SECTION TWO

STRUCTURAL EVALUATION

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2 STRUCTURAL EVALUATION

2.1 Description of Structural Design

2.1.1 Discussion

The Versa-Pac is a packaging designed for the shipment of radioactive materials containing less than or equal to 350 grams U-235, including uranium oxides (U_yO_x), uranium metal (U-metal), uranyl nitrate crystals (UNX), and other uranium compounds (e.g., Uranyl Fluorides and Uranyl Carbonates) enriched up to 100 Wt% U-235. The material may be pre-packaged in plastic, metal or Teflon containers.

The 55-gallon Versa-Pac consists of a 15" inner diameter by 25-7/8" inner height (IH) containment area centered within an insulated 55-gallon drum. Drawings of the 55-gallon version Versa-Pac are provided in Appendix 1.3.1. The Versa-Pac design utilizes standard shop dimensions, tolerances and structural materials as outlined in the drawings in Appendix 1.3.1 and the General Note Sheet in Appendix 1.3.2. An illustration of the packaging is provided in Figure 1-1.

The overall nominal dimensions of the 55-gallon package are 23-1/16" Outside Diameter (OD) x 34-3/4" in height to the top of the outer drum bolt ring. The containment area is protected with a gasketed inner containment lid that is closed with twelve ½" bolts. A polyurethane insulation plug is encapsulated in 16-gauge carbon steel welded onto the drum lid (see Appendix 1.3.3). The gasketed drum lid is closed with four ½" bolts and a standard drum ring. A gasket at the drum lid's stiffening ring provides an additional barrier against water in-leakage.

The 55-gallon drum is strengthened with four longitudinal stiffeners fabricated from 1-1/4" carbon steel square tubing equally spaced around the circumference of the drum. A 16-gauge outer liner and a 16ga inner liner provide additional insulated radial stiffness to the drum. The volume between the inner liner and the 10-gauge containment body is filled with ceramic fiber insulation (see Appendix 1.3.4).

The 110-gallon Versa-Pac consists of a 21" Inside Diameter (ID) x 32-3/4" Inside Height (IH) containment area centered within an insulated 110-gallon drum. Drawings of the 110-gallon version Versa-Pac are provided in Appendix 1.3.1. The Versa-Pac design utilizes standard shop dimensions, tolerances and structural materials as outlined in the drawings in Appendix 1.3.1 and the General Note Sheet in Appendix 1.3.2. An illustration of the packaging is provided in Figure 1-1.

The overall nominal dimensions of the 110-gallon package are 30-7/16" Outside Diameter (OD) x 42-3/4" in height to the top of the outer drum bolt ring. The containment area is protected with a gasketed inner containment lid that is closed with twelve ½" bolts. A polyurethane insulation plug is encapsulated in 16-gauge carbon steel welded onto the drum lid (see Appendix 1.3.3). The gasketed drum lid is closed with eight ½" bolts and a standard drum ring. A gasket at the drum lid's stiffening ring provides an additional barrier against water in-leakage.

The 110-gallon drum is strengthened with eight longitudinal stiffeners fabricated from 1-1/4" carbon steel square tubing equally spaced around the circumference of the drum. A 16ga outer liner and a 16ga inner liner provide additional insulated radial stiffness to the drum. The volume between the inner liner and the 10-gauge containment body is filled with ceramic fiber insulation (see Appendix 1.3.4).

The Versa-Pac design does not include lifting or tie down devices. Handling is accomplished using a standard drum handling equipment and/or a forklift. Shielding and pressure relief devices are not required for the Versa-Pac payloads. Plastic plugs, located on the inner liner and the acetate plug located on the exterior of the package are designed to vent any combustion products generated by the insulation under Hypothetical Accident Conditions. The containment boundary is the containment area, the containment area blind flange and containment flat gasket seal. The containment area is attached to the structural components of the Versa-Pac using 12 equally spaced ½" bolts thru a ¼" connection ring, a ½" thick fiberglass thermal break connected to the structural frame. Bolts are torqued and the bolt/nut connection spot welded to prevent potential loss of the connection.

Performance of the package to the required regulations and design criteria is demonstrated through the analytical evaluations and prototype testing discussed in the remainder of this section. The package performs as required to the applicable regulations, assuring safe transport of the payload. Table 2-1 provides a summary of the evaluations performed and their results.

2.1.2 Design Criteria

The Versa-Pac was designed to meet all of the performance requirements of 10CFR71 for fissile materials. The Versa-Pac is manufactured under a quality assurance program that meets the requirements of 10CFR71, Subpart H. All welding is conducted by qualified personnel in accordance with AWS D1.1. All inspections are conducted by personnel qualified under ASNT-TC-1A and/or for visual inspection certified as an AWS certified welding inspector or assistant.

The containment boundary is defined as the containment area, its seal and blind flange. The structural design criteria for the packaging under the Normal condition are:

- The packaging is maintained within the allowable temperature, pressure and stress ranges as stated in each Section and Table 2-1;
- 55 Gallon Version - The package outer diameter and the height are essentially maintained at their nominal as-built dimensions;
- 110 Gallon Version - The package outer diameter and the height are essentially maintained at their nominal as-built dimensions;
- Positive closure is maintained during transport;
- Moderators are evaluated inside the payload vessel (criticality control requirement);
- Chemical and Galvanic reactions do not impair the function of the packaging within its 10-year design lifetime;

- The package is stackable and meets the applicable regulations; and
- Performance and design of the packaging meets other minimum regulatory requirements for licensure.

The design criteria under Hypothetical Accident Conditions are:

- The packaging is maintained within the allowable temperature, pressure and stress ranges as stated in each Section and Table 2-1;
- 55-Gallon Version - The average OD of the packaging is maintained greater than 21.1" and the minimum height of the packaging is maintained greater than 33.6" under all conditions (criticality control requirement);
- 110-Gallon Version - The average OD of the packaging is maintained greater than 28.5"and the minimum height of the packaging is maintained greater than 41.8" under all conditions (criticality control requirement);

Table 2-1 provides a summary of the structural evaluation, design criteria, and results of the evaluation.

2.1.3 Weights and Centers of Gravity

The weight of each component of the Versa-Pac is provided Table 1-1. The center of gravity of an empty 55-gallon packaging is located 20.2" from the absolute base of the package along a vertical axis in the geometric center of the package. The center of gravity of a loaded package will shift downward by 1.3". The center of gravity of an empty 110-gallon package is located at 17.5".

2.1.4 Identification of Codes and Standards for Package Design

The Versa-Pac is a Type A fissile package, based on the maximum U-235 payload of 350 grams enriched up to 100wt%.

The Versa-Pac Shipping Container was designed to meet the requirements of 10 CFR 71 and IAEA Safety Standards Series – Regulations for the Safe Transport of Radioactive Material, 1996 Edition (Revised) No. TS-R-1.

Fabrication and the assembly of the Versa-Pac Shipping Container will be conducted in accordance with Century Industries Quality Assurance Program and normal shop Standard Operating Procedures. Welding shall be conduct by qualified personnel and procedures in accordance with AWS D1.1.

