ATTACHMENT 3

VSC-24 HELIUM LEAKAGE ANALYSIS

(17 PAGES TOTAL)

| EnergySolutions Spent Fuel Division | CALCULATION PACKAGE | Calc. Pkg No. VSC-04.3202<br>File No.: VSC-04.3202<br>Revision: 0 |
|---|---|---|

**PROJECT/CUSTOMER:**

Generic VSC-24

**TITLE:**

He Leakage Analysis

**SCOPE:**

| | | | | |
|---|---|---|---|---|
| Product: | ☐ FuelSolutions™ | ☒ VSC-24 | | ☐ Other ______ |
| Service: | ☒ Storage | ☐ Transportation | | ☐ Other ______ |
| Conditions: | ☒ Normal | ☒ Off-Normal | ☒ Accident | ☐ Other ______ |

Component(s):

VSC-24 MSB

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Verified by:

Lazer Vandenhoek — [signature] 12-2-11

Approved by Engineering Manager:

[signature] 12/4/11

 

# RECORD OF REVISIONS

| REV. | AFFECTED PAGES | AFFECTED MEDIA | DESCRIPTION | NAMES (Print or Type) | |
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| 0 | all | - | Initial Issue | James Hopf | L. Vandenhoek |
| | | | | | |
| | | | | | |
| | | | | | |

| *RECORD OF VERIFICATION* | YES | NO | N/A |
|---|---|---|---|
| (a) The objective is clear and consistent with the analysis. | ☒ | ☐ | |
| (b) The inputs are correctly selected and incorporated into the design. | ☒ | ☐ | ☐ |
| (c) References are complete, accurate, and retrievable. | ☒ | ☐ | ☐ |
| (d) Basis for engineering judgments is adequately documented. | ☒ | ☐ | ☐ |
| (e) The assumptions necessary to perform the design activity are adequately described and reasonable. | ☒ | ☐ | ☐ |
| (f) Assumptions and references, which are preliminary, are noted as being preliminary. | ☐ | ☐ | ☒ |
| (g) Methods and units are clearly identified. | ☒ | ☐ | ☐ |
| (h) Any limits of applicability are identified. | ☒ | ☐ | ☐ |
| (i) Computer calculations are properly identified. | ☐ | ☐ | ☒ |
| (j) Computer codes used are under configuration control. | ☐ | ☐ | ☒ |
| (k) Computer codes used are applicable to the calculation. | ☐ | ☐ | ☒ |
| (l) Input parameters and boundary conditions are appropriate and correct. | ☒ | ☐ | |
| (m) An appropriate design method is used. | ☒ | ☐ | |
| (n) The output is reasonable compared to the inputs. | ☒ | ☐ | |
| (o) Conclusions are clear and consistent with analysis results. | ☒ | ☐ | |

COMMENTS:

None

Verifier:

Lazer Vandenhoek [signature]

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**None.**

# 1. INTRODUCTION

## 1.1 Objective

This document determines postulated gas leakage flow rates for the confinement boundary of the VSC-24 Multi-assembly Sealed Baskets (MSBs) for normal, off-normal, and accident storage conditions for a given set of helium test conditions. It also determines the maximum fraction of helium lost from the MSB interior, over a 60-year storage life, during normal operation.

This calculation is a copy of the original VSC-24 system helium leakage calculation (Reference 3.1.1), with the only difference being that a 60 year design life is evaluated, as opposed to 50 years. This calculation is performed in support of the VSC-24 license extension, which will increase the licensed storage period from 20 to 60 years.

## 1.2 Purpose

The gas leakage characteristics determined herein are (a) to be used in support of VSC-24 storage system atmospheric release calculations and (b) to confirm the ability to maintain an adequate inert gas inventory in the MSB over its 60-year storage design life, during normal operation.

## 1.3 Scope

These analyses apply to VSC-24 MSBs used in dry spent fuel storage. The analyses follow NRC guidelines for normal, off-normal, and accident storage conditions, and for helium test conditions (Ref. 2.2.1, 2.2.2, and 2.2.3).

