Appendix 2.12.4
Century Industries Test Report for the 55 Gallon Versa-Pac Shipping Container (Shallow Angle Drops)
(61 Pages)

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Test Report
Performance Evaluation Test Series Of Century Industries' Model VP-55 Versa-Pac Shipping Container

US NRC Docket Number 71-9342

Test Conducted in Accordance with Test Plan TP-002 Revision 0
And
Test Specification TS-002 Revision 0
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Prepared By: Signature on File - WMA Date: September 25, 2009

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1.0 INTRODUCTION

This Report describes the methods and guidelines Century Industries followed for the preparation and testing of the Versa-Pac Shipping Container in accordance with the requirements specified in Century Industries Test Plan TP-002 Revision 0 and Century Industries Test Specification TS-002 Revision 0 (Attachment A and B). The test program was conducted by Century Industries located in Bristol, Virginia between September 23 and September 25, 2009. This report includes the program objective, test procedure, item description, test results, test records (Attachment C) and other applicable documents including photographs of the testing.

2.0 OBJECTIVE

The objective of this test program was to conduct the accelerated shallow angle drop (slap-down) physical performance evaluation tests for Century Industries VP-55, Versa-Pac Shipping Container to provide additional information and demonstrate the capabilities of the 55 gallon version to meet the requirement in accordance with the normal conditions and hypothetical accident conditions specified in Title 10 Part 71.73 [1], Test Plan TP-002 Revision 0 and Test Specification TS-002 Revision 0.

The test item was identified as 55 gallon Versa-Pac shipping container prototype and subjected to the following performance tests:

1. Initial visual inspection of the outer and inner container surfaces.

2. Drop testing in accordance with 10 CFR 71.71(c)(7), Shallow Angle Drop, 71.73 (c)(3), Puncture Drop, along with NUREG 6818, 30' Shallow Angle Drop.

3. Post Test Visual Inspection of the outer and interior container surfaces.

Following each test the physical condition of the shipping container was inspected and the results recorded.

3.0 RESPONSIBILITIES

Century Industries personnel conducted the test program and were responsible for the base analysis of the test articles, the test plan and oversight of the test series. All test personnel completed the Pre-test Readiness Review and associated procedures.

The test series was performed in accordance with the applicable requirements and guidance of Century Industries QA Program QA-1 Revision 1, 10 CFR 71 and this test plan.

The program manager was William M. Arnold, President of Century Industries who also acted as the Quality Assurance Coordinator for the test series.

4.0 TEST ITEM IDENTIFICATION

Century Industries was responsible for the design, fabrication, inspection, recording the preliminary measurements and the loading of payload and payload containers with multiple size gravels, steel bars and loose sand.

5.0 TEST ITEM DESCRIPTION

The Versa-Pac Shipping Container is designed for the shipment of Type A radioactive and fissile materials in the form U-metal, oxides, fluorides and nitrate for both product and scrap materials. The fissile payload was design for 350 grams at 100% enrichment and a criticality safety index of 1.5.

The Versa-Pac Shipping Container was designed in two basic versions, a UN1A2 -55 gallon and 110 gallon outer drum with a 16 gauge body, bottom and cover, in addition to the standard 12 gauge closure ring with a 5/8" ASTM A307 bolt, the cover is reinforced and secured using the addition of bolts attached to the internal structure of the package as detailed in the design drawings. The internal structure consists of vertical and horizontal stiffeners at specific points around the package. Outer and inner 16 gauge liners, with an insulating ceramic fiber blanket between the liners complete the primary inner structural components. A secondary barrier of insulation consisting of ceramic fiber blanket; surround the inner containment body. The payload gasket is a woven fiberglass yarn in a flexible substrate, coated with high grade silicone rubber. The gasketed payload containment cavity is made of 10 gauge body and bottom with a ¼" thick top flange to which in the initial series of testing, a 1/2" thick top flange was secure using 12 -1/2" bolts. The payload cavity is attached to the internal structural components by use of a bolted connection through a fiberglass thermal break between the payload cavity and the structure. Closed cell polyurethane foam is utilized to provide insulation and added impact protection, to both the top and bottom of the Versa-Pac. The top insulation plug is encapsulated in sheet metal welded to the outer drum closure lid. Plastic plugs enclosed within the body of the structure provide a path for venting to the external acetate plug on the exterior of the drum. The cavity is designed to be loaded directly or with the use of an insert to reduce the diameter or with up to a 30 gallon standard drum in the 110 gallon version.

The Versa-Pac was designed in accordance with the requirements of 10 CRF 71 [1] and Century Industries – QA-8, Plan for Manufacture of Versa-Pac Shipping Containers [2].

Pre-Test Photographs 55 Gallon Version

55 Gallon - Outer Side Top View

55 Gallon - Internal Loaded View

55 Gallon – Blind Flange Bolted

55 Gallon - Top Closure Side View

55 Gallon Version - Side View

6.0 TEST FACILITES & EQUIPMENT

6.1 Environmental Conditioning

The test series was conducted at ambient air temperatures.

6.2 Drop Test Pad Facilities

The drop test pad consists of a 70 ton concrete pad made in accordance with IAEA Safety Series No. 37. The pad is 10 feet wide by 10 feet long by 10 feet deep, reinforced with a grid of ¾ inch re-bar spaced on 12 inch centers and capped with a 1 inch thick by 8 feet wide by 10 feet long carbon steel plate, which is embedded into the surface of the concrete and secured by fourteen 1-1/2 inch diameter bolts by 16 inches long.

6.3 Release Device

The release device utilized was capable of releasing the package in a manner that provided a smooth clean drop without imparting any twisting or turning of the package. The device has a safe working load limit of 18,000 pounds. The test articles were lifted into place by use of a crane.

6.4 Orientation and Angles

The orientation if each drop was controlled by the use of nylon fixed straps and adjustable straps used to set the angles required. The orientation of the container was verified using a magnetic protractor attached to the test article surface.

6.5 Measurements and Weights

Drop heights were determined by use of a pre-measured plumb line set by a 100 foot steel tape measure Serial Number 08461846, calibrated by Starett Company and traceable to NIST. The test items tare and payload weights were made using a set of scales calibrated by Carlton Scales, Kingsport, Tennessee.

6.6 Temperature and Wind Speed

Surface and air temperatures were obtained using calibrated surface gauge Serial Number 05548 with a range of -100°F to +160°F and Dickson Temperature Recorder Model SM320 and traceable to NIST. Wind speed was obtained thru the local metro airport service.

6.7 Puncture Device

The puncture device consist of a 6 inch diameter by 22 inches long carbon steel round bar welded to a ¾ inch thick plate, which was then secured to the drop test pad by means of tack welding to the center of the pad.

6.8 Photographic Equipment

Color photographs were taken with a Sony 4.1 Mega pixel digital camera by Century Industries

7.0 EQUIPMENT AND INSTRUMENT CALIBRATION

All applicable test and measurement equipment were calibrated in accordance with Century Industries Quality Assurance Program. Test and measurement calibration certificates are found in Attachment E. The instrumentation used during testing is listed in Table 1 below.

ITEM	MODEL	S/N	CALIBRATION DUE DATE	COMENTS
Starett 100' Tape Measure	N/A	08461846	November 17, 2009	Used to measure length of plumb bob drop heights
Dickson Temperature Recorder	SM320	09057179	February 01, 2009	Used to calibrate surface thermometer and record air temperature
PTC Instruments Surface Thermometer	330F	05548	July 09, 2009	Used to measure the temperature of the test articles during the conditioning
Floor Scale	0-300 Pound	98530806V1812	February 15, 2009	Used to measure the weight of the payload
Elizabethton Airport	N/A	N/A	N/A	Used to check wind speed
Protractor	N/A	N/A	N/A	Used to measure angles, Calibration not required
4 ' Level	N/A	N/A	N/A	Used as straight edge for measurements
Plumb Bob 30', 4' & 1 Meter Drop height	N/A	N/A	N/A	Used during drop series length determined by calibrated tape

Table 1 – Test Instruments

8.0 ACCEPTANCE CRITERIA

The acceptance criteria for this series of testing was retention of the outer closure, no openings, tears or failure that would lead to loss of materials, no open pathway to the insulation materials and no loss of the inner containment payload.

9.0 TEST PREPARATION AND RESULTS

9.1 Initial Inspection

On September 23, 2009, the visual inspection of the test item was conducted prior to performing any of the physical evaluation tests. During the inspection no damage was found to the exterior or interior surface of the shipping containers. Measurements were taken and recorded on all test articles.

Test Article Serial Number 10553

Location	Pre-Test Measurement	Description
A-C	15" ID	Inner Container
A-C	23-1/2" Ø	Outer Container
A	34"	Drum Height
A	2-1/8"	Wall – In/Out
A	4-1/4"	Inside Container/Outside
A	4-1/8"	Top Rim – Inside Top Flange
B	33-15/16"	Drum Height
B	4"	Top Rim – Inside Top Flange
B	2-1/16"	Wall – In/Out
B	4-1/4"	Inside Container/Outside
B-D	15" ID	Inner Container
B-D	23-5/8"Ø	Outer Container
C	4-1/4"	Inside Container/Outside
C	2-3/16"	Wall – In/Out
C	34"	Drum Height
C	4"	Top Rim – Inside Flange
D	4-3/16"	Inside Container/Outside
D	33-15/16"	Outer Container
D	4-1/8"	Top Rim – Inside Flange
D	2-1/4"	Wall – In/Out

9.2 Weights and Payload

The package tare weight was recorded on the individual test record. In order to provide the test articles with the most aggressive challenge to the inner payload containment of the Versa-Pac it was decided to use contents of multiple size gravel, steel bar and sand. The materials once place into the containment are partially filled the containment. The payload provided a secondary piston action occurring from the payload materials to containment flange impact. 1-1/2 pounds of loose sand was place within the containment area in order to provide content material capable of breaching the containment flange seal.

Item/Serial Number	**10553**
Package Tare Weight	390
Payload Drum/Gravel and Sand	253
Loose Sand Weight	1.5
Total	**644.5 lbs.**

9.3 Loading of the Test Item

The 1/8" thick silicone coated fiberglass gasket and 1/2" thick containment flange were placed into position and the bolts inserted and hand tightened. The flange bolts were then tightened using an alternating method and torqued to 60 ft/lbs. The top gasket and outer closure, which includes the attached encased polyurethane foam insulation top plug, was installed on the test article and the top outer bolts installed and torqued using the same alternating method to a tension of 60 ft/lbs. The outer drum closure ring was then installed and tightened to a torque of 60 ft/lbs.

Containment Loaded With 254-1/2 Pounds of Loose Gravel

Bolted Inner Blind Flange and Top Gasket

Side View – 55 Gallon Acetate Plug

9.4 Test Article Temperature

To measure the temperature a calibrated surface thermometer was placed on the surface of the test articles and at time of the test the test article temperature was 89°F.

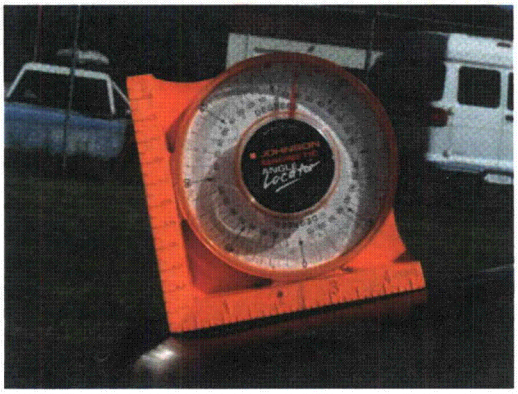
10.0 DROP TEST SEQUENCES

The drop test sequences were chosen to provide additional information for the Versa-Pac application and support for the previous NCT and HAC drop test series reported on March 25, 2009, Appendix 2.12.2 and the original prototype testing results are included in Attachment D. The test article was produced in accordance with the fabrication drawings and QA-8, plan for the Manufacture of Versa-Pac Shipping Containers. The test article was tested in accordance with Century Industries Test Plan TP-002 Revision 0.

11.0 TEST PACAKGE SERIAL NUMBER 10553 – TEST RECORD TS-002-1

11.1 Test Number 1-55-A – NCT - 4' Shallow Angle Accelerated Drop (Slap-Down)

The drop test performance evaluation describe in the Test Plan TP-0002 Revision 0 was performed with the undamaged Versa-Pac Shipping Container. Test Configuration 1-55-A was a 4' shallow angle accelerated free drop onto the bolted closure end of the test article at an angle of 17 degrees from horizontal. The air temperature at the start of this series was 90°F and wind speed was 2 mph. The test article was suspended from a crane by use of a sling connected to the release mechanism. It was lifted above the test pad so that the lowest point of the package was at 4 feet above the top surface of the test pad.

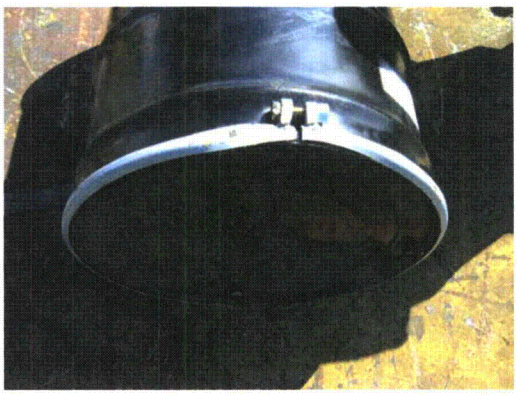


NCT 55-Gallon 17 Degree Angle

Side View 4' Shallow Angle Set-up

The test article was released so that it did not impart rotational motion into the package free fall to the test pad.

End View- NCT 4' Set-up



Post Drop Damage to Bolt End Impact Area

View of Long Side Post Impact

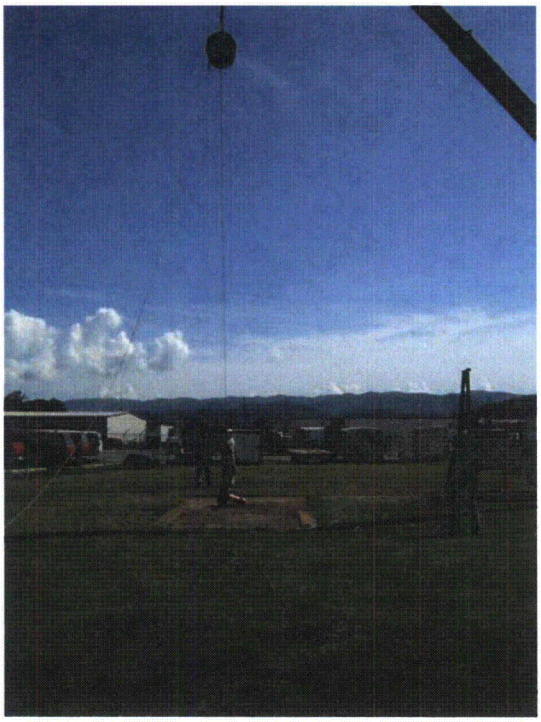
View of Bottom End Post Impact

The container impact on to the test pad surface and produced a 7-1/4" long x ¼" deep indentation at the rim on the top drum closure ring with no openings or tearing. The long impact side showed only minor indentations along the length of the container. The bottom secondary impact produced a 5-3/4" long x ¼" deep flat area at the bottom edge of the outer package wall. No other damage was noted. Measurements and photographs were taken showing the extent of the damage.

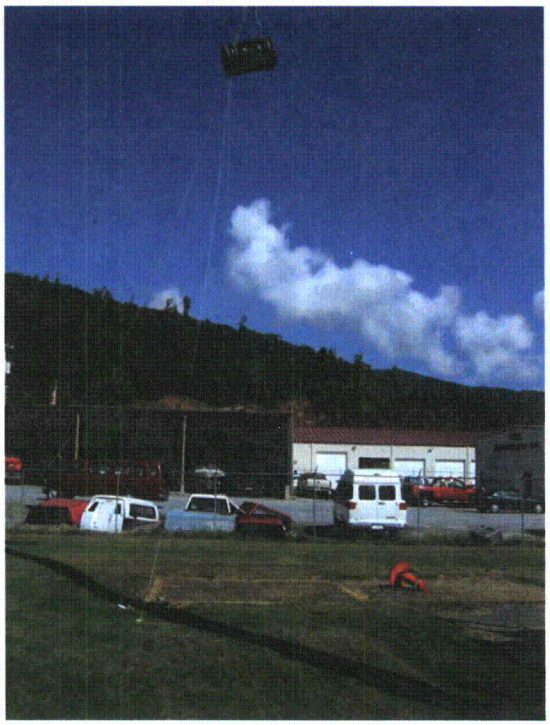
There were no tears or openings to the drum surface. All bolts remained in tact.

11.2 Test Number 1-55-B – HAC 30' Shallow Angle Accelerated Drop (Slap-Down)

Configuration 1-55-B was a free drop in the shallow angle configuration onto the same impact area thru the bolted closure end of the previously used test article from test number 1-55-A from a height of 30 feet-1-1/2 inch from the lowest point of the package to the test pad surface. It was positioned at an angle of 17 degrees from the horizontal. The air temperature at the start of this series was 90°F and wind speed was 2 mph. The test article was suspended from a crane by use of a sling connected to the release mechanism. It was lifted above the test pad in the shallow angle accelerated drop orientation to appropriate height listed above. The test article was released so that it did not impart rotational motion into the package free fall to the test pad. Measurements and photographs were taken showing the extent of damage.

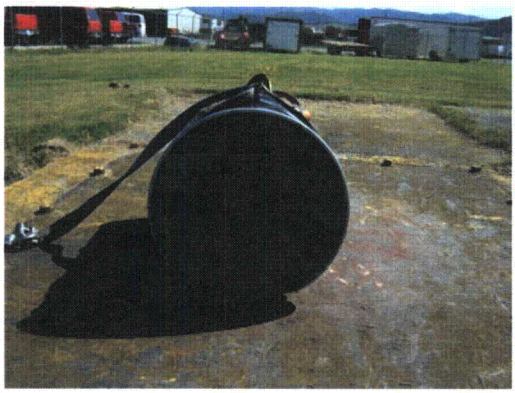


Shallow Angle Accelerated 30' HAC Drop Position

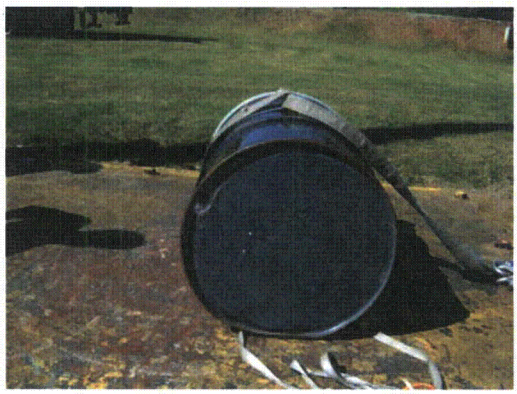


Side View of HAC 30' Shallow Angle Accelerated Drop Position

Upon impact to the top end of the package the flat area at the outer drum lid closure to drum body rim was increased to a length of 11-1/2" x 3/8" deep from the previous NCT impact. The package remained sealed and closed with no opening. A small tear in the outer drum sidewall material occurred due to the impact of the drum ring closure lug/bolt impact on to the outer drum rolling hoop (top swedge), but due to the design of the Versa-Pac's inner liner, which is in contact with the outer drum wall, there was no damage to the inner liner and no breach of the package integrity. The secondary impact increased the damaged area along the bottom edge to a length of 10" x ¼" deep in the same location as the previous NCT drop. Although the closure ring had a lug break all bolts on the reinforced top remained in tact and secure.

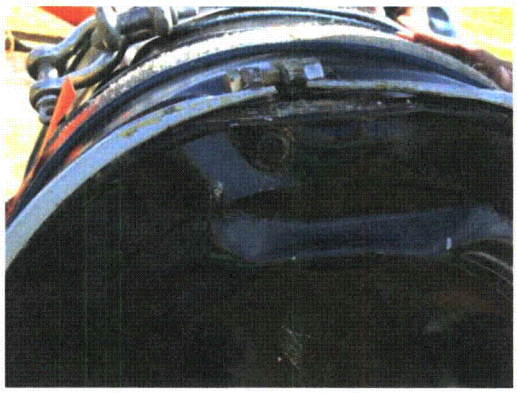


End View – Top End Damage

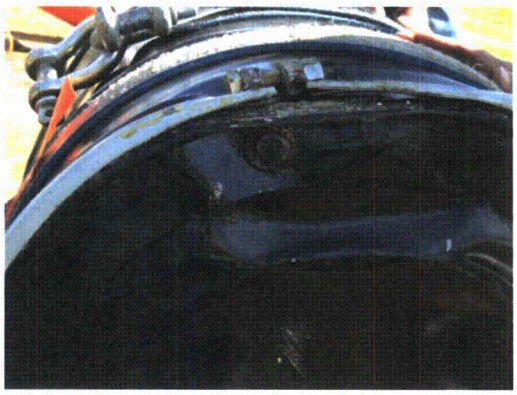


End View – Bottom End Damage

Impact Damage to Closure End



Close-up of Closure End Damage

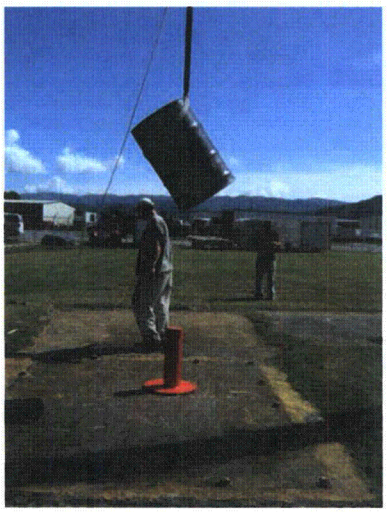


Close-up of Closure End Damage

Close-up of Sealed Lid to Package Interface

11.3 Test Number 1C – HAC 1 Meter Puncture Drop – Center of Gravity thru the Bolted Closure

Configuration 1-55-C was a puncture drop from a height of 41 inches from the lowest point of the package top closure to the top of the puncture ram, this impact location was chosen due to the previous damage incurred during the accelerated impact drops as the area most vulnerable to the puncture drop. The package was suspended by use of nylon straps which were attached to the release mechanism at a height of 41 inches measured from the lowest point of the package to the top of the puncture ram. The angle of orientation was 56-1/2 degrees from the horizontal position. The air temperature was 90°F and the wind speed was 2 mph. The test package was released so as not to impart rotation motion to the test article free fall to the impact point of the puncture ram.

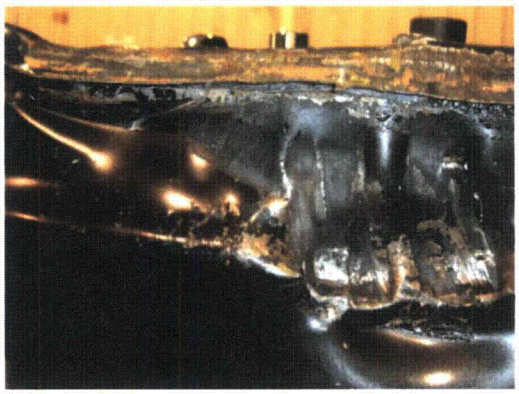


Center of Gravity – Puncture Drop Positioned over the Puncture Ram

Upon impact the deformation to the impact area of the test article was measured at showing an affect area of 8-3/8" wide with a diameter of 23" at the top of the closure area. There were no tears or opening of the package as a result of the puncture drop.

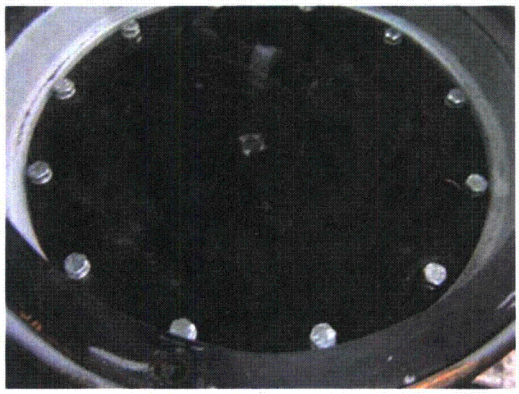
Puncture Impact Damage – No Opening

As a result of this test series the outer closure bolts recorded a post test torque of 42 to 55 ft/lbs with the bolt at the impact area at 49 ft/lbs. The outer lid was removed and no loss of containment or damage to the inner containment blind flange was found. The bolt torque of the inner blind flange was found to have a range between 30-50 ft/lbs. The gaskets and the internal cavity of the containment were found to be in good condition with no damage.



Side View - Damage from Impact of Bolt Lug onto Side Wall

Top View of Package Prior to Opening



Inner Containment Blind Flange

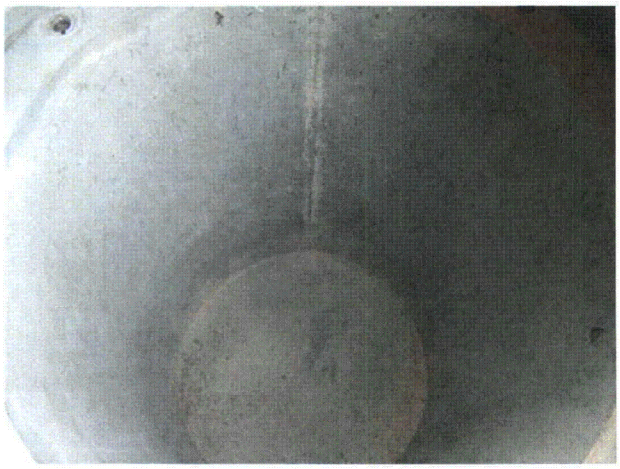
Top End Impact Area Damage

View of Damage to Top Closure

View of Outside Impact Area

Post Test View of Test Payload

Post Test View of Inner Containment



Post Test View of Inner Containment

12.0 POST TEST MEASEUREMENTS

On September 24, 2009, the post test inspection and measurements were taken and recorded on all test articles.

Test Article Serial Number 10553

Location	Post-Test Measurement	Description
A-C	14-15/16" ID	Inner Container
A-C	23" Ø	Outer Container
A	33-15/16"	Drum Height
A	2-1/8"	Wall – In/Out
A	4-5/16"	Inside Container/Outside
A	4-1/4"	Top Rim – Inside Top Flange
B	34"	Drum Height
B	4-1/8"	Top Rim – Inside Top Flange
B	2"	Wall – In/Out
B	4-1/8"	Inside Container/Outside
B-D	15" ID	Inner Container
B-D	23-1/2"Ø	Outer Container
C	4-5/16"	Inside Container/Outside
C	2-7/16"	Wall – In/Out
C	33-5/8"	Drum Height
C	3-15/16"	Top Rim – Inside Flange
D	4-1/4"	Inside Container/Outside
D	33-15/16"	Outer Container
D	4-1/8"	Top Rim – Inside Flange
D	2-1/8"	Wall – In/Out

Final Tare Weight – 390 Pounds
Final Gross Weight – 644-1/2 Pounds

13.0 Results and Conclusions

The objective of this test program was to conduct additional physical evaluation testing of Century Industries 55 gallon version of the Versa-Pac Shipping Container design in accordance with the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC) specified in 10 CFR 71 and Century Industries Test Plan TP-002 Revision 0 to verify the performance capabilities under specified conditions. The 55 gallon Versa-Pac was subjected to performance test simulating normal conditions testing and hypothetical accident condition for shallow angle and puncture described in NUREG 6818, 10 CFR 71.71 and 73. Following each test, the physical condition of the test package was inspected and the results were recorded and photographed.

The acceptance criteria for the all testing was retention of the outer closure, no openings, tears or failure that would lead to loss of material, no open pathways to the insulation materials and no loss of the inner containment payload.

The conclusion of this test series provides additional support that the 55 gallon version of the Versa-Pac is bound by the previously conducted physical test series of the 110 gallon version and previous preliminary testing of the Versa-Pac shipping container. Additionally, with the completion of the shallow angle (accelerated slap –down) drops, the results of this series of tests demonstrate that the 55 gallon version is capable of meeting the requirements set forth in 10 CFR 71 and Century Industries Test Plan TP-0002 Revision 0.

14.0 ATTACHMENTS & CALIBRATION RECORDS

Attachment A – Test Plan TP-002 Revision 0
Attachment B – Test Specification TS-001-2 Revision 0
Attachment C – Century Industries NCT and HAC Test Record
Attachment E – Training & Calibration Records

Attachment A

Test Plan TP-002 Revision 0

(Consisting of 14 pages)

Century Industries
Bristol, Virginia 24209

Versa-Pac Shipping Container
Test Plan
TP-002 Revision 0

US NRC Docket No. 71-9342

Prepared By:
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William M. Arnold

Prepared By: William M. Arnold – Signature of File Date: September 1, 2009

Reviewed By: Heather Little – Signature on File Date: September 1, 2009

Record of Revision

Revision No.	Description of Revision	Date
0	Original Issue	09-01-09

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1.0 INTRODUCTION

Century Industries Versa-Pac Shipping Container is designed for the shipment of Type A radioactive and fissile materials in the form of U-metal oxides, fluorides and nitrates for both product and scrap materials. The fissile payload was design for 350 grams at 100% enrichment and a criticality safety index of 0.9.

The Versa-Pac Shipping Container was designed in two basic versions, a UN1A2 - 55 gallon and 110 gallon outer drum with a 16 gauge body, bottom and cover, in addition to the standard 12 gauge closure ring with a 5/8" ASTM A307 bolt; the cover is reinforced and secured using the addition of bolts attached to the internal structure of the package as detailed in the design drawings. The internal structure consists of vertical and horizontal stiffeners at specified points around the package. Outer and inner 16 gauge liners, with an inner insulating ceramic fiber blanket between the liners complete the primary inner structural components. A secondary barrier of insulation consisting of ceramic fiber blankets, surround the inner containment body. The payload gasket is a woven fiberglass yarn in a flexible substrate, coated with a high grade silicone rubber. The gasketed payload containment cavity is made of 10 gauge body and bottom with a ½" thick top flange to which a 3/16" top cover is secured using 12 – ½" bolts. The payload cavity is attached to the internal structural components by use of a bolted connection through a fiberglass thermal break between the payload cavity and the structure. Closed Cell Polyurethane foam is utilized to provide insulation and added impact protection to both the top and bottom of the Vera-Pac. Plastic plugs enclosed within the body of the structure provide a path for venting to external acetate vent plug on the exterior of the drum. The cavity is designed to be loaded directly or with the use of an insert to reduce the inside diameter or with up to a 30 gallon drum.

It was designed in accordance the requirements of 10 CFR Part 71 [1]] and Century Industries – QA-8 Plan for Manufacture of Versa-Pac Shipping Containers [2].

In order to resolve concerns regarding the ability of the 55 gallon version to successfully meet the HAC test conditions including the slap-down (shallow angle) drop orientation Century Industries is conducting an additional test series consisting of a three foot center of gravity drop, 30 foot center of gravity drop, along with a slap-down (accelerated drop) from a height of 30 feet.

2.0 SCOPE AND OBJECTIVE

2.1 Scope

This test plan describes the methods, guidelines and requirements that are to be utilized during the performance of the task described in this procedure.

2.2 Objective

The objective of this test plan is to provide the requirements for a series if physical test to demonstrate the performance capabilities of the 55 gallon Versa-Pac Shipping Container to supplement Century Industries, Safety Analysis Report under Docket Number 71-09342, in satisfying the requirements of 10 CFR 71 [1], Century Industries – Test Specification TS-0001 [3] and this test plan for both normal and hypothetical accident conditions of transport.

The primary objectives of this test plan are as follows:

1. Define the responsibilities of the personnel performing the drop test series.
2. Define the general requirements
3. Define the test sequences that will be performed.
4. Define the required configurations for each test.
5. Define the required pre-test and post test measurements.
6. Define the data acquisition requirements for each test.
7. Define the documentation requirements.

3.0 RESPONSIBILITIES

Century Industries has the overall responsibility for the test program and is responsible for the design and analysis of the test articles, development of the test specification, the test plan and oversight of the Versa-Pac test series. Century Industries is also responsible for the procurement, fabrication and inspection of the test articles. The test series will be performed in accordance with the applicable requirements of Century Industries QA Program QA-1 [4], Test Specification TS-001 [3] and this test plan.

Individual responsibilities include the following:

1. Test Program Manager: This individual is responsible for the overall management and implementation of the test program. The Test Manager has the authority to resolve any question that may arise between members of the team.
2. Test Engineer: This individual is responsible for preparation of the equipment and facilities required to conduct the testing. They are also responsible for the both the pre-test and post test measurements and documentation.
3. Quality Assurance: This individual, is responsible for the QA oversight and witness of the test series

4.0 TEST SEQUENCES

Based upon preliminary prototype testing of both the 55 and 110 gallon versions, testing indicated that the 110 gallon version would bind the 55 gallon Versa-Pac version. Three prototypes were fabricated for the test series. All test articles were tested using a 30 gallon drum containing 250 pounds of the test media, placed within the inner package cavity; a residual amount of sand was placed into the inner cavity so that some material would face the possibility of release from within the inner cavity to the external surface of the package between the inner and outer closures. The inner drum was being utilized to simulate a piston action within the inner containment cavity of the test articles. Upon completion and adjustments to the 110 gallon version all test series were successful in meeting the requirements set-forth in the original test program. After initial review and questions regarding the lack of an accelerated drop in the preliminary testing previously conducted and used to establish reasoning for use of the 110 gallon version to bind the 55 gallon package a test sample previously fabricated will be prepared to conduct the testing described within the following sections of this test plan. The 55 gallon test package will be loaded with 250 pounds of test media in the payload area of the package.

The test series is planned, as shown in Table 1 below to verify satisfactory compliance with 10 CFR 71 [1] and this plan.

4.1 Test Series No. 1-55 – NCT & HAC Shallow Angle Drop

This series will include an NCT shallow angle drop and one HAC shallow angle drop. During this test surfaces are to be examined and measured and the damage recorded between drops.

Note: A Puncture Test will be conducted on one of the test packages based upon initial drop damage.

Table 1 –Planned Test Sequences

Package Number	Test Number	Test Description	Test Objective
1-55	1-55-A	NCT 4' Shallow Angle Accelerated Drop	Evaluate the Damage From an Accelerated Shallow Angle Drop
	1-55-B	HAC 30' Shallow Angle Accelerated Drop	Evaluate the Damage From an Accelerated Shallow Angle Drop
To Be Determined	1-55-C	HAC 1 Meter Puncture Drop	Evaluate & Attack a Vulnerable Area

Notes:

1. All NCT Drops are from a height of 4' feet, HAC drops are from a height of 30 feet and all puncture drops are from a height of 40 inches. Distance measured from the lowest point of the package to the test pad surface.
2. All tests are conducted at the ambient air temperature.

5.0 TEST SERIES REQUIREMENTS

5.1 General Requirements

5.1.1 Quality Assurance

All testing shall be witnessed using the Quality Assurance oversight as required in the test specification.

5.1.2 Rigging

Rigging methods shall be chosen such that the test article is lifted in the correct inclination and orientation as necessary. Rigging locations shall be positioned so as not to interfere or affect the performance or response of the Versa-Pac during the test series.

5.1.3 Measuring and Equipment

The guidelines for measurement and test equipment are described in the Test Specification TS-001 []. All items that require calibration shall be conducted against a certified known that are referenced to the National Institute of Standards and Technology (NIST), for scales the applicable state standards and bureaus are acceptable. Where such standards do not exist, the basis for the calibration shall be documented.

Height measurements may be established using either, a pre-measured line and plumb bob attached to the lowest point of the test article, a properly calibrated laser or other means that are verifiable.

5.1.4 Test Media

The test media may consist of the proper combination of either lead, gravel, sand, steel shot and/or clean soil needed to obtain the appropriate payload test weight. The test weight of each test article must be within +5/-0 pounds of the required test weight of 250 pounds.

5.1.5 Environmental

The requirements for environmental controls are described in the Test Specification TS-001 [3] and shall be recorded as required by each individual test sequence.

5.1.6 Electronic Recording Documentation

All aspects of the test series shall be recorded as required in the test plan using equipment as specified within the Test Specification TS-001 [3].

6.0 TEST PACAKAGE NO. 1-55

6.1 Test Number 1-55-A – NCT Center of Gravity Top Closure Drop

6.1.1 Test Configuration

Test 1-55-A is a free drop thru the center of gravity onto the top closure of an undamaged test article from a height of 1.2 meters (4 Feet) as shown in Figure 3. The test article suspended from a crane by slings and attached to a release mechanism is to be lifted above the test pad in a center of gravity thru the top closure orientation so that the lowest point of the package is at 1.2 meters (4 feet) above the top surface of the test pad. The test article should be released so that it does not impart rotational motion into the package free fall to the test pad.

6.1.2 Pre-test Requirements & Measurements

Prior to performing Test Number 1-55-A, the following pre-test activities are to be complete:

- Measure and record the test article temperature prior to drop.
- Record the test article serial number.
- Measure the centerline and the near side distance to the edge of the cavity, prior to closure of the inner containment cavity. All measurement locations should be marked on the package.
- Take photographs of the interior and exterior of the package to provide visual evidence of the pre-test condition.
- Weigh and record the empty test article.
- Load the test media into the test article inner containment cavity.
- Spread one (1) pound of residual sand/dirt into the inner containment cavity.
- Verify that components used for the inner containment cavity are in good condition and are the proper components per the drawings.
- Install the containment cavity gasket and blind flange. Snug all lid bolts prior to applying the required torque of 60 ft. lbs. in an alternating torque rotation.
- Install the outer gasket and reinforced drum lid using the appropriate bolts as required by the drawing, applying torque of 60 ft. lbs to the closure bolts in the proper alternating manner.

- Install outer drum ring and torque to 60 ft. lbs. and install security seal.
- Weigh and record the loaded test article.
- Upon closure, measure the height, from the bottom rim to the top of the closure ring and diameter of the outer package at the center rolling hoop of the drum. All measurement locations should be marked on the package.
- Verify that the external acetate vent plug is in place.
- Take photographs of the exterior of the test article to provide visual evidence of the test article pre-test condition.
- Measure and record the air temperature at the drop pad.
- Measure and record the temperature on the surface of the package.
- Once suspended measure and record the angle at which the test article is oriented to the nearest 1° increment. The measurement is to be within ± 1.0° of the specified drop orientation.
- Lift the test article to the required drop height. Measure and record the height from the surface of the test pad to the lowest point of the test article. The measured height must be at least the specified height required for the drop, but no more than plus 2 inches.

6.1.3 Post-Test Requirements

Following the NCT shallow angle drop (Test Number 1-55-A), the following activities are required:

- Photograph the exterior surfaces of the test article to provide visual evidence of any apparent damage.
- Document any apparent damage to the package, e.g. deformation or bolt failure.
- Measure the height and diameter of the test article and record the information.
- Record the information on the applicable test forms and proceed to next test sequence.

6.2 Test Sequence Number 1-55-B – HAC 30' Shallow Angle Accelerated Drop

6.2.1 Test Configuration

Test 1-55-B is a shallow angle accelerated drop at an angle of 17 degrees from the horizontal side of the damaged test article from a height of 9 meters (30 feet) as shown in Figure 1-55. The test article should be oriented so that the top closure makes the initial impact with test pad surface. The test article suspended from a crane by slings and attached to a release mechanism is to be lifted above the test pad so that the lowest point of the package is at 9 meters (30 feet) above the top surface of the test pad. The test article should be released so that it does not impart rotational motion into the package free fall to the test pad.

6.2.2 Pre-test Requirements & Measurements

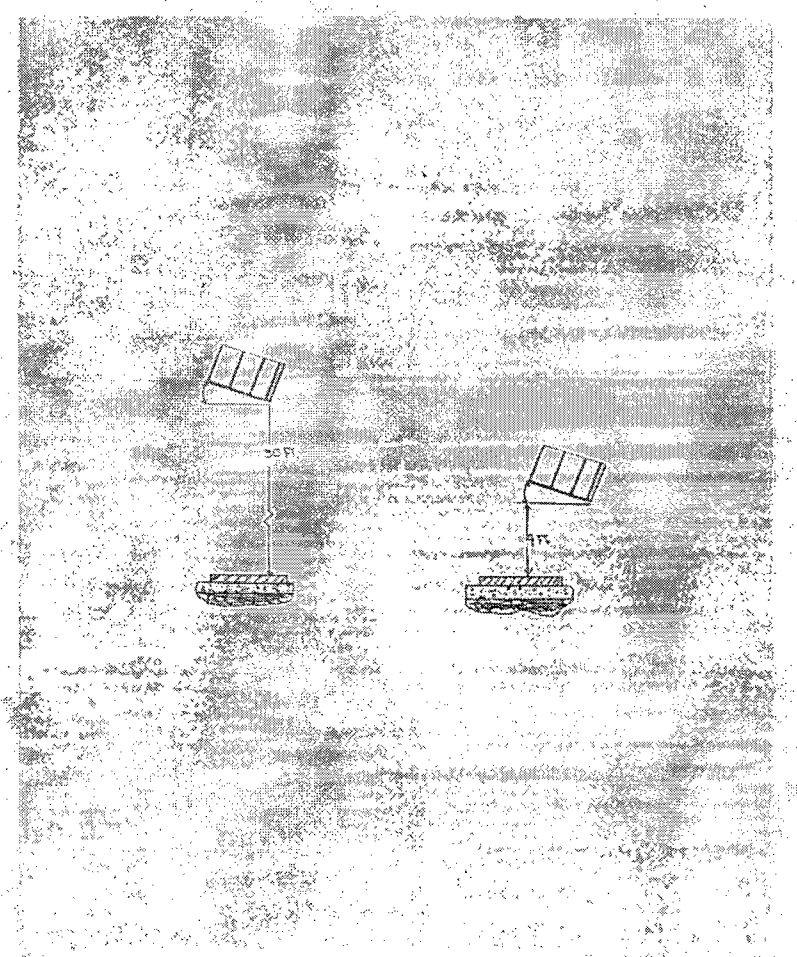
- Record measurements taken from previous test of the test article on the test record.
- Take photographs of the exterior of the test article to provide visual evidence of the test article pre-test condition.
- Measure and record the air temperature at the drop pad.
- Measure and record the temperature on the surface of the package.
- Once suspended measure and record the angle at which the test article is oriented to the nearest 1° increment. The measurement is to be within ± 1.0° of the specified drop orientation.
- Lift the test article to the required drop height. Measure and record the height from the surface of the test pad to the lowest point of the test article. The measured height must be at least the specified height required for the drop, but no more than plus 2 inches.

6.2.3 Post-Test Requirements

Following the HAC shallow angle accelerated drop (Test Number 1-55-B), the following activities are required:

- Photograph the exterior surfaces of the test article to provide visual evidence of any additional apparent damage.
- Document any additional damage to the package, e.g. deformation or bolt failure.
- Measure the height and diameter of the test article and record the information.

- Record the information on the applicable test forms and proceed to next test sequence.



Test No. 1-55-B
HAC Shallow Angle
Accelerated Drop

Test No. 1-55-A
HAC Shallow Angle
Accelerated Drop

Figure 1-55 – Test Package No. 1-55 – Test Configurations

6.3 Test Sequence Number 1-55-C – HAC 1 Meter Puncture Drop

6.3.1 Test Configuration

Test number 1-55-C is a free drop onto the damaged test article used in a previous, to be determined based upon particular damage assessed after the initial package series testing, from a height of 1 meter (40 inches) as shown in Figure 4. The test article will be suspended from a crane by slings and attached to a release mechanism is to be lifted above the test pad at an angle orientated to impact the damaged area so that the lowest point of the package is at 1 meter (40 inches) above the top surface of the puncture pin. The test article should be released so that it does not impart rotational motion into the package free fall to the impact point on the puncture pin.

6.3.2 Pre-test Requirements & Measurements

- Record measurements taken from previous test of the test article on the test record.
- Take photographs of the exterior of the test article to provide visual evidence of the test article pre-test condition.
- Measure and record the air temperature at the drop pad.
- Measure and record the temperature on the surface of the package.
- Once suspended measure and record the angle at which the test article is oriented to the nearest 1° increment. The measurement is to be within ± 10° of the specified drop orientation.
- Lift the test article to the required drop height. Measure and record the height from the surface of the test pad to the lowest point of the test article. The measured height must be at least the specified height required for the drop, but no more than plus 2 inches.

6.3.3 Post-Test Requirements

Following the HAC puncture drop (Test Number 1-55-C), the following activities are required:

- Photograph the exterior surfaces of the test article to provide visual evidence of any additional apparent damage.
- Document any additional damage to the package, e.g. deformation or bolt failure.
- Record the information on the applicable test forms and proceed to next test sequence.

- Measure and record the torque of outer closure bolts.
- Open outer package and remove the outer lid.
- Photograph the interior surface of the test article and examine for any apparent indications of containment boundary loss, e.g. payload materials.
- Measure and record the torque of interior bolts and remove the inner containment cavity blind flange.
- Examine the condition of the gasket and payload contents and record the information on the test record.
- Measure and record the centerline and near side distance to the edge of the cavity.
- Remove the inner payload (if possible) and record any apparent damage or movement to the inner containment cavity.
- Photograph the inner cavity to provide visual evidence of any apparent damage.
- Complete the test sequence record.

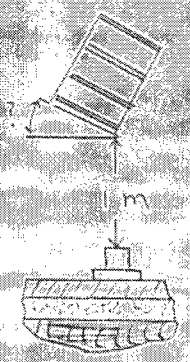


Figure 2 -55 - Meter Puncture Drop – Example Configuration

7.0 References

1. Title 10, Code of Federal Regulations, Part 71, Packaging and Transportation of Radioactive Materials
2. Century Industries, QA-8 Plan for Manufacture of Versa-Pac Shipping
3. Title 10 Code of Federal Regulations, Part 21, Reporting of Defects and Noncompliance
4. Century Industries, Versa-Pac Shipping Container Test Specification TS-001
5. Century Industries, Quality Assurance Manual, QA-1

Attachment B

Test Specification TS-002 Revision 0

(Consisting of 12 Pages)

Century Industries
Bristol, Virginia 24209

Versa-Pac Shipping Container
Test Specification
TS-002 Revision 0

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1.0 INTRODUCTION

Century Industries is designing and licensing a new transportation package, called the Vera-Pac Shipping Container, in accordance with the requirements of 10 CFR Part 71 [Ref. 1]. The results of this series of test may also be used as part of the analytic information evaluating other areas of the package performance for the Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) tests of 10 CFR Part 71.

This document specifies the requirements for the confirmatory test program. A separate Test Plan will be prepared describing the specific test conditions, configurations and the sequence in which they will be carried out. Included in this document will be the fabrication specification for the test packages used in this series of test for the Versa-Pac Shipping Container.

2.0 TEST REQUIREMENTS

2.1 Pre-Test Readiness Review

Prior to performing any test series a readiness review will be conducted by Century Industries to assure the following:

1. All necessary test plans and/or procedures have been prepared in accordance with Century Industries QA program, reviewed and approved.
2. All required test articles and test facilities have been received and inspected by Century Industries personnel.
3. The documentation packages for the test articles have been reviewed and accepted by Century Industries inspection personnel.
4. Personnel are trained and available to perform the test series.
5. Test and inspection personnel have been trained in accordance with the appropriate test plans and/or procedures as required.
6. All test and Measurement equipment to be used fro the test series are current and will remain current during the testing period for which they are required.
7. Any subcontractors to be used have been trained in accordance with the test plan and/or procedures.

2.2 Pre-Test Measurements

Prior to performing any test, any per-test measurements required by the test plan must be taken and documented.

2.3 Instrumentation and Data Acquisition Systems

Prior to performing any test, the instrumentation and data acquisition system, if any, shall be checked to assure that it is properly functioning. Any instrumentation that is not properly functioning shall be either repaired or replaced. The test procedures shall include QA inspection hold points to verify that the instrumentation and acquisition equipment meets pre-test requirements.

2.3.1 Photographic Equipment

At least two consumer grade color video cameras shall be used to record the package response for each drop test series. One camera should have a field of view sufficient to capture the entire drop sequence, both free fall and impact. The field of view of the second camera should concentrate on the lower half of the impact area to provide more detailed footage of the drop sequence. The video recording of each drop test series shall be maintained for visual evidence.

Color still photographs shall be taken to document the test set-up and test results. Photographs should be taken with a minimum 3.0 Mega pixel digital camera or 35 mm standard camera equipment.

2.4 Environmental Conditions

2.4.1 Drop Test

Prior to performing each drop test series the following environmental conditions must be recorded:

1. Precipitation: Any precipitation (i.e. rain, snow, etc.) directly on the test article or test pad surface during the drop test shall be noted.

2. Wind Speed: The wind speed at the time of the drop series shall be recorded. If wind speed is considered to be strong enough to effect the drop orientation the drop test series should be delayed.

3. Package Temperature: Record the package temperature at prior to drop series.

4. Air Temperature: Record the air temperature at the drop site prior to conducting the drop series.

2.5 Test Components

2.5.1 Test Articles

The test article shall be fabricated in accordance with the requirements Section 3 of this test specification and QA-8 - Plan for Manufacture of the Versa-Pac Shipping Container [7].

2.5.2 Puncture Pin

The puncture pin must meet the requirements of 10 CFR 71(c)(3)[1]. The puncture pin must be a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 inches) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 inches) and a length as to cause maximum damage to the package, but not less than 20 cm (8 inches) long. The long axis of the bar must be vertical. The puncture pin must be attached so as to prevent it from sliding or overturning during the 1-meter puncture drop test.

2.5.3 Drop Test Facility

The drop test facility must have a suitable drop test pad, lifting equipment and drop release mechanism. The drop test facilities must meet the following specifications:

1. Drop Test Pad

The drop test pad must satisfy the requirements of IAEA [2] recommendations for an unyielding target. An example of an unyielding surface is: The drop test pad should consist of a rigid steel plate mounted on a concrete pad with the combined mass of the steel and concrete at least 10 times that of the test article, with a surface area sufficient in size so as to allow the entire test article to contact the steel surface plate. The steel and concrete interface should be floated on grout and mechanically anchored to the concrete base (e.g. anchor blots). The concrete must reach design strength prior to performing any drop test series. The drop test pad steel plate should be clean, and free from any significant surface imperfections (e.g. large gouges) that could affect the response of the package.

The drop test pad must also include a provision for attaching the puncture pin device used in the 1-meter puncture drop.

2. Lifting Equipment

The drop test facility must be equipped with a lifting device (e.g. crane) and lifting slings that are capable of lifting the lowest point of the test packages to the height prescribe above the top surface of the drop test pad for all drops in the test series. The lifting equipment (e.g. crane, slings) shall have at least the working load capacity to safely handle the test article weight.

3. Drop Release Mechanism

The drop test release mechanism must be capable of releasing the test articles without causing the package to rotate during the free fall to the test pad. Mechanical or administrative means shall be provided to prevent inadvertent release of the test article.

2.6 Test Plan and Procedures

Detailed test plans and procedures shall be developed for each droop test series and approved by Century Industries prior to perform any drop test. The test plan and procedures shall include step-by-step instructions for performing the test series. Each step or sequence shall include a provision for the responsible person to initial and date to indicate completion of the step(s). Each sequence shall allow for QA Hold Points necessary to confirm critical test items.

2.7 Test Sequences

Test sequences shall comply with the requirements of 10 CFR 71 [1]. A separate test article may be used for the NCT test series. When assessing cumulative package damage for the HAC test series, the test must be performed in the order shown within the Versa-Pac Shipping Container Test Plan [9] using the same test article within any given test series.

2.8 Quality Assurance Requirements

2.8.1 Test Inspection Personnel

All personnel performing measurements and inspections required by the test plan shall be qualified and trained in accordance with the requirements of the applicable test plan and procedures.

2.8.2 Quality Assurance Hold Points

The test package manufacturing plan and test plan shall establish appropriate hold points for QA for QA personnel to perform the following activities:

1. Receipt inspection of test articles.
2. Verification that all test personnel have been trained in accordance with the test plan prior to test activities.
3. Verification that all prerequisites have been satisfied.

2.8.3 Material and Test Equipment

When calibrated measurement and test equipment is required by the test plan, the equipment shall meet the applicable requirements of Century Industries QA Program QA-1[10].

2.9 Documentation and Reporting Requirements

The following documents must be provided after the test series has been completed:

1. Test article documentation package(s).
2. Measurement and test equipment records.
3. Personnel training and qualification records.
4. Test Plan and procedures.
5. Pre-test and post-test inspection data, photographic records, video recordings and other pertinent records.

3.0 Responsibilities

Century Industries is responsible for all activities including the preparation of fabrication control records, shop drawings, material procurement, testing and inspection, material certification records as required, welding procedures and final documentation packages.

3.1 Design Requirements

The Century Industries Versa-Pac is designed in accordance with the requirements of 10 CFR 71 [1] and the structural design in accordance with the American Welding Society D1.1 [4]. Welder and welding procedure are in accordance with the applicable requirements of AWS D1.1 [4].

3.2 Fabrication and Material Requirements

Century Industries Versa-Pac shall be fabricated in accordance with the requirements as outlined in the appropriate manufacturing plan and instructions referenced in the sections below. Century Industries Versa-Pac Shipping Container Test Plan [9]

3.2.1 Manufacturing Plan

Century Industries shall prepare a manufacturing plan for the Versa-Pac Shipping Container which should address the following items as a minimum:

- Receipt of materials
- Cutting and Preparation Instructions (Route Sheets)
- Fabrication Control Records (FCR's)
- Performance of functional tests
- Final inspections
- Package documentation review

3.2.2 Fabrication Procedures and Processes

All operations associated with the fabrication of the Versa-Pac shall include written instructions (e.g. Fabrication Control Records and/or Standard Operating Procedures). Additional instructions may be given in the form of drawings and/or sketches, along with verbal communications.

3.2.3 Base Materials

Base materials shall conform to the requirements given in the purchase orders and/or drawings as applicable.

3.2.4 Welding Materials

All weld filler materials shall conform to the requirements of the appropriate welding procedure and be in compliance with the requirements in AWS D1.1 [4].

General welding material certificates are acceptable.

3.2.5 Polyurethane Foam Insulation Materials

The Versa-Pac Shipping Container utilizes polyurethane closed cell foam to provide thermal insulation and impact protection in both the top and bottom ends of the container, this material shall be manufactured in accordance with the requirements of Century Industries Standard Operation Procedure 6.11 Revision 1 [5]. Sample foam specimens shall be taken and analyzed in accordance with the requirements of the procedure to confirm that the product meets the requirements for density, compressive strength, thermal conductivity, flame retardancy, water absorption moisture content and chloride content. The foam manufacturer shall provide a Certificate of Compliance and a written report of all testing required by the procedure.

3.2.6 Ceramic Fiber Insulation Materials

The Versa-Pac Shipping Container body is surrounded by two separate insulation chambers which utilize a 6# refractory ceramic fiber blanket (Aluminosilicate Fiber) in accordance with the requirements of Century Industries Standard Operating Procedure 6.12 Revision 1 [6].

3.2.7 Welding

All welding shall be in accordance with applicable requirements of AWS D1.1 [4], qualified welding procedures and written instructions.

All welding personnel shall be qualified in accordance with AWS D1.1 [4].

Precautions should be taken to minimize objectionable weld spatter and arc strikes outside the weld joint.

AWS Pre-qualified Welding Procedures and/or qualified welding procedures shall be used.

3.3 Testing and Inspection Requirements

3.3.1 General

1. All test articles shall be inspected to assure that the dimensions of the test article satisfy the requirements of the drawings.

2. Inspection personnel are qualified in accordance AWS CWI or CAWI and/or ASNT-TC-1A [8], as applicable.

3. Welds requiring NDE examination are performed in accordance with Century Industries Standard Operating Procedures, as applicable.

4. Written reports for any NDE shall be completed as required by the appropriate test procedure.

5. Acceptance criteria shall meet AWS D1.1 [4] and/or the requirements of the manufacturing plan and drawings.

6. Functional tests shall be performed as required by the Fabrication Control Records.

7. All test and measurement equipment shall be properly calibrated.

3.4 Quality Assurance

All work shall be performed in accordance with Century Industries QA Program or specific requirements imposed upon its subcontractors.

The Vera-Pac Shipping Container specifications require the application of 10 CR Part 21 [3]. Century Industries is responsible for providing notification to its suppliers and subcontractors.

3.5 Material Traceability

Material traceability shall be maintained throughout the fabrication process thru the use of Route Sheets and Fabrication Control Records as appropriate and by marking on necessary components that will not result in harmful contamination or damage affecting the performance of that component in the end product.

3.6 Storage, Handling and Shipping Requirements

All test articles that must be shipped to a subcontractor's facility shall be packaged using blocking, straps, hold-down devices and/or other materials required to prevent damage to the test article during transportation. Storage and handling may be conducted using the appropriate equipment needed to safely handle the test articles.

4.0 References

1. Title 10, Code of Federal Regulations, Part 71, Packaging and Transportation of Radioactive Materials
2. International Atomic Energy Agency (IAEA), Regulations for the Safe Transportation of Radioactive Material, No. TS-R-1
3. Title 10, Code of Federal Regulations, Part 21, Reporting of Defects and Noncompliance
4. American Welding Society, Structural Welding Code D1.1
5. Century Industries, Standard Operating Procedure, Polyurethane Closed Cell Foam Specification for Century Products
6. Century Industries, Standard Operating Procedure, Ceramic Fiber Insulation Specification for Century Products
7. Century Industries, QA-8, Plan for the Manufacture of Versa-Pac Shipping Containers
8. American Society of Nondestructive Testing (ASNT), Recommended Practice No. SNT-TC-1A
9. Century Industries, Versa-Pac Shipping Container Test Plan – TP-002
10. Century Industries, Quality Assurance Manual, QA-1

Attachment C

NCT & HAC Test Series Records

(5 Pages)

Century Industries **NCT and HAC Test Record No.** TS-002-1 **Page 1 of 5**
Bristol, Virginia **in accordance with**
Versa- Pac Test Specification, TS-002, Rev. 0

Test Package Serial No: 10553 Package Description: Versa-Pac (55-Gallon Version)

Test Program Manager: [illegible] Date: 9-24-09
Test Engineer: [illegible] Date: 9-24-09
Quality Assurance Coordinator: [illegible] Date: 9-24-09

Photographic Equipment

Sony Cybershot (4.1 Mega Pixel) Digital Camera DSC-P73

Calibrated Equipment Utilized

Simpson Ohmmeter S/N: 05598
Stanley Tape Measure S/N: 0rucl496
16' Tape measure S/N: QC-001

Package Preparation Checklist and Measurements

Procedure Step No.	Description	Date	Initials
6.1.2	Photograph interior and exterior of the package prior to loading	9-23-09	WMA
	Measure centerline and near side distance to edge of cavity and mark on package	9-23-09	WMA
	Weigh empty test package 396 Package tare weight (lbs)	9-23-09	WMA
	Load simulated test payload 254 1/2 Lbs	9-23-09	WMA
	Spread one (1) pound of residual sand/dirt into the inner containment cavity	9-23-09	WMA
	Inspect the inner containment components for good condition and in accordance with drawings	9-23-09	WMA
	Install cavity gasket and blind flange, snug all bolts, then torque to 60 ft-lbs	9-24-09	WMA
	Install outer gasket and reinforced drum lid with proper bolts per drawing and torque to 60 ft-lbs	9-24-09	WMA
	Install outer drum ring and torque to 60 ft-lbs	9-24-09	WMA
	Weigh loaded test package 644 1/2 Package test weight (lbs)	9-23-09	WMA
	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX		

Century Industries
Bristol, Virginia

NCT and HAC Test Record No. TS-002-1
in accordance with
Versa- Pac Test Specification, TS-002, Rev. 0

Page 2 of 5

Procedure Step No.	Description	Date	Initials
6.1.2	Measure height from bottom rim to top of closure ring and diameter of outer package at center rolling hoop of drum and mark measurements on the test package 34" Package height (in.) 23½" Package diameter (in.)	9-24-09	WMA
	Verify the external acetate vent plug is in place	9-24-09	WMA
	Photograph exterior of test package for evidence of pre-test condition	9-24-09	WMA

1-55-A

Test Number (Description): NCT 4' Shallow Angle (Accelerated – Slap-Down) Drop

Procedure Step No.	Description	Date	Initials
6.1.2	Measure and record package surface &air temperature at drop pad 89 Package Surface Temperature (°F) 90 Air Temperature(°F) 2 Wind speed (mph)	9-24-09	WMA
	Measure and record the angle at which the test article is oriented to the nearest degree (within ±1 degree of specified drop orientation) 15° Angle of orientation	9-24-09	WMA
	Lift test article to required drop height	9-24-09	WMA
	Measure and record height from test pad surface to lowest point on test package (at least the specified drop height and not more than +2 inches) 48½" Drop test height (in.)	9-24-09	WMA
6.1.3	Photograph exterior surfaces of test article for visual evidence of damage	9-24-09	WMA
	Document visual damage to package (e.g. deformation or bolt failure) 7¼" Long x ¼" At Rim on Top Dome Ring - INDENTATION on OUTER Drum Rolling Hoop 5¾" Flat at Bottom EDGE x ¼" Deep NO TEARING OR OPENING Sketch of Damage	9-24-09	WMA
	Measure height and diameter of test package 33 1/16 Package height (in.) AT BOLT IMPACT 23 1/16 Package diameter (in.) AT BOLT IMPACT	9-24-09	WMA

Century Industries NCT and HAC Test Record No. TS-009-3 Page 3 of 5
Bristol, Virginia in accordance with
Versa-Pac Test Specification, TS-002, Rev. 0

1-55-B

Test Number (Description): HAC 30' Shallow Angle (Accelerated – Slap-Down) Drop

Procedure Step No.	Description	Date	Initials
6.2.2	Photograph exterior surfaces of test article for visual evidence of pre-test condition	9-24-09	WMA
	Measure and record the package surface & air temperature at the drop pad 89 Package Surface Temperature (°F) 90 Air temperature (°F) 2 Wind speed (mph)	9-24-09	WMA
	Once suspended, measure and record the angle at which the test article is oriented to the nearest degree (within ±1 degree of specified drop orientation) 17° Angle of orientation	9-24-09	WMA
	Measure and record height from test pad surface to lowest point on test package (at least the specified drop height and not more than +2 inches) 36 1/2 Drop test height (in.)	9-24-09	WMA
6.2.3	Photograph exterior surfaces of test article for visual evidence of additional damage	9-24-09	WMA
	Document visual damage to package (e.g. deformation or bolt failure) Minor Bolt Closure Lug Small Ripple in Inside of Lower Drum Lid Minor Flat Area Flat Impact Side of Drum Drum No Opening or Closure 11 1/2" Long x 3/8" Deep at Lid Into Face of Bolt Ring Bolt Ring Broken Into 10" Long x 1/4" Deep at Bottom Edge Sketch of Damage Top	9-24-09	WMA
	Measure and record height and diameter of test article 34 1/4" Package height (in.) at Bolt Impact 22 1/8" Package diameter (in.) at Bolt Impact	9-24-09	WMA

1-55-C

Test Number (Description): HAC 1 Meter Puncture Drop C/G Thru Previous Impact Areas

Procedure Step No.	Description	Date	Initials
6.3.2	Photograph exterior surfaces of test article for visual evidence of pre-test condition	9-24-09	WMA
	Measure and record the package surface & air temperature at the drop pad 89 Package Surface Temperature (°F) 90 Air temperature (°F) 2 Wind speed (mph)	9-24-09	WMA

Century Industries NCT and HAC Test Record No. TS-002-1 Page 4 of 5
Bristol, Virginia in accordance with
Versa- Pac Test Specification, TS-002, Rev. 0

Procedure Step No.	Description	Date	Initials
6.3.2	Once suspended, measure and record the angle at which the test article is oriented to the nearest degree (within ±1 degree of specified drop orientation) 56½° Angle of orientation C/G	9-24-09	WMA
	Measure and record height from test pad surface to lowest point on test package (at least the specified drop height and not more than +2 inches) 41" Drop test height (in.)	9-24-09	WMA
6.3.3	Photograph exterior surfaces of test article for visual evidence of additional damage	9-24-09	WMA
	Document visual damage to package (e.g. deformation or bolt failure) 8 3/4" WIDE AREA FLAT FROM PUNCTURE TEST Sketch of Damage Top	9-24-09	WMA
	Measure and record height and diameter of test article 33 3/16" Package height (in.) AT BOLT AREA 23" Package diameter (in.) AT BOLT AREA	9-25-09	WMA

Test Number (Description): N/A

Procedure Step No.	Description	Date	Initials
N/A	Photograph exterior surfaces of test article for visual evidence of pre-test condition	N/A	N/A
	Measure and record the air temperature at the drop pad _____ Air temperature(°F) _____ Wind speed (mph)		
	Once suspended, measure and record the angle at which the test article is oriented to the nearest degree (within ±1 degree of specified drop orientation) _____ Angle of orientation		
	Measure and record height from test pad surface to lowest point on test package (at least the specified drop height and not more than +2 inches) _____ Drop test height (in.)		
	Photograph exterior surfaces of test article for visual evidence of additional damage		

Century Industries
Bristol, Virginia

NCT and HAC Test Record No. TS-0021-1
in accordance with
Versa-Pac Test Specification, TS-002, Rev. 0

Page 5 of 5

Procedure Step No.	Description	Date	Initials
N/A	Document visual damage to package (e.g. deformation or bolt failure) Sketch of Damage Top	N/A	N/A
N/A	Measure and record height and diameter of test article _____ Package height (in.) _____ Package diameter (in.)	N/A	N/A

Final Test Record Measurements

Procedure Step No.	Description	Date	Initials
4.3.3	Measure and record torque of outer closure bolts 42 to 55 Torque (ft-lbs) Inspection Top Bolt 49 FTLB	9-24-09	WMA
	Open outer package and remove outer lid	9-24-09	WMA
	Photograph interior surface of test article and examine for any apparent indications of containment boundary loss, e.g. payload materials No Loss of Containment No Damage To Blind Flg or Flg To Blind Flg Intact	9-24-09	WMA
	Measure and record torque of interior bolts 30-50 Torque (ft-lbs)	9-24-09	WMA
	Remove inner containment cavity blind flange	9-24-09	WMA
	Examine and document condition of the gasket and payload contents Inner Gaskets in Good Condition No Loss of Payload Contents Payload in Tact	9-24-09	WMA
	Measure and record the pre-test and post-test centerline and near side distance to edge of cavity for comparison (See attached Measurement Data Sheet)	9-24-09	WMA
	Remove (if possible) and document any apparent damage or movement to the inner containment cavity Payload Removed - No Damage or Change of Containment Found	9-24-09	WMA
	Photograph inner cavity to provide visual evidence of any apparent damage	9-24-09	WMA

Attachment D

Training & Equipment Calibration Records

(8 Pages)

Starett 100' Tape Measure Calibration Record

CENTURY INDUSTRIES D42

Calibration Record of Measurement and Test Equipment

Page 1 of 1

Equipment No: S/N 08461846 Description: 100 Ft. Tape

Frequency: 5 Years Location: Office

Calibrated by: Starrett Company ☐ CPI ☑ Outside Lab For Certification see File No:

CALIBRATION INSTRUCTIONS:

Testing is conducted in accordance with ISO 17025, ISO Guide 25, ANSI/NCSL Z540-1 and Mil-STD-45662A and shall be traceable to N.I.S.T.