Testing and inspection of the Versa-Pac Shipping Containers will be conducted in accordance with Standard Operating Procedures in compliance with the appropriate code, such as ASNT, ASME and AWS.

Maintenance and use of the Versa-Pac Shipping Container shall be conducted in accordance with Section 7.0, Operating Procedures and Section 8.0, Acceptance Tests and Maintenance Program and the Certificate of Compliance.

2.2 Materials

2.2.1 Mechanical Properties of Materials

The mechanical material properties used to evaluate the Versa-Pac performance are provided in Table 2-2. The thermal material properties used to evaluate the Versa-Pac performance are provided in Table 3.5.1-3.

2.2.2 Chemical, Galvanic Reactions and Other Reactions

Appendix 2.12.1 contains information concerning the compatibility of the materials used to fabricate the Versa-Pac. This information demonstrates that the combined materials of construction do not experience significant material loss due to galvanic reactions.

There are two combinations of Versa-Pac materials of construction with a potential to react galvanically. The first combination is steel, primer, ceramic fiber insulation, and polyurethane foam insulation. The second combination is steel and the payload. Other packages have successfully used this combination of materials without galvanic reactions and have done accelerated corrosion tests to support the combined use.

All of the insulation materials used in the construction of the Versa-Pac container are low in chloride content. The fiber insulation used has been tested for its corrosive action on steel with acceptable results (see Appendix 2.12.1). Therefore, the first combination of materials is acceptable for use.

The payload material is pre-packaged to limit contact with the containment area. Therefore, a galvanic reaction with the payload is not considered credible. However, pre-shipment and maintenance inspections would identify any corrosion due to contact with the payload well before the structural integrity of the containment area would be compromised.

Additionally, the contents and plastic pre-packaging materials do not produce significant amounts of hydrogen gas by radiolysis, as the available decay to support the reaction is essentially zero (less than 11.4 W). The Versa-Pac is not a sealed system as the RTV (Silicone Rubber Compound) coated fibrous sleeve allows gas venting without passage of solids.

Therefore, interactions among contents, packaging materials of construction and packing material satisfy the requirements of 10 CFR 71.43(d).

2.2.3 Effects of Radiation on Materials

The radiation produced by the authorized payloads is very low. The packaging materials used (steel, rigid polyurethane insulation products, ceramic fiber insulation products, silicone rubber, fluorocarbon) do not undergo significant changes in properties or performance due to their exposure to the authorized payloads.

2.3 Fabrication and Examination

2.3.1 Fabrication

The Versa-Pac Shipping Container is fabricated using Century Industries Standard

Operating Procedures, Fabrication Control Records, which document each step of the fabrication process (i.e., cutting of material, fitting, welding and other special processes) and becomes a part of the permanent Quality Assurance Record for the package. All welding is conducted in accordance with approved procedures, which are in compliance with the applicable code such as AWS D1.1. All insulation materials are installed in accordance with Century Industries SOP 6.11, 6.12, and 6.13 as referenced in Appendices 1.3.3, 1.3.4, and 1.3.5.

A typical fabrication sequence for the Versa-Pac Shipping Container begins with the cutting and forming of the individual components which is carried out thru the use of a Route Sheet system which provides the preparation group the details for all items. These items are inspected and once approved, released for production to begin the process of manufacturing the Versa-Pac.

The Fabrication Control Record (FCR) provides sequenced steps for the manufacturing of the Versa-Pac. These individual sequences give the quality assurance and production departments the instructions, standard operating procedures, welding procedures and inspection hold points for proper fabrication of the package.

Each sequence must be completed in order and the FCR step signed and dated by the individual responsible for that work, prior to moving to the next sequence. The FCR allows for QA or the customer to insert additional hold points at any location in the production process.

2.3.2 Examination

All non-destructive examinations methods utilized in the fabrication of the Versa-Pac Shipping Container, are conducted in accordance with Century Industries, Standard Operating Procedures, which are in accordance with appropriate codes, such as ASME and AWS D1.1 and/or 1.3 and applicable engineering specifications. Section 8 of this report specifies the requirements for fabrication acceptance and maintenance examinations of this package.

2.4 General Requirements for All Packages

2.4.1 Minimum Package Size

The smallest overall dimension of the 55 gallon version of the Versa-Pac is 22-1/2 inches in diameter and the smallest overall dimension of the 110 gallon version of the Versa-Pac is 30-7/16 inches in diameter. The Versa-Pac thereby complies with the minimum package size requirement of 10 CFR 71.43(a) which states that the smallest overall dimension of a package may not be less that 4 inches.

2.4.2 Tamper-Indicating Feature

The Versa-Pac utilizes the outer drum ring closure bolt for installation of tamper indicating devices, typically individually numbered seals.

2.4.3 Positive Closure

The primary containment is close by use of a gasketed ½” thick blind flange with 12 carbon steel clad ½”bolts, flat washers and lock washers. The outer opening of the Versa-Pac is closed utilizing a reinforced insulated drum cover initially bolted through a gasketed surface with

4 carbon steel clad ½" bolts and flat washers on the 55 gallon version and 8 bolts on the 110 gallon version. In addition the standard 12-gauge drum closure ring with a 5/8" bolt. All closure bolts are torqued at 60 ft.-lbs.

2.5 Lifting and Tie-down Devices

2.5.1 Lifting Devices

The Versa-Pac shipping container may be handled by normal industry standards for the safe movement of drums; such equipment might include specifically designed devices, forklifts, pallet jacks or other methods as determined by the user. However, the Versa-Pac package does not utilize any specific device or attachment for lifting.

2.5.2 Tie-down Devices

There are no specific provisions for tie-down of the Versa-Pac Shipping Container.

2.6 Normal Conditions of Transport

The Versa-Pac meets the standards specified by 10CFR71 when subjected to the conditions and tests required. The effectiveness of the package is maintained throughout all normal conditions of transport.

Evaluation by Test

Full-scale prototypes of both versions of the Versa-Pac Shipping Container were first tested in accordance with the (Structural) requirements specified by 10 CFR 71.71, Normal Conditions of Transport, and 10 CFR71.73, Hypothetical Accident Conditions, in July 2008. For package certification, additional NCT and HAC test series were conducted during the months of February and March of 2009 and the results are reported in Appendix 2.12.2. Additional testing including a shallow angle series of the 55 gallon in September, 2009 and NCT penetration and stacking test in December of 2009.

The packages used for the test series were fabricated as specified by the packaging drawings provided in Appendix 1.3.1.

Evaluation by Analysis

The drop test angles for the mechanical performance test series described in Appendix 2.12.2 were previously evaluated to determine the worst-case damage using finite element analyses in combination with a preliminary mechanical performance test series involving the Champion Type B package. The results of these analyses suggested that the crush tests would be most damaging to the package. The most damaging condition was observed in the subsequent testing of the Champion package. The calculations and test orientations for the Champion package are directly applicable to the Versa-Pac package due to the similarity of the package design. The most damaging configuration was further demonstrated through a preliminary series of tests conducted on both Versa-Pac package design versions during July 2008. Crush tests were conducted to impact the package side in the vicinity of the containment closure, main body below the containment closure and between vertical stiffeners, and the top of the package. A

final series of tests with the 110-gallon package version produced similar results. A complete description of the latter tests is provided in Appendix 2.12.2.