## 2. REQUIREMENTS

### 2.1 Design Inputs

2.1.1. 10CFR72, *Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Waste.)*

(10 CFR72.24(l)(1) states that the applicant must estimate the quantity of radionuclides expected to be released annually to the environment.)

(10 CFR 72.122(h)(1) states that the design must adequately protect the spent fuel cladding against degradation that might otherwise lead to gross ruptures during storage. Otherwise, the fuel must be confined through other means such that fuel degradation during storage will not pose operational safety problems with respect to removal of the fuel from storage.)

(10 CFR 72.236(f) states that the cask must be designed to provide adequate heat removal capacity without active cooling systems.)

(10 CFR 72.236(g) states that the cask must be designed to store the spent fuel safely for a minimum of 20 years and permit maintenance as required.)

(10 CFR 72.236(l) and 10 CFR 72.24(d) state that the applicant must evaluate the cask and its systems important to safety. This evaluation must use appropriate tests or other means acceptable to the Commission, to demonstrate that they will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.)

### 2.2 Regulatory Commitments

2.2.1. U.S. Nuclear Regulatory Commission (NRC), Spent Fuel Project Office Interim Staff Guidance-5, Revision 1, Issue: Confinement Evaluation, May 21,1999.

(This document provides NRC guidance for adequately demonstrating the confinement capabilities of a dry cask storage system.).

2.2.2. U. S. NRC NUREG-1536, Standard Review Plan for Dry Cask Storage Systems, January 1997, as modified by the ISG-5 Rev. 1 attachment that replaces SRP Chapter 7.

(This document provides guidance to NRC staff in the Spent Fuel Project Office for performing safety reviews of dry cask storage systems. Thus, the document also provides the applicant with guidance on performing safety evaluations of dry cask storage systems.)

2.2.3. American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment, ANSI N14.5-1997, American National Standards Institute, Inc., February 5,1998.

(This document describes a method for calculating cask leakage rates.)

# 3. REFERENCES

## 3.1 SFD Calculation Packages

3.1.1 VSC02.6.2.5.02, Rev. 1, Helium Leakage Analysis.

3.1.2 VSC02.6.2.3.05, Rev. 2, Normal, Off-Normal, and Maximum Accident Pressure in the MSB.

(Provides bounding minimum volumes and maximum operating pressures and temperatures.)

## 3.2 SFD Drawings

3.2.1 MSB-24-001, Sht. 2/2, Rev. 5, MSB Assembly, (Provides weld lengths.)

## 3.3 General References

3.3.1 B.L. Anderson, R.W. Carlson, L.E. Fischer, "Containment Analysis for Type B Packages Used to Transport Various Contents", NUREG/CR-6487, UCRL-ID-124822, LLNL, prepared for the Office of Nuclear Material Safety and Safeguards, U.S. NRC, Washington DC, November 1996.

3.3.2 *American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment,* ANSI N14.5-1997, American National Standards Institute, Inc., February 5,1998.

3.3.3 Petersen, Helge, "Tables of Thermophysical Properties of Helium", Dragon Project Report 734, Danish AEC Research Establishment.

## 4. ASSUMPTIONS

### 4.1 Design Configuration

4.1.1 The postulated leak path is through the confinement boundary of the MSB. The MSB is located within the Ventilated Concrete Cask (VCC) during storage conditions, and within the Multi-purpose Transfer Cask (MTC) during transfer operations. Both the depth of the shield-lid-to-shell weld and the combined depth of the welds of both lids to the shell are evaluated, because this range of weld depths envelopes the postulated leak path length. Based on the weld sizes shown in Ref. 3.2.1, the postulated leak path is thus assumed to be between 1/4 in. and 1 in. long.