RESULTS: Acceptable N.I.S.T. Test No. 821/271887

BY: The L.S. Starrett Company

DUE DATE: November 17, 2013

DATE CALIBRATED: November 17, 2008

Starrett

The L.S. Starrett Company
121 Crescent Street
Athol, MA 01331-1915 USA
Tel: 978 249-3551
Fax: 978 249-8495
www.starrett.com

ATTN: QUALITY ASSURANCE
MCMASTER-CARR SUP CO
6100 FULTON IND BLVD
ATLANTA GA 30336-2853

NOVEMBER 17, 2008

STANDARD LETTER of CERTIFICATION

THIS IS TO CERTIFY THAT THE ITEM LISTED BELOW MEETS THE REQUIREMENTS OF ACCURACY OF THE APPLICABLE SPECIFICATION ON DATE OF SHIPMENT.

STANDARDS AND EQUIPMENT USED FOR INSPECTION ARE CERTIFIED ACCURATE WITH REFERENCE TO 68 DEGREES F. TRACEABLE TO MASTER STANDARDS AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, WASHINGTON, D.C. CALIBRATION IS PERFORMED WITH TRANSFER STANDARDS WHICH ARE PROGRESSIVELY MORE ACCURATE IN THE ORDER OF 4:1.

WE ATTEST THAT OUR MEASURING AND TEST EQUIPMENT, AND CALIBRATIONS PERFORMED ON THE ITEM (S) LISTED BELOW, ARE IN ACCORDANCE WITH ISO 17025, ISO GUIDE 25, ANSI/NCSL Z540-1 AND MIL-STD-45662A.

YOURS VERY TRULY,
THE L.S. STARRETT COMPANY

DEXTER J. CARLSON
CHIEF INSPECTOR

YOUR ORDER NO.	OUR ORDER NO.	TOOL	SPECIFICATION
QA-87917960	1355247	530-100 TAPE S/N 08461846	GGG-T-106F NIST HANDBOOK #44

N.I.S.T. TEST NO.
821/271887

ACCURACY: WHEN THE TAPE IS SUPPORTED ON A HORIZONTAL SURFACE AND PULLED WITH A TENSION OF 10 POUNDS AT A TEMPERATURE OF 68 DEGREES FAHRENHEIT THE OVERALL LENGTH WILL NOT BE IN ERROR BY MORE THAN .100" IN 100' OR LESS.

The estimated uncertainties reflect a Confidence Probability of approximately 95%.
This Certificate or Report shall not be reproduced except in full, without the written approval of the Chief Inspector of The L.S. Starrett Company.

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E-2

Calibration Record for Dickson Data Thermometer

CENTURY INDUSTRIES D42

Calibration Record of Measurement and Test Equipment

Page 1 of 1

Equipment No: 09057179 Description: Dickson Temperature Recorder Model SM320

Frequency: 1 Year Location: Office

Calibrated by: Dickson Calibration Services ☐ CPI ☐ Outside Lab For Certification see File No:

CALIBRATION INSTRUCTIONS:

Calibrate in accordance with the ISO 17025 and ANSI/NCSL Z540-1 1994

And Traceable to the National Institute of Standards and Technology

RESULTS: Acceptable

BY: Dickson Calibration Services

DUE DATE: February 01, 2010

DATE CALIBRATED: February 01, 2009

Dickson Certificate of Instrument's Initial Calibration

Re-calibration instructions below

Models: SM300/320/325/420/720/725, TM320/325/725, VFC320/325

Calibration Procedure: The customer instrument was compared to the calibration standard. Drifts and faults were determined, and any necessary mechanical or electronic adjustments were taken. The Dickson calibration system conforms to the requirements of ISO 17025 and ANSI/NCSL Z540-1-1994 as appropriate.

Calibration Standards: (The Dickson Calibration Standards are traceable through NIST and are re-certified anually)

- General Eastern Chilled mirrors and RTD (± .4RH, ± .4°F)
- Azonix A1011 PRTD (±.2°F)- Ectron Thermocouple Simulator (± .4°F)

Accuracy Specifications:

- SM300 / SM320 / SM720 internal temperature: ± 8.°F / ± 1.8 °F
- TM320 / TM325 / TM725 temperature accuracy: ± 8°F
- TM320 / TM325 / TM725 RH: ±2%RH from 0 to 60%; ±3% from 60 to 95%
- SM320 / SM325 SM720 / SM725 VFC320/325 external temperature: ±1.8°F (Unit Only)
- SM420 Platinum RTD: ±0.5°F

For Your Next Calibration

This is a precision instrument that requires re-calibration. We recommend every 6-12 months.

Just send this completed form along with your instrument to Dickson, labeling the outside of the box with "CCM" it's that simple!

A) Purchase Order #:

Name: Phone:

Model Serial #:

B) **A 3-pt Deluxe NIST will be performed unless otherwise requested**

1-Point NIST Calibration $156.00

3-Point NIST Calibration $209.00

3-Point A2LA Accredited 3-pt Calibration: $315.00 (includes incoming readings)

N995 - User selectable NIST Temperature points $50.00 each

(to be selected in addition to one of the above calibration options)

Prices are subject to change

C) Please Return:

Ground Freight*

2nd Day Air*

Next Day*

***Charges added at factory**

Returned UPS 2nd Day unless otherwise requested

D) Ship to:

Bill to:

Let Dickson remind you the next time your unit is due for calibration. Join Calibration Club and receive calibration reminders free on all of instruments, including all non-Dickson brands of instrumentation. Learn more and register on-line at www.dicksonweb.com

Dickson Calibration Services
930 South Westwood Avenue Addison, Illinois 60101
Phone: 630-543-3747 Fax: 630-543-0498
www.dicksondata.com

Calibration Record for PTC Surface Thermometer

CENTURY INDUSTRIES D42

Calibration Record of Measurement and Test Equipment

Page 1 of 1

Equipment No: 05548 Description: PTC Instruments Model 330F -100°F to +160°F

Frequency: 3 Months Location: Office

Calibrated by: Century Industries ☐ CPI ☐ Outside Lab For Certification see File No:

CALIBRATION INSTRUCTIONS:

Surface thermometer shall be place on a flat surface next to the NIST Traceable gauge. The thermometers should be allowed to equalize for a period of not less than 15 minutes at the ambient air temperature. The readings shall be within ± 2°F. A second reading shall also be obtained by placing both units in a cooling chamber, allowing the gauges to equalize for not less than 15 minutes. The reading shall be within ± 2°F. Calibrate in accordance with the ISO 17025 and ANSI/NCSL Z540-1 1994 and Traceable to the National Institute of Standards and Technology.

RESULTS: Acceptable

BY: Century Industries

DUE DATE: October 09, 2009

DATE CALIBRATED: July 09, 2009

Floor Scale

CENTURY INDUSTRIES D42

Calibration Record of Measurement and Test Equipment

Page 1 of 1

Equipment No: 98530806V1812 Description: 0-330 Pounds Scale

Frequency: 12 Months Location: Office

Calibrated by: Carlton Scale ☐ CPI X☐ Outside Lab For Certification see File No:

CALIBRATION INSTRUCTIONS:

1. Using certified check weights verify that readings are within ± 2 pounds of full scale.

RESULTS: Acceptable

BY: Carlton Scale

DUE DATE: February 15, 2010

DATE CALIBRATED: February 15, 2009

Indoctrination or Training Session Outline D52

Century Industries

P.O. Box 17084
Bristol, VA 24209
423-646-1864

Page 1 of 1

Title **TEST SPECIFICATION & TEST PLAN FOR THE VERSA-PAC SHIPPING CONTIANER**	**Dept** Testing Assistants **Outline No** 4F **Rev.** 0 **APPROVED:** Department Manager 2-25-09 Date
Type: ☑ Indoct. ☑ Training **Recommended Min. Duration:** 40 min.	QA Manager 2-25-09 Date

1. Review duties and responsibilities per:

TS-001 Rev. 0 – Versa-Pac Test Specification

TP-001 Rev. 0 – Versa-Pac Shipping Container Test Plan

Session Record **D50**

Century Industries
P.O. Box 17084
Bristol, VA 24209
423-646-1864

TEST PERSONNEL
Department

Position/Job Classification: Test Assistant

Outline Number: 4F **Date Completed** 2-25-09 **Duration** 1 HR.

Remarks:

Instructor 2-25-09
Date

The following Personnel have satisfactorily completed the above indoctrination or training outline:

Employee	Employee
Steve Fallin	
Jamie Butler	
Drew Fuller	
Teddy Brown	
Mark Osborne	
Heather Little	

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SECTION THREE
THERMAL EVALUATION

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3 THERMAL EVALUATION

The Century Industries Versa-Pac is designed to maintain the temperatures of the payload and containment boundary within specified limits during normal transportation and hypothetical accident conditions. This section presents an evaluation of the thermal performance of the packaging.

3.1 Description of the Thermal Design

3.1.1 Design Features

The 55-gallon Versa-Pac consists of a 15" ID x 28" payload cavity centered within an insulated 55-gallon drum. Drawings of the 55-gallon version Versa-Pac are provided in Appendix 1.3.1. An illustration of the packaging is provided in Figure 1-1.

The overall nominal dimensions of the 55-gallon Versa-Pac shipping container are 23" OD x 34-1/2" in height. The payload cavity is protected from water intrusion with a gasketed lid that is closed with twelve ½" diameter bolts. Exterior to the payload cavity lid, the 55-gallon drum lid is modified with a 20ga steel encapsulated polyurethane insulation plug. The gasketed drum lid is closed with four ½" diameter bolts and a standard drum ring. A gasket at the drum lid's stiffening ring provides a third 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 16ga outer liner and a 16ga inner liner provide additional radial stiffness to the drum. A ½" thick fiberglass ring is used as a thermal break at the payload cavity flange. The thermal break is sandwiched between the steel components and effectively limits the flow of heat to the payload cavity through the steel flange components. The volume between the inner liner and the 10ga containment body is filled with ceramic fiber insulation (see Appendix 1.3.4).

The 110-gallon Versa-Pac consists of a 21" ID x 29-3/4" payload cavity centered within an insulated 110-gallon drum. Drawings of the 110-gallon version Versa-Pac are provided in Appendix 1.3.1. An illustration of the packaging is provided in Figure 1-1. The overall nominal dimensions of the package are 30-7/16" OD x 42-1/2" in height. The basic design of the 110-gallon Versa-Pac is identical to that of the 55-gallon Versa-Pac, except for the larger exterior diameter and payload cavity diameter. The thickness of the walls and insulation remain the same.

3.1.2 Contents Decay Heat

The decay heat for the payload is limited to 10W total for the 55-gallon and 110-gallon packages, with no single item having a decay heat greater than 20 W/m^3.

3.1.3 Summary Tables of Temperatures

Table 3-1 provides a summary of the Normal and HAC temperatures for the Versa-Pac. The maximum peak content temperature occurs for the HAC fire event 22 minutes into the cooldown sequence and is 552°F at the top of payload cavity.

3.1.4 Summary Tables of Maximum Pressures

Since the Versa-Pac is not a sealed system, the maximum normal and HAC operating pressure is near atmospheric pressure. Thus, the Versa-Pac meets the requirements of 10CFR71.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

Thermal material properties are provided in Table 3.5.1-3. Mechanical material properties, including the linear thermal expansion coefficient, are provided in Table 2-2.

The payload is a stable solid that does not undergo any physical state changes (solid to liquid or solid to gas) below 600°F. Additionally, the auto-ignition temperature of the contents must be greater than or equal to 600°F. Water moisture may be present (standing water is not permitted); however, during the fire it is converted to steam and is allowed to escape via the package closure gaskets. Payloads that are unstable or decompose at temperatures below 600°F that further pressurize the containment may not be shipped in the Versa-Pac.

3.2.2 Component Specifications

The Versa-Pac is insulated to protect the containment boundary during Hypothetical Accident Conditions (HAC). The volume between the drum and the liner is filled with ceramic fiber insulation. The volume between the liner and the payload canister is also filled with ceramic fiber insulation. A fiberglass thermal break is used to limit the flow of heat to the payload cavity through the steel flange components. The relevant thermal material properties and specifications are provided in Table 3.5.1-2. These insulators have been shown by the manufacturers to perform adequately over extended periods of time, with no shrinkage, settling, or loss of insulating properties. Additionally, these insulators do not burn. The melting point of the ceramic fiber insulation and the fiberglass thermal break are well above the temperature of the 1475°F fire specified by 10CFR71.73. These insulation products are provided as fire-protection and are sacrificial components during a fire event. Steel components are serviceable to 800°F per the ASME Code, and have a melting point of about 2500°F.

The payload cavity gaskets are rated for operating temperatures between -40°F and 1800°F; however, the Versa-Pac isn't designed as a sealed system and the function of the gaskets is to prevent dispersal of the contents only. Since the system is not sealed, the internal pressure is maintained near atmospheric conditions during all conditions of transport. The nominal payload vessel internal pressure is 0 psig.

The fiberglass thermal break is fabricated to the specification provided in Appendix 1.3.5. The fiberglass consists of a reinforced thermoset plastic composite that is thermally nonconductive and fire retardant.

To avoid collapse of the payload cavity, the maximum allowable external and internal working pressure is 15 psig.

3.3 Thermal Evaluation for Normal Conditions of Transport (NCT)

The Versa-Pac is designed to meet the requirements specified by the United States Code of Federal Regulations (Title 10 and 49) and IAEA Safety Standards (TS-R-1). The package was evaluated for all conditions of transport utilizing a transient quarter-symmetric finite element model as described in Appendix 3.5.1. Material properties used in the analyses are provided in Appendix 3.5.1. Table 3-2 provides a summary of the parameters analyzed for each scenario examined, including initial conditions and heat loads.

3.3.1 Heat and Cold

The absorptivity of the outer shell is conservatively assumed to be 1.0. The convection heat transfer coefficient is conservatively assumed to be 1.0 Btu/hr-F-ft^2. The decay heat is assumed to be at the maximum for normal hot conditions. The maximum temperatures for Normal Conditions of Transport occur when the conditions specified by 10CFR71.71(c)(1) are applied. The specified insolation rate of 800 g-cal/cm^2 per 12-hour period is applied to the top surface of the packaging and an insolation rate of 400 g-cal/cm^2 per 12-hour period is applied to the curved sides of the packaging. Insolation is not applied to the base of the packaging. The NCT model configuration, including input heat and boundary conditions, is further illustrated in Appendix 3.5.4.

With these insolation rates applied for 12-hours and alternated with 12-hours without insolation, the peak daytime temperature at the external surface of the package for the normal condition of transport is 140°F (60°C) at the drum lid as illustrated in Figures 3-1 and 3-2. The peak temperature of the contents for the normal condition is 144°F (62°C), as shown in Figure 3-3.

Under normal cold conditions as specified by 10CFR71.71(c)(2), the minimum temperature of the packaging and payload, assuming zero decay heat, is -40°F. This temperature is within the limits specified in Section 3.1.

3.3.2 Maximum Normal Operating Pressure

Since the Versa-Pac is not a sealed system, the maximum normal operating pressure is near atmospheric pressure.

3.4 Thermal Evaluation for Hypothetical Accident Conditions (HAC)

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 552°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 600°F.

3.4.1 Initial Conditions

The model imposes an initial condition of 100°F on all nodes at the start of the thermal event. Damage from the mechanical tests was not simulated; however, local reductions in wall thickness were shown in the drop tests to be limited to the outer 1-1/2" of the package. Since

this portion of the package quickly attains the temperature of the fire, a local reduction isn't expected to influence the temperature of the contents.

3.4.2 Fire Test Conditions

For the fire analysis, the external surface nodes were constrained to a temperature of 1475°F for the 30-minute event. For the 55-gallon version, the contents are modeled with a decay heat load of 0.022 in-lb_f/s / in^3, for a conservative total package heat load of 11.4 W. The decay heat load of the 110-gallon version modeled is 0.0085 for a total of 11.4 W. The HAC model configuration for the fire test sequence, including input and boundary conditions, is further illustrated in Appendix 3.5.4.

3.4.3 Cooldown Conditions

The cooldown sequence is initialized with the temperatures recorded for each node at the end of the 30 minute fire sequence. Insolation is applied using the insolation rates and 12-hours on, 12-hours off application described for the NCT evaluation. The ambient temperature is 100°F. Surface temperature dependant external surface natural convection coefficients are applied at the outer surfaces of the package, with the exception of the base, which is assumed to be adiabatic[1]. The remainder of the model and specifications are identical to those used during the fire sequence. The cooldown sequence was run for a 2-hour cooldown period, with the peak payload temperatures occurring within the first hour after cessation of the fire. The HAC model configuration for the cooldown sequence, including input and boundary conditions, is further illustrated in Appendix 3.5.4.

3.4.4 Maximum HAC Temperatures and Pressures

3.4.4.1 HAC Temperatures

The maximum temperature recorded at the payload cavity during the fire event was 552°F at the top of payload cavity, just below the polyurethane plug, for the 55-gallon package as shown in Figure 3-4. The temperature distributions of the various package components are shown in Figures 3-4 through 3-14. A time dependent graph of the peak temperature locations on the payload cavity is provided in Figure 3-15. The 110-gallon package performance is bounded by that of the 55-gallon package.

3.4.4.2 HAC Pressures

Since the Versa-Pac is not a sealed system, the maximum normal operating pressure is near atmospheric pressure.

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[1] An *adiabatic process* is a thermodynamic process in which there is no heat transfer into or out of the system. In this case, the surface that the package is sitting on is assumed to be a perfect insulator, and no heat can be removed from the base unless it moves through the sides of the package. This is considered to be the conservative orientation for the package during cooldown conditions.

3.4.5 Maximum Thermal Stresses

The performance of the Versa-Pac with respect to thermal stresses is demonstrated through the fire tests performed for similar packages. A summary of one such test is provided in Appendix 3.5.3. The flexible construction of the connection between the payload cavity and the flange assures that thermal gradients do not impose excessive stress on the package joints.

3.4.6 Accident Conditions for Fissile Material Packages for Air Transport

This section is not applicable.

3.5 List of Appendices

3.5.1 Description of the Thermal Model

3.5.2 Excerpted from ALGOR Non-Linear Thermal Transient Heat Transfer Analysis Manual, Emulation of body-to-body radiation as temperature dependent conduction

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

3.5.4 Thermal Model Illustrations for NCT and HAC Fire Test Duration and Cooldown Sequence

3.6 References

3.6.1 MatWeb material database, a division of Automation Creations, Inc. (ACI) of Blacksburg, Virginia.

3.6.2 ALGOR FEMPRO FEA Software by Autodesk, Pittsburgh, PA, version 18.1.

3.6.3 Incropera & DeWitt, *Fundamentals of Heat and Mass Transfer 3rd Edition*, John Wiley & Sons, New York, 1990.

Table 3-1 Evaluation Results

Evaluation	Component	Evaluation Result	Evaluation Criteria	Margin of Safety [Note 1]
Normal Hot Maximum Temperature	External surface	140°F	800°F	660°F
	Payload cavity gasket	130°F	1800°F	1670°F
	Payload	144°F	500°F	356°F
Normal Cold Minimum Temperature	External surface	-40°F	N/A	N/A
	Payload cavity gasket	-40°F	-40°F	0°F
	Payload	-40°F	N/A	N/A
Normal Maximum internal pressure	Payload cavity	0 psig	15 psig	15 psig
HAC Maximum Temperature	External surface	1475°F	2500°F	1025°F
	Payload cavity gasket	623°F	1800°F	1177°F
	Payload	552°F	600°F	48°F
HAC Maximum Internal Pressure	Payload cavity	0 psig	15 psig	15 psig
HAC Thermal Stress	package	Demonstrated by test as acceptable	No failure due to fire event temperature distribution	N/A

Notes on Table 3-1

1. The margin of safety is (allowable – actual)
2. Results shown are for the 55-gallon package. The 110-gallon package performance is bounded by that of the 55-gallon package.

Table 3-2 Applied Heat Loads, Heat Transfer Coefficients and Initial Conditions

Parameter	Normal Transport Hot	Normal Transport Cold	HAC Transport
Ambient Temperature, °F	100.00	-40.00	1475 for 30min, 100.00 until peak temperatures are identified
Top surface insolation, BTU/hr-ft^2, 12 hours on, 12 hours off	246.00	0.00	N/A during the fire, 246.00 during cooldown
Curved surface insolation, BTU/hr-ft^2, 12 hours on, 12 hours off	123.0	0.00	N/A during the fire, 123.00 during cooldown
Base surface insolation, BTU/hr-ft^2, 12 hours on, 12 hours off	0.00	0.00	N/A during the fire, 0.00 during cooldown
Radiological Decay Heat, 55 gal / 110 gal, W	10.0 / 10.0	0.00	10.0 / 10.0
Analysis performed	Transient	N/A	Transient
Initial Package/Content Temperature	100.00	N/A	100°F
External surface absorptivity/emissivity	1.0	N/A	1.0
External surface convection coefficient, Btu/hr-F-ft^2	1.0	N/A	During fire transient, N/A During cooldown, see Table 3.5.1-5

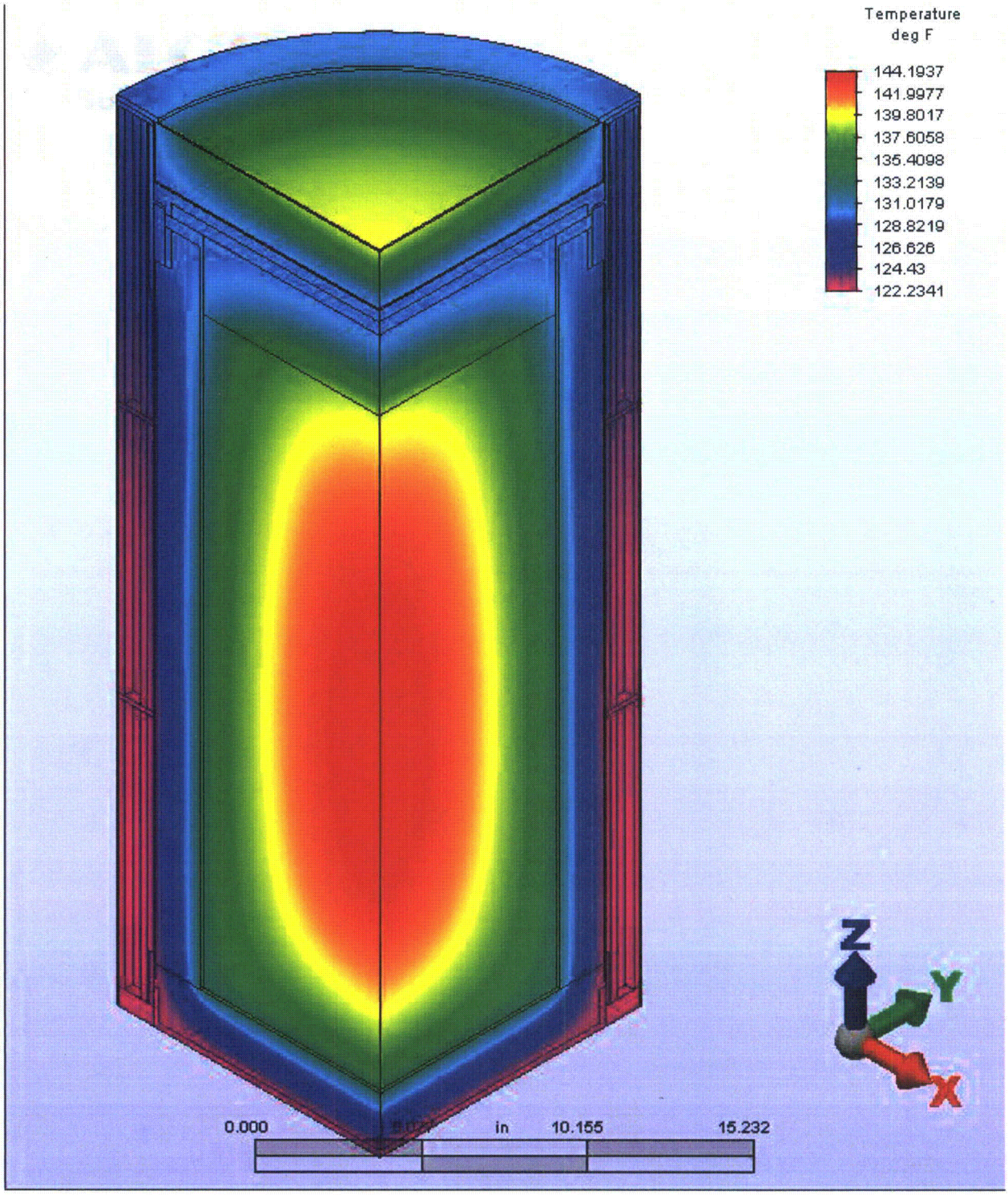


Figure 3-1 Normal Hot Package Peak Temperature Distribution, 55-gallon VersaPac

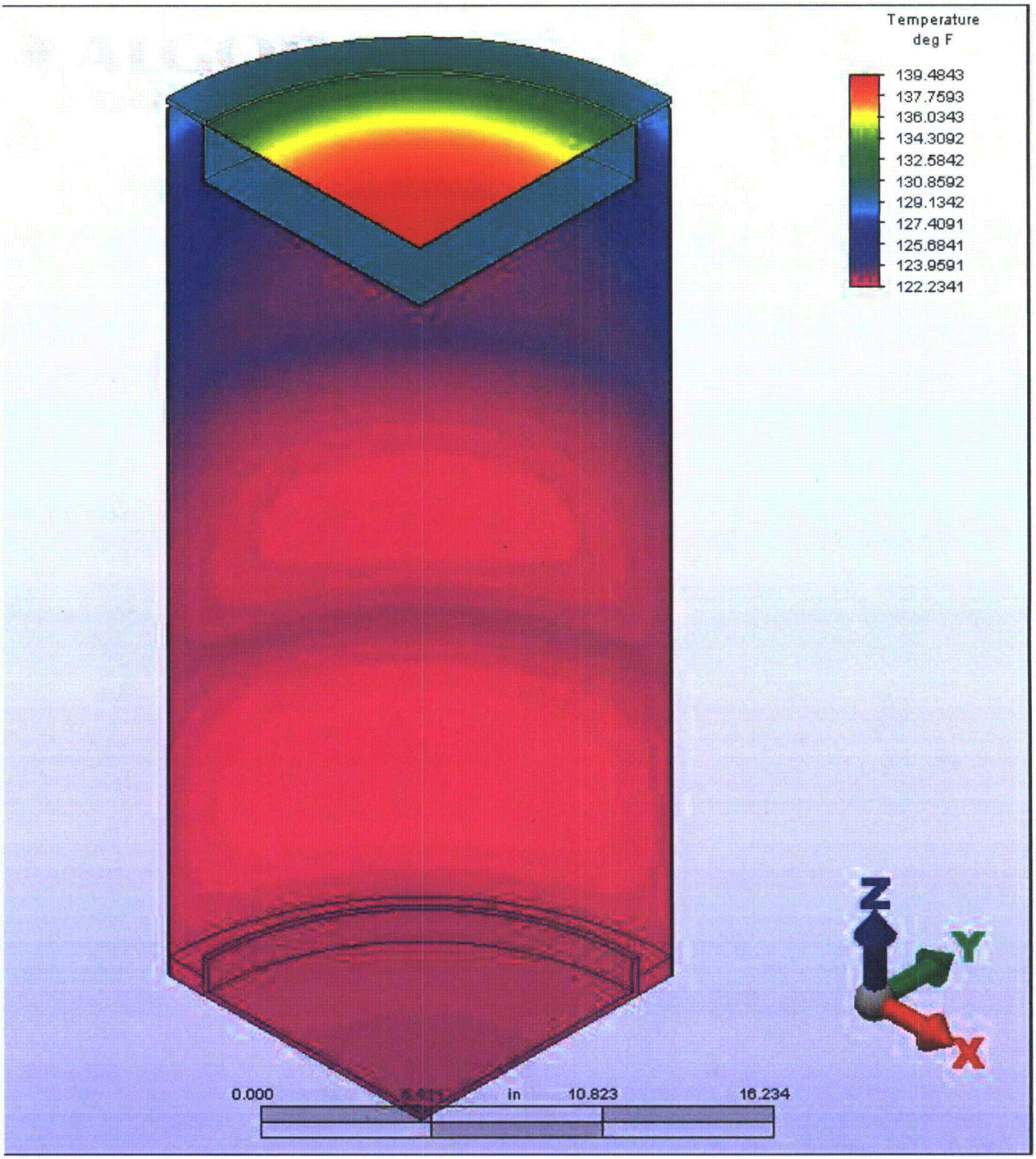


Figure 3-2 Normal Hot Outer Surface Peak Temperature Distribution, 55-gallon Versa-Pac

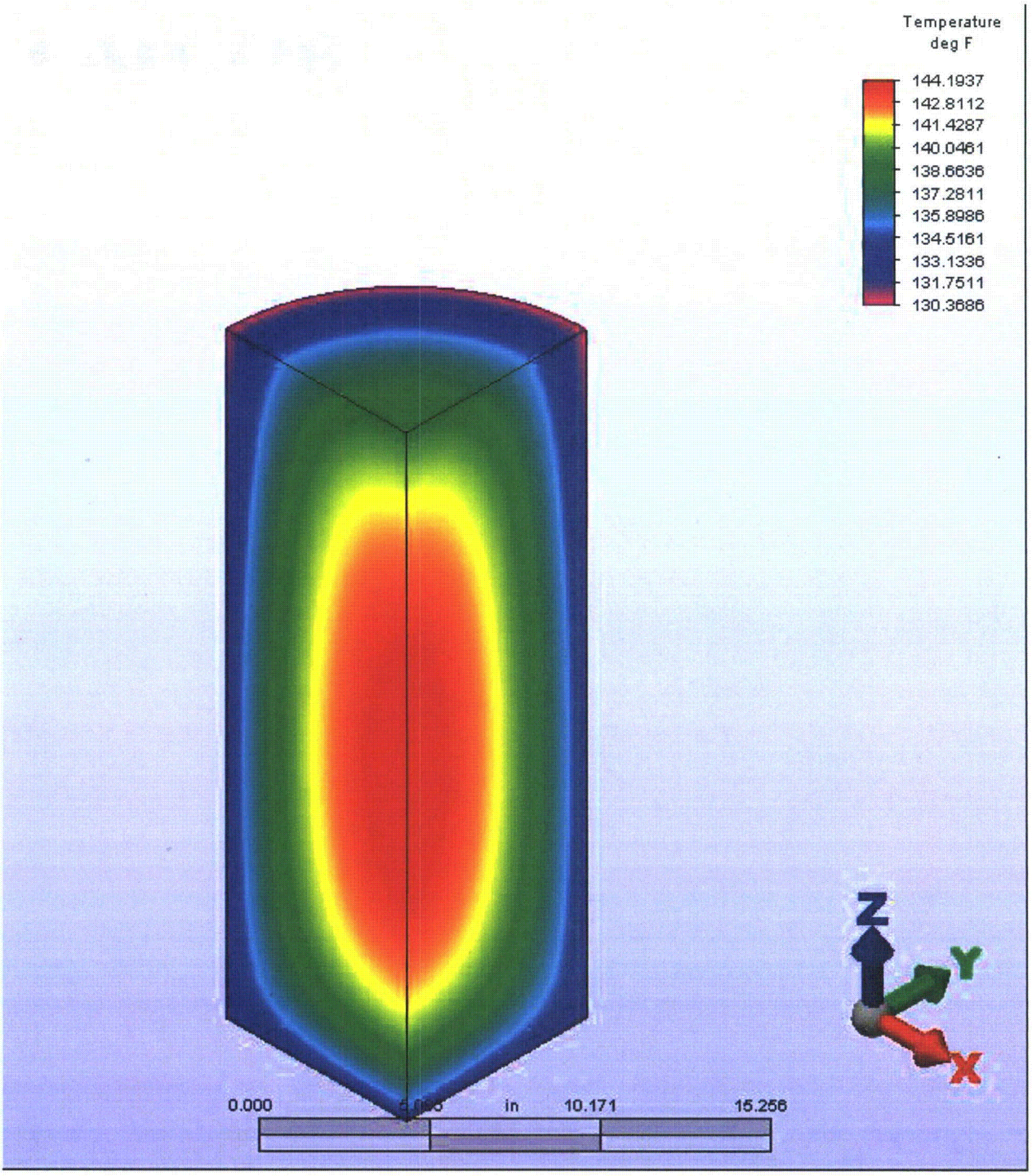


Figure 3-3 Normal Hot Contents Peak Temperature Distribution, 55-gallon Versa-Pac

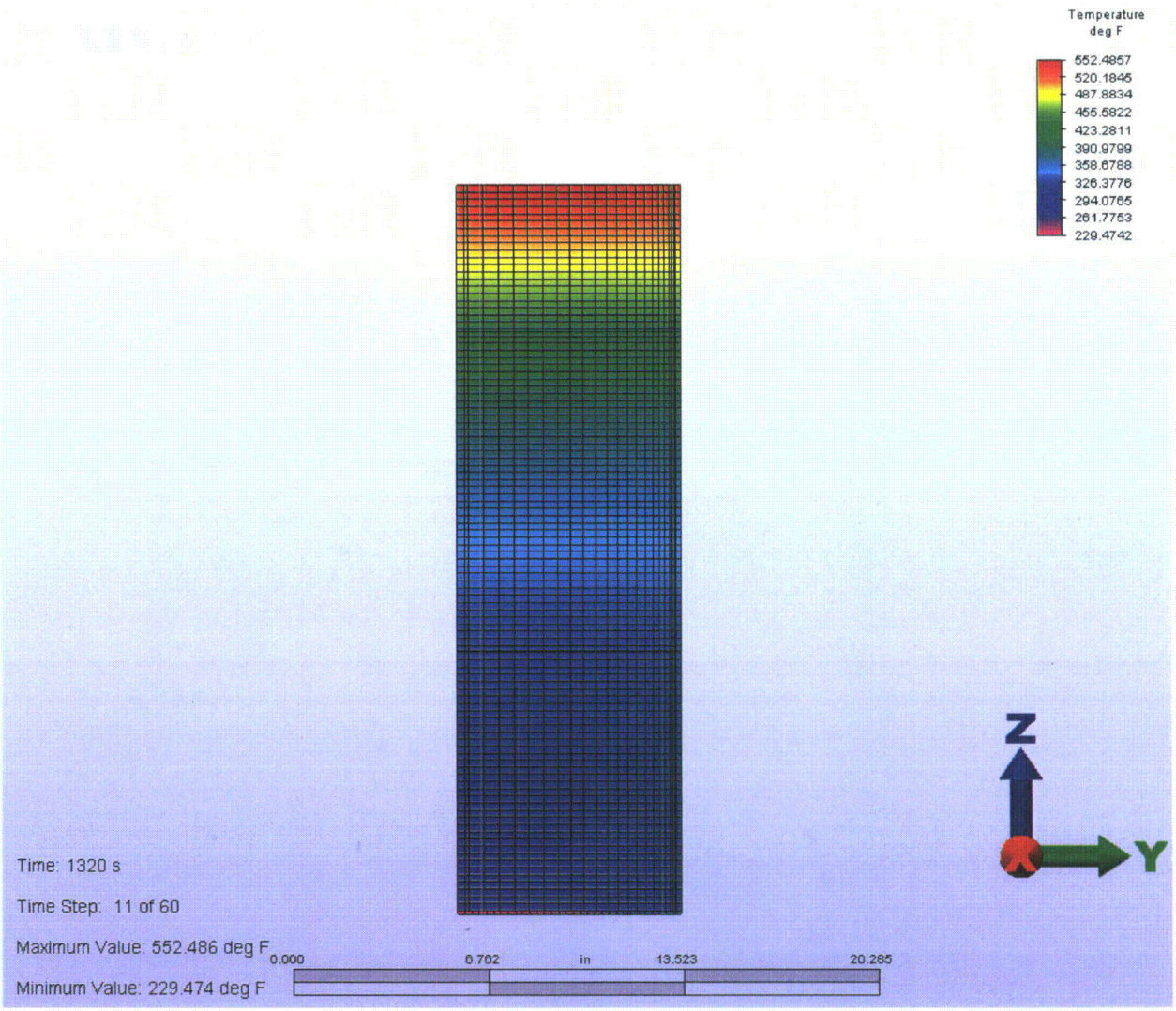


Figure 3-4 Maximum Fire Event Temperature at Cooldown Sequence, 22 minutes after Cessation of Fire, Contents

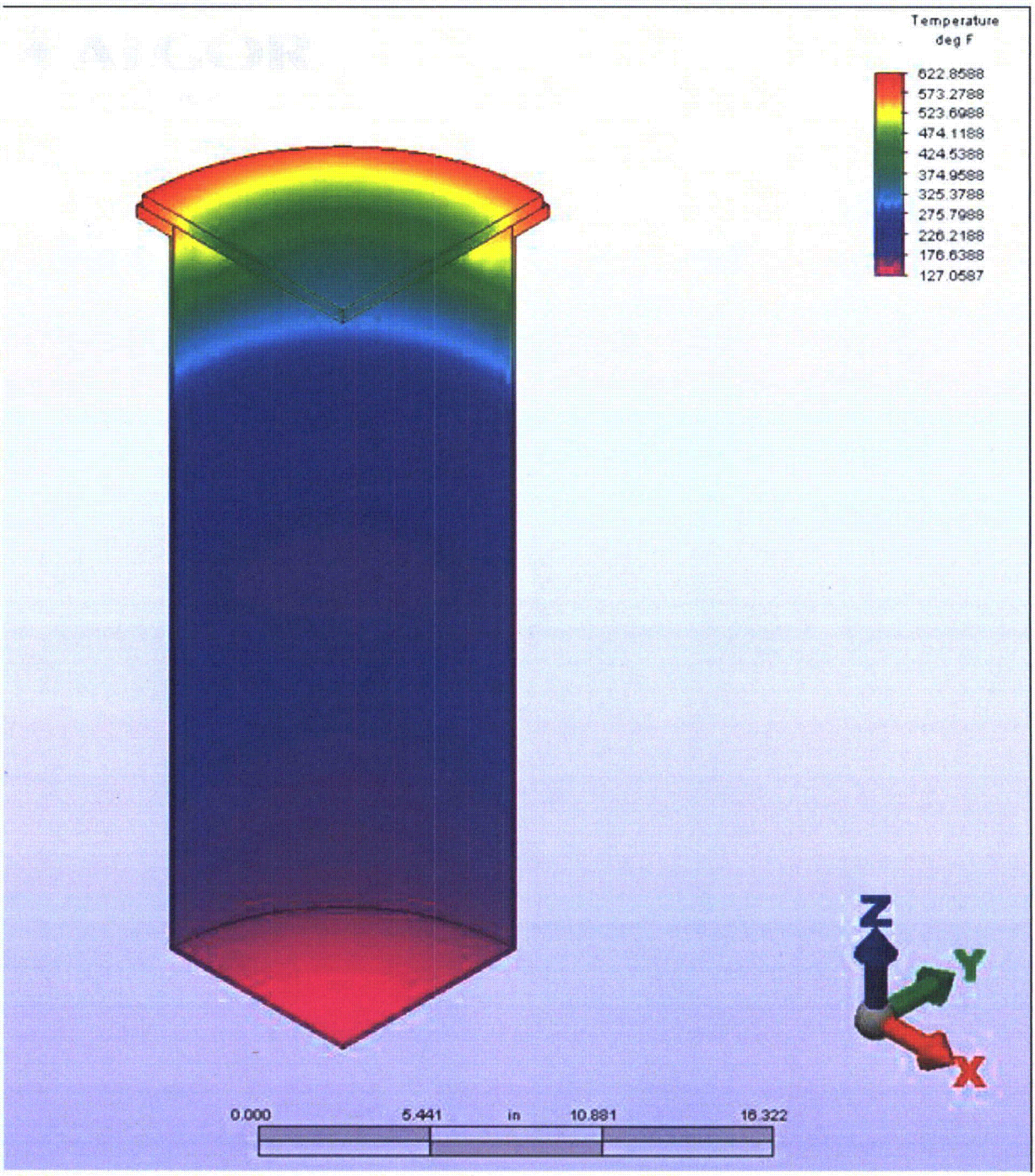


Figure 3-5 Fire Event temperature at 30 minutes, Payload Cavity and Flanges (including polyurethane plug area)

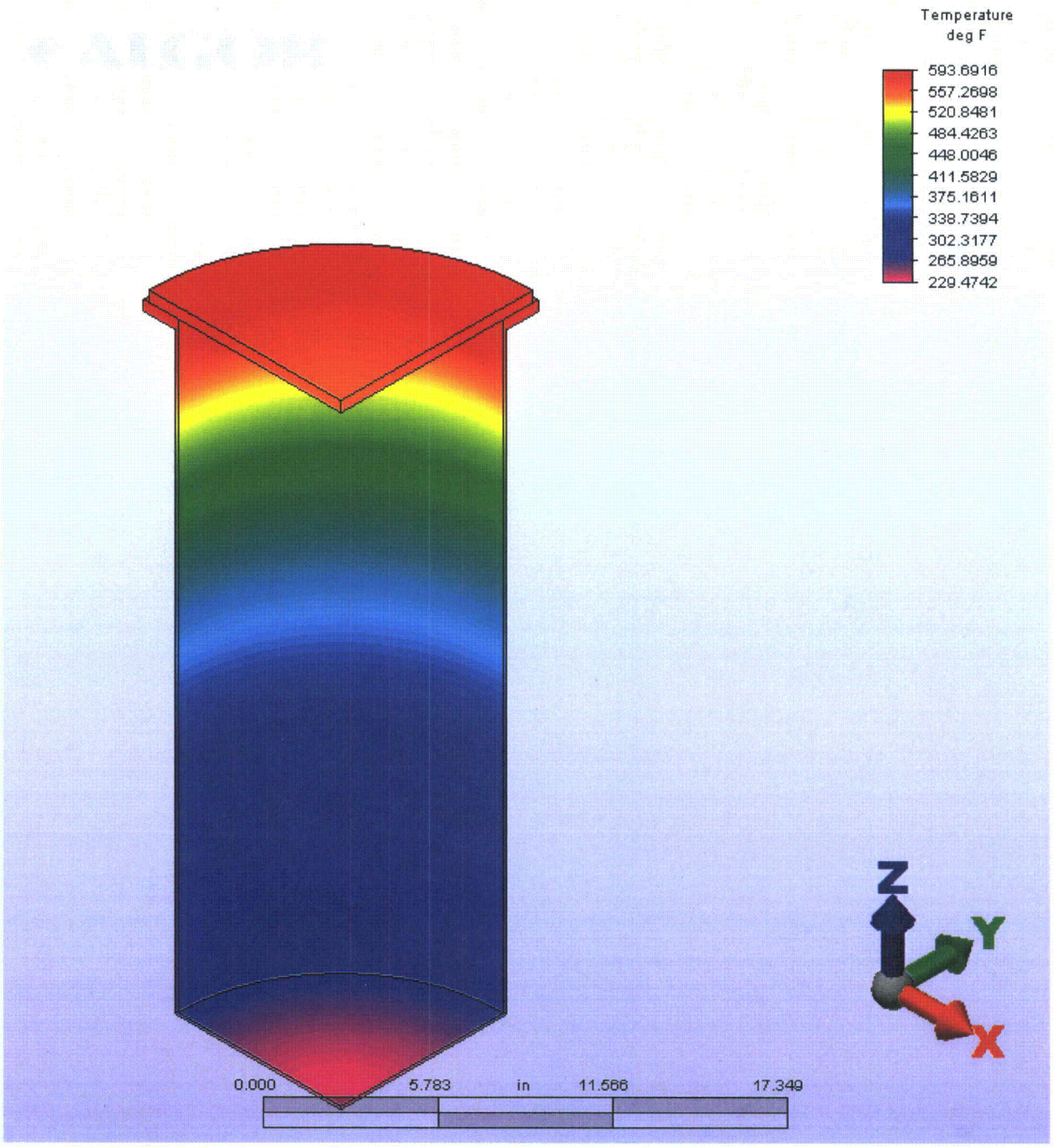


Figure 3-6 Fire Event & Cooldown temperature at 55 total minutes, Payload Cavity and Flanges (including polyurethane plug area)

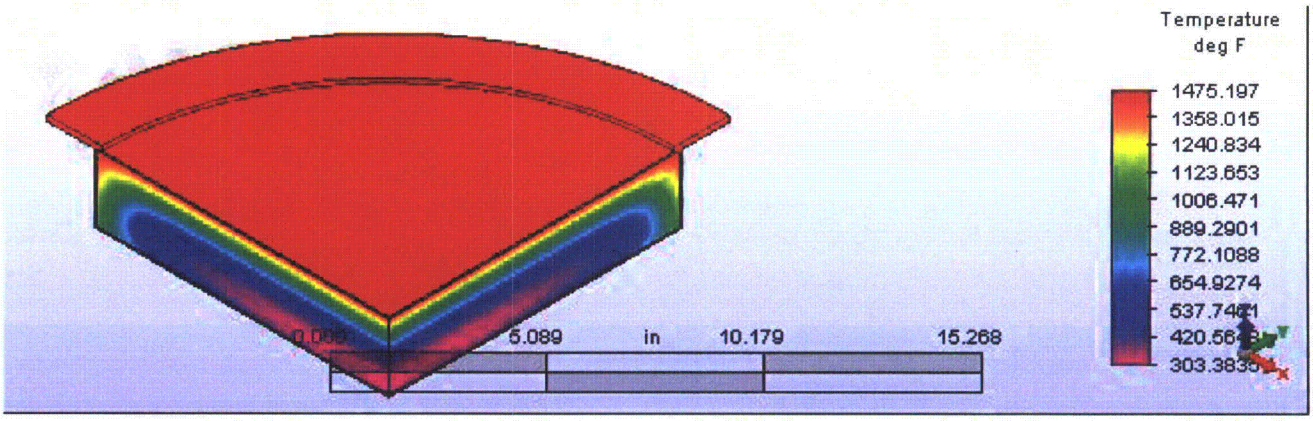


Figure 3-7 Fire Event temperature at 30 minutes, Package Lid

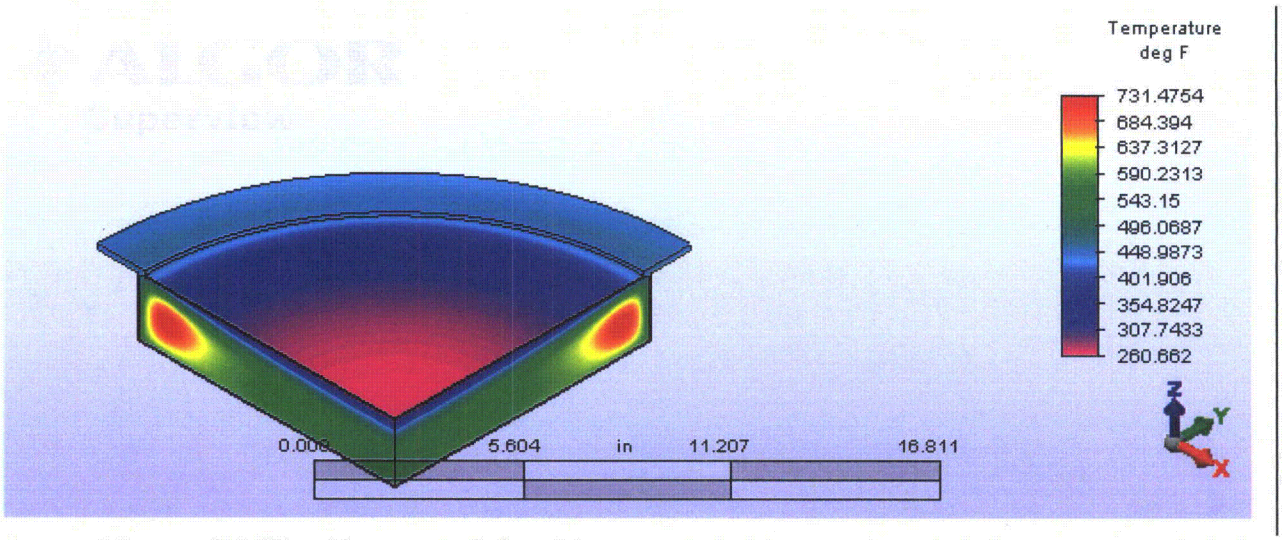


Figure 3-8 Fire Event and Cooldown temperature at 55 total minutes, Package Lid

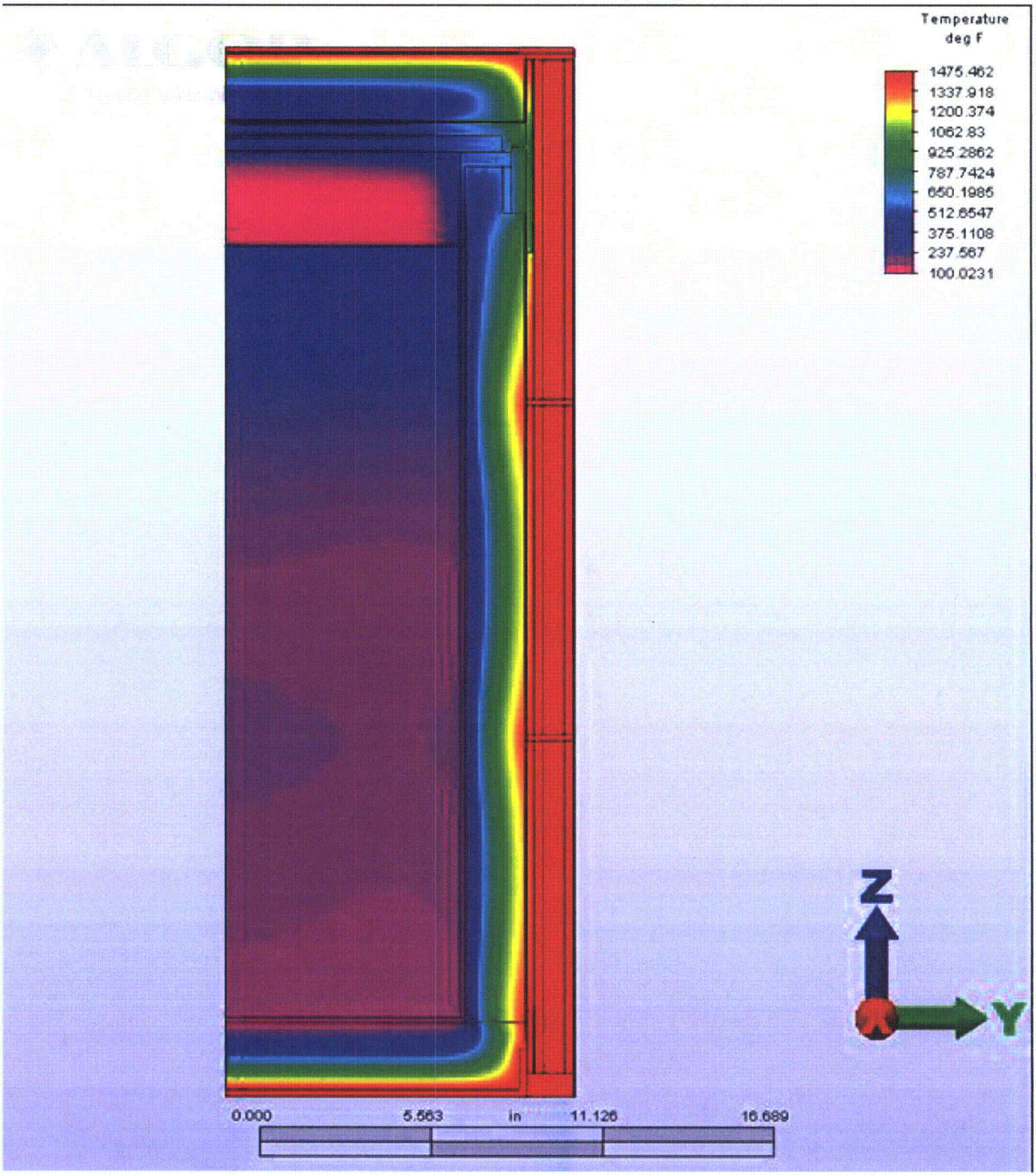


Figure 3-9 Fire Event temperature at 30 minutes, Package side view

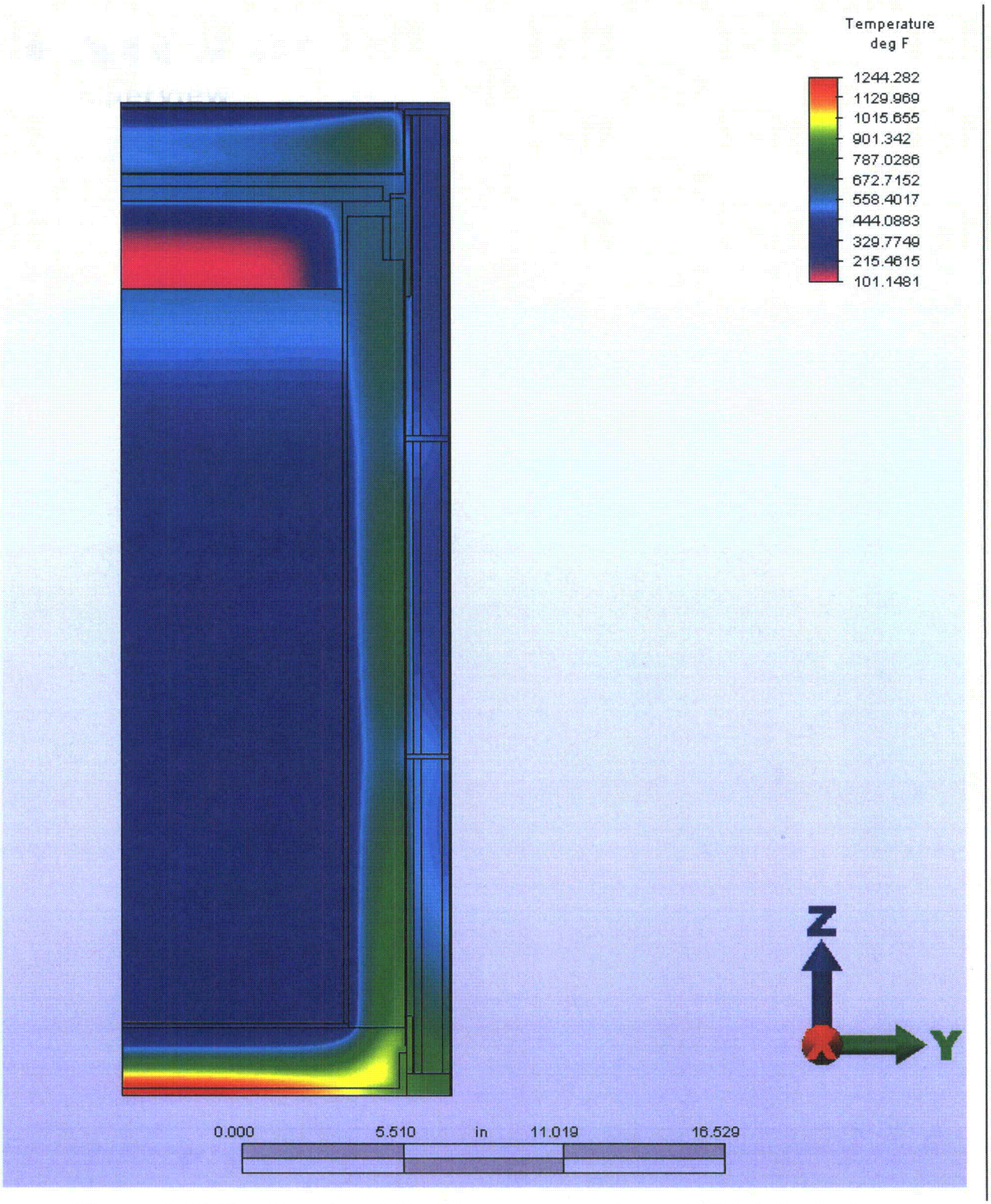


Figure 3-10 Fire Event and Cooldown temperature at 55 total minutes, Package side view

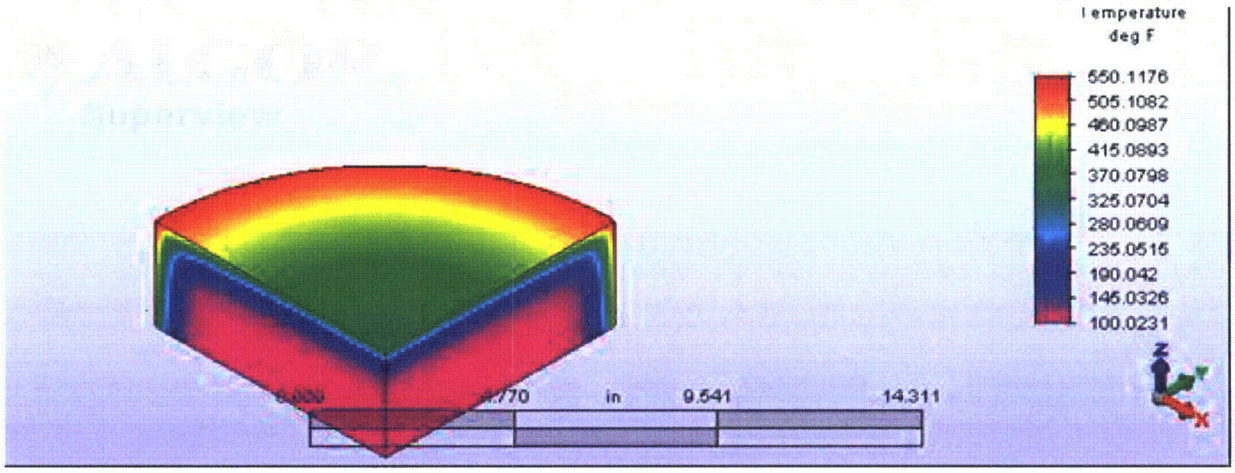


Figure 3-11 Fire Event temperature at 30 minutes, polyurethane plug

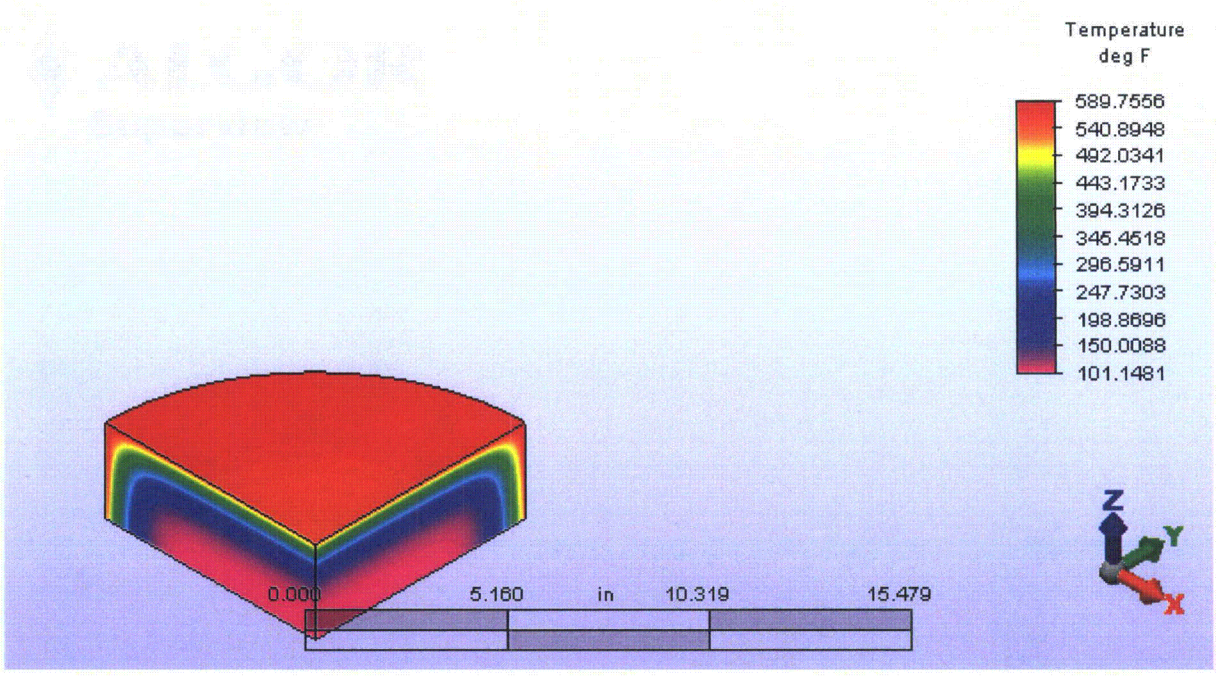


Figure 3-12 Fire Event and Cooldown temperature at 55 total minutes, polyurethane plug

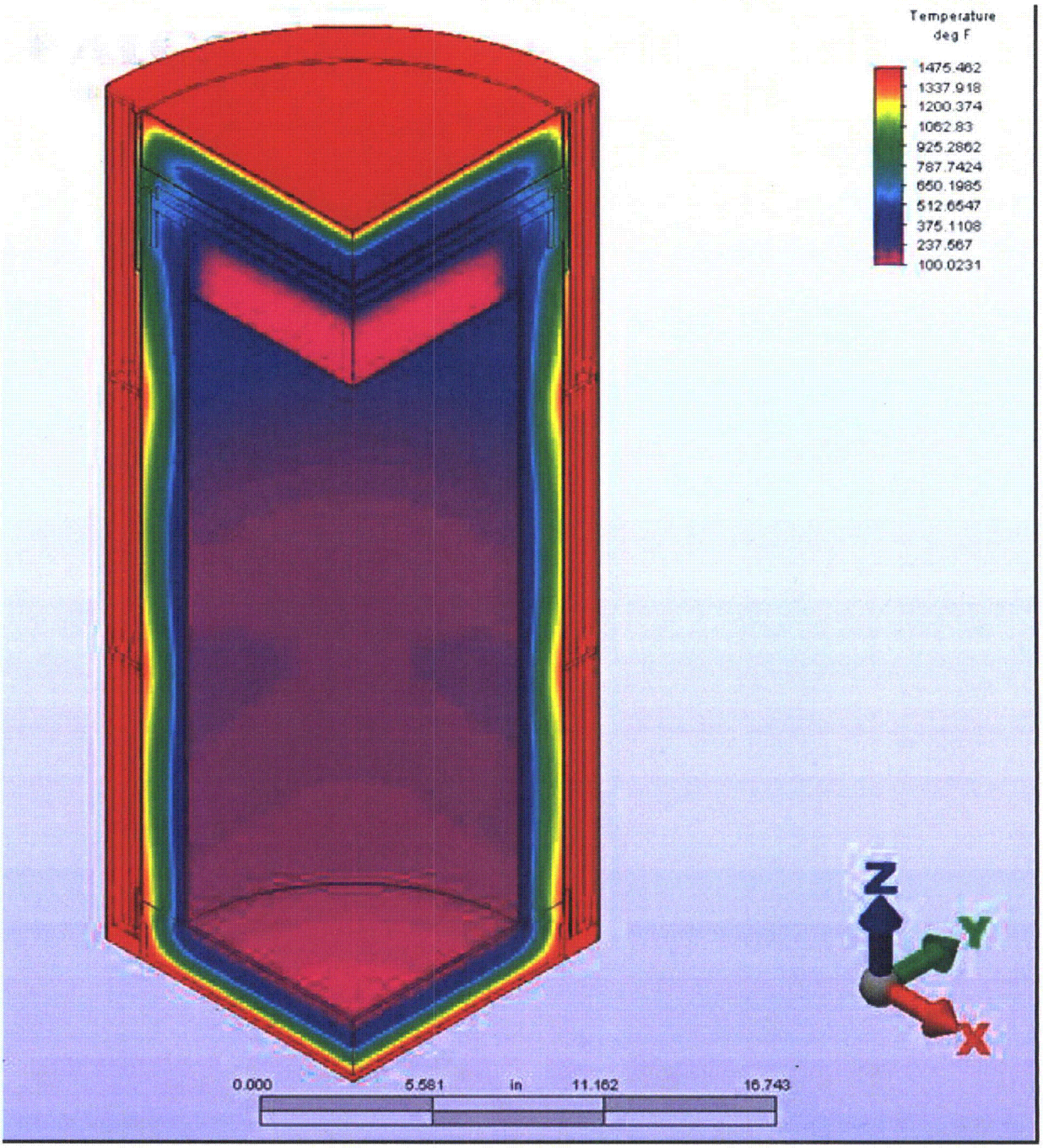


Figure 3-13 Fire Event temperature at 30 minutes, Isometric view of temperature distribution

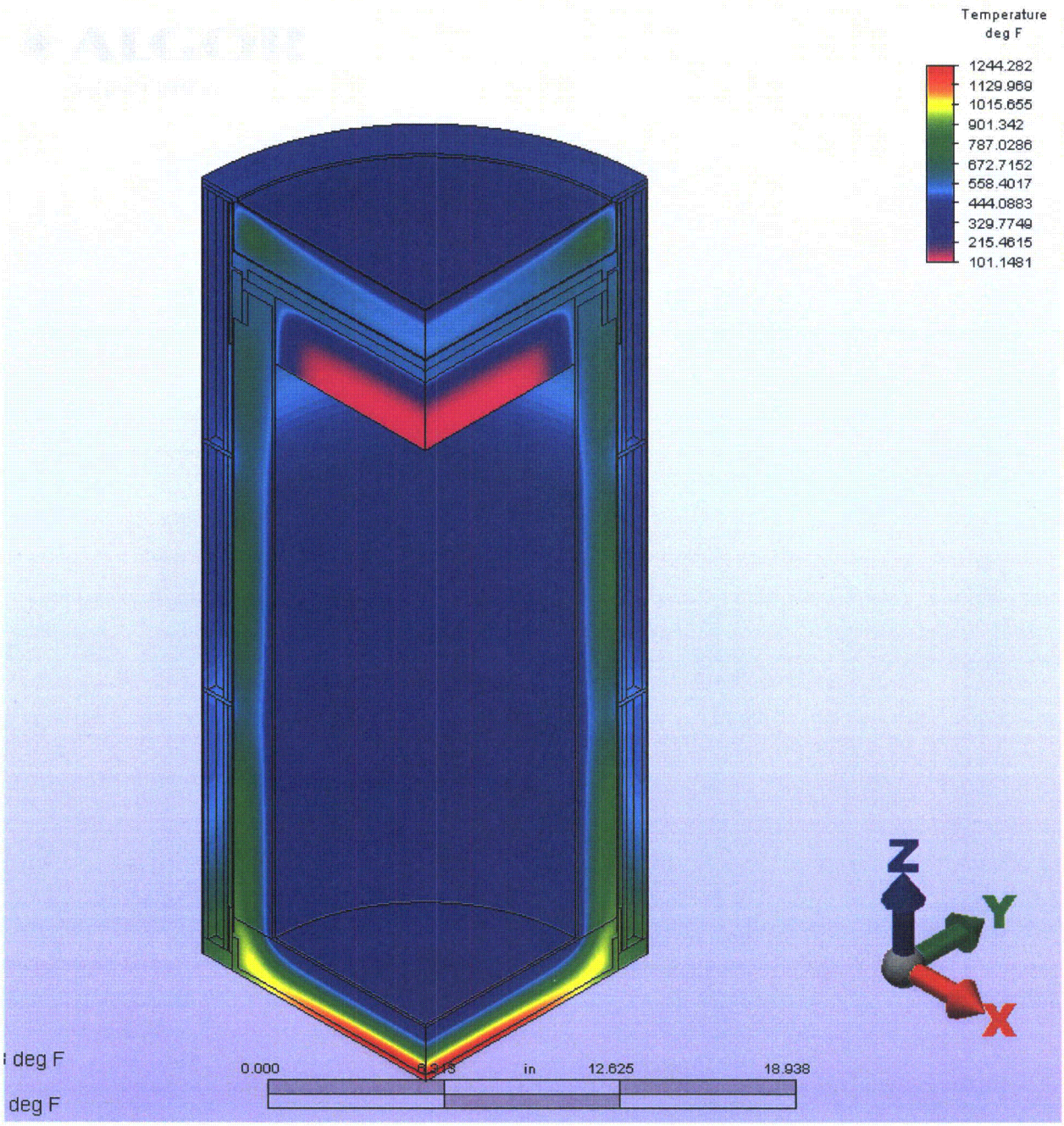


Figure 3-14 Fire Event and Cooldown temperature at 55 total minutes, Isometric view of temperature distribution

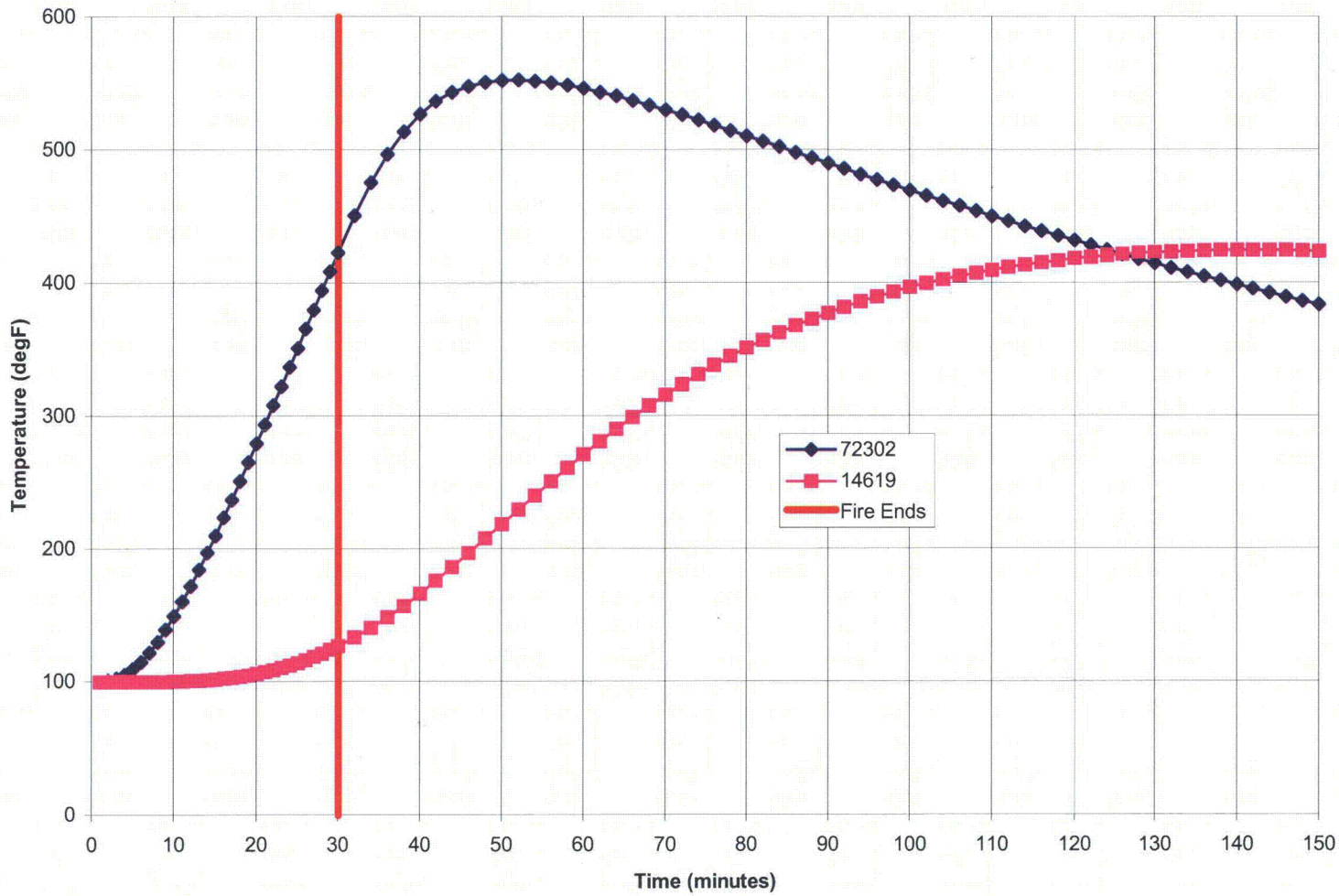


Figure 3-15 Fire Event and Cooldown temperature as a function of Seconds (beginning of cooldown = 0sec) for Payload Cavity Nodes 72302 (at the bottom of the polyurethane insert) and 14619 (at the center of the payload cavity floor part PB)

Appendix 3.5.1 Description of the Thermal Model

In order to evaluate the performance of the Versa-Pac for all conditions of transport, a quarter-symmetric transient finite element analysis (FEA) model was developed using ALGOR Release 18.1. This appendix provides a description of the thermal models.

