TRANSNUCLEAR
AN AREVA COMPANY

September 8, 2011
E-31428

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852

Subject: Transnuclear, Inc. (TN) Application for Revision 5 to CoC 9301 Model No. TNF-XI Transport Packaging, Docket No. 71-9301

In accordance with 10 CFR 71.31(b), Transnuclear, Inc. (TN) herewith submits its application to revise Certificate of Compliance (CoC) 9301 for the TNF-XI packaging. This application proposes to add polyethylene bags to the content description and to remove the requirement of surface temperature measurement prior to transport. This application also proposes to update the design in order to be assigned a package identification number of AF-96.

Enclosure 2 provides a brief description of, and justification for, the changes, and discusses the evaluation of the requested changes. Enclosure 3 provides disposition of the "-96" designator issues affecting 10 CFR 71 licensees. Enclosure 4 provides a listing of TNF-XI Safety Analysis Report (SAR) changed and additional pages. Enclosure 5 and 6 provide the proprietary and non-proprietary versions of the SAR changed and additional pages, respectively. Changed areas are indicated by italicized text and revision bars. Appendix A.6 is entirely new and therefore does not contain change-tracking indicators for this Revision 5 submittal.

Computer input and output files used for criticality analyses are listed in Enclosure 7 and provided in Enclosure 8 to facilitate expediting the staff's review of this application. Since the information provided in Enclosure 8 is entirely proprietary, a non-proprietary version is not provided.

Enclosure 9 provides a mark-up of CoC 9301 showing proposed changes related to this application.

The proposed changes in the criticality analysis are required to enable use of polyethylene bags (or other bags with less hydrogen content) for the shipment of material. The review of the criticality evaluation in this application will support the approval of upcoming USDOT Competent Authority Certification (CAC) for a TNF-XI packaging certified by French authorities. The French certified TNF-XI packaging is planned to ship material to and from Japan in January 2012 in order to meet the increased manufacturing needs to compensate for the reduction of other companies capacities impacted by the earthquake on March 11, 2011. For the upcoming shipment, the packing operation into pails has been completed with polyethylene bags. Repacking into plastic bags other than polyethylene requires equipment, which are not available

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NMSS01

at this time. Furthermore, considering the large quantity of the material to be shipped, the repacking might not be feasible. The scheduling of the shipments is of considerable importance to maintain the operation of Japanese nuclear power plants. Recognizing the consequences of any delay in the shipment and the required time frames for review and approval by USDOT, Transnuclear requests the review of at least the criticality evaluation in this application to be completed before the January 2012.

This submittal includes proprietary information which may not be used for any purpose other than NRC staff review of the application. In accordance with 10 CFR 2.390, I am providing an affidavit (Enclosure 1) specifically requesting that NRC withhold this proprietary information from public disclosure.

Should the NRC staff require additional information to support review of this application, please do not hesitate to contact Mr. Kamran Tavassoli at 410-910-6944 or me at 410-910-6881.

Sincerely,

Jayant Bondre

Jayant Bondre, PhD
Vice President - Engineering

cc: Jennivine Rankin (NRC SFST), as follows provided in a separate mailing:

  - 5 paper copies of this cover letter and Enclosures 1 through 5, 7, and 9
  - 5 CDs containing this cover letter and Enclosures 1 through 5, 7, and 9
  - 2 electronic copies of Enclosure 8 (two DVDs)

Enclosures:

1. Affidavit Pursuant to 10 CFR 2.390
2. Description, Justification, and Evaluation of the Changes
3. Disposition of the "-96" Designator Issues Affecting 10 CFR 71 Licensees
4. List of Changed and Additional Pages to the TNF-XI Safety Analysis Report
5. Changed Pages for Safety Analysis Report, Revision 5, Proprietary Version
6. Changed Pages for Safety Analysis Report, Revision 5, Non-proprietary Version
7. Listing of Computer Files Contained in Enclosure 8
8. One electronic copy of computer input and output files listed in Enclosure 8 (Proprietary)
9. CoC Marked up for Proposed Changes related to Application for Revision 5 to CoC 9301

Enclosure 1 to TN E-31428

AFFIDAVIT PURSUANT TO 10 CFR 2.390

Transnuclear, Inc.)
State of Maryland) SS.
County of Howard)

I, Jayant Bondre, depose and say that I am a Vice President of Transnuclear, Inc., duly authorized to execute this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conformance with the provisions of 10 CFR 2.390 of the Commission's regulations for withholding this information.

