Final - SAFETY EVALUATION REPORT
[Structural/Material Discipline]
Prepared By: Ata Istar, Neil Day, Matt Gordon
Approved By: Bhasker (Bob) P. Tripathi
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B-27

2.0 Structural Evaluation

The objective of the structural review is to verify that the structural performance of the Safkeg-LS 3979A package meets the regulatory requirements of 10 CFR Part 71. The Safety Analysis Report (SAR), CTR 2008/10, Rev. 2, was organized and formatted in accordance with Revision 2 of Regulatory Guide 7.9 "Standard Format and Content of Part 71 Applications for Approval of Packaging for Radioactive Materials."

2.1. Description of Structural Design

The Safkeg-LS 3979A is designed as a general purpose package to transport a range of non-fissile and fissile nuclides in solid, liquid, and gaseous forms.

The principal structural components of the Safekeg-LS 3979A package are the keg (drawing: 0C-6042, Issue A), top and inner cork packing (drawing: OC-6043, Issue A), and the containment vessel (drawing: OC-6044, Issue C). There are three (3) inserts for contents that can provide additional containment and shielding (drawings: 2C-6175, Issue A, 2C-6172, Issue A and 2C-6171, Issue A). The external dimensions of the package are 48.3 cm (19.02 in) in height and 42.4 cm (16.69 in) in diameter.

The keg and cork assemblies are designed to absorb impact loading. The keg is constructed from ASTM A240/A240M, type 304L material. The material density of top and inner cork is 250 - 290 kg/m^3 (0.00903 - 0.01048 lb/in^3). The containment vessel is designed to provide a containment boundary and shielding for the contents. The body assembly is formed from the following materials: ASTM A479/A479M, type 304L, ASTM A511/A511M, type MT304L, and BS 3909/2 (lead).

A full scale prototype packaging with appropriate instrumentation was tested for thermal, drop, penetration, and thermal test conditions. Two (2) Dytran Model Number 3023A mini triaxial accelerometers capable of operating at -40°C (-40°F) were used to determine deceleration values during free drop cases. The accelerometers were mounted on the lid. The lid was considered the most susceptible part of the packaging for the containment boundary where the linear elastic range under all required testing conditions were to be ensured. Two accelerometers measured the same decelerations, with one being a backup for the other, and to provide confidence in the results. Several modifications were made to the containment vessel, cork and keg to accommodate the wiring for the test equipment. The testing sequence was tabulated in Table 3 of CTR 2009/21, Issue C, and performed at three separate test facilities. The 1.2 m (4 ft) drop and the 1 m (40 in) puncture tests were performed at the Pipaway Engineering testing facility. The 10.2 m (33.46 ft) and the additional penetration test at -40°C (-40°F) were performed at the Croft Associates, Ltd testing facility. The 800°C (1472°F) thermal test was performed at the Hovel Ltd test facility. The HAC drop tests were performed from a height of 10.2 m (33.46 ft) instead of 9 m (30 ft) as required by 10 CFR 71.73(c)(1).

The maximum mass of the packaging is 59 kg (130 lbs) excluding the contents. The maximum mass of content is 5.8 kg (12.85 lbs). The gross mass of the package was identified as 64.8 kg (142.85 lbs) in Table 2-7 of CTR 2008/10, Rev. 2. The actual mass of the tested package was identified as 61.72 kg (136 lbs) in Table 1 of CTR 2009/21, Issue C. The mass of the tested package was approximately 5% less than that of the designed package. However, the tested package was dropped from a height of 10.2 m (33.46 ft) in lieu of 9 m (30 ft) for the HAC as required by 10 CFR 71.73(c)(1). This increase in drop height corresponds to a 13% increase in energy input to the HAC impact. The maximum pass of the package in the Certificate is limited to 65 kg.

Besides performing the required tests under 10 CFR Parts 71.71 and 71.73, VECTRA Group Limited (report 925-3272/R1, Rev. 4) performed quasi-static analyses using ABAQUS v6.8 finite element program on an half-symmetry mathematical model in the vertical plane through the center of the containment vessel of the Safkeg-LS 3979A to determine stress intensities at critical locations of the containment vessel for the conditions of Normal Condition of Transport (NCT) and Hypothetical Accident Condition (HAC). First order brick elements were used throughout the model. At least four (4) elements were used to capture the stress distribution throughout the thickness. Friction coefficient of 0.1 was defined between all the sliding parts. A preload of 8.12 kN (1825.45 lbf) was applied axially to the lid closure screws, and they were free to slide.

2.1.2 Design Criteria

The design criteria in Regulatory Guide 7.6, Rev. 1 "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels" were used to evaluate the structural integrity of the Safkeg-LS 3979A package. The containment vessel inner shell was evaluated for buckling in accordance with the requirements of ASME Code Case N-284-2 for free drop cases. Fatigue analysis was performed in accordance with section C3 in Regulatory Guide 7.6, Rev. 1, and using the design fatigue curve in Figure 1-9.2.2 in Appendix I of ASME B&PV Section III. The allowable stress values for bearing stress and for the bolts were taken from ASME Code Section III, Division 3, since they were not given in Regulatory Guide 7.6. At critical locations from each load case, minimum design margins were calculated and reported for all loading combinations.