4.1.2 The average gas temperatures VSC-24 MSB thermodynamic state properties for the normal, off-normal, and accident storage conditions are required for this calculation. The values are identified in Table 4-1 below. The off-normal cases use the same assumptions and method as the normal cases, except that 10% of the fuel rods and BPRA rods are assumed to fail. The accident case assumes 100% fuel rod cladding failure. The MSB gas volumes, pressures, and operating temperatures are obtained from Reference 3.1.2. The gas volumes, pressures, and operating temperatures are chosen in such a way as to provide the maximum leak rates and result in a bounding condition. The MSB gas volumes are minimum free volumes from Section 6.3, 6.4, and 6.5 of Reference 3.1.2. The maximum operating pressures are from Section 7 of Reference 3.1.2. These pressures are bounding pressures from Reference 3.1.2 and have been adjusted for the helium loading temperature and the storage temperature. The operating temperatures are the lower of the temperatures for each operating condition of those from Sections 6.3 through 6.5 of Reference 3.1.2. These pressures and temperatures are chosen to provide maximum leak rates through selection of the combination of maximum pressure and the lowest temperature at which that pressure can occur for MSBs with and without BPRAs.

**Table 4-1 VSC-24 MSB Gas Volumes, Temperatures, and Pressures**

| Operating Condition | Volume (inch$^3$/cc) | Max. Pressure (psig) | At Average Gas Temperature (F/K) |
|---|---|---|---|
| Normal Conditions | 269,500 / 4.42E+6 | 5.23 | 439°F / 499°K |
| Off-Normal Conditions | 270,100 / 4.43E+6 | 10.0 | 445°F / 503°K |
| Accident Conditions | 276,100 / 4.52E+6 | 55.7 | 460°F / 511°K |

4.1.3 The following helium gas properties are from Reference 3.3.3:

Molecular Weight, M = 4.0025 gm/gmole
Specific Heat Ratio, k = cp/cv = 5195 / 3117 = 1.6667
Dynamic Viscosity, μ(T) = 3.674 E-7 $[T(K)]^{0.7}$ kgm/m-sec
[See Ref. 3.3.3, Eq. (3a)] = 3.674 E-6 $[T(K)]^{0.7}$ gm/cm-sec
= 3.674 E-4 $[T(K)]^{0.7}$ centiPoise (cP)

Reference 3.3.3 provides accuracies for the above properties. All of the numbers are more than 100 times as accurate as the assumptions made regarding configuration of the MSB and the postulated leak path.

The helium density is obtained from the ideal gas law

$P = \rho R_u T / M$

where

| | |
|---|---|
| P | = Gas pressure, atm |
| $R_u$ | = Gas Constant = 82.057 cc-atm/gmole-°K |
| ρ | = Gas density, gm/cc |
| T | = Gas temperature, °K |
| M | = Molecular weight, gm/gmole |

## 4.2 Design Criteria

4.2.1 The design life for the VSC-24 MSB is 60 years.

4.2.2 The VSC-24 MSB will be subjected to a helium leak test at a pressure of 7.3 psig of dry helium (>99% pure), at an upstream temperature of 50-260°F (283-400°K), and at a downstream pressure of 1 atm abs, with an acceptance criteria of $1.0 \times 10^{-4}$ std cc/sec. (The standard condition is pressure of 1 atm abs and temperature of 298°K). This acceptance criterion is selected based on past practice and availability of measuring instruments.

## 4.3 Calculation Assumptions

4.3.1 Gas Leakage

(a) The radioactive gases required to be considered for release effects are tritium, iodine, krypton, and xenon. For this calculation, the leaking gas is assumed to be all helium. The presence of these possible fission gases and/or suspended fine particles in the helium gas are neglected. Because the combination of atomic mass and viscosity of these gases are higher than for helium, and because the vast majority of the gas is helium (due to the helium backfill), this provides a conservatively low gas viscosity and molecular weight, and thus a conservative flow resistance. This, in turn, provides a conservative maximum flow rate for a given leak diameter.