The information for which proprietary treatment is sought is contained in Enclosures 5 and 8 listed below:

- Portions of the Safety Analysis report (SAR) concerning the criticality evaluation.
- Computer Input and output files.

These documents have been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by Transnuclear, Inc. in designating information as a trade secret, privileged or as confidential commercial or financial information.

Pursuant to the provisions of paragraph (b) (4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure, included in the above referenced document, should be withheld.

1) The information sought to be withheld from public disclosure involves certain portions of the safety analysis report and the computer files associated with the criticality analysis related to the design of the TNF-XI transport packaging, which are owned and have been held in confidence by Transnuclear, Inc.

2) The information is of a type customarily held in confidence by Transnuclear, Inc. and not customarily disclosed to the public. Transnuclear, Inc. has a rational basis for determining the types of information customarily held in confidence by it.

3) Public disclosure of the information is likely to cause substantial harm to the competitive position of Transnuclear, Inc. because the information consists of descriptions of the design of nuclear material transportation systems, the application of which provide a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with Transnuclear, Inc., take marketing or other actions to improve their product's position or impair the position of Transnuclear, Inc.'s product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

Further the deponent sayeth not.

Jayant Bondre
Jayant Bondre
Vice President, Transnuclear, Inc.

Subscribed and sworn to me before this 8th day of September, 2011.

Lewis A. Piccolino
Notary Public

My Commission Expires 03 / 26 / 2014.

LEWIS A. PICCOLINO
Notary Public
Montgomery Co., MD
My Comm. Exps. March 26, 2014

Description, Justification, and Evaluation of the Changes

1.0 Introduction

The scope of this revision to CoC 9301 for the TNF-XI transport packaging is:

to add polyethylene bags to the content description,

to update the design in order to be assigned a package identification number of AF-96 and

to remove the stipulation of surface temperature measurement in shade prior to transport.

The proposed changes make this revision to the NRC CoC consistent with the French CoC, which is also currently being revised.

2.0 Brief Description of the Changes

TNF-XI packaging consists of a stainless steel outer shell and lid encasing a body of phenolic foam. The authorized contents include up to 300 kg of uranium oxide powder, pellets or scraps enriched up to 5.0 wt. % U-235. Uranium oxide is loaded into individual pails that are contained in 4 inner cavities – 3 pails per cavity. In order to add the polyethylene bags to the content description, the criticality evaluation is revised as follows.

- The limits on the mass of uranium (enrichment of U-235) are updated to account for a maximum mass of 390 g per cavity for the polyethylene bags

- The computer code and cross section library are updated to the latest applicable standards
  - CSAS5 Module of SCALE 6 code system
  - 238 Group, ENDF/B-V cross section library using NITAWL for cross section processing and resonance corrections for pellets and scraps
  - INFHOMEDIUM for cross section preparation for powders

- The criticality benchmarks and the associated evaluation methods (USL) are updated to the latest applicable standards
  - Benchmarks are based on NUREG CR/6361 or Fresh Fuel Benchmarks for SCALE 6 for pellet and scrap contents and are based on ORNL/CSD/TM-238 powder benchmarks for KENO Va for powder content
  - Upper Subcritical Limit (USL) calculated using Method-1
  - USL functions are calculated for Energy of the Average Lethargy for Fission (EALF), enrichment, and Hydrogen to Fissile Ratio (H/X)

The criticality analysis methodology is consistent with that used in the recently approved application for the ANF-250 transport packaging (CoC 9217). The following approaches are considered in the criticality evaluation of TNF-XI package.