2.1.2.1 Load combinations

The load combinations of the Safekeg-LS 3979A package were developed per the requirements of Regulatory Guide 7.8, Rev. 1, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material." The load combinations for the containment vessel under NCT and HAC were provided in Tables 2-1 and 2-2 of CTR 2008/10, Rev. 2.

Based on the review of the tables, the staff determined that the applied load combinations are in accordance with the requirements per Regulatory Guide 7.8.

2.1.2.2 Allowable Stress

The stress categories and allowable limits of stress intensities for NCT and HAC were provide in Table 2-3 of CTR 2008/10, Rev. 2, which were based on the 1977 edition of the ASME Boiler and Pressure Vessel Code. The material allowable stresses for bolt bearing stress were taken from ASME Section III Div. 3. Classifications for stress intensities were taken from Table WB-3217-1 in ASME Section III Div. 3.

The material properties for each part of the model were provided in Section 3.0 of VECTRA report 925-3272/R1, Rev. 4, and were taken from Section II of ASME B&PV Code.
The applicant determined and tabulated critical stress intensities for stress categories of primary membrane stress (P_m), primary plus bending stress ($P_m + P_b$) and primary plus secondary stress ($P_m + P_b + Q$). The appropriate allowable stress intensity limits (S_m) for each stress category for the conditions of NCT and HAC was compared for acceptance at the locations shown in Figure 2-1 of CTR 2008/10, Rev. 2.

The design margins (DMs) were calculated by taking the ratio of allowable stress and calculated stress intensities and by subtracting the quotient by one. The negative design margin indicates a failure. The DMs were also tabulated for all required conditions performed in VECTRA report 925-3272/R1, Rev. 4.

Based on the review, the staff determined that the allowable stresses for the containment vessel are within the requirements of regulatory guidance of 10 CFR Part 71.

2.1.2.3 Buckling

The applicant used the ASME Code Case N-284-2 to determine allowable elastic and inelastic buckling stresses for the containment vessel inner shell for the conditions of NCT and HAC at hot and cold temperature levels. The results of the allowable stresses were tabulated in Table 2-6 of VECTRA report 925-3272/R1, Rev. 4. The required parameters for the containment vessel shell buckling, reduction factors, and allowable buckling stress values for elastic and inelastic buckling were tabulated in Tables 2-4 and 2-5 in VECTRA report 925-3272/R1, Rev. 4.

Based on the check of the tabulated results, the staff determined that the containment vessel shell allowable buckling stresses for elastic and inelastic buckling regimes for the conditions of NCT and HAC at hot and cold conditions were calculated correctly.

The applicant tabulated the results from the stresses from analytical analyses with design margins for the containment vessel inner shell for the analyzed conditions of NCT and HAC in VECTRA report 925-3272/R1, Rev. 4.

Based on the review of the tabulated results, the staff determined that the stresses are within the design margins, and concluded that the structural integrity of the containment vessel inner shell can be maintained.

2.1.2.4 Fatigue

The fatigue analysis was performed in accordance with section C3 in Regulatory Guide 7.6. The design fatigue curve in Figure 1-9.2.2 in Appendix I of ASME B&PV Section III was used to determine allowable number of cycles by using the calculated alternating stresses as follows. The alternating stresses at the identified critical locations of the containment vessel were calculated as one-half the maximum absolute values for all possible principal stresses generated from the first state of pre-load of lid closure screws to containment vessel body to second state of all the other loads. The calculated alternating stresses was multiplied by the ratio of the modulus of elasticity given design fatigue curve in the Appendix I of ASME B&PV code to the modulus of elasticity used in the analysis to obtain the maximum alternating stresses that were used with the design fatigue curve to determine the allowable cycles.

The applicant performed a cycle based fatigue determination of the containment vessel for 20 years of service-life that included a multiplier of 10 to provide a conservative safety margin. The number of cycles was determined to be 10^4 over 20 years of operation.

The fatigue evaluation results performed by analyses were tabulated for the NCT conditions in VECTRA report 925-3272/R1, Rev. 4. Based on the review, the staff determined the results meet the regulatory requirement of 10 CFR 71.71(c)(5).

2.1.2.5 Brittle Fracture

The structural components of the package will be fabricated from austenitic stainless steel, which are ductile at low temperature levels.

The HAC drop tests at -40°C (-40°F) was considered as conditions for compliance of brittle fracture. However, HAC drop test at -40°C (-40°F) may or may not provide brittle fracture state on package components fabricated from the austenitic stainless steel materials.

Nevertheless, the staff agrees that austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport and that no tests are needed to demonstrate resistance to brittle failure per Regulatory Guide 7.11 "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 inches".

2.1.3 Weights and Centers of Gravity

The weights of components of Safkeg-LS 3979A packaging including the mass of inserts plus contents were tabulated in Table 2-7 of CTR 2008/10 Rev. 2. The maximum mass of the package was calculated to be 64.8 kg (142.85 lbs). The center of gravity of the assembled package was identified at the geometric center of the keg.