Both 55-gallon and 110-gallon packages were modeled; the 55-gallon package was found to be bounding in performance and therefore the results for the 110-gallon package are not reported. Also, the package was modeled with and without contents, and the model without contents, even without the decay heat input, was found to be bounding. These results are expected, as can be demonstrated by a simple inspection of the equation of state used in the transient analyses:

$$Q = m\, C_p\, \Delta T$$

Where

Q	is the heat input (fixed by the fire boundary condition),
m	is the mass of the package,
C_p	is the equivalent specific heat of the package, and
ΔT	is the change in temperature of the package.

Since Q is constrained, any increase in m due to the addition or exclusion of contents leads to a lower ΔT. Also, any increase in C_p due to the addition or exclusion of contents leads to a lower ΔT. Thus, exclusion of the contents is expected to produce the highest temperatures on the interior wall of the package. Although Q is slightly higher for the 110-gallon Versa-Pac due to the slightly higher external surface area to which the fire is applied, this is greatly offset by the increased payload capacity and volume of steel and insulation added to the package.

All components were modeled using brick elements. The typical and maximum element side lengths used in the model are 0.25" and 0.79", respectively. With the exception of the air gap between the outer lid and the payload cavity lid, the package is a conduction-only problem. In order to simplify the calculation matrix, the air gap was also reduced to a conduction equivalent condition using the method described in Appendix 3.5.2.

Table 3.5.1.1 provides a comparison of the modeled dimensions versus the nominal package dimensions for the 55-gallon Versa-Pac. Table 3.5.1.2 provides a comparison of the modeled dimensions versus the nominal package dimensions for the 110-gallon Versa-Pac. Table 3.5.1.3 provides the thermal material properties used in the analyses. Table 3.2 lists the conditions analyzed, including the initial conditions and heat loads.

For the fire analysis, the external surface nodes were constrained to a temperature of 1475°F. For both the 55-gallon and 110-gallon versions, the contents was modeled with a decay heat load of 0.022 in-lb_f/s / in^3 and 0.0085 in-lb_f/s / in^3 for the 55-gallon and 110-gallon packages, respectively for a conservative total package heat load of 11.4 W (with the exception of the void case, where the contents is not included in the model). The model was run for 30 time steps, with each time step 60 seconds long. The convergence tolerance was set to 0.000001 for the non-linear analysis.

For the cooldown sequence, natural convection was applied to the external nodes, assuming an ambient temperature of 100°F. The convection coefficients are applied based on the nodal temperature of the external nodes and are updated at each timestep. The convection coefficients are calculated based on the Rayleigh number and free convection coefficients as presented by Reference 1:

$$Ra_L = [g\,\beta\,(T_s - T_\infty)\,L^3]/\nu\alpha$$

Where:

Ra_L is the Rayleigh number based on the characteristic plate length,

g is gravitational acceleration, 9.81 m/s,

β is the volumetric thermal expansion coefficient for air, evaluated at the average film temperature, $(T_s - T_\infty)/2$, and approximated as $1/T_{\text{film average, absolute}}$,

T_s is the surface temperature of the heated plate at the node of interest, °C,

T_∞ is the ambient air temperature, 38°C (100°F),

L is the characteristic length of the heated plate, 0.8128 m (32"),

ν is the kinematic viscosity of air evaluated at the average film temperature, $(T_s - T_\infty)/2$, in m^2/s, and

α is the thermal diffusivity of air evaluated at the average film temperature, $(T_s - T_\infty)/2$, in m^2/s.

Note that for evaluation of the Rayleigh Number the temperatures need not be in absolute units, since the delta is used in the formulation.

The sides of the package are treated as a vertical heated plate:

$$Nu_{L,\,avg} = [0.825 + (0.387\,Ra_L^{1/6})/(1 + (0.492/Pr)^{9/16})^{8/27}]^2$$

Where:

$Nu_{L,\,avg}$ is the average Nusselt number,

Ra_L is the Rayleigh number based on the characteristic plate length, and

Pr is the Prandtl number for air evaluated at the average film temperature, $(T_s - T_\infty)/2$.

Per Reference 1, this correlation is deemed appropriate for vertical cylinders if:

$$D/L \geq 35/Gr^{1/4},$$

Where:

D is the diameter of the cylinder, 0.57 m (22.5") for the 55-gallon Versa-Pac,

L is the height of the cylinder, 0.81 m (32"),

Gr is the Grashof number and is defined as:

$$Gr = [g\,\beta\,(T_s - T_\infty)\,L^3]\,/\,\nu^2$$

For the range of potential package surface temperatures, the correlation is well within the appropriate range for use of the vertical heated plate correlation.

The circular top of the package is treated as a horizontal plate:

$$Nu_{L,\,avg} = 0.54\,Ra_L^{1/4} \quad (10^4 \leq Ra_L \leq 10^7).$$

Per Reference 1, the characteristic length to be used in the Rayleigh number calculation is defined as:

$$L = A_s / P = 0.14 \text{ m}$$

Where:

A_s is the surface area of the plate, $\pi D^2/4$, and

P is the perimeter of the plate, πD.

For the range of potential package surface temperatures and the characteristic length, the correlation is well within the appropriate range for use of the horizontal heated plate correlation.

The natural convection coefficient input to the code is calculated from the Nusselt Number as:

$$h_{avg} = Nu_{L,\,avg}\, k / L,$$

Where:

h_{avg} is the natural convection coefficient for the horizontal or vertical heated plates,

$Nu_{L,\,avg}$ is the average Nusselt Number as defined previously, and

k is the thermal conductivity of air evaluated at the average film temperature, $(T_s - T_\infty)/2$.

For purposes of calculating the convection coefficients, 24 discrete package wall temperatures were selected for evaluation, ranging from 39°C to 810°C. Using an ambient air temperature of 100°F (37.8°C), the convection coefficient was calculated in units of W/m^2K and were then converted to the units used in the Algor code (in-lb_f/s-R-in^2). When the nodal temperature falls between the evaluated points, the Algor code linearly interpolates the convection coefficient.

Table 3.5.1.4 summarizes the material properties of air from Reference 1. Table 3.5.1.5 presents the convection coefficient calculations and the coefficients that were input to the code. For both the 55-gallon and 110-gallon versions, the contents was modeled with a decay heat load of 0.022 in-lbf/s / in^3 and 0.0085 in-lbf/s / in^3 for the 55-gallon and 110-gallon packages, respectively for a conservative total package heat load of 11.4 W (with the exception of the void case, where the contents is not modeled). The cooldown sequence utilized the fire sequence nodal temperatures at the end of the 30 minute fire sequence as the initial temperature of the nodes. Insolation was applied to the exterior surface nodes at the rate specified by regulation (see Table 3.2) for 12-hours on and 12-hours off. The model was run for 120 time steps, with each time step 60 seconds long (in order to conserve space, the results were recorded at every third time step only). The convergence tolerance was set to 0.000001 for the non-linear analysis. Since the peak temperatures were reached within the first hour of the cooldown, the results bound the remainder of the cooldown to equilibrium NCT conditions.

The 55-gallon model is illustrated in Figures 3.5.1-1 through 3.5.1-14. The 110-gallon model is illustrated in Figure 3.5.1-15. These same models were used for all NCT and HAC fire and cooldown sequences.

Reference 1: Incropera, Frank P. and David P. DeWitt, *Fundamentals of Heat and Mass Transfer Third Edition, John Wiley & Sons*, New York, 1981, pp. 530-554, A15.

Table 3.5.1- 1 Comparison of Modeled Components versus Nominal Package Components for the 55-gallon Versa-Pac

Model Part #	Drawing component ID	Material of construction	Modeled material (see Table 3.5.1-2)	Component nominal thickness	Modeled component thickness
1	PE & FD	A36	Isotropic steel	1 / 4"	0.250"
2	PF	A36	Isotropic steel	3 / 4"	0.750"
3	FA	A36	Isotropic steel	3/16"	0.188"
4	SA & FA	A1011	Isotropic steel	16 ga.	0.060"
5	FB	A36	Isotropic steel	3/16"	0.188"
9	FC	A1011	Isotropic steel	16 ga.	0.060"
10	PG	A36	Isotropic steel	3/16"	0.188"
11	PB	A1011	Isotropic steel	10 ga.	0.140"
12	PI	A36	Isotropic steel	3/16"	0.188"
13	PA & PH	A1011 & A36	Isotropic steel	10 ga. & 1/4"	0.140" & 0.500"[1]
14	PC, DL, SB, SC	A1011	Isotropic steel	10 ga., 16 ga., 16 ga. & 16 ga.	0.140", 0.060", 0.060" & 0.060"
15	FK	A36	Isotropic steel	¼" x 1½" tall	0.250" x 1.50" tall
16, 17, 18	IA	Alumina silica insulation	Temperature dependent isotropic alumina silica	1.5"	1.25"
19	IB	6pcf polyurethane	6pcf polyurethane	2 1/8"	2.125"
24	IA	Alumina silica insulation	Temperature dependent isotropic alumina silica	2"	1.94"
25	IC	6pcf polyurethane	6pcf polyurethane	2 3/16"	2.188"
26, 27, 28, 29, 30, 31	TB	A500 GR.B	Isotropic steel	1¼" sq x $^3/_{16}$" x ~32" tall, volume=25.5 in^3 each	~1.18" sq x 0.2125", ~32" tall, volume = 26.3 in^3 each
62	PolyU insert	10 pcf polyurethane	9.8 pcf polyurethane	3"	3.00"
71	PI	A36	Isotropic steel	3/16"	0.188"
79	IE & IF	Fiberglass	Fiberglass	0.5"	0.500"
96	PD	A36	Isotropic steel	½"	0.500"
104	N/A	N/A	Air	0.5" thick at lid	0.44" thick at lid
115	BB	A36	Isotropic steel	1¼" x 1¼" x 1½"	1.25" x 1.25" x 1.5"
120	N/A	N/A	CONTENTS	15" diameter x 24.06" tall	15.22" diameter x 25.24" tall

[1] Although this component thickness is modeled at twice the actual component thickness, this is considered to be conservative, since it provides an enhanced pathway for heat conduction to the interior of the package.

Table 3.5.1- 2 Comparison of Modeled Components versus Nominal Package Components for the 110-gallon Versa-Pac

Model Part #	Drawing component ID	Material of construction	Modeled material (see Table 3.5.1-2)	Component nominal thickness	Modeled component thickness
1	PE & FD	A36	Isotropic steel	1 / 4"	0.250"
2	PF	A36	Isotropic steel	3 / 4"	0.750"
3	FA	A36	Isotropic steel	3/16"	0.188"
4	SA & FA	A1011	Isotropic steel	16 ga.	0.060"
5	FB	A36	Isotropic steel	3/16"	0.188"
9	FC	A1011	Isotropic steel	16 ga.	0.060"
10	PG	A36	Isotropic steel	3/16"	0.188"
11	PB	A1011	Isotropic steel	10 ga.	0.140"
12	PI	A36	Isotropic steel	3/16"	0.188"
13	PA & PH	A1011 & A36	Isotropic steel	10 ga. & 1/4"	0.140" & 0.500"[2]
14	PC, DL, SB, SC	A1011	Isotropic steel	10 ga., 16 ga., 16 ga. & 16 ga.	0.140", 0.060", 0.060" & 0.060"
15	FK	A36	Isotropic steel	¼" x 1½" tall	0.250" x 1.50" tall
16, 17, 18	IA	Alumina silica insulation	Temperature dependent isotropic alumina silica	1.5"	1.25"
19	IB	6pcf polyurethane	6pcf polyurethane	3 ½"	2.125"
24	IA	Alumina silica insulation	Temperature dependent isotropic alumina silica	2 ½"	1.94"
25	IC	6pcf polyurethane	6pcf polyurethane	3 ¼"	2.188"
26, 27, 28, 29, 30, 31	TB	A500 GR.B	Isotropic steel	1¼" sq x $^3/_{16}$" x ~40 $^3/_4$" tall, volume=32.5 in^3 each	~1.18" sq x 0.2125" x ~40 $^3/_4$" tall, volume = 33.5 in^3 each
62	PolyU insert	10 pcf polyurethane	9.8 pcf polyurethane	3"	3.00"
71	PI	A36	Isotropic steel	3/16"	0.188"
79	IE & IF	Fiberglass	Fiberglass	0.5"	0.500"
96	PD	A36	Isotropic steel	½"	0.500"
104	N/A	N/A	Air	0.5" thick at lid	0.44" thick at lid
115, 116 & 117	BB	A36	Isotropic steel	1¼" x 1¼" x 1½"	1.25" x 1.25" x 1.5"
120	N/A	N/A	CONTENTS	21" diameter x 32.25" tall	NA

[2] Although this component thickness is modeled at twice the actual component thickness, this is considered to be conservative, since it provides an enhanced pathway for heat conduction to the interior of the package.

Table 3.5.1- 3 Thermal Material Properties for the Versa-Pac

Material	Density (lb_f-s^2/in)/(in^3)	Thermal Conductivity (in-lb_f)/(s-in-8F)	Specific Heat (in-lb_f)/(lb_f s^2/in)- 8F	Heat Generation Rate (in-lb_f)/(s-in^3)	Source
Isotropic steel	7.35E-4	5.84	4.1849E5	N/A	General industry data (matweb, ALGOR material library)
8 pcf Temperature dependent isotropic alumina silica	1.199E-5	8F TC 27 0.007926 500 0.007926 1000 0.016 1500 0.026 1800 0.037 2000 0.048	9.374E5	N/A	Century Industries SOP6.12; general industry data (matweb, Cer-wool, Fiberfrax)
Fiberglass – Extren525 Isophthalic polyester resin	1.606E-4	0.072	1.009E6	N/A	Century Industries SOP6.13, also "Typical Properties – FRP Structural Shapes", Enduro Systems, Inc., www.endurocomposites.com.
Isotropic 6.0 pcf Polyurethane	8.993E-6	3.386E-3	1.273E6	N/A	Century Industries SOP6.11, also General industry data (matweb). Not used in model since alumina silica is bounding
Isotropic 9.8 pcf Polyurethane	1.469E-5	5.026E-3	1.576E6	N/A	Century Industries SOP6.11, also General industry data (matweb).
Air, conduction + radiation	1.087E-7	L=0.44" $8F_{average}$ TC -40 0.017 22.4 0.017 202.4 0.040 382.4 0.083 562.4 0.147 742.4 0.237 922.4 0.357 1102 0.513 1282 0.709 1462 0.949 1642 1.239	8.671E5	N/A	see Appendix 3.5.2
Contents 1, wood	8.094E-5	0.022	3.358E5	0.022 (55-gal) 0.0085 (110 gal)	General industry data (matweb)
Contents 2, void	N/A	N/A	N/A	N/A	N/A
Contents 3, solid steel	7.35E-4	5.84	4.1849E5	0.022 (55-gal) 0.0085 (110 gal)	General industry data (matweb, ALGOR material library)

Table 3.5.1- 4 Material Properties for Air used to evaluate Natural Convection Coefficients

All values taken from Reference 1.

Air Temperature (K)	$\nu * 10^6$ m^2/s	$k * 10^3$ W/m-K	$\alpha * 10^6$ m^2/s	Pr
300	15.89	26.3	22.5	0.707
350	20.92	30.0	29.9	0.700
400	26.41	33.8	38.3	0.690
450	32.39	37.3	47.2	0.686
500	38.79	40.7	56.7	0.684
550	45.57	43.9	66.7	0.683
600	52.69	46.9	76.9	0.685
650	60.21	49.7	87.3	0.690
700	68.10	52.4	98.0	0.695

Table 3.5.1- 5 Natural Convection Coefficients for the Versa-Pac Cooldown Sequence

Film Temperature (K) (note 2)	Film Temperature (C) (note 2)	Film Temperature (F) (note 2)	v (10^6 m^2/s) (note 1 & 2)	K (10^3 W/m-K) (note 1 & 2)	α (10^6 m^2/s) (note 1 &2)	Pr (note 1 &2)	Nodal Wall temperature (F)	Nodal Wall temperature (C)	Ra vertical	Ra Horizontal	Nu Vertical (note 3)	Nu Horizontal (note 4)	h vertical, (W/m^2-K)	h horizontal, (W/m^2-K)	h vertical (in-lb_f/s-R-in^2)	h horizontal (in-lb_f/s-R-in^2)
300	27.0	80.6	15.89	26.3	22.5	0.707	61.2	16.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
311	37.9	100.2	16.99	27.1	24.1	0.705	100.4	38.0	9.23E+06	4.71E+04	30.48	7.96	1.02	1.54	3.2245E-03	4.8868E-03
312	38.9	102.0	17.09	27.2	24.3	0.705	104.0	40.0	9.05E+07	4.63E+05	59.23	14.08	1.98	2.73	6.2827E-03	8.6728E-03
317	43.9	111.0	17.59	27.5	25.0	0.705	122.0	50.0	4.62E+08	2.36E+06	96.82	21.17	3.28	4.17	1.0409E-02	1.3212E-02
322	48.9	120.0	18.09	27.9	25.7	0.704	140.0	60.0	7.81E+08	3.99E+06	113.70	24.13	3.91	4.81	1.2388E-02	1.5266E-02
327	53.9	129.0	18.59	28.3	26.5	0.703	158.0	70.0	1.05E+09	5.39E+06	124.70	26.01	4.34	5.26	1.3768E-02	1.6675E-02
332	58.9	138.0	19.10	28.7	27.2	0.703	176.0	80.0	1.29E+09	6.58E+06	132.67	27.35	4.68	5.60	1.4839E-02	1.7763E-02
337	63.9	147.0	19.60	29.0	28.0	0.702	194.0	90.0	1.49E+09	7.61E+06	138.74	28.36	4.96	5.88	1.5718E-02	1.8655E-02
342	68.9	156.0	20.10	29.4	28.7	0.701	212.0	100.0	1.66E+09	8.49E+06	143.49	29.15	5.19	6.12	1.6463E-02	1.9415E-02
350	77.0	170.6	20.92	30.0	29.9	0.700	241.2	116.2	1.89E+09	9.65E+06	149.27	30.09	5.51	6.45	1.7476E-02	2.0455E-02
392	118.9	246.0	25.52	33.2	36.9	0.692	392.0	200.0	2.31E+09	1.18E+07	158.76	31.66 (note 5)	6.48	7.51	2.0559E-02	2.3806E-02
400	127.0	260.6	26.41	33.8	38.3	0.690	421.2	216.2	2.32E+09	1.19E+07	158.92	31.70 (note 5)	6.61	7.65	2.0962E-02	2.4274E-02
442	168.9	336.0	31.42	36.7	45.8	0.687	572.0	300.0	2.17E+09	1.11E+07	155.57	31.18 (note 5)	7.03	8.18	2.2300E-02	2.5947E-02
450	177.0	350.6	32.39	37.3	47.2	0.686	601.2	316.2	2.13E+09	1.09E+07	154.60	31.02 (note 5)	7.09	8.27	2.2504E-02	2.6219E-02
492	218.9	426.0	37.75	40.1	55.2	0.684	752.0	400.0	1.86E+09	9.52E+06	148.19	29.99	7.32	8.60	2.3219E-02	2.7285E-02
500	227.0	440.6	38.79	40.7	56.7	0.684	781.2	416.2	1.81E+09	9.26E+06	146.93	29.79	7.36	8.66	2.3338E-02	2.7472E-02
542	268.9	516.0	44.47	43.4	65.1	0.683	932.0	500.0	1.55E+09	7.93E+06	140.01	28.66	7.47	8.88	2.3703E-02	2.8169E-02
550	277.0	530.6	45.57	43.9	66.7	0.683	961.2	516.2	1.51E+09	7.70E+06	138.73	28.45	7.49	8.92	2.3768E-02	2.8297E-02
592	318.9	606.0	51.53	46.4	75.2	0.685	1112.0	600.0	1.29E+09	6.59E+06	132.25	27.36	7.55	9.07	2.3955E-02	2.8776E-02
600	327.0	620.6	52.69	46.9	76.9	0.685	1141.2	616.2	1.25E+09	6.40E+06	131.08	27.17	7.56	9.10	2.3991E-02	2.8867E-02
642	368.9	696.0	58.99	49.2	85.6	0.689	1292.0	700.0	1.08E+09	5.50E+06	125.15	26.15	7.58	9.20	2.4052E-02	2.9177E-02
650	377.0	710.6	60.21	49.7	87.3	0.690	1321.2	716.2	1.05E+09	5.35E+06	124.08	25.96	7.59	9.22	2.4066E-02	2.9238E-02

Film Temperature (K) (note 2)	Film Temperature (C) (note 2)	Film Temperature (F) (note 2)	v (10^6 m^2/s) (note 1 & 2)	K (10^3 W/m-K) (note 1 & 2)	α (10^6 m^2/s) (note 1 &2)	Pr (note 1 &2)	Nodal Wall temperature (F)	Nodal Wall temperature (C)	Ra vertical	Ra Horizontal	Nu Vertical (note 3)	Nu Horizontal (note 4)	h vertical, (W/m^2-K)	h horizontal, (W/m^2-K)	h vertical (in-lb_f/s-R-in^2)	h horizontal (in-lb_f/s-R-in^2)
692	418.9	786.0	66.82	52.0	96.3	0.694	1472.0	800.0	9.02E+08	4.61E+06	118.65	25.02	7.59	9.29	2.4060E-02	2.9459E-02
697	423.9	795.0	67.61	52.2	97.3	0.695	1490.0	810.0	8.87E+08	4.53E+06	118.04	24.92	7.59	9.30	2.4061E-02	2.9487E-02
700	427.0	800.6	68.10	52.4	98.0	0.695	1501.2	816.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Notes on Table 3.5.1-5:

1. Air material properties are taken from Reference 1 as presented by Table 3.5.1-4. For temperatures between the values provided by the Reference, the material properties are linearly interpolated.
2. The material property values presented are for the air film temperature, which is assumed to be the average of the wall temperature and ambient (1008F≈37.88C≈310.98K).
3. Per Reference 1, the correlation is valid over all ranges of Rayleigh numbers.
4. Per Reference 1, the correlation is valid over a range of Rayleigh numbers from 10^4 to 10^7.
5. Although these Rayleigh numbers are slightly out of range of the correlation, they are conservatively lower than that calculated using the correlation provided by Reference 1 applicable at higher Rayleigh numbers and so is considered acceptable for use.

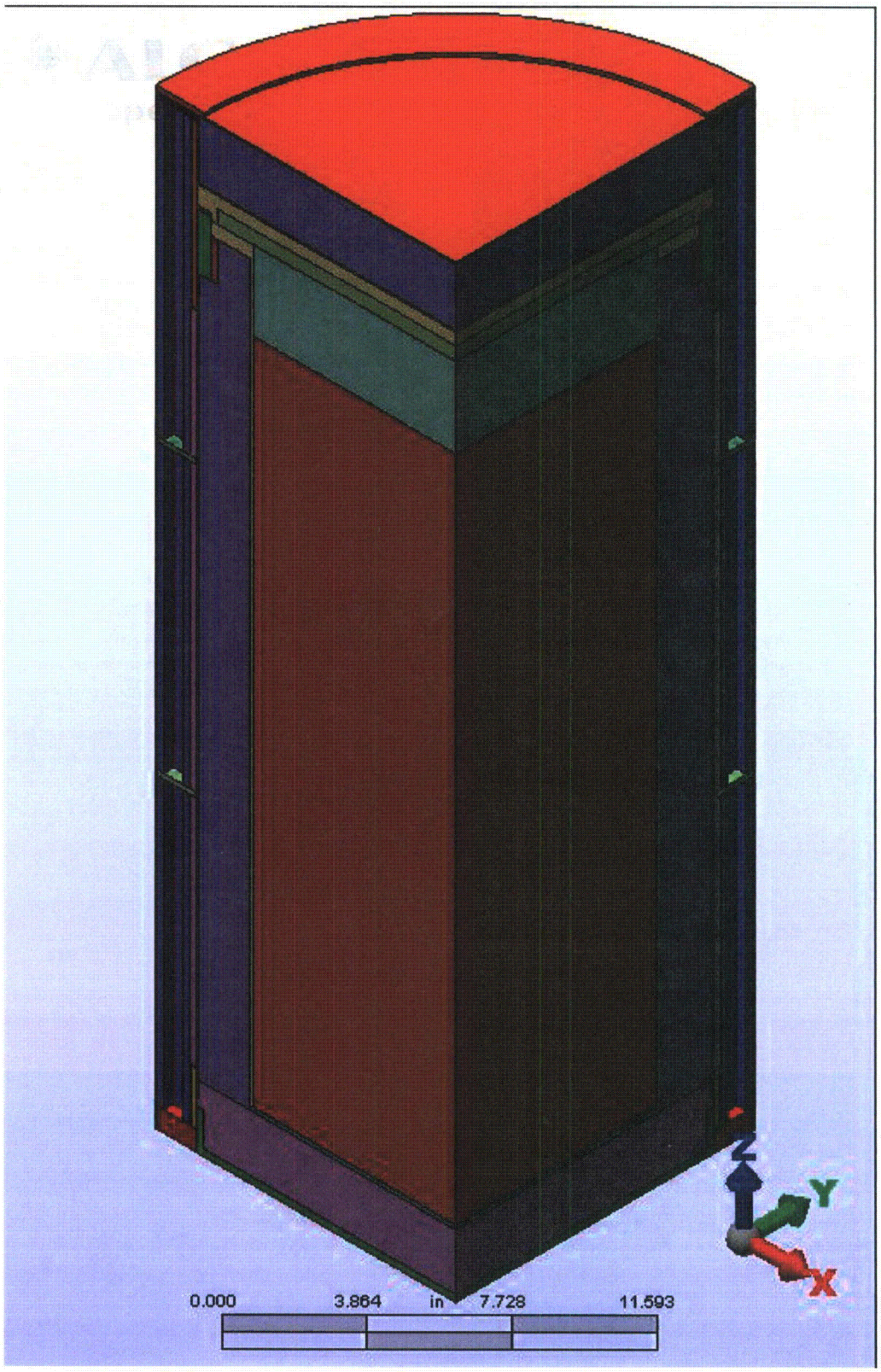


Figure 3.5.1- 1 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, all parts shown

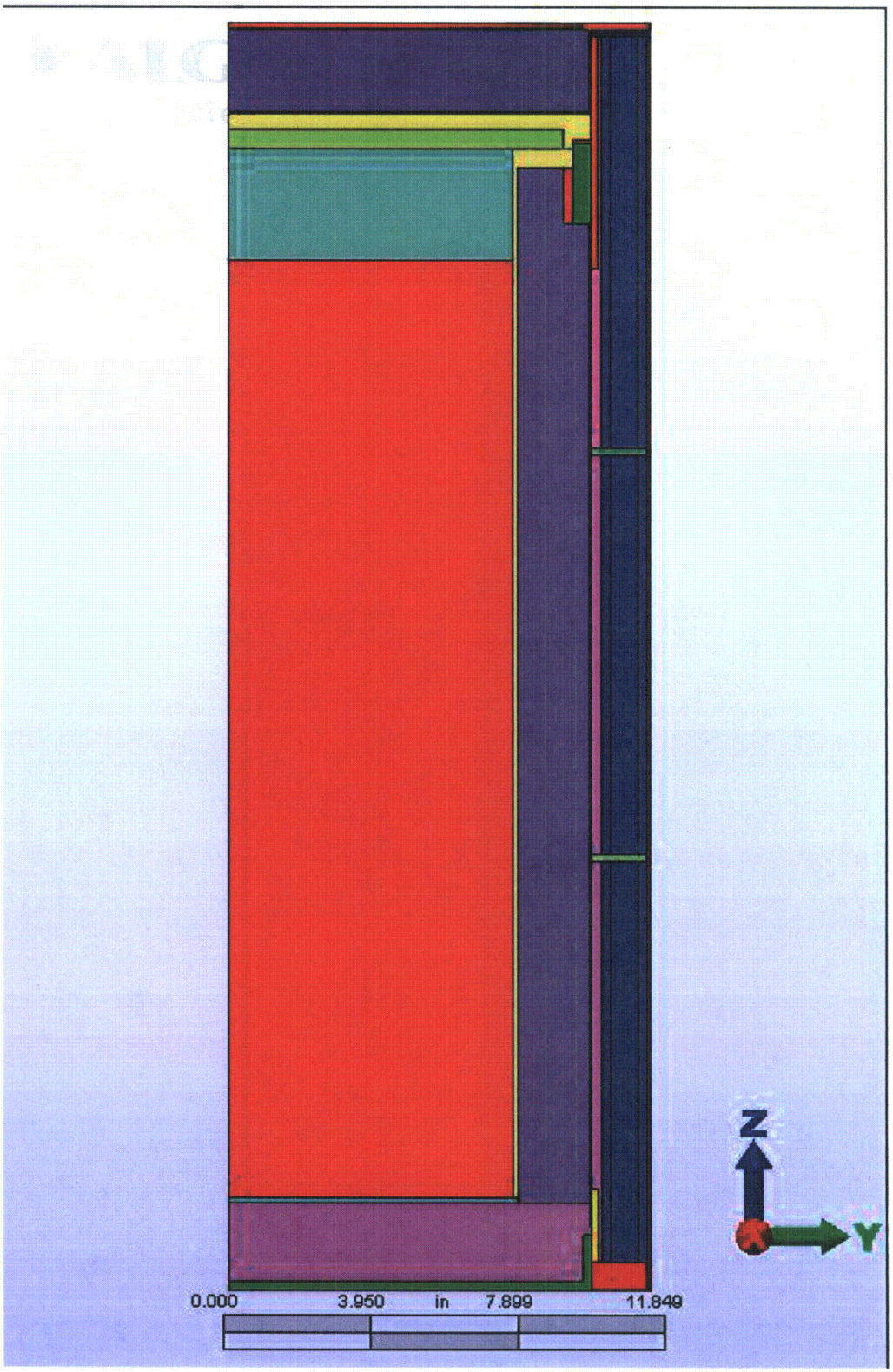


Figure 3.5.1- 2 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, all parts shown, side view

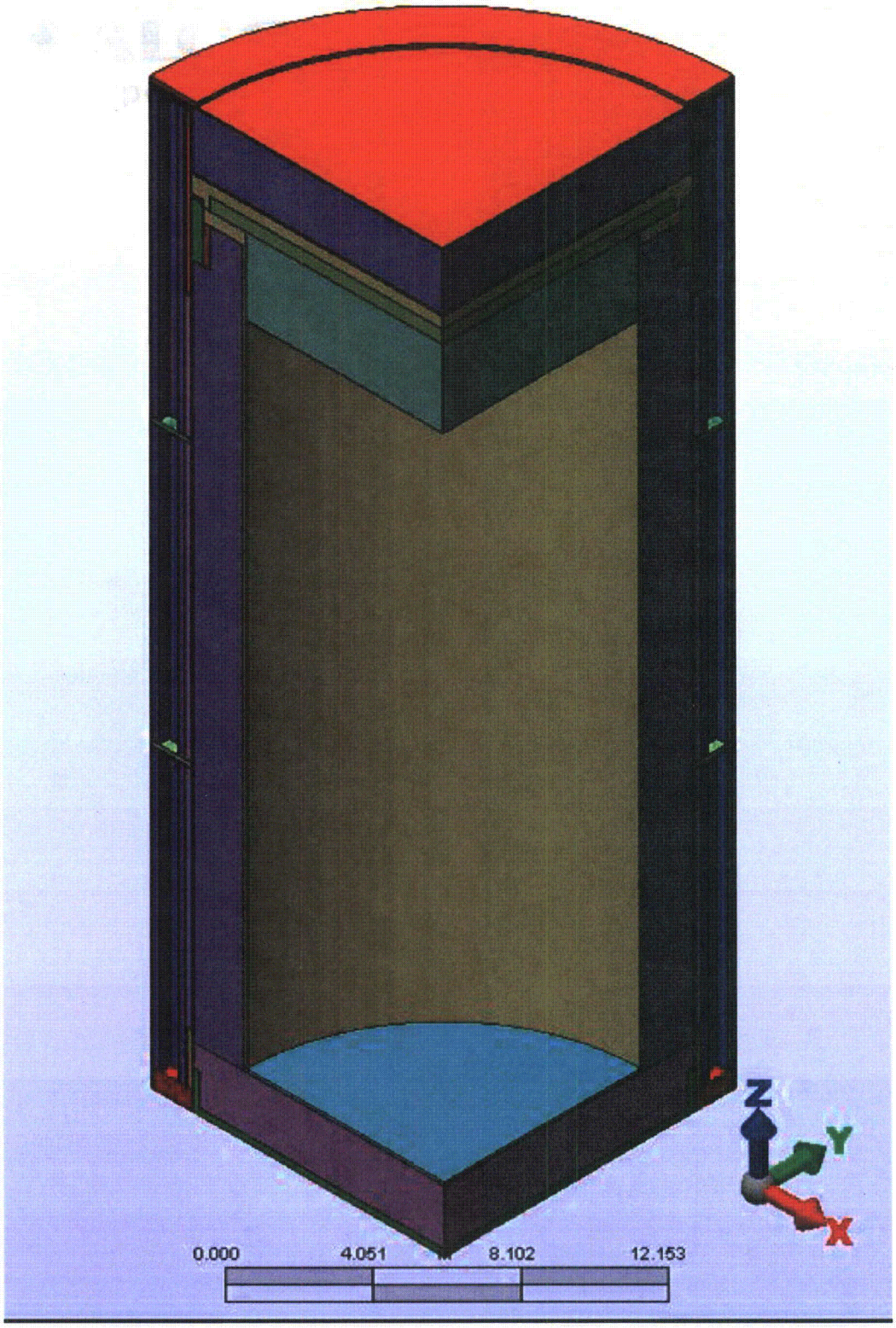


Figure 3.5.1- 3 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, contents not shown

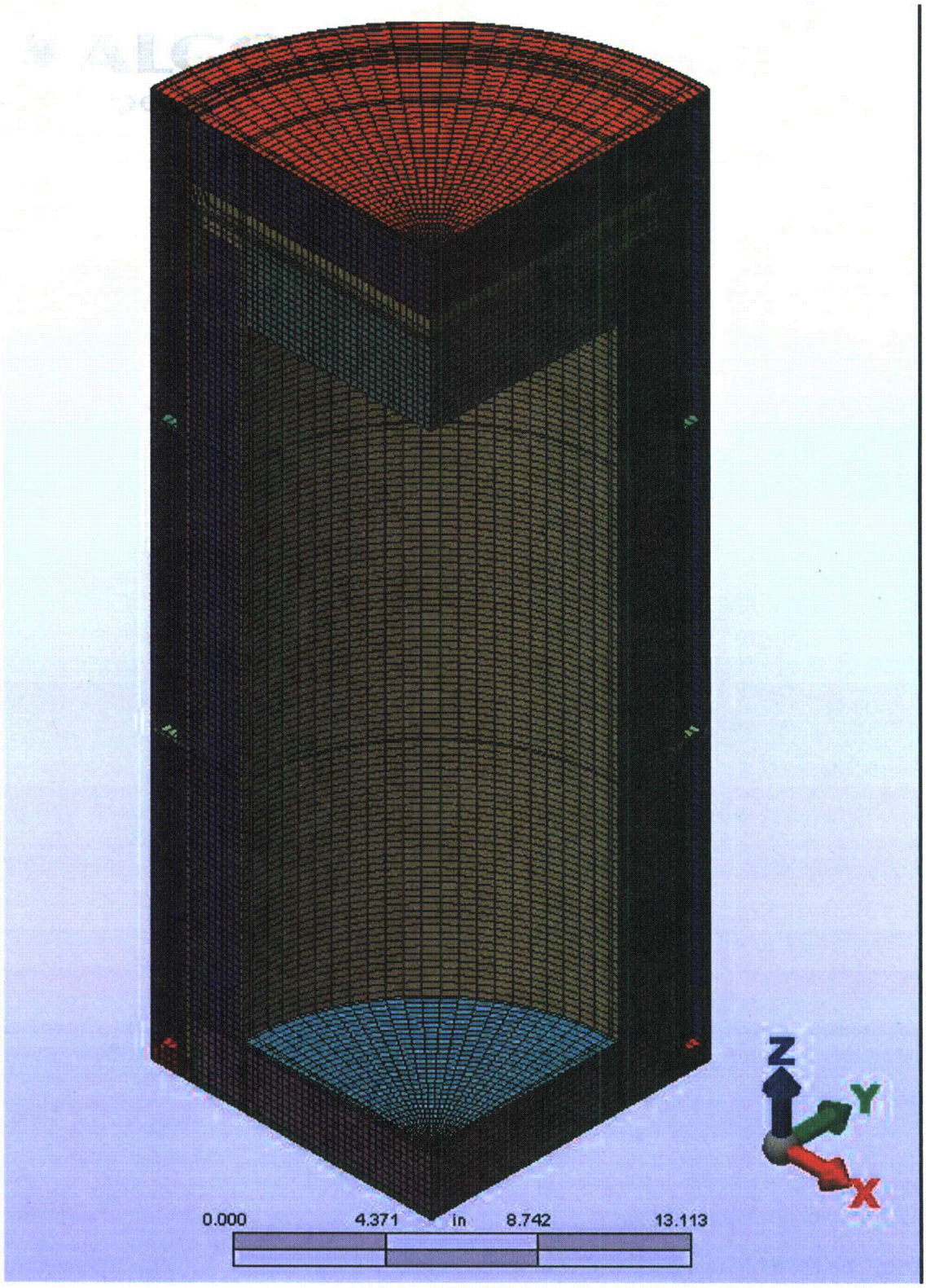


Figure 3.5.1- 4 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, contents not shown, mesh view

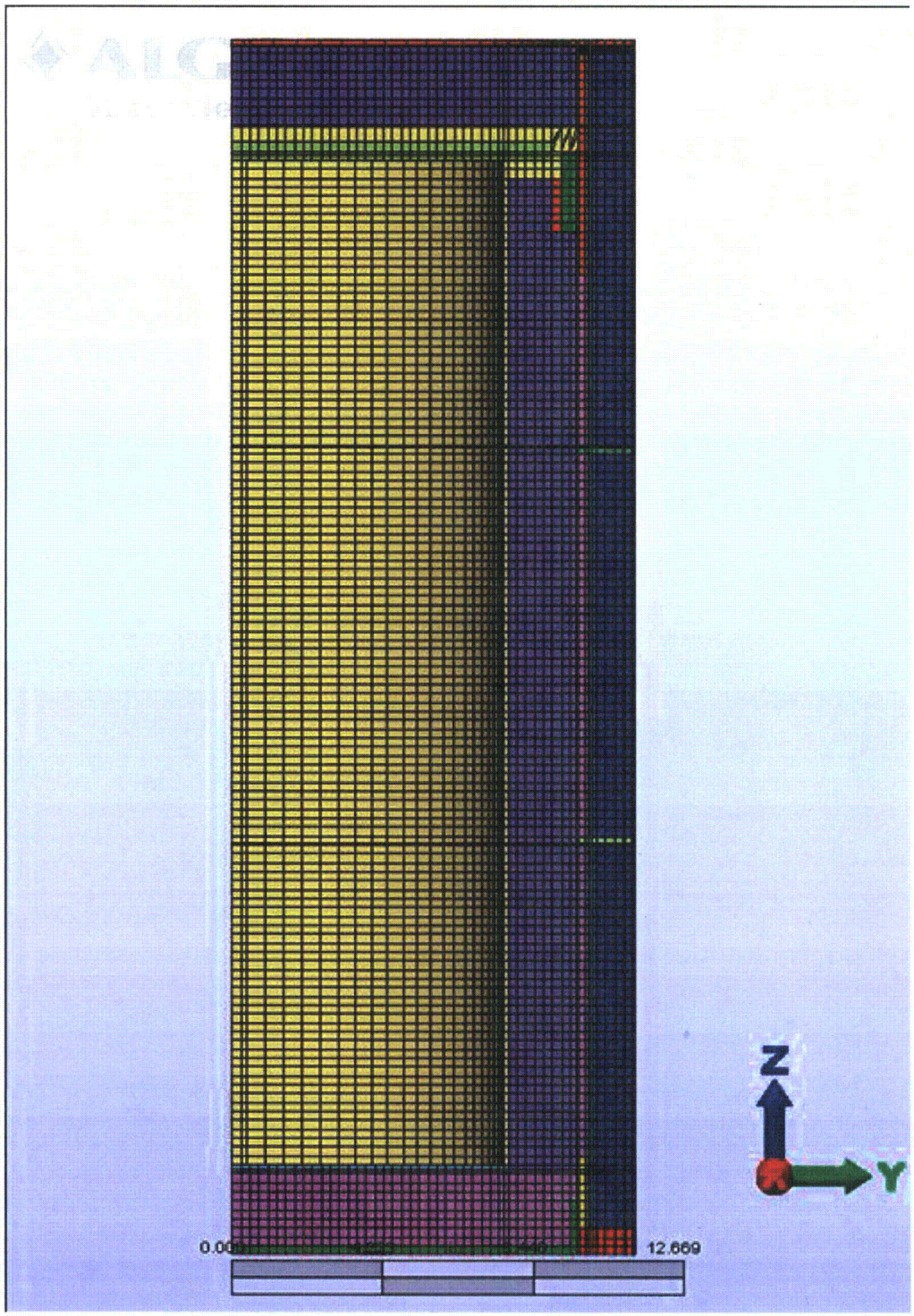


Figure 3.5.1- 5 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, contents not shown, side view with mesh

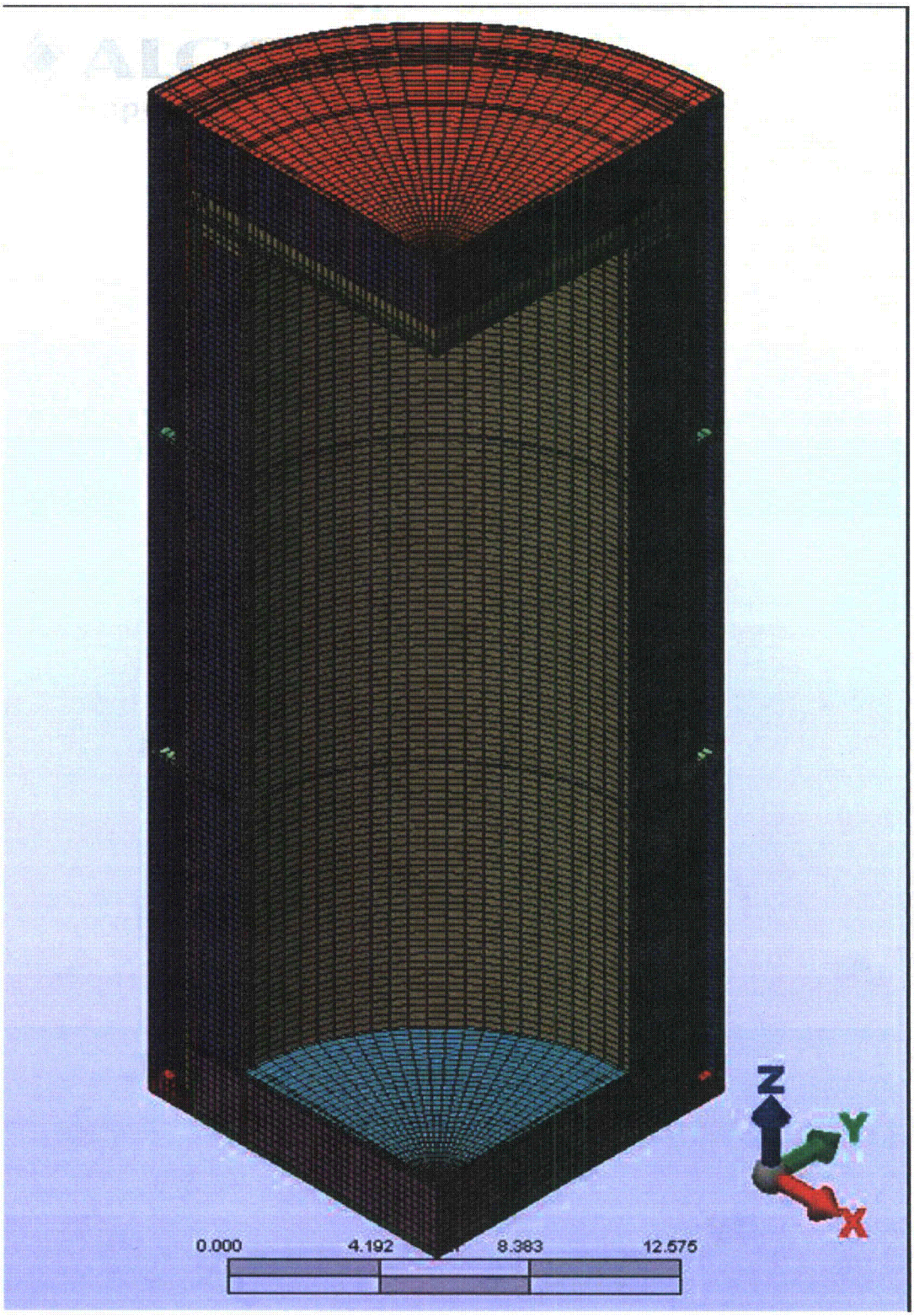


Figure 3.5.1- 6 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, Drum Lid removed (air gap between lids is shown in yellow)

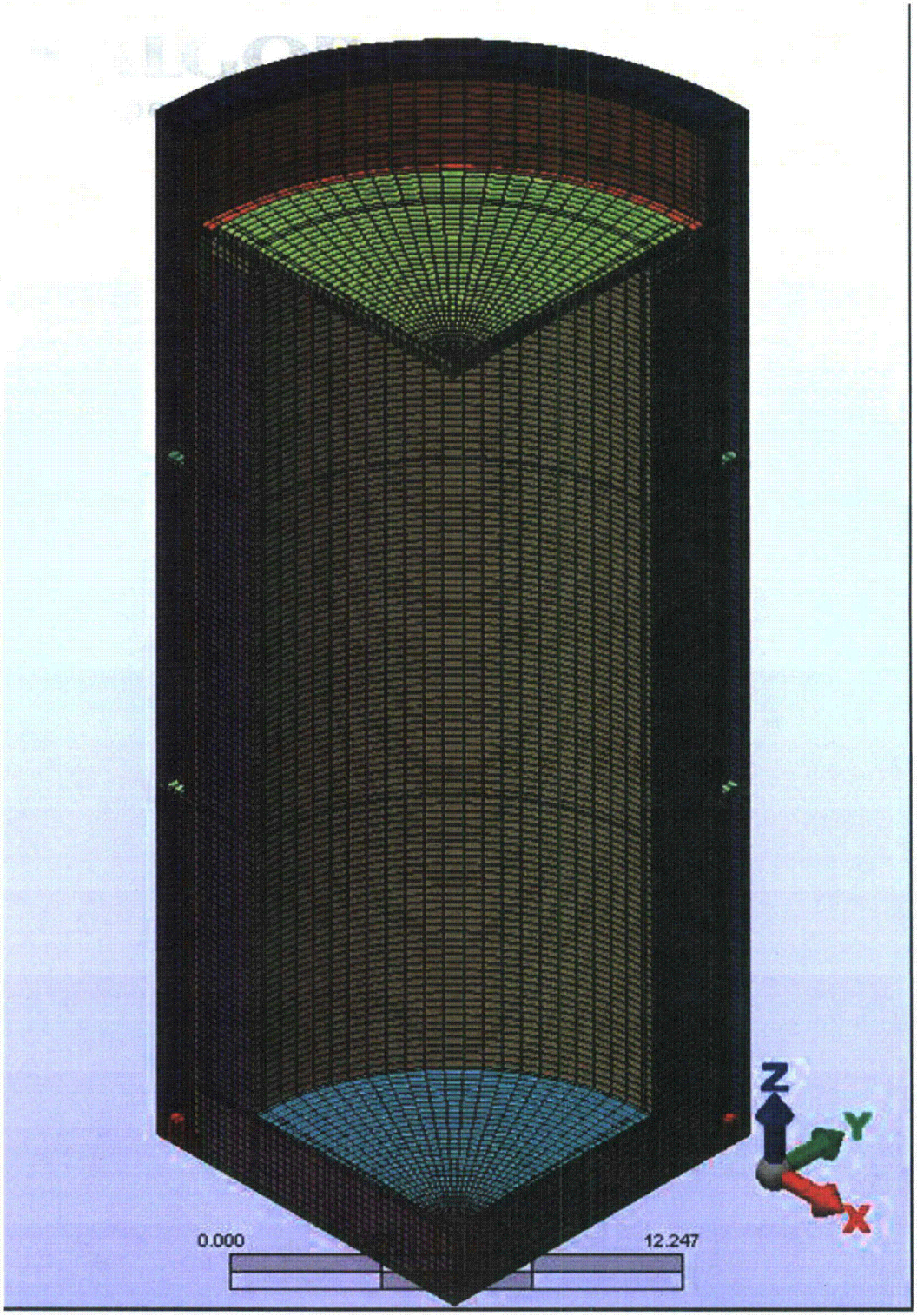


Figure 3.5.1- 7 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac (drum lid & insulation plug not shown)

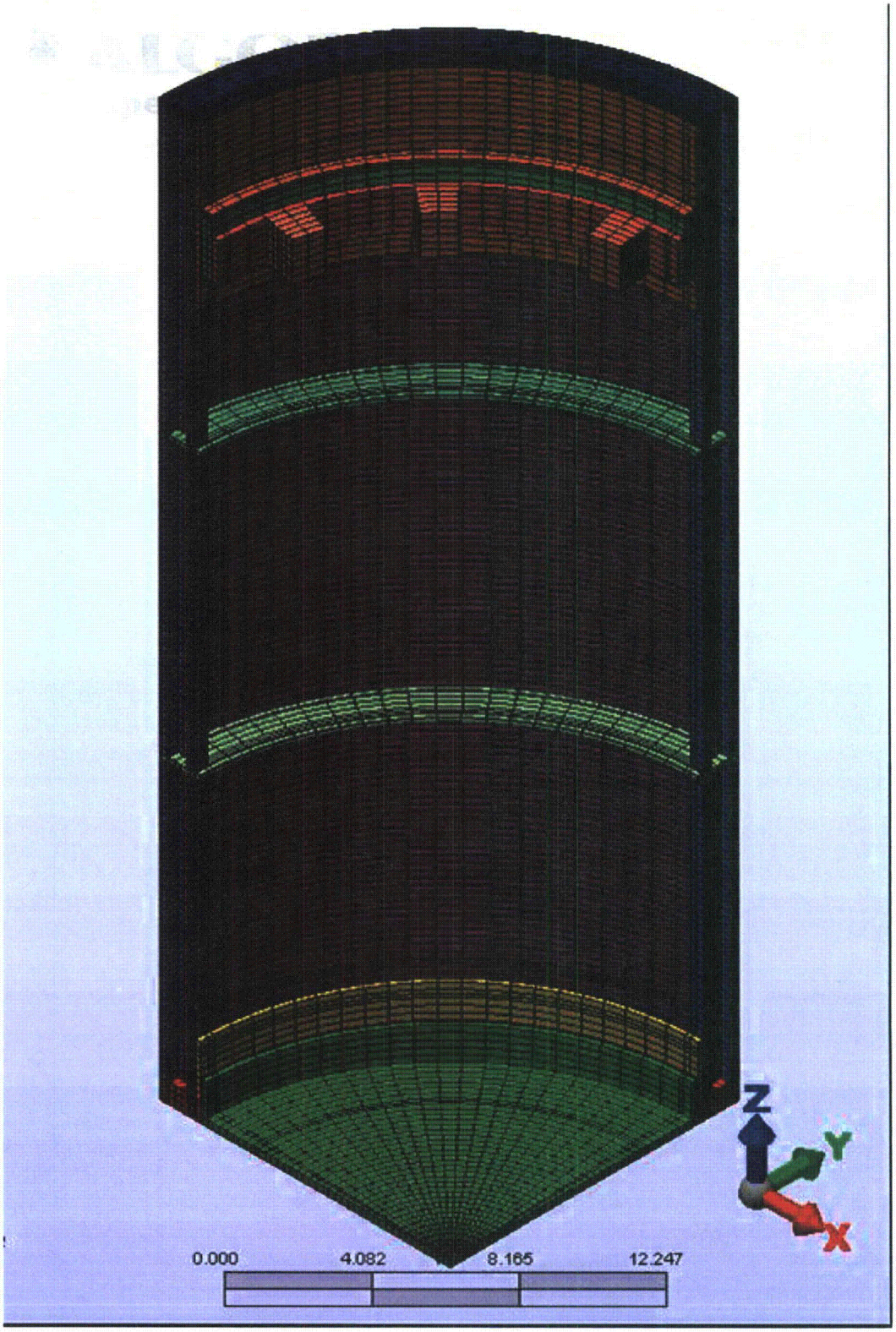


Figure 3.5.1- 8 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, External Metal structure, Fiberglass, & Payload Cavity bolting blocks (payload cavity, drum lid, insulation plug & component SA not shown)

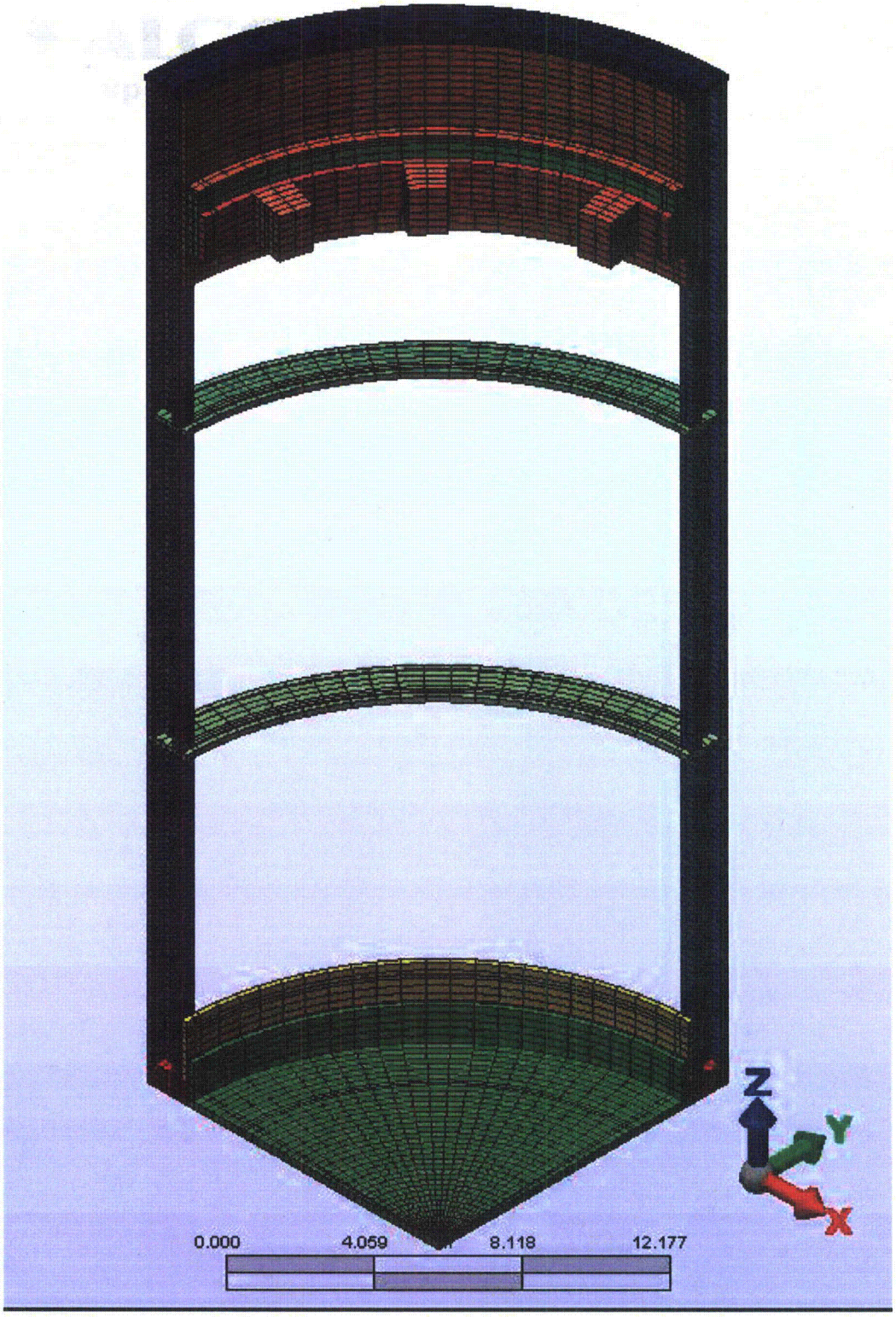


Figure 3.5.1- 9 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, Metal Reinforcing Members