- Powder/scrap/pellet, pails and packaging are modeled explicitly
- Pellets are modeled with both square and triangular pitch
- Scraps are modeled as spheres with triangular pitch
- Powder is modeled with theoretical density
- Variation in diameter and pitch parameters are considered in modeling of scraps which bounds the pellets
- Flooding is considered at optimum moderation in NCT and HAC

- Single package and array of packages are evaluated

In order to update the design to be assigned a package identification number of AF-96, the only necessary change was to replace the term “transport index” with “criticality safety index” in SAR Chapter 1 and SAR Chapter 6.

The payload is acknowledged to generate no heat. Therefore the package surface temperature would be equal to ambient and the condition of 10 CFR 71.43(g) that the surface temperature shall remain below 85 °C (185 °F) in still air and in the shade is always satisfied. Due to this fact, the stipulation that package surface temperature be measured prior to transport can be removed.

3.0 Justification of the Changes

The packing operation of the material into pails has been completed with polyethylene bags for the shipment. Repacking into plastic bags other than polyethylene requires equipment which is not available at this moment and may not be feasible considering the quantity of the material proposed to be shipped. The surface temperature of the package with no heat load always satisfies the condition of 10 CFR 71.43(g). Measuring this temperature is an unnecessary burden on the user which does not add any additional margin to the safety of the package.

4.0 Evaluation of the Changes

TN has evaluated the TNF-XI transportation packaging for the criticality adequacy and has concluded that the changes described herein have no significant adverse effect on safety. This evaluation is documented in Safety Analysis Report, included in this application.

Disposition of the "-96" Designator Issues Affecting 10 CFR 71 Licensees

Issue No.	Issue	Impact on "-96" Designator Regarding the TNF-XI
Issue 1	System of Units (SI) Only	No effect
Issue 2	Radionuclide Exemption Values	Does not apply to TNF-XI
Issue 3	Revision of A_1 and A_2	Does not apply to TNF-XI
Issue 4	Uranium Hexafluoride (UF6) Package Requirements	Does not apply to TNF-XI
Issue 5	Criticality Safety Index Requirements	Changes made to SAR
Issue 6	Type C Packages	Not adopted in 10 CFR 71
Issue 7	Deep Immersion Test	Does not apply to TNF-XI
Issue 8	Grandfathering Previously Approved Packages	Not applicable to TNF-XI
Issue 9	Changes to Various Definitions	Does not apply to TNF-XI
Issue 10	Crush Test for Fissile Material Package Design	Does not apply to TNF-XI
Issue 11	Fissile Material Package Design for Transport by Aircraft B.	Does not apply to TNF-XI
Issue 12	Special Package Authorizations	Does not apply to TNF-XI
Issue 13	Expansion of Part 71 Quality Assurance (QA) Requirements	Current QA program meets Subpart H
Issue 14	Adoption of the ASME Code	Not adopted in 10 CFR 71
Issue 15	Change Authority for Dual- Purpose Package Certificate Holders	Not adopted in 10 CFR 71
Issue 16	Fissile Material Exemptions and General License Provisions	Does not apply to TNF-XI
Issue 17	Double Containment of Plutonium (PRM–71–12)	Does not apply to TNF-XI
Issue 18	Contamination Limits for Spent Fuel and HLW Packages	Not adopted in 10 CFR 71
Issue 19	Modifications of Event Reporting Requirements	No effect on TNF-XI

Enclosure 4 to TN E-31428

List of Changed and Additional Pages to the TNF-XI Safety Analysis Report

Safety Analysis Report – Proprietary and Nonproprietary Versions		
Current Page No.	**Replacement Page No.**	**Reason for change**
Cover Page	Cover Page	Update
i through v	i through v	Update TOC
1-1	1-1	Addition of PE bags Update of package identification to AF-96
2-2	2-2	Editorial correction
2-5	2-5	Editorial correction
2-13	2-13	Editorial correction
2-15	2-15	Clarifications for consistency with 10 CFR 71
3-2	3-2	Removal of stipulation for surface temperature measurement prior to transport
6-1	6-1	Editorial correction
6-2	6-2	Update of package identification to AF-96
6-11	6-11	Update of package identification to AF-96
6-111	6-111	Update of package identification to AF-96
7-2	7-2	Removal of stipulation for surface temperature measurement prior to transport
New pages	A.6-i to A.6-70	Criticality evaluation to add polyethylene bags