2.1.4 Identification of Codes and Standards for Package Design

The Safkeg-LS 3979A package was designed to transport normal and special forms of material in quantities of greater than 3000 A_2, therefore it was classified as a Category I package per NUERG/CR-6407 "Classification of Transportation Packaging and Dry Spent Fuel Storage Systems Components According to Importance of Safety," February 1996.

The standards to which the package was designed were selected based on the guidance provided in Regulatory Guide 7.6, Rev. 1, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," and NUREG/CR-3854 "Fabrication Criteria for Shipping Containers," April 1984. The allowable stress values for bearing stress and for the bolts were taken from ASME Code Section III, Division 3, since they were not given in Regulatory Guide 7.6. The load combinations used for the structural evaluation were taken from Regulatory Guide 7.8, Rev. 1, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material." The buckling evaluation of the containment vessel shell was evaluated in accordance with the requirements of ASME Code Case N-284-2. The package containment system will be fabricated in accordance with the applicable requirements of ASME Section III, Division 1, Subsection NB. Welds are qualified in accordance with ASME section IX and subjected to non-destructive visual and liquid penetration examination in accordance with ASME section V.

As indicated above, the design criteria used was in accordance with Regulatory Guide 7.6, which is consistent with ASME B&PV Section III, Subsection NB.

2.2. Material

The exterior body and containment vessel of the SafeKeg is made of 2 stock ASTM A240/240M 304L austenitic stainless steel. This steel is immune to low-temperature nil-ductility issues, and has a low carbon content, reducing the steel's susceptibility to weld sensitization. Bolting on the containment vessel is made to L43 ASTM A320/A320M specifications. This high alloy steel is intended for low-temperature service; the staff finds that is adequate for the application. The Keg Closure Nut on the exterior of the package is specified by an ISO or DIN standard. The Staff typically requests applicants to demonstrate how international standards are comparable to widely recognized American industry standards for safety-related components. The Staff finds in general, however that the operational requirements for materials used to manufacture nuts do not need to be particularly stringent, therefore the staff finds the specified ISO and DIN standards are acceptable for the application.

All welding of the SafeKeg package is done in accordance with Section VIII of the American Society for Mechanical Engineers Boiler and Pressure Vessel Code (ASME B&PVC) with visual and liquid penetration testing done in accordance with Section V of the ASME B&PVC. The confinement vessel is not welded, but is machined from a stock of 304L stainless steel. Drop and puncture tests demonstrated that the SafeKeg is constructed in a manner, and with materials which are sufficient for the package to meet the regulatory requirements.

The maximum radiation dose for the elastomeric containment seals is 1.71×10^5 rads, assuming the package was loaded with Ir-192 for one year. This dose is an order of magnitude lower than the 10^6 rads that is typically required to damage elastomeric materials. The Staff finds that radiation damage to the elastomeric seals is not a concern for this package (Page 4-3) since the seals are replaced on an annual basis. Finite element analysis showed that the maximum temperature of the elastomeric seal during accident conditions reached 183°C, which is acceptable for short durations of time.

Shielding is provided by a lead / 4% antimony alloy meeting British Standard 309/2 and (depending on the configuration) Class 3 tungsten alloy meeting ASTM B777 specifications. Although the shielding materials are safety related, the staff finds that in general, nominal specifications for shielding materials (e.g., "lead" or "tungsten") is usually adequate. Typically, applicants specify a minimum and maximum mass for cast shielding materials, in order to detect exclude internal porosity which would affect the efficacy of the shielding component. Section 8.1.6 of the Safety Analysis Report, however, specifies shielding tests which will verify the efficacy of the shielding material. Modeling of the fire test showed a maximum temperature of 182°C for the lead shielding. The staff finds that the shielding materials listed by the applicant are acceptable.

Thermal insulation and additional impact resistance is offered by agglomerated cork, placed between the outer shell of the package and the containment vessel. Physical testing of the package under hypothetical fire conditions caused significant charring of the cork, but containment was not compromised. Thermal modeling indicated a maximum containment temperature of 184°C (Table 3-2,Page 3-3). During a fire a low-temperature lead/tin/bismuth alloy inside a stainless steel fuse plug on the outside of the package melts, allowing combustion gases from the cork to escape. Although the fuse plug is safety related, the staff finds there is no reason to specify an industry standard associated with this component, due to the nature of its operation. The staff also finds that any stainless steel material would be sufficient for this component. Note 2 on licensing drawing 0C-6042 specifies the bounding melting temperatures of the alloy, thereby guaranteeing the critical characteristics of the alloy. The staff finds the use of cork, and the materials used for the fuse plug and low-melting temperature alloy acceptable for the use in the package.

2.3. Fabrication and Examination

2.3.1 Fabrication

The Safkeg-LS 3979A package shall be fabricated in accordance with Subsection NB of ASME Section III, Division 1. All welding shall be performed in accordance with the requirements of ASME Section IX.

The staff agrees with the use of approved fabrication code requirements for the Safkeg-LS 3979A packaging.