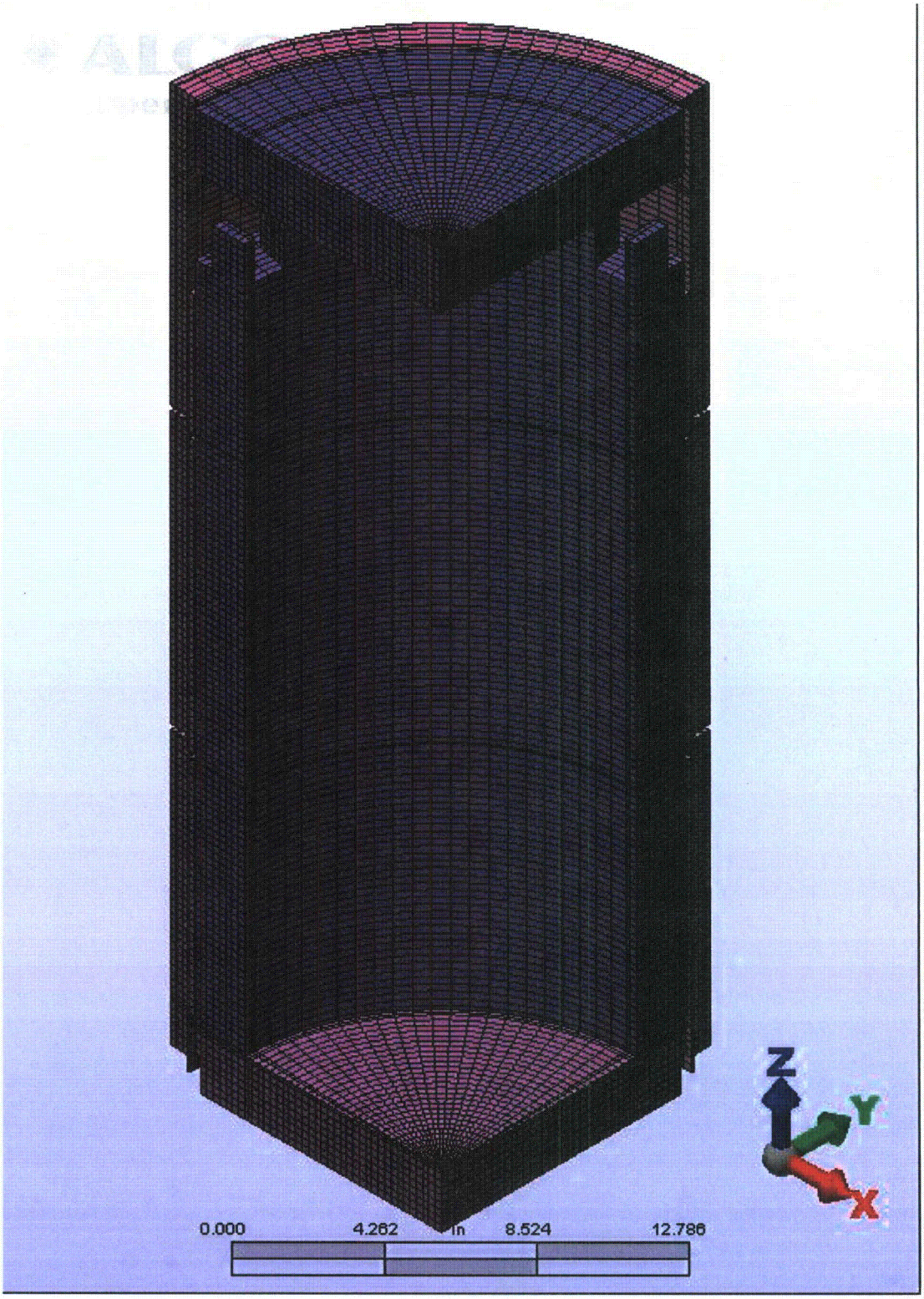


Figure 3.5.1- 10 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, Insulation

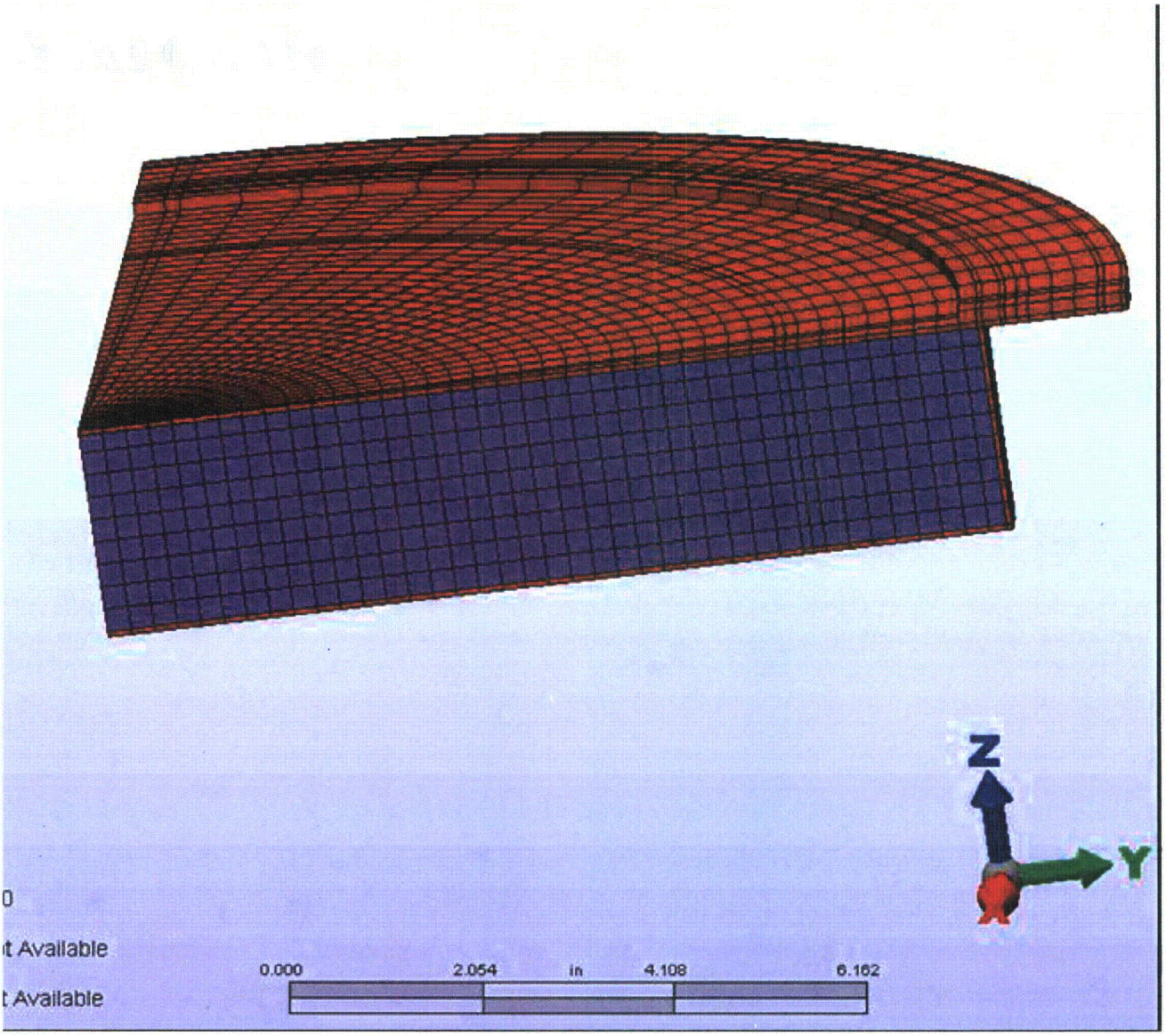


Figure 3.5.1- 11 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, Outer Lid

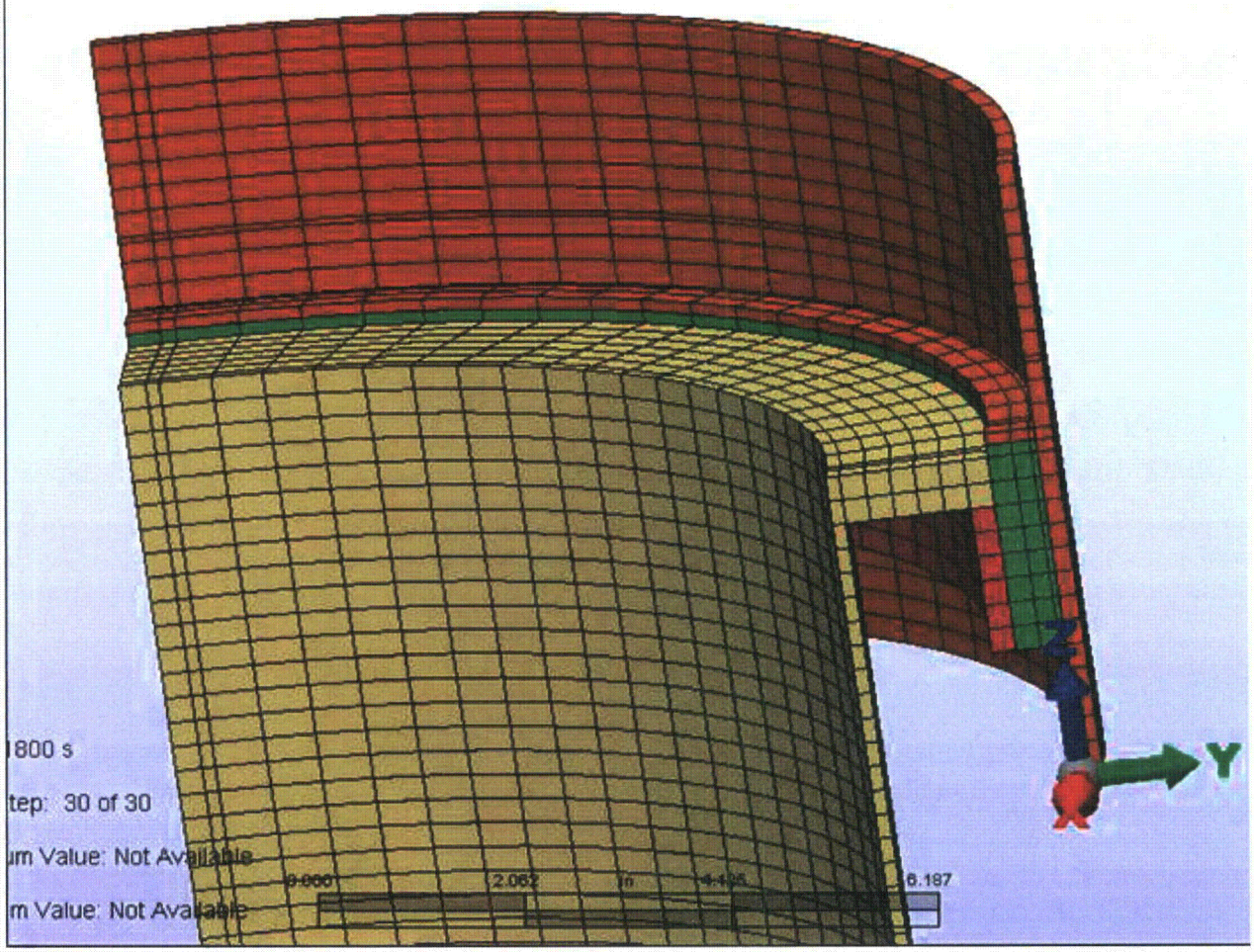


Figure 3.5.1- 12 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, Detail View, Payload Cavity, Fiberglass, and Rivet block (bolting block BB not shown)

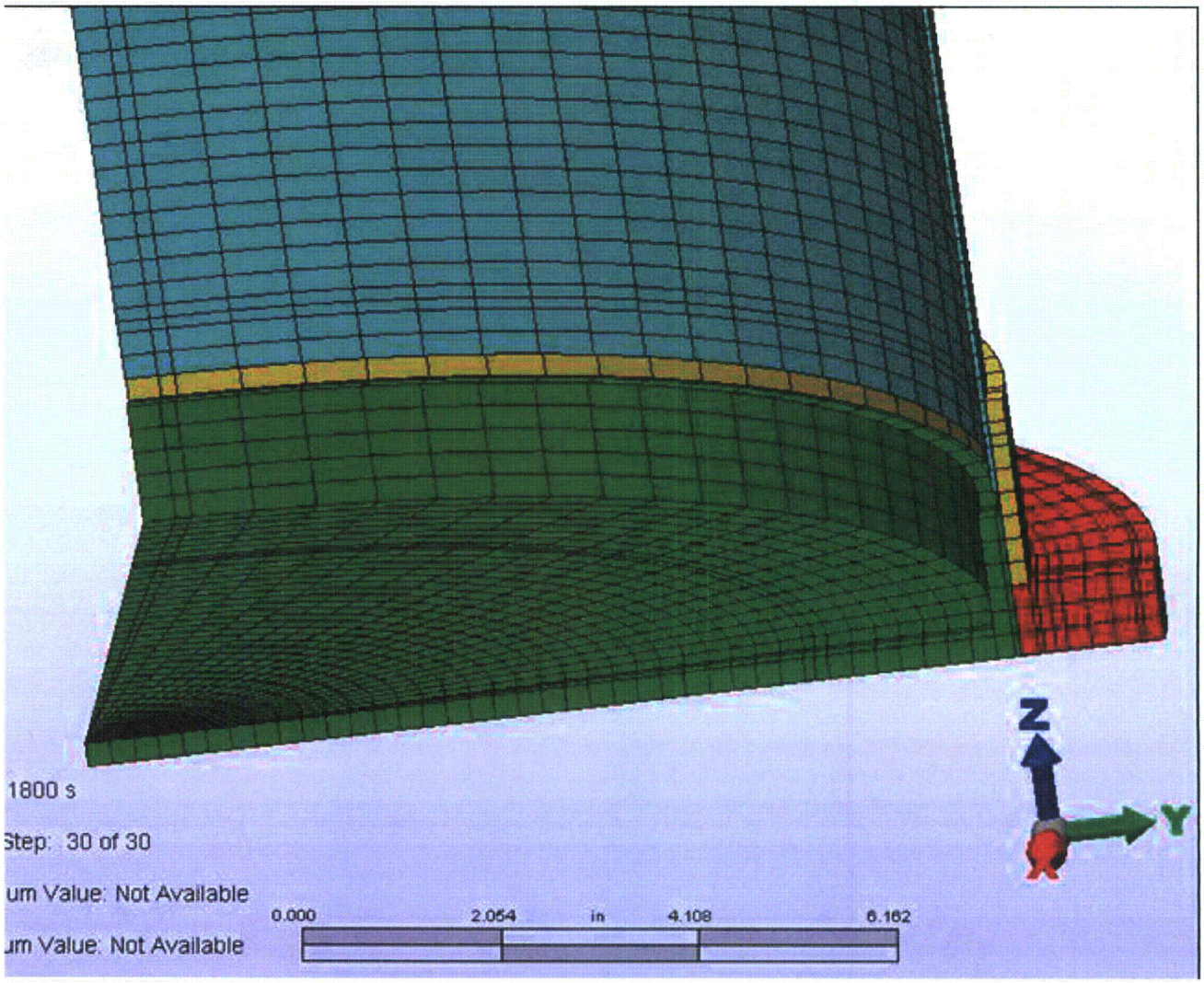


Figure 3.5.1- 13 Quarter-symmetric Thermal Model of the 55-gallon Versa-Pac, Detail View, Lower reinforcing structure

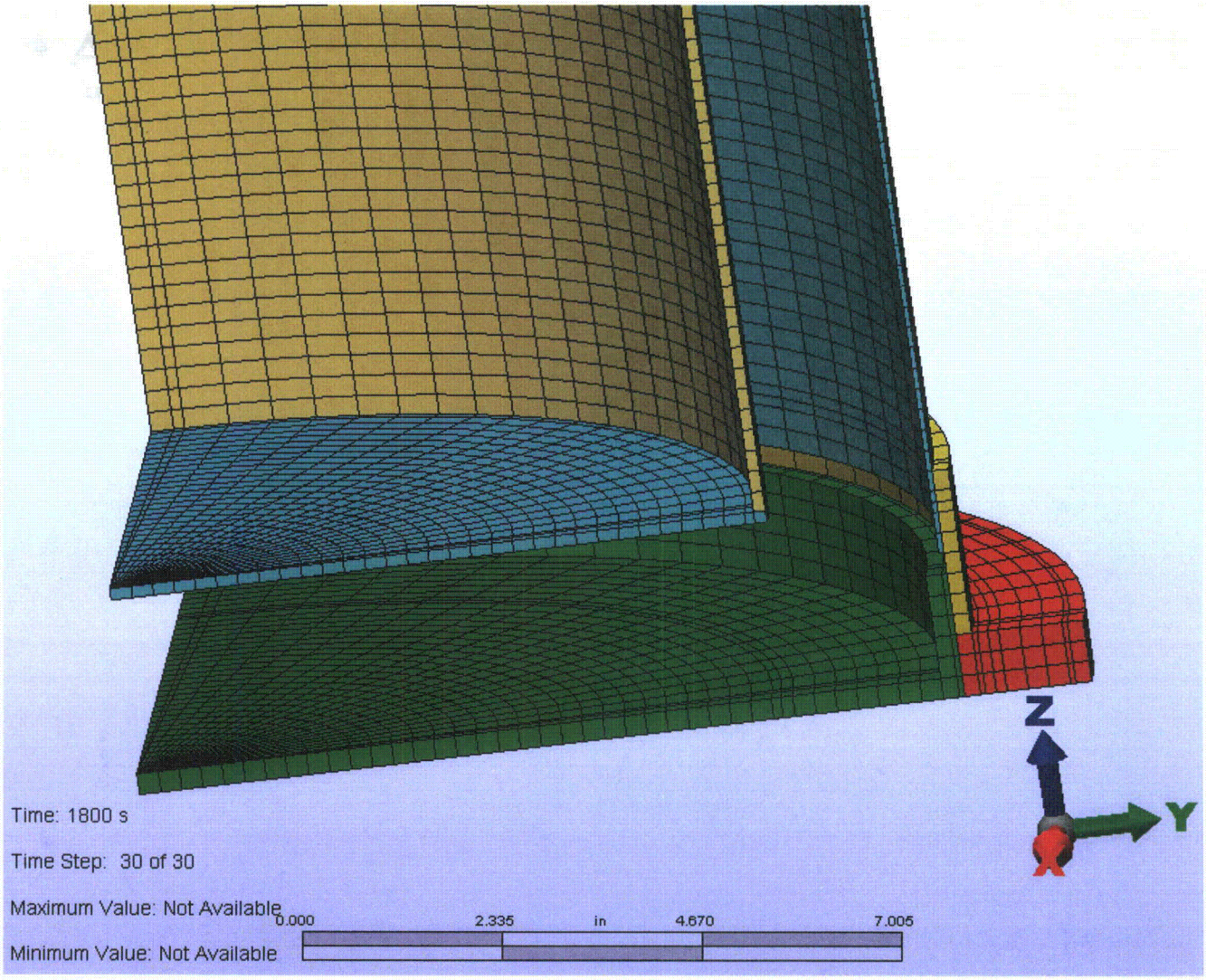


Figure 3.5.1- 14 Quarter-symmetric Thermal Model of 55-gallon Versa-Pac, Detail View, Lower Reinforcing structure with Payload Cavity shown

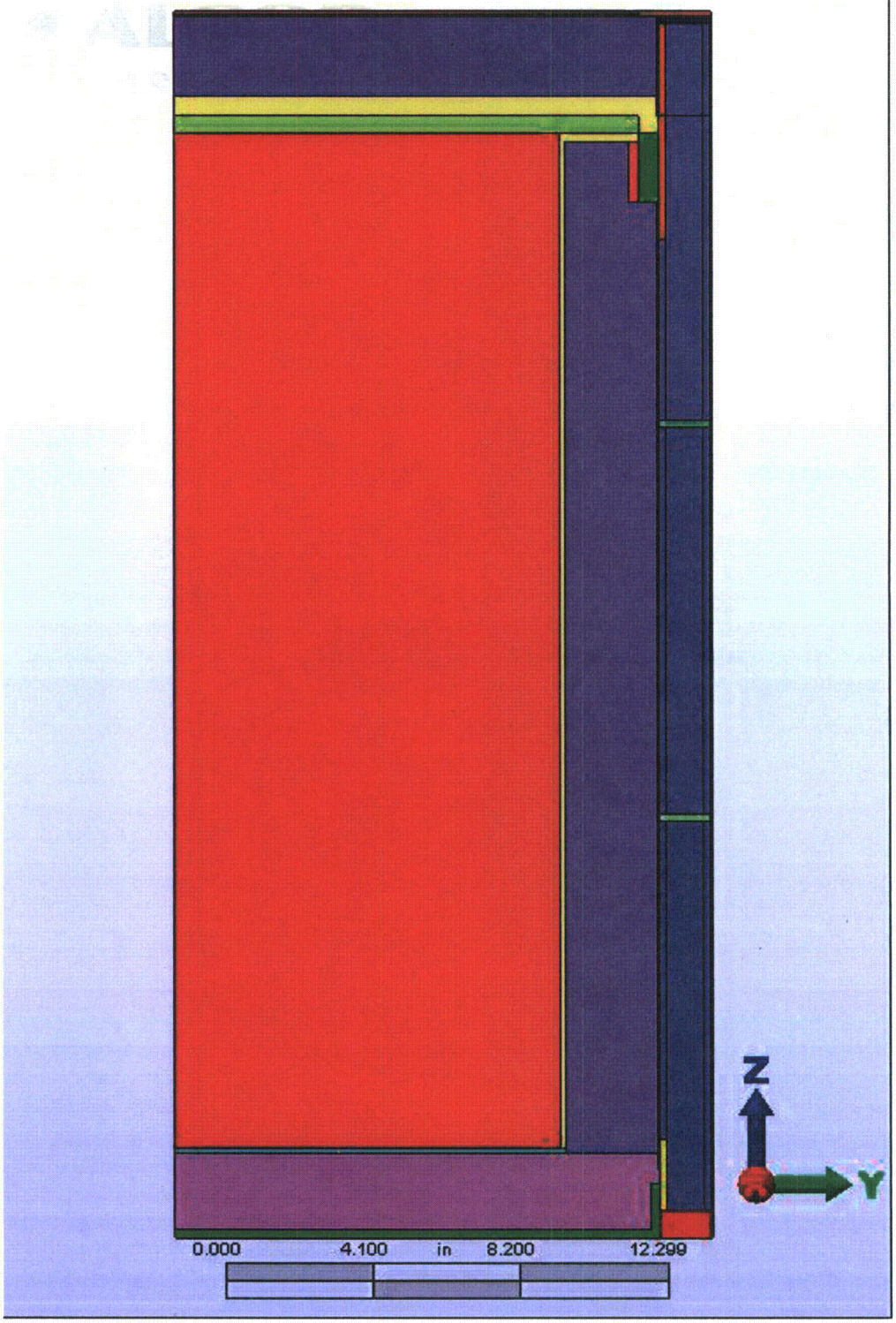


Figure 3.5.1- 15 Quarter-symmetric Thermal Model of 110-gallon Versa-Pac, all parts shown except polyurethane plug, side view

Appendix 3.5.2, Excerpted from ALGOR Non-Linear Thermal Transient Heat Transfer Analysis Manual, *Emulation of body-to-body radiation as temperature dependent conduction*

In some cases, body-to-body radiation can be emulated using temperature dependent conduction as shown in the figure below:

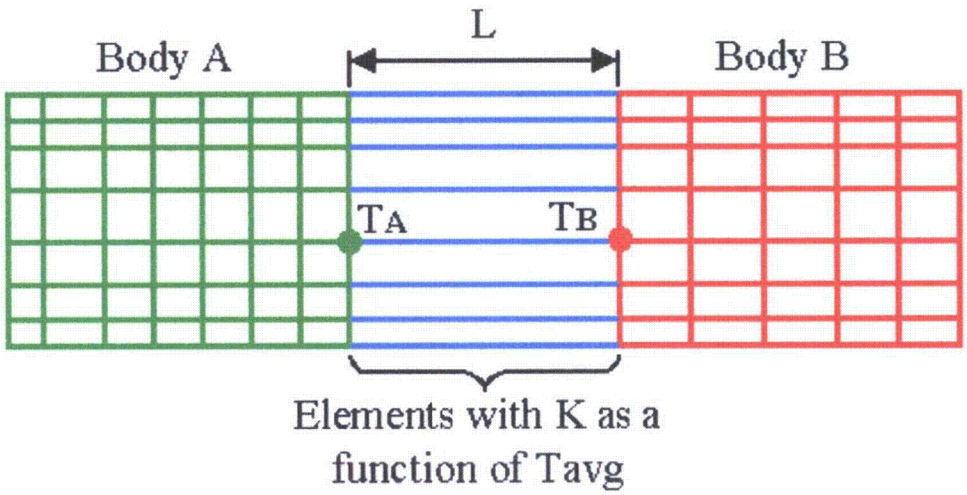


Figure 2: Body to Body Radiation

The requirements for this approximation to be accurate are as follows:

1. The view factor between the bodies must be close to 1.
2. The heat flux out of the system is negligible;that is, there is no radiation to the environment.
3. The surface area of each body is equal.
4. The expected temperatures of the surfaces are approximately known either from hand calculations, experimentation or previous analysis (multiple iterations).

The heat exchanged between two bodies which see each other and nothing else can be written based on the "surface resistance" and "space resistance" of the bodies as

$$q = \frac{A\sigma\left(T_A^4 - T_B^4\right)}{\frac{1-\varepsilon_A}{\varepsilon_A} + \frac{1}{VF_{AB}} + \frac{1-\varepsilon_B}{\varepsilon_B}}$$

Where T_A and T_B are the temperatures of surfaces A and B (in absolute temperatures), ε_A and ε_B are the emissivities of surfaces A and B, and VF_{AB} is the view factor between the two surfaces.

The heat flow due to conduction between the two bodies is

$$q = kA\frac{\Delta T}{L}$$

Since the heat flow due to radiation must equal the heat flow by conduction, equating the above two equations and expanding $T_A^4 - T_B^4$ as follows

$$T_A^4 - T_B^4 = \left(T_A^2 + T_B^2\right)\left(T_A^2 - T_B^2\right) = \left(T_A^2 + T_B^2\right)\left(T_A + T_B\right)\left(T_A - T_B\right)$$

leads to the solution

$$K = \frac{L\sigma\left(T_A^2 + T_B^2\right)\left(T_A + T_B\right)}{\frac{1-\varepsilon_A}{\varepsilon_A} + \frac{1}{VF_{AB}} + \frac{1-\varepsilon_B}{\varepsilon_B}}$$

using absolute temperatures.

Letting $T_{average} = (T_A+T_B)/2$, then $T^2_{average}$ is approximately $(T^2_A+T^2_B)/4$.

Using this substitution, and assuming the emissivities are 1 and the view factor is 1, this is further simplified to:

$$K \cong L\sigma(8)(T_{average})^3$$

Since the radiant heat transfer and conduction through the air occur in parallel the conduction coefficient is added to the psuedo radiant coefficient for input into the problem.

One layer of elements is constructed in a new part between the two bodies. The material model is set to orthotropic so that the material properties are temperature dependent. The conductivity is calculated at estimated surface temperatures T_A and T_B (in absolute temperature) using the above equation. The calculated conductivity is entered in the material properties at a temperature of $T_{average}=0.5(T_A+T_B)$. Additional data points are entered by evaluating $T_{average}$ and K at other values of T_A and T_B. A range of temperatures $T_{average}$ is included in the material properties so that the calculated temperature is not outside of the range of material properties.

Appendix 3.5.3, Excerpted from Safety Analysis Report for the Century Champion Type B Package Thermal Test

Introduction

The Century Industries Versa-Pac Shipping Container is an evolutionary package design based on the design and testing of the Century Industries Champion Type B package. Due to the similarity in both package designs, tests involving the Century Industries Champion, although not directly applicable, can be used to support the safety basis of the Versa-Pac design as supplemented by further analysis and tests. Tests involving the Champion package that are applicable to the design of the Versa-Pac include drop tests, thermal and immersion tests. The thermal test further indicates the lack of the thermal stresses in the design. The design similarities are further presented with attachment of the test results for the Champion package.

Design Comparison

Both packages share the same basic structural components in that they have an inner and outer liner of sheet metal that is surrounded by vertical and horizontal stiffeners. Both package designs use the same ceramic fiber blanket insulation between the inner and outer liners and also surrounding the radial portion of the containment boundary. Both designs have approximately the same polyurethane foam in their respective bottom and top portions of the container. Both designs are based on an inner structure that slides into an outer drum. Therefore, both package designs should have a similar thermal response including thermal stresses. However, the temperature profiles may be different as further discussed.

The package designs differ in the type of insulation that surrounds the inner containment area. The Champion surrounds the containment area with polyurethane foam that is poured in place while the Versa-Pac utilizes ceramic fiber blanket insulation within the same area.

The Champion utilizes a leak testable inner vessel as the primary containment with a secondary blind cap flange on top of the main sealing flange while the Versa-Pac uses only a ½" blind flange with a high temperature fibrous sleeve at the containment boundary.

Thermal Test

Figure 3.5.3-1 shows the Century Champion Package rigging for the thermal test. Figure 3.5.3-2 displays a typical view of the package during the 30 minute 1475°F thermal test phase. Figure 3.5.3-3 displays the package upon completion of the thermal testing prior to conduct of the immersion test.

Summary of Results

The package shown in Figure 3.5.3-3 does not show any signs of failure or fatigue at the conclusion of the thermal test. This suggests the lack of thermal stresses induced during and post-thermal testing. The 30 minute thermal test including the post-test natural cool-down did not cause any seam or closure separation in the package. The package structure including outer closure drum does not shown any signs of failure or fatigue. These observations from the testing of the Century Champion are directly applicable to the Versa-Pac design since their outer structures are identical. Therefore, the Versa-Pac design is not anticipated to be subject to thermal stresses during the required 30 minute thermal test at 1475°F.

Pages 14 and 15 of the Champion Safety Analysis Report are provided as pages 5 and 6 to Appendix 3.5.3. The test results indicate that during a 44-minute fire exposure, the lower portion of the inner vessel attained a maximum temperature of 450°F. Testing of the Versa-Pac would be expected to produce similar results since the structures and thermal insulation are similar to the Champion. The analytical analysis presented in Section 3.0, Thermal Evaluation, indicate a maximum temperature to the contents of 423°F for the Versa-Pac using a 3-inch polyurethane foam plug in the top of the containment vessel. With the plug removed, the analytical results approach 500°F. The analytical results seem reasonable and are generally performed to bound actual thermal tests with sufficient margin to ensure the design meets the requirements. Therefore, the lower temperature experienced in the fire testing of the Champion seems reasonable. In an actual fire test of the Versa-Pac, the maximum temperature at the containment bound would be expected to be less than 450°F. A lower temperature is anticipated since the Versa-Pac design uses a fiberglass thermal break in the area of the containment boundary closure.

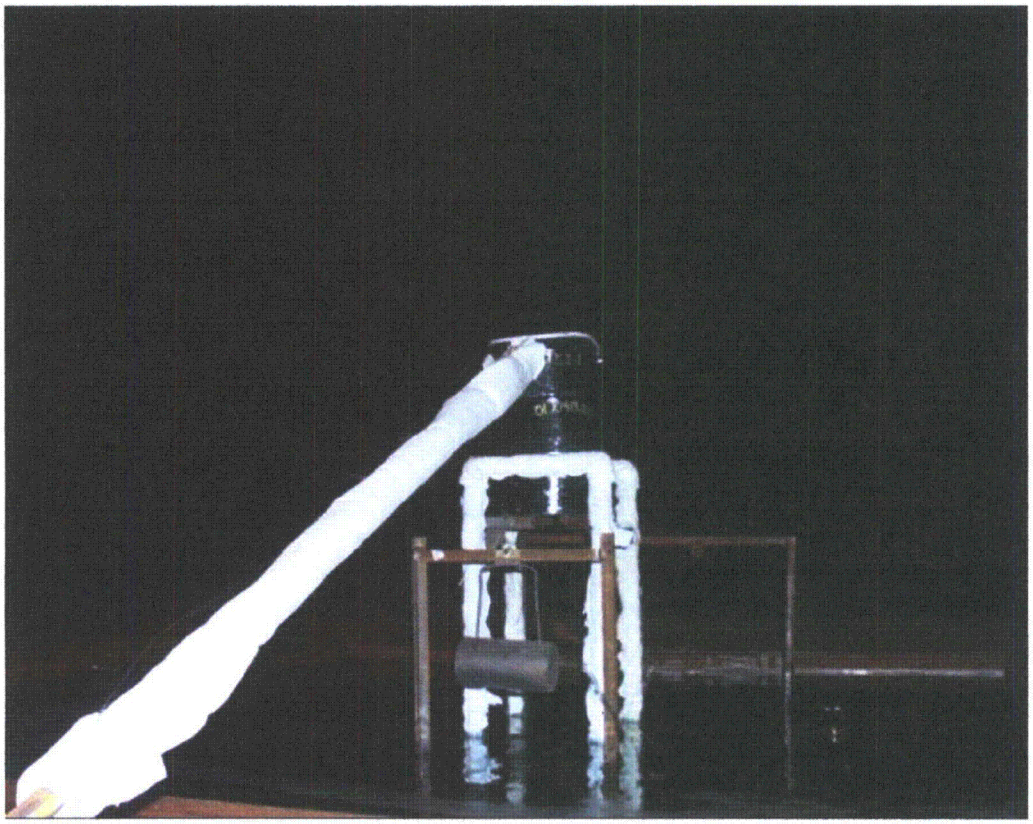


Figure 3.5.3-1 Champion Package on Test Stand – View from Thermocouple Shielding Tube

Figure 3.5.3-2 Champion Package during Thermal Testing Phase

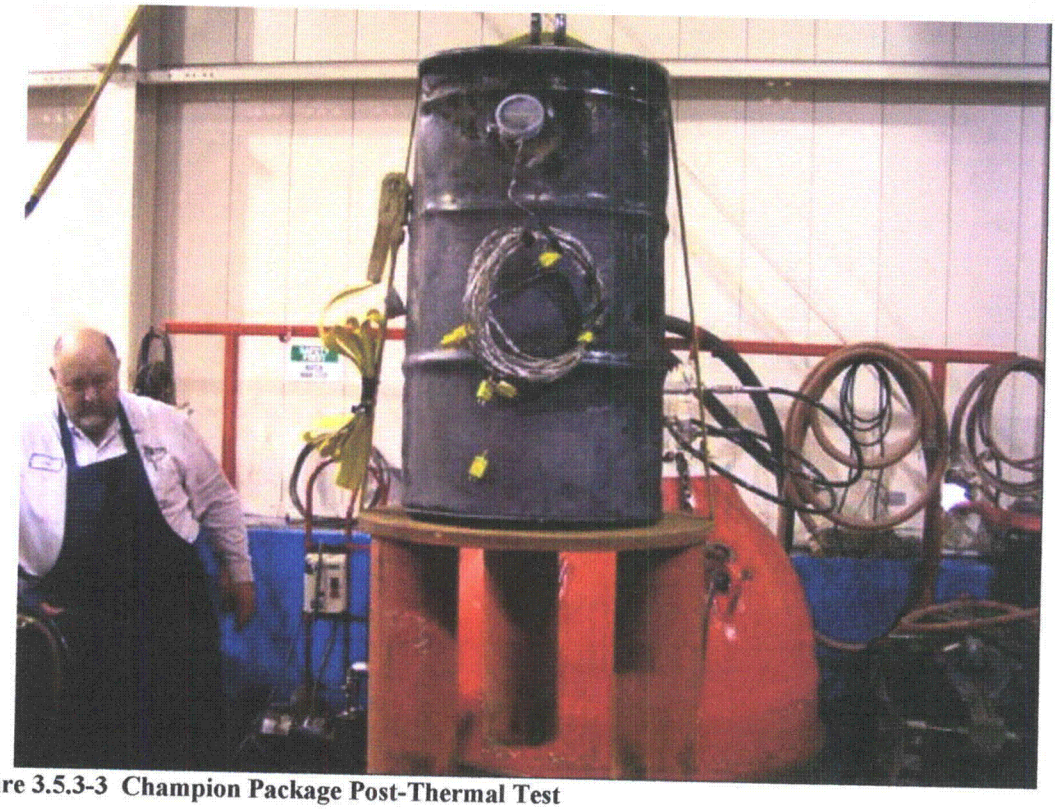


Figure 3.5.3-3 Champion Package Post-Thermal Test

9.2.3.4 Drop Test 4

Figure D-30 shows Drop Test 4 (puncture test, side orientation). Pre-test conditions were:

a) Drop Angle 0° (measured horizontally)
b) Drop Height 40 in. to impact face

The shipping container was released cleanly and impacted the puncture bar in the proper location and orientation. The container remained on its side after impacting the cylindrical puncture bar (see Figure D-32). Deformation data of the exterior was measured and recorded by Fire Technology personnel. Video was taken of the drop event and color photographs showing the extent of damage were taken and are included with this report.

All testing was completed successfully, and all phases of this testing were witnessed by SwRI QA/QC and NSF and Century Industries personnel.

After all drops were completed the CI-1 shipping container was placed in a conditioning chamber overnight and the test article was exposed to warm heat. The test article was exposed to ambient air at a temperature of 140°F ± 10°F for more than 15 hours prior to the fire test.

9.3 Pool Fire Performance Evaluation Test

The CI-1 shipping container was transported to the remote test site in Sabinal, Texas, and the pool fire test described in Title 10 CFR 71.73 (c)(4) was performed on January 28, 2004. Messrs. Mike Arnold and Rick McVey representing Century Industries, Mr. Preston Foster representing BMX Technologies, and Mr. Joseph Pugh representing Nuclear Fuel Services were present to witness the tests. Following initial startup procedures and transfer of 950 gal of diesel fuel to the burn pan, the data acquisition equipment was verified and the fuel was ignited to begin the 30-min pool fire test. Based on visual observation and flame temperatures, it was decided by Century Industries and SwRI to extend the fire exposure due to the lack of complete fire engulfment to the shipping container. An additional 310 gallons of diesel fuel was added for the additional 14 min of burn to compensate for the incomplete engulfment and low flame temperatures. A total of 1260 gallons of diesel fuel was used for the 44 min burn period. A larger pool fire may mitigate these adverse affects. Table 3 lists the significant observations during the pool fire exposure and post-test cool down period.

Following extinguishment, temperature data was recorded during the cool down period. During the cool down, the test article was protected from precipitation and wind effects to eliminate enhanced cooling of the test article.

Table 3. Pool Fire Test Observations.

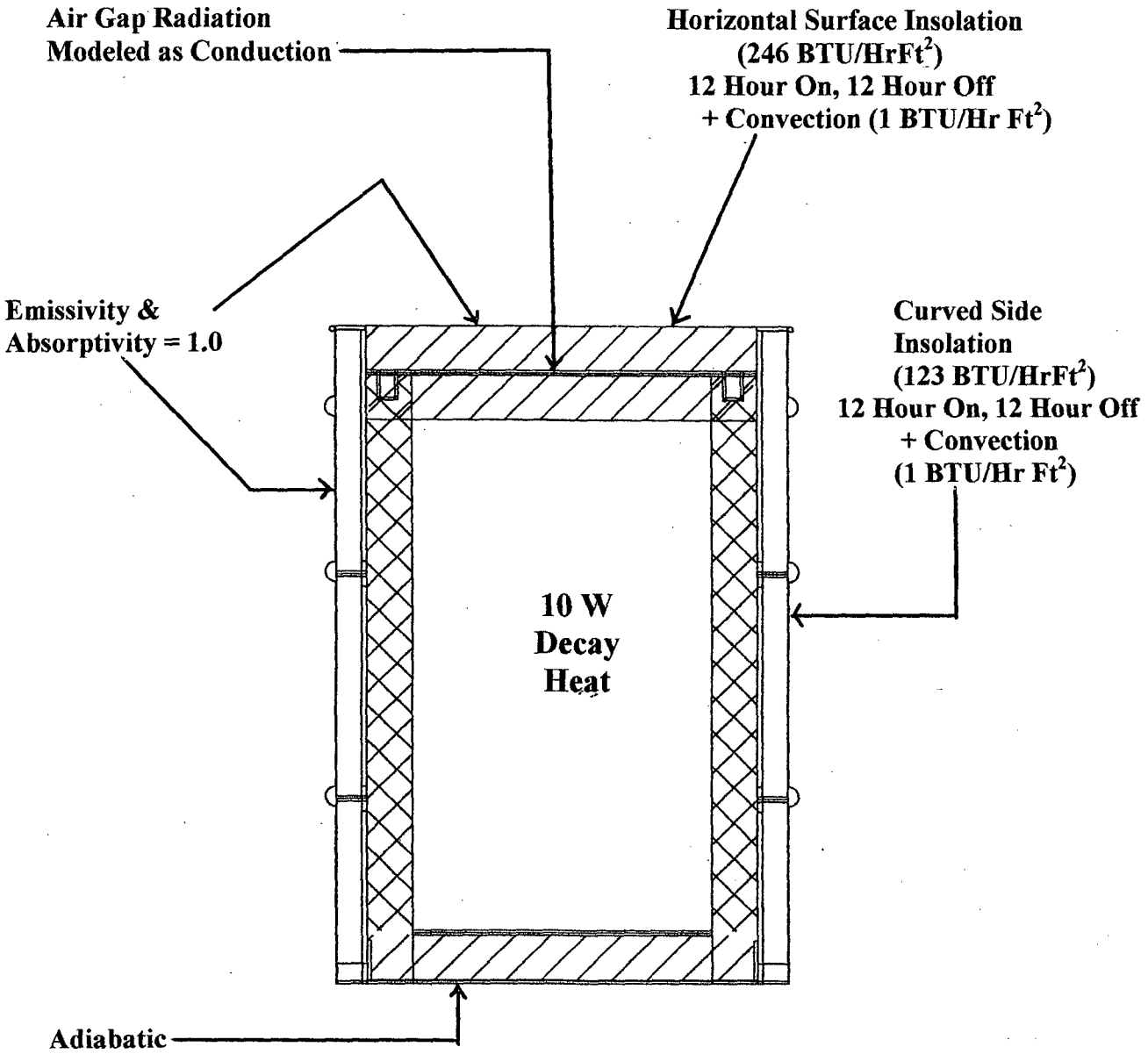
TIME (Min:Sec)	OBSERVATIONS
0:00	Test started. Flames fully developed across pool surface.
1:00	CI-1 shipping container engulfed by flames. Light southeast wind blowing flames northwest. Shipping container mostly engulfed by flames.
17:00	Plug melted and off-gassing from side of container at plug location.
30:00	Decision was made to extend time of exposure.
32:30	Additional 310 gallons of diesel started. Ended with 1260 gallons of diesel fuel.
38:00	Off-gassing burning from crease on bottom of container and off-gassing not burning from plug location.
44:15	Fuel beginning to burn out.
46:30	Residual burning continues on container.
47:00	Off-gassing at TC outlet port and at crease. Both continue to burn.
48:00	No visible flames in pool.
55:00	Temperature monitoring of shipping container continuing (5-10 min stop between burn and cool-down period).

Time-temperature profiles and test condition graphs taken during the pool fire exposure and cool down period are shown in Figures 10 through 15. The average flame temperature recorded by the TCs used to measure the pool fire was 1350°F and the average wind speed during the test was 3.1 mph. During the 44-min fire exposure, TC Nos. 5 and 8 attained maximum temperatures of 450°F and 303°F, respectively. TC Nos. 5 and 8 were located on the lower portion of the inner vessel. As a result of the crush tests, a tear developed at the base of the 55-gal drum. It is SwRI's opinion that the tear provided ventilation, allowing the foam to decompose and burn, causing the elevated temperatures recorded by TC Nos. 5 and 8. Tabular data for the test conditions TC measurements appear in Appendix E.

9.4 Hydrostatic Immersion Test

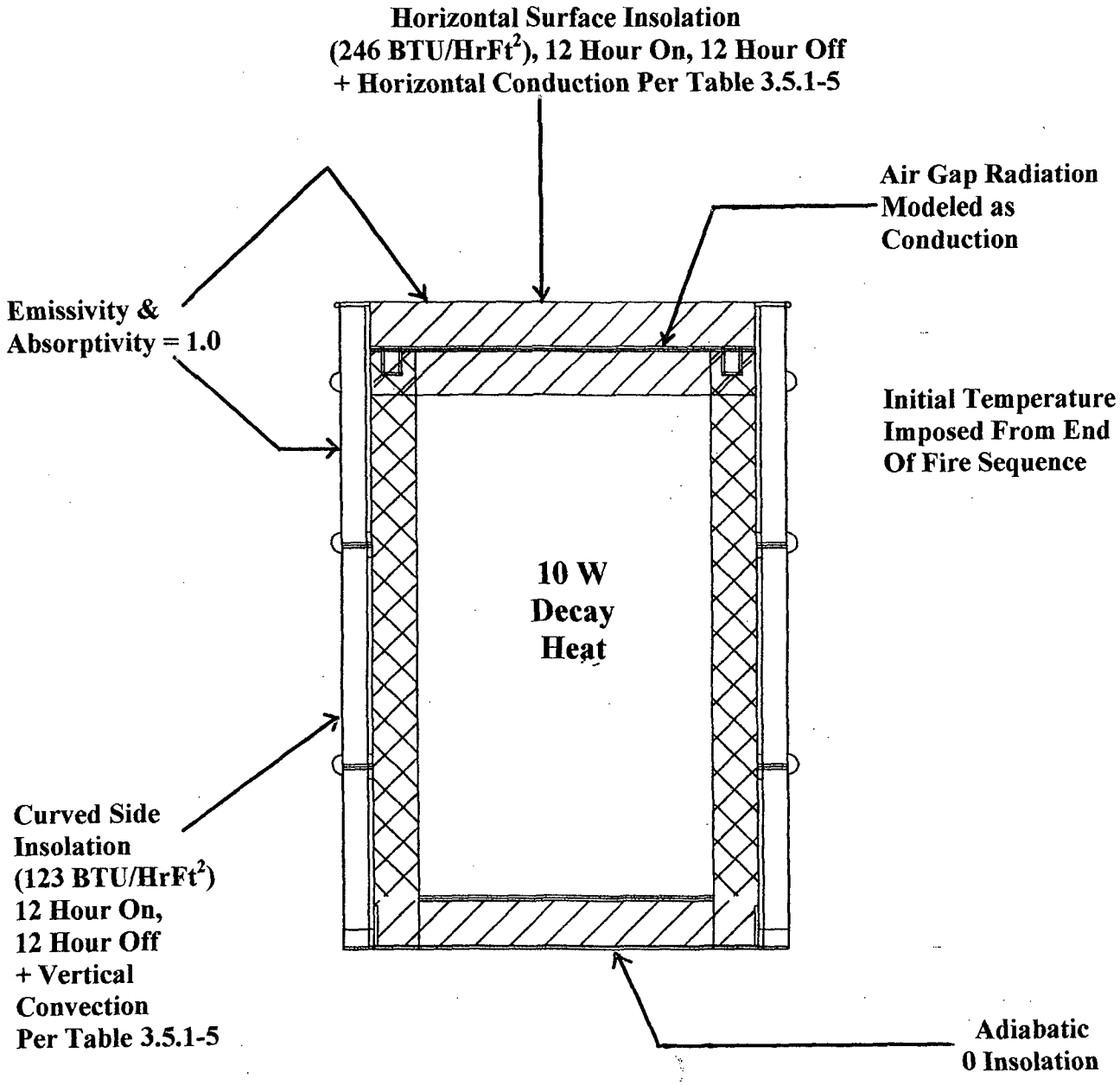
On January 29, 2004, the CI-1 shipping container was transported back to SwRI's main campus facility and delivered to the Test and Evaluation Section of the Department of Structural Engineering. The weight of the container as received from the off-site test facility was 386 lbs. The reduction of weight of 4 lb was due to the consumption of the insulation during the fire exposure.

Appendix 3.5.4



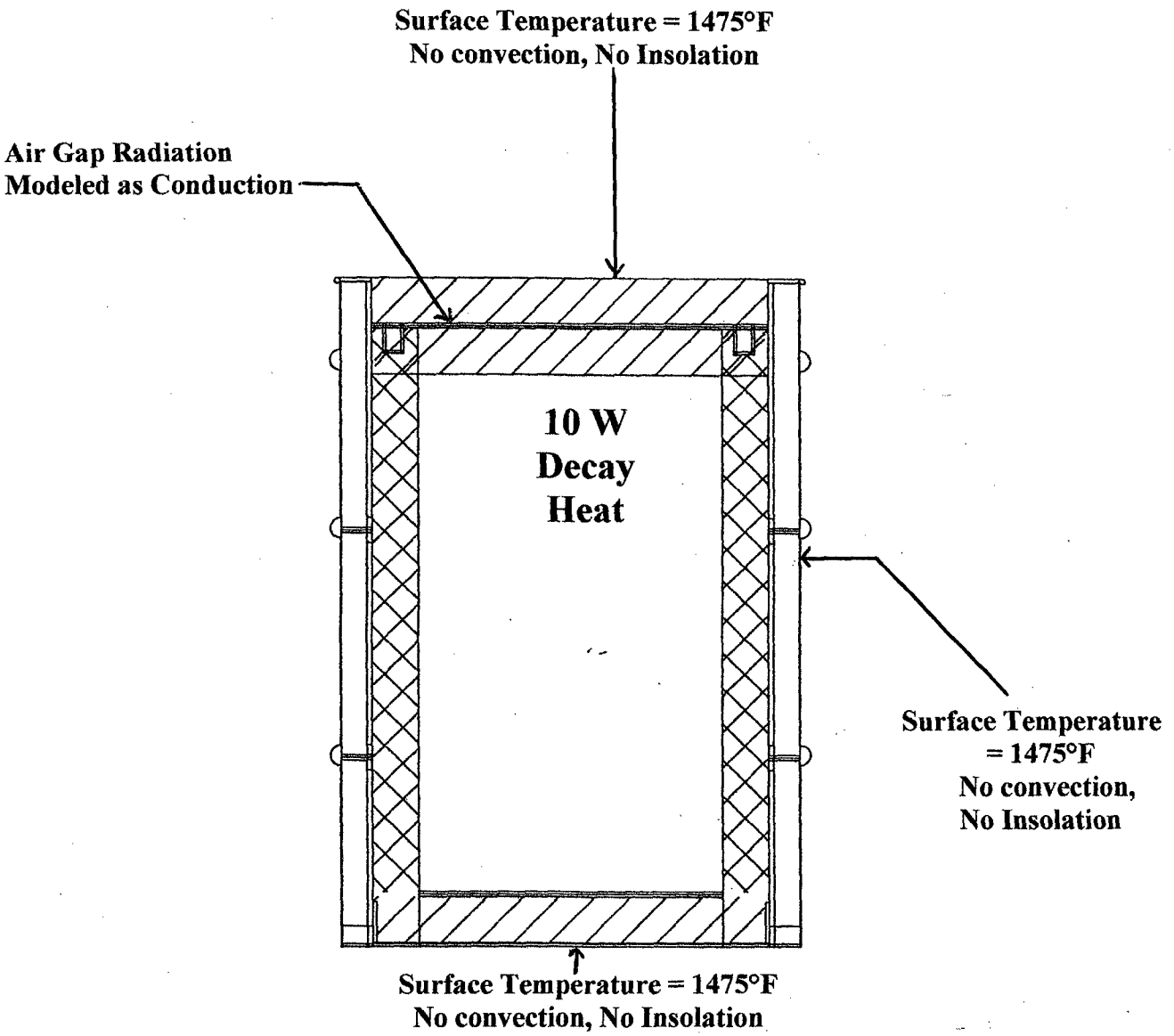
NCT

Package is Modeled Using Conduction Only. ¼ Symmetry, All Brick Elements.
Default Node Temperature = 100°F



Cool-Down Sequence

2 Hour Duration,
Conduction Only,
¼ Symmetry, All Brick Elements



Fire Sequence

30 Minutes Duration,
Emissivity & Absorptivity = 1.0
Conduction Only, ¼ Symmetry, All Brick Elements

SECTION FOUR

CONTAINMENT

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4 CONTAINMENT

4.1 Description of the Containment System

The containment boundary of the package is defined as the payload vessel with its associated welds, payload vessel high temperature heat resistant fiberglass sleeve gasket, payload vessel blind flange, and reinforcing ring.

The payload vessel is comprised of a 10-gauge carbon steel sheet for the body and bottom. The upper end of the vessel is fitted with a ¼" inner carbon steel flange ring with a $^1/_2$" thick carbon steel blind flange. The vessel has three circumferential welds (two at the flange, one at the base) and one longitudinal weld. An $^1/_8$" high temperature resistant fiberglass sleeve gasket is used between the steel flange ring and blind flange. The payload vessel blind flange is secured to the flange with twelve ½" bolts. There are no penetrations, valves or venting devices used within the containment boundary.

A specified torque is applied to the closure bolts and tightened as part of the closure steps defined within Section 7.1.3 to assure positive closure of the containment boundary, and given the mode of the closure, it cannot be opened unintentionally. The use of lock washers assures that the closure bolts are not loosed due to vibration during shipment. A location for installation of a tamper-indicating device is provided at the drum closure.

4.2 Containment under Normal Conditions of Transport

The Versa-Pac Shipping Container is classified as a Type A Fissile package. Performance tests consistent with the requirements of 10CFR71.71 and 10CFR71.73 have demonstrated that the Versa-Pac effectively prevents loss or dispersal of the radioactive contents under the postulated conditions of transport. Additionally, the tests have demonstrated that there is no substantial reduction in the effectiveness of the packaging during normal conditions of transport; thus, there is no significant increase in external surface radiation levels resulting from the postulated conditions of transport. Section 2.0 provides a description of the tests performed and analyses completed. Section 6.0 demonstrates that the package remains subcritical under normal and hypothetical accident conditions.

Since the package is not a sealed system, the internal pressure is maintained near atmospheric pressure for all conditions of transport. The maximum normal hot contents temperature is less than 212°F; thus, any water moisture remains in the liquid state and within the payload cavity.

4.3 Containment Requirements for Hypothetical Accident Conditions

As discussed in Section 4.2 and Section 2.0, performance tests consistent with the requirements of 10CFR71.71 and 10CFR71.73 have demonstrated that the Versa-Pac effectively prevents loss or dispersal of the radioactive contents under the postulated conditions of transport. Section 6.0 demonstrates that the package remains subcritical under normal and hypothetical accident conditions.

Since the package is not a sealed system, the internal pressure of the package is maintained near atmospheric pressure for all conditions of transport. During the fire event, some water moisture within the payload will be converted to steam. Any pressure build up will be relieved through the package gaskets.

4.4 Leakage Rate Tests for Type B Packages

This section is not applicable.

4.5 List of Appendices

This section is not applicable.

SECTION FIVE

SHIELDING EVALUATION

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5 SHIELDING EVALUATION

Gamma and neutron shielding are not required for the materials transported in the Century Versa-Pac Shipping Container. However, it is the responsibility of the shipper to assure compliance with 10 CFR 71.47 regarding radiation standards for each individual shipment.

SECTION 6
CRITICALITY EVALUATION

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6 Criticality Evaluation

The Century Versa-Pac Shipping Container is described in Section 1.2, *Package Description*. The package exists in two distinct but similar versions consisting of outer 55-gallon and 110-gallon drums.

The 55-gallon drum version of the Versa-Pac Shipping Container consists of a 16 gauge body, bottom and cover. The drum uses a 12 gauge bolted closure ring, standard carbon steel lugs, 5/8" diameter, ASTM A307 bolts and nuts, and a closed-cell EPDM gasket. The overall outer dimensions of the 55 gallon package are 23" OD x 34-1/2" in height. The drum cover is reinforced by an eighth-inch thick 22-3/8" OD x 18-3/8" ID plate, and four ½" bolts are provided to lend additional strength to the drum closure ring.

The 110-gallon version utilizes a 16 gauge body, bottom and cover. The drum uses a 12 gauge bolted closure ring, standard carbon steel lugs, 5/8" diameter ASTM A307 bolts and nuts, and a closed-cell EPDM gasket. The overall outer dimensions for the 110 gallon package are 30-7/16" OD x 42-3/4" in height. The drum cover is reinforced by an eighth-inch thick 29-3/4" OD x 27-1/4" ID plate and eight ½" bolts are provided to lend additional strength to the drum closure ring.

Both drums are further strengthened with vertical stiffeners fabricated from 1-1/4" carbon steel square tubing, two inner liners of rolled 16 gauge carbon steel insulated by ceramic fiber blanket encase the vertical tubing, and a ¼" carbon steel reinforcing plate on the bottom. Reinforcing angles and solid bars within the liners provides additional strength.

The package's interior is completely insulated with layered ceramic fiber blanket around the containment area with rigid polyurethane foam disks on the top and bottom. The ceramic fiber blanket and polyurethane foam provide shock and thermal protection to the containment area.

The containment and exterior structure including their respective closures provide two barriers to prevent the payload dispersion and water inleakage. An illustration of the packaging is provided in Figure 1-1.

The payload material may be pre-packaged in hydrogenous or non-hydrogenous containers within the payload vessel. Hydrogenous pre-packaging materials consist of polyethylene, polypropylene, or PVC. PTFE or Teflon® pre-packaging material are also allowed. Metallic pre-packaging materials consisting of aluminum, stainless and carbon steel are further allowed provided their total weight is controlled to within the payload allotment of the package.

A summary of the results for the most reactive HAC cofiguration for the criticality evaluation is provided in Table 6-1. The most reactive HAC configuration was determined to consist of an arrangement of in-homogeneous spheres placed within the containment area of the package to achieve maximum interaction from contiguous packages.

6.1 Description of Criticality Design

6.1.1 Design Features

The Century Versa-Pac Shipping Container does not use any neutron moderators or absorbers, however minimum thicknesses of continuous sheet and plate carbon steel (e.g., containment liner, inner/outer liner, drum lid, body and bottom, including top and bottom reinforcing plates) are modeled in the analysis. Descrete carbon steel consisting of the vertical stiffeners, flanges, angles, and bars are not modeled. Also not modeled are the flange ring interfaces with the flange which are model assuming a continuous thickness of the flange material.

Criticality control of the Century Versa-Pac Shipping Container relies on control of the payload vessel diameter, the vessel-to-vessel spacing provided by the drum, and number of packagings that may be shipped together. Additionally, each payload is subject to a mass limit of 350 gram U-235. The U-235 mass limit is an absolute value which is typically defined as a nominal measured value with a measurement uncertainty at a 95% confidence level.

Further, the payload does not rely on moderation-control. Moderation in the payload vessel is evaluated using optimum polyethylene. The moderator is evaluated by varying the corresponding volume fractions. Polyethylene is further evaluated at an increased density. A polyethylene density of 0.98 g/cc conservatively bounds the use of pre-packaging materials containing carbon (including graphite and high density paraffin) and hydrogen.

Thus, the physical packaging design features that are important to criticality safety are the payload vessel diameter, the drum outer diameter, and the payload vessel body, body welds, blind flange and seals. Administrative control of the payload mass and shipment array must also be implemented.

6.1.2 Summary Table of Criticality Evaluation

Table 6-1 provides a summary of the results of the criticality evaluation of the Century Versa-Pac Shipping Container for the most reactive configuration. The 350 gram U-235 fissile mass modeled as a lumped 12.0-cm radius sphere leads to the most reactive configuration. A detailed description of the analytical models and methodology is provided in Section 6.3. All results are less than the conservative administrative Upper Subcritical Limit of 0.95 minus the code bias and bias uncertainty[1].

As indicated in Section 6.3, a single model is conservatively constructed to represent the Normal Condition of Transport (NCT) and Hypothetical Accident Condition (HAC) package configurations for both the 55-gallon and 110-gallon package

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[1] The k_{eff} used in all cases represents the KENO k_{eff} plus two sigma (sigma was typically on the order of 0.002). Discussion on the code bias and bias uncertainty is provided in Section 6.5.

versions. As further indicated in Section 2.12.3, the tested 110-gallon package version sustained little damage from both the NCT and HAC testing suggesting small differences in the final evaluated package array sizes. Section 2.0 also indicates that prototype testing of both package designs shows that more damage resulted to the 110-gallon package version due to the heavier weight and greater distance between vertical stiffeners. Therefore, the criticality analysis model is conservatively constructed based on the 55-gallon package dimensions, due to the potential for higher package and fissile mass densities, with the conservative application of actual damage sustained during testing of the 110-gallon package version. This model conservatively bounds the HAC testing and is very conservative with respect to the NCT configuration for both package versions.

6.1.3 Criticality Safety Index (CSI)

The Criticality Safety Index (CSI) is 0.90. Arrays of 300 packages are evaluated for the Normal and Hypothetical Accident Conditions. Thus, N is 300/5 = 60 or 300/2 = 150, and the minimum CSI is 50/60 = 0.83, which is rounded upto 0.90.

6.2 Fissile Material Contents

All materials shall be in solid form with no freestanding liquids; density is not limited. These materials must contain not more than an A_1 or A_2 quantity as appropriate, and the quantity may not exceed 350 grams U-235 in any non-pyrophoric form, enriched up to 100 Wt%. Materials that may be shipped in the Versa-Pac include 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 uranium compounds may also contain carbon or graphite. UNX may be in the form of uranyl nitrate hexahydrate, trihydrate or dihydrate, and may contain any amount of moisture; however, the UNX must be in solid form with no freestanding liquid. The payload may be in homogeneous (powder or crystalline) or non-homogeneous (pelleted or lumped) form.

The package is evaluated assuming optimum moderation using a bounding high-density polyethylene plastic (Density = 0.98 g/cc) and supports packaging applications containing both carbon (graphite) and hydrogen based materials. Non-fissile chemical impurities do not increase the reactivity of the system; therefore, they may be present in any quantity. The payload may be enriched in U-235 to 100 Wt%.

The payload material may be pre-packaged in hydrogenous or non-hydrogenous containers within the payload vessel. Hydrogenous pre-packaging materials may include polyethylene, polypropylene, and PVC. PTFE or Teflon pre-packaging material are also allowed. Metallic pre-packaging materials such as aluminum, stainless and carbon steel are further allowed provided their total weight is controlled to within the payload allotment of the package.

No materials, excluding the minimum steel wall thickness of the package, are used as neutron absorbers or moderators.

6.3 General Considerations

6.3.1 Model Configuration

Figure 6-1 provides a representation of the unit model used in the criticality analysis. The modeled dimensions represent a damaged 55-gallon package. The packaging consists of a cylindrical carbon steel shell surrounded by insulation, an inner/outer steel liner, and an outer carbon steel shell. The steel payload vessel, flange, and blind flange are modeled as carbon steel with reduced minimum dimensions. The drum, inner and outer liners, and upper and lower drum plates are also modeled as carbon steel with reduced minimum dimensions. An enrichment of 100 Wt% U-235 is used to evaluate all cases.

The constructed model evaluated in the criticality analysis, as also discussed in Section 6.1.2, conservatively represents the HAC package configuration (damaged package configuration) for the 55-gallon package design. The model is constructed considering worst case damage to both the 55-gallon and 110-gallon package designs. Due to the smaller package envelope of the 55-galon package design the package is inherently more reactive when compared to the 110-gallon package design. The modeled reduction in package dimensions leads to significant more interaction between packages and results in a lower CSI. The reduced dimensions of the modeled 55-gallon package (damaged package configuration) design results in a more reactive package array when compared to undamaged 55-gallon and 110-gallon designs. Therefore, the conservatively modeled HAC package configuration for the 55-gallon package design bounds the NCT (undamaged package configurations) for both the 55-gallon and 110-gallon packages and further bounds the HAC (damaged package configuration) for the 110-gallon package design. Further evaluation of the HAC (damaged package configuration) modeled array size to the more restrictive NCT criteria (5N) the resulting CSI (0.9) conservatively bounds the NCT criteria (5N) and HAC criteria (2N) for evaluation of package arrays using the single model.

With construction of a NCT model (undamaged package design) based on the 55-gallon design, the evaluated array size would be increased due to additional spacing afforded between fissile material in adjacent packages. This would further lead to a reduced CSI. Thus, a smaller package design, considering worst case damage of the two designs, to the most restrictive CSI criteria can conservative represent the Versa-Pak 55-gallon and 110-gallon packages.