Enclosure 6 to TN E-31428

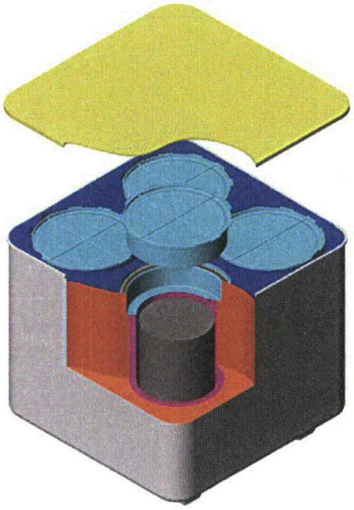
Changed Pages for
Safety Analysis Report, Revision 5, Non-proprietary Version

NON-PROPRIETARY

AREVA

TRANSNUCLEAR, INC.

TNF-XI Package



SAFETY ANALYSIS REPORT

Docket Number 71-9301

Revision 5
September 2011

7135 Minstrel Way, Suite 300 • Columbia, MD 21045

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8.5 Appendix C

1.0 GENERAL INFORMATION

This chapter of the Transnuclear (TN) TNF-XI Packaging Safety Analysis Report presents a general introduction and description of the TNF-XI. The major components comprising the TNF-XI are presented in Figure 1-1. A detailed description of the major packaging and payload components is presented in the following sections. Several appendices are included which consist of English translations of *Transnuclear* licensing documents. Since all these documents use the metric SI units, this SAR is also written using only SI units to avoid confusion. Detailed drawings are presented in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

1.1 Introduction

The TNF-XI Packaging is a transportation system designed to transport homogeneous oxide forms of uranium oxides (UO_2, UO_3 and U_3O_8) enriched to a maximum of 5 % (w/o). The packaging consists of a sheet metal outer box, made of 2 mm thick stainless steel sheet, equipped with a top face including four outer bayonets. Thermo-mechanical protection is provided by three types of phenolic foam: type 1, type 2, and type 3. Containment of the payload is provided by four internal wells, made of stainless steel sheets 1 mm thick enclosing a layer of neutron-poisoning resin. A primary lid closes each internal well. Each lid is made of stainless steel plate 6 mm thick and includes four outer bayonets, and sealed by an elastomer gasket. Four thermo-mechanical protection upper plugs protect the primary lids. Each upper plug includes an added stainless steel upper lip with internal bayonet. A flat seal closes the interface between the upper lip and the upper surface of the package. A polymer cleanness cover protects the upper face of the package.

The package is a Type A-fissile package. To provide criticality control, the inner wells include a layer of neutron-poisoning resin. The uranium oxide powder is contained in individual stainless steel pails contained in the inner wells. *The uranium oxide powder, scraps or pellets, may be packaged in polyethylene bags or bags with hydrogen concentration less than polyethylene, that are then placed in the pails. The maximum hydrogen content of the bags within each cavity is 56g H, which is equivalent to a maximum mass of 390g polyethylene, considering all sources of hydrogenous material within each cavity.*

Authorization is sought for shipment of 300 kg of enriched uranium oxide powder (sometimes granules) of uranium oxides (UO_2, UO_3, U_3O_8), or scraps or pellets of UO_2 corresponding to enriched commercial grade uranium, following the ASTM-C 996-*10* standard, with variable enrichment of up to 5% of U^{235} (per package) as a Type A(F)-*96*, fissile material package per the definitions delineated in 10 CFR §71.4[1]. The *criticality safety index (CSI)* for the package, determined in accordance with the definitions of 10 CFR §71.4 *(and described in 10CFR 71.59)*, is determined for each shipment. The *CSI* is based on the number of packages for criticality control purposes (the method for the *CSI* determination is defined in Chapter 6.0, *Criticality Safety Evaluation*) *and Appendix A.6.*

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

2.1.2.2.2 Fatigue

Because the inner wells of the TNF-XI package are constructed of ductile stainless steel and are essentially a rigid body within the phenolic foam, no structural failures of the containment boundary due to fatigue will occur.