2.6.1 Heat

2.6.1.1 Summary of Pressures and Temperatures

The peak payload temperature of the packaging is 144°F (49°C), under Normal Conditions of Transport (see Section 3.4). The material properties of the packaging remain essentially nominal at this temperature. At the steady state, the temperature of the contents cannot be hotter than the exterior of the packaging, since there is no appreciable decay heat associated with the contents. Therefore, the maximum average temperature of the contents is less than 144°F (61°C). This is well below the maximum allowable temperature of 500°F (defined in Section 3.4) for the contents. At the maximum temperature of the payload, the bounding maximum pressure developed is 9.8 psig, well below the maximum allowable for the containment boundary (15 psig). Although the internal pressure of a filled package is normally atmospheric, the internal pressure of the containment may range from 0 to 9.8 psig (24.5 psia). However, since the Versa-Pac is not a sealed system, the maximum normal operating pressure is near atmospheric pressure.

2.6.1.2 Differential Thermal Expansion

The Versa-Pac is basically constructed of steel and insulation components. Due to its relatively high thermal conductivity and the relative uniformity of the heat application, the steel components do not independently develop significant stresses due to differential thermal expansion.

The blanket insulation used is compressible, and therefore is not damaged by thermal expansion effects.

The linear thermal expansion coefficient of the rigid foam insulation is approximately four times that of the steel; therefore it is possible that the foam insulation expands more than the steel shell. If the entire volume of the foam increases in temperature from 72ºF to the peak steady state surface temperature of 144ºF, the average maximum linear differential thermal expansion of the foam is about 1/16”. However, due to the cyclic loading of the insulation, the actual volume of foam at 144ºF is limited to less than 15% of the total foam volume and a more realistic estimate of the expansion is about 1/240”. These very small expansion lengths are absorbed by the microstructure of the foam at the steel surface and by the allowable tolerances on the parts themselves. Therefore, no significant stresses are generated as a result of differential thermal expansion.

2.6.1.3 Thermal Stress Calculations

Due to the decoupled design of the packaging, thermal stresses generated by the packaging are negligible.

2.6.1.4 Comparison with Allowable Stresses

Not applicable.

2.6.2 Cold

At an ambient temperature of -40^{0}F with no insolation and zero decay heat generated by the contents, the package attains a uniform temperature of -40^{0}F. At this temperature, the foam insulation compression strength and compressive modulus are increased. The increased foam (top and bottom of the package) strength and modulus result in a stiffer package response under drop conditions, and therefore more of the load is transferred to the containment boundary on impact. Also, the carbon steel components may be brittle below -20^{0}F. Performance testing of the package was completed at low temperature, demonstrating that the packaging performs as required under cold conditions.

No observable differences in damage were noted by comparison of prototype testing of the package at normal ambient temperatures (see *Evaluation by Test*, Section 2.6) to the performance testing conducted at low temperatures. Therefore, low temperature effects have little impact on the Versa-Pac package performance.

2.6.3 Reduced External Pressure

Although the internal pressure of a filled package is nominally atmospheric, the internal pressure of the containment may range from 0 to 2.0 psig (16.7 psia) for the normal condition. In the worst case, a reduced external pressure of 3.5 psia results in a net internal pressure of 13.2 psia or a net external pressure of 3.5 psia. These pressures are within the design internal and external pressure (25 psig) of the containment.

2.6.4 Increased External Pressure

Although the internal pressure of a filled payload canister is nominally atmospheric, the internal pressure of the sealed canister may range from 0 to 2.0 psig (16.7 psia) for the normal condition. In the worst case, an increased external pressure of 20 psia results in a net external pressure of 20 psia or a net external pressure of 3.3 psia. These pressures are within the design internal and external pressure (25 psig) of the containment.

2.6.5 Vibration

Vibration incident to transport does not produce settling, compaction or a loss of structural cohesion for any of the materials used in the packaging. Vibrational compaction of the payload does not impact the performance of the packaging, since the criticality evaluation (see Section 6) applies a variable payload density up to the theoretical limit to evaluate the optimum condition. Vibration testing conducted on the outer drum during the performance design qualification test as set forth in 49 CFR 178.608 were successfully performed with past experience indicating no failure to the drum ring closure. In addition, the Versa-Pac includes an additional bolted closure thru the top lid attached to the internal structure. This bolted closure utilizes ½" bolts and locking washers that are torqued to a prescribed rating of 60 ft/lbs. to prevent the loss of the bolts during transportation. Thus, normal vibration incident to transport does not impact the performance of the Versa-Pac.

2.6.6 Water Spray

A one-hour water spray simulating rainfall at a rate of 2 in/hr has no effect on the Versa-Pac, as the outer vessel is designed to withstand exterior pressure loads much higher than those applied by the water spray.

The Versa-Pac utilizes multiple seals to prevent the loss or dispersal of its contents. Because it is clear that the water spray test has no effect on the package or contents, it was not conducted during the performance test sequence.

2.6.7 Free Drop

Per regulatory requirement, the package must maintain its integrity and effectiveness when subjected to a free drop from a height of 4 feet (1.2 meters) onto a flat, essentially unyielding horizontal surface. Although the damage from a 4-foot free drop results in some local deformation of the transport unit, the deformation is well within the allowable specified for criticality safety, and structural stability. Three different drop orientations were conducted and the results of all five normal condition performance tests of the Versa-Pac are provided in Appendix 2.12.2.

2.6.8 Corner Drop

This test is not applicable to the Versa-Pac packaging, as its weight exceeds the specified maximum of 220 lb.

2.6.9 Compression

The primary load bearing members of the Versa-Pac are the steel 55 or 110-gallon drum shell, the vertical stiffeners, and the inner liner. These components, when assembled as a unit, can be analyzed as an axial member in compression. Assuming the metal thickness is 0.036" and 0.05" for the drum and inner liner, respectively, and using 1-1/4" x 1-1/4" x 0.12" for conservatism (the actual thicknesses are 0.06", 0.0598", and 0.135" respectively), the load-bearing cross-sectional area is approximated as:

$$\pi(22.5")(0.036") + \pi(19.25")(0.05") + 4(1.25"^2 - 1.01"^2) = 7.738 \text{ in}^2$$

Five times the weight of the package is: (5) (965 lb) = 4,825 lb

The compressive stress on the steel members is:

$$4{,}825 \text{ lb} / 7.738 \text{ in}^2 = 623 \text{ psi}$$

The margin of safety against compressive failure is:

$$\text{M.S.} = (36{,}000/623) - 1 = 56.7.$$

Empty Package – Five times the weight of the package is: (5) (390 lb) = 1,950 lb

The compressive stress on the steel members is: 1,950 lb /7.738 in^2 – 252 psi

The margin of safety against compressive failure is: M.S. = (36,000/252) – 1 = 141.85.