2.3.2 Examination

The applicant provided requirements for Material Tests, Fabrication Tests & Examinations and Acceptance Tests in CTR 2008/10 Rev. 2. The applicable examinations ensure the integrity of the structure of the Safkeg-LS 3979A packaging, and allow the transportation of radioactive materials safely. It was stated that welds are required to be subjected to non-destructive visual and liquid penetration examination in accordance with ASME section V. One of the most important measurements during fabrication is ensuring that the mass of fully assembled packaging meets the mass requirement addressed in Table 2-7 of CTR 2008/10 Rev. 2.

The staff determined that the applicant provided reasonable details to describe the examination and measurement requirements.

2.4. General Requirements for All Packages

2.4.1 Minimum Package Size

The smallest overall dimension exceeds the specified requirement of 10.16 cm (4 inches), therefore, the package meets the requirements of 10 CFR 71.43(a) for minimum size.

2.4.2 Tamper Indicating Feature

A tamper-indicating seal is installed on one impact limiter attachment bolt after installation of the lid-end impact limiter. Failure of the seal provides evidence of possible unauthorized access. Thus the requirements of 10 CFR 71.43(b) is satisfied.

2.4.3 Positive Closure

10 CFR 71.43(c) states that "Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package."

The lid of the containment vessel is held in place using 8 closure screws, which are torqued into the containment vessel flange. The containment vessel closure screws are tightened or released using appropriate tools. The keg lid is attached by permanently fitted studs and secured by nuts. Therefore, the package cannot be inadvertently opened.

The package cannot be opened unintentionally by any pressure that may arise within the package. The information presented in Section 2.6.3 of CTR 2008/10, Rev. 2 shows that the containment vessels remain closed under the design pressure (which bounds the maximum internal pressure that can be generated), and will not cause deformation of the screws. The keg lid will remain in place under any pressure that may arise within the package. This has been demonstrated by the thermal test reported in Section 2.7.4 of CTR 2008/10, Rev. 2.

The package was adequately tested and analytically analyzed for maximum internal and external differential pressures as well as during NCT and HAC. Thus, the requirements of 10 CFR 71.43(c) are satisfied.

2.4.4 Valves

This section was not discussed in CTR 2008/10, Rev. 2. Since the packaging is not equipped with valve(s) the requirements of 10 CFR 71.43(e) are not applicable.

2.4.5 Venting

This section was not discussed in CTR 2008/10, Rev. 2. Since the packaging is not equipped with vent(s) the requirements of 10 CFR 71.43(h) are not applicable.

2.5. *Lifting and Tie-Down Standards for the Package [10 CFR Part 71.45]*

2.5.1. Lifting Devices

10 CFR Part 71.45(a) requires that the following three (3) regulatory standards are to be met for all packages: [1] Any lifting attachment of a package must be designed with a minimum safety factor of three against yielding, [2] failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements, and [3] Any other structural part of the package that could be used to lift the package must be rendered inoperable for lifting the package.

The package has no structural device designed for lifting the Safkeg-LS 3979A package. The package will be man handled into position and lifted on a truck tail lift or lifted using a forklift truck with drum clamps fitted. These types of handling do not exert stresses to the structure of the package.

2.5.2. Tie-Down Devices

10 CFR Part 71.45(b) requires that the following three (3) regulatory standard to be met for all packages: [1] a static force applied to the center of gravity of the package having: a vertical component of 2 times, along the direction in which the vehicle travels of 10 times, and in the transverse direction of 5 times the magnitude of the weight of a package (packaging with contents), [2] Any other structural part of the package that may be used for tie-down must be rendered inoperable, [3] failure of the device under excessive load would not impair the ability of the package to meet other requirements.

The Safkeg-LS 3979A package has no specifically designed tie-down devices. The package is secured in either the horizontal or vertical position by the use of dunnage, cargo nets, or an equivalent system. These types of tie-down do not exert stress levels on the structure of the package.

The staff agrees with the chosen method of lifting and tie-down. The applied loads during lifting and tie-down would not exert notable (relative to yield) stresses on the package, and therefore, the requirements of 10 CFR Part 71.45 are met.

2.6. Normal Conditions of Transport

The NCT tests were performed on the prototype package. The recorded deceleration values during the free drop tests were tabulated in Table 8 of CTR 2009/21, Issue C. The maximum recorded deceleration value from the drop tests was 139g for the CG over top rim edge (corner) orientation (test number 6).

The half-symmetry finite element model (FEM) using ABAQUS, v6.8 of the containment vessel of the Safkeg-LS 3979A package was developed to evaluate for the requirement of 10 CFR Part 71.71. The stress analysis report No. 925-3272/R1, Rev. 4 performed by VECTRA Group Limited was included in the appendices of the CTR 2008/10 Rev. 2. The staff reviewed of the ABAQUS input files for correctness and accuracy. The applicant used a conservative deceleration value of 180g in the FEM for NCT free drop conditions, which is well over the recorded deceleration values during tests. Load combinations were performed in accordance with Regulatory Guide 7.8, and tabulated in Table 2-1 of CTR 2008/21, Rev. 2. Figure 7 of VECTRA report 925-3272/R1, Rev. 4, provides the critical locations of stress intensities. The following sections provide the results of the staff review of the package subjected to NCT conditions, which is required by 10 CFR Part 71.71.