2.1.2.2.3 Buckling

The TNF-XI package provides both a confinement and a containment boundary. For normal and hypothetical accident conditions, the containment boundary will not buckle due to free or puncture drops. This behavior has been demonstrated via full-scale testing of the TNF-XI package.

2.2 Weights and Center of Gravity

The maximum gross weight of the TNF-XI package, including a maximum payload weight of 300 kg, is 1,050 kg, slightly higher than the original design mass of 1,042 kg. The center of gravity is approximately at the geometric center of the outer assembly, approximately 470 mm above the base of the package.

The mass of the prototypes are conservative compared to the maximum mass of the package of 1,050 kg, with the exception of the P3 prototype (1,040 kg). However, the P3 prototype underwent the same drop tests as the P2 prototype and sustained similar damage. This small *difference in* mass does not impact the safety demonstrations presented in the safety analysis report.

Table 2-1 WEIGHTS SUMMARY OF TNF-XI PACKAGE

TNF-XI packaging	660 kg
12 NFI pails	86 kg
Cleanness cover	4 kg
Maximum radioactive content	300 kg
Maximum total weight	**1,050 kg**

temperature with the negligible internal heat and no insolation is 38 °C. Since no surface temperature exceeds 50 °C, the requirements of 10 CFR §71.43(g) are satisfied.

2.4.8 Venting

The TNF-XI package does not incorporate any feature that would permit continuous venting during transport. Thus, the requirements of 10 CFR §71.43(h) are satisfied.

2.5 Lifting and Tie-down Devices for All Packages

2.5.1 Lifting Devices

The TNF-XI is lifted only by means of the forklift paths. Thus, there are no lifting devices used on the package and the requirements of 10 CFR §71.45*(a)* are met.

2.5.2 Tie-down Devices

The TNF-XI package is secured for transport within an overseas shipping container. The package is secured in the container using a structural tube frame on each side and on the top of the package. The loads reacted by the package during transport are analyzed in Paragraph 3.1 of Appendix 2.10.1. The TNF-XI package does not incorporate any feature that is utilized as a tie-down device or system to secure the package. Thus, the requirements of 10 CFR §71.45(b) are satisfied.

2.6 Normal Conditions of Transport

2.6.1 Heat

The NCT thermal analyses presented in Section 3.4, *Thermal Evaluation for Normal Conditions of Transport*, consists of exposing the TNF-XI package to direct sunlight and 38 °C still air per the requirements of 10 CFR §71.71(b).

2.6.1.1 Summary of Pressures and Temperatures

The Maximum Normal Operating Pressure (MNOP) for the Inner Wells is 122 kPa, as determined in Section 3.4.1, *Maximum Internal Pressure*. Combining the MNOP with the reduced external pressure, per 10 CFR §71.71(c)(3), of 25 kPa results in a maximum internal pressure of 97 kPa.

$S_1 = 4 \times \pi / 4 \times 444^2 = 619\ 321\ mm^2$ area of 4 upper plugs.

$\sigma_2 = 3.25\ MPa$ crushing stress of the foam of the body,

$S_1 = 1096 \times 1096 - S_1 = 581\ 895\ mm^2$ area of 4 upper plugs.

$F = 2.9 \times 10^6\ N$

The corresponding acceleration taking into account the weight of 1056 kg of the package is:

$\gamma = 2.9 \times 10^6 / 1056 / 9.81 = 280\ g$

This acceleration is much less than the actual case, where the bayonet system of the upper plugs and the external casing will add rigidity during the drop. The load seen by the primary lid would be greater than this. Nevertheless, this acceleration is greater than the load seen during the corner drop test at -40°C.