(b) Because the pressures involve are relatively low, the helium and gas mixtures are assumed to be calorically and thermally perfect-gases. Thus, the ideal gas law (see 4.1.3) approximates the state equation for these gases.

(c) Because temperature and pressure changes in the MSB (over hours or days, rather than seconds) occur relatively slowly, the gas leakage for each operating condition is assumed to occur at a steady state flow rate.

(d) A conservatively high upstream temperature of 260°F is assumed. If a lower temperature exists upstream during the helium leak test, a correspondingly smaller diameter would be calculated for the same volumetric flow rate and upstream pressure.

## 5. CALCULATION METHODOLOGY

This section describes the steps and formulae used for the leakage analyses in this calculation.

### 5.1 Volumetric Flow Rate for Normal and Accident Storage Conditions

5.1.1 Leak Path Geometry

The methodology used for modeling gas flow through the postulated leakage path in the MSB confinement boundary is as described in Section 2.2 on page 4 of Reference 3.3.1 and Section B.3 on page 27 of Reference 3.3.2.

5.1.2 The volumetric flow rates for the normal, off-normal, and accident storage conditions are calculated, for the postulated test conditions and at reference conditions (25°C and 1 atm abs), in accordance with the following.

5.1.3 Given the reference flow rate $Q_r$ (std-cc/sec) (see 4.2.2), the equivalent volumetric average flow rate is calculated as $(Q_r)(T_a/T_{ref})/P_{ave}$

where
$T_a$ =average gas temperature, °K
$T_{ref}$ =standard temperature, °K
$P_{ave}$ =average pressure, atm

5.1.4 Then a hole diameter, D, is determined by iteration (using the Microsoft Excel spreadsheet shown in Table 6-1), such that it will provide a volumetric leakage rate, at the average pressure of the helium leak test, equal to the above equivalent volumetric average flow rate. Equations (B.1) through (B.4) of Section B.3 of Reference 3.3.2 are used for this calculation, as follows:

$$Qa = ((2.49\times10^6 D^4)/(a\ \mu) + (3.81\times10^3\ D^3\ (T/M)^{0.5})/(a\ P_a))\ (P_u - P_d) \qquad \text{(Eq. 1)}$$

where
$Q_a$ = average volumetric leakage rate in leak path, cc/sec
D = leak path diameter, cm
a = leak path length, cm.
μ = dynamic viscosity, cP
T = temperature, °K
M = molecular weight, gm/gm-mole
$P_a$ = average pressure, atm
$P_u$ = upstream pressure, atm
$P_d$ = downstream pressure, atm

5.1.5 The upstream flow rate is calculated by multiplying the calculated average volumetric leakage rate by the ratio $(T_u/T_a)$ $(P_a/P_u)$, and downstream flow rate is calculated by multiplying the calculated average volumetric leakage rate by the ratio $(T_d/T_a)$ $(P_a/P_d)$ , where $T_u$ and $T_d$ are the upstream and downstream temperatures, $^oK$.

5.1.6 The upstream and downstream flow rates based on the postulated operating conditions (see 4.1.2) are then calculated using Eq. 1 and the diameter determined in accordance with 5.1.4, above, followed by applying the adjustments of 5.1.5, above.

5.1.7 The results are shown in Table 6-1 and are summarized in Table 7-1.

**5.2 Long Term MSB Inert Gas Inventory**

5.2.1 Based on the maximum leak rate for the Normal Storage Condition, the inert gas inventory is evaluated to ensure that it is adequate at the end of the 60-year life of the MSB.