The structural members of the Versa-Pac are comprised of a variety of thicknesses of steel components, although when combined thru the process of manufacturing act in conjunction with one another to produce an exceptionally strong unit. To further demonstrate that the Versa-Pac meets the requirements set forth in 10 CFR 71.71(c)(9) the Versa-Pac was subjected to a load greater than 5 times the weight of the package for a period of 24 hours without any damage. The 55-gallon version was tested and the results provide in Appendix 2.12.5 NCT Versa-Pac Test Report for Compression and Penetration.

Conclusion

Based upon the calculations providing a large margin of safety against compressive failure and the physical testing performed using the previously tested 55 gallon version described above and reported in Appendix 2.12.5 NCT Versa-Pac Test Report for Compression and Penetration, the Versa-Pac meets and exceeds the requirements specified in 10 CFR 71.

2.6.10 Penetration

Impact from a 13-pound rod as described in 10CFR71 does not penetrate the steel shell of the Versa-Pac.

The Versa-Pac shipping container was subject the penetration described under 10 CFR 71.71(10) for penetration using a 1.25 inch diameter steel bar weighing 13.2 pounds and dropped from a height of 40 inches (1 Meter) onto several different areas of the test package considered to be the weakest parts of the package without measurable damage at the impact point. These results are supplied in Appendix 2.12.5 NCT Versa-Pac Test Report for Compression and Penetration.

2.7 Hypothetical Accident Conditions (HAC)

The Versa-Pac meets the standards specified by 10CFR71 when subjected to the conditions and tests required. Analytical techniques were used to determine the test orientations producing the maximum damage. Representative prototypes were constructed and tested on two separate occasions using both package design variations (55-gallon and 110-gallon) to demonstrate that the package performs as required to transport the payload. A detailed report of the tests performed is provided in Appendix 2.12.2.

The compliance testing demonstrated:

- The Versa-Pac provides sufficient thermal protection to prevent the internal temperature of the payload container from exceeding the maximum design temperature of the containment boundary (500^{O}F) during and following HAC;
- The average OD of the package, and the required package height is maintained under HAC (specified in Section 6) is maintained under all conditions; and
- Containment of the payload is maintained.

Therefore, the Versa-Pac provides adequate protection to the payload during HAC as defined by 10CFR71.73.

2.7.1 Free Drop

The full-scale representatives of the 110 gallon Versa-Pac containing a simulated payload were subjected to a variety of sequenced drops, punctures, shallow angle drops and crush test, specified by 10CFR71.73 and outlined in the test plan and report in Appendix 2.12.3. The same prototype was used for each test sequence in succession, with no repairs between the tests. The test prototypes were fabricated to the drawings and specifications provided in Appendix 2.12.2.

All drop tests were performed on the same 70 ton pad which is 10' x 10' x 10' deep reinforced with a grid of ¾" re-bar spaced on 12 "center and capped with an 8' x 10' x 1" thick steel plate which is embedded to the surface of the concrete and secured to it with fourteen 1-1/2" diameter x 16' long bolts. A quick release mechanism was used to release the prototypes from the drop height without imparting rotational or translational motion to the prototype. For the puncture drop, a puncture ram was welded to the test pad. The ram is a 6" diameter by 18" long right circular cylinder, fabricated from mild steel and welded to the pad reinforcement plate. The solid steel plate used for the dynamic crush test weighs 500 kg and is 1m by 1m in cross section. The tests were video taped and photographed, and post-drop damage measurements were recorded after each drop.

In order to determine the worst-case initial temperature conditions for the drop tests, the performance characteristics of the primary Versa-Pac fabrication materials were evaluated. The primary structural and sealing materials include carbon steel, polyurethane foam, and silicone rubber. Because carbon steel may exhibit brittle failure mechanisms at temperatures below 0°F and the other materials are essentially unaffected over the design temperature range, the initial condition temperature selected is –20°F. For consistency with the minimum design operating temperature specified by international regulations, the impact testing initial ambient condition selected is –40°F.

The payload utilized for the drop test series consisted of a 30-gallon drum that was filled with approximately 226 lb of different size gravel with an additional 1 to 1-1/2 lbs. of loose play sand which was placed on the top of the 30 gallon drum, combining for a test payload of 260 lbs. The blind flange was secured by tightening the bolts to an initial torque of 40 ft-lbs. The decay heat generated by the contents is negligible; therefore, heat generated by the contents was not simulated. The Versa-Pac was then subjected to an ambient air temperature of approximately -40°F for 12 hours. Upon removal from the conditioning chamber, the exterior skin of the shipping package recorded a temperature of -28°F at time of transport to the test pad.

2.7.1.1 End Drop

After cooling, test package serial number 10552 was positioned with the top end of the package positioned over the test pad at an angle of 0 degrees so as to impact the container directly onto the top surface of the package. This drop series is intended to test the top closure of the package and the internal containment closure components.

Test Record Number – TS-001-1

Test Number 1A – NCT 4' Top End Drop

The initial drop was made from a height of 4' onto the target pad, and the external damage was recorded and documented with both video and still photography. As result of the impact no visible damage was accumulated. All welds, closures and bolts remained intact. The package was not opened after the Normal Condition Drop, but was prepared for the 30' HAC Drop.

Test Number 1B – HAC 30' Top End Drop

Following the Normal Conditions Drop, the package was positioned for the HAC 30' drop onto the same surface and orientation of 0 degrees. Post drop inspection documented that the overall height of the package was reduced by 1/4 inch and that the diameter was increased by 1/6 inch. An area measuring a total of 2 and 3/8 inches long at the bolt closure was crumpled in slightly. All welds, closures and blots remained in tact. The package was not opened, but was set aside for use in the puncture test listed in Test Record TS-001-1 Number 1C.

2.7.1.2 Side Drop

After cooling, test package number 10551 was positioned in a level horizontal position over the test pad. This drop series was designed to test the impact on the bolt closure of the package on its side, along with inner containment closure when exposed to the impact.

Test Record Number – TS-001-2

Test Number 2A – NCT Horizontal Side Drop

The initial drop was made from a height of 4' onto the target pad, and the external damage was recorded and documented with both video and still photography. The result of the impact to the exterior surface of the package was that the closure bolt was pushed into the package side wall approximately 5/8 inch. No reduction in height or diameter occurred. All welds, closures and bolts remained in tact.

Test Record Number – 2B – HAC 30' Horizontal Side Drop

The same test package was positioned for the HAC 30' drop onto the same horizontal surface as the Normal Conditions Drop in an effort to shown accumulated damage in the side drop orientation. Resultant damage from this drop accounted for a buckling around the closure bolt area and on the lid and a decrease in the diameter of I inch in the bolt impact direction. There was no loss of bolts or closure and all welds remained in tact. The package was then subjected to the crush plate drop described below and recorded in TS-001-2 Record Number 3C.

2.7.1.3 Corner Drop

Upon cooling, test package number 10550 was in a position with the center of gravity impact to be through the package bolt closure over the test pad. This drop series was designed to test the impact on the bolted closure of the package through its center of gravity, along with inner containment closure when exposed to the impact.

