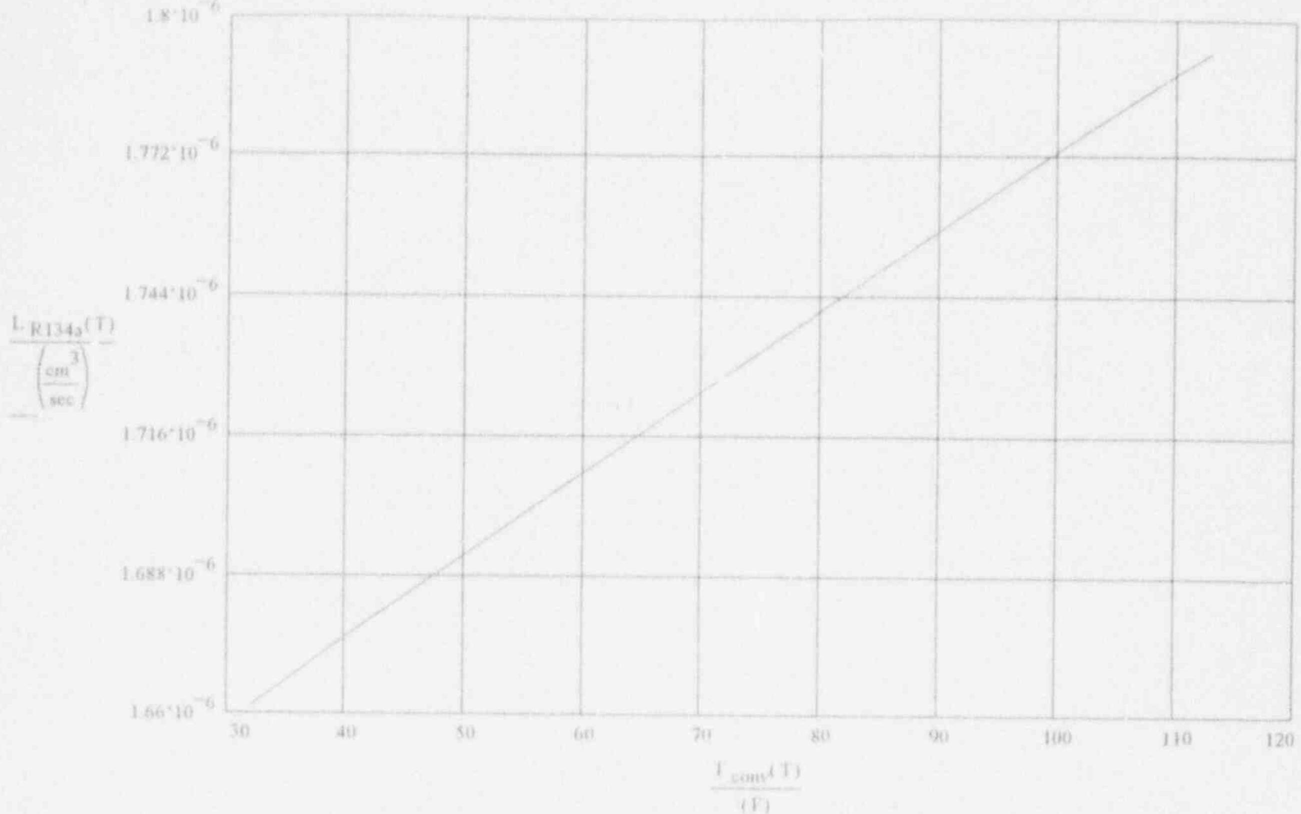

Figure 4.2 - Allowable R-134a Test Leakage, cm^3/sec, versus Test temperature, deg F

This leak test value can be converted to an equivalent value in oz/yr, the value used by the leak detector. This calculation can be performed using the ideal gas law, as follows:

$$N := \frac{P \cdot V}{R_o \cdot T}$$

where,

$P := P_{R134a}$ (Pressure of R-134a gas during test)

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

$V := 1 \cdot cm^3$ (Unit volume to determine number of moles per volume)

The above values are then used to calculate the number of moles of R-134a gas in a unit volume of the gas.