2.6.1 Heat

10 CFR Part 71.71(c)(1) requires that the package must be evaluated in an ambient temperature of 38°C, in still air and insolation.

This normal condition for transport heat case was identified as NCT1 in VECTRA report 925-3272/R1, Rev. 4. The thermal analysis was conservatively performed to a bounding thermal condition for a containment vessel 110°C (230°F) with an internal pressure of 700 kPa (102 psig) gauge. The staff confirmed the loading conditions by reviewing the ABAQUS input file for the NCT1 case, and the results were tabulated in Tables 4-1, 4-2, 4-3, and 4-4 in VECTRA report 925-3272/R1, Rev. 4. The results of maximum stress intensity levels were compared to the allowable limit that were conservatively taken at 149°C (300°F), and that demonstrate acceptable stress design margins at critical locations of the containment vessel.

Based on the review of the results, the staff determined that the stress intensity values at critical components are within the allowable limits of the material and meets the regulatory requirements of 71.71(c)(1).

2.6.2 Cold

10 CFR Part 71.71(c)(2) requires that the package is subjected to temperature of -40°C (-40°F) in still air and shade.

This normal condition for transport of cold case was identified as NCT2 in VECTRA report 925-3272/R1, Rev. 4. In this case, the package was evaluated for an ambient temperature of -40°C (-40°F) in still air, zero insulation and zero decay heat with an external pressure of 100 kPa (14.5 psi). The staff confirmed the loading conditions by reviewing the ABAQUS input file for the NCT2 case, and the results were tabulated in Tables 4-5, 4-6, 4-7, and 4-8 in VECTRA report 925-3272/R1, Rev. 4. The results of the maximum stress intensity levels were compared to the allowable limits that demonstrate acceptable stress design margins at critical locations of the containment vessel.

Brittle fracture was considered because the containment vessel and keg are fabricated from austenitic stainless steel which is ductile even and low temperatures and therefore not susceptible to brittle fracture as discussed in section 2.1.2.5 of CTR 2008/10, Rev. 2, and in accordance with Regulatory Guide 7.11 "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 inches," June 1991.

Based on the review of the results, the staff determined that the stress intensity values at critical components are within the allowable limits of the material, and meets the regulatory requirement of 71.71(c)(2).

2.6.3 Reduced External Pressure

10 CFR Part 71.71(c)(3) requires that the package is subjected to a reduced external pressure of 25 kPa (3.5 lbf/in^2) absolute.

This normal condition for transport for the reduced external pressure case was identified as NCT3 in VECTRA report 925-3272/R1, Rev. 4. As stated in Section 4.3.1 of VECTRA Report 925-3272/R1, Rev. 4, the package was evaluated for a temperature of 110°C (230°F) with internal pressure of 775.5 kPa (112.5 lbf/in^2) gauge, which bounds the 25 kPa (3.5 lbf/in^2) absolute external condition. The staff confirmed the loading conditions by reviewing the ABAQUS input file for the NCT3 case, and the results were tabulated in Tables 4-9, 4-10, 4-11, and 4-12 in VECTRA report 925-3272/R1, Rev. 4. It was concluded that reduced external pressure would not cause any permanent deformation to the containment vessel.

Based on the review of the results, the staff determined that the stress intensity values at critical components are within the allowable limits of the material, and meets the regulatory requirement of 71.71(c)(3).

2.6.4 Increased External Pressure

10 CFR Part 71.71(c)(4) requires that the package is subjected to an external pressure of 140 kPa (20 lbf/in^2) absolute.

This normal condition for transport case for increased external pressure was identified as NCT4 in VECTRA report 925-3272/R1, Rev. 4. The package was subjected to temperature of -29°C (-20.2°F), still air with internal pressure of -140 kPa (-20 lbf/in^2) gauge. Internal pressure was conservatively considered to be 0.0 kPa (0 lbf/in^2) absolute. The staff confirmed the loading conditions by reviewing the ABAQUS input file for the NCT4 case in Tables 4-13, 4-14, 4-15, and 4-16 in VECTRA report 925-3272/R1, Rev. 4. It was also concluded that increased external pressure would not cause any permanent deformation to the containment vessel.

Based on the review of the results, the staff determined that the stress intensity values at critical components are within the allowable limits of the material, and meets the regulatory requirements of 71.71(c)(4).

2.6.5 Vibration

10 CFR Part 71.71(c)(5) requires that the package is subjected to vibration normal incident to transport.

The normal condition for transport cases for vibration were identified as NCT5 and NCT6 for hot and cold conditions, respectively; in VECTRA report 925-3272/R1, Rev. 4. The hot vibration analyses were performed with a vertical downward acceleration of 10g and 110°C (-166°F) with internal pressure of 700 kPa (101.53 lbf/in^2) gauge. The cold vibration analyses were performed for vertical downward acceleration of 10g and -29°C (-20.2°F) with an internal pressure of -100 kPa (-14.5 #/in^2) gauge. The staff confirmed the loading conditions by reviewing the ABAQUS input files for the NCT5 and NCT6 cases, and the results were tabulated in Tables 4-17, 4-18, 4-19, 4-20, 4-21, and 4-22 in VECTRA report 925-3272/R1, Rev. 4. The calculations for the containment vessel satisfy the allowable design criteria.