That means that just taking into account the foam crushing, the closure lids receive greater load during the drop test onto the face of the package, than during the drop test onto the corner even if at the cold temperature of -40°C.

2.7.4.3 Drop test onto a puncture bar:

Because the compression stress is higher at –40°C, the resistance to puncture is also higher.

2.7.5 Thermal

Subpart F of 10 CFR 71 requires performing a thermal test in accordance with the requirements of 10 CFR §71.*73*(c)(4). To demonstrate the performance capabilities of the TNF-XI packaging when subjected to the HAC thermal test specified in 10 CFR §71.*73*(c)(4), thermal testing was performed. Given the small dimensions of the package, this test was performed on two full-scale prototypes (which had first undergone the drop tests in the two most penalising configurations, representative of transport accident conditions as discussed in Section 2.71, *Free Drop*, and Section 2.7.3, *Puncture*), in a high emittance oven. Following the 30-minute oven test, each TNF-XI was allowed to cool naturally in air, without any active cooling systems.

2.7.5.1 Summary of Pressures and Temperatures

Since the Outer Shell does not act as a containment or confinement boundary, the Inner Well and Primary Lid are the only components that may experience a pressure build-up. The maximum cavity temperature during normal conditions is 70 °C. Therefore, the maximum internal pressure for the Inner Well is conservatively determined by assuming the air temperature within the Inner Well is at the maximum temperature of the simulated payload:

$$\frac{P_{80^\circ C}}{P_{10^\circ C}} = \frac{T_{air\max}}{T_{init}}$$

As the package model criticality study assumes water is present in the Inner Wells package is exempted from this water immersion tests.

The TNF-XI package thus satisfies the requirements of 10 §71.73(c)(5).

2.7.7 Immersion - All Packages

Subpart F of 10 CFR 71 requires performing an immersion test for fissile material packages in accordance with the requirements of 10 CFR §71.73(c)(6). Because of the seal configuration (see Appendix 1.3.1), the TNF-XI package is not leaktight under external overpressure. Under the immersion test, the water will fill the cavity. Because of the pressure equalisation, the packaging structure is not therefore subjected to loading during these tests.

As the package model criticality study assumes water is present in the Inner Wells package is exempted from this water immersion tests.

The TNF-XI package thus satisfies the requirements of 10 §71.73(c)(6).

2.7.8 Summary of Damage

As discussed in the previous sections, the cumulative damaging effects of free drop, puncture drop, and thermal tests were satisfactorily withstood by the TNF-XI packaging certification testing. Subsequent destructive examinations of the tested packages confirmed that integrity of the criticality control components was maintained throughout the test series. Therefore, the requirements of 10 CFR §71.73 have been adequately satisfied.

2.8 Accident Conditions for Air Transport of Plutonium and Fissile Material Packages for Air Transport

This section does not apply, since the TNF-XI package will not be transported by air.

2.9 Special Form and Fuel Rods

This section does not apply, since the contents of the TNF-XI package are not classed as special form material and fuel rods are not shipped in the TNF-XI package.

Table 3-1. Specific Heat of BORA Resin

Temperature (°C)	Cp (J. g^{-1}.°C^{-1})
30	[redacted]
40	[redacted]
50	[redacted]
60	[redacted]
70	[redacted]
80	[redacted]
90	[redacted]
100	[redacted]
110	[redacted]
120	[redacted]
130	[redacted]
140	[redacted]
150	[redacted]
160	[redacted]
170	[redacted]
180	[redacted]
190	[redacted]
200	[redacted]

Trade Secret

3.4 THERMAL ANALYSIS IN NORMAL CONDITIONS OF TRANSPORT

The temperatures reached by each package component are the results of calculation in normal conditions of transport in accordance with the IAEA regulations.