6.3.1.1 Model Conservatisms

Table 6-2 summarizes the dimensional changes to the test packages indicated as Test Articles with Serial Numbers 10550, 10551, and 10553. The pre and post test measured results for each package is provided in Section 2.12.3, *Century Industries Performance Test Report for the Versa-Pac.* The worst case dimensional reductions from these tests, as summarized in Table 6-2, are + 1/8" increase in the inner containment diameter, - 5/16" reduction in the outer drum diameter, and -1/4" reducion in the outer drum height (including lid). Note that the measured dimensions provided in Section

2.12.3 do not include the outer drum lid. Also, the outer drum diameter reduction only occurs on one side of the drum mostly due to compression of the area between drum stiffeners at the impact location of the test plate.

The overall outer dimensions of the 55 gallon package are 23" OD x 34-1/2" in height. Neglicting the drum stiffeners and bolt ring reduces the outer diameter to 22-1/2". For the bounding HAC/NCT model, the 55-gallon drum is further modeled with a reduced outer diameter of 1.313" which significantly bounds the maximum reduced dimension resulting from the tests of 0.313" (5/16"). The reduced outer diameter further bounds and still provides margin for the 1/8" increase in the inner containment diameter. The 55-gallon drum is further modeled with a reduced outer height of 0.875" which bounds the maximum reduced dimension resulting from the tests of 0.250" (1/4"). The containment area is further modeled at both nominal and with increased dimensions of 1/8" for the diameter and 1/16" for the height. The nominal dimensions being 15" inner diameter with a height of 27 1/16". The overall outer dimensions of the 55 gallon package model are then 21.1875" OD x 33.625" in height. The drum and payload vessel walls, upper and lower plates are modeled at their minimum thickness as indicated in Table 6-3.

The four vertical members, reinforcing angles, and bottom plate ring constructed from carbon steel have been conservatively neglected resulting in modeling less than 50% of the package carbon steel. All insulation products are conservatively modeled as optimum interspersed water moderation.

Packages and arrays of packages were also modeled with full density water boundary reflection.

6.3.2 Material Properties

Table 6-3 provides the materials and key dimensions used to evaluate the Century Versa-Pac Shipping Container. The density for each material used in the models is provided in Table 6-4. The default atomic number densities from the SCALE library were used for all materials and mixtures.

6.3.3 Computer Codes and Cross Section Libraries

The SCALE 4.4a code with the 44-Group Standard Cross Section Library was used to evaluate k_{eff} of the Century Versa-Pac Shipping Container under all conditions of transport. The code sequence BOMANI, NITAWL, and KENO VI (CSAS6) was used in all analyses.

The verification cases CSAS6 and KENOVI, as provided with the code for verification purposes, were executed prior to commencement of calculations and then upon completion of the final calculations. Other than time and date differences no additional differences were noted in a comparison of the different verification runs.

6.3.4 Demonstration of Maximum Reactivity

6.3.4.1 Fuel Density and Distribution

The fissile payload consisting of a maximum of 350 grams U-235 was modeled in all cases as U-Metal at an enrichment of 100 Wt%. This bounds other uranium compounds including oxides, fluorides, and nitrates. Moderation by both carbon and hydrogen, as discussed in Section 6.3.4.3, further bounds the presence of uranium containing carbon or graphite.

A fissile payload consisting of 350 grams U-235 was initially modeled as a function of the drum fill percentage ranging from 5% to 100% of the drum fill volume. The payload was also modeled as both spherical and cylindrical lumped configurations. The diameters of the spheres and cylinders were further varied to determine the effect on the fissile mass density. Also, the cylindrical heights were further varied to determine the effect on fissile mass density and interaction. The sensivity of k_{eff} with the fissile mass was further investigated at 375 and 400 grams U-235.

Polyethylene was modeled filling the voids of the fissile material with reductions in its volume fraction to consider partial moderation. The inner payload cavity, insulated package regions and exterior regions of the package were further evaluated with moderation ranging from partial to full water densities.

6.3.4.2 Heterogeneous Effects

All of the analyses of the Century Versa-Pac Shipping Container were completed using a homogeneous source material at an enrichment of 100 Wt%. The heterogenic effect noted with enriched Uranium is caused by the presence of U-238, which is not present in the model configurations. Therefore, the modeled homogeneous souce material is representative of and bounding of the proposed payload.

The material was modeled as descrete lumps as both spheres and cylinders to study in-homogeneous distribution effects of the fissile mass. The height-to-diameter ratio of the modeled cylinder was also varied. Spheres are typically more reactive than cylinders while cylinders are more interactive. The modeled conditions of the package will dictate the more reactive geometry. For instance, the modeled package carbon steel will have a more significant effect on the cylindrical geometry due to the higher degree of interaction between neibhoring cylinders.

6.3.4.3 Internal Moderation

6.3.4.3.1 Poly-Moderation

The fissile uranium mass was modeled with polyethylene (CH_2) moderation to bound a full range of packaging materials. The polyethylene was modeled at a density of 0.92 g/cc which results in a hydrogen density of 0.132 g/cc. This bounds water moderation (density of about 0.998 g/cc) with a corresponding hydrogen density of 0.112 g/cc. To bound other compounds containing more carbon and hydrogen, the polyethylene compound density is increased to 0.98 g/cc which increases the hydrogen

density to 0.141 g/cc. At this increased density, the polyethylene moderation would bound paraffin ($C_{25}H_{52}$) at a density of 0.90 g/cc. Paraffin has a hydrogen density of 0.134 g/cc. Optimum poly-moderation with an increased poly-density is therefore demonstrated for the package.

With evaluation of partial poly-moderation of the fissile contents a full range of moderation is considered for the package. Since water-moderation is bounded by poly-moderation, any amount of water- or poly-moderation may be present in the package, and pre-packaging materials having a hydrogen density less than or equal to that of polyethylene (density of 0.98 g/cc) do not need to be controlled for criticality purposes.

6.3.4.3.2 Carbon-Moderation

The fissile uranium mass was modeled with polyethylene (CH_2) moderation to bound a full range of packaging materials. The polyethylene was modeled at a density of 0.98 g/cc which results in an evaluated carbon density of 0.840 g/cc.

In all instances, the carbon-moderated cases are bounded by the poly-moderated cases. For the unlimited moderation case, there is no limit imposed on pre-packaging material or carbon-containing pre-packaging materials, as the carbon-moderation case is bounded by the increased density poly-moderation case.

6.3.4.4 Interspersed Moderation

A range of interspersed moderator (water) densities from 0.0001 to 1.00 g/cc were evaluated to determine the optimum interspersed moderator density for the packaging. Interspersed water moderation was evaluated for the thermal blanket and foam regions of the package. Water moderation was also considered in the package area that contains the vertical carbon steel stiffeners (e.g., square tubing and support angles) and further above the payload within the containment boundary. Also, interspersed water moderation was considered between packages.

The analysis results, as further presented, show that increasing the interspersed moderation from 0.0001 g/cc causes an increase in the single package multiplication factor and further causes a reduction in the multiplication factor for arrays of packages.

6.3.4.5 Package Array Configurations

Several different shipment package array configurations were evaluated to determine the most reactive arrangement. The package was evaluated using both square-pitched close-packed arrays and triangular-pitched close-packed arrays. The triangular-pitched arrays provide slightly more interaction between packages and yield the higher system k_{eff}.

The homogeneously distributed fissile mass systems, as indicated in Section 6.3.4.1, only considered the triangular-pitch close-packaged array. Square-pitched close-packed array calculations were not performed with the homogeneously distributed fissile mass since the k_{eff} results for these calculations were low and the results were significantly lower than the lumped fissile mass sytems.

However, the lumped fissile mass systems, as indicated in Section 6.3.4.2, considered both square-pitched close-packed arrays and triangular-pitched close-packed arrays. These calculations further considered the fissile mass as both spheres and cylinders. Both spheres and cylinders were considered in the array calculations due to the lower than expected differences noted in the k_{eff} results.

6.4 Single Package Evaluation

6.4.1 Configuration

The single package evaluation considered both the distributed fissile mass and a lumped fissile mass. The package geometry was considered in the distributed fissile mass calculations for the single package. Variations in the fissile mass moderator density and interspersed moderation were also considered in these calculations. A single model was constructed as previously indicated based on the HAC test results which is further bounding of the NCT configuration.

A lumped fissile mass is further evaluated without considering the package geometry since the mass could be essentially fully reflected with flooding of the package. Only variations in the fissile mass poly-moderator density were considered in these calculations since the lumped fissile mass is modeled with full boundary water reflection.

The HAC model would in general have the higher k_{eff} results when compared to a similar NCT model due to the reduced exterior package dimensions resulting from the required performance testing. However, the lumped spherical fissile mass with full boundary reflection bounds both NCT and HAC models in all cases since it is independent of the package modeled geometry. Therefore, the single package safety can be assessed with the use of a single very conservative model.

6.4.2 Results

The single package results are summarized in Table 6-5. All results are less than the conservative administrative Upper Subcritical Limit of 0.95 minus any code bias and uncertainty. Table 6-5 provides a summary of the multiplication factors for all calculations for the single package configurations. Figures 6-2 through 6-5 graphically display the results of the calculations.

The fully poly-moderated and reflected lumped spherical fissile mass provides the most reactive arrangement, Figure 6-5. However, the single package with distributed fissile mass is most reactive when the drum is filled to about 20%, Figures 6-2 and 6-4. Increasing the interspersed water moderation (within the package) density to about 1.0 g/cc maximizes the k_{eff} result (Figure 6-4) while reducing the poly-moderator density decreases the k_{eff} result (Figure 6-3).

Due to their simplicity, single package input cases are not provided in Section 6.9. However input cases can be constructed using the provided array input cases with modification of the array boundaries.

6.5 Evaluation of Package Arrays Under Normal Conditions of Transport

6.5.1 Configuration

The Normal Transport condition postulates a group of 5N Century Versa-Pac Shipping Containers (5(60)=300), optimized as discussed in Section 6.3.4. Close full water reflection is applied at the array boundary. Table 6-1 summarizes the evaluated fuel loadings and conditions for the Hypothetical Accident Conditions. Tables 6-6 through 6-9 provide summaries of the multiplication factors for all calculations for the Hypothetical Accident Condition package configuration including sensitivity studies.

A single model was constructed as previously indicated based on the HAC test results which is further bounding of the NCT configuration. The HAC model would in general have higher k_{eff} results when compared to a similar NCT model due to the more extensive damage resulting from testing. Therefore, the package array safety can be assessed with the use of a single very conservative model.

The package array evaluation considered both the distributed fissile mass and a lumped fissile mass. The package geometry was considered in the distributed fissile mass calculations for the package array evaluation. Variations in the fissile mass moderator density and interspersed moderation were also considered in these calculations.

6.5.2 Results

The results of these calculations are further detailed in Section 6.6.2.

6.6 Evaluation of Package Arrays Under Hypothetical Accident Conditions

6.6.1 Configuration

Regulation requires that a minimum of 2N damaged packages (2(150)=300), arranged in the most reactive array, be evaluated for Hypothetical Accident Conditions (HAC). However, since a single model is used for both NCT and HAC, the more limiting NCT 5N criterion is used in the determination of the appropriate CSI. Additionally, the evaluation includes optimum interspersed moderation, optimum fissile mass moderation, and close full reflection by water at the boundaries. Also, the fissile payload contents are arranged within the package in support of the most reactive array determination.

The package bottom offers the lowest amount of carbon steel interms of amount and thicknesses and further provides the shortest distance to the boundary of the package. Therefore, the most reactive package orientation occurs when the fissile mass is oriented at the base of the package with the bottom package further inverted and the top package stacked in its normal orientation. This places the lumped fissile mass within two contiguous packages in their closest proximity. The packages are then evaluated in both

square and triangular configurations with the lumped fissile mass further oriented to achieve maximum interaction between contiguous drums. Large package arrays are then constructed with duplication of the inverted and normal package arrangement. Figures 6-17 and 6-18 illustrate the package arrangement with lumped fissile mass for the triangular and square configurations, respectively. By comparison of both Figures 6-17 and 6-18 it is evident that more packages can be placed in a triangular array. Figure 6-19 illustrates the stacked package configuration with inverted bottom package and normally positioned top package and further shows the duplicated stack in a 4-high package array.

The results of the drop tests reported in Section 2 were used as a basis for determining the structural damage to the package under HAC. The overall OD and height of the package are modeled at 21.1875" and 33.625", respectively, per the configuration, conservatisms and approximations discussed in Section 6.3. This reduction in package diameter conservatively encompasses the damage resulting from both the side and top impact tests (see Section 2).

The density for each material used in the models is provided in Table 6-4. The default atomic number densities from the SCALE library were used for all materials and mixtures. Specific package orientations are further discussed.

6.6.1.1 Homogeneous Model

Two homogeneous model configuarations are investigated. The first model is similar to the single package array model but imployes specular reflection in a triangular array to produce an infinite array of packages. For the second model, the 350 gram U-235 fissile mass is evenly distributed in the base of the package with two packages oriented with one inverted such that the fissile mass within the two stacked drums are in a closer proximity. A finite model is constructed of this double stacked arrangement with specular boundary reflection applied to generate an infinite 3D array of packages. The packages are modeled in both a square and triangular configuration. The effect of interspersed moderation and variations in the fissile mass moderation density are further investigated.

The calculation results are significantly lower than that for the in-homogeneous models as further discussed in Section 6.6.1.2. The results are further presented in Section 6.6.2.

6.6.1.2 In-Homogeneous Model

Similar to the homogeneous model discussed in Section 6.6.1.1, the 350 gram U-235 fissile mass is lumped in the base of the containment region of the package with two packages oriented with one inverted such that the fissile mass within the two stacked packages are in close proximity. A finite model is constructed of this double stacked arrangement with placement of additional packages (drums) in a similar arrangement with their lumped fissile mass further placed in a similar fashion. A finite array of packages are then configured with explicitly modeled full water boundary reflection. The packages are modeled in both a square and triangular configuration with the lumped fissile masses further oriented in their respective packages to optimize interaction

between the lumped masses of adjacent packages. The effect of interspersed moderation and variations in the fissile mass poly-moderation density are further investigated.

Figures 6-17 and 6-18 display the modeled drum arrays in both the triangular and square lattice, respectively. Figure 6-19 further shows the Y-view of the model which in this case shows the sphere placement. A cylinder, with an H/D of 1.0, would occupy the same region as the sphere allowing easy conversion of the model from either sphere to cylinder and visa-versa. The package model places the fissile lump in the bottom of the package since the package bottom recognizies the shortest distance to a neibhoring lump in an adjacent package. The bottom portion of the package also has the least amount of carbon steel as the bottom plate is ¼" and the top containment closure is ½". The bottom package is then inverted, with the lump further in the bottom, with a normally oriented package above also with the fissile lump positioned in the base of the package containment region.

The calculated results for the lumped spherical and cylindrical results are anticipated to be very close. Additional sensitivity studies will be performed for the most reactive lumped configuration within the Century Versa-Pac Shipping Containers. The sensitivity calculations consider different cross section libraries, an increased fissile mass, further reductions in the minimum modeled carbon steel thicknesses, and an increased poly-moderation density.

The results are further discussed in Section 6.6.2.

6.6.2 Results

The maximum $k_{eff} + 2\sigma$ evaluated for an array of 300 packages for HAC is less than 0.94. This result is based on a fissile mass of 350 grams U-235 with poly-moderation at an increased density of 0.98 g/cc. The arrangement models about 50% of the carbon steel of the package with those selected components modeled at their minimum values based on standard manufacturing tolerances.

The maximum result occurs with a finite arrangement of Century Versa-Pac Shipping Containers oriented in a triangular configuration with the fissile mass modeled as spheres and further oriented within the package to achieve optimum interaction. A fully poly-moderated sphere diameter of 12.0-cm produces the maximum k_{eff} result for the evaluated package array. Sensitivity calculations as discussed in Section 6.6.1.2 are further provided.

Table 6-1 summarizes the evaluated fuel loadings and conditions for the most reactive Hypothetical Accident Condition model. However, Tables 6-6 through 6-9 provide summaries of the multiplication factors for all calculations for the Hypothetical Accident Condition package configuration.

6.6.2.1 Homogeneous Model

The infinite array calculations for the model discussed in Section 6.6.1.1 produced a maximum $k_{eff} + 2\sigma$ of 0.7175 with a 10% volume fill level for a homogeneously distributed 350 gram U-235 mass. Little difference is observed between packages

modeled in a triangular and square lattice but the triangular lattice does yield the higher k_{eff} by a difference of 0.0016. Reductions in the poly-moderation density cause the k_{eff} to be reduced. Likewise, increasing the interspersed water moderation also causes the keff to be reduced. Table 6-5 provides a summary of the multiplication factors for all calculations for the homogneous model Hypothetical Accident Condition package configuration.

Figure 6-6 displays the results of the homogeneously distributed fissile mass calculations for the inverted bottom/top package model in both triangular and square configurations as a function of the package fill percentage. Packages with a 10% fill volume appear to produce the higher k_{eff} results for this modeled configuration. Although not shown the the figure, the normally oriented packages have lower k_{eff} results and appear to have a maximum value also corresponding to a 10% fill volume. The results of both modeled configurations appear to be consistent.

Figure 6-7 displays the calculation results for conditions with reduced poly-moderation. The array k_{eff} is reduced with reduced poly-moderation density. The array k_{eff} is also reduced with increased interspersed moderation.

The maximum $k_{eff} + 2\sigma$ for this modeled configuration is 0.7175 and results in an EALF of 3.46E-02 eV. Due to the low k_{eff} results further sensitivity studies are not performed for the homogeneous model.

Two input cases are provided in Section 6.9. Case Versa_HAC_INFH_10_A represents an infinite (INF) array of packages with their fissile mass content occupying the bottom 10 volume percent of the inner package (containment). The package is modeled in a hexagonal (H) lattice arrangement with full fissile mass poly-moderation (A). Case Versa_HAC_INFH2_10_A represents an infinite (INF) array of packages with their fissile mass content occupying the bottom 10 volume percent of the inner package (containment). The packages are stacked in an array with the bottom package being inverted to achieve maximum interaction with a top package in its normal orientation. The package is modeled in a hexagonal (H) lattice arrangement as the second evaluated model (2) with full fissile mass poly-moderation (A). The results of these cases are presented in Table 6-5. These input cases can be modified to produce other input cases as referenced in Table 6-5.

6.6.2.2 In-Homogeneous Model

Both spheres and cylinders are evaluated in the lumped fissile mass model for the Century Versa-Pac Shipping Containers. Sphere and cylinder diameters ranging from 8-cm to 14-cm are modeled with cylinders further modeled by varying their height-to-diameter H/D ratios. Since the fissile mass is fixed at 350 grams U-235, cylinders modeled with a high H/D ratio will have a lower U-235 density when compared to cylinders with a lower H/D ratio. Thus, as the cylinder height is increased to further increase interaction between cylinders in adjacent packages the single unit reactivity is reduce with the reduction in the fissile mass density. The drums are arrangement in both a triangular and square lattice. Calculations are initially performed with expansion of a 2x2x2 drum array to a final array size of 10x10x8. Drum arrays are initially modeled

consisting of 8, 64, 144, 216, 384, 512, and 800 packages.

The 12.0-cm diameter sphere consistently produces the higher k_{eff} results in both triangular and square arrays with the triangular arrays consistently producing the highest result. The results of the lumped spherical mass calculations indicate that the triangular configuration is more reactive than the square arrays with an optimum sphere diameter of 12.0-cm. The triangular array is more reactive with increased sphere diameters of 14.0-cm, however reducing the sphere diameter to 10.0-cm causes the square array to become slightly more reactive. The lumped cylindrical fissile mass calculations are further described below. The cylindrical mass calculations will only consider arrangement in a triangular configuration since these arrays produced the higher k_{eff} results in the spherical model calculations.

The 10.0-cm and 12.0-cm diameter cylinders consistently produce the higher k_{eff} results. The 10.0-cm diameter cylinder produces a maximum value at an H/D of 1.0 while the 12.0-cm diameter cylinder produces a maximum value at an H/D of 0.80 with the k_{eff} results differing by only 0.0005. The results of the lumped spherical mass calculations for the 12.0-cm diameter sphere produce higher k_{eff} results with a k_{eff} difference of about 0.02. Therefore, sensitivity studies as indicated in Section 6.6.1.2 will be performed with the lumped spherical mass model.

The results of these cases are summarized in Table 6-7. Table 6-8 summarizes the results of increased poly-moderation density studies. Table 6-9 provides the sensitivity studies for the lumped spherical mass models as indicated in the preceding paragraph.

Two input cases are provided in Section 6.9. Case Versa_HAC_FINS_12S_A7 and Versa_HAC_FINH_12S_A7 represent finite (FIN) arrays of packages in square (S) and hexagonal lattices (H). The fissile mass is modeled as a 12-cm radius sphere in both cases (12S) with full fissile mass poly-moderation (A). The modeled array size is 800 packages (7) in an 10x10x8 array. Corresponding cases A1 through A6, as indicated in Table 6-7, can be reproduced with modification of the array parameters. Likewise, the cylindrical fissile mass models can be duplicated by changing the modeled sphere to a cylinder with further indication of the cylindrical height.

6.6.2.2.1 Expanded Array Analysis

The lumped 12.0-cm diameter spherical mass is used in an expanded array interaction analysis. The purpose of the analysis being to evaluate arrays of at least 400 packages starting with a single layer (Z=1) and continuing to a multiple stacked layer (Z=10). The object being to stack 400 packages in layers until the USL is exceeded and then reduce the number of packages in each layer and proceed with additional stacking. Stacked layers with a Z>10 were not modeled due to the decreased k_{eff} trend with the same package array size as the Z is increased from 8 to 10. The calculation results are combined with the initial drum array calculations as show in Figure 6-14. The initial results are indicated by "Trend 1" while the latter results are shown as "Trend 2". The results of these calculations indicate that package arrays consisting of 400, each containing a lumped fissile mass, has a $k_{eff} + 2\sigma$ of 0.94.

The results of these cases are further summarized in Table 6-8. A single input case is provided in Section 6.9. Case Versa_HAC_FINH_12S_10x064, representing an 8x8x10 package array. The nomenclature is similar to that described for other array input cases, however the 10x064 designation represents a modeled array with 10 packages in the Z with a single layer of 64 packages modeled in the X-Y direction (an 8x8 array). Other cases, as indicated in Table 6-8, can be reproduced with modification of the array parameters. Likewise, the cylindrical fissile mass models can be duplicated by changing the modeled sphere to a cylinder with further indication of the cylindrical height.

6.6.2.2.2 Increased Poly-Moderation Density

The calculations performed in Section 6.6.2.2.1 were duplicated with an increased poly-moderation density from 0.92 to 0.98 g/cc. The results, shown in Figures 6-14 and 6-15, indicate that an increase in the poly-moderation density causes a reduction in the drum array size from 400 to 300 while maintaining a $k_{eff} + 2\sigma$ of 0.94. For conservatism, the CSI is based on a 300 drum array.

Increasing the evaluated poly-moderation density to 0.98 g/cc bounds other carbon-hydrogen based moderators (paraffin) with sufficient margin.

Replacing the poly-moderation with graphite causes the array k_{eff}'s to decrease significantly. A single calculation for an 10x10x8 package array with the 12.0-cm diameter lumped 350 gram U-235 fissile mass moderated exclusive with graphite reported a k_{eff} of 0.1554. Therefore, the package array reactivity is dictated exclusively by the presence of hydrogen based moderation.

The results of these cases are summarized in Table 6-8. The single calculation with only graphite moderation is provided in Table 6-9. The input cases provided in Section 6.9 can be modified to duplicate the cases described in this section by changing the poly-moderation density from 0.92 to 0.98 and by further substitution of the poly-moderation input with graphite.

6.6.2.2.3 Interspersed Moderation

The initial array calculation model involving 800 drums with a 12.0-cm diameter sphere with an interspersed moderation volume fraction (VF) of 0.0001 were duplicated with the interspersed moderation values of 0.001, 0.01, 0.1, 0.5, and 1.0. The results, provided in Table 6-9, show that increasing the interspersed moderation causes the array k_{eff} to be reduced. With full interspersed moderation the k_{eff} result approaches the value of a single fully reflected sphere.

Input cases can be duplicated by changing mixture 5 in the provided input cases to the desired value.

6.6.2.2.4 Fissile Moderation Density

The initial array calculation model involving 800 drums with a fully poly-moderated (VF=1.0) 12.0-cm diameter sphere with an interspersed moderation volume fraction (VF) of 0.0001 were duplicated with reduced poly-moderation values (VF) of 90,

80, 70, 60, and 50. The results, provided in Table 6-9, show that decreasing the poly-moderation volume fraction causes the array k_{eff} to be reduced.

Input cases can be duplicated by changing the poly-moderation in mixture 1 in the provided input cases to the desired value.

6.6.2.2.5 Carbon Steel Reduction

The drum arrays initially modeled consisting of 8, 64, 144, 216, 384, 512, and 800 packages, as presented in Section 6.6.2.2, were duplicated by changing the Material and Volume Fraction for Carbon Steel to Water with a Volume Fraction of 0.0001. The results, provided in Table 6-9, show that eliminating the minimum modeled carbon steel causes the array k_{eff} to be increased. By comparison, the analysis involving the minimum modeled carbon steel thicknesses supported an array size of 400 drums.

A reduction of the minimum fabricated carbon steel thicknesses to values below the manufacturing tolerances causes a significant impact on the results. The original analysis essentially considered approximately 50% of the carbon steel of the package. Eliminating the minimum carbon steel in the modeled configuration decreases the array size from 400 to about 216. Further reductions may be necessary when considering a cylindrical lumped fissile mass. Therefore, the minimum modeled carbon steel thicknesses are not only required for structural integrity but also needed to ensure that the USL is not exceeded.

Input cases can be duplicated by changing the volume fraction of mixture 3 in the provided input cases to 0.50.

6.6.2.2.6 Cross Section and Neutron Histories

The initial array calculation model involving 800 drums is executed again by changing the modeled cross sections from the 44-Group Standard Cross Section Library to the 238 group. The case is executed with 600 generations and 1000 neutrons per group (600,000 neutron histories). The results differ by 0.0001 with the 44-Group generating the larger value.

To determine the sensitivity to the magnitude of the neutron histories the case is again executed with the 238-group cross sections with 600 generations and the neutrons per group increased from 1000 to 2000 (1,200,000 neutron histories). Although the $k_{eff} + 2\sigma$ for the case increases by 0.0017 the result is within 2σ of the original result. For comparison, the case using the 44-group cross sections is executed with 600 generations and 2000 neutrons per group. The raw k_{eff} for this case increases by 0.0010 however with reduction in the uncertainty the final $k_{eff} + 2\sigma$ result remains the same.

The use of differenct cross sections and increasing the neutron histories did not change the final result. Therefore, the cases used in the original analysis are sufficient and properly converged. There is also no observed benefit with migration of a larger group cross section library as the 44-group produces consistent results. The results are further summarized in Table 6-9.

Input cases can be duplicated by changing the cross section input, neutron

generations and neutrons per group to their desired values.

6.6.2.2.7 Increased Fissile Mass

The drum arrays initially modeled consisting of 8, 64, 144, 216, 384, 512, and 800 packages, as presented in Section 6.6.2.2, were each duplicated by increasing the fissile mass from 350 grams U-235 to 375 and 400 grams U-235. The results, provided in Table 6-9, show that increasing the fissile mass by 25 grams requires that the drum array size be reduced. The 350 gram U-235 model, as originally evaluated, could potentially support a 550 package array and remain below a $k_{eff} + 2\sigma$ of 0.94. The 375 and 400 gram U-235 models require that the array, using the original array models, be reduced to 350 and 275 packages to remain below a $k_{eff} + 2\sigma$ of 0.94, respectively.

Increasing the fissile mass above 350 grams U-235 requires additional sensitivity analysis as it is quite possible that a larger or smaller fissile lump could become more reactive than the 12.0-cm diameter sphere as modeled in the above cases. Therefore, a fissile mass content no greater than 350 grams U-235 is recommended for the Century Versa-Pac Shipping Containers.

Input cases can be duplicated from those provided in Section 6.9 by changing the fissile constituent volume fraction of mixture 1 to correspond to the increased fissile mass.

6.7 Fissile Material Packages for Air Transport

The Century Versa-Pac Shipping Container is not authorized for air transport.

6.8 Benchmark Evaluations

6.8.1 Benchmark Experiments and Applicability

Reference 6-1 documents 161 critical experiments modeled using the SCALE 4.4a code (KENO VI) with the 44 Group Standard Cross Section Library. Uranium compounds used in the experiments include uranyl nitrate, uranium fluoride, uranium dioxide, uranium-aluminum alloys, and uranium metal. Moderators included water, alcohol, nitric acid, hydrofluoric acid, beryllium, aluminum and silicon oxides, water, D_2O, iron, tungsten, plastics and graphite. Reflectors included aluminum, steel, concrete, water, D_2O, titanium, tungsten, lead, iron, and graphite. Enrichments ranged from 62.4 to 97.68 wt% U-235. The H/X ratio ranged from 0 to 1,837. ALCF (eV) ranged from 3.0E-02 to 9.14E+05. The fuel density ranged from 0.014 to 18.6 gU-235/cc.

The HEU experiments were selected and categorized into four distinct groups. These groupings consisted of:

Group 1: All experiments (161) used in this validation,

Group 2: Experiments (81) with ALCF $\leq 10^{-2}$ eV, data sets 1-82, and

Group 3: Experiments (56) with ALCF > 10^{-2} eV and ≤ 10^5 eV, data sets 83-138, and

Group 4: Experiments (24) with ALCF > 10^5 eV, data sets 139-162.

The cases evaluated for the Century Versa-Pac Shipping Container include uranium metal, water, graphite, steel, and plastic moderation/reflection. The Century Versa-Pac Shipping Container cases were evaluated at an enrichment of 100 wt% ^{235}U, and the H/X ratio ranged from 0 to 1,011. The ALCF for the Century Versa-Pac Shipping Container cases ranged from 3.00E-02 to 9.90E-02. The fuel density ranged from 0.00160 to 0.020 gU-235/cc. Although the evaluated higher enrichment falls very slightly outside the validated range, the benchmark results for Group 2 and Group 3 are directly applicable to the Century Versa-Pac Shipping Container cases.

6.8.2 Bias Determination

Details of the benchmark calculations are provided in Reference 6-1. In order to validate the SCALE 4.4a code for use with high-enriched uranium systems, it is necessary to determine if KENO predicts the multiplication factor in an accurate and precise manner throughout the range of fission energies of interest. To evaluate the accuracy of the code, the mean of each Group of experiments was compared to the mean of the experimental results. A t-test was performed for each Group to determine whether or not the average result of a KENO calculation (the mean calculated k_{eff} for each Group) is statistically the same as the experimental result (unity). Passing the t-test affirms that the KENO code predicts multiplication factors accurately for the Group being tested, without bias. Failure of the t-test indicates that the mean KENO k_{eff} is statistically different from the experimental mean, and that a bias exists in the data. Groups that failed the t-test were further evaluated for bias and uncertainty, and these parameters applied to provide an upper limit subcritical multiplication factor for the Group.

Each Group of KENO-calculated k_{eff}s are also graphed against key system parameters (Energy of the Average Lethargy Causing Fission (ALCF), Hydrogen-to-Fissile Atom Ratio (H/^{235}U), enrichment, and fissile material density (g ^{235}U/cc)) to identify trends within the data that may indicate inaccurate cross-sections or instabilities in the code. The normality of residuals is also tested using the Anderson-Darling method. The null hypothesis of a normality test is that there is no significant departure from normality. When the probability level, ρ is greater than 0.05, it fails to reject the null hypothesis and thus the assumption holds. Histogram, skewness and kurtosis plots are also provided for each group.

Jaech's[2] method for bias determination is applied, and the upper subcritical limit is calculated based upon NUREG/CR-6361.[3]

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[2] Jaech, J., *Statistical Methods in Nuclear Material Control,* Exxon Nuclear Company, Richland, WA (1973).

[3] *Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and*

6.8.3 Benchmark Results

For the groups of interest for the Century Versa-Pac Shipping Container, the bounding combined bias and bias uncertainty was reported as 0.0026 (Group 3). Thus, including a conservative 5% administrative margin, the applicable upper subcritical limit for the Century Versa-Pac Shipping Container is 0.9466 for the calculated k_{eff} $+2\sigma$. For conservatism, a USL of 0.94 is further adopted.

6.9 List of Appendices

6.9.1 Selected SCALE 4.4a Input Cases

6.9.2 Reference [6-1]

6.10 References

[6-1] Montgomery, Richard D. Validation of SCALE-PC for High Enriched Uranium (HEU) Systems, MTS423, Rev. 1, 5/30/09.

Storage Packages, NUREG/CR-6361 (ORNL/TM-13211), (March 1997).

Table 6-1 Summary of Results for the Most Reactive Case

Number of Packages	Package Array Size	Material	Poly-Moderation Density	^{235}U Mass (kg)	Interspersed Moderation (water volume fraction)	Close Water Reflection	H/X Note 1	EALF (eV)	k_{eff}	σ	$k_{eff} + 2\sigma$	Applicable USL
Lumped Spherical Fissile Mass Model – Triangular Lattice – Increased Poly-Moderation Density												
400	16x26x1	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.92E-02	0.8240	0.0011	0.8262	0.94
416	16x26x1	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.92E-02	0.8273	0.0012	0.8297	0.94
468	18x26x1	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.93E-02	0.8249	0.0012	0.8273	0.94
720	20x18x2	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.95E-02	0.9077	0.0011	0.9099	0.94
800	16x25x2	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9076	0.0010	0.9096	0.94
832	16x26x2	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9074	0.0013	0.9100	0.94
936	18x26x2	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9110	0.0012	0.9134	0.94
360	10x12x3	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9202	0.0012	0.9226	0.94
432	12x12x3	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9253	0.0011	0.9275	0.94
672	14x16x3	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.95E-02	0.9371	0.0013	0.9397	0.94

Table 6-1 Summary of Results for the Most Reactive Case

Number of Packages	Package Array Size	Material	Poly-Moderation Density	^{235}U Mass (kg)	Interspersed Moderation (water volume fraction)	Close Water Reflection	H/X Note 1	EALF (eV)	k_{eff}	σ	$k_{eff} + 2\sigma$	Applicable USL
Lumped Spherical Fissile Mass Model – Triangular Lattice – Increased Poly-Moderation Density												
144	6x6x4	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.93E-02	0.8720	0.0011	0.8742	0.94
480	10x12x4	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.95E-02	0.9359	0.0011	0.9381	0.94
400	8x10x5	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.95E-02	0.9322	0.0012	0.9346	0.94
216	6x6x6	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.93E-02	0.8814	0.0012	0.8838	0.94
384	8x8x6	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9154	0.0012	0.9178	0.94
480	8x10x6	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9373	0.0012	0.9397	0.94
448	8x8x7	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9319	0.0012	0.9343	0.94
512	8x8x8	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9219	0.0012	0.9243	0.94
640	8x8x10	U-Metal, 12.0-cm Dia. Sphere	0.98	0.350	0.0001	Yes	636	3.94E-02	0.9340	0.0011	0.9362	0.94

Notes on Table 6-1:

1. X in this case refers to U-235; since the modeled enrichment is 100 Wt%.

Table 6-2 Century Versa-Pac Shipping Container – Test Package Dimensional Changes

Location	Description	Package 10550	Package 10551	Package 10552
A-C	Inner Container Inner Diameter	+ 1/8	NC	+ 1/16
A-C	Outer Container Outer Diameter	+ 1/16	NC	- 3/16
A	Drum Height	+ 1/8	+ 1/16	- 3/16
A	Wall – In/Out	+ 1/8	- 1/16	+ 1/8
A	Inside Height	NC	NC	NC
A	Top Rim – Inside Flange	+ 1/8	+ 1/8	- 3/8
B	Drum Height	+ 1/16	NC	- 1/4
B	Top Rim – Inside Flange	+ 1/16	NC	- 1/4
B	Wall – In/Out	- 1/8	NC	+ 1/8
B-D	Inner Container Inner Diameter	+ 1/16	NC	NC
B-D	Outer Container Outer Diameter	- 1/16	+ 1/8	- 5/16
C	Drum Height	NC	NC	NC
C	Wall – In/Out	+ 3/16	+ 1/16	- 11/16
C	Inside Height	NC	+ 5/16	- 1/8
C	Top Rim – Inside Flange	- 1/16	NC	- 1/4
D	Drum Height	NC	NC	NC
D	Top Rim – Inside Flange	NC	+ 1/16	- 1/16
D	Wall – In/Out	- 1/16	+ 1/16	- 7/16
D	Inner Container	+ 7/16	- 1/8	NC

NC – Denotes No Change (Dimensional) with tested orientation

Table 6-3 Century Versa-Pac Shipping Container Dimensions and Materials

Component	Actual Dimension		Modeled Dimension		Actual material	Modeled material/Notes
	(in)	(cm)	(in)	(cm)		
Radial Direction						
Payload vessel Inner diameter	15.0	38.1	15.0 – 15.125	38.1 – 38.4175	Payload – Containment Boundary	0.350 kg U-235 payload with varying poly-moderation using void to create all densities that physically fit in the cylinder for the maximum mass allowed. Both homogeneous and in-homogeneous (lumped) fissile masses are modeled.
Payload vessel Wall thickness	0.1345 (10 ga)	0.3416	0.1211	0.3076	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Insulation thickness	3.0	7.62	2.5	6.35	Insulation	Optimum interspersed moderator
Inner liner wall thickness	0.0598 (16 ga)	0.1518	0.0533	0.1354	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Outer insulation, vertical and horizonal tubing and angles	1.25	3.175	1.25 NCT 0.25 HAC	3.175 NCT 0.6356 HAC	Carbon Steel & Insulation	Optimum interspersed moderator. Carbon steel tubing and angles are neglected for conservatism.
Outer liner wall thickness	0.0598 (16 ga)	0.1518	0.0533	0.1354	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Drum wall thickness	0.0598 (16 ga)	0.1518	0.0533	0.1354	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Drum outer radius	11.531 [Note 1]	29.2887	11.250 NCT [Note 2] 10.593 HAC	28.575 NCT 26.908 HAC	N/A	The outer radius of the 55 gallon package is 23". Neglicting the drum stiffeners and bolt ring reduces the outer diameter to 22-1/2". For the bounding HAC/NCT model, the 55-gallon drum is further modeled with a reduced outer diameter of 1.313" which significantly bounds the maximum reduced dimension resulting from the tests of 0.313" (5/16") as indicated in Section 2. The outer radius of the 55 gallon package HAC model is then 21.1875".
Axial Direction From Bottom of Package						
Drum bottom thickness	0.0598 (16 ga)	0.1518	0.0533	0.1354	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Bottom reinforcing plate	0.25	0.635	0.24	0.6096	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Bottom insulation layer thickness	2.5	6.35	2.5	6.35	Insulation	Optimum interspersed moderator
Payload vessel Bottom wall thickness	0.1345 (10 ga)	0.3416	0.1211	0.3076	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance

Payload vessel *Inner height*	27.0625	38.1	27.0625 – 27.1875	38.1 – 38.4175	Payload – Containment Boundary	0.350 kg U-235 payload with varying poly-moderation using void to create all densities that physically fit in the cylinder for the maximum mass allowed. Both homogeneous and in-homogeneous (lumped) fissile masses are modeled.
Payload vessel Closure lid wall thickness	0.50	1.27	0.49	1.2446	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Lid-to-plug gap	0.9065	2.3025	0.4265	1.0833	Gasket, Carbon steel bolts, Air	Clearance for gasket and inner fasteners. Modeled as optimum interspersed moderator
Inner plug liner	0.0598 (16 ga)	0.1518	0.0533	0.1354	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Top insulation layer thickness	2.5	6.35	2.5	6.35	Insulation	Optimum interspersed moderator
Drum lid	0.0598 (16 ga)	0.1518	0.0533	0.1354	Carbon steel	Carbon steel modeled with reduced manufacturing tolerance
Drum outer height	34.5 [Note 3]	87.63	34.0 NCT [Note 4] 33.625 HAC	86.36 NCT 85.4075 HAC	N/A	The outer height of the 55 gallon package is 34-1/2". Neglicting the drum bottom chime reduces the outer height to 34". For the bounding HAC model, the 55-gallon drum is modeled with a reduced outer height of 0.875" which bounds the maximum reduced dimension resulting from the tests of 0.250" (1/4") as indicated in Section 2. The outer height of the 55 gallon package HAC model is then 33.625".

Notes on Table 6-3:

1. Dimension includes the drum ring stiffeners, lid, chime, and lock ring.
2. Dimension does not include the drum ring stiffeners, lid, chime, or lock ring.
3. Dimension includes the drum bottom chime.
4. Dimension does not include the drum bottom chime.

Table 6-4 Package Regional Densities

Material	Maximum Material Density (g/cc) at 21°C	Material Hydrogen Density (g/cc)
UO_2	10.96	N/A
U-metal	19.05	N/A
UNX at 1,274 gU/L	2.705	N/A
H_2O	0.9982	0.1117
Carbon Steel (CS)	7.8212	N/A
Polyethylene – CH_2	0.92 – 0.98	0.1323 – 0.1409
Pariffin – $C_{25}H_{52}$	0.90	0.1338
Carbon (graphite)	2.300	N/A

Table 6-5 Summary of Single Package Results

Case ID	Drum Fill Percent	Poly-Moderation	^{235}U Mass (kg)	Interspersed Moderation (water volume fraction)	Close Water Reflection	k_{eff}	σ	$k_{eff} + 2\sigma$	EALF (eV)	Comments
Homogeneous Fissile Material as a Function of Drum Fill Percentage										
VERSAPAK_HAC_SIN_5_A	5	100	0.350	0.0001	Yes	0.1546	0.0006	0.1558	4.87E-02	
VERSAPAK_HAC_SIN_10_A	10	100	0.350	0.0001	Yes	0.3155	0.0007	0.3169	3.45E-02	
VERSAPAK_HAC_SIN_15_A	15	100	0.350	0.0001	Yes	0.3950	0.0006	0.3962	3.11E-02	
VERSAPAK_HAC_SIN_20_A Note 1	20	100	0.350	0.0001	Yes	0.4193	0.0006	0.4205	2.97E-02	
VERSAPAK_HAC_SIN_30_A	30	100	0.350	0.0001	Yes	0.3993	0.0007	0.4007	2.84E-02	
VERSAPAK_HAC_SIN_40_A	40	100	0.350	0.0001	Yes	0.3591	0.0005	0.3601	2.79E-02	
VERSAPAK_HAC_SIN_60_A	60	100	0.350	0.0001	Yes	0.2849	0.0003	0.2855	2.74E-02	
VERSAPAK_HAC_SIN_80_A	80	100	0.350	0.0001	Yes	0.2318	0.0002	0.2322	2.71E-02	
VERSAPAK_HAC_SIN_100_A	100	100	0.350	0.0001	Yes	0.1946	0.0002	0.1950	2.70E-02	
Homogeneous Fissile Material as a Function of Poly-Moderation Density										
VERSAPAK_HAC_SIN_20_A Note 1	20	100	0.350	0.0001	Yes	0.4193	0.0006	0.4205	2.97E-02	k_{eff} decreases with reduced poly-moderation density
VERSAPAK_HAC_SIN_20_B	20	90	0.350	0.0001	Yes	0.4003	0.0007	0.4017	3.02E-02	
VERSAPAK_HAC_SIN_20_C	20	80	0.350	0.0001	Yes	0.3741	0.0007	0.3755	3.09E-02	
VERSAPAK_HAC_SIN_20_D	20	70	0.350	0.0001	Yes	0.3385	0.0006	0.3397	3.19E-02	
VERSAPAK_HAC_SIN_20_E	20	60	0.350	0.0001	Yes	0.2936	0.0006	0.2948	3.33E-02	
VERSAPAK_HAC_SIN_20_F	20	50	0.350	0.0001	Yes	0.2397	0.0006	0.2409	3.54E-02	
Homogeneous Fissile Material as a Function of Interspersed-Moderator Density										
VERSAPAK_HAC_SIN_20_A Note 1	100	100	0.350	0.0001	Yes	0.4193	0.0006	0.4205	2.97E-02	k_{eff} increases with increased interspersed moderation density
VERSAPAK_HAC_SIN_20_Aa	100	100	0.350	0.001	Yes	0.4195	0.0006	0.4207	2.97E-02	
VERSAPAK_HAC_SIN_20_Ab	100	100	0.350	0.01	Yes	0.4215	0.0006	0.4227	2.96E-02	
VERSAPAK_HAC_SIN_20_Ac	100	100	0.350	0.1	Yes	0.4335	0.0006	0.4347	2.95E-02	
VERSAPAK_HAC_SIN_20_Ad	100	100	0.350	0.5	Yes	0.4708	0.0007	0.4722	2.91E-02	
VERSAPAK_HAC_SIN_20_Ae	100	100	0.350	1.0	Yes	0.4839	0.0006	0.4851	2.90E-02	Maximum Homogeneous Result
Single Lumped Fissile Mass	**Sphere Diameter, in**									
VERSAPAK_HAC_SIN_6S_A	6	100	0.350	0.0001	Yes	0.6471	0.0012	0.6495	1.45E-01	

VERSAPAK_HAC_SIN_8S_A	8	100	0.350	0.0001	Yes	0.7927	0.0012	0.7951	6.55E-02	
VERSAPAK_HAC_SIN_10S_A	10	100	0.350	0.0001	Yes	0.8683	0.0012	0.8707	4.47E-02	
VERSAPAK_HAC_SIN_12S_A[Note 2]	12	100	0.350	0.0001	Yes	0.8814	0.0012	0.8838	3.66E-02	**Maximum Lumped Result**
VERSAPAK_HAC_SIN_14S_A	14	100	0.350	0.0001	Yes	0.8429	0.0011	0.8451	3.27E-02	
Single Lumped Fissile Mass as a Function of Poly-Moderation Density										
VERSAPAK_HAC_SIN_12S_A[Note 2]	12	100	0.350	0.0001	Yes	0.8814	0.0012	0.8838	3.66E-02	**k_{eff} decreases with reduced poly-moderation density**
VERSAPAK_HAC_SIN_12S_B	12	90	0.350	0.0001	Yes	0.8431	0.0012	0.8455	3.77E-02	
VERSAPAK_HAC_SIN_12S_C	12	80	0.350	0.0001	Yes	0.7952	0.0011	0.7974	3.90E-02	
VERSAPAK_HAC_SIN_12S_D	12	70	0.350	0.0001	Yes	0.7411	0.0011	0.7433	4.07E-02	
VERSAPAK_HAC_SIN_12S_E	12	60	0.350	0.0001	Yes	0.6800	0.0012	0.6824	4.27E-02	

Notes on Table 6-5:

1. Duplicate entry for observance of trend.
2. Duplicate entry for observance of trend.

Table 6-6 Summary of Hypothetical Accident Condition Package Results for Homogeneous Models

Case ID	Drum Fill Percent	Poly-Moderation	^{235}U Mass (kg)	Interspersed Moderation (water volume fraction)	Close Water Reflection	k_{eff}	σ	$k_{eff}+2\sigma$	EALF (eV)	Comments
Infinite Triangular Package Array - Homogeneous Fissile Material as a Function of Drum Fill Percentage – Bottom Filled Package Model										
VERSAPAK_HAC_INFH_5_A	5	100	0.350	0.0001	Yes	0.6807	0.0008	0.6823	4.77E-02	
VERSAPAK_HAC_INFH_10_A Note 1	10	100	0.350	0.0001	Yes	0.7158	0.0006	0.7170	3.46E-02	
VERSAPAK_HAC_INFH_15_A	15	100	0.350	0.0001	Yes	0.6673	0.0005	0.6683	3.14E-02	
VERSAPAK_HAC_INFH_20_A	20	100	0.350	0.0001	Yes	0.6104	0.0005	0.6114	3.00E-02	
Infinite Triangular Package Array - Homogeneous Fissile Material as a Function of Poly-Moderation Density – Bottom Filled Package Model										
VERSAPAK_HAC_INFH_10_A Note 1	10	100	0.350	0.0001	Yes	0.7158	0.0006	0.7170	3.46E-02	**k_{eff} decreases with reduced poly-moderation density**
VERSAPAK_HAC_INFH_10_B	10	90	0.350	0.0001	Yes	0.7149	0.0006	0.7161	3.58E-02	
VERSAPAK_HAC_INFH_10_C	10	80	0.350	0.0001	Yes	0.7082	0.0006	0.7094	3.76E-02	
Infinite Triangular Package Array - Homogeneous Fissile Material as a Function of Interspersed Moderator Density – Bottom Filled Package Model										
VERSAPAK_HAC_INFH_10_Aa	10	100	0.350	0.001	Yes	0.7083	0.0006	0.7095	3.45E-02	**k_{eff} decreases with increased interspersed moderator density**
VERSAPAK_HAC_INFH_10_Ba	10	90	0.350	0.001	Yes	0.7063	0.0006	0.7075	3.58E-02	
VERSAPAK_HAC_INFH_10_Ca	10	80	0.350	0.001	Yes	0.7002	0.0007	0.7016	3.75E-02	
VERSAPAK_HAC_INFH_10_Ab	10	100	0.350	0.01	Yes	0.6420	0.0006	0.6432	3.42E-02	
VERSAPAK_HAC_INFH_10_Bb	10	90	0.350	0.01	Yes	0.6347	0.0006	0.6359	3.54E-02	
VERSAPAK_HAC_INFH_10_Cb	10	80	0.350	0.01	Yes	0.6209	0.0007	0.6223	3.70E-02	
VERSAPAK_HAC_INFH_10_Ac	10	100	0.350	0.1	Yes	0.4959	0.0007	0.4973	3.30E-02	
VERSAPAK_HAC_INFH_10_Bc	10	90	0.350	0.1	Yes	0.4780	0.0007	0.4794	3.39E-02	
VERSAPAK_HAC_INFH_10_Cc	10	80	0.350	0.1	Yes	0.4551	0.0007	0.4565	3.49E-02	
Infinite Triangular Package Array - Homogeneous Fissile Material as a Function of Drum Fill Percentage – Bottom Filled Inverted Bottom Package Model										
VERSAPAK_HAC_INFH2_5_A	5	100	0.350	0.0001	Yes	0.6817	0.0007	0.6831	4.77E-02	**Bottom filled inverted model is more reactive than previous bottom filled model**
VERSAPAK_HAC_INFH2_5_B	5	90	0.350	0.0001	Yes	0.6625	0.0006	0.6637	5.15E-02	
VERSAPAK_HAC_INFH2_5_C	5	80	0.350	0.0001	Yes	0.6374	0.0006	0.6386	5.70E-02	
VERSAPAK_HAC_INFH2_5_D	5	70	0.350	0.0001	Yes	0.608	0.0007	0.6094	6.50E-02	
VERSAPAK_HAC_INFH2_5_E	5	60	0.350	0.0001	Yes	0.5727	0.0006	0.5739	7.74E-02	
VERSAPAK_HAC_INFH2_5_F	5	50	0.350	0.0001	Yes	0.5317	0.0006	0.5329	9.90E-02	
VERSAPAK_HAC_INFH2_10_A	10	100	0.350	0.0001	Yes	0.7161	0.0007	0.7175	3.46E-02	

VERSAPAK_HAC_INFH2_10_B	10	90	0.350	0.0001	Yes	0.7141	0.0006	0.7153	3.58E-02	
VERSAPAK_HAC_INFH2_10_C	10	80	0.350	0.0001	Yes	0.7082	0.0006	0.7094	3.76E-02	
VERSAPAK_HAC_INFH2_10_D	10	70	0.350	0.0001	Yes	0.697	0.0007	0.6984	3.99E-02	
VERSAPAK_HAC_INFH2_10_E	10	60	0.350	0.0001	Yes	0.6769	0.0007	0.6783	4.34E-02	
VERSAPAK_HAC_INFH2_10_F	10	50	0.350	0.0001	Yes	0.6465	0.0007	0.6479	4.91E-02	
VERSAPAK_HAC_INFH2_15_A	15	100	0.350	0.0001	Yes	0.6664	0.0006	0.6676	3.15E-02	
VERSAPAK_HAC_INFH2_15_B	15	90	0.350	0.0001	Yes	0.6773	0.0005	0.6783	3.22E-02	
VERSAPAK_HAC_INFH2_15_C	15	80	0.350	0.0001	Yes	0.6829	0.0006	0.6841	3.32E-02	
VERSAPAK_HAC_INFH2_15_D	15	70	0.350	0.0001	Yes	0.6874	0.0006	0.6886	3.45E-02	
VERSAPAK_HAC_INFH2_15_E	15	60	0.350	0.0001	Yes	0.6824	0.0006	0.6836	3.65E-02	
VERSAPAK_HAC_INFH2_15_F	15	50	0.350	0.0001	Yes	0.6707	0.0006	0.6719	3.94E-02	
VERSAPAK_HAC_INFH2_20_A	20	100	0.350	0.0001	Yes	0.6089	0.0005	0.6099	3.00E-02	
Infinite Triangular Package Array - Homogeneous Fissile Material as a Function of Poly-Moderation Density – Bottom Filled Inverted Bottom Package Model										
VERSAPAK_HAC_INFH2_10_Aa	10	100	0.350	0.001	Yes	0.7090	0.0006	0.7102	3.45E-02	**k_{eff} decreases with reduced poly-moderation density**
VERSAPAK_HAC_INFH2_10_Ba	10	100	0.350	0.001	Yes	0.7060	0.0006	0.7072	3.58E-02	
VERSAPAK_HAC_INFH2_10_Ca	10	100	0.350	0.001	Yes	0.6990	0.0006	0.7002	3.75E-02	
VERSAPAK_HAC_INFH2_10_Ab	10	100	0.350	0.01	Yes	0.6431	0.0007	0.6445	3.42E-02	
VERSAPAK_HAC_INFH2_10_Bb	10	100	0.350	0.01	Yes	0.6325	0.0007	0.6339	3.54E-02	
VERSAPAK_HAC_INFH2_10_Cb	10	100	0.350	0.01	Yes	0.6197	0.0007	0.6211	3.70E-02	
VERSAPAK_HAC_INFH2_10_Ac	10	100	0.350	0.1	Yes	0.4956	0.0008	0.4972	3.30E-02	
VERSAPAK_HAC_INFH2_10_Bc	10	100	0.350	0.1	Yes	0.4762	0.0007	0.4776	3.39E-02	
VERSAPAK_HAC_INFH2_10_Cc	10	100	0.350	0.1	Yes	0.4530	0.0007	0.4544	3.50E-02	
Infinite Square Package Array - Homogeneous Fissile Material as a Function of Drum Fill Percentage – Bottom Filled Inverted Bottom Package Model										
VERSAPAK_HAC_INFS2_5_A	5	100	0.350	0.0001	Yes	0.6800	0.0007	0.6814	4.77E-02	**k_{eff} decreases for square array**
VERSAPAK_HAC_INFS2_10_A	10	100	0.350	0.0001	Yes	0.7145	0.0007	0.7159	3.46E-02	
VERSAPAK_HAC_INFS2_15_A	15	100	0.350	0.0001	Yes	0.6663	0.0005	0.6673	3.14E-02	
VERSAPAK_HAC_INFS2_20_A	20	100	0.350	0.0001	Yes	0.6082	0.0005	0.6092	3.01E-02	
VERSAPAK_HAC_INFS2_30_A	30	100	0.350	0.0001	Yes	0.5063	0.0004	0.5071	2.88E-02	
Infinite Triangular Package Array - Homogeneous Fissile Material as a Function of Drum Fill Percentage – Bottom Filled Inverted Bottom Package Model – Reduced Containment Cavity Radius										
VERSAPAK_HAC_INFH2_10M_A	10	100	0.350	0.0001	Yes	0.7292	0.0006	0.7304	3.46E-02	**Containment radius reduced from 19.2088 to 19.05-cm**

Notes on Table 6-6:

1. Duplicate entry for observance of trend.

Table 6-7 Summary of Hypothetical Accident Condition Package Results for Lumped Fissile Mass Models

Case ID	Radius (cm) of Sphere or Cylinder (H/D)	Modeled Package Array	Poly-Moderation	^{235}U Mass (kg)	Interspersed Moderation (water volume fraction)	Close Water Reflection	k_{eff}	σ	$k_{eff} + 2\sigma$	EALF (eV)	Comments
Triangular Package Arrays – Lumped Spherical Fissile Mass – Initial Array Sensitivity Study											
VERSAPAK_HAC_FINH_8S_A1	8	2x2x2=8	100	0.350	0.0001	Yes	0.5932	0.0013	0.5958	8.89E-02	
VERSAPAK_HAC_FINH_8S_A2	8	4x4x4=64	100	0.350	0.0001	Yes	0.6311	0.0013	0.6337	8.84E-02	
VERSAPAK_HAC_FINH_8S_A3	8	6x6x4=144	100	0.350	0.0001	Yes	0.6672	0.0014	0.6700	8.82E-02	
VERSAPAK_HAC_FINH_8S_A4	8	6x6x6=216	100	0.350	0.0001	Yes	0.6827	0.0014	0.6855	8.79E-02	
VERSAPAK_HAC_FINH_8S_A5	8	8x8x6=384	100	0.350	0.0001	Yes	0.7182	0.0014	0.7210	8.79E-02	
VERSAPAK_HAC_FINH_8S_A6	8	8x8x8=512	100	0.350	0.0001	Yes	0.7282	0.0013	0.7308	8.76E-02	
VERSAPAK_HAC_FINH_8S_A7	8	10x10x8=800	100	0.350	0.0001	Yes	0.7695	0.0014	0.7723	8.74E-02	
VERSAPAK_HAC_FINH_10S_A1	10	2x2x2=8	100	0.350	0.0001	Yes	0.7381	0.0014	0.7409	5.11E-02	
VERSAPAK_HAC_FINH_10S_A2	10	4x4x4=64	100	0.350	0.0001	Yes	0.7804	0.0012	0.7828	5.11E-02	
VERSAPAK_HAC_FINH_10S_A3	10	6x6x4=144	100	0.350	0.0001	Yes	0.8214	0.0012	0.8238	5.10E-02	
VERSAPAK_HAC_FINH_10S_A4	10	6x6x6=216	100	0.350	0.0001	Yes	0.8346	0.0011	0.8368	5.12E-02	
VERSAPAK_HAC_FINH_10S_A5	10	8x8x6=384	100	0.350	0.0001	Yes	0.8712	0.0015	0.8742	5.11E-02	
VERSAPAK_HAC_FINH_10S_A6	10	8x8x8=512	100	0.350	0.0001	Yes	0.8841	0.0014	0.8869	5.10E-02	
VERSAPAK_HAC_FINH_10S_A7	10	10x10x8=800	100	0.350	0.0001	Yes	0.9210	0.0013	0.9236	5.11E-02	
VERSAPAK_HAC_FINH_12S_A1	12	2x2x2=8	100	0.350	0.0001	Yes	0.7973	0.0011	0.7995	3.92E-02	
VERSAPAK_HAC_FINH_12S_A2	12	4x4x4=64	100	0.350	0.0001	Yes	0.8403	0.0012	0.8427	3.93E-02	
VERSAPAK_HAC_FINH_12S_A3	12	6x6x4=144	100	0.350	0.0001	Yes	0.8791	0.0012	0.8815	3.94E-02	
VERSAPAK_HAC_FINH_12S_A4	12	6x6x6=216	100	0.350	0.0001	Yes	0.8889	0.0013	0.8915	3.94E-02	
VERSAPAK_HAC_FINH_12S_A5	12	8x8x6=384	100	0.350	0.0001	Yes	0.9220	0.0011	0.9242	3.94E-02	
VERSAPAK_HAC_FINH_12S_A6	12	8x8x8=512	100	0.350	0.0001	Yes	0.9341	0.0012	0.9365	3.94E-02	
VERSAPAK_HAC_FINH_12S_A7	12	10x10x8=800	100	0.350	0.0001	Yes	0.9623	0.0013	0.9649	3.95E-02	
VERSAPAK_HAC_FINH_14S_A1	14	2x2x2=8	100	0.350	0.0001	Yes	0.7929	0.0010	0.7949	3.41E-02	
VERSAPAK_HAC_FINH_14S_A2	14	4x4x4=64	100	0.350	0.0001	Yes	0.8359	0.0010	0.8379	3.41E-02	
VERSAPAK_HAC_FINH_14S_A3	14	6x6x4=144	100	0.350	0.0001	Yes	0.8662	0.0011	0.8684	3.42E-02	
VERSAPAK_HAC_FINH_14S_A4	14	6x6x6=216	100	0.350	0.0001	Yes	0.8762	0.0010	0.8782	3.42E-02	
VERSAPAK_HAC_FINH_14S_A5	14	8x8x6=384	100	0.350	0.0001	Yes	0.9037	0.0011	0.9059	3.43E-02	
VERSAPAK_HAC_FINH_14S_A6	14	8x8x8=512	100	0.350	0.0001	Yes	0.9084	0.0010	0.9104	3.43E-02	

VERSAPAK_HAC_FINH_14S_A7	14	10x10x8=800	100	0.350	0.0001	Yes	0.9314	0.0010	0.9334	3.43E-02	
Square Package Arrays – Lumped Spherical Fissile Mass – Initial Array Sensitivity Study											
VERSAPAK_HAC_FINS_10S_A1	10	2x2x2=8	100	0.350	0.0001	Yes	0.7348	0.0012	0.7372	5.11E-02	
VERSAPAK_HAC_FINS_10S_A2	10	4x4x4=64	100	0.350	0.0001	Yes	0.7780	0.0012	0.7804	5.12E-02	
VERSAPAK_HAC_FINS_10S_A3	10	6x6x4=144	100	0.350	0.0001	Yes	0.8118	0.0012	0.8142	5.12E-02	
VERSAPAK_HAC_FINS_10S_A4	10	6x6x6=216	100	0.350	0.0001	Yes	0.8241	0.0012	0.8265	5.11E-02	
VERSAPAK_HAC_FINS_10S_A5	10	8x8x6=384	100	0.350	0.0001	Yes	0.8583	0.0014	0.8611	5.12E-02	
VERSAPAK_HAC_FINS_10S_A6	10	8x8x8=512	100	0.350	0.0001	Yes	0.8706	0.0014	0.8734	5.13E-02	
VERSAPAK_HAC_FINS_10S_A7	10	10x10x8=800	100	0.350	0.0001	Yes	0.9056	0.0014	0.9084	5.11E-02	
VERSAPAK_HAC_FINS_12S_A1	12	2x2x2=8	100	0.350	0.0001	Yes	0.7923	0.0012	0.7947	3.92E-02	
VERSAPAK_HAC_FINS_12S_A2	12	4x4x4=64	100	0.350	0.0001	Yes	0.8381	0.0014	0.8409	3.93E-02	
VERSAPAK_HAC_FINS_12S_A3	12	6x6x4=144	100	0.350	0.0001	Yes	0.8720	0.0011	0.8742	3.93E-02	
VERSAPAK_HAC_FINS_12S_A4	12	6x6x6=216	100	0.350	0.0001	Yes	0.8814	0.0012	0.8838	3.93E-02	
VERSAPAK_HAC_FINS_12S_A5	12	8x8x6=384	100	0.350	0.0001	Yes	0.9154	0.0012	0.9178	3.94E-02	
VERSAPAK_HAC_FINS_12S_A6	12	8x8x8=512	100	0.350	0.0001	Yes	0.9219	0.0012	0.9243	3.94E-02	
VERSAPAK_HAC_FINS_12S_A7	12	10x10x8=800	100	0.350	0.0001	Yes	0.9505	0.0012	0.9529	3.95E-02	
VERSAPAK_HAC_FINS_14S_A1	14	2x2x2=8	100	0.350	0.0001	Yes	0.7926	0.0010	0.7946	3.41E-02	
VERSAPAK_HAC_FINS_14S_A2	14	4x4x4=64	100	0.350	0.0001	Yes	0.8331	0.0011	0.8353	3.42E-02	
VERSAPAK_HAC_FINS_14S_A3	14	6x6x4=144	100	0.350	0.0001	Yes	0.8573	0.0010	0.8593	3.42E-02	
VERSAPAK_HAC_FINS_14S_A4	14	6x6x6=216	100	0.350	0.0001	Yes	0.8713	0.0010	0.8733	3.42E-02	
VERSAPAK_HAC_FINS_14S_A5	14	8x8x6=384	100	0.350	0.0001	Yes	0.8962	0.0010	0.8982	3.43E-02	
VERSAPAK_HAC_FINS_14S_A6	14	8x8x8=512	100	0.350	0.0001	Yes	0.9047	0.0010	0.9067	3.43E-02	
VERSAPAK_HAC_FINS_14S_A7	14	10x10x8=800	100	0.350	0.0001	Yes	0.9236	0.0010	0.9256	3.43E-02	
Triangular Package Arrays – Lumped Cylindrical Fissile Mass – Initial Array Sensitivity Study											
VERSAPAK_HAC_FINH_8C_A1	8 (1.0)	2x2x2=8	100	0.350	0.0001	Yes	0.6623	0.0012	0.6647	6.18E-02	
VERSAPAK_HAC_FINH_8C_A2	8 (1.0)	4x4x4=64	100	0.350	0.0001	Yes	0.7005	0.0012	0.7029	6.18E-02	
VERSAPAK_HAC_FINH_8C_A3	8 (1.0)	6x6x4=144	100	0.350	0.0001	Yes	0.7433	0.0014	0.7461	6.20E-02	
VERSAPAK_HAC_FINH_8C_A4	8 (1.0)	6x6x6=216	100	0.350	0.0001	Yes	0.7562	0.0013	0.7588	6.18E-02	
VERSAPAK_HAC_FINH_8C_A5	8 (1.0)	8x8x6=384	100	0.350	0.0001	Yes	0.7955	0.0013	0.7981	6.19E-02	
VERSAPAK_HAC_FINH_8C_A6	8 (1.0)	8x8x8=512	100	0.350	0.0001	Yes	0.8075	0.0013	0.8101	6.17E-02	
VERSAPAK_HAC_FINH_8C_A7	8 (1.0)	10x10x8=800	100	0.350	0.0001	Yes	0.8462	0.0013	0.8488	6.19E-02	
VERSAPAK_HAC_FINH_10C_A1	10 (1.0)	2x2x2=8	100	0.350	0.0001	Yes	0.7741	0.0011	0.7763	4.17E-02	
VERSAPAK_HAC_FINH_10C_A2	10 (1.0)	4x4x4=64	100	0.350	0.0001	Yes	0.8179	0.0013	0.8205	4.18E-02	
VERSAPAK_HAC_FINH_10C_A3	10 (1.0)	6x6x4=144	100	0.350	0.0001	Yes	0.8546	0.0013	0.8572	4.19E-02	
VERSAPAK_HAC_FINH_10C_A4	10 (1.0)	6x6x6=216	100	0.350	0.0001	Yes	0.8657	0.0012	0.8681	4.19E-02	
VERSAPAK_HAC_FINH_10C_A5	10 (1.0)	8x8x6=384	100	0.350	0.0001	Yes	0.9033	0.0012	0.9057	4.19E-02	