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

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.

$\frac{gm}{sec} = 1.113 \cdot 10^6 \cdot \frac{oz}{yr}$ (Conversion Factor from grams per second to ounces per year)

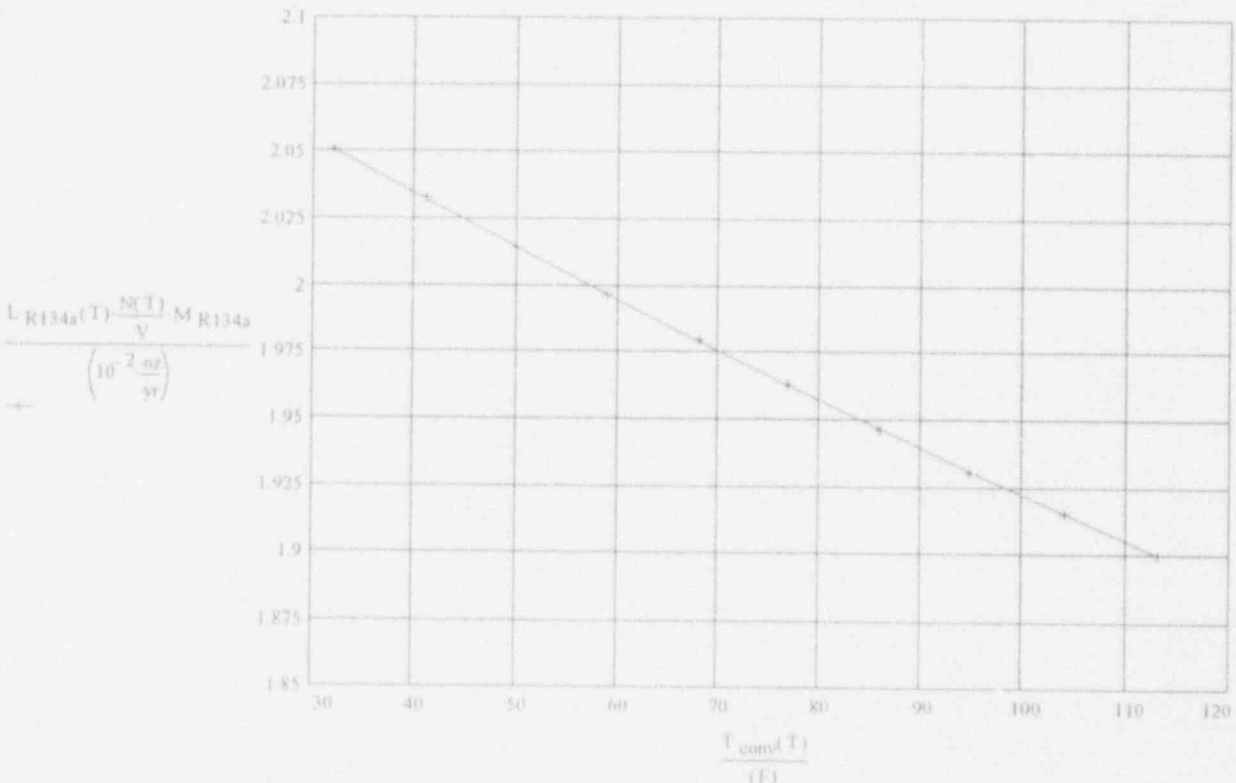

Figure 4.3 - <u>Allowable Test Leakage, oz/yr, versus Test temperature, deg F</u>

The graph above can be used to determine the maximum 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:

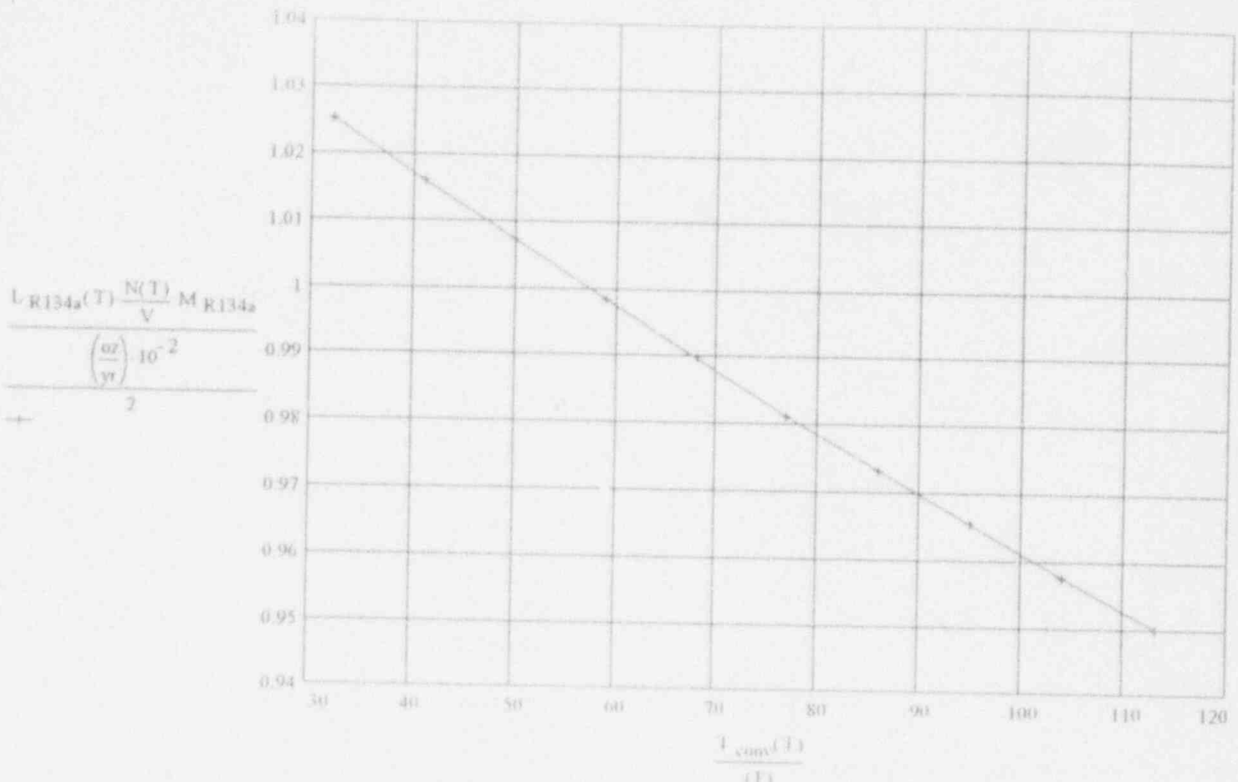

Figure 4.4 - Allowable Test Leakage sensitivity, oz/yr, versus Test temperature, deg F

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

4.7 Appendix

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

dichlorodifluoromethane (R-12) or sulfur hexafluoride (R-134a). The detector probe shall be moved along the exterior surface of the outer seals according to the specifications of ASTM E 427.

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

8.1.4 Component Tests

Gaskets and seals will be procured and examined in accordance with the CNSI Quality Assurance Program.

8.1.5 Test for Shielding Integrity

Shielding integrity of the package will be verified by gamma scan or gamma probe methods to assure package is free of significant voids in the poured lead shield annulus. All gamma scanning will be performed on a 4-inch square or less grid system. The acceptance criteria will be that voids resulting in shield loss in excess of 10% of the normal lead thickness in the direction measured shall not be acceptable.

8.1.6 Thermal Acceptance Tests

No thermal acceptance testing will be performed on the CNS 8-120B package. Refer to the Thermal Evaluation, Section 3.0 of this report.

8.2 Maintenance Program

CNSI is committed to an ongoing preventative maintenance program for all shipping packages. The 8-120B package will be subjected to routine and periodic inspections and tests as outlined in this section and CNSI approved procedures.