Test Record Number TS-001-3

Test Number 3A – NCT Center of Gravity Drop

The normal condition drop center of gravity drop from a height of 4' through the bolted closure at an angle of 57 degrees was recorded and documented using both video and still photography. The impact resulted in a deformation on the drum side at the closure bolt with measurements of 1-1/16 inch deep by 2 inches long. All welds, bolts and closures remained in tact.

Test Record 3B – HAC Center of Gravity Drop

The package was repositioned in the same attitude of 57 degrees so as to impact the identical area tested in 3A above over the test pad at a height of 30' form the lowest point of the package. The impact resulted in a depression 11/16 inches deep into the lid and additional side deformation totaling 2-1/2" deep by 20 inches long. All welds, bolts and closure remained intact. The package was then readied for the HAC oblique (Shallow) angle drop described below.

2.7.1.4 Oblique Drop

Using test package number 10550 an oblique drop of 17 degrees was positioned of the test pad so as to initially impact the top closure with the resulting acceleration impact to attack the bottom of the package. This drop was also intended to test the inner containment area closure system.

Test Record Number 3C – HAC Shallow Angle Drop (Slap Test)

The package was positioned over the test pad at 17 degrees from the horizontal position with the lowest point of the package 30' from the target surface. The damage to the package exterior surface produced a tear at the exterior drum side to bottom rim connection point measuring 3/16 inch at its widest point by 7 inches in length. Although this slit in the outer drum occurred, no internal breach of the inner liner occurred, remaining completely sealed from the exterior atmosphere. Additional deformation at the bolted closure affected an area measuring 2-15/16 inches deep with a 1-inch crumple in the lid. The diameter of the package across the top surface only, of the outer drum lid, was reduced in the direction of the impact upon the bolt, by approximately 3 inches, which coincides with the deformation described above. The package was then readied for a puncture test to be described below and listed in Test Record TS-001-3 Number 3D.

2.7.1.5 Summary of Results

The initial drops of this test series provided information showing that the package design was capable of withstanding multiple impacts with only minor damage to the exterior surfaces of the package this point. Complete measurements along with full photographic and written documentation are included in Appendix 2.12.3. Drop test series complete summary of results are noted in 2.7.3.1 below.

2.7.2 Crush

Based upon past history and an attempt to attack the top closure mechanism of the package system, the test package previously used in horizontal drop of Test Record TS-001-2 was positioned on the test pad in a horizontal attitude. The crush plate was placed to impact the package directly on both the closure and top flange areas and also over the bottom edge of the package. The purpose of this test was to test both the internal and exterior closures and surfaces of the test package.

Test Record Number 2C – HAC 30' Crush Plate Side Drop

The crush plate was suspended at an angle of 0 degrees directly over the test package and lifted to a height of 361 inches from the lowest point of the test plate to the top of the test package surface. Upon impact the overall diameter of the package in the direction of the impact was reduced by 2-1/2 inches from its original shape at its maximum point. A gap of ¼ inch by 1-1/4 inch long was documented at the drum lid to drum rim interface. Due to the design of the closure lid a metal-metal interface was visible with no direct opening to the internal structure or seals.

2.7.3 Puncture

Prototypes of both the 55 and 110-gallon versions of the Versa-Pac were subjected to the puncture test in a variety of orientations including side, center bottom, center top and center of gravity through the bolt closure. The most damage to the exterior surface of the package was through the center of gravity onto the closure and by attacking the side between the vertical stiffeners. Based upon this data both areas were punctured during this test series. The packages were lifted to a height of 41 inches above the top of the puncture ram, which was welded to the top surface of the drop test pad.

Test Record Number 1C – HAC 1 Meter Puncture Drop – Horizontal

The suspended package was positioned level and horizontal (1 degree) so that the impact location was between two of the vertical stiffeners and in the middle of package. The test was recorded and documented using video and still photography. The deformation upon measurement was a maximum of 3/8 inch deep. The package sustained no tears as a result of the puncture drop.

Test Record Number 3D – HAC 1 Meter Puncture Drop – CG Over Bolt Closure

The package was positioned with the center of gravity through the bolted closure at an angle of 56 degrees from a height of 41 inches from the lowest point of the package to the top of the puncture ram. The drop test was recorded and documented using both video and still photography. The impact resulted in additional damage on the drum side at the closure bolt with a small separation of ¼ inch by 3 inches long at the drum lid and drum rim interface. The opening was sealed by metal-metal contact between the flange and the drum lid insulation sheet metal cover and the top gasket material, which remained in tact.

2.7.3.1 Summary of Damage

Upon completion of the drop test series all test packages were inspected for damage, the torque of the bolts recorded and internal condition and damage noted.

Test Record Number TS-001-1 – Top End Drops - Package Serial Number 10552

The series of test conducted included a 4-foot top end drop, a 30-foot top end drop and a horizontal side puncture drop. Outer closure bolts recorded a torque of 30 ft-lbs. The outer lid was removed exposing a bulge in the inner containment flange. The bulge in the inner flange allowed sand, which was placed on the top of the payload 30-gallon drum to be forced under the containment gasket. It is believed that the piston action within the inner drum payload provided a secondary impact force upon the primary containment flange thus causing the flange to bulge. Containment flange bolts were torqued prior to removal and recorded at 20 ft-lbs. Gaskets and the internal condition of the package were found to be in good condition with no damage.

Test Record Number TS-001-2 – Horizontal Side & Crush Plate Drops - Package Serial Number 10551

The test article series of drops included a 4-foot horizontal side drop, a30-foot horizontal side drop and a 30-foot crush plate side drop. Although**,** the outer drum ring was dislodged during previous testing the package remained closed and in place due to the additional top closure bolt design of the Versa-Pac Shipping Container. The outer closure bolts of the top cover were torqued and recorded a reading of 25 ft-lbs. Upon removal of the outer lid inspection revealed a slight interior wall deformation in the upper plug well of the package. There was no loss of contents. The containment flange was in good condition and the bolts recorded a torque of 25 ft-lbs. Gaskets were in good condition. The inner payload drum lid exhibited some buckling from the piston action of the internal payload within the drum. This payload comprised of gravel and sand acted as an additional piston action within the body of the drum. Upon removal of the inner containment payload visual inspection was conducted with no damage shown within the inner containment cavity.

Test Record Number TS-001-3 – Center of Gravity, Shallow Angle & Puncture - Package Serial Number 10550

This series consisted of a 4-foot center of gravity drop, a 30-foot center of gravity drop, a 30-foot shallow angle drop and a center of gravity puncture drop. Upon completion of these drops the test package outer closure bolts were torqued with readings found to be less than 20 ft-lbs. upon removal of the outer lid inspection revealed a deformation of the inner wall at the impact area. A bulge in the inner containment flange was also noted along with some sand from the inner containment area. This again was due to the piston action coming from the internal payload during the impact and corresponding secondary impact from the payload. The gaskets were found to be in good condition. Upon removal of the inner containment payload a visual inspection was conducted with no damage found to the internal cavity.