VERSAPAK_HAC_FINH_10C_A6	10 (1.0)	8x8x8=512	100	0.350	0.0001	Yes	0.9126	0.0013	0.9152	4.20E-02	
VERSAPAK_HAC_FINH_10C_A7	10 (1.0)	10x10x8=800	100	0.350	0.0001	Yes	0.9427	0.0014	0.9455	4.21E-02	
VERSAPAK_HAC_FINH_12C_A1	12 (1.0)	2x2x2=8	100	0.350	0.0001	Yes	0.7854	0.0010	0.7874	3.47E-02	
VERSAPAK_HAC_FINH_12C_A2	12 (1.0)	4x4x4=64	100	0.350	0.0001	Yes	0.8248	0.0011	0.8270	3.48E-02	
VERSAPAK_HAC_FINH_12C_A3	12 (1.0)	6x6x4=144	100	0.350	0.0001	Yes	0.8592	0.0010	0.8612	3.49E-02	
VERSAPAK_HAC_FINH_12C_A4	12 (1.0)	6x6x6=216	100	0.350	0.0001	Yes	0.8674	0.0011	0.8696	3.49E-02	
VERSAPAK_HAC_FINH_12C_A5	12 (1.0)	8x8x6=384	100	0.350	0.0001	Yes	0.8958	0.0010	0.8978	3.49E-02	
VERSAPAK_HAC_FINH_12C_A6	12 (1.0)	8x8x8=512	100	0.350	0.0001	Yes	0.9000	0.0010	0.9020	3.50E-02	
VERSAPAK_HAC_FINH_12C_A7	12 (1.0)	10x10x8=800	100	0.350	0.0001	Yes	0.9227	0.0010	0.9247	3.50E-02	
VERSAPAK_HAC_FINH_14C_A1	14 (1.0)	2x2x2=8	100	0.350	0.0001	Yes	0.7377	0.0009	0.7395	3.15E-02	
VERSAPAK_HAC_FINH_14C_A2	14 (1.0)	4x4x4=64	100	0.350	0.0001	Yes	0.7737	0.0011	0.7759	3.16E-02	
VERSAPAK_HAC_FINH_14C_A3	14 (1.0)	6x6x4=144	100	0.350	0.0001	Yes	0.7985	0.0009	0.8003	3.17E-02	
VERSAPAK_HAC_FINH_14C_A4	14 (1.0)	6x6x6=216	100	0.350	0.0001	Yes	0.8057	0.0008	0.8073	3.17E-02	
VERSAPAK_HAC_FINH_14C_A5	14 (1.0)	8x8x6=384	100	0.350	0.0001	Yes	0.8247	0.0009	0.8265	3.17E-02	
VERSAPAK_HAC_FINH_14C_A6	14 (1.0)	8x8x8=512	100	0.350	0.0001	Yes	0.8296	0.0008	0.8312	3.17E-02	
VERSAPAK_HAC_FINH_14C_A7	14 (1.0)	10x10x8=800	100	0.350	0.0001	Yes	0.8436	0.0009	0.8454	3.17E-02	
Triangular Package Arrays – Lumped Cylindrical Fissile Mass – Initial Array Sensitivity Study – 10.0" Cylinder Height-to-Diameter Sensitivity											
VERSAPAK_HAC_FINH_10C12_A1	10 (1.2)	2x2x2=8	100	0.350	0.0001	Yes	0.7777	0.0013	0.7803	3.88E-02	
VERSAPAK_HAC_FINH_10C12_A2	10 (1.2)	4x4x4=64	100	0.350	0.0001	Yes	0.8204	0.0012	0.8228	3.89E-02	
VERSAPAK_HAC_FINH_10C12_A3	10 (1.2)	6x6x4=144	100	0.350	0.0001	Yes	0.8587	0.0010	0.8607	3.91E-02	
VERSAPAK_HAC_FINH_10C12_A4	10 (1.2)	6x6x6=216	100	0.350	0.0001	Yes	0.8711	0.0010	0.8731	3.90E-02	
VERSAPAK_HAC_FINH_10C12_A5	10 (1.2)	8x8x6=384	100	0.350	0.0001	Yes	0.9041	0.0011	0.9063	3.91E-02	
VERSAPAK_HAC_FINH_10C12_A6	10 (1.2)	8x8x8=512	100	0.350	0.0001	Yes	0.9130	0.0011	0.9152	3.91E-02	
VERSAPAK_HAC_FINH_10C12_A7	10 (1.2)	10x10x8=800	100	0.350	0.0001	Yes	0.9428	0.0012	0.9452	3.92E-02	
VERSAPAK_HAC_FINH_10C11_A1	10 (1.1)	2x2x2=8	100	0.350	0.0001	Yes	0.8229	0.0012	0.8253	4.34E-02	
VERSAPAK_HAC_FINH_10C11_A2	10 (1.1)	4x4x4=64	100	0.350	0.0001	Yes	0.8202	0.0011	0.8224	4.03E-02	
VERSAPAK_HAC_FINH_10C11_A3	10 (1.1)	6x6x4=144	100	0.350	0.0001	Yes	0.8570	0.0014	0.8598	4.03E-02	
VERSAPAK_HAC_FINH_10C11_A4	10 (1.1)	6x6x6=216	100	0.350	0.0001	Yes	0.8723	0.0011	0.8745	4.03E-02	
VERSAPAK_HAC_FINH_10C11_A5	10 (1.1)	8x8x6=384	100	0.350	0.0001	Yes	0.9038	0.0012	0.9062	4.04E-02	
VERSAPAK_HAC_FINH_10C11_A6	10 (1.1)	8x8x8=512	100	0.350	0.0001	Yes	0.9131	0.0014	0.9159	4.04E-02	
VERSAPAK_HAC_FINH_10C11_A7	10 (1.1)	10x10x8=800	100	0.350	0.0001	Yes	0.9430	0.0012	0.9454	4.05E-02	
VERSAPAK_HAC_FINH_10C9_A1	10 (0.9)	2x2x2=8	100	0.350	0.0001	Yes	0.7676	0.0013	0.7702	4.37E-02	
VERSAPAK_HAC_FINH_10C9_A2	10 (0.9)	4x4x4=64	100	0.350	0.0001	Yes	0.8099	0.0012	0.8123	4.38E-02	
VERSAPAK_HAC_FINH_10C9_A3	10 (0.9)	6x6x4=144	100	0.350	0.0001	Yes	0.8485	0.0012	0.8509	4.39E-02	
VERSAPAK_HAC_FINH_10C9_A4	10 (0.9)	6x6x6=216	100	0.350	0.0001	Yes	0.8581	0.0012	0.8605	4.39E-02	

VERSAPAK_HAC_FINH_10C9_A5	10 (0.9)	8x8x6=384	100	0.350	0.0001	Yes	0.8954	0.0013	0.8980	4.40E-02	
VERSAPAK_HAC_FINH_10C9_A6	10 (0.9)	8x8x8=512	100	0.350	0.0001	Yes	0.9035	0.0013	0.9061	4.41E-02	
VERSAPAK_HAC_FINH_10C9_A7	10 (0.9)	10x10x8=800	100	0.350	0.0001	Yes	0.9373	0.0013	0.9399	4.41E-02	
Triangular Package Arrays – Lumped Cylindrical Fissile Mass – Initial Array Sensitivity Study – 12.0" Cylinder Height-to-Diameter Sensitivity											
VERSAPAK_HAC_FINH_12C11_A1	12 (1.1)	2x2x2=8	100	0.350	0.0001	Yes	0.7787	0.0010	0.7807	3.39E-02	
VERSAPAK_HAC_FINH_12C11_A2	12 (1.1)	4x4x4=64	100	0.350	0.0001	Yes	0.8178	0.0009	0.8196	3.40E-02	
VERSAPAK_HAC_FINH_12C11_A3	12 (1.1)	6x6x4=144	100	0.350	0.0001	Yes	0.8481	0.0010	0.8501	3.41E-02	
VERSAPAK_HAC_FINH_12C11_A4	12 (1.1)	6x6x6=216	100	0.350	0.0001	Yes	0.8568	0.0011	0.8590	3.41E-02	
VERSAPAK_HAC_FINH_12C11_A5	12 (1.1)	8x8x6=384	100	0.350	0.0001	Yes	0.8819	0.0010	0.8839	3.41E-02	
VERSAPAK_HAC_FINH_12C11_A6	12 (1.1)	8x8x8=512	100	0.350	0.0001	Yes	0.8904	0.0010	0.8924	3.42E-02	
VERSAPAK_HAC_FINH_12C11_A7	12 (1.1)	10x10x8=800	100	0.350	0.0001	Yes	0.9103	0.0010	0.9123	3.42E-02	
VERSAPAK_HAC_FINH_12C9_A1	12 (0.9)	2x2x2=8	100	0.350	0.0001	Yes	0.7917	0.0011	0.7939	3.57E-02	
VERSAPAK_HAC_FINH_12C9_A2	12 (0.9)	4x4x4=64	100	0.350	0.0001	Yes	0.8308	0.0010	0.8328	3.58E-02	
VERSAPAK_HAC_FINH_12C9_A3	12 (0.9)	6x6x4=144	100	0.350	0.0001	Yes	0.8661	0.0009	0.8679	3.59E-02	
VERSAPAK_HAC_FINH_12C9_A4	12 (0.9)	6x6x6=216	100	0.350	0.0001	Yes	0.8769	0.0010	0.8789	3.59E-02	
VERSAPAK_HAC_FINH_12C9_A5	12 (0.9)	8x8x6=384	100	0.350	0.0001	Yes	0.9043	0.0011	0.9065	3.60E-02	
VERSAPAK_HAC_FINH_12C9_A6	12 (0.9)	8x8x8=512	100	0.350	0.0001	Yes	0.9125	0.0009	0.9143	3.60E-02	
VERSAPAK_HAC_FINH_12C9_A7	12 (0.9)	10x10x8=800	100	0.350	0.0001	Yes	0.9391	0.0009	0.9409	3.60E-02	
VERSAPAK_HAC_FINH_12C8_A1	12 (0.8)	2x2x2=8	100	0.350	0.0001	Yes	0.7908	0.0011	0.7930	3.70E-02	
VERSAPAK_HAC_FINH_12C8_A2	12 (0.8)	4x4x4=64	100	0.350	0.0001	Yes	0.8317	0.0012	0.8341	3.71E-02	
VERSAPAK_HAC_FINH_12C8_A3	12 (0.8)	6x6x4=144	100	0.350	0.0001	Yes	0.8657	0.0011	0.8679	3.72E-02	
VERSAPAK_HAC_FINH_12C8_A4	12 (0.8)	6x6x6=216	100	0.350	0.0001	Yes	0.8794	0.0011	0.8816	3.72E-02	
VERSAPAK_HAC_FINH_12C8_A5	12 (0.8)	8x8x6=384	100	0.350	0.0001	Yes	0.9061	0.0010	0.9081	3.73E-02	
VERSAPAK_HAC_FINH_12C8_A6	12 (0.8)	8x8x8=512	100	0.350	0.0001	Yes	0.9158	0.0011	0.9180	3.73E-02	
VERSAPAK_HAC_FINH_12C8_A7	12 (0.8)	10x10x8=800	100	0.350	0.0001	Yes	0.9426	0.0012	0.9450	3.73E-02	
VERSAPAK_HAC_FINH_12C6_A1	12 (0.6)	2x2x2=8	100	0.350	0.0001	Yes	0.7631	0.0013	0.7657	4.13E-02	
VERSAPAK_HAC_FINH_12C6_A2	12 (0.6)	4x4x4=64	100	0.350	0.0001	Yes	0.8088	0.0011	0.8110	4.13E-02	
VERSAPAK_HAC_FINH_12C6_A3	12 (0.6)	6x6x4=144	100	0.350	0.0001	Yes	0.8469	0.0010	0.8489	4.14E-02	
VERSAPAK_HAC_FINH_12C6_A4	12 (0.6)	6x6x6=216	100	0.350	0.0001	Yes	0.8471	0.0013	0.8497	4.14E-02	
VERSAPAK_HAC_FINH_12C6_A5	12 (0.6)	8x8x6=384	100	0.350	0.0001	Yes	0.8913	0.0012	0.8937	4.16E-02	
VERSAPAK_HAC_FINH_12C6_A6	12 (0.6)	8x8x8=512	100	0.350	0.0001	Yes	0.9029	0.0015	0.9059	4.15E-02	
VERSAPAK_HAC_FINH_12C6_A7	12 (0.6)	10x10x8=800	100	0.350	0.0001	Yes	0.9336	0.0012	0.9360	4.16E-02	

Table 6-8 Summary of Hypothetical Accident Condition Package Results for Lumped Fissile Mass Models – Increased Array Size and Increased Poly-Moderation Sensitivity

Case ID	Radius (cm) of Sphere	Modeled Package Array	Poly-Moderation Density	^{235}U Mass (kg)	Interspersed Moderation (water volume fraction)	Close Water Reflection	k_{eff}	σ	$k_{eff} + 2\sigma$	EALF (eV)	Comments
Triangular Package Arrays – Lumped Spherical Fissile Mass – Normal Density Poly-Moderation Sensitivity Study											
VERSAPAK_HAC_FINH_12S_1X400	12	16x26x1=400	0.92	0.350	0.0001	Yes	0.8240	0.0011	0.8262	3.92E-02	
VERSAPAK_HAC_FINH_12S_1x416	12	16x26x1=416	0.92	0.350	0.0001	Yes	0.8273	0.0012	0.8297	3.92E-02	
VERSAPAK_HAC_FINH_12S_1x468	12	18x26x1=468	0.92	0.350	0.0001	Yes	0.8249	0.0012	0.8273	3.93E-02	
VERSAPAK_HAC_FINH_12S_2X324	12	20x18x2=720	0.92	0.350	0.0001	Yes	0.9077	0.0011	0.9099	3.95E-02	
VERSAPAK_HAC_FINH_12S_2x400	12	16x25x2=800	0.92	0.350	0.0001	Yes	0.9076	0.0010	0.9096	3.94E-02	
VERSAPAK_HAC_FINH_12S_2x416	12	16x26x2=832	0.92	0.350	0.0001	Yes	0.9074	0.0013	0.9100	3.94E-02	
VERSAPAK_HAC_FINH_12S_2x468	12	18x26x2=936	0.92	0.350	0.0001	Yes	0.9110	0.0012	0.9134	3.94E-02	
VERSAPAK_HAC_FINH_12S_3X120	12	10x12x3=360	0.92	0.350	0.0001	Yes	0.9202	0.0012	0.9226	3.94E-02	
VERSAPAK_HAC_FINH_12S_3X144	12	12x12x3=432	0.92	0.350	0.0001	Yes	0.9253	0.0011	0.9275	3.94E-02	
VERSAPAK_HAC_FINH_12S_3X224	12	14x16x3=672	0.92	0.350	0.0001	Yes	0.9371	0.0013	0.9397	3.95E-02	
VERSAPAK_HAC_FINH_12S_3X324	12	20x18x3=1080	0.92	0.350	0.0001	Yes	0.9500	0.0011	0.9522	3.95E-02	
VERSAPAK_HAC_FINH_12S_3x400	12	16x25x3=1200	0.92	0.350	0.0001	Yes	0.9491	0.0012	0.9515	3.95E-02	
VERSAPAK_HAC_FINH_12S_3x416	12	16x26x3=1248	0.92	0.350	0.0001	Yes	0.9504	0.0011	0.9526	3.94E-02	
VERSAPAK_HAC_FINH_12S_3x468	12	18x26x3=1404	0.92	0.350	0.0001	Yes	0.9548	0.0011	0.9570	3.94E-02	
VERSAPAK_HAC_FINS_12_A3	12	6x6x4=144	0.92	0.350	0.0001	Yes	0.8720	0.0011	0.8742	3.93E-02	
VERSAPAK_HAC_FINH_12S_4X120	12	10x12x4=480	0.92	0.350	0.0001	Yes	0.9359	0.0011	0.9381	3.95E-02	
VERSAPAK_HAC_FINH_12S_4x400	12	16x25x4=1600	0.92	0.350	0.0001	Yes	0.9779	0.0010	0.9799	3.95E-02	
VERSAPAK_HAC_FINH_12S_4x416	12	16x26x4=1664	0.92	0.350	0.0001	Yes	0.9754	0.0011	0.9776	3.95E-02	
VERSAPAK_HAC_FINH_12S_4x468	12	18x26x4=1872	0.92	0.350	0.0001	Yes	0.9825	0.0012	0.9849	3.95E-02	
VERSAPAK_HAC_FINH_12S_5X080	12	8x10x5=400	0.92	0.350	0.0001	Yes	0.9322	0.0012	0.9346	3.95E-02	
VERSAPAK_HAC_FINH_12S_5X120	12	10x12x5=600	0.92	0.350	0.0001	Yes	0.9554	0.0012	0.9578	3.94E-02	
VERSAPAK_HAC_FINS_12_A4	12	6x6x6=216	0.92	0.350	0.0001	Yes	0.8814	0.0012	0.8838	3.93E-02	
VERSAPAK_HAC_FINS_12_A5	12	8x8x6=384	0.92	0.350	0.0001	Yes	0.9154	0.0012	0.9178	3.94E-02	
VERSAPAK_HAC_FINH_12S_6X080	12	8x10x6=480	0.92	0.350	0.0001	Yes	0.9373	0.0012	0.9397	3.94E-02	
VERSAPAK_HAC_FINH_12S_7X064	12	8x8x7=448	0.92	0.350	0.0001	Yes	0.9319	0.0012	0.9343	3.94E-02	
VERSAPAK_HAC_FINH_12S_7X080	12	8x10x7=560	0.92	0.350	0.0001	Yes	0.9436	0.0012	0.9460	3.95E-02	
VERSAPAK_HAC_FINS_12_A6	12	8x8x8=512	0.92	0.350	0.0001	Yes	0.9219	0.0012	0.9243	3.94E-02	

VERSAPAK_HAC_FINH_12S_8X080	12	8x10x8=640	0.92	0.350	0.0001	Yes	0.9507	0.0012	0.9531	3.94E-02	
VERSAPAK_HAC_FINS_12_A7	12	10x10x8=800	0.92	0.350	0.0001	Yes	0.9505	0.0012	0.9529	3.95E-02	
VERSAPAK_HAC_FINH_12S_7X064	12	8x8x10=640	0.92	0.350	0.0001	Yes	0.9340	0.0011	0.9362	3.94E-02	
Triangular Package Arrays – Lumped Spherical Fissile Mass – Increased Density Poly-Moderation Sensitivity Study											
VERSAPAK_HAC_FINH_12S_1X400PM	12	16x26x1=400	0.98	0.350	0.0001	Yes	0.8240	0.0011	0.8262	3.92E-02	
VERSAPAK_HAC_FINH_12S_1x416PM	12	16x26x1=416	0.98	0.350	0.0001	Yes	0.8273	0.0012	0.8297	3.92E-02	
VERSAPAK_HAC_FINH_12S_1x468PM	12	18x26x1=468	0.98	0.350	0.0001	Yes	0.8249	0.0012	0.8273	3.93E-02	
VERSAPAK_HAC_FINH_12S_2X324PM	12	20x18x2=720	0.98	0.350	0.0001	Yes	0.9077	0.0011	0.9099	3.95E-02	
VERSAPAK_HAC_FINH_12S_2x400PM	12	16x25x2=800	0.98	0.350	0.0001	Yes	0.9076	0.0010	0.9096	3.94E-02	
VERSAPAK_HAC_FINH_12S_2x416PM	12	16x26x2=832	0.98	0.350	0.0001	Yes	0.9074	0.0013	0.9100	3.94E-02	
VERSAPAK_HAC_FINH_12S_2x468PM	12	18x26x2=936	0.98	0.350	0.0001	Yes	0.9110	0.0012	0.9134	3.94E-02	
VERSAPAK_HAC_FINH_12S_3X120PM	12	10x12x3=360	0.98	0.350	0.0001	Yes	0.9202	0.0012	0.9226	3.94E-02	
VERSAPAK_HAC_FINH_12S_3X144PM	12	12x12x3=432	0.98	0.350	0.0001	Yes	0.9253	0.0011	0.9275	3.94E-02	
VERSAPAK_HAC_FINH_12S_3X224PM	12	14x16x3=672	0.98	0.350	0.0001	Yes	0.9371	0.0013	0.9397	3.95E-02	
VERSAPAK_HAC_FINH_12S_3X324PM	12	20x18x3=1080	0.98	0.350	0.0001	Yes	0.9500	0.0011	0.9522	3.95E-02	
VERSAPAK_HAC_FINH_12S_3x400PM	12	16x25x3=1200	0.98	0.350	0.0001	Yes	0.9491	0.0012	0.9515	3.95E-02	
VERSAPAK_HAC_FINH_12S_3x416PM	12	16x26x3=1248	0.98	0.350	0.0001	Yes	0.9504	0.0011	0.9526	3.94E-02	
VERSAPAK_HAC_FINH_12S_3x468PM	12	18x26x3=1404	0.98	0.350	0.0001	Yes	0.9548	0.0011	0.9570	3.94E-02	
VERSAPAK_HAC_FINS_12_A3PM	12	6x6x4=144	0.98	0.350	0.0001	Yes	0.8720	0.0011	0.8742	3.93E-02	
VERSAPAK_HAC_FINH_12S_4X120PM	12	10x12x4=480	0.98	0.350	0.0001	Yes	0.9359	0.0011	0.9381	3.95E-02	
VERSAPAK_HAC_FINH_12S_4x400PM	12	16x25x4=1600	0.98	0.350	0.0001	Yes	0.9779	0.0010	0.9799	3.95E-02	
VERSAPAK_HAC_FINH_12S_4x416PM	12	16x26x4=1664	0.98	0.350	0.0001	Yes	0.9754	0.0011	0.9776	3.95E-02	
VERSAPAK_HAC_FINH_12S_4x468PM	12	18x26x4=1872	0.98	0.350	0.0001	Yes	0.9825	0.0012	0.9849	3.95E-02	
VERSAPAK_HAC_FINH_12S_5X080PM	12	8x10x5=400	0.98	0.350	0.0001	Yes	0.9322	0.0012	0.9346	3.95E-02	
VERSAPAK_HAC_FINH_12S_5X120PM	12	10x12x5=600	0.98	0.350	0.0001	Yes	0.9554	0.0012	0.9578	3.94E-02	
VERSAPAK_HAC_FINS_12_A4PM	12	6x6x6=216	0.98	0.350	0.0001	Yes	0.8814	0.0012	0.8838	3.93E-02	
VERSAPAK_HAC_FINS_12_A5PM	12	8x8x6=384	0.98	0.350	0.0001	Yes	0.9154	0.0012	0.9178	3.94E-02	
VERSAPAK_HAC_FINH_12S_6X080PM	12	8x10x6=480	0.98	0.350	0.0001	Yes	0.9373	0.0012	0.9397	3.94E-02	
VERSAPAK_HAC_FINH_12S_7X064PM	12	8x8x7=448	0.98	0.350	0.0001	Yes	0.9319	0.0012	0.9343	3.94E-02	
VERSAPAK_HAC_FINH_12S_7X080PM	12	8x10x7=560	0.98	0.350	0.0001	Yes	0.9436	0.0012	0.9460	3.95E-02	
VERSAPAK_HAC_FINS_12_A6PM	12	8x8x8=512	0.98	0.350	0.0001	Yes	0.9219	0.0012	0.9243	3.94E-02	
VERSAPAK_HAC_FINH_12S_8X080PM	12	8x10x8=640	0.98	0.350	0.0001	Yes	0.9507	0.0012	0.9531	3.94E-02	
VERSAPAK_HAC_FINS_12_A7PM	12	10x10x8=800	0.98	0.350	0.0001	Yes	0.9505	0.0012	0.9529	3.95E-02	
VERSAPAK_HAC_FINH_12S_7X064PM	12	8x8x10=640	0.98	0.350	0.0001	Yes	0.9340	0.0011	0.9362	3.94E-02	

Table 6-9 Summary of Hypothetical Accident Condition Package Results for Lumped Fissile Mass Models – Cross Section, Fissile Mass, Interspersed Moderation, Fissile Moderator Density, Package Carbon Steel Sensitivity, and Graphite Moderation

Case ID	Radius (cm) of Sphere	Modeled Package Array	Poly-Moderation	^{235}U Mass (kg)	Interspersed Moderation (water volume fraction)	Close Water Reflection	k_{eff}	σ	$k_{eff} + 2\sigma$	EALF (eV)	Comments
Triangular Package Arrays – Lumped Spherical Fissile Mass – Normal Density Poly-Moderation - Cross Section Sensitivity Study											
VERSAPAK_HAC_FINH_12S_A7	12	10x10x8=800	100	0.350	0.0001	Yes	0.9623	0.0013	0.9649	3.95E-02	**44 Group**
VERSAPAK_HAC_FINH_12S_A7X	12	10x10x8=800	100	0.350	0.0001	Yes	0.9624	0.0012	0.9648	4.12E-02	**238 Group**
VERSAPAK_HAC_FINH_12S_A7X1	12	10x10x8=800	100	0.350	0.0001	Yes	0.9650	0.0008	0.9666	4.11E-02	**238 Group Increased Histories**
VERSAPAK_HAC_FINH_12S_A7XN	12	10x10x8=800	100	0.350	0.0001	Yes	0.9633	0.0008	0.9649	3.95E-02	**44 Group Increased Histories**
Triangular Package Arrays – Lumped Spherical Fissile Mass – Normal Density Poly-Moderation – Increased Fissile Mass Sensitivity Study											
VERSAPAK_HAC_FINH_12S_A1_375	12	2x2x2=8	100	0.375	0.0001	Yes	0.8135	0.0012	0.8159	4.01E-02	**Increasing the fissile mass above 350 gcarbon steel content requires array size reduction**
VERSAPAK_HAC_FINH_12S_A2_375	12	4x4x4=64	100	0.375	0.0001	Yes	0.8585	0.0011	0.8607	4.02E-02	
VERSAPAK_HAC_FINH_12S_A3_375	12	6x6x4=144	100	0.375	0.0001	Yes	0.8957	0.0011	0.8979	4.03E-02	
VERSAPAK_HAC_FINH_12S_A4_375	12	6x6x6=216	100	0.375	0.0001	Yes	0.9094	0.0014	0.9122	4.03E-02	
VERSAPAK_HAC_FINH_12S_A5_375	12	8x8x6=384	100	0.375	0.0001	Yes	0.9416	0.0012	0.9440	4.04E-02	
VERSAPAK_HAC_FINH_12S_A6_375	12	8x8x8=512	100	0.375	0.0001	Yes	0.9502	0.0011	0.9524	4.04E-02	
VERSAPAK_HAC_FINH_12S_A7_375	12	10x10x8=800	100	0.375	0.0001	Yes	0.9818	0.0010	0.9838	4.04E-02	
VERSAPAK_HAC_FINH_12S_A1_400	12	2x2x2=8	100	0.400	0.0001	Yes	0.8276	0.0012	0.8300	4.11E-02	
VERSAPAK_HAC_FINH_12S_A2_400	12	4x4x4=64	100	0.400	0.0001	Yes	0.8741	0.0013	0.8767	4.12E-02	
VERSAPAK_HAC_FINH_12S_A3_400	12	6x6x4=144	100	0.400	0.0001	Yes	0.9118	0.0012	0.9142	4.13E-02	
VERSAPAK_HAC_FINH_12S_A4_400	12	6x6x6=216	100	0.400	0.0001	Yes	0.9258	0.0012	0.9282	4.12E-02	
VERSAPAK_HAC_FINH_12S_A5_400	12	8x8x6=384	100	0.400	0.0001	Yes	0.9594	0.0012	0.9618	4.14E-02	
VERSAPAK_HAC_FINH_12S_A6_400	12	8x8x8=512	100	0.400	0.0001	Yes	0.9704	0.0013	0.9730	4.14E-02	
VERSAPAK_HAC_FINH_12S_A7_400	12	10x10x8=800	100	0.400	0.0001	Yes	1.0043	0.0011	1.0065	4.13E-02	
Triangular Package Arrays – Lumped Spherical Fissile Mass – Normal Density Poly-Moderation – Interspersed Moderation Sensitivity Study											
VERSAPAK_HAC_FINH_12S_A7	12	10x10x8=800	100	0.350	0.0001	Yes	0.9623	0.0013	0.9649	3.95E-02	**Increased interspersed moderation reduces k_{ef}**
VERSAPAK_HAC_FINH_12S_A7a	12	10x10x8=800	100	0.350	0.001	Yes	0.9621	0.0011	0.9643	3.94E-02	
VERSAPAK_HAC_FINH_12S_A7b	12	10x10x8=800	100	0.350	0.01	Yes	0.9405	0.0012	0.9429	3.93E-02	
VERSAPAK_HAC_FINH_12S_A7c	12	10x10x8=800	100	0.350	0.1	Yes	0.8527	0.0012	0.8551	3.83E-02	
VERSAPAK_HAC_FINH_12S_A7d	12	10x10x8=800	100	0.350	0.5	Yes	0.8517	0.0013	0.8543	3.72E-02	

VERSAPAK_HAC_FINH_12S_A7e	12	10x10x8=800	100	0.350	1.0	Yes	0.8793	0.0016	0.8825	3.67E-02	
Triangular Package Arrays – Lumped Spherical Fissile Mass – Normal Density Poly-Moderation – Reduced Poly-Moderation Sensitivity Study											
VERSAPAK_HAC_FINH_12S_A7	12	10x10x8=800	100	0.350	0.0001	Yes	0.9623	0.0013	0.9649	3.95E-02	**Reduced poly-moderation reduces k_{eff}**
VERSAPAK_HAC_FINH_12S_A7B	12	10x10x8=800	90	0.350	0.0001	Yes	0.9315	0.0012	0.9339	4.14E-02	
VERSAPAK_HAC_FINH_12S_A7C	12	10x10x8=800	80	0.350	0.0001	Yes	0.8906	0.0013	0.8932	4.40E-02	
VERSAPAK_HAC_FINH_12S_A7D	12	10x10x8=800	70	0.350	0.0001	Yes	0.8358	0.0012	0.8382	4.76E-02	
VERSAPAK_HAC_FINH_12S_A7E	12	10x10x8=800	60	0.350	0.0001	Yes	0.7677	0.0014	0.7705	5.30E-02	
VERSAPAK_HAC_FINH_12S_A7F	12	10x10x8=800	50	0.350	0.0001	Yes	0.6809	0.0012	0.6833	6.15E-02	
Triangular Package Arrays – Lumped Spherical Fissile Mass – Normal Density Poly-Moderation – No Carbon Steel Sensitivity Study											
VERSAPAK_HAC_FINH_12S_A1NS	12	2x2x2=8	100	0.350	0.0001	Yes	0.8046	0.0010	0.8066	3.81E-02	**Not crediting the minimum carbon steel content requires array size reduction**
VERSAPAK_HAC_FINH_12S_A2NS	12	4x4x4=64	100	0.350	0.0001	Yes	0.8666	0.0011	0.8688	3.76E-02	
VERSAPAK_HAC_FINH_12S_A3NS	12	6x6x4=144	100	0.350	0.0001	Yes	0.9097	0.0012	0.9121	3.73E-02	
VERSAPAK_HAC_FINH_12S_A4NS	12	6x6x6=216	100	0.350	0.0001	Yes	0.9276	0.0012	0.9300	3.72E-02	
VERSAPAK_HAC_FINH_12S_A5NS	12	8x8x6=384	100	0.350	0.0001	Yes	0.9677	0.0013	0.9703	3.69E-02	
VERSAPAK_HAC_FINH_12S_A6NS	12	8x8x8=512	100	0.350	0.0001	Yes	0.9793	0.0011	0.9815	3.69E-02	
VERSAPAK_HAC_FINH_12S_A7NS	12	10x10x8=800	100	0.350	0.0001	Yes	1.0168	0.0010	1.0188	3.69E-02	
Triangular Package Arrays – Lumped Spherical Fissile Mass – Graphite Moderation Sensitivity Study											
VERSAPAK_HAC_FINH_12S_A7G	12	10x10x8=800	100	0.350	0.0001	Yes	0.1544	0.0005	0.1554	3.43E+00	

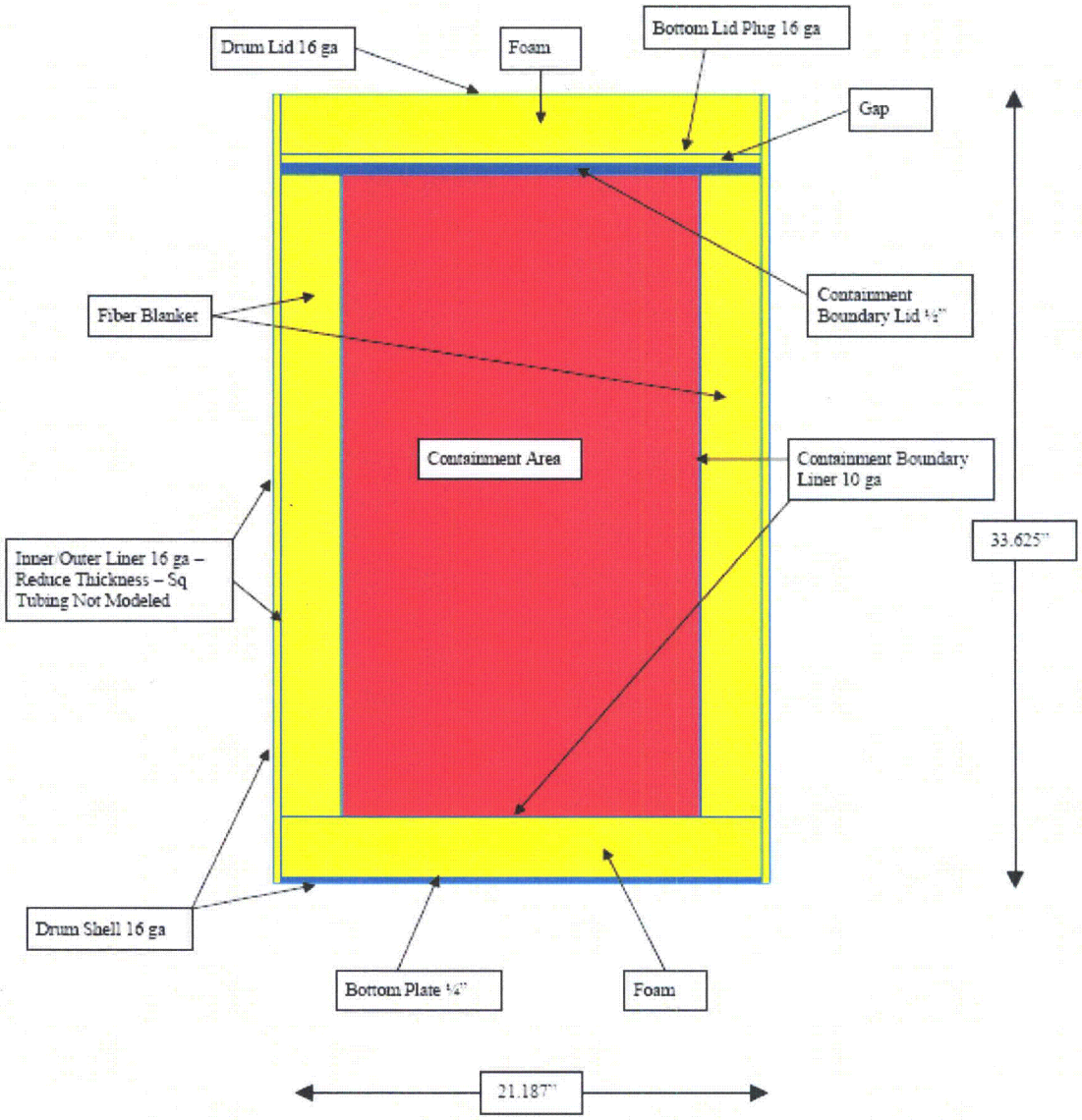

Figure 6-1 Illustration of the KENO Model of the Century Versa-Pac Shipping Container for the Normal Condition of Transport and Hypothetical Accident Condition.

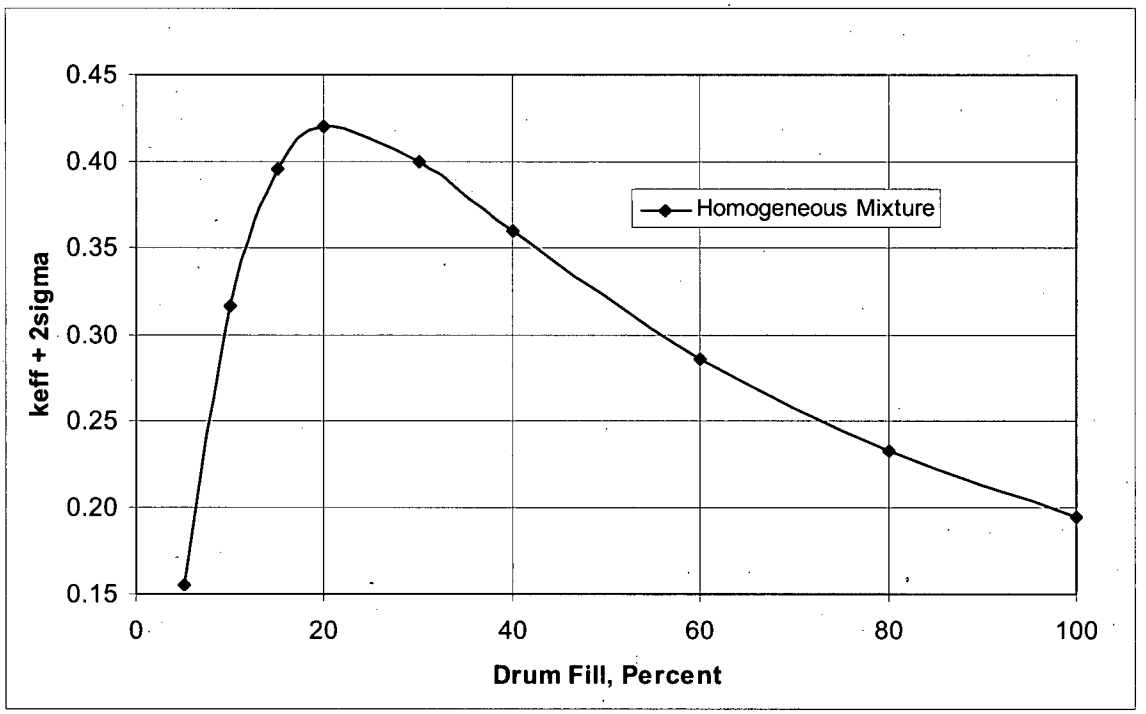

Figure 6-2 KENO VI results for single model calculation as a function of drum fill percentage for the Normal Condition of Transport and Hypothetical Condition.

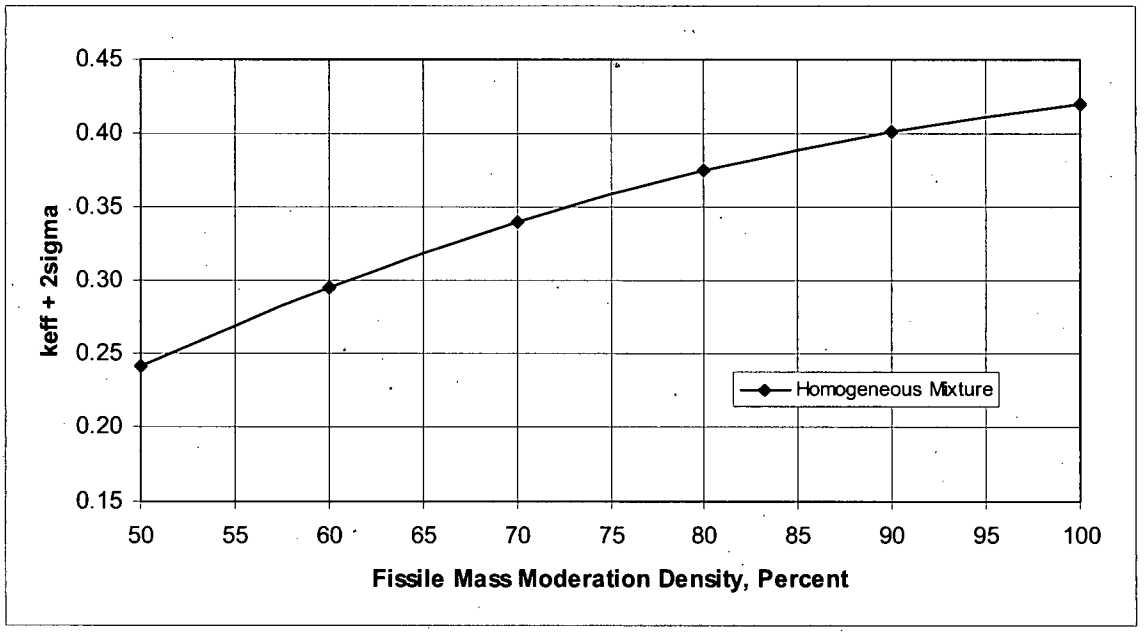

Figure 6-3 KENO VI results for single model calculation as a function of poly-moderator density (20% filled drum) for the Normal Condition of Transport and Hypothetical Condition.

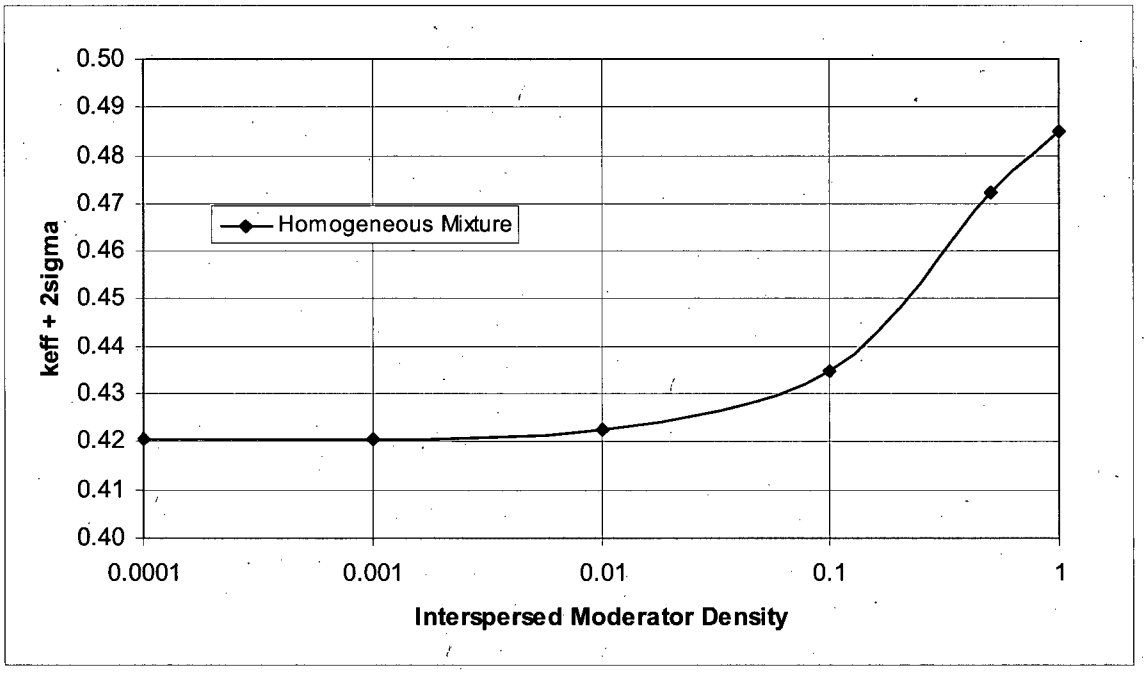

Figure 6-4 KENO VI results for single model calculation as a function of interspersed moderator (20% filled drum) for the Normal Condition of Transport and Hypothetical Condition.

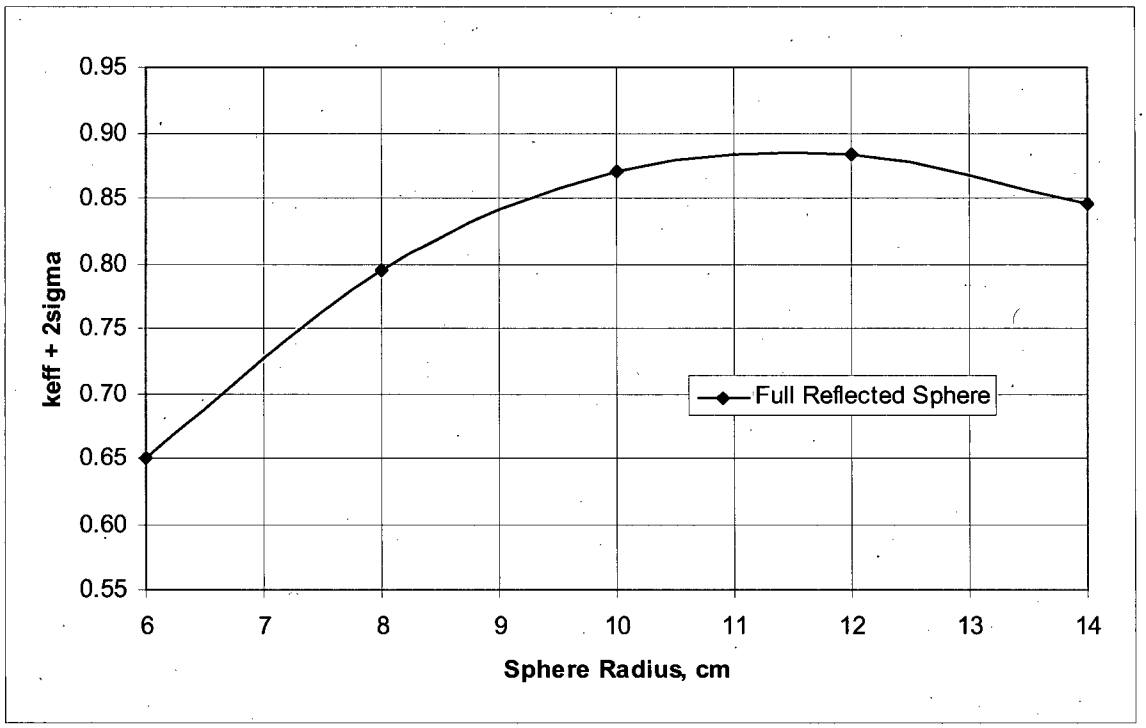

Figure 6-5 KENO VI results for fully reflected spheres representing the Normal Condition of Transport and Hypothetical Condition for a single package.

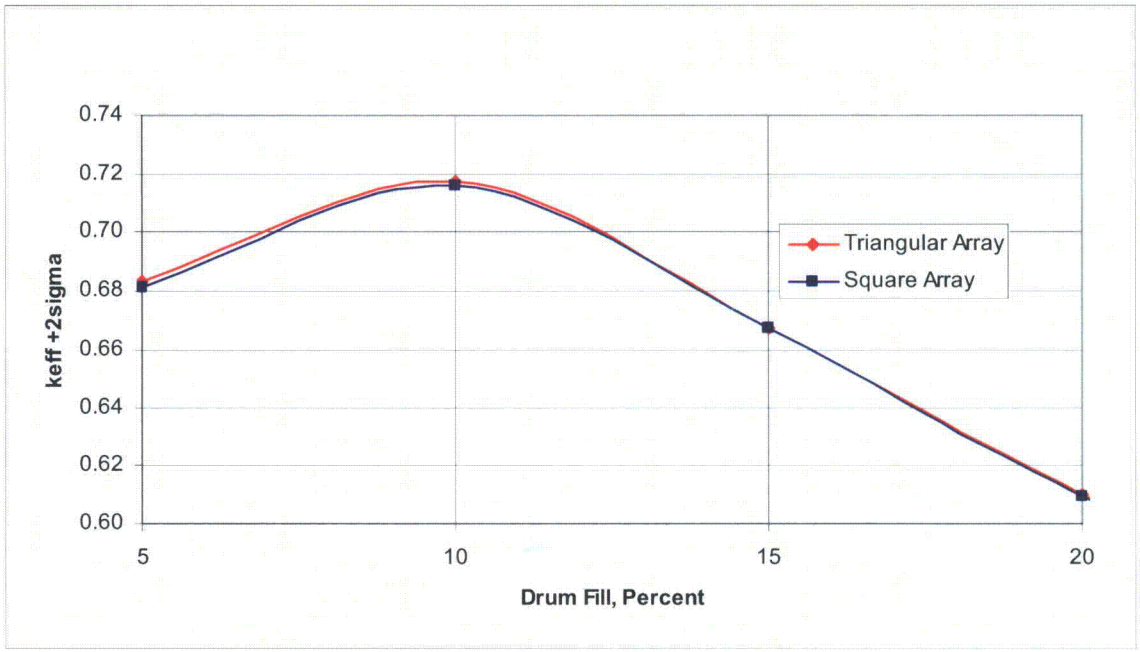

Figure 6-6 KENO VI results for infinite array model calculation as a function of drum fill percentage for the Normal Condition of Transport and Hypothetical Condition.

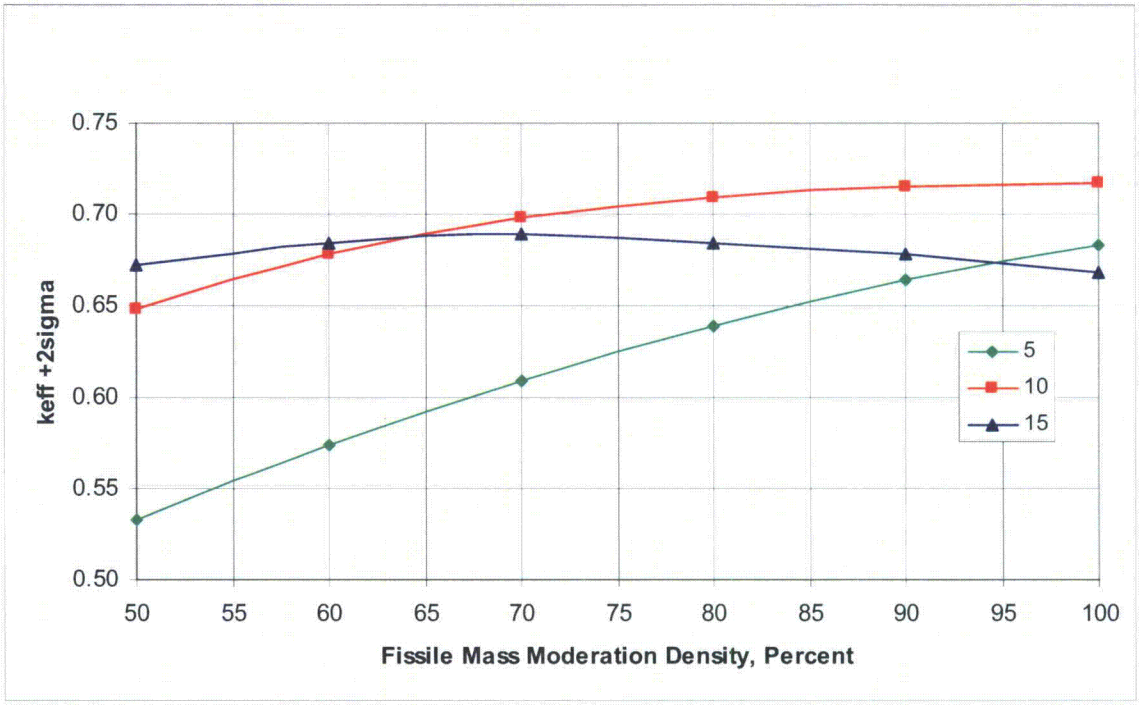

Figure 6-7 KENO VI results for infinite array model calculation as a function of poly-moderator density (10% filled drum) for the Normal Condition of Transport and Hypothetical Condition.

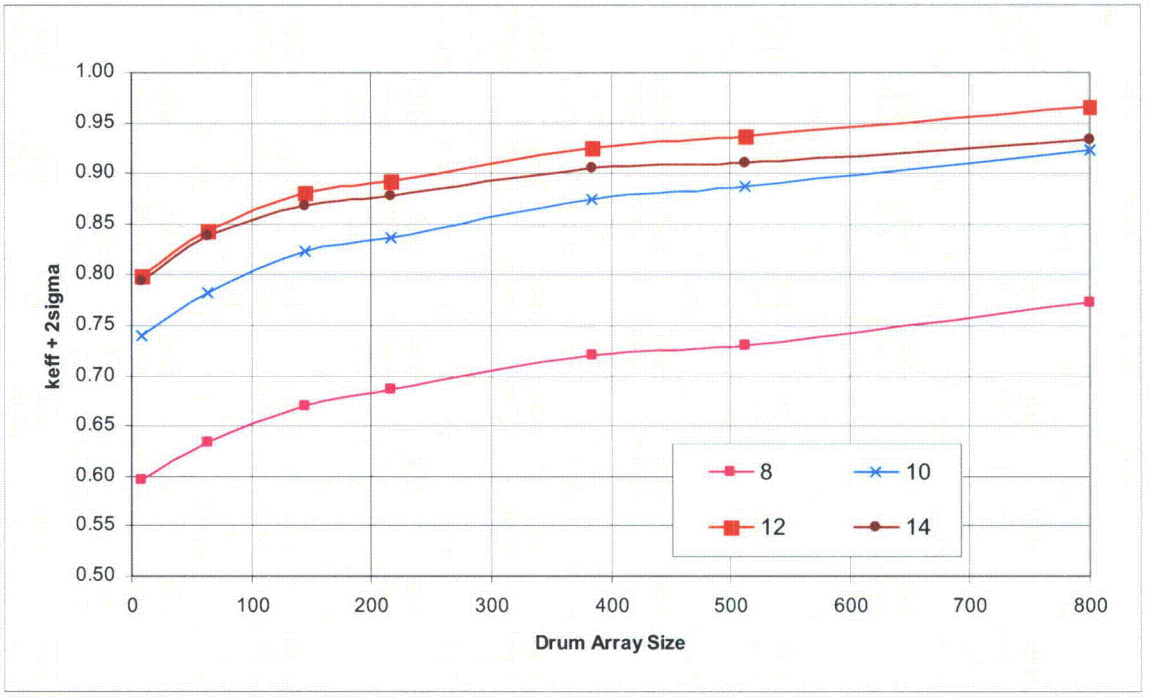

Figure 6-8 KENO VI results for triangular package array model calculation with lumped spheres as a function of package array size for the Normal Condition of Transport and Hypothetical Condition.

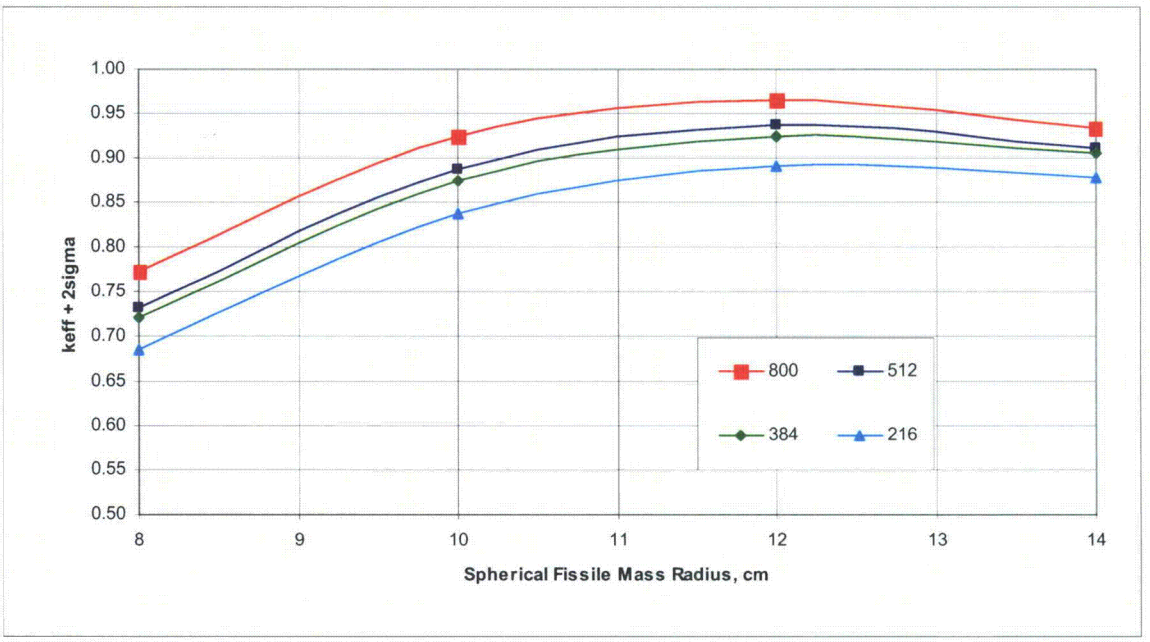

Figure 6-9 KENO VI results for triangular package array model calculation with lumped spheres as a function of sphere diameter for the Normal Condition of Transport and Hypothetical Condition.

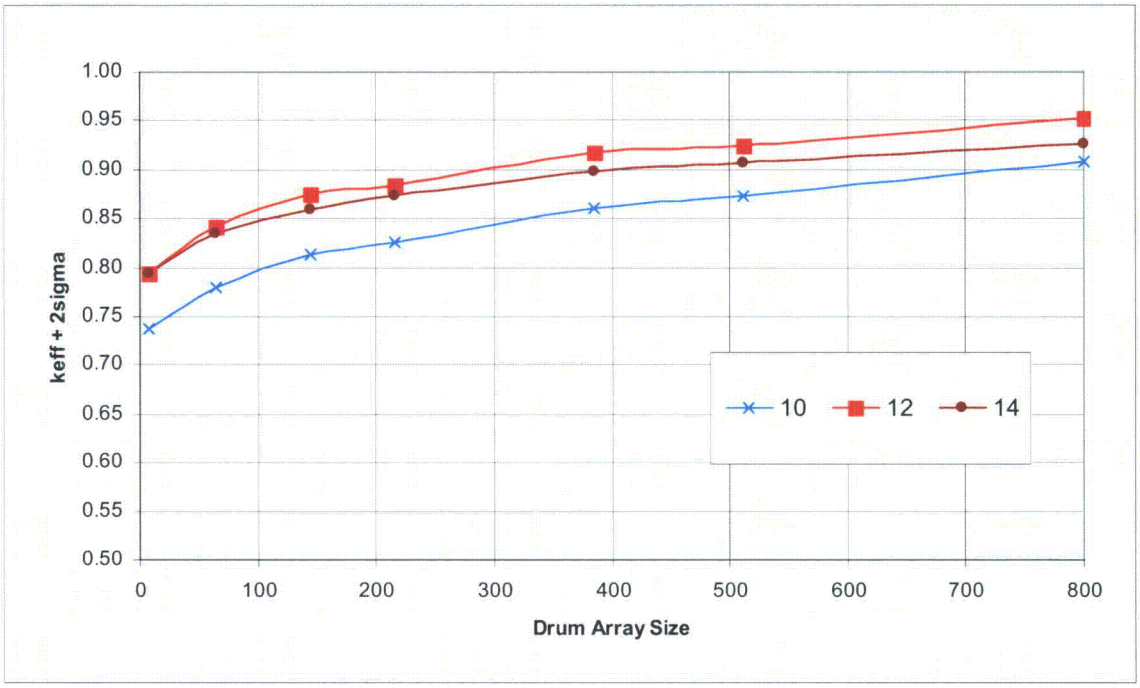

Figure 6-10 KENO VI results for square package array model calculation with lumped spheres as a function of package array size for the Normal Condition of Transport and Hypothetical Condition.

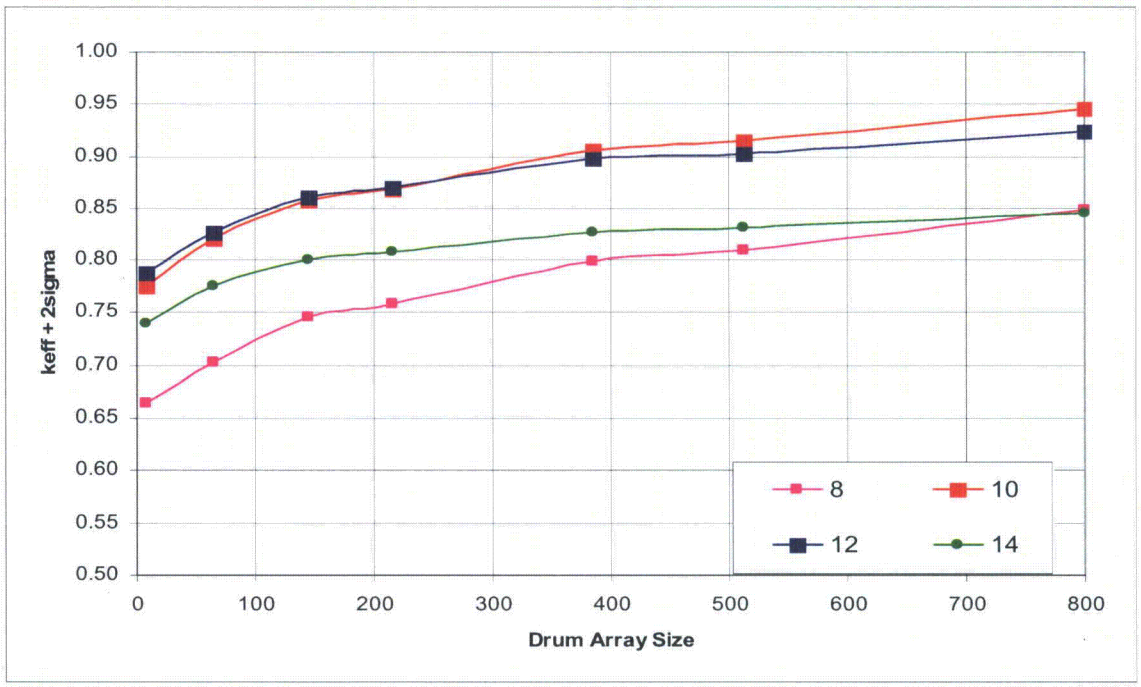

Figure 6-11 KENO VI results for triangular package array model calculation with lumped cylinders as a function of package array size for the Normal Condition of Transport and Hypothetical Condition.