Let: $V_{initial}$ = Initial helium volume stored in the MSB, cc
$V_{final}$ = Final helium volume in the MSB at end of life, defined below, cc
$V_{loss}$ = Helium volume loss due to leakage over the 60 year life, defined below, cc
$Q_{tu}$ = Maximum upstream helium leak rate for normal storage conditions, cc/sec
$t_{loss}$ = Maximum time for the normal loss to occur, sec

Then: $V_{loss} = Q_{tu} \times t_{loss}$ , for either the BWR or the PWR MSB
$V_{final} = V_{initial} - V_{loss}$
Percent Inert Gas Retained = $[V_{final} / V_{intial}]$ 100%

## 6. CALCULATIONS

### 6.1 Leak Path Diameter

6.1.1 The leak path diameter is determined, by iteration, from the limiting helium test volumetric flow rate and test conditions. The helium leak rates for normal, off-normal, and accident storage conditions are tabulated for the both the 1/4-in. and 1-in. leak path length, and for both 50°F and 260°F, to show the effects of variations in path length and temperature. Table 6-1 shows the results of these calculations.

### 6.2 Long Term MSB Inert Gas Inventory

6.2.1 Given the maximum leak rate for normal storage conditions, this section provides a check that the inert gas inventory remains adequate throughout the 60-year life of the MSB. From the input from Sections 4.2 and 6.1, together with the method described in Section 5.2, the maximum leak rate is determined in Table 6-1. Based on the maximum leak rate of $6.2 \times 10^{-5}$ cc/sec shown in Table 6-1, the gas volume lost during 60 years of normal operation is determined below.

$$V_{loss} = Q_{tu} \times t_{loss}$$
$$= [6.2\text{ E-5 cc/sec}]\ [(3600\text{ sec/hr})\ (24\text{ hr/day})(365\text{ days/yr})(60\text{ yrs})]$$
$$= [6.2\text{ E-5 cc/sec}]\ [1.8922\text{ E+9 sec}]$$
$$= 117{,}310\text{ cc lost} = 0.117\text{ E+6 cc lost from the MSB.}$$

$$V_{initial} = 4.42\text{ E+6 cc}$$
$$V_{final} = V_{initial} - V_{loss} = 4.42\text{ E+6 cc} - 0.117\text{ E+6 cc} = 4.30\text{ E+6 cc}$$

$$\text{Percent Inert Gas Retained} = [V_{final} / V_{initial}]\ 100\%$$
$$= [4.30\text{ E+6 cc} / 4.42\text{ E+6 cc}]\ 100\% = 97.3\ \%$$