Based on the review of the results, the staff determined that the stress intensity values at critical components are within the allowable limits of the material, and meets the regulatory requirements of 71.71(c)(5).

2.6.6 Water Spray

10 CFR Part 71.71(c)(6) requires that the package must be subjected to a water spray test that simulates exposure to rainfall of approximately 5 cm/hour (2 inch/hour) for at least 1 hour. The applicant did not perform this test, and stated that the lid of the keg is fitted with an o-ring seal for weather protection, which would prevent water entry.

The water spray test is primarily intended for packaging relying on material that absorb water and/or are softened by water material bounded by water-soluble glue. Packaging outer layers constructed entirely of metal can be shown to meet this regulatory requirement without performing the test.

The staff concluded that the outer package materials of construction are not affected by the water spray test. Therefore, the water spray test of 10 CFR 71.71(c)(6) has negligible effect on the package, and is not required to be performed.

2.6.7 Free Drop

10 CFR Part 71.71(c)(7) requires that between 1.5 and 2.5 hours after the conclusion of the water spray test, 1.2 m (4 ft) free-drop of the package should be performed onto a flat unyielding horizontal surface in a position for which maximum damage is expected.

The reports CTR 2009/21, Issue C, and VECTRA Report 925-3272/R1, Rev. 4, provide the results of tests and finite element analyses, respectively. The analytical analysis for the normal condition for transport cases for free-drop were identified as NCT7, NCT8, NCT9, NCT10, NCT11, and NCT12 for cold and hot cases in VECTRA report 925-3272/R1, Rev. 4. The package was evaluated by performing tests in three different orientations: Test #4: CG over side, Test #5: CG over top end, and Test #6: CG over top rim edge (corner) as discussed in the test report CRT 2009/21, Issue C. The mass of the tested package was 61.72 kg (136 lbs), which is 5% lighter than the design mass of 64.8 kg (142.85 lbs). The tests were performed at a temperature of 14°C (57.2°F). The maximum recorded acceleration values during drop tests were tabulated in Table 2-28 of CTR 2008/10, Rev. 2.

The staff confirmed the loading conditions by reviewing the ABAQUS input file for the NCT7, NCT8, NCT9, NCT10, NCT11, NCT12 cases, and the results tabulated in Tables 4-23 through 4-40 in VECTRA report 925-3272/R1, Rev. 4. The staff reviewed the test report of CRT 2009/21, Issue C as well. It was reported that the drop tests caused minor denting on the body of the keg, and the calculated stress intensities at critical locations of the containment vessel are well within the allowable limits. Therefore, the staff determined that the regulatory requirement of 71.71(c)(7) is met.

2.6.8 Corner Drop

10 CFR Part 71.71(c)(8) requires that a free drop of a cylindrical package onto each quarter of each rim, from a height of 0.3 m (1 ft) onto a flat, essentially unyielding, horizontal surface.

This test applies only to fiberboard, wood, or fissile material rectangular packages not exceeding 50 kg (110 lbs) and fiberboard, wood, or fissile material cylindrical packages not exceeding 100 kg (220 lbs).

It was demonstrated that the prototype Safkeg-LS 3979A package met the regulatory requirements of 10 CFR Part 71.71(c)(7) and 10 CFR 71.73(c)(1) by the NCT and HAC corner drop tests, and by performing analytical analyses as discussed in CTR 2009/21, Issue C and VECTRA report 925-3272/R1, Rev. 4, respectively. Therefore, the staff agrees that the package will survive the 0.3 m (1 ft) drop condition required by the regulatory requirement of 10 CFR 71.71(c)(8).

2.6.9 Compression

10 CFR Part 71.71(c)(9) requires that the package must be subjected, for a period of 24 hours, to a compressive load applied uniformly to the top and bottom of the package in the position in which the package would normally be transported. The compressive load must be the greater of the following: (i) The equivalent of 5 times the mass of the package; or (ii) The equivalent of 13 kPa (2 lbf/in^2) multiplied by the vertically projected area of the package. The maximum mass of the package is 68 kg (150 lbs); five times of the mass is 340 kg (750 lbs). The vertical projected area of the package is 0.116 m^2 (1.25 ft^2) multiply by 13 kPa (2 lbf/in^2), which resulted with 1,505 N (338 lbf), which is equal to mass of 154 kg (338 lbs).

The keg body was physically tested under a 500 kg (1,100 lbs) load, which is well over the required mass of 340 kg (748 lbs). Table 7 in report CTR 2009/21, Issue C lists the measurements taken before and after the compression test. No change in dimensions of the keg were measured. Therefore, the performed compression test provided an adequate evidence that the regulatory requirement of 10 CFR Part 71.71(c)(9) is met.