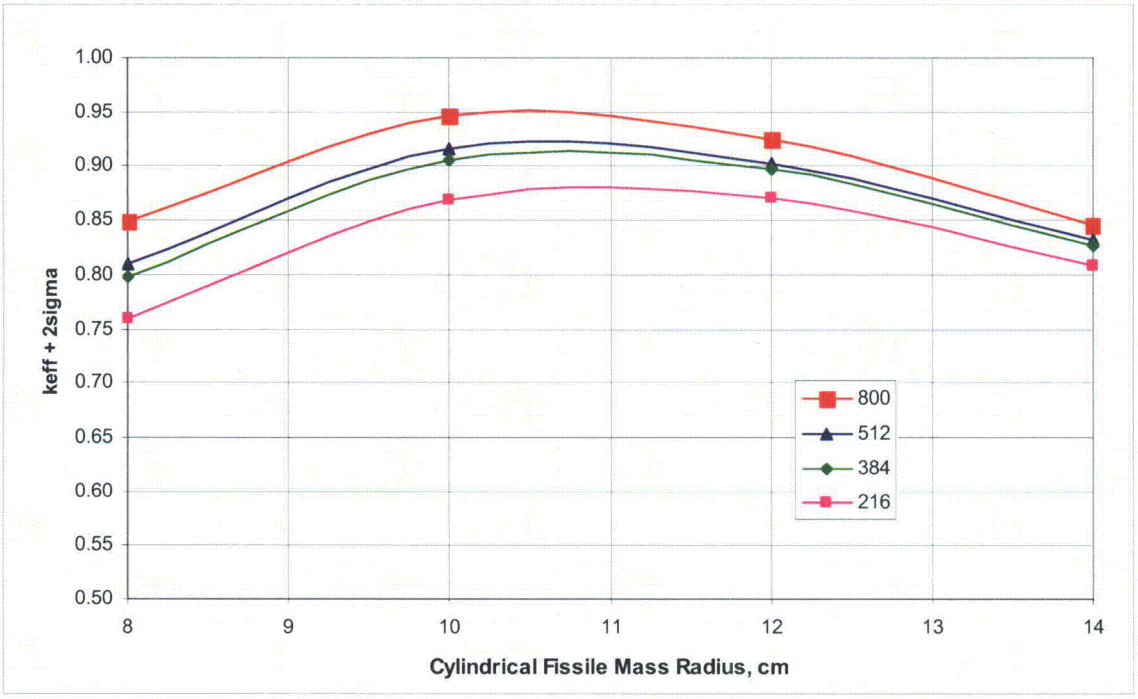

Figure 6-12 KENO VI results for triangular package array model calculation with lumped cylinders as a function of cylinder diameter for the Normal Condition of Transport and Hypothetical Condition.

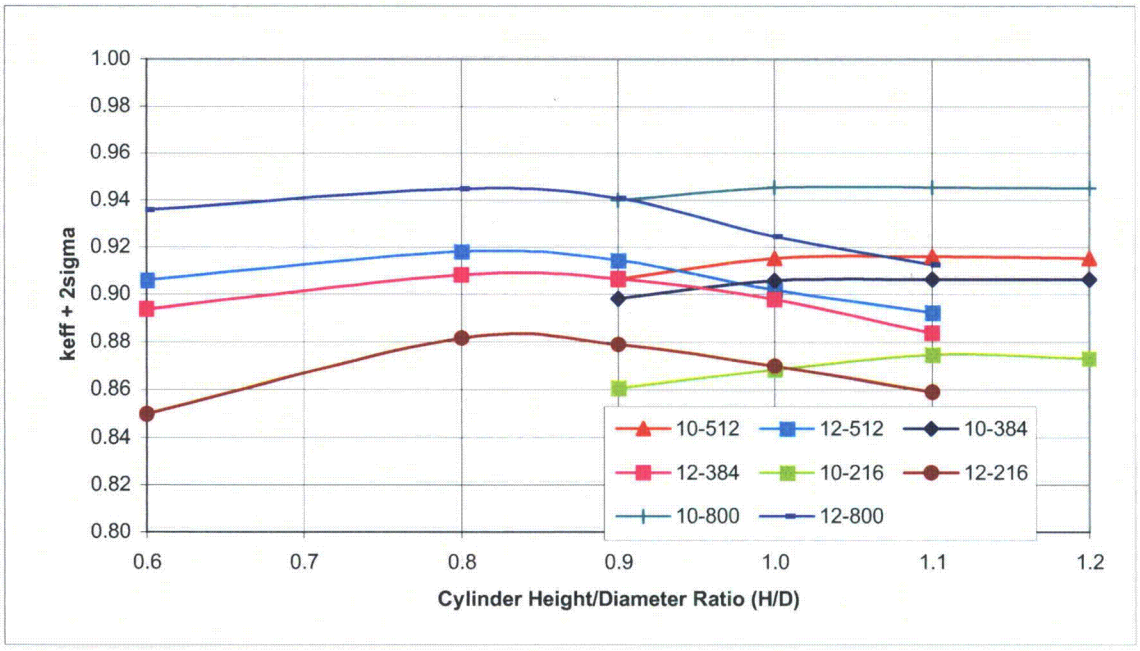

Figure 6-13 KENO VI results for triangular package array model calculation with lumped cylinders as a function of cylinder height-to-diameter ratio for the Normal Condition of Transport and Hypothetical Condition.

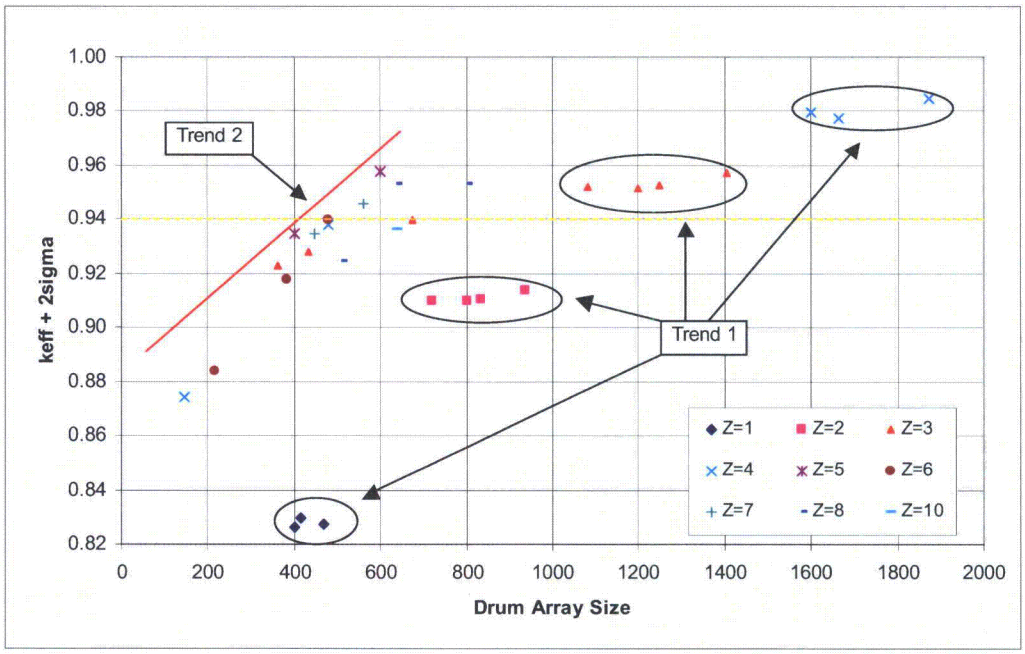

Figure 6-14 KENO VI results for triangular package array model calculation with poly-moderated (0.92 g/cc) lumped spheres as a function of package array size for the Normal Condition of Transport and Hypothetical Condition.

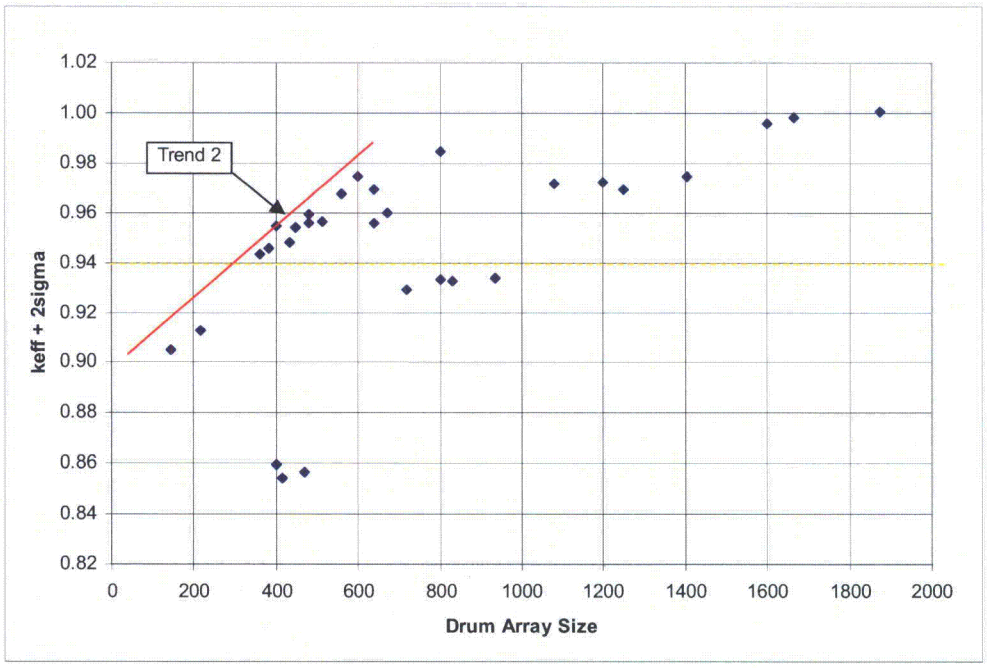

Figure 6-15 KENO VI results for triangular package array model calculation with poly-moderated (0.98 g/cc) lumped spheres as a function of package array size for the Normal Condition of Transport and Hypothetical Condition.

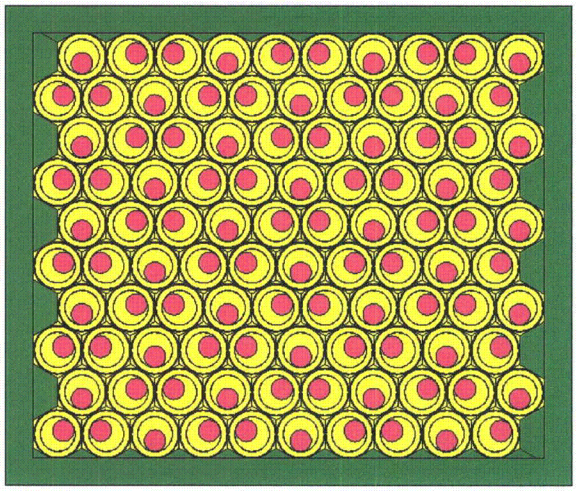

Figure 6-16 Illustration of KENO VI triangular package array model with orientation of lumped fissile mass for the Normal Condition of Transport and Hypothetical Condition.

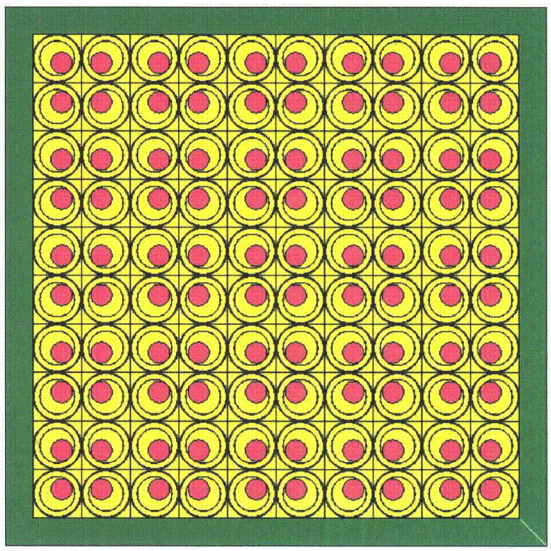

Figure 6-17 Illustration of KENO VI square package array model with orientation of lumped fissile mass for the Normal Condition of Transport and Hypothetical Condition.

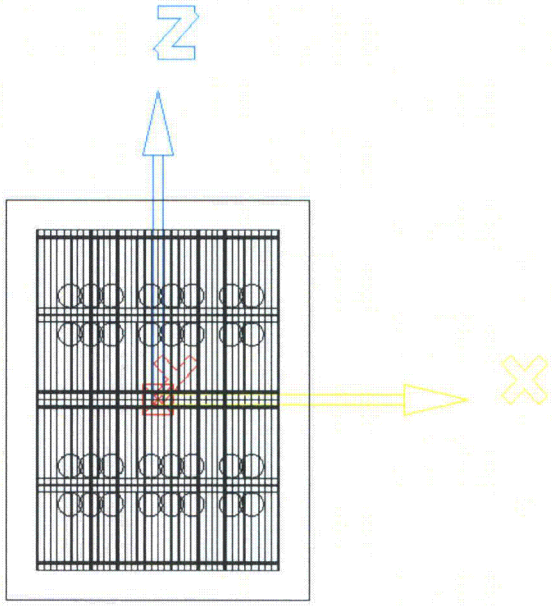

Figure 6-18 Illustration of KENO VI stacked "Y" view of the inverted bottom package and normally orientated top package in a triangular package array model with orientation of lumped fissile mass for the Normal Condition of Transport and Hypothetical Condition.

Input Case: VERSA_HAC_INFH_10_A
HAC Case Infinite Homogeneous Hexagonal 10% Fill

```
=CSAS26     PARM='SIZE=00100000'
CENTURY INDUSTRIES VERSA-PAK
44GR     INFHOM
'URANIUM METAL
U         1 0.00114760 294.0 92235 100.0 END
POLYETHYLENE    1 0.99885 294.0  END
'GRAPHITE   1 0.100 294.0  END
'INTERSPERSED MODERATOR
H2O          2 1.0  294.0  END
'PACKAGE STEEL
CARBONSTEEL  3 1.0  294.0  END
'REFLECTOR
H2O          4 1.0   294.0  END
'INSULATION
H2O          5 0.0001 294.0 END
END COMP
READ PARM  NUB=YES GEN=600 NPG=1000 NSK=5
END PARM
READ GEOMETRY

UNIT  10
CYLINDER  1  19.2088  -27.6225  -34.5281
MEDIA  1  1  1
CYLINDER  2  19.2088  34.5281  -34.5281
MEDIA  5  1  2  -1
CYLINDER  3  19.5163  34.5281  -34.8357
MEDIA  3  1  3  -2  -1
CYLINDER  4  25.8663  34.5281  -34.8357
MEDIA  5  1  4  -3  -2  -1
CYLINDER  5  25.8663  35.7727  -34.8357
MEDIA  3  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.8560  -34.8357
MEDIA  5  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  36.9914  -34.8357
MEDIA  3  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  25.8663  43.3414  -41.1857
MEDIA  5  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.0017  43.3414  -41.7953
MEDIA  3  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.6374  43.3414  -41.7963
MEDIA  5  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.7727  43.3414  -41.7953
MEDIA  3  1  11  -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  12  26.9081  43.4768  -41.9307
MEDIA  3  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  13  26.9081  43.4768  -41.9307
MEDIA  5  1  13 -12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
```

```
BOUNDARY  13

GLOBAL
UNIT  100
CUBOID  10  26.9081 -26.9081  93.2124  0.00  85.4075  0.00
ARRAY  1  10  PLACE 2 1 1  2*0.0 41.9307
BOUNDARY  10
END GEOMETRY
READ ARRAY
GBL=1 ARA=1 TYP=TRIANGULAR NUX=3  NUY=3  NUZ=1
 FILL  10 10 10
      10 10 10
     10 10 10  END FILL
END ARRAY
READ BOUNDS
ALL=SPEC
END BOUNDS
END DATA
END
```

Input Case: VERSA_HAC_INFH2_10_A
HAC Case Infinite Homogeneous Model 2 Hexagonal Inverted 10% Fill

```
=CSAS26     PARM='SIZE=00100000'
CENTURY INDUSTRIES VERSA-PAK
44GR     INFHOM
'URANIUM METAL
U         1 0.00114760 294.0 92235 100.0 END
POLYETHYLENE    1 0.99885 294.0  END
'GRAPHITE   1 0.100 294.0  END
'INTERSPERSED MODERATOR
H2O          2 1.0  294.0  END
'PACKAGE STEEL
CARBONSTEEL  3 1.0  294.0  END
'REFLECTOR
H2O          4 1.0   294.0  END
'INSULATION
H2O          5 0.0001 294.0 END
END COMP
READ PARM  NUB=YES GEN=600 NPG=1000 NSK=5
END PARM
READ GEOMETRY

UNIT  10
CYLINDER  1  19.2088  -27.6225  -34.5281
MEDIA  1  1  1
CYLINDER  2  19.2088  34.5281  -34.5281
MEDIA  5  1  2  -1
CYLINDER  3  19.5163  34.5281  -34.8357
MEDIA  3  1  3  -2  -1
CYLINDER  4  25.8663  34.5281  -34.8357
MEDIA  5  1  4  -3  -2  -1
CYLINDER  5  25.8663  35.7727  -34.8357
MEDIA  3  1  5  -4  -3  -2  -1
```

```
CYLINDER  6  25.8663  36.8560  -34.8357
MEDIA  5  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  36.9914  -34.8357
MEDIA  3  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  25.8663  43.3414  -41.1857
MEDIA  5  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.0017  43.3414  -41.7953
MEDIA  3  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.6374  43.3414  -41.7963
MEDIA  5  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.7727  43.3414  -41.7953
MEDIA  3  1  11  -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  12  26.9081  43.4768  -41.9307
MEDIA  3  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  13  26.9081  43.4768  -41.9307
MEDIA  5  1  13 -12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  13

UNIT  20
CYLINDER  1  19.2088  34.5281   27.6225
MEDIA  1  1  1
CYLINDER  2  19.2088  34.5281  -34.5281
MEDIA  5  1  2  -1
CYLINDER  3  19.5163  34.8357  -34.5281
MEDIA  3  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -34.5281
MEDIA  5  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -35.7727
MEDIA  3  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.8560
MEDIA  5  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  34.8357  -36.9914
MEDIA  3  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  25.8663  41.1857  -43.3414
MEDIA  5  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.0017  41.7953  -43.3414
MEDIA  3  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.6374 41.7963  -43.3414
MEDIA  5  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.7727 41.7953  -43.3414
MEDIA  3  1  11  -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  12  26.9081 41.9307  -43.4768
MEDIA  3  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  13  26.9081 41.9307  -43.4768
MEDIA  5  1  13 -12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  13

GLOBAL
UNIT  100
CUBOID  10  26.9081 -26.9081  93.2124  0.00 170.8150  0.00
ARRAY  1  10  PLACE 2 1 1  2*0.0 43.4768
BOUNDARY  10
END GEOMETRY
READ ARRAY
GBL=1 ARA=1 TYP=TRIANGULAR NUX=3  NUY=3  NUZ=2
```

```
 FILL  20 20 20
      20 20 20
     20 20 20
       10 10 10
      10 10 10
     10 10 10  END FILL
END ARRAY
READ BOUNDS
ALL=SPEC
END BOUNDS
END DATA
END
```

Input Case: VERSA_HAC_FINS_12S_A7
HAC Case Finite In-Homogeneous Square Lattice 12-cm Spheres 800 Packages

```
=CSAS26     PARM='SIZE=00100000'
CENTURY INDUSTRIES VERSA-PAK
44GR     INFHOM
'URANIUM METAL
U         1 0.00253829 294.0 92235 100.0 END
POLYETHYLENE    1 0.99746 294.0  END
'GRAPHITE   1 0.100 294.0  END
'INTERSPERSED MODERATOR
H2O          2 1.0  294.0  END
'PACKAGE STEEL
CARBONSTEEL  3 1.0  294.0  END
'REFLECTOR
H2O          4 1.0   294.0  END
'INSULATION
H2O          5 0.0001 294.0 END
END COMP
READ PARM  NUB=YES GEN=600 NPG=1000 NSK=5
END PARM
READ GEOMETRY

UNIT  10
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE   100  ORIGIN  X=5.097 Y=5.097  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
```

```
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  11
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=5.097 Y=5.097  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  20
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-5.097 Y=5.097  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
```

```
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  21
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-5.097 Y=5.097  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  30
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=5.097 Y=-5.097  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
```

```
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  31
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=5.097 Y=-5.097  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  40
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-5.097 Y=-5.097  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
```

```
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  41
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-5.097 Y=-5.097  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1 10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CUBOID  12  4P26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  100
SPHERE  1  12.00
MEDIA  1  1  1
BOUNDARY  1

UNIT  200
CUBOID  10  107.6324  0.00  107.6324  0.00  170.815  0.00
ARRAY  1  10  PLACE 1 1 1 26.9081  26.9081  43.4768
BOUNDARY  10
GLOBAL
UNIT  300
CUBOID  10  538.16  0.00  538.16  0.00  683.260  0.00
ARRAY  2  10  PLACE 1 1 1  3*0.00
CUBOID  20  568.64  -30.48  568.64  -30.48  713.74  -30.48
```

```
MEDIA  4  10  20  -10
BOUNDARY  20
END GEOMETRY
READ ARRAY
ARA=1 NUX=2 NUY=2 NUZ=2
      FILL 11 21 31 41 10 20 30 40  END FILL
ARA=2 NUX=5 NUY=5 NUZ=4
      FILL  F200  END FILL
END ARRAY
READ BOUNDS
ALL=VACUUM
END BOUNDS
END DATA
END
```

Input Case: VERSA_HAC_FINH_12S_A7
HAC Case Finite In-Homogeneous Hexagonal Lattice 12-cm Spheres 800 Packages

```
=CSAS26     PARM='SIZE=00100000'
CENTURY INDUSTRIES VERSA-PAK
44GR     INFHOM
'URANIUM METAL
U         1 0.00253829 294.0 92235 100.0 END
POLYETHYLENE    1 0.99746 294.0  END
'SUB FOR HIGH DENSITY POLY
'POLYETHYLENE    1  DEN=0.98  0.99746 294.0  END
'SUB FOR GRAPHITE
'GRAPHITE   1 0.99746 294.0  END
'INTERSPERSED MODERATOR
H2O         2 1.0  294.0  END
'PACKAGE STEEL
CARBONSTEEL  3 1.0  294.0  END
'REFLECTOR
H2O          4 1.0   294.0  END
'INSULATION
H2O          5 0.0001 294.0 END
END COMP
READ PARM  NUB=YES GEN=600 NPG=1000 NSK=5
END PARM
READ GEOMETRY

UNIT  10
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE   100  ORIGIN  X=6.24  Y=3.60  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
```

```
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  11
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN X=6.24  Y=3.60  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  20
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-6.24  Y=3.60  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
```

```
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  21
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-6.24  Y=3.60  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  30
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=0.00  Y=-7.208  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
```

```
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  31
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=0.00  Y=-7.208  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  40
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-6.24  Y=-3.60  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
```

```
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  41
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-6.24  Y=-3.60  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT 50
HEXPRISM  10  26.9081  43.4768 -41.9307
MEDIA  4  1  10
BOUNDARY  10

UNIT 51
HEXPRISM  10  26.9081  41.9307 -43.4768
MEDIA  4  1  10
BOUNDARY  10
```

```
UNIT  100
SPHERE  1  12.00
MEDIA  1  1  1
BOUNDARY  1

GLOBAL
UNIT  1000
CUBOID  10  565.1  0.00  473.3  0.00  683.260  0.00
ARRAY  1  10  PLACE 6 2 1  26.9081  26.9081  43.4768
CUBOID  20  595.55  -30.48  503.75  -30.48  713.74  -30.48
MEDIA  4  10  20  -10
BOUNDARY  20
END GEOMETRY
READ ARRAY
GBL=1 ARA=1 TYP=TRIANGULAR NUX=16 NUY=12 NUZ=8
      FILL 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51
          51 51 51 51 51 11 21 31 11 21 31 11 21 31 11 51
        51 51 51 51 51 31 11 21 31 11 21 31 11 21 31 51
       51 51 51 51 11 21 31 11 21 31 11 21 31 11 51 51
      51 51 51 51 31 11 21 31 11 21 31 11 21 31 51 51
     51 51 51 11 21 31 11 21 31 11 21 31 11 51 51 51
    51 51 31 11 21 31 11 21 31 11 21 31 51 51 51 51
   51 51 11 21 31 11 21 31 11 21 31 11 51 51 51 51 51
  51 51 31 11 21 31 11 21 31 11 21 31 51 51 51 51 51
 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51
           50 50 50 50 50 50 50 50 50 50 50 50 50 50 50
          50 50 50 50 50 10 20 30 10 20 30 10 20 30 10 50
        50 50 50 50 50 30 10 20 30 10 20 30 10 20 30 50
       50 50 50 50 10 20 30 10 20 30 10 20 30 10 50 50
      50 50 50 50 30 10 20 30 10 20 30 10 20 30 50 50
     50 50 50 10 20 30 10 20 30 10 20 30 10 50 50 50
    50 50 50 30 10 20 30 10 20 30 10 20 30 50 50 50
   50 50 10 20 30 10 20 30 10 20 30 10 50 50 50 50
  50 50 30 10 20 30 10 20 30 10 20 30 50 50 50 50
 50 10 20 30 10 20 30 10 20 30 10 50 50 50 50 50
50 30 10 20 30 10 20 30 10 20 30 50 50 50 50 50
50 50 50 50 50 50 50 50 50 50 50 50 50 50 50 50
3Q384 END FILL
END ARRAY
READ BOUNDS
ALL=VACUUM
END BOUNDS
END DATA
END
```

Input Case: VERSA_HAC_FINH_12S_10X064
HAC Case Finite In-Homogeneous Hexagonal Lattice 12-cm Spheres 8X8X10 Packages

```
=CSAS26     PARM='SIZE=00100000'
CENTURY INDUSTRIES VERSA-PAK
```

```
44GR     INFHOM
'URANIUM METAL
U          1 0.00253829 294.0 92235 100.0 END
POLYETHYLENE    1 0.99746 294.0  END
'GRAPHITE   1 0.100 294.0  END
'INTERSPERSED MODERATOR
H2O          2 1.0  294.0  END
'PACKAGE STEEL
CARBONSTEEL  3 1.0  294.0  END
'REFLECTOR
H2O          4 1.0   294.0  END
'INSULATION
H2O          5 0.0001 294.0 END
END COMP
READ PARM  NUB=YES GEN=600 NPG=1000 NSK=5
END PARM
READ GEOMETRY

UNIT  10
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE   100  ORIGIN  X=6.24  Y=3.60  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  11
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN X=6.24  Y=3.60  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
```

```
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  20
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE   100  ORIGIN  X=-6.24  Y=3.60  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  21
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE   100  ORIGIN  X=-6.24  Y=3.60  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
```

```
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  30
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE   100  ORIGIN  X=0.00  Y=-7.208  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  31
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE   100  ORIGIN  X=0.00  Y=-7.208  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.8357  -34.5281
```

```
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  40
CYLINDER  1  19.2088 34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-6.24  Y=-3.60  Z=-22.528
CYLINDER  2  19.5163  34.5281  -34.8357
MEDIA  3  1  2  -1
CYLINDER  3  25.8663  34.5281  -34.8357
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  35.7727  -34.8357
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  36.8560  -34.8357
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  36.9914  -34.8357
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  43.3414  -41.1857
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  43.3414  -41.7953
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374  43.3414  -41.7963
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727  43.3414  -41.7953
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081  43.4768  -41.9307
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081  43.4768  -41.9307
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT  41
CYLINDER  1  19.2088  34.5281 -34.5281
MEDIA  5  1  1
HOLE  100  ORIGIN  X=-6.24  Y=-3.60  Z=22.528
CYLINDER  2  19.5163  34.8357  -34.5281
MEDIA  3  1  2  -1
```

```
CYLINDER  3  25.8663  34.8357  -34.5281
MEDIA  5  1  3  -2  -1
CYLINDER  4  25.8663  34.8357  -35.7727
MEDIA  3  1  4  -3  -2  -1
CYLINDER  5  25.8663  34.8357  -36.8560
MEDIA  5  1  5  -4  -3  -2  -1
CYLINDER  6  25.8663  34.8357  -36.9914
MEDIA  3  1  6  -5  -4  -3  -2  -1
CYLINDER  7  25.8663  41.1857  -43.3414
MEDIA  5  1  7  -6  -5  -4  -3  -2  -1
CYLINDER  8  26.0017  41.7953  -43.3414
MEDIA  3  1  8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  9  26.6374 41.7963  -43.3414
MEDIA  5  1  9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  10  26.7727 41.7953  -43.3414
MEDIA  3  1  10  -9  -8  -7  -6  -5  -4  -3  -2  -1
CYLINDER  11  26.9081 41.9307  -43.4768
MEDIA  3  1  11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
HEXPRISM  12  26.9081 41.9307  -43.4768
MEDIA  5  1  12 -11 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1
BOUNDARY  12

UNIT 50
HEXPRISM  10  26.9081  43.4768 -41.9307
MEDIA  4  1  10
BOUNDARY  10

UNIT 51
HEXPRISM  10  26.9081  41.9307 -43.4768
MEDIA  4  1  10
BOUNDARY  10

UNIT  100
SPHERE  1  12.00
MEDIA  1  1  1
BOUNDARY  1

GLOBAL
UNIT  1000
CUBOID  10  457.5  0.00  380.1  0.00  854.075  0.00
ARRAY  1  10  PLACE 5 2 1  26.9081  26.9081  43.4768
CUBOID  20  487.91  -30.48  410.53  -30.48  884.555  -30.48
MEDIA  4  10  20  -10
BOUNDARY  20
END GEOMETRY
READ ARRAY
GBL=1 ARA=1 TYP=TRIANGULAR NUX=13  NUY=10  NUZ=10
    FILL 51 51 51 51 51 51 51 51 51 51 51 51 51
        51 51 51 51 11 21 31 11 21 31 11 21 51
       51 51 51 51 31 11 21 31 11 21 31 11 51
      51 51 51 11 21 31 11 21 31 11 21 51 51
     51 51 51 31 11 21 31 11 21 31 11 51 51
    51 51 11 21 31 11 21 31 11 21 51 51 51
   51 51 31 11 21 31 11 21 31 11 51 51 51
  51 11 21 31 11 21 31 11 21 51 51 51 51
```

```
 51 31 11 21 31 11 21 31 11 51 51 51 51
51 51 51 51 51 51 51 51 51 51 51 51 51
         50 50 50 50 50 50 50 50 50 50 50 50 50
        50 50 50 50 10 20 30 10 20 30 10 20 50
       50 50 50 50 30 10 20 30 10 20 30 10 50
      50 50 50 10 20 30 10 20 30 10 20 50 50
     50 50 50 30 10 20 30 10 20 30 10 50 50
    50 50 10 20 30 10 20 30 10 20 50 50 50
   50 50 30 10 20 30 10 20 30 10 50 50 50
  50 10 20 30 10 20 30 10 20 50 50 50 50
 50 30 10 20 30 10 20 30 10 50 50 50 50
50 50 50 50 50 50 50 50 50 50 50 50 50
8Q130  END FILL
END ARRAY
READ BOUNDS
ALL=VACUUM
END BOUNDS
END DATA
END
```

Validation of SCALE4.4a-PC for High Enriched Uranium Systems

Richard D. Montgomery

Montgomery Engineering & Technical Services

June 2009

MTS-424 Rev. 1

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1.0 Introduction

The SCALE4.4a KENO code [**Reference 1**] has been validated for enriched uranium systems using several different methods [**References 2** through **5**]. The objective of this evaluation is to establish that the CSAS25, CSAS26, and CSAS2X sequences will conservatively predict the multiplication factor (k_{eff}) of High Enriched Uranium (HEU) systems. In order to demonstrate the applicability of the SCALE4.4a KENO code for HEU systems, several critical experiments [**References 6** through **53**] using a variety of material forms were modeled with the SCALE4.4a KENO code and run on a desktop PC. The critical experiments were segregated into various groups based on the uranium system, and the results were evaluated using various statistical methods. Validations are performed using both KENO Va and KENO VI.

2.0 Methodology

2.1 Experiment Selection

Table 1 provides a summary of the critical experiments that were modeled. The critical experiments selected were chosen for analysis because they consist of HEU systems and are documented in sufficient detail to develop an accurate analytical model. Each critical experiment report provides comprehensive data on the materials of construction, dimensions, fissionable material, and experimental uncertainties.

The HEU experiments were selected and categorized into four distinct groups. These groupings consisted of:

Group 1: All experiments (161) used in this validation,
Group 2: Experiments (81) with ALCF $\leq 10^2$ eV, data sets 1-82, and
Group 3: Experiments (56) with ALCF $> 10^2$ eV and $\leq 10^5$ eV, data sets 83-138, and
Group 4: Experiments (24) with ALCF $> 10^5$ eV, data sets 139-162.

The experimental and calculated results were then compared based on a review of the k_{eff} distribution, enrichment (wt%^{235}U), average lethargy causing fission (ALCF), the hydrogen-to-fissile atom ratio (H/X), and the fissile material density (g ^{235}U/l).

2.2 SCALE4.4a Models

Each critical experiment was modeled exactly as described in **References 6** and **53**. All criticality calculations were run to convergence, which typically required 600 generations and 1000 neutrons per generation for a total of 600,000 histories. Default values were used for all other parameters. All calculations were performed using the SCALE4.4a KENO Va Code with the 44-Group Standard Cross Section Library [**Reference 1**]. **Appendix A** contains the input decks for each critical experiment modeled. All dimensional and material information is identical to that reported in **References 6** and **53**. C5TOC6 is then executed to generate the initial KENO VI cases. Each case is then reviewed and further edited by the analyst (incorporate evaluator specific traits) and then executed for the validation.

2.3 Methodology for Statistical Evaluation of Results

The results of the SCALE4.4a KENO calculations were compared with the experimental results of the critical experiments through the use of various statistical analyses. The multiplication factor for each critical experiment is equal to unity; therefore, an accurate prediction of the multiplication factor using

SCALE4.4a KENO must be equivalent to unity also. The KENO program uses a Monte Carlo probability-based method, and as a result of this method, the calculated multiplication factors of an infinite number of critical experiments should provide a normal distribution about a mean multiplication factor of unity. However, it is known that biases exist in the SCALE4.4a program that lead to over-estimation of the multiplication factor for specific groups of fissile systems. Therefore, the objective of the statistical evaluation is to determine whether or not the results for each Group are normally distributed about unity (KENO predicts accurately for the Group) with an acceptable deviation (KENO predicts precisely for the Group). If KENO does not provide an accurate prediction, further evaluations are provided to determine whether or not a bias exists. The methods used to calculate the SCALE4.4a KENO Va bias and bias uncertainty is outlined in **References 54** and **55**.

2.3.1 Accuracy measures: Comparison of the Means

The calculated multiplication factors and the experimental multiplication factors represent two populations having the means μ_1 and μ_2 and the variances σ_1 and σ_2. The objective of this comparison is to determine whether or not the means of the experimental and calculated data are statistically equivalent, and if they are not, whether or not there is an identifiable bias. A two-tailed t-test for the difference between two means [**Reference 55**] is used to test the hypothesis that the means of the two data sets are equal, or $\mu_1 = \mu_2$. The alternative hypothesis is $\mu_1 \neq \mu_2$, or the mean of the two populations are not equal, and that a bias exists in the calculated data. The t-value is calculated using Equation 1:

$$t = \frac{\mu_1 - \mu_2 - \delta}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}, \qquad \text{(Equation 1)}$$

where:

μ_1 is the mean of the standard data set,
μ_2 is the mean of the data set to be tested,
δ is the null hypothesis constant (0 here for the hypothesis of $\mu_1 = \mu_2$),
σ_1 is the standard deviation of the standard data set,
σ_2 is the standard deviation of the data set to be tested,
n_1 is the number of observation in the standard data set, and
n_2 is the number of observations in the data set to be tested.

2.3.2 Accuracy Measures: Determination Of Method Bias

The bias is defined as:

$$Bias = \bar{k}_{calc} - \bar{k}_{exp}, \qquad \text{(Equation 2)}$$

where k_{exp} and k_{calc} are the mean of the experimental and calculated (KENO) k_{eff} values, respectively.

2.3.3 Precision Measures: Determination Of Calculational Variance and Standard Deviation

The variance, S^2, of the calculated KENO k_{eff} is defined as:

$$S^2 = \frac{\sum(\overline{k_{calc}} - k_i)^2}{n-1}, \qquad \text{(Equation 3)}$$

where k_i is the calculated k_{eff} for the ith critical experiment and n is the total number of experiments.

The standard deviation, σ_{calc}, of the KENO-calculated k_{eff} is the positive square root of the variance, S^2. Note that this is *not* the KENO-calculated standard deviation, $\sigma_{KENO\text{-}calc}$, presented in **Table 3**, which is an average value of the calculated k_{eff} uncertainties.

2.3.4 Precision Measures: Determination Of Experimental Variance and Standard Deviation

The variance of the experimental k_{eff} is generally ignored, since the uncertainty associated with the measured k_{eff} (the known standard) is typically very small. Values reported for various experiments range from 0.0004 to 0.0019. Since the experimental uncertainties are usually reported as standard deviations, the experimental variance, S_o, is simply the average standard deviation of the group of experiments, $\overline{\sigma_{exp}}$, squared:

$$S_0^2 = (\overline{\sigma_{exp}})^2. \qquad \text{(Equation 4)}$$

2.3.5 Precision Measures: Determination Of Bias Uncertainty

According to **Reference 55**, the variance associated with the bias is given by the following equation:

$$V_B = \frac{S^2}{n} + S_0^2, \qquad \text{(Equation 5)}$$

where S^2 is the calculated k_{eff} variance (Equation 3), and S_o^2 is the experimental k_{eff} variance (Equation 4).

For conservatism, an additional term is added to Equation 5 to incorporate the effect of the individual uncertainties of the KENO-calculated k_{eff} value for each critical experiment model. The variance of the KENO-calculated uncertainty, S_u^2, is defined as:

$$S_u^2 = \frac{\sum(\sigma_{calc,i})^2}{n}, \qquad \text{(Equation 6)}$$

where, $\sigma_{calc,i}$ is the uncertainty associated with the KENO results for experiment i, and n is the number of experiments. This equation is the square-weighted average of the individual KENO uncertainties. The standard deviation of the KENO-calculated uncertainties is the square root of the variance, S_u^2.

Incorporating Equation 6 into Equation 5, the final equation for the variance associated with the KENO-calculated k_{eff} bias is:

$$V = \frac{(S^2 + S_u^2)}{n} + S_0^2. \qquad \text{(Equation 7)}$$

The standard deviation of the bias value is then simply the square root of the variance:

$$U = \kappa\sqrt{V}\,, \qquad \text{(Equation 8)}$$

where, κ is the 95/95 one-sided tolerance factor that is applied to the bias uncertainty for the number of critical experiments **[Reference 54]**.

2.4 Methodology for Determination Applicable Limits

With the determination of the KENO bias and bias uncertainty associated with each Group of experiments, it is possible to calculate the Upper Subcritical Limits and the maximum allowable or biased KENO k_{eff} to maintain subcriticality for each system type.

2.4.1 Practical application: Calculation of an Upper Subcritical k_{eff} Limit

Starting at a multiplication factor of 1 (critical), the biases and uncertainties are subtracted, and the resulting number is the Upper Subcritical Limit for the system. At a 95% confidence level:

$$\textit{Upper Subcritical Limit} = 1 + \textit{bias} - U, \qquad \text{(Equation 9)}$$

where the *bias* and *U* are substituted from **Equations 2** and **8**, respectively. Values determined using this method are provided in **Table 3.** For systems with a positive bias, the second term of **Equation 9**, *bias,* is omitted.

In practice, the calculated system is considered to be subcritical if the following condition is met:

$$KENO_{\text{-}calc}\text{-}k_{eff} + \kappa(\sigma_{\text{KENO-calc}}) < \textit{Upper Subcritical Limit}, \qquad \text{(Equation 10)}$$

where the system is subcritical at a 95% confidence level. A bounding κ factor of 1.645 is historically applied to the corresponding $\sigma_{\text{KENO-calc}}$ uncertainty for the calculation. This κ factor is different from that used in **Equation 8** for determination of the bias uncertainty.

2.4.2 Practical application: Calculation of the biased KENO Multiplication Factor

Alternatively starting with the calculated $\text{KENO}_{\text{-calc}}\text{-}k_{eff}$, a biased k_{eff} can be calculated:

$$\textit{Biased KENO-}k_{eff} = \text{KENO}_{\text{-calc}}\text{-}k_{eff} + \kappa(\sigma_{\text{KENO-calc}}) - \textit{bias} + U. \qquad \text{(Equation 11)}$$

And the system is considered to be subcritical if the following condition is met:

$$\textit{Biased KENO-}k_{eff} < 1. \qquad \text{(Equation 12)}$$

In the case where the bias is positive (KENO consistently over-estimates k_{eff}), the bias term is omitted for conservatism.

3.0 Calculation Results

Table 2 presents the multiplication factor (k_{eff}), standard deviation (σ), and average lethargy causing fission (ALCF) calculated for each critical experiment modeled using the SCALE4.4a code with the 44 group cross-section library. **Table 3** provides the results of the statistical evaluations from different groupings of critical experiment data sets. The Upper Limit Subcritical k_{eff} for each group was calculated using the mean KENO-calculated uncertainty for the Group. In practice, it is preferable to use the actual

KENO-calculated standard deviation for the calculation being performed. However, it is conservative to use the mean KENO-calculated uncertainty to establish the bias for the group and then use the actual KENO-calculated standard deviation for the calculation to ensure a margin below the established limit.

4.0 Discussion

In order to validate the SCALE4.4a code for use with high enriched uranium systems, it is necessary to determine if KENO predicts the multiplication factor in an accurate and precise manner throughout the range of fission energies of interest. To evaluate the accuracy of the code, the mean of each Group of experiments was compared to the mean of the experimental results. A t-test was performed for each Group to determine whether or not the average result of a KENO calculation (the mean calculated k_{eff} for each Group) is statistically the same as the experimental result (unity). Passing the t-test affirms that the KENO code predicts multiplication factors accurately for the Group being tested, without bias. Failure of the t-test indicates that the mean KENO k_{eff} is statistically different from the experimental mean, and that a bias exists in the data. Groups that failed the t-test were further evaluated for bias and uncertainty, and these parameters applied to provide an upper limit subcritical multiplication factor for the Group.

Each Group of KENO-calculated k_{eff}s are also graphed against key system parameters (Enrichment {wtg%^{235}U}, Energy of the Average Lethargy Causing Fission {ALCF}, Hydrogen-to-Fissile Atom Ratio {H/^{235}U}, and fissile material density {g ^{235}U/cc}) to identify trends within the data that may indicate inaccurate cross-sections or instabilities in the code. The normality of residuals is also tested using the Anderson-Darling method. The null hypothesis of a normality test is that there is no significant departure from normality. When the probability level, ρ is greater than 0.05, it fails to reject the null hypothesis and thus the assumption holds. Histogram, skewness and kurtosis plots are also provided for each group.

4.1 Comparison of the Means

The t-statistic for each Group evaluated against the experimental data is provided in **Table 3**. A two-tailed test at the 95% confidence limit was performed. All Groupings of the data were found to have statistically different means, and therefore, the mean KENO-calculated k_{eff} is biased.

4.2 Comparison of Uncertainty

In order to benchmark the performance of the code, the uncertainty associated with the KENO-calculated k_{eff}, must take into account the uncertainty associated with the critical experiment, since it is inherently a part of the result. The experimental uncertainty impacting the modeling of the experiment stems from material and geometric tolerances, rather than measurement of the experimental k_{eff}. Unfortunately, this type of uncertainty is not well evaluated or documented. Therefore, an average uncertainty of 0.0011 was assigned to those experiments that did not report an uncertainty value.

The bias uncertainty associated with Groups 1 though 4 are 0.0022, 0.0024, 0.0027, and 0.0037, respectively, at a 95% confidence level. For Groups 3 and 4, the uncertainty is higher than the bias. This fact leads to the conclusion that there is no detectable bias (either positive or negative) in the data, since application of the uncertainty obscures it. The uncertainty is lower than the bias for Groups 1 and 2 suggesting that there is a detectable bias in this data. However, as indicated in **Table 3** the bias is positive for all data groups.

4.3 Comparison of System Behavior as a Function of the System Attributes

For hydrogen moderated ^{235}U systems, the fission energy is proportional to the degree of moderation. Variations in the bias over the data range for the fissile density ($g^{235}U/cc$), energy of the average lethargy causing fission (ALCF) and the hydrogen-to-fissile atomic ratio ($H/^{235}U$) should be similar. However, differences will be evident due to statistical variations in the experimental and calculated results.

4.3.1 Oxide and Solution Systems

Dry (non-hydrogenous moderated) UO_2 systems at any enrichment are fast (neutronic) systems. The results of the critical experiments documented elsewhere, as well as the results of the critical experiments modeled here; show that the typical average lethargy causing fission in a fast system ranges from 10^4 to 10^6 eV. Fast critical UO_2 systems enriched to less than 15wt% are not feasible due to the large quantity of material required. However, a few LEU fast critical systems (metal) have been performed ranging in enrichment from 10 – 15wt%. The neutronic attributes of these fast metal experiments are very similar to the fast metal experiments with enrichments ranging from 93 - 97wt%. Several of these types of experiments are evaluated in this validation. The only major difference between the experiments at these different enrichments is the fact that more material is required for the lower enriched systems to achieve criticality. Various analytical methods have shown that an infinite UO_2 mass system has sufficient ^{235}U density to achieve criticality for enrichments near 7.0 wt %. However, without moderation, the system is fast. A few low-enriched (<5wt%) metal critical experiments have been performed; however, these systems also required moderation (water) to achieve critical configurations and therefore were driven by intermediate and thermal energy neutrons.

As moderator is introduced to the system, the neutronics of the system changes. A fast system becomes an under-moderated intermediate system. The typical average lethargy causing fission in an intermediate system ranges from 10^0 to 10^4 eV. Very few low enriched intermediate critical experiments have been performed. These systems are difficult to construct and maintain due to the under-moderated configurations. However, a few intermediate experiments have been completed using mixtures of low-enriched metals and fissile solutions. Several of these types of experiments are evaluated in this validation.

With additional moderation the intermediate system becomes a thermal system. The typical average lethargy causing fission in a thermal system ranges from 10^{-2} to 10^0 eV. The large majority of critical experiments are thermal. These systems are easily constructed at all enrichments. For a low enriched UO_2 system approximately 5.0wt% water is required to change the neutronics of the system from fast to thermal. Little difference is observed for enrichments less than 5.0wt% and those ranging from 5 to 10wt%. However, for enrichments ranging from 90 to 97wt%, a large amount of water, approximately 90wt%, is necessary to change the neutronics of a fast system to an intermediate, and finally a thermal, system.

Given that the mechanics of hydrogen moderated critical systems are the same regardless of enrichment, analytical computer codes predicting the k_{eff} of enriched systems should perform equally well at all enrichments. Since the SCALE4.4a KENO Code has been validated as performing accurately over a large range of enrichments with a variety of moderators and moderation levels, it is reasonable that it should also perform accurately in the remaining ranges. The results of these calculations demonstrate that the SCALE4.4a KENO Code is accurate in the high enrichment range. These results also demonstrate that the level of accuracy is the same as the accuracy of the KENO Code at other enrichment ranges [**Reference 56**].

4.3.2 Metal Systems

Metal systems are typically fast due to experimental configurations involving single and arrays of units at high densities with little or no moderation. Several experiments display similar attributes when the fissile media is further diluted with non-fissile metals. A few metal (fast) experiments exist at 10wt% however the majority of these experiments are highly enriched. Several of these types of experiments are evaluated in this validation.

4.4 Comparison of the k_{eff} Distributions

The KENO-calculated, unbiased k_{eff} was plotted for Groups 1 through 4 using a histogram to demonstrate the relative distributions about the mean value, as shown in **Figures 1** through **4**, respectively. If the CSAS25 sequence performs accurately without systemic errors, then the k_{eff} results will be normally distributed about a mean k_{eff}. This is expected since KENO is a Monte Carlo probability-based program. Also, a k_{eff} of unity is expected since the experiments were reported as being critical. As shown in the histograms, the distribution appears to be normal, with a slight positive bias indicating that the CSAS25 sequence contains a systemic conservative bias.

The normality of residuals, using the Anderson-Darling method, indicated that the probability level ρ is greater than 0.05 for **Groups 2** through **4**. Therefore, the test fails to reject the null hypothesis and thus the assumption, normal data, holds. The null hypothesis of a normality test is that there is no significant departure from normality. Since the probability level ρ is greater than 0.05, it fails to reject the null hypothesis and thus the assumption holds. Histogram, skewness and kurtosis plots are also provided for each group in **Figures 1** through **3** for **Groups 2** through **4**, respectively.

4.5 Bias Trends with Enrichment

Figure 5 shows the KENO-calculated, unbiased k_{eff} plotted as a function of the system enrichment. The enrichments of the selected benchmarks ranged from 62.40 to 97.68 wt% ^{235}U. Based on this plot, there appears to be no distinct or observable bias in the k_{eff} as a function of enrichment. Based on this, the proposed enrichment range for the validation can be extended from 97.68 wt% to 100.00 wt%.

4.6 Bias Trends with Average Lethargy Causing Fission (ALCF)

Figure 6 shows the KENO-calculated unbiased k_{eff} plotted as a function of the energy of the average lethargy causing fission (ALCF). The ALCF plots use a logarithmic scale to distinguish between the different neutron energy ranges. Based on this plot, there appears to be no distinct or observable bias in the k_{eff} as a function of the ALCF. Considering all experiments presented in this validation, the ALCF covers a range of energies from 0.0291eV to 914,000eV, spanning the thermal, intermediate, and fast fission groups.

4.7 Bias Trends with Hydrogen-to-Fissile Atom Ratio (H/X)

Figure 7 shows the KENO-calculated unbiased k_{eff} plotted as a function of the hydrogen-to-fissile atom ratio (H/X, where X is ^{235}U). Considering all experiments, the H/X covers a range from 0 to 1,836. This spans the under-moderated (less than 200), optimum (200 to 300), and over-moderated (greater than 300) regions. The H/X plots use a logarithmic scale to distinguish the different ranges of H/X values for the experiments. Overall, there appears to be no distinct or observable bias in the k_{eff} as a function of the hydrogen-to-fissile atom ratio.

4.8 Fissile Density (g ^{235}U/cc)

Figure 8 shows the KENO-calculated unbiased k_{eff} plotted as a function of the fissile material density for all experiments. Considering all experiments, the fissile density covers a range from 0.014 to 18.36 g ^{235}U/cc. The plot of the fissile density is similar to the plot of the ALCF. Overall, there appears to be no distinct or observable bias in the k_{eff} as a function of the fissile density.

4.9 KENO VI and KENO Va Comparison

Figure 9 shows the KENO VI-calculated unbiased k_{eff} plotted as a function of the KENO Va-calculated unbiased k_{eff}. The KENO VI results appear to be slightly higher for k_{eff} results less than 1.00 and slightly lower for k_{eff} results greater than 1.00. However, these observed k_{eff} differences are less than 0.0025. The results of both code versions statistically give essentially the same result. The KENO VI results are further provided in Table 2. The statistical results (bias and bias uncertainty) are further provided in Table 3.

5.0 Conclusions

The SCALE4.4a KENO Code provides precise results (slight positive bias for Groups 1 through 4) using the 44-Group Standard Cross Section Library for high enrichments with a variety of material forms, geometry, neutron energy, water-to-fuel ratio, density and ALCF. The precision of the code varies somewhat depending upon the fissile system being analyzed, as demonstrated by the results of the statistical evaluations. For the Group 1 (all experiments) at a 95% confidence level, the bias uncertainty of the KENO results is ±0.0022. The overall bias (Group 1) associated with the KENO results is +0.0031.

Additionally, the results of the parametric studies indicate that there appears to be no distinct or observable trends with the energy of the average lethargy causing fission, the moderator-to-fissile atom ratio, fissile density or enrichment. The recommended application of the KENO-calculated standard deviation, uncertainty, and Upper Subcritical Limits will prevent a critical system from being mistakenly evaluated as subcritical. The Group 1 data is normally distributed about a mean k_{eff} value of 1.0030 such that a one-sided 95% confidence level can be used to establish the Upper Limit k_{eff}. Based on this validation, the Upper Limit k_{eff} for Group 1 (All Data) is 0.9969 (includes the bias and bias uncertainty at a 95% confidence level). This value does not include an arbitrary administrative margin.

Many of the critical experiments available for code validation do not document experimental uncertainties that may impact the modeling of the system; therefore, it is difficult to assess whether poor results are due to faulty code performance or simply poor modeling of the experiment due to lack of proper information.

The overall (Group 1) Upper Subcritical Limit is 0.9969. However, an Upper Subcritical Limit of 0.9966 should be used for Groups 2 and 3 for ALCF values to 10^5eV. An Upper Subcritical Limit of 0.9958 must be used (Group 4) for ALCF values greater than 10^5eV. For all cases, including both KENO VI and KENO Va, an Upper Subcritical Limit of 0.9958 is bounding for ALCF values ranging from less than 10^{-2}eV to greater than 10^5eV.

Based on these results, an administrative upper subcritical limit of 0.95 is overly restrictive. An administrative upper subcritical limit of 0.97 is justified based on this validation. This provides an arbitrary administrative margin of 3%. With a 3% margin the Upper Subcritical Limit is 0.9658. However, with a 5% margin the Upper Subcritical Limit is 0.9458. Values provided in Table 3 implement the Upper Subcritical Limit with a 5% margin. As applied to analyses, since the bias is

positive in all cases and neglected, limiting the $k_{eff} + 2\sigma$ to less than or equal to 0.9458 (5% administrative margin) meets the intended requirements of this validation.

6.0 Area of Applicability

An essential portion of a code validation effort is to define the area of applicability for the code. The area of applicability defines the types of materials, options, and range of parameter values that were used or were bounded by the validation. This study has demonstrated that Scale 4.4a/KENO V.a with the ENDF/B-V 44 group cross-sectional data is accurate for use in evaluating the multiplication factor for high enriched uranium (60.0-100.0 wt%), moderated, reflected and unreflected systems or configurations. The $H/^{235}U$ values used in the benchmark experiments varied from 0 to 1,836. The fissile density (g ^{235}U/cc) ranges from 0.014 to 18.36. The average lethargy causing fission (ALCF) ranges from 0.0291eV to 914,000eV. This defines the range of applicability for the enrichment, $H/^{235}U$, ACLF, and fissile density of this validation.

The MULTIREGION and INFHOM cross-sectional modeling options were used in the benchmark modeling. This validation specifically covers uranium systems (homogeneous and heterogeneous) moderated by hydrogen (water- or poly-bound hydrogen) with carbon, nitrogen, fluorine and oxygen also present as a portion of the uranium compound. This validation further covers various moderator and reflector materials such as water, carbon, concrete, paraffin, plexiglas, aluminum, natural uranium and polyethylene. The basic geometry package consisting of cuboid, cylinder, sphere and hemisphere were used in modeling the benchmark critical experiments. Several other materials including boron, chlorine, gadolinium, stainless steel, and carbon steel were also used in modeling the benchmark experiments.

If the parameters of a fissile system or configuration being evaluated are outside of the boundaries or limits of this evaluation, then an additional margin of subcriticality determined from an alternate code or specific experimental benchmark will be used to ensure that the system remains subcritical.

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Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heust-032-001	1	1836.68	0.01411	Uranyl Nitrate	Spherical	Water/NO3	Aluminum/Steel	93.21
Heust-002-009	2	458.76	0.05558	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum	93.17
Heust-012-001	3	1272.25	0.02047	Uranyl Fluoride	Spherical	Water/HF	Water/Aluminum	93.18
Heust-037-005	4	463.05	0.05469	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.08
Heust-028-001	5	374.56	0.06770	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.08
Heust-014-002	6	418.13	0.06064	Uranyl Nitrate	Cylinder	Water/NO3	Water/Steel	89.04
Heust-035-005	7	378.60	0.06670	Uranyl Nitrate	Cylinder	Water/NO3	Water/Steel	89.08
Heust-035-001	8	766.63	0.03341	Uranyl Nitrate	Cylinder	Water/NO3	Water/Steel	89.08
Heust-007-009	9	336.62	0.07520	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum/Stainless Steel	93.17
Heust-037-002	10	684.46	0.03732	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.08
Heust-011-001	11	523.41	0.04940	Uranyl Fluoride	Spherical	Water/HF	Water/Aluminum	93.20
Heumt-006-012	12	0.00	0.72167	U-Al Metal	Cuboid	Aluminum	Water	93.17
Heust-025-006	13	586.11	0.04336	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.04
Heust-008-007	14	453.75	0.05620	Uranyl Nitrate	Cylinder	Water/NO3	Plexiglass/Aluminum/Stainless Steel	93.17
Heust-002-010	15	458.76	0.05558	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum	93.17

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	H/^{235}U Atom Ratio	g^{235}U/cc	Material	Geometry	Moderator	Reflector	Enrichment
Heust-003-001	16	453.75	0.05620	Uranyl Nitrate	Cylinder	Water/NO3	Plexiglass/Stainless Steel	93.17
Heumt-006-005	17	0.00	0.72167	U-Al Metal	Cuboid	Aluminum	Water	93.17
Heust-028-008	18	374.56	0.06770	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.08
Heumt-006-016	19	0.00	0.72167	U-Al Metal	Cuboid	Aluminum	Water	93.17
Heust-007-010	20	325.16	0.07779	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum/Stainless Steel	93.17
Heust-037-009	21	339.68	0.07393	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.08
Heust-010-003	22	245.70	0.10190	Uranyl Fluoride	Spherical	Water/HF	Water/Aluminum	93.13
Heust-036-002	23	302.47	0.08263	Uranyl Nitrate	Cuboid	Water/NO3	Steel	89.14
Heumt-006-018	24	0.00	0.72167	U-Al Metal	Cuboid	Aluminum	Water	93.17
Heust-015-003	25	278.39	0.08948	Uranyl Nitrate	Cylinder	Water/NO3	Water/Steel	89.04
Heumt-006-010	26	0.00	0.72167	U-Al Metal	Cuboid	Aluminum	Water	93.17
Heust-027-001	27	203.61	0.12115	Uranyl Nitrate	Cylinder	Water/NO3	None	89.08
Heust-027-005	28	203.61	0.12115	Uranyl Nitrate	Cylinder	Water/NO3	None	89.08
Heust-002-012	29	183.79	0.13452	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum	93.17
Heust-002-011	30	183.79	0.13452	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum	93.17

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heuct-010-021	31	0.00	1.49407	Uranium Dioxide	Cylinder	Beryllium/Borated Uranyl Nitrate/Water	Water	62.40
Heuct-010-010	32	0.00	1.49410	Uranium Dioxide	Cylinder	Beryllium/Water	Water	62.40
Heuct-014-002	33	0.00	1.03792	Uranium Dioxide	Cylinder	Aluminum/Silicon Oxides	Water	79.38
Heuct-010-017	34	0.00	1.49407	Uranium Dioxide	Cylinder	Beryllium/Boric Acid/Water	Water	62.40
Heuct-010-015	35	0.00	1.49407	Uranium Dioxide	Cylinder	Beryllium/Water	Water	62.40
Heuct-010-008	36	0.00	1.49407	Uranium Dioxide	Cylinder	Beryllium/Water	Water	62.40
Heuct-014-001	37	0.00	1.03792	Uranium Dioxide	Cylinder	Aluminum/Silicon Oxides	Water	79.38
Heust-020-003	38	847.40	0.03010	Uranyl Fluoride	Cylinder	D2O/Water/HF	D2O/Water/Steel/Aluminum	93.65
Heuct-010-005	39	0.00	1.49407	Uranium Dioxide	Cylinder	Beryllium/Water	Water	62.40
Heuct-010-006	40	0.00	1.49407	Uranium Dioxide	Cylinder	Beryllium/Water	Water	62.40
Heust-030-004	41	91.14	0.25745	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.08
Heust-025-017	42	62.68	0.35010	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.04
Heust-025-016	43	61.85	0.35616	Uranyl Nitrate	Cylinder	Water/NO3	Water	89.04
Heuct-010-004	44	0.00	1.49407	Uranium Dioxide	Cylinder	Beryllium/Water	Water	62.40

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heust-008-014	45	68.75	0.33164	Uranyl Nitrate	Cylinder	Water/NO3	Plexiglass/Aluminum/ Stainless Steel	93.17
Heust-021-006	46	58.78	0.38429	Uranyl Nitrate	Cylinder	Water/NO3	Paraffin	92.60
heust-005-015	47	80.26	0.28947	Uranyl Nitrate	Cylinder	Water/NO3	None	87.40
Heust-003-011	48	70.94	0.32175	Uranyl Nitrate	Cylinder	Water/NO3	Plexiglass/Aluminum	93.17
Heust-005-008	49	80.26	0.28947	Uranyl Nitrate	Cylinder	Water/NO3	Water	87.40
Heust-008-008	50	80.26	0.28947	Uranyl Nitrate	Cylinder	Water/NO3	Water	87.40
Heust-002-003	51	73.50	0.31191	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Stainless Steel	93.17
Heust-003-018	52	70.94	0.32175	Uranyl Nitrate	Cylinder	Water/NO3	Plexiglass/Aluminum	93.17
Heust-007-008	53	66.78	0.33925	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum/Stainless Steel	93.17
Heust-007-006	54	67.50	0.33576	Uranyl Nitrate	Cylinder	Water/NO3	Concrete/Aluminum/Stainless Steel	93.17
Heust-021-018	55	58.78	0.38429	Uranyl Nitrate	Cylinder	Water/NO3	top (paraffin), bottom (paraffin)	92.60
Heust-033-003	56	68.10	0.33317	Uranyl Nitrate	Annular	Water/NO3	Concrete	93.22
Heust-021-023	57	58.78	0.38429	Uranyl Nitrate	Cylinder	Water/NO3	top (plexiglass), bottom (plexiglass)	92.60

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heust-033-008	58	68.10	0.33317	Uranyl Nitrate	Annular	Water/NO3	Concrete	93.22
Heuct-013-002	59	0.00	1.03792	Uranium Dioxide	Cylinder	Aluminum/Silicon Oxides	Water	79.38
Heust-006-022	60	84.54	0.27481	Uranyl Nitrate	Cylinder	Water/NO3	Borated Water	93.06
Heust-009-002	61	47.23	0.50603	Uranyl Fluoride	Spherical	Water/HF	Water/Aluminum	93.19
Heuct-010-003	62	0.00	1.49407	Uranium Dioxide	Cylinder	Berrylium/Water	Water	62.40
Heucm-001-002	63	0.00	1.74728	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heust-006-014	64	84.98	0.27452	Uranyl Nitrate	Cylinder	Water/NO3	Nickel	93.06
Heust-006-021	65	84.24	0.27360	Uranyl Nitrate	Cylinder	Water/NO3	Nickel/Borated Water	93.06
Heuct-013-001	66	0.00	1.03792	Uranium Dioxide	Cylinder	Aluminum/Silicon Oxides	Water	79.38
Heuct-011-002	67	0.00	1.03792	Uranium Dioxide	Cylinder	Aluminum/Silicon Oxides	Water	79.38
Heuct-012-001	68	0.00	1.03792	Uranium Dioxide	Cylinder	Aluminum/Silicon Oxides	Water	79.48
Heuct-011-001	69	0.00	1.03792	Uranium Dioxide	Cylinder	Aluminum/Silicon Oxides	Water	79.38
Heust-004-004	70	134.90	0.18499	Uranyl Fluoride	Spherical	D2O/Water/HF	D2O/Water/Steel	93.65

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heust-020-001	71	227.70	0.10940	Uranyl Fluoride	Cylinder	D2O/Water/HF	D2O/Water/Steel/Aluminum	93.65
Heust-004-003	72	80.96	0.30200	Uranyl Fluoride	Spherical	D2O/Water/HF	D2O/Water/Steel	93.65
Heumt-003-005	73	0.00	17.69982	U-Metal	Cuboid	None	Water	94.52
Heust-004-002	74	53.54	0.44298	Uranyl Fluoride	Spherical	D2O/Water/HF	D2O/Water/Steel	93.65
Heust-004-001	75	34.10	0.67902	Uranyl Fluoride	Spherical	D2O/Water/HF	D2O/Water/Steel	93.65
Heucm-001-018	76	34.10	0.67902	Uranyl Fluoride	Spherical	D2O/Water/HF	D2O/Water/Steel	93.65
Heucm-001-017	77	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heucm-001-015	78	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heucm-001-016	79	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumf-007-043	80	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heucm-001-019	81	0.00	17.18152	U-Metal	Cuboid	None	Polyethylene	93.15
Heuci-004-001	82	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heucm-001-013	83	0.45	0.09763	Uranium Dioxide	Cuboid	Graphite/Water	None	92.28

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heucm-001-011	84	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heucm-001-012	85	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumf-007-042	86	0.00	17.18338	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-041	87	0.00	17.21505	U-Metal	Cuboid	None	Polyethylene	93.15
Heucm-001-009	88	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumf-007-018	89	0.00	17.23368	U-Metal	Cuboid	None	Polyethylene	93.15
Heucm-001-010	90	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumf-007-017	91	0.00	17.23554	U-Metal	Cuboid	None	Polyethylene	93.15
Heucm-001-027	92	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-026	93	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-025	94	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-023	95	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heucm-001-024	96	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-029	97	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-028	98	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-022	99	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-021	100	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-020	101	1.56	5.41384	Uranium Dioxide	Cylinder	Alcohol	Alcohol/Plexiglass/Polyethylene	93.15
Heucm-001-008	102	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumm-002-001	103	0.00	16.52425	U-Metal	Sphere	None	Polyethylene	90.00
Heumm-003-001	104	0.00	16.52425	U-Metal	Sphere	None	Polyethylene	90.00
Heucm-001-005	105	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumf-007-031	106	0.00	17.37061	U-Metal	Cuboid	None	Plexiglass	93.15
Heumf-007-039	107	0.00	17.24859	U-Metal	Cuboid	None	Polyethylene	93.15