## Table 6-1 Leak Test Temperature Sensitivity to Leak Diameter and Fill Temperature

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LEAK GEOMETRY: | | | | | | | | | | | | |
| Hole Length, L (in) | 1/4 | | | 1 | | | 1/4 | | | 1 | | |
| Hole Length, L (cm) | 0.6350 | | | 2.5400 | | | 0.6350 | | | 2.5400 | | |
| Hole Diameter, D (cm) | 8.824E-04 | | | 1.266E-03 | | | 1.007E-03 | | | 1.450E-03 | | |
| GAS PROPERTIES: | He | | | He | | | He | | | He | | |
| Molecular Weight, M (gm/gmole) | 4.0025 | | | 4.0026 | | | 4.0025 | | | 4.0025 | | |
| Upstream Pressure, $P_u$ (atm) (7.3 psig) | 1.6 | | | 1.6 | | | 1.6 | | | 1.6 | | |
| Temperature (F) | 50 | | | 50 | | | 260 | | | 260 | | |
| Temperature (K) | 283 | | | 283 | | | 400 | | | 400 | | |
| Upstream Density, r (gm/cc) | 2.584E-04 | | | 2.584E-04 | | | 1.830E-04 | | | 1.830E-04 | | |
| Downstream Pressure, $P_d$ (atm) | 1.000E+00 | | | 1.000E+00 | | | 1.000E+00 | | | 1.000E+00 | | |
| Downstream Density, (gm/cc) | 1.723E-04 | | | 1.723E-04 | | | 1.220E-04 | | | 1.220E-04 | | |
| ANSI Reference Density, (gm/cc) | 1.637E-04 | | | 1.637E-04 | | | 1.637E-04 | | | 1.637E-04 | | |
| Avg Pressure, $P_a=(P_u+P_d)/2$ (atm) | 1.250E+00 | | | 1.260E+00 | | | 1.250E+00 | | | 1.250E+00 | | |
| Average Density, (gm/cc) | 2.163E-04 | | | 2.153E-04 | | | 1.525E-04 | | | 1.525E-04 | | |
| Dynamic Viscosity, m (cP) | 1.912E-02 | | | 1.912E-02 | | | 2.435E-02 | | | 2.435E-02 | | |
| FLOW PARAMETERS DURING TEST: | | | | | | | | | | | | |
| Reference Flow, $Q_r$ (std cc/sec) | 1.000E-04 | | | 1.000E-04 | | | 1.000E-04 | | | 1.000E-04 | | |
| Mass Flow Rate (gm/sec) | 1.637E-08 | | | 1.637E-08 | | | 1.637E-08 | | | 1.637E-08 | | |
| Specified Average Vol. Flow, $Q_a$ (cc/sec) | 7.601E-05 | | | 7.601E-05 | | | 1.073E-04 | | | 1.073E-04 | | |
| Fc=(2.49E6)D^4/(mL) | 1.243E-04 | | | 1.316E-04 | | | 1.667E-04 | | | 1.781E-04 | | |
| Fm=(3.81E3)(D^3)SQ(T/M)/(L*Pa) | 2.773E-05 | | | 2.046E-05 | | | 4.900E-05 | | | 3.658E-05 | | |
| rf = Fc/Fm | 4.482E+00 | | | 6.429E+00 | | | 3.381E+00 | | | 4.869E+00 | | |
| $Q_c = Fc*(P_u-P_d)$ (cc/sec) | 6.216E-05 | | | 6.578E-05 | | | 8.283E-05 | | | 8.904E-05 | | |
| $Q_m = Fm*(P_u-P_d)$ (cc/sec) | 1.387E-05 | | | 1.023E-05 | | | 2.450E-05 | | | 1.829E-05 | | |
| $Q_t = Q_c + Q_m$ (cc/sec) | 7.601E-05 | | | 7.601E-05 | | | 1.073E-04 | | | 1.073E-04 | | |
| Flow Rate Error = [(Calc-Spec)/Spec]% | -5.170E-13 | | | -1.248E-13 | | | -1.263E-14 | | | 0.000E+00 | | |
| FLOW DURING STORAGE: | | | | | | | | | | | | |
| Storage Condition | Normal | Off-Normal | Accident | Normal | Off-Normal | Accident | Normal | Off-Normal | Accident | Normal | Off-Normal | Accident |
| GAS PROPERTIES: | He | He | He | He | He | He | He | He | He | He | He | He |