The maximum surface temperature when insolation is not considered is equal to the ambient temperature of 38 °C since there is no heat generated by the payload.

The maximum Normal Conditions of Transport ambient temperature (38°C ambient temperature) and insolation are *also* considered. This calculation is presented in paragraph 4.1 of Appendix 3.6.2.

The Normal Conditions of Transport calculation results in a maximal temperature value in the package of 70 °C. This temperature is naturally compatible with all the packaging materials, which are therefore not degraded.

3.4.1 Maximum Internal Pressures

The containment of the TNF-XI package is provided by the four Inner Wells. The determination of the maximum internal pressure within the Inner Wells is based on the ideal gas law. Assume an Inner Well is filled at the normal operating temperature, 10 °C, and is allowed to reach the NCT maximum bulk temperature for the payload of 70 °C. The maximum pressure would be the product of the ratio of the absolute gas temperature to 10 °C and atmospheric pressure, 1.01×10^5 Pa. Specifically,

6.0 CRITICALITY SAFETY EVALUATION

6.1 General Description

This criticality safety analysis is performed to demonstrate safety of the *Transnuclear*, Inc. (TN) TNF-XI package. This package meets applicable 10 CFR 71 [1] and IAEA [2] requirements for a Type A fissile material shipping container for homogeneous and heterogeneous uranium dioxide enriched to a maximum of 5.0% ^{235}U.

The packaging consists of a stainless steel outer shell and lid that encases a body of phenolic foam. Four individually sealed stainless steel inner wells are located in the body. The uranium oxide powder/compounds are positioned within these inner wells in pails.

Water exclusion from the package under accident conditions is not required for this package design. The contents of the package are analyzed in the damaged container under optimal moderation conditions and favorable geometry.

This analysis is performed for an enrichment range of 4.05 to 5.0 wt. percent ^{235}U for homogeneous UO_2 powder and heterogeneous UO_2 material. This work demonstrates safety for a maximum homogeneous UO_2 powder or heterogeneous UO_2 material loading *with water moderation (moderation provided by materials with a hydrogen content less than or equal to that provided by water)* per TNF-XI package as shown in Table 6-1. *A separate criticality evaluation to determine the Uranium loading limits that allows for the use of up to 390 grams of polyethylene (or materials with a hydrogen content less than or equal to that of polyethylene) per cavity of the TNF-XI package is documented in Appendix A.6.* Other oxide forms (e.g., U_3O_8 or $UO_{X,\,x>2}$) are also equally valid provided the UO_2 equivalent total payload is not violated.

Table 6-1. Uranium Dioxide Weight Limits per TNF-XI Package

^{235}U Enrichment	Homogeneous UO_2 Powder Maximum Loading, kg	Heterogeneous UO_2 Material Maximum Loading, kg
4.05%	300	300
4.10%	300	293
4.15%	300	287
4.25%	300	271
4.35%	300	259
4.45%	300	247
4.55%	294	238
4.65%	281	228
4.75%	265	219
4.85%	255	208
4.95%	244	202
5.00%	239	197

Based on the current analysis, the *Criticality Safety Index (CSI)* for the TNF-XI package with the above specified contents is shown in Table 6-2. The number of undamaged or damaged (10 CFR §71.73) packages that will remain subcritical in any arrangement with close water reflection and optimum interspersed hydrogenous moderation is 216. Using the rounded *CSI* result of 50/108 = 0.5, the maximum allowable number of packages per non-exclusive use vehicle is 50/0.5 = 100.

Table 6-2. *Criticality Safety Index* for Nuclear Criticality Control

Case	N	Array Size	Packages	*CSI*
Normal Conditions of Transport	115	8×9×8	576	0.5
Hypothetical Accident Conditions	108	6×6×6	216	0.5

6.2 Package Fuel Loading

6.2.1 Contents

The package shall be used to transport homogeneous uranium in oxide form (UO_2, U_3O_8, or $UO_{x, x>2}$) which meet the requirements for Enriched Commercial Grade Uranium defined in ASTM C996-96. The uranium isotopic uranium distribution is shown in Table 6-3.