2.7.3.2 Conclusions

Based upon the information obtained from the series of drops conducted it was determined that the two of the drop series results were unsatisfactory and that additional testing would be conducted. It was determined that three primary causes were responsible for the

bugling of the internal containment flange and the resultant loss of sand from the top of the inner payload. The first being that the flange in itself was under sized at $^{3}/_{16}$ inch thick and secondly, that the thickness of the silicone coated fiberglass gasket used in sealing the containment allowed a flexing at the interface of gasket and flange. The third potential cause was the removal of the gasket pad located between the inner flange and the payload.

In order to correct this condition the flange was increased to a thickness of ½ inch. This would accommodate a greater torque to be applied to the sealing of the inner containment area and provide a much higher strength to support the internal piston action within the payload area. Also the gasket pad would be reinstalled between the payload and the inner flange surface.

After evaluating the three test articles, two were chosen for reuse in an additional round of testing. The packages chosen were in good condition and were able to be resealed after their original series of testing. These package serial numbers were 10551 and 10552.

2.7.3.3 Package Preparation

Both previously drop packages were carefully inspected and measurements of height and diameter recorded on new testing records. The payloads were identical to the original test series, with 1-1/2 pounds of sand place on top of and around the payload as before. The test articles were fitted with new ½ inch thick inner containment flanges with 3/8 inch thick neoprene sponge rubber pads affixed to the inside of the inner flange lid prior to installation. The torque of the inner containment bolts was also increased for a better seal on the 1.8 inch thick silicone rubber coated fiberglass gasket to 60 ft-lbs. The outer container lid was put into place and bolts torqued to 60 ft-lbs.

The test articles were then placed in the cooling chamber for 18 hours prior to the new drop tests.

2.7.3.4 Second Round End Drops

After cooling, test package serial number 10551 was positioned with the top end of the package positioned over the test pad at an angle of 0 degrees so as to impact the container directly onto the top surface of the package. This second round drop test series was intended to test the top closure of the package and the internal containment closure components and to validate that the changes made to the inner containment flange would prove to correct the loss of materials previous found during the original drop testing.

Second Round Test Record Number – TS-001-4

Second Round Test Number 1A – NCT 4' Top End Drop

This drop was made from a height of 4' onto the target pad, and the external damage was recorded and documented with both video and still photography. As result of the impact no visible damage was accumulated. All welds, closures and bolts remained intact. The package was not opened after the Normal Condition Drop, but was prepared for the 30' HAC Drop.

Second Round Test Number 1B – HAC 30' Top End Drop

Following the Normal Conditions Drop, the package was positioned for the HAC 30' drop onto the same surface and orientation of 0 degrees. Post drop inspection documented that

the overall height of the package was reduced by 7/16 inch and that the drop test did not affect the diameter. All welds, closures and blots remained in tact.

Prior to opening the test article the bolt torque of the outer closure was measured and found to be between 20 to 80 ft-lbs. with all bolts in tact. After opening the package photographs were taken and the interior well surfaces inspected with no damage found. The new thicker blind flange remained flat, sealed and no loss of payload contents were found outside the inner containment area. The bolts of the interior containment were torqued and found to be at a torque of 30 to 50 ft-lbs. The gasket and payload were in good condition.

2.7.3.5 Second Round Corner Drop

After cooling, test package number 10552 was in a position with the center of gravity impact to be through the package bolt closure over the test pad. This second round drop series was designed to test the impact on the bolted closure of the package through its center of gravity, along with inner containment closure when exposed to the impact and to verify that the changes made to the test article were sufficient to correct the loss of contents in this previously tested series of drops.

Second Round Test Record Number TS-001-5

Second Round Test Number 3A – NCT Center of Gravity Drop

The normal condition drop center of gravity drop from a height of 4' through the bolted closure at an angle of 57 degrees was recorded and documented using both video and still photography. The impact resulted in a deformation on the closure bolt area with measurements of 1-3/16 inch deep by 21/4 inches long. All welds, bolts and closures remained in tact.

Second Round Test Record 3B – HAC Center of Gravity Drop

The package was repositioned in the same attitude of 57 degrees so as to impact the identical area tested in 3A above over the test pad at a height of 30' form the lowest point of the package. The impact resulted deformation totaling 2-9/16" deep by 20-1/2 inches long. All welds, bolts and closure remained intact. The package was then readied for the HAC oblique (Shallow) angle drop described below.

2.7.3.6 Second Round Oblique Drop

Using test package number 10552 a second oblique drop of 17 degrees was positioned of the test pad so as to impact the top closure with the resulting acceleration impact to attack the bottom of the package. This second round drop was also intended to test the inner containment area closure system and to provide evidence that the changes made to the test article corrected the loss of content problem previously found in the original testing.

Second Round Test Record Number 3C – HAC Shallow Angle Drop (Slap Test)

The package was positioned over the test pad at 17 degrees from the horizontal position with the lowest point of the package 30' from the target surface. The damage to the package exterior surface produced deformation on the initial top closure measuring 2-15/16 inches deep

with a 1 inch crumple in the lid. Secondary impact produced damage measuring 5 inches in length on the bottom rim of the test article. Diameter of the package was reduced in the direction of the impact area through the bolt by approximately 1 inch.

Before opening the outer closure the torque was measured and found to be less than 20 ft-lbs. Photographs were taken and inspection of the inner well area found only minor deformation within the sidewalls of the well area, no other damage was found. The inner flange was flat and sealed with no loss of contents form the internal containment area.

2.7.3.7 Secondary Test Series Conclusion

With the changes made to the inner blind flange closure, increasing the thickness of the flange, increasing the torque of the bolts and reinstalling the containment flange pad the Versa-Pac Shipping Container successfully completed the drop test evaluation series.

2.7.3.8 55 Gallon Shallow Angle (Slap-Down) Drop Test Series - Test Record Number TS-002-1

This series of testing was conducted to provide additional information and verification that the 55 gallon version of the Versa-Pac shipping container would demonstrate the capability to successfully meet the requirements set forth with similar results provided by previously conducted testing of the 110 gallon version when subjected to the affects of both NCT and HAC Shallow Angle Drops. The package contained 254-1/2 pounds of payload consisting of gravel, steel bars (to amplify the secondary piston impact effect) and 1-1/2 pounds of loose sand for a total weight of 644-1/2 pounds. All bolts were torqued to 60 ft/lbs. at closure of the blind flange and top closure lid.

2.7.3.9 Oblique Drop

Using 55 gallon test package number 10553 an oblique drop of 17 degrees was positioned of the test pad so as to initially impact the top closure with the resulting acceleration impact to attack the bottom of the package. This drop was also intended to test the inner containment area closure system. The drop angle of 17 degrees was chosen based upon previous drop history of like packages and drop information found and recorded in NUREG 6818. The puncture drop was chosen after the initial drops to attack the most vulnerable area of the package base upon the damage from the shallow angle NCT and HAC drops to the package.

Test Record Number 1-55-A – NCT Shallow Angle Drop (Slap Test)

The package was positioned over the test pad at 17 degrees from the horizontal position with the lowest point of the package 4’ from the target surface. The damage to the package exterior surface produced only minimal damage to the impact side of the test package, with an area 7-1/4” long at the widest points on the top closure end and a impact are 5-3/4” in width at the bottom edge. Minor indentation along the outer drum rolling hoops was also noted. Both flattened areas were approximately ¼” in depth. There was no tearing or opening of the package. The package was then readied for a puncture test to be described below and listed in Test Record TS-001-3 Number 3D.