| Upstream Pressure, $P_u$ (psig) | 5.23 | 10.0 | 55.7 | 5.23 | 10.0 | 55.7 | 5.23 | 10.0 | 55.7 | 5.23 | 10.0 | 55.7 |
| Upstream Pressure, $P_u$ (atm abs) | 1.36 | 1.68 | 4.79 | 1.36 | 1.68 | 4.79 | 1.36 | 1.68 | 4.79 | 1.36 | 1.68 | 4.79 |
| Temperature (K) | 499 | 503 | 611 | 499 | 503 | 611 | 499 | 503 | 611 | 499 | 503 | 611 |
| Upstream Density, r (gm/cc) | 1.325E-04 | 1.629E-04 | 4.571E-04 | 1.325E-04 | 1.629E-04 | 4.571E-04 | 1.325E-04 | 1.629E-04 | 4.571E-04 | 1.325E-04 | 1.629E-04 | 4.571E-04 |
| Downstream Pressure, $P_d$ (atm) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Downstream Density, (gm/cc) | 9.775E-05 | 9.697E-05 | 9.645E-05 | 9.775E-05 | 9.697E-05 | 9.645E-05 | 9.775E-05 | 9.697E-05 | 9.645E-05 | 9.775E-05 | 9.697E-05 | 9.645E-05 |
| Reference Density, (gm/cc) | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 | 1.637E-04 |
| Avg Pressure, $P_a=(P_u+P_d)/2$ (atm) | 1.18 | 1.34 | 2.89 | 1.18 | 1.34 | 2.89 | 1.18 | 1.34 | 2.89 | 1.18 | 1.34 | 2.89 |
| Average Density, (gm/cc) | 1.151E-04 | 1.300E-04 | 2.763E-04 | 1.151E-04 | 1.300E-04 | 2.763E-04 | 1.151E-04 | 1.300E-04 | 2.763E-04 | 1.151E-04 | 1.300E-04 | 2.763E-04 |
| Dynamic Viscosity, m (cP) | 2.843E-02 | 2.859E-02 | 2.891E-02 | 2.843E-02 | 2.859E-02 | 2.891E-02 | 2.843E-02 | 2.859E-02 | 2.891E-02 | 2.843E-02 | 2.859E-02 | 2.891E-02 |
| FLOW PARAMETERS: | | | | | | | | | | | | |
| Fc=(2.49E6)D^4/(mL) | 8.360E-05 | 8.313E-05 | 8.222E-05 | 8.849E-05 | 8.799E-05 | 8.703E-05 | 1.419E-04 | 1.411E-04 | 1.395E-04 | 1.625E-04 | 1.616E-04 | 1.600E-04 |
| Fm=(3.81E3)(D^3)SQ(T/M)/(L*Pa) | 3.907E-05 | 3.448E-05 | 1.609E-05 | 2.883E-05 | 2.544E-05 | 1.187E-05 | 5.809E-05 | 5.126E-05 | 2.392E-05 | 4.337E-05 | 3.827E-05 | 1.786E-05 |
| $Q_c = Fc*(P_u-P_d)$ (cc/sec) | 2.974E-05 | 6.655E-05 | 3.115E-04 | 3.148E-05 | 6.986E-05 | 3.298E-04 | 5.047E-05 | 9.697E-05 | 5.287E-04 | 5.426E-05 | 1.032E-04 | 6.063E-04 |
| $Q_m = Fm*(P_u-P_d)$ (cc/sec) | 1.390E-05 | 2.345E-05 | 6.096E-05 | 1.026E-05 | 1.731E-05 | 4.499E-05 | 2.067E-05 | 3.487E-05 | 9.064E-05 | 1.543E-05 | 2.603E-05 | 6.767E-05 |
| Qtransition-avg (cc/sec) | 4.364E-05 | 9.001E-05 | 3.725E-04 | 4.174E-05 | 8.717E-05 | 3.747E-04 | 7.114E-05 | 1.318E-04 | 6.193E-04 | 6.969E-05 | 1.292E-04 | 6.740E-04 |
| Mass Flow Rate (gm/sec) | 5.025E-09 | 1.040E-08 | 1.029E-07 | 4.806E-09 | 1.003E-08 | 1.035E-07 | 8.191E-09 | 1.700E-08 | 1.711E-07 | 8.023E-09 | 1.679E-08 | 1.757E-07 |
| Qin, Inlet Flowrate (cc/sec) | 3.792E-05 | 6.381E-05 | 2.251E-04 | 3.626E-05 | 6.155E-05 | 2.265E-04 | 6.181E-05 | 1.044E-04 | 3.743E-04 | 6.054E-05 | 1.030E-04 | 3.844E-04 |
| Qout, Outlet Flowrate (cc/sec) | 5.14E-05 | 1.07E-04 | 1.05E-03 | 4.92E-05 | 1.03E-04 | 1.06E-03 | 8.38E-06 | 1.75E-04 | 1.79E-03 | 8.21E-05 | 1.75E-04 | 1.84E-03 |