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heumf-007-040	108	0.00	17.28957	U-Metal	Cuboid	None	Polyethylene	93.15
Heucm-001-007	109	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumf-007-038	110	0.00	17.17034	U-Metal	Cuboid	None	Polyethylene	93.15
Heucm-001-006	111	0.00	4.49781	Uranium Dioxide	Cylinder	Oxygen	Water/Plexiglass/Polyethylene	93.15
Heumf-007-037	112	0.00	17.18897	U-Metal	Cuboid	None	Polyethylene	93.15
Heumm-001-001	113	0.00	17.83457	U-Metal	Cylinder/Slab	None	Titanium/Polyethylene	95.98
Heumf-007-013	114	0.00	17.20853	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-016	115	0.00	17.28212	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-015	116	0.00	17.28957	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-014	117	0.00	17.17872	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-036	118	0.00	17.34639	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-023-020	119	0.00	17.48432	U-Metal	Cylinder	None	Polyethylene	93.20
Heumf-007-011	120	0.00	17.20853	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-031	121	0.00	17.83087	U-Metal	Cylinder	Carbon/Iron/Tungsten	Polyethylene	95.96
Heumf-007-035	122	0.00	17.11072	U-Metal	Cuboid	None	Polyethylene	93.15

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heumf-026-004	123	0.00	17.48432	U-Metal	Cylinder	None	Paraffin	93.20
Heumf-034-003	124	0.00	17.83087	U-Metal	Cylinder	Carbon/Iron/Tungsten	Titanium/Polyethylene /Aluminum	95.96
Heumf-034-001	125	0.00	17.60018	U-Metal	Cuboid	None	Water	94.01
Heumf-034-002	126	0.00	17.83087	U-Metal	Cylinder	Carbon/Iron/Tungsten	Titanium/Polyethylene /Aluminum	95.96
Heumf-026-006	127	0.00	17.48432	U-Metal	Cylinder	None	Paraffin	93.20
Heumf-007-030	128	0.00	17.37806	U-Metal	Cuboid	None	Plexiglass	93.15
Heumt-003-001	129	0.00	17.60018	U-Metal	Cuboid	None	Water	94.01
Heumf-007-026	130	0.00	17.27374	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-010	131	0.00	17.24113	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-025	132	0.00	17.28212	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-026-003	133	0.00	17.48432	U-Metal	Cylinder	None	Paraffin	93.20
Heumf-004-002	134	0.00	18.35603	U-Metal	Sphere	None	Water	97.68
Heumf-004-001	135	0.00	18.35603	U-Metal	Sphere	None	Water, Plexiglass	97.68
Heumf-007-024	136	0.00	0.44400	U-Metal	Cylinder	Iron/Nickel/Chromium	Carbon Steel	93.18
Heumf-007-023	137	0.00	17.27933	U-Metal	Cuboid	None	Polyethylene	93.15

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heumf-007-006	138	0.00	17.31752	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-022	139	0.00	17.30541	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-009	140	0.00	17.27001	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-008	141	0.00	17.27839	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-005	142	0.00	17.26442	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-007-003	143	0.00	17.26256	U-Metal	Cuboid	None	Polyethylene	93.15
Heumf-020	144	0.00	17.29423	U-Metal	Cuboid	None	Plexiglass	93.15
Heumf-007-002	145	0.00	16.58525	U-Metal	Sphere	Carbon/Iron/Tungsten	Polyethylene	89.65
Heumf-003-004	146	0.00	17.53125	U-Metal	Sphere	None	Tungsten Carbide	93.50
Heumf-041	147	0.00	17.37150	U-Metal	Cuboid	None	Beryillum	93.90
Heumf-003-003	148	0.00	17.53125	U-Metal	Sphere	None	Tungsten Carbide	93.50
Heumf-003-002	149	0.00	17.53125	U-Metal	Sphere	None	Tungsten Carbide	93.50
Heumf-007-034	150	0.00	17.13215	U-Metal	Cuboid	None	Teflon	93.15
Heumf-003-001	151	0.00	17.53125	U-Metal	Sphere	None	Tungsten Carbide	93.50
Heumf-007-033	152	0.00	17.17779	U-Metal	Cuboid	None	Teflon	93.15
Heumf-007-032	153	0.00	17.17779	U-Metal	Cuboid	None	Teflon	93.15

Table 1 Summary of Critical Experiments Modeled

Case ID	Case Number	$H/^{235}U$ Atom Ratio	$g^{235}U/cc$	Material	Geometry	Moderator	Reflector	Enrichment
Heumf-019	154	0.00	16.54912	U-Metal	Sphere	Carbon/Iron/Tungsten	Graphite	89.60
Heumf-027	155	0.00	16.29293	U-Metal	Sphere	Carbon/Iron/Tungsten	Lead/Iron	89.47
Heumf-023-016	156	0.00	17.48430	U-Metal	Cylinder	None	Polyethylene	93.20
Heumf-018	157	0.00	16.33423	U-Metal	Sphere	Carbon/Iron/Tungsten	None	89.65
Heumf-026-001	158	0.00	17.48432	U-Metal	Cylinder	None	None	93.20
Heumf-001-001	159	0.00	17.65883	U-Metal	Sphere	None	None	93.90
Heumf-007-019	160	0.00	17.31845	U-Metal	Cuboid	None	None	93.15
Heumf-007-001	161	0.00	17.21598	U-Metal	Cuboid	None	None	93.15

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heust-032-001	1	1.0000	0.0004	0.9994	0.0008	0.9979	0.0009	2.91E-02
Heust-002-009	2	1.0000	0.0004	1.0081	0.0017	1.0077	0.0018	3.05E-02
Heust-012-001	3	1.0000	0.0004	1.0047	0.0009	1.0018	0.0010	3.08E-02
Heust-037-005	4	1.0000	0.0004	1.0092	0.0012	1.0046	0.0011	3.16E-02
Heust-028-001	5	1.0000	0.0004	1.0019	0.0017	1.0014	0.0021	3.28E-02
Heust-014-002	6	1.0000	0.0004	1.0149	0.0014	1.0157	0.0014	3.31E-02
Heust-035-005	7	1.0000	0.0004	1.0066	0.0013	1.0096	0.0012	3.45E-02
Heust-035-001	8	1.0000	0.0004	1.0045	0.0013	1.0014	0.0011	3.52E-02
Heust-007-009	9	1.0000	0.0004	1.0085	0.0013	1.0080	0.0013	3.61E-02
Heust-037-002	10	1.0000	0.0004	1.0061	0.0011	1.0044	0.0013	3.71E-02
Heust-011-001	11	1.0000	0.0004	1.0075	0.0012	1.0049	0.0013	3.79E-02
Heumt-006-012	12	1.0000	0.0004	1.0054	0.0016	1.0049	0.0014	4.00E-02
Heust-025-006	13	1.0000	0.0004	1.0107	0.0009	1.0120	0.0009	4.07E-02
Heust-008-007	14	1.0000	0.0004	1.0003	0.0014	0.9986	0.0014	4.13E-02

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heust-002-010	15	1.0000	0.0004	1.0079	0.0013	1.0089	0.0014	4.19E-02
Heust-003-001	16	1.0000	0.0004	1.0070	0.0014	1.0008	0.0014	4.19E-02
Heumt-006-005	17	1.0000	0.0004	1.0023	0.0015	1.0048	0.0016	4.34E-02
Heust-028-008	18	1.0000	0.0004	1.0010	0.0014	0.9992	0.0015	4.56E-02
Heumt-006-016	19	1.0000	0.0004	1.0030	0.0014	1.0008	0.0017	4.73E-02
Heust-007-010	20	1.0000	0.0004	1.0142	0.0013	1.0162	0.0011	5.06E-02
Heust-037-009	21	1.0000	0.0004	1.0057	0.0013	1.0057	0.0015	5.20E-02
Heust-010-003	22	1.0000	0.0004	1.0023	0.0016	1.0012	0.0015	5.33E-02
Heust-036-002	23	1.0000	0.0004	1.0006	0.0015	0.9966	0.0015	5.56E-02
Heumt-006-018	24	1.0000	0.0004	1.0036	0.0018	1.0031	0.0016	6.04E-02
Heust-015-003	25	1.0000	0.0004	1.0124	0.0013	1.0128	0.0013	6.04E-02
Heumt-006-010	26	1.0000	0.0004	1.0040	0.0015	1.0040	0.0016	6.28E-02
Heust-027-001	27	1.0000	0.0004	0.9983	0.0019	0.9999	0.0016	7.18E-02
Heust-027-005	28	1.0000	0.0004	0.9946	0.0014	0.9989	0.0014	7.33E-02
Heust-002-012	29	1.0000	0.0004	1.0113	0.0014	1.0082	0.0013	7.52E-02

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heust-002-011	30	1.0000	0.0004	1.0041	0.0015	1.0034	0.0015	7.69E-02
Heuct-010-021	31	1.0000	0.0004	1.0059	0.0012	1.0040	0.0013	9.09E-02
Heuct-010-010	32	1.0000	0.0004	1.0009	0.0011	1.0019	0.0011	9.57E-02
Heuct-014-002	33	1.0000	0.0004	1.0028	0.0013	1.0000	0.0013	9.61E-02
Heuct-010-017	34	1.0000	0.0004	1.0056	0.0013	1.0042	0.0012	9.69E-02
Heuct-010-015	35	1.0000	0.0004	1.0027	0.0011	1.0031	0.0012	9.96E-02
Heuct-010-008	36	1.0000	0.0004	1.0025	0.0012	1.0029	0.0012	1.09E-01
Heuct-014-001	37	1.0000	0.0004	1.0001	0.0013	1.0036	0.0012	1.16E-01
Heust-020-003	38	1.0000	0.0004	1.0098	0.0016	1.0083	0.0017	1.32E-01
Heuct-010-005	39	1.0000	0.0004	0.9968	0.0011	0.9963	0.0012	1.37E-01
Heuct-010-006	40	1.0000	0.0004	0.9947	0.0013	0.9965	0.0012	1.38E-01
Heust-030-004	41	1.0000	0.0004	1.0028	0.0015	1.0016	0.0015	1.56E-01
Heust-025-017	42	1.0000	0.0004	1.0057	0.0010	1.0062	0.0010	1.67E-01
Heust-025-016	43	1.0000	0.0004	1.0148	0.0010	1.0134	0.0010	1.79E-01
Heuct-010-004	44	1.0000	0.0004	0.9964	0.0013	0.9958	0.0014	1.90E-01

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heust-008-014	45	1.0000	0.0004	1.0000	0.0017	1.0005	0.0014	2.06E-01
Heust-021-006	46	1.0000	0.0004	1.0132	0.0015	1.0138	0.0014	2.15E-01
Heust-005-015	47	1.0000	0.0004	0.9984	0.0014	0.9985	0.0014	2.23E-01
Heust-003-011	48	1.0000	0.0004	1.0024	0.0017	1.0012	0.0014	2.28E-01
Heust-005-008	49	1.0000	0.0004	1.0039	0.0012	1.0031	0.0013	2.33E-01
Heust-008-008	50	1.0000	0.0004	1.0004	0.0016	0.9998	0.0015	2.40E-01
Heust-002-003	51	1.0000	0.0004	1.0020	0.0017	1.0029	0.0017	2.48E-01
Heust-003-018	52	1.0000	0.0004	0.9990	0.0016	1.0003	0.0014	2.54E-01
Heust-007-008	53	1.0000	0.0004	1.0046	0.0015	1.0040	0.0015	2.66E-01
Heust-007-006	54	1.0000	0.0004	1.0065	0.0014	1.0059	0.0016	2.70E-01
Heust-021-018	55	1.0000	0.0004	1.0030	0.0015	1.0061	0.0016	2.79E-01
Heust-033-003	56	1.0000	0.0004	1.0033	0.0013	1.0020	0.0013	2.90E-01
Heust-021-023	57	1.0000	0.0004	0.9989	0.0014	1.0014	0.0014	2.98E-01
Heust-033-008	58	1.0000	0.0004	1.0029	0.0013	1.0041	0.0014	3.07E-01
Heuct-013-002	59	1.0000	0.0004	0.9993	0.0012	1.0004	0.0011	3.12E-01

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heust-006-022	60	1.0000	0.0004	1.0037	0.0012	1.0024	0.0011	3.14E-01
Heust-009-002	61	1.0000	0.0004	1.0046	0.0014	1.0045	0.0014	3.18E-01
Heuct-010-003	62	1.0000	0.0004	0.9947	0.0015	0.9912	0.0014	3.24E-01
Heucm-001-002	63	1.0000	0.0004	1.0102	0.0014	1.0111	0.0013	3.56E-01
Heust-006-014	64	1.0000	0.0004	1.0048	0.0010	1.0029	0.0012	3.58E-01
Heust-006-021	65	1.0000	0.0004	1.0040	0.0008	1.0043	0.0009	4.44E-01
Heuct-013-001	66	1.0000	0.0004	0.9995	0.0014	0.9994	0.0012	4.49E-01
Heuct-011-002	67	1.0000	0.0004	0.9976	0.0012	0.9954	0.0011	5.39E-01
Heuct-012-001	68	1.0000	0.0004	0.9957	0.0015	0.9963	0.0014	5.94E-01
Heuct-011-001	69	1.0000	0.0004	0.9972	0.0012	0.9972	0.0012	7.04E-01
Heust-004-004	70	1.0000	0.0004	1.0027	0.0017	1.0044	0.0016	1.09E+00
Heust-020-001	71	1.0000	0.0004	1.0065	0.0020	1.0037	0.0019	1.35E+00
Heust-004-003	72	1.0000	0.0004	1.0017	0.0015	1.0015	0.0016	2.68E+00
Heumt-003-005	73	1.0000	0.0004	0.9943	0.0017	0.9917	0.0015	2.73E+00
Heust-004-002	74	1.0000	0.0004	1.0000	0.0017	1.0015	0.0017	5.59E+00

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heust-004-001	75	1.0000	0.0004	1.0049	0.0016	1.0013	0.0016	1.30E+01
Heucm-001-018	76	1.0000	0.0004	1.0072	0.0016	1.0079	0.0014	2.35E+01
Heucm-001-017	77	1.0000	0.0004	1.0022	0.0010	1.0019	0.0010	2.50E+01
Heucm-001-015	78	1.0000	0.0004	1.0129	0.0011	1.0129	0.0012	2.88E+01
Heucm-001-016	79	1.0000	0.0004	1.0024	0.0011	1.0051	0.0010	2.92E+01
Heumf-007-043	80	1.0000	0.0004	1.0081	0.0017	1.0073	0.0017	3.32E+01
Heucm-001-019	81	1.0000	0.0004	1.0061	0.0014	1.0075	0.0017	5.81E+01
Heuci-004-001	82	1.0000	0.0004	1.0138	0.0004	1.0141	0.0004	1.45E+02
Heucm-001-013	83	1.0000	0.0004	1.0061	0.0011	1.0081	0.0010	2.32E+02
Heucm-001-011	84	1.0000	0.0004	1.0074	0.0013	1.0085	0.0012	2.58E+02
Heucm-001-012	85	1.0000	0.0004	1.0050	0.0012	1.0011	0.0011	2.59E+02
Heumf-007-042	86	1.0000	0.0004	1.0066	0.0011	1.0037	0.0013	2.91E+02
Heumf-007-041	87	1.0000	0.0004	1.0044	0.0015	1.0035	0.0014	3.05E+02
Heucm-001-009	88	1.0000	0.0004	1.0061	0.0012	1.0042	0.0012	3.46E+02
Heumf-007-018	89	1.0000	0.0004	0.9972	0.0014	0.9959	0.0013	3.47E+02

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heucm-001-010	90	1.0000	0.0004	0.9996	0.0012	1.0004	0.0012	3.50E+02
Heumf-007-017	91	1.0000	0.0004	0.9943	0.0014	0.9959	0.0013	3.72E+02
Heucm-001-027	92	1.0000	0.0004	1.0066	0.0012	1.0063	0.0012	3.83E+02
Heucm-001-026	93	1.0000	0.0004	1.0049	0.0012	1.0052	0.0012	4.01E+02
Heucm-001-025	94	1.0000	0.0004	1.0021	0.0014	1.0025	0.0012	4.42E+02
Heucm-001-023	95	1.0000	0.0004	1.0131	0.0011	1.0107	0.0013	4.54E+02
Heucm-001-024	96	1.0000	0.0004	1.0056	0.0011	1.0080	0.0013	4.54E+02
Heucm-001-029	97	1.0000	0.0004	1.0096	0.0013	1.0064	0.0012	4.64E+02
Heucm-001-028	98	1.0000	0.0004	1.0089	0.0012	1.0112	0.0012	4.82E+02
Heucm-001-022	99	1.0000	0.0004	1.0059	0.0011	1.0046	0.0011	5.28E+02
Heucm-001-021	100	1.0000	0.0004	1.0067	0.0011	1.0077	0.0010	5.35E+02
Heucm-001-020	101	1.0000	0.0004	1.0122	0.0011	1.0100	0.0012	5.39E+02
Heucm-001-008	102	1.0000	0.0004	1.0017	0.0012	1.0017	0.0013	5.54E+02
Heumm-002-001	103	1.0000	0.0004	1.0096	0.0011	1.0108	0.0012	1.18E+03
Heumm-003-001	104	1.0000	0.0004	1.0107	0.0012	1.0084	0.0012	1.18E+03

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heucm-001-005	105	1.0000	0.0004	1.0084	0.0011	1.0082	0.0011	1.54E+03
Heumf-007-031	106	1.0000	0.0004	1.0002	0.0015	1.0011	0.0014	1.61E+03
Heumf-007-039	107	1.0000	0.0004	1.0041	0.0011	1.0019	0.0013	1.70E+03
Heumf-007-040	108	1.0000	0.0004	1.0066	0.0012	1.0071	0.0014	1.70E+03
Heucm-001-007	109	1.0000	0.0004	1.0092	0.0012	1.0073	0.0011	1.72E+03
Heumf-007-038	110	1.0000	0.0004	1.0016	0.0011	1.0008	0.0012	1.74E+03
Heucm-001-006	111	1.0000	0.0004	1.0035	0.0010	1.0024	0.0010	1.82E+03
Heumf-007-037	112	1.0000	0.0004	1.0032	0.0012	1.0032	0.0011	1.90E+03
Heumm-001-001	113	1.0000	0.0004	1.0053	0.0012	1.0050	0.0012	2.26E+03
Heumf-007-013	114	1.0000	0.0004	0.9972	0.0014	0.9997	0.0012	2.54E+03
Heumf-007-016	115	1.0000	0.0004	0.9947	0.0014	0.9954	0.0014	2.82E+03
Heumf-007-015	116	1.0000	0.0004	0.9949	0.0013	0.9925	0.0012	2.83E+03
Heumf-007-014	117	1.0000	0.0004	0.9974	0.0013	0.9953	0.0013	3.70E+03
Heumf-007-036	118	1.0000	0.0004	1.0049	0.0011	1.0046	0.0013	3.90E+03
Heumf-023-020	119	1.0000	0.0004	1.0036	0.0013	1.0020	0.0012	5.14E+03

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heumf-007-011	120	1.0000	0.0004	0.9931	0.0012	0.9955	0.0015	5.53E+03
Heumf-031	121	1.0000	0.0004	1.0018	0.0012	1.0045	0.0012	6.81E+03
Heumf-007-035	122	1.0000	0.0004	0.9971	0.0012	0.9964	0.0012	7.53E+03
Heumf-026-004	123	1.0000	0.0004	1.0013	0.0012	1.0033	0.0011	1.08E+04
Heumf-034-003	124	1.0000	0.0004	1.0006	0.0011	1.0003	0.0013	1.51E+04
Heumf-034-001	125	1.0000	0.0004	0.9963	0.0012	0.9966	0.0012	1.58E+04
Heumf-034-002	126	1.0000	0.0004	0.9937	0.0012	0.9940	0.0013	1.62E+04
Heumf-026-006	127	1.0000	0.0004	0.9999	0.0011	1.0029	0.0011	1.65E+04
Heumf-007-030	128	1.0000	0.0004	0.9942	0.0013	0.9946	0.0013	1.75E+04
Heumt-003-001	129	1.0000	0.0004	1.0009	0.0013	1.0013	0.0012	1.83E+04
Heumf-007-026	130	1.0000	0.0004	0.9943	0.0014	0.9934	0.0013	2.50E+04
Heumf-007-010	131	1.0000	0.0004	0.9970	0.0012	0.9934	0.0013	2.64E+04
Heumf-007-025	132	1.0000	0.0004	0.9940	0.0012	0.9970	0.0013	2.66E+04
Heumf-026-003	133	1.0000	0.0004	1.0036	0.0012	1.0037	0.0011	3.06E+04
Heumf-004-002	134	1.0000	0.0004	0.9972	0.0013	1.0002	0.0011	3.10E+04

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heumf-004-001	135	1.0000	0.0004	0.9988	0.0011	0.9954	0.0011	3.12E+04
Heumf-007-024	136	1.0000	0.0004	0.9975	0.0011	0.9959	0.0012	5.84E+04
Heumf-007-023	137	1.0000	0.0004	0.9975	0.0014	0.9969	0.0013	6.25E+04
Heumf-007-006	138	1.0000	0.0004	1.0011	0.0015	1.0035	0.0012	1.61E+05
Heumf-007-022	139	1.0000	0.0004	0.9979	0.0012	0.9961	0.0013	1.80E+05
Heumf-007-009	140	1.0000	0.0004	0.9965	0.0013	1.0004	0.0013	1.82E+05
Heumf-007-008	141	1.0000	0.0004	0.9960	0.0012	0.9946	0.0012	2.06E+05
Heumf-007-005	142	1.0000	0.0004	0.9965	0.0013	0.9949	0.0012	2.54E+05
Heumf-007-003	143	1.0000	0.0004	0.9964	0.0014	0.9994	0.0012	3.76E+05
Heumf-020	144	1.0000	0.0004	1.0016	0.0013	1.0001	0.0013	4.82E+05
Heumf-007-002	145	1.0000	0.0004	0.9962	0.0012	0.9969	0.0010	4.98E+05
Heumf-003-004	146	1.0000	0.0004	1.0135	0.0011	1.0143	0.0012	5.60E+05
Heumf-041	147	1.0000	0.0004	1.0066	0.0012	1.0065	0.0011	5.65E+05
Heumf-003-003	148	1.0000	0.0004	1.0088	0.0010	1.0083	0.0011	5.75E+05
Heumf-003-002	149	1.0000	0.0004	1.0045	0.0011	1.0048	0.0011	6.23E+05

Table 2 Experimental and Calculation Results								
Case ID	**Case Number**	**Kexp**	**Sigexp**	**K5calc**	**Sig5calc**	**K6calc**	**Sig6calc**	**ALCF, eV**
Heumf-007-034	150	1.0000	0.0004	1.0105	0.0013	1.0099	0.0012	6.59E+05
Heumf-003-001	151	1.0000	0.0004	1.0063	0.0011	1.0048	0.0011	6.82E+05
Heumf-007-033	152	1.0000	0.0004	1.0064	0.0013	1.0082	0.0013	7.23E+05
Heumf-007-032	153	1.0000	0.0004	1.0005	0.0012	0.9991	0.0011	7.97E+05
Heumf-019	154	1.0000	0.0004	1.0061	0.0010	1.0047	0.0012	8.16E+05
Heumf-027	155	1.0000	0.0004	1.0131	0.0012	1.0131	0.0012	8.55E+05
Heumf-023-016	156	1.0000	0.0004	1.0019	0.0012	0.9999	0.0013	8.85E+05
Heumf-018	157	1.0000	0.0004	0.9987	0.0012	1.0019	0.0011	8.89E+05
Heumf-026-001	158	1.0000	0.0004	1.0021	0.0013	1.0031	0.0011	8.99E+05
Heumf-001-001	159	1.0000	0.0004	1.0014	0.0011	0.9999	0.0011	9.05E+05
Heumf-007-019	160	1.0000	0.0004	0.9962	0.0012	0.9971	0.0013	9.08E+05
Heumf-007-001	161	1.0000	0.0004	0.9960	0.0011	0.9937	0.0012	9.14E+05

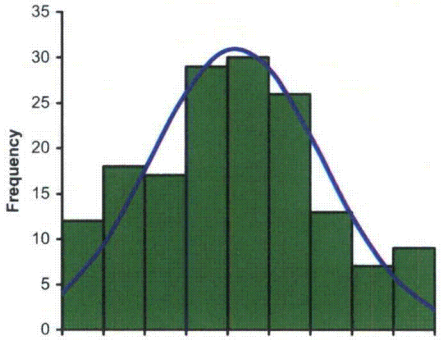
Table 3 Summary of Analysis Results

	K5Group 1 All Data	K5Group 2 ALCF ≤ 10^2 eV	K5Group 3 10^2 eV < ALCF ≤ 10^5 eV	K5Group 4 ALCF > 10^5 eV	K6Group 1 All Data	K6Group 2 ALCF ≤ 10^2 eV	K6Group 3 10^2 eV < ALCF ≤ 10^5 eV	K6Group 4 ALCF > 10^5 eV
Number of Experiments	161	81	56	24	161	81	56	24
Mean Experimental k_{eff}	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Mean Calculated k_{eff}	1.0030	1.0037	1.0024	1.0023	1.0028	1.0033	1.0022	1.0023
Experimental k_{eff} variance	1.6000E-07	1.6000E-07	1.6000E-07	1.6000E-07	1.6000E-07	1.6000E-07	1.6000E-07	1.6000E-07
Calculated k_{eff} variance	2.6907E-05	2.3170E-05	3.0155E-05	3.1154E-05	2.6907E-05	2.3170E-05	3.0155E-05	3.1154E-05
σKENO-calc mean	0.0013	0.0014	0.0012	0.0012	0.0013	0.0014	0.0012	0.0012
t-value	-2543	-1876	-1365	-879				
t-critical 1 tail (95%)	1.8610	1.9620	2.0380	2.3090				
t-critical 2 tail (95%)	1.9674	1.9750	1.9750	1.9818				
t-test 2 tail pass/fail	Fail	Fail	Fail	Fail				
Method Bias	+0.0030	+0.0037	+0.0024	+0.0023	+0.0030	+0.0037	+0.0024	+0.0023
Uncertainty (*U*) {1 tail (95%)}	0.0022	0.0024	0.0027	0.0037	0.0022	0.0024	0.0027	0.0037
Total Uncertainty *κ(σKENO-calc) + (U)*	0.0031	0.0033	0.0034	0.0042	0.0030	0.0033	0.0034	0.0042
Upper Limit k_{eff}	0.9469	0.9467	0.9466	0.9458	0.9470	0.9467	0.9466	0.9458

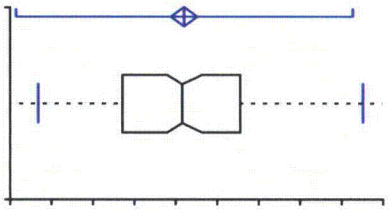
Notes; Positive biases were neglected in the determination of the k_{eff} limits and the mean KENO-calculated standard deviation (σ) was used to determine the Upper Limit.

analysed with: Analyse-it + General 1.65

Test	**Continuous summary descriptives**
	Group 1
	Kcalc
Performed by	RDMontgomery
Date	7 July 2004

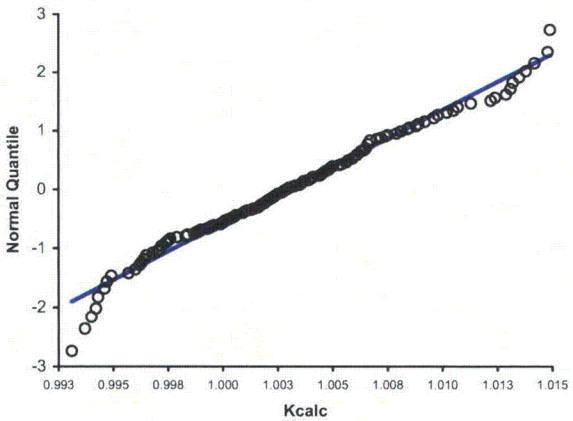


n	161
Mean	1.00302
95% CI	1.00222 to 1.00383
Variance	0.000027
SD	0.005187
SE	0.000409
CV	1%



Median	1.00290
96.0% CI	1.00200 to 1.00410
Range	0.0218
IQR	0.0071

Percentile	
2.5th	0.99421
25th	0.99930
50th	1.00290
75th	1.00640
97.5th	1.01379

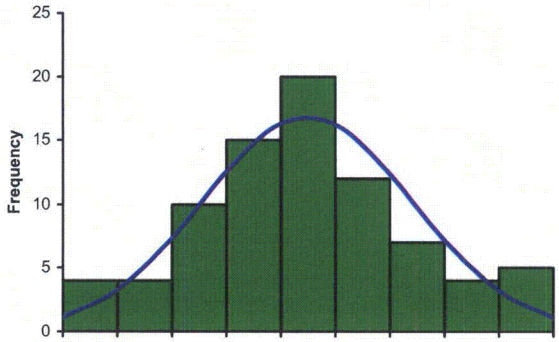


	Coefficient	p
Anderson-Darling	0.4951	0.2146
Skewness	0.1862	0.3228
Kurtosis	-0.5371	0.0741

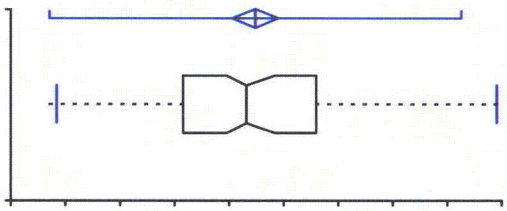
Figure 1, Group 1 Histogram, Skewness and Kurtosis.

analysed with: Analyse-it + General 1.65

Test	**Continuous summary descriptives** **Group 2** kcalc
Performed by	RDMontgomery
Date	10 September 2003

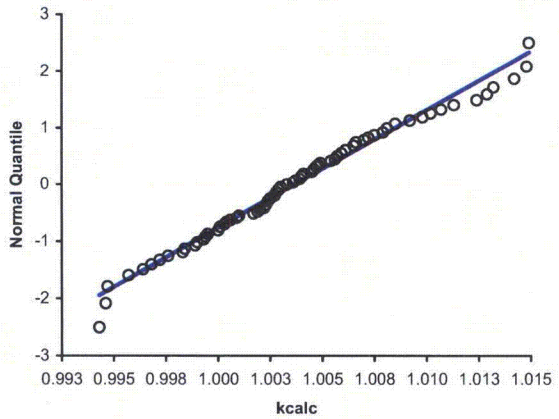


n	81
Mean	1.00371
95% CI	1.00264 to 1.00477
Variance	0.000023
SD	0.004814
SE	0.000535
CV	0%



Median	1.00330
95.5% CI	1.00240 to 1.00460
Range	0.0206
IQR	0.0061

Percentile	
2.5th	0.99461
25th	1.00040
50th	1.00330
75th	1.00650
97.5th	1.01477

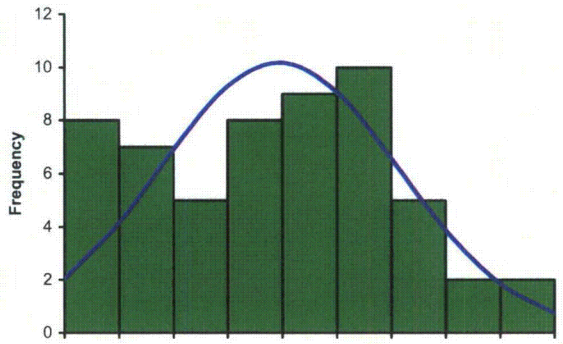


	Coefficient	p
Anderson-Darling	0.3513	0.4696
Skewness	0.2746	0.2927
Kurtosis	-0.0750	0.9661

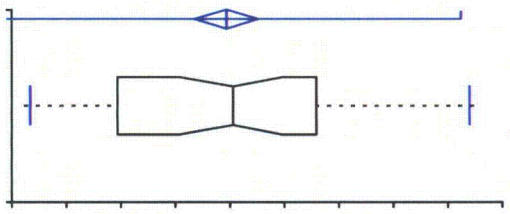
Figure 2, Group 2 Histogram, Skewness and Kurtosis.

analysed with: Analyse-it + General 1.65

Test	**Continuous summary descriptives** **Group 3** kcalc		
Performed by	RDMontgomery	**Date**	10 September 2003

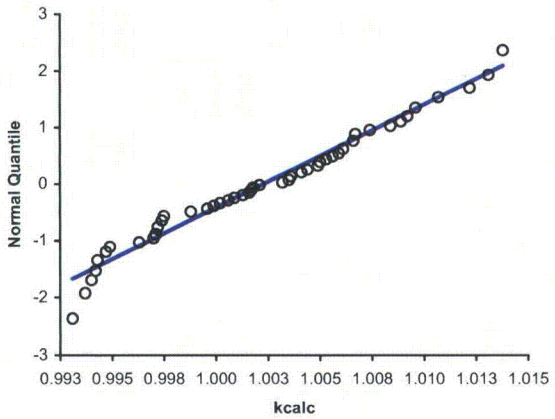


n	56
Mean	1.00235
95% CI	1.00088 to 1.00382
Variance	0.000030
SD	0.005491
SE	0.000734
CV	1%



Median	1.00265
95.6% CI	1.00020 to 1.00490
Range	0.0207
IQR	0.0091

Percentile	
2.5th	0.99336
25th	0.99735
50th	1.00265
75th	1.00648
97.5th	1.01350

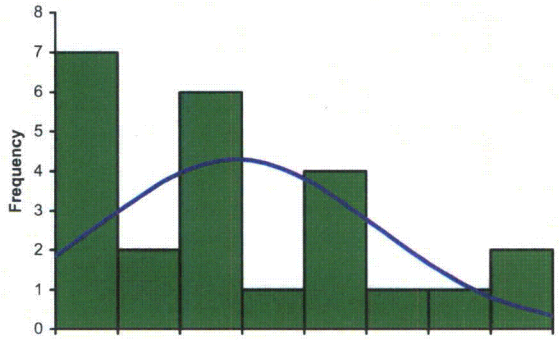


	Coefficient	p
Anderson-Darling	0.5075	0.2000
Skewness	0.0838	0.7834
Kurtosis	-0.8797	0.0391

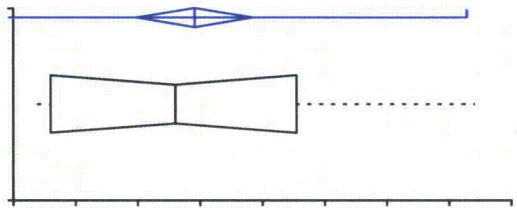
Figure 3, Group 3 Histogram, Skewness and Kurtosis.

analysed with: Analyse-it + General 1.65

Test	Continuous summary descriptives
	Group 4
	kcalc
Performed by	RDMontgomery
Date	10 September 2003

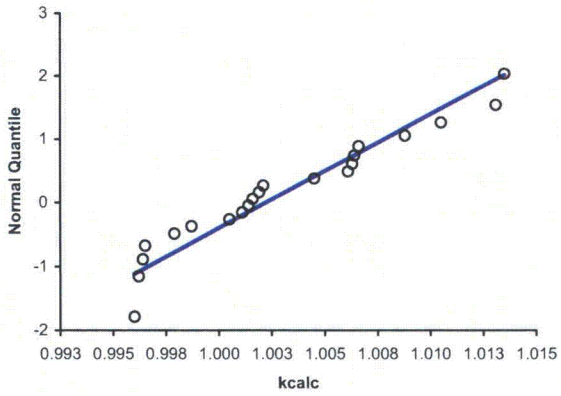


n	24
Mean	1.00228
95% CI	0.99993 to 1.00464
Variance	0.000031
SD	0.005582
SE	0.001139
CV	1%



Median	1.00150
97.7% CI	0.99650 to 1.00630
Range	0.0175
IQR	0.0099

Percentile	
2.5th	-
25th	0.99650
50th	1.00150
75th	1.00638
97.5th	-



	Coefficient	p
Anderson-Darling	0.7342	0.0557
Skewness	0.5767	0.2084
Kurtosis	-0.7094	0.4126

Figure 4, Group 4 Histogram, Skewness and Kurtosis.

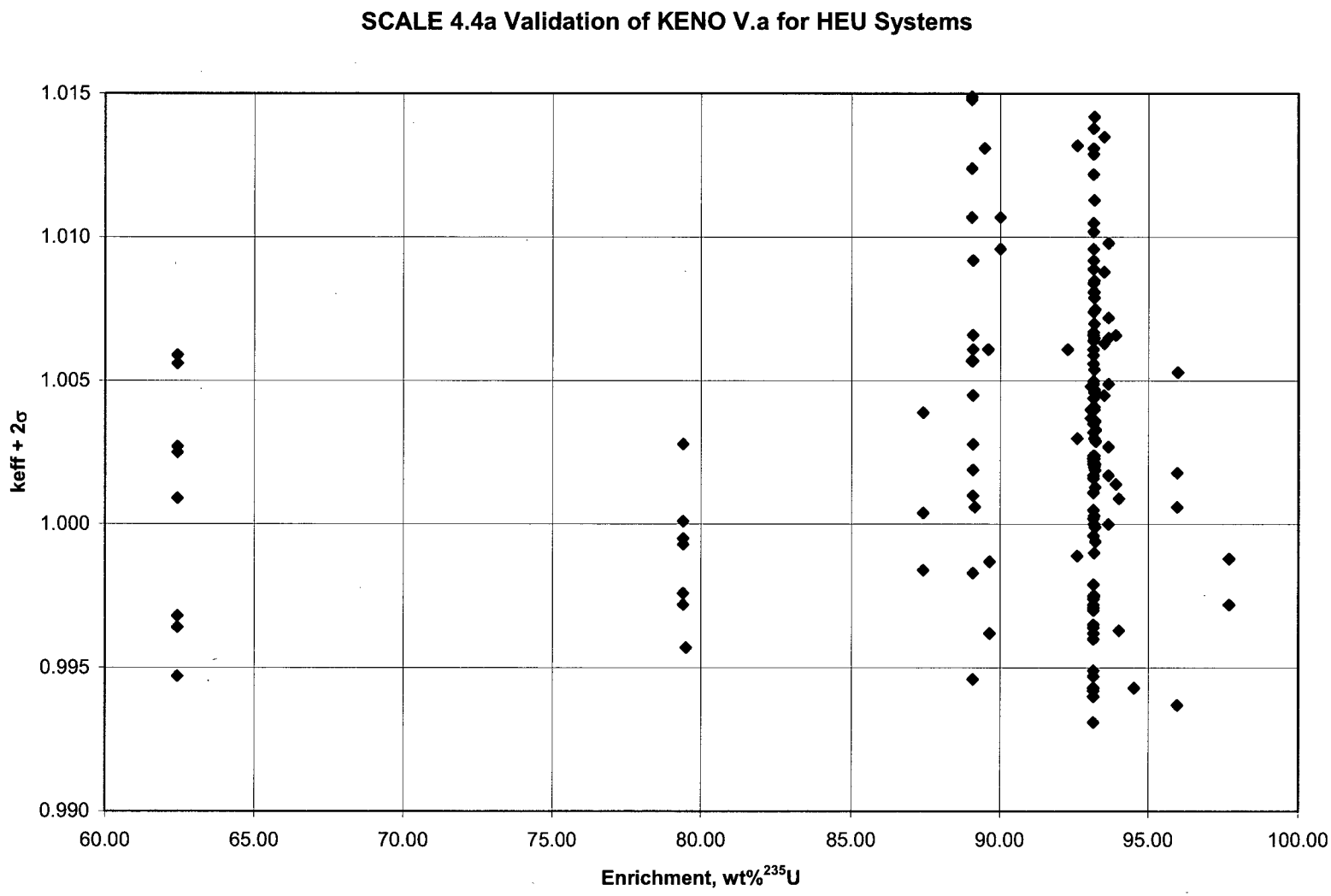


Figure 5, Plot of k_{eff} with the Enrichment (wt%^{235}U).

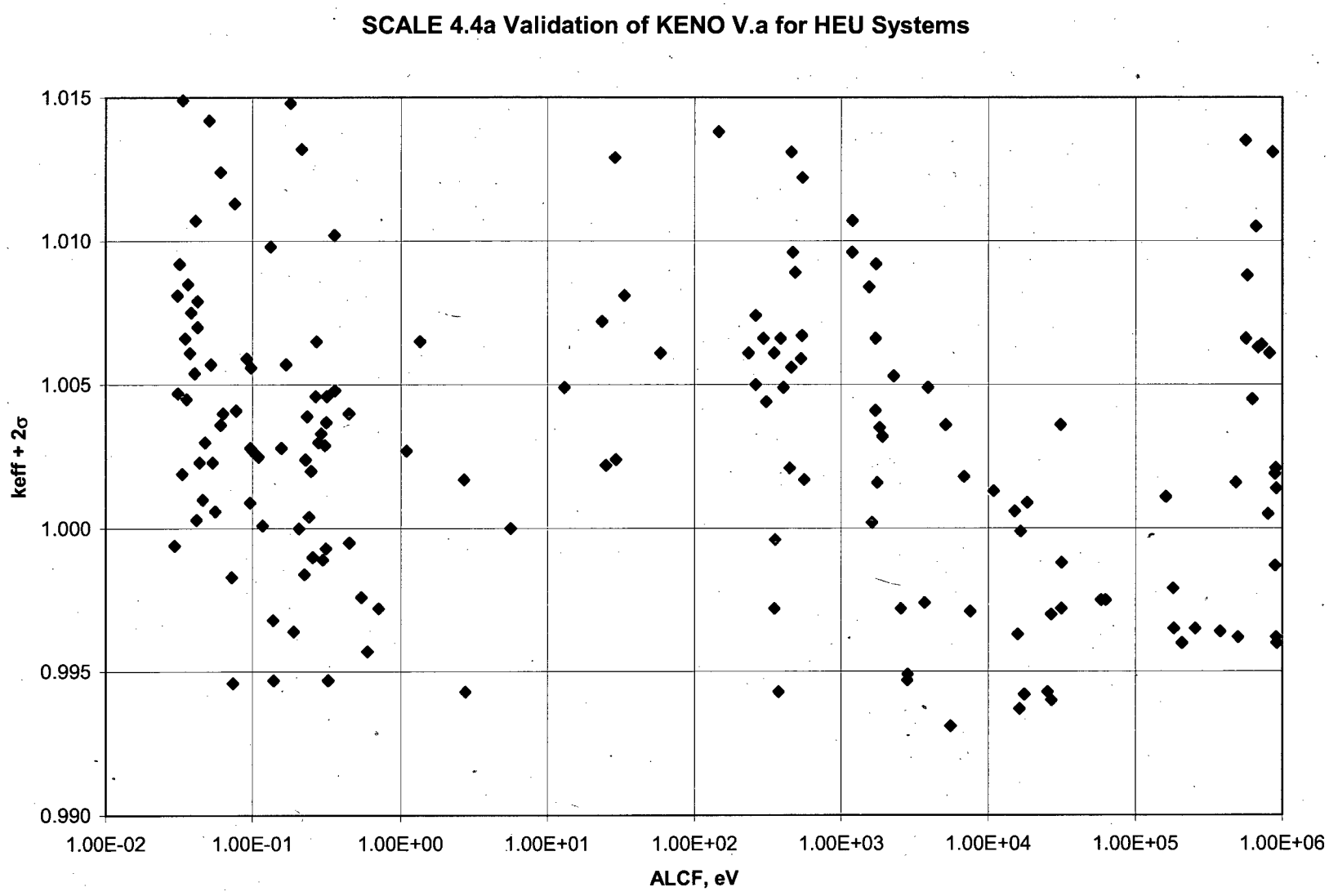


Figure 6, Plot of k_{eff} with the Energy of the Average Lethargy Causing Fission (ALCF).

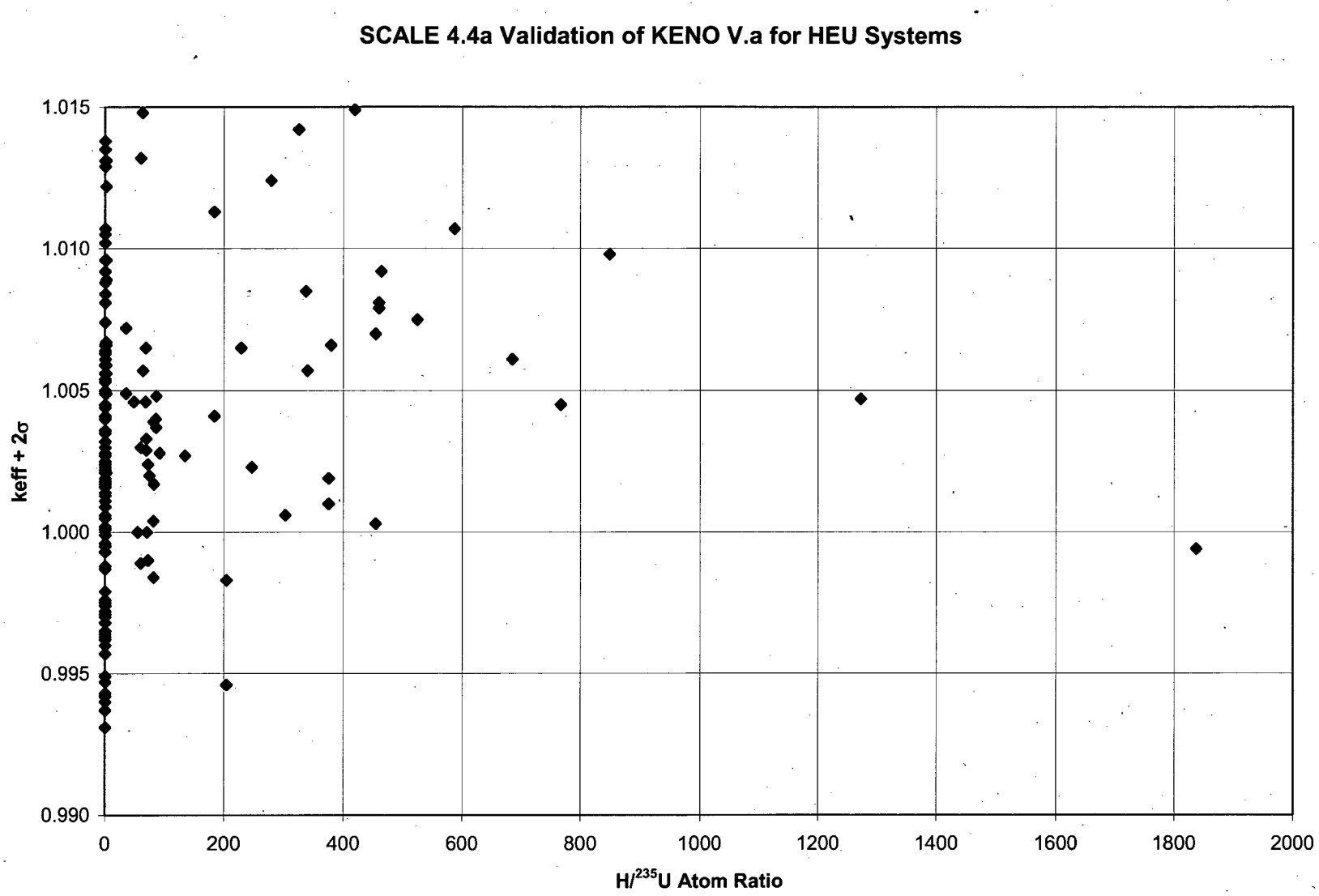


Figure 7, Plot of the k_{eff} with the Moderator-to-Fissile atom ratio ($H/^{235}U$).

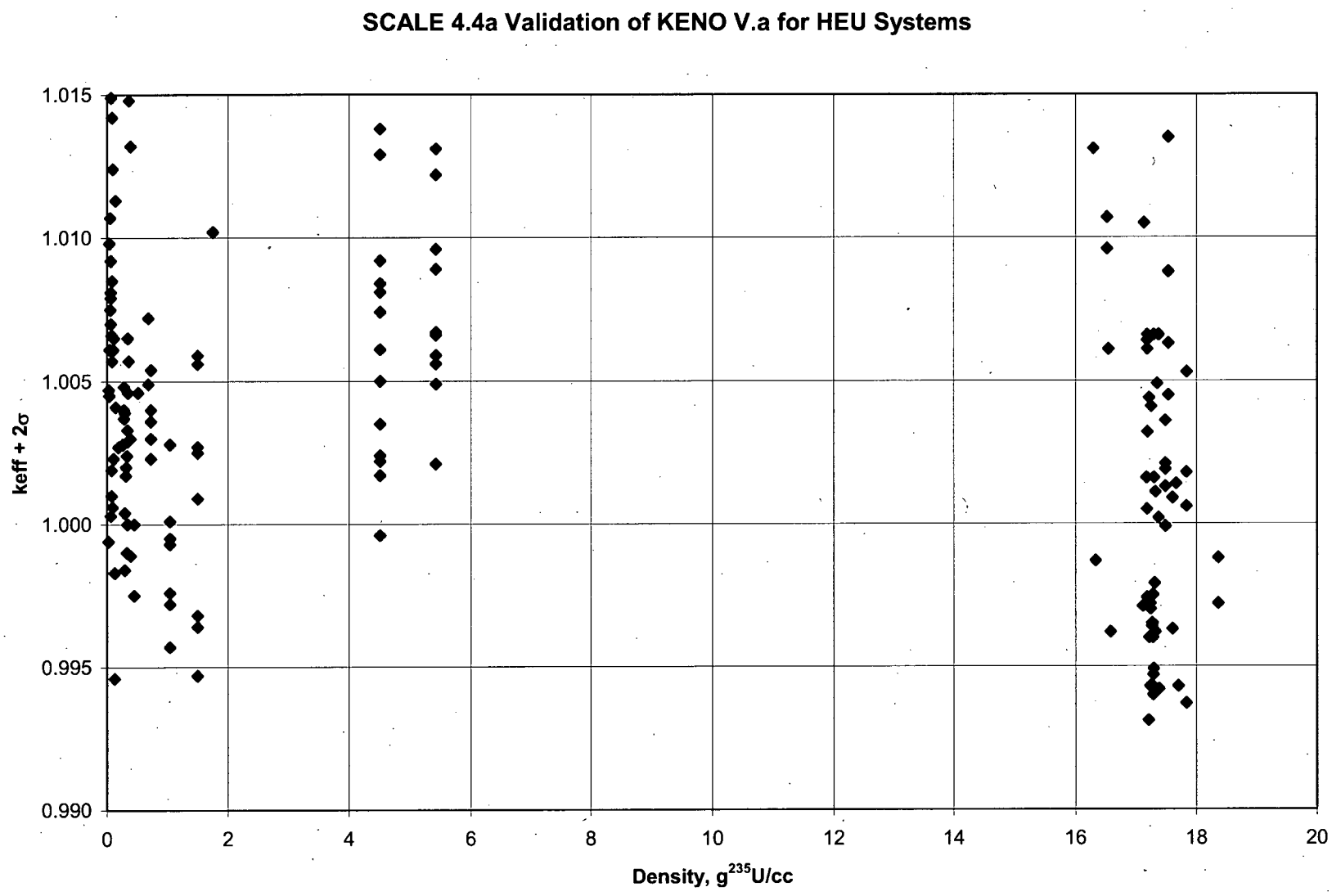


Figure 8, Plot of k_{eff} with the Fissile Denstiy (g ^{235}U/cc)

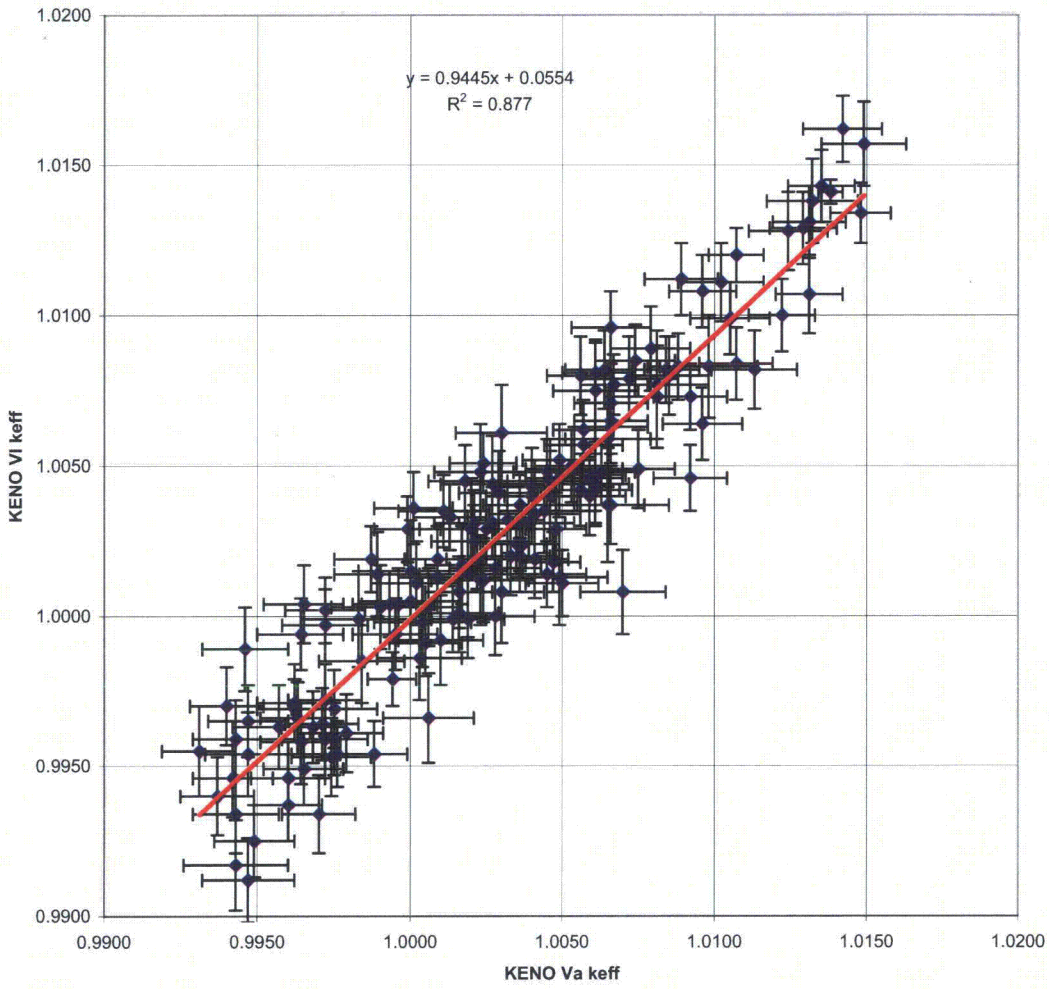


Figure 9, Plot of KENO VI k_{eff} with the KENO Va k_{eff}

APPENDIX A

SCALE INPUT CASES FOR DATA SETS 1 THROUGH 161 CRITICAL EXPERIMENTS

(This information available in electronic media only)

SECTION SEVEN

OPERATING PROCEDURES

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7.0 PACKAGE OPERATIONS

The Century Versa-Pac (US Patent Pending) Shipping Container is used to transport a variety of materials. It is to be loaded, inspected and handled in accordance with standard, plant operating procedures.

Due to the low specific activity and low abundance of gamma emitting radionuclides, dose rates from the contents of the package are minimal. As a result of the low dose rates, there are no special handling requirements for radiation protection.

As a minimum, the operating procedure should include the steps described in the subsequent sections.

7.1 PACKAGE LOADING

7.1.1 Preparation for Loading

Prior to loading the Century Versa-Pac, the packaging is inspected to ensure that it is in unimpaired physical condition. The inspection looks for damage, dents, corrosion, and missing hardware. Acceptance criteria and detailed loading procedures derived from this application are specified in user written procedures. These user procedures are specific to the authorized content of the package inspected to ensure packaging complies with Appendix 1.3.1, Packaging General Arrangement Drawings.

Components requiring repair will be fixed prior to shipping in accordance with approved procedures consistent with the quality program.

The User shall inspect the accessible surfaces of the closure and sealing devices in accordance with approved procedures prior to loading of the container to assure the following at a minimum:

a. Ensure that the most recent certification performed is in accordance with Section 8.2.

b. The contents are within the limits of the Certificate of Compliance.

c. The package inner and outer surfaces are visually free from damage that may impair the safe use of the package.

d. The Package is free of debris or other foreign matter that could interfere with the proper and safe use of the container.

e. Verify that the outer drum and visible inner plugs are in place.

f. Gaskets are in place and intact and are not deteriorated or damaged. Replace as needed.

g. The containment flange and outer drum cover and all mating surfaces are sound and fit properly.

h. Closure bolts are the proper type and size and that thread inserts are in working order.

i. Ensure that security seal holes are functional and capable of maintaining their integrity when seals are required.

7.1.2 Loading of Contents

The radioactive contents of the Century Versa-Pac package must be contained inside the containment area of the package. The maximum loading shall comply with the limits given in Section 1.2.2, Contents.

The User shall load the container in accordance with in-plant approved procedures and at a minimum include the following items:

a. Verify that the steps previously outlined by Section 7.1.1 have been completed at a minimum.

b. The contents may be pre-packaged within plastic jars, sealed metal cans, plastic bags, drums or other appropriate forms; however, these items are not required for transport.

c. Carefully load the package content into the containment area.

7.1.3 Preparation for Transportation

a. Place the containment blind flange and gasket into place and tighten the bolts lock washers to the specified torque of 38 to 42 foot-pounds.

b. Place the outer gasket in place and carefully install the outer reinforced insulated drum cover.

c. Install the appropriate bolts and washers and tighten to the specified torque of 38 to 42 foot-pounds.

d. Secure the outer drum closure ring and tighten to 60 ±2 foot pounds and tighten the jam nut against the bolt lug.

e. Install the security seals and record their numbers, if applicable.

f. Complete a radiation and contamination survey in compliance with the applicable regulations.

g. Remove any old labels and re-label per the applicable regulations.

h. Records should be maintained in accordance with the appropriate regulations.

7.2 PACKAGE UNLOADING

The User shall unload the Century Versa-Pac in accordance with in-plant approved procedures and at a minimum include the following items:

7.2.1 Receipt of Package from Carrier

a. Complete a receiving report and complete any survey's that are appropriate.

b. Remove and record the package seal, if applicable.

7.2.2 Removal of Contents

a. Loosen and remove the outer drum lid closure ring, reinforcing ring blots and insulated drum cover.

b. Loosen and remove the bolts from the containment flange.

c. Remove the contents from the containment area.

7.3 PREPARTION OF EMPTY PACKAGE FOR TRANSPORT

Empty Century Versa-Pac packaging are prepared and transported per the requirements of 49 CFR §173.428. Prior to shipping as an empty Century Versa-Pac packaging, the packaging is surveyed to ensure that contamination levels are less than the 49 CFR §173.433(a) limit. The packaging is inspected to ensure that it is in an unimpaired condition and is securely closed so that there will be no leakage of material under conditions normally incident to transportation.

Any labels previously applied in conformance with subpart E of part 172 of this subchapter are removed, obliterated, or covered and the "Empty" label prescribed in 49 CFR §172.450 of this subchapter is affixed to the packaging.

7.4 OTHER OPERATIONS

Not Applicable.

7.5 APPENDIX

Not Applicable.

SECTION EIGHT

ACCEPTANCE TESTS AND MANTENANCE PROGRAM

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8.0 ACCEPTANCE AND MAINTENANCE PROGRAMS

Per the requirements of 10 CFR §71.85(c)[1], this section discusses the inspections and tests to be performed prior to first use of the Century Versa-Pac (U.S. Patent Pending) package.

8.1. FABRICATION ACCEPTANCE TESTS

All Century Versa-Pac packaging materials of construction shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.1, *Packaging General Arrangement Drawings*, per the requirements of 10 CFR §71.85(a).

Source inspections and final release of the package will be performed, verifying the quality characteristics were inspected and that the packaging is acceptable. Any characteristic that is out of specification must be reported. It will then be dispositioned according to procedure. The following tests are performed by the fabricator prior to release of the packaging for use by the User.

8.1.1. Visual Inspection and Measurements

Prior to the initial use, a visual inspection is performed including the following items at a minimum:

a. Confirm that the package dimensions are in compliance with the appropriate drawings (This may be accomplished by a review of the Quality Assurance and Fabrication Records).

b. Insure that the visible seals (Internal and External) are in place.

c. Insure that all bolts and washers are the correct type and size per the drawing.

d. Insure that all gaskets are in place and are in compliance with the drawings.

e. Verify that the nameplates and markings are correct.

8.1.2. Weld Examinations

As part of the normal course of fabrication, the Century Versa-Pac Shipping Container is subjected to visual inspections of all welds and magnetic particle inspection of those welds shown on the fabrication drawings to insure that the welds of the package are in compliance with the applicable codes and standards required by the drawings and specifications of the Century Versa-Pac. These inspections are recorded on the Fabrication Control Record as part of the Quality Assurance program.

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[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

8.1.3. Structural and Pressure Tests

The Century Versa-Pac Shipping packaging does not contain any tie-down devices that are a structural part of the package. The Century Versa-Pac Shipping Container is handled, loaded, and unloaded using standard handling equipment.

The Century Versa-Pac Shipping package is not a pressure-retaining package and no per unit pressure testing is required prior to use. As identified in Section 2.2.1, Mechanical Properties and Specifications, the drum design is qualified with a hydrostatic pressure, 29 psig (200 kPa), as part of the UN drum qualification testing.

No other Structural or Pressure testing is performed.

8.1.4. Leakage Tests

The Century Versa-Pac Shipping packaging does not contain any seals or containment boundaries that require leak testing. Therefore, this section is not applicable.

8.1.5. Component and Materials Tests

The closed cell polyurethane foam, alumina silica paper, and gasket materials are acceptance in accordance with the drawing requirements. Inspect package containment components for any damage that would prove detrimental to their ability to properly function as required.

8.1.6. Tests for Shielding Integrity

Shielding tests are not applicable to the Century Versa-Pac Shipping Container. The Century Versa-Pac Shipping packaging does not contain any biological shielding.

8.1.7. Thermal Acceptance Tests

The material properties utilized in Chapter 3.0, *Thermal*, are consistently conservative for the Normal Conditions of Transport (NCT) and Hypothetical Accident Condition (HAC) thermal analyses. As such, with the exception of the tests required for specific packaging components, as discussed in Section 8.1.5, *Component and Material Tests*, specific acceptance tests for material thermal properties are not required or performed.

8.1.8. Miscellaneous Tests

No other additional tests are required prior to use of the Century Versa-Pac Shipping Container.

8.2. MAINTENANCE PROGRAM

This section describes the maintenance program used to ensure continued performance of the Century Versa-Pac Shipping packaging. The Century Versa-Pac Shipping packaging is maintained consistent with a 10 CFR 71 subpart H QA program. Packagings that do not conform to the license drawings are removed from service until they are brought back into compliance. Repairs are performed in accordance with approved procedures and consistent with the quality assurance program.

The User shall establish written procedures for the periodic maintenance and inspection of the Century Versa-Pac Shipping Container requiring the following as a minimum:

8.2.1. Structural and Pressure Tests

The Century Versa-Pac Shipping packaging does not contain any lifting/tie-down devices that require load testing. No pressure tests are necessary to ensure continued performance of the Century Versa-Pac Shipping packaging.

8.2.2. Leakage Tests

No leakage tests are necessary to ensure continued performance of the Century Versa-Pac Shipping packaging.

8.2.3. Component and Material Tests

8.2.3.1. Prior to Each Use

The following items shall be performed as a minimum prior to each package use for shipment:

a. Visually inspect the outer and inner surfaces as appropriate for rust or other superficial discontinuities. Properly trained personnel should repair any adverse indications as necessary in accordance with the drawing requirements.

b. Visually inspect all gaskets and pads for wear and/or deterioration and replace as necessary.

c. Inspect all sealing surfaces for damage that would interfere with the safe use of the package.

8.2.3.2. Every Five Years

The Owner of the individual Century Versa-Pac Shipping Container shall perform and maintain a record of the following inspections at a minimum:

a. All inspections listed in Section 8.2.3.1.

b. Full visual of all accessible surfaces and welds for the presence of cracks or other unacceptable discontinuities. Any questionable condition of a weld shall be subject to further examination to assure proper compliance. Any weld defects shall be repaired in accordance with the appropriate procedures.

c. Check flanges and covers for warpage and/or distortion that prevent proper closure.

d. During the visual inspection of exterior surfaces, if areas are suspected of having corrosion, the inspection should insure that corrosion has not reduced the outer package wall thickness by more than 10% of the nominal thickness over a 6"

square area. When visual inspection cannot assure sufficient wall thickness, other methods of inspection should be utilized, such as ultrasonic testing, to assure acceptability.

e. All repairs shall be performed by sources that are competent and properly trained. Allowable repairs shall include repairs made to welds and base metal. Repairs that require welding shall be made by welders that are qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel Code and/or Section 5 of AWS D1.1. The repair shop shall provide certification of weld procedures and welder qualifications.

f. Weigh the container to verify that the container is within 10 pounds of the original fabrication weight recorded on the nameplate.

g. If the package contains payload or is in transit at the test due date, the inspection may be deferred to allow unloading and/or transport of the package, as necessary.

8.2.4. Thermal Tests

No thermal tests are necessary to ensure continued performance of the Century Versa-Pac packaging.

8.2.5. Miscellaneous Tests

Localized deformations in the outer drum of the Century Versa-Pac packaging are permitted up to 1-inch provided the shell material is not breached. The packaging may be repaired in accordance with the drawings in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

8.3. List of Appendices

Not applicable to the Century Versa-Pac packaging.