Test Record Number 1-55-B – HAC Shallow Angle Drop (Slap Test)

The test package was then positioned over the test pad at 17 degrees from the horizontal position with the lowest point of the package 30' from the target surface. Damage to the package consisted of a small ripple in the middle of the outer drum lid with minor flattening of the outer drum rolling hoops. Additional damage to the top closure, initial impact area was noted increasing the length of the area to 11-1/2" long by 3/8" deep and the bottom, secondary impact increasing to 100 long by ¼" deep. The bolt closure ring of the outer drum was pushed into the side wall of the outer drum producing a small tear in the drum sidewall material at the top rolling hoop, but due to the design of the package there was no breach or tearing of the Versa-Pac's inner liner, which is adjacent to the outer drum. The drum closure ring lug was also broken with the impact, but the top closure, remained in tact and secure due to the top closure bolts of the package.

Test Record Number 1-55-C – HAC 1 Meter Puncture Drop – CG Over Bolt Closure

The package was positioned with the center of gravity through the bolted closure at an angle of 56-1/2 degrees from a height of 41 inches from the lowest point of the package to the top of the puncture ram. The drop test was recorded and documented. The impact resulted in additional damage to the outer drum closure ring and lid interface with an impact deformation measuring 8-3/8" in diameter. There was no tearing or opening of the package as a result of the puncture drop.

2.7.3.10 55 Gallon Test Series Conclusion

Based upon the results of the test series the 55 gallon version of the Versa-Pac has demonstrated that it is capable of meeting the requirements set forth in 10 CFR 71 and Century Industries Test Plan TP-002 Revision 0 by retention of the outer closure, no openings, tears or failure that would lead to the loss of material, no open pathway to the insulation materials and no loss of the inner containment payload. The overall diameter of the package thru the impact area was reduced by ½", but remained the same in the opposite direction.

2.7.4 Thermal

A thermal test was not performed on the test prototype in its damaged condition following the drop test sequence. However, the package was analytically evaluated as indicated in Section 3. Based on testing of a similar package (Champion) as presented in Section 3.5.3, the analytically calculated values appear to be conservative.

2.7.4.1 Summary of Pressures and Temperatures

The Versa-Pac was evaluated for HAC using the finite element models described in Appendix 3.5.1 and under the conditions listed in Table 3-2. The maximum temperature recorded at the payload cavity during the fire event was 423^{o}F at the top of payload cavity, just below the polyurethane plug, as shown in Figure 3.1. This temperature is well below the maximum HAC allowable temperature of 500^{o}F. Although the internal pressure of a filled package is nominally atmospheric, the internal pressure of the containment may range from 0 to

9.8 psig (24.5 psia) for the HAC condition. However, since the Versa-Pac is not a sealed system, the maximum normal operating pressure is near atmospheric pressure.

2.7.4.2 Differential Thermal Expansion

As discussed in Section 2.6.1.2, the materials used to fabricate the Versa-Pac and the arrangement of the packaging limit the effects of differential thermal expansion. No significant stresses are generated as a result of differential thermal expansion.

2.7.4.3 Stress Calculations

Due to the decoupled design of the packaging, thermal stresses generated by the packaging are negligible.

2.7.5 Immersion – Fissile Material

Moderator inleakage to the most reactive credible extent is assumed for the Versa-Pac and evaluated in Section 6.0. Thus, the fissile material immersion test is not required.

2.7.6 Immersion – All Packages

Regulations require that an undamaged package be capable of sustaining a hydraulic pressure of 50 feet of water. As indicated in Appendix 2.12.3, a similar damaged prototype was placed in an immersion chamber at 23 psig for 15 minutes. As expected, due to the reinforcements within the drum, no further damage was noted.

2.7.7 Deep Water Immersion Test

This section is not applicable to the Versa-Pac Shipping Container.

2.7.8 Summary of Damage

The series of drop tests (3 initial series and 2 second round series a total of 5 in all) completed were performed for the worst-case package orientations, worst-case initial packaging temperature, and with a maximum payload on board. The test article was slightly too moderately deformed at the impact sites. Due to impact from testing only minor changes in the diameter were found with measured diameter changing primarily at the impact points only. The worst case of oval conditions at impact points were measured major and minor diameters at 31.625” and 28.5”, respectively following the center of gravity and shallow angle drops in Test Series TS-001-3. The majority of test article diameters remained constant through out the test series. The maximum overall height of a deformed package was 42-1/4” and the minimum height was 41-5/8”. All bolts remained in tact during all test series with the exception of the loss drum ring in test number 2C Crush Plate Drop, although the closure ring was lost there was no opening of the test article due to the design of the Versa-Pac and its top bolts. The impact of the puncture test conducted produce only minor damage with indentations of ¼” and 3/8”. One exterior drum surface tear occurred at the bottom of the drum rim upon impact, during the secondary impact of the initial shallow angle drop 3C, but due to the inner liner design of the Vera-Pac, with a sealed steel liner directly adjacent to the drum skin no breach of the container occurred. A small gap

from the impact in test number 2C at the lid to drum rim interface was sealed with a metal to metal contact of the lid steel insulation cover and the top side wall and gasket.

The second series of tests conducted to confirm that the changes made to the inner containment blind flange and seal validated that the increase in thickness of the blind flange, the increase in torque and the addition of the neoprene sponge rubber pad attached to the inside of the flange corrected the loss of payload contents that occurred in the original test series. With the changes no tears, no broken welds, no openings and no broken bolts were found. The inner flange remained flat and sealed as required.

The 55 gallon drop test series produced expected damage to the impact areas with no loose of containment and no damage that would lead to loss of materials. It provided additional information supporting evidence based upon physical testing that the 110 gallon version binds the smaller 55 gallon version of the Versa-Pac shipping container system.

There was no damage or shift to the inner containment area during any of the five separate test series.

The results of the test series demonstrate that the packaging is maintained within the allowable temperature, pressure and stress ranges. The average OD of the packaging is maintained greater than 21.5" and the minimum height of the packaging is maintained greater than 34" under all conditions as required for criticality control. There is no breach of the containment area and thus no loss or dispersal of radioactive contents. Thus, the packaging is acceptable for use.

2.8 Accident Conditions For Air Transport of Plutonium

This Section is not applicable to the Versa-Pac Shipping Container.

2.9 Accident Conditions For Fissile Material Packages For Air Transport

This section is not applicable to the Versa-Pac Shipping Container.

2.10 Special Form

Special form material as defined in 10CFR71 is not applicable to the Versa-Pac.

2.11 Fuel Rods

This section is not applicable to the Versa-Pac.