## 7. CONCLUSIONS

### 7.1 Results

7.1.1 Based on the results documented in Table 6-1, the highest upstream helium leak test temperature of 260°F leads to the largest leak diameter. The limiting leak path geometry is a right-circular cylinder with a leak path length of 1/4 in. for the normal and off-normal conditions and I in. for the accident condition. The helium leak test temperature of 260°F results in the highest storage condition leak rates. For the normal and off-normal conditions, the shorter leak path provides the highest upstream flow rates, and for the accident condition, the longer leak path provides the highest upstream flow rates. Table 7-1 summarizes the basket leakage analysis results for the maximum normal, off-normal, and accident storage conditions analyzed herein.

**Table 7-1 VSC-24 Multi-Assembly Sealed Basket Leakage Rates**

| Storage or Test Condition | Inlet / Outlet Volumetric Flow Rate (cc/sec) | He Flow Rate at Reference Conditions (std cc/sec) |
|---|---|---|
| Helium Leak Test | Not Applicable | 1.0 E-4 |
| Normal Storage | 6.18 E-5 / 8.38 E-5 | Not Applicable |
| Off-Normal Storage | 1.04 E-4 / 1.75 E-4 | Not Applicable |
| Accident Storage | 3.84 E-4 / 1.84 E-3 | Not Applicable |

7.1.2 The MSB will maintain essentially all of the helium inventory over the 60 year life. The loss of up to 2.7% helium during the 60-year life has a smaller effect on the MSB thermal performance than the effect of the time-dependent reduction of the fuel heat-generation rate. It also has a negligible effect on the corrosion protection of the MSB internals, due to lack of oxygen.

### 7.2 Compliance With Requirements

7.2.1 This VSC-24 storage system leakage analysis has followed the guidelines in Regulatory Commitment 2.2.1. Regulatory Commitment 2.2.2 (Standard Review Plan), as modified by Regulatory Commitment 2.2.1, contains the same information as in Regulatory Commitment 2.2.1. The leak analysis methods follow the guidance in Regulatory Commitment 2.2.3 and Reference 3.3.1. Therefore, Regulatory Commitments 2.2.1 and 2.2.2 have been met by these analyses.

### 7.3 Range of Validity

The analyses and leakage results presented herein apply only to a VSC-24 MSB fabricated in accordance with the referenced drawings and containing 24 fuel assemblies with a maximum thermal load of 24 kW, and operated and tested in accordance with the criteria specified in Section 4.2, above.

### 7.4 Summary of Conservatism

7.4.1 This calculation incorporates the following conservative assumptions.

(a) For the off-normal and accident conditions, pure helium is assumed to leak rather than a mixture of fuel rod fill gases. As stated in 4.3.1, above, the resulting mixture would have a higher combination of viscosity and molecular weight, and thus larger hydraulic losses, which would cause lower leakage flow rates for the off-normal and accident conditions.

(b) The leak path is assumed to be the more conservative of the shortest possible length and the sum of the lid-to-shell weld depths.

(c) The upstream temperature for the helium leak test is set at a conservatively high value of 260°F (400°K), which, in turn, is based on the maximum permitted thermal load of 24 kW.

(d) Conservative assumptions are inherent in the analysis of the upstream gas conditions for the normal, off-normal, and accident storage conditions. These include the following:

- Minimized gas free volume within the MSB due to conservative allowances for MSB internals and irradiation growth of 2 inches for all fuel rods
- Conservatively low helium backfill temperature (220°F), which maximizes He fill gas moles, is assumed in Ref. 3.1.1
- 3% failed rods are assumed for maximum normal conditions, although only intact rods are loaded
- 10% failed rods are assumed for off-normal conditions
- 100% failed rods are assumed for accident conditions

### 7.5 Limitations or Special Instructions

None.

## 8. ELECTRONIC FILES

None.

SFD/NRC 13-003
February 14, 2013

Enclosure 2

Certificate of Compliance Renewal Application for the VSC-24 Ventilated Storage Cask System (Docket No. 72-1007), Document No. LAR 1007-007, Revision 1

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