2.6.10 Penetration

10 CFR Part 71.71(c)(10) requires that impact of a hemispherical end of a vertical steel cylinder of 3.2 cm (1.24 in) diameter and 6 kg (13 lbs) mass dropped from a height of 1 m (40 in) onto the exposed surface of the package that is expected to be most vulnerable to puncher.

The test was performed, and reported in report CTR 2009/21, Issue C. The test resulted with a dent of 8.9 mm (0.35 in) in depth and 105 mm (4.13 in) width in the keg skin. The keg skin was not punctured. Photograph 24 in CTR 2009/21, Issue C shows the dent in the skin of the keg.

The performed penetration test provided evidence that the regulatory requirement of 10 CFR Part 71.71(c)(10) is met.

2.7. Hypothetical Accident Conditions

The HAC tests were performed on the prototype package after the NCT penetration and drop tests. The HAC was performed sequentially in the order of puncture test free drop tests, puncture test, and thermal test. Thus, the keg was tested for the cumulative effects of both the NCT and HAC tests. The recorded deceleration values during the free drop tests were tabulated in Table 2-28 of CTR 2008/10 Rev. 2 and Table 8 of CTR 2009/21, Issue C. The maximum recorded deceleration value from the drop test was 224g for the CG over top rim edge (corner) orientation at -40°C (-40°F) (Test #: 12).

The half-symmetry finite element model (FEM) using ABAQUS, v6.8 of the containment vessel for the Safkeg-LS 3979A package was developed to evaluate for the requirement of 10 CFR Part 71.73. The stress analysis report No. 925-3272/R1, Rev. 4 performed by VECTRA Group Limited was included in the appendices of the CTR 2008/10 Rev. 2. The staff also reviewed the ABAQUS input files for correctness and accuracy. The applicant used a conservative deceleration value of 300g in the FEM for HAC free drop cases, which is well over the recorded deceleration values during tests. Load combinations were performed in accordance with Regulatory Guide 7.8, and tabulated in Table 2-2 of CTR 2008/21, Rev. 2. Figure 7 of VECTRA report 925-3272/R1, Rev. 4, provides the critical locations of stress intensities. The following sections provide the results of the staff review of the package subjected to HAC, which is required by 10 CFR Part 71.73.

2.7.1 Free Drop

10 CFR Part 71.73(c)(1) requires that a free drop of the specimen through a distance of 9 m (30ft) onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.

The reports CTR 2009/21, Issue C, and VECTRA Report 925-3272/R1, Rev. 4, provide the results of tests and finite element analyses, respectively. The HAC cases for free-drop were identified as HAC1, HAC2, HAC3, HAC4, HAC5, and HAC6 for hot and cold conditions in VECTRA report 925-3272/R1, Rev. 4. The prototype package was tested in three (3) orientations: Test # 10: CG over top end, Test # 11: CG over side, and Test # 12: CG over top rim edge (corner) at -40°C (-40° F). The HAC free drop tests were conservatively performed through a distance of 10.2 m (33.46 ft) instead of 9 m (30 ft). However, the mass of the test package was determined to be 61.72 kg (135.8 lbs), which is less than the design mass of 64.8 kg (142.85 lbs).

The staff performed independent hand calculations to estimate the differences due to tested mass against the gross mass of the package at drop distances of 10.2 m (33.46 ft) and of 9 m (30 ft) to determine decelerations and impact force using recorded pulse durations from Table 2-28 in CTR 2008/10, Rev 2.

Based on the review of results of the tests in CTR 2009/21, Issue C, and the stress calculations in VECTRA report 925-3272/R1, Rev. 4 as well as the staff's independent calculations, the staff concluded that the regulatory requirement of 10 CFR Part 71.73(c)(1) is met.

2.7.2 Crush

10 CFR Part 71.73(c)(2) requires that performing a dynamic crush test by positioning the specimen on a flat, essentially unyielding horizontal surface, so as to suffer maximum damage by the drop of a 500 kg (1100 lbf) mass from 9 m (30 ft) onto the specimen. The mass must consist of a solid mild steel plate 1 m (40 in) by 1 m (40 in) and must fall in a horizontal attitude. The crush test is required only when the specimen has a mass not greater than 500 kg (1100 lb), an overall density not greater than 1000 kg/m^3 (62.43 lbf/ft^3) based on external dimension, and radioactive contents greater than 1000 A_2 not as special form radioactive material. For packages containing fissile material, the radioactive contents greater than 1000 A_2 criterion does not apply.

The Safkeg-LS 3979A package has a density of 1478 kg/m^3 (92.27 lbf/ft^3), which is larger than 1000 kg/m^3. Therefore, the regulatory requirement of 10 CFR Part 71.73(c)(2) is not applicable.

2.7.3 Puncture

10 CFR Part 71.73(c)(3) requires that a free drop of the specimen through a distance of 1 m (40 in) in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 in) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in), and of a length as to cause maximum damage to the package, but not less than 20 cm (8 in) long. The long axis of the bar must be vertical.

The Safkeg-LS 3979A prototype package was dropped in the four (4) orientations shown in Figure 2-4 of CTR 2008/10, Rev. 2. Test #s: 7, 8, 9, and 12, in test report CTR 2009/21, Issue C.