2.12 List of Appendices

Table 2.1 Evaluation Results

Table 2.2 Mechanical Properties of Materials

2.12.1 MACTEC Report on Material Compatibility

2.12.2 Century Industries Performance Test Report for the Versa-Pac

2.12.3 Excerpted from Safety Analysis Report for the Century Champion Type B Package Immersion Test

2.12.4 Century Industries Performance Test Report for the 55 Gallon Versa-Pac (Shallow Angle Drops)

Table 2-1 Evaluation Results

Evaluation	Evaluation Result	Evaluation Criteria	Minimum Factor of Safety (FS)[1] or Design Margin (DM)[2]
Minimum package size	Versa-Pac is 24" x 35"	10CFR71.43(a)	N/A Package is acceptable
Tamperproof feature	One per package, Closure Ring Bolt	10CFR71.43(b)	N/A Package is acceptable
Positive Closure	110 Gallon Versa-Pac uses 20 bolts to secure the packaging & the 55 Gallon Versa-Pac uses 16	10CFR71.43(c)	N/A Package is acceptable
Chemical & Galvanic reactions	The materials do not react chemically and galvanic reactions are acceptable over the packaging life	10CFR71.43(d)	N/A Package is acceptable
Lifting	N/A	10CFR71.45(a)	N/A Package is acceptable
Tie down	N/A	10CFR71.45(b)(1)	N/A Package is acceptable
Differential thermal expansion	Foam maximum expansion ~0.004" Stress developed ~ 0 psi in both foam and steel components	Yield strength	FS $\rightarrow \infty$
Thermal Stress	N/A Package uses a de-coupled design that minimizes thermal stresses	Steel yield strength Foam compressive strength	FS $\rightarrow \infty$
Cold	Packaging temperature = -40°F	Minimum allowable, -40°F	FS = 1.0
Reduced External Pressure	Effective pressure differential = 16.7 psia internal or 3.3 psia external	Containment rated to 15 psig	FS = 1.7
Increased External Pressure	Effective pressure differential = 20 psia external or 3.3 psia external	Containment rated to 15 psig	FS = 1.4
Transport Vibration	No loss of containment, no loss of packaging effectiveness	10CFR71.71(5)	N/A Package is acceptable
Water Spray	No effect on packaging effectiveness	10CFR71.71(6)	N/A Package is acceptable

Table 2-1 Evaluation Results

Evaluation	**Evaluation Result**	**Evaluation Criteria**	**Minimum Factor of Safety (FS)[1] or Design Margin (DM)[2]**
Normal Condition Free Drop	No effect on packaging effectiveness	10CFR71.71(7)	N/A Package is acceptable
Compression	623 psi	10CFR71.71(9) steel yield strength	FS = 25.7
Penetration	No effect on packaging effectiveness	10CFR71.71(9)	N/A Package is acceptable
Hypothetical Accident Condition Free Drop and Puncture Drop	No effect on packaging effectiveness	10CFR71.73(1) and (3)	N/A Package is acceptable
Hypothetical Accident Condition Fire	Maximum payload vessel temperature 423°F	10CFR71.73(4) Maximum allowable payload/seal temperature = 500°F	DM = 131 °F FS = 1.18
Fissile Immersion	No in-leakage	10CFR71.73(5)	N/A
Immersion	No in-leakage	10CFR71.73(6)	N/A

Notes on Table 2-1:

1. The Factor of Safety is defined as the ratio of the allowable to the actual, rounded down the nearest tenth.
2. The Design Margin is defined as the allowable minus the actual.

Table 2-2 Mechanical Properties of Materials[Note 1]

Property/Material	Carbon Steel Plate and Sheet	Carbon Steel Bolts
Density (lb/ft^3)	491 [Note 2]	N/A
Thermal Expansion Coefficient (in/in/F)	[9.22 x 10^{-6}]	N/A
Min Yield Strength (psi x 1,000)	[36]	[81]
Min Tensile Strength (psi x 1,000)	[58]	[105]
Elongation in 2” (%) *Elongation in 4D (%)	[21*]	[14]
Property	**Impact Absorbing Foam Insulation**	
Density (lb/ft^3)	5.0 – 11.0 [Note 3]	
Nominal Thermal Expansion Coefficient (in/in/F)	3.4 x 10^{-5} [Note 4]	
Compressive Strength (psi)	85 – 300 [Note 3]	

Notes on Table 2-2:

1. Information provided in [brackets] is an average or nominal for the material used and is provided for comparison purposes only, as it is not used in any evaluation presented for the packaging.
2. Ross, R. B. Metallic Materials Specification Handbook, 4th Edition, London, Chapman and Hall, 1992.
3. Century Industries SOP 6.11, Versa-Pac Polyurethane Closed Cell Foam Specification for Century Products.
4. General Plastics Last-a-Foam FR-3700 for Crash & Fire Protection of Nuclear Material Shipping Packages, General Plastics Manufacturing Company, Tacoma Washington, 2/99.

Appendix 2.12.1

MACTEC Report on Material Compatibility

MACTEC

May 6, 2004

Mr. Mike Arnold
Centuries Industries
P.O Box 17084
Bristol, Virginia 24209

Subject: **Corrosion of carbon and stainless steel in contact with foam**
MACTEC Project 6230-03-0989

Mactec Engineering and Consulting, Inc. (MACTEC) previously performed chemical analysis of a foam sample. The results of our testing were provided to you in our report dated January 15, 2004.

The results of our testing indicated that the chloride content of the foam sample tested was less than the detection level (25ppm) of the test method and apparatus utilized.

Based on the low chloride content, it is our opinion that significant chloride related corrosion of carbon steel and 316L stainless steel material in contact with this foam is not likely to occur.

We appreciate the opportunity to provide this letter. Please contact us if we can be of further assistance.

Sincerely,
Mactec Engineering and Consulting, Inc.

Lakshman Santanam, P.E.
Principal Engineer

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FILE

REPORT OF CHEMICAL ANALYSIS

Client: Century Industries
P.O. Box 17084
Bristol, VA 24209

Attn: Mr. Mike Arnold

Project: General
Office: Charlotte
Lab No.: 6230-03-0989
Page: 1 of 1
Date: January 15, 2004

Client P.O.: PWAS
Material: Reported as Foam Samples
Heat/Lot No.: See Below
Date Tested: Completed December 31, 2004
Procedure: In general accordance with Client's Instructions and ASTM D-1411-99

Test Results (%)

MACTEC Piece No.	pH Value (units)	Chlorides (ppm)	Sulfate (ppm)	Comments
Foam Sample Leachable	4.3	< 25	287	
Foam Sample Total	---	< 25	21,248	

Reviewed By: [signature]
Lakshman Santanam, P.E.
Principal Engineer

Respectfully Submitted,
MACTEC ENGINEERING & CONSULTING, INC.
Carol J. Pilarczyk [signature]
Carol J. Pilarczyk, Staff Engineer

Appendix 2.12.2

Century Industries Performance Test Report for the Versa-Pac

(133 Pages)

Note: Paragraph 6.5 has been revised to add missing information regarding the NIST Traceability requirements.

Appendix 2.12.3

Excerpted from Safety Analysis Report for the Century Champion Type B Package Immersion Test

Appendix 2.12.4

Century Industries Test Report for the 55 Gallon Versa-Pac Shipping Container (Shallow Angle Drops)

(61 Pages)

Appendix 2.12.5

NCT Versa-Pac Test Report for Compression & Penetration
(Consisting of 16 Pages)