The first 3 puncture test orientations were performed at ambient temperature prior to the HAC free drop condition, which is not consistent with the sequential application that is required by 10 CFR Part 71.73(a). The applicant stated that since the HAC drop test could result in an increase in cork crush density and crush strength, that the HAC puncture test before the HAC free drop is more conservative. The staff agreed that the applicant's testing sequence would provide more conservative results.

The final puncher test (Test #: 12a) was performed at -40°C (-40°F) on the top end orientation – as shown in photograph 21 in CTR 2009/21, Issue C. The staff acknowledged that the Safkeg-LS 3979A prototype package was tested after the HAC free drop for puncture at -40°C (-40°F), in the orientation that maximum damage could occur (on top end orientation). The puncture drop photographs are shown in Photographs 15, 16, 17, 21, and 48 in CTR 2009/21, Issue C.

The staff concluded that, performed puncher tests provided conservative results, which meets regulatory requirement of 10 CFR Part 71.73(c)(3).

2.7.4 Thermal

10 CFR Part 71.73(c)(4) requires exposure of the package with an average flame temperature of at least 800°C (1475°F) for a period of 30 minutes.

Section 3.0 of this Safety Evaluation Report provides an evaluation of the thermal performance of the package.

2.7.5 Immersion – Fissile

10 CFR Part 71.73(c)(5) requires that for fissile material subject to 10 CFR Part 71.55, in those cases where water inleakage has not been assumed for criticality analysis, immersion under a head of water of at least 0.9 m (3 ft) in the attitude for which maximum leakage is expected.

The applicant stated that the quantity of fissile material to be carried does not depend on water exclusion for criticality safety. The staff agrees with this conclusion that the package need not to be subjected to the water immersion test per the regulatory requirement of 10 CFR Part 71.73(c)(5).

2.7.6 Immersion - All Packages

10 CFR Part 71.73(c)(6) is required for all packages. A separate, undamaged specimen must be subjected to water pressure equivalent to immersion under a head of water of at least 15 m (50 ft). For test purposes, an external pressure of water of 150 kPa (21.7 lbf/in^2) gauge is considered to meet these conditions.

The package was subjected to the NCT case of Increased External Pressure (10 CFR Part 71.71(c)(4)) with a temperature of -29°C (-20.2°F), still air with internal pressure of -140 kPa (-20 lbf/in^2) gauge. Internal pressure was conservatively considered to be 0.0 kPa (0 lbf/in^2) absolute. The staff reviewed the ABAQUS input file and results of the NCT4 case in Tables 4-13 in VECTRA report 925-3272/R1, Rev. 4. It was also concluded that increased external pressure would not cause any permanent deformation to the containment vessel.

The NCT case of Increased External Pressure (10 CFR Part 71.71(c)(4)) can be scaled linearly to the HAC Immersion (10 CFR Part 71.73(c)(6)) using higher applied pressure levels. The stress intensities were scaled using the factor of 1.07, and are within the acceptable design margins as tabulated in Table 2-41 of CTR 2008/10, Rev. 2.

Based on the review of the results in the staff determined that the stress intensity values at critical components are within the allowable limits of the material, and meets the regulatory requirement of 71.73(c)(6).

2.7.7 Deep Water Immersion Test - Special requirements for Type B packages containing more than $10^5 A_2$.

10 CFR Part 71.61 requires that a Type B package containing more than $10^5 A_2$ must be designed so that its undamaged containment system can withstand an external water pressure of 2 MPa (290 psi) for a period of not less than 1 hour without collapse, buckling, or inleakage of water.

The Safkeg-LS 3979A contents are not greater than $10^5 A_2$ and therefore the package need not be subjected to the Deep Water Immersion Test per 10 CFR Part 71.61.

2.7.8 Summary of Damage

As discussed in the evaluations above, the package was demonstrated to perform adequately under the cumulative damaging effects from the drop tests.

The following criteria were concluded from the series of tests performed on the prototype package.

- The containment vessel remained leak-tight.
- The dimensions and the mass of the containment vessel did not alter.
- The keg remained intact with the keg-lid in place.
- The keg shell was not penetrated, and welds remained intact.
- The drop tests only caused damage to the keg rims while the penetration test caused minor damage to the keg shell.

The leakage rate tests performed prior to and subsequent to each test series confirmed that integrity of the containment boundary of the prototype Safkeg-LS 3979A package was maintained for all the tests performed. The tests were supplemented by analytical analyses confirming that the stress intensities at the critical locations of containment vessel were within the material allowable limits under NCT and HAC.

Therefore, the staff concludes that the package has adequate structural integrity to meet the regulatory requirements of 10 CFR Part 71.

Notes for PM:

- The regulatory requirement of 10 CFR 71.74 "Accident Conditions for Air Transport of Plutonium" was not provided, and addressed in the CTR 2008/10, Rev. 2. Therefore, air transport of plutonium must not be allowed in the certificate of compliance.
- The maximum gross mass of the package [packaging + insert(s) w/content(s)] should be limited to 65 kg (143 lbs) in the certificate of compliance