This analysis demonstrates safety for UO_2 powder over the entire range of UO_2 densities. The maximum net UO_2 equivalent payload demonstrated safe in the TNF-XI is presented in Table 6-1.

Table 6-3. Uranium Isotopic Distribution

Isotope	wt %	Modeled wt %
^{234}U	0.0054 - 0.0500	0.0000
^{235}U	0.7110 - 5.0000	4.0500 to 5.0000
^{236}U	0.0000 - 0.0250	0.0000
^{238}U	99.2836 - 94.9295	95.9500 to 95.0000

6.2.2 Packaging

A discussion of the TNF-XI package designed for transportation of UO_2 enriched up to 5% ^{235}U is provided in Section 1.2.1, *Packaging*. A detailed set of drawings of the TNF-XI package is provided in the general packaging arrangement drawings (refer to Appendix 1.3.1, *Packaging General Arrangement Drawings*).

Table 6-4 provides a listing of the applicable material specifications used in the TNF-XI model construct. Atomic density is calculated by the SCALE package [3] for the KENO-Va results.

The first package array model consists of an 8×9×8 array of undamaged, normal condition TNF-XI packages. IAEA and 10 CFR §71.59 standards for arrays of fissile material packages stipulates undamaged package arrays are to be evaluated with void between the packages and fully reflected. The undamaged array is modeled using single units containing a homogeneous mixture of UO_2 powder and various volume fractions of water or heterogeneous UO_2 modeled as cylindrical stacks of pellets. The array is modeled with optimum moderation within each package and full water reflection around the array.

The damaged package array models a 6×6×6 array of damaged TNF-XI packages. As required by IAEA and 10 CFR §71.59, the damaged package array are evaluated as if each package was subjected to the tests specified in 10 CFR §71.73, hypothetical accident conditions, with optimum moderation within each package and full water reflection around the array.

6.4 Criticality Calculation

This evaluation demonstrates the subcriticality of an array of packages during normal conditions of transport and hypothetical accident conditions. The determined *CSI* for criticality control of damaged and undamaged shipment is given in Section 6.4.3. All calculations were performed for the range of allowable ^{235}U enrichment of 4.05 wt.% to 5.0 wt.% to ensure maximum reactivity. The analysis results are summarized in Table 6-6 through Table 6-11.

6.4.1 Calculational or Experimental Method

The effective neutron multiplication factor (k_{eff}) was calculated using the CSAS25 module of the SCALE 4.4 Code with the 44-group ENDF/B-V cross-section library for the homogeneous powder cases and CSAS2X module of the SCALE 4.4 Code with the 44-group ENDF/B-V cross-section library for the heterogeneous cases [3]. The control module CSAS25 includes the three dimensional criticality code KENO-Va and the preprocessing codes BONAMI-S, NITAWL-II and XSDRNPM-S. To represent the package loaded with pellets and/or scrap material, the CSAS2X sequence is used. In CSAS2X, the lattice unit cell option is required in the input so the XSDRNPM code can generate cell-weighted cross sections for the fuel/water pin cell. Those cross-sections are then used in the entire fuel region.

KENO Va, in conjunction with a suitable working library of nuclear cross section data, is used to calculate the k_{eff} of systems of fissile material. It can also compute lifetime and generation time, energy dependent leakages, energy and region-dependent absorptions, fissions, fluxes, and fission densities. KENO Va utilizes a three-dimensional Monte-Carlo computation scheme. BONAMI-S has the function of performing Bondarenko calculations for resonance self-shielding. The main function of NITAWL-II is to change the format of the master cross-section libraries to one that the criticality code (KENO Va) can access. It also provides the Nordheim Integral Treatment for resonance self-shielding.

The criticality analysis was performed assuming a mixture of UO_2 powder and water and heterogeneous UO_2 material as described in Section 6.3. Calculations were performed using the range of ^{235}U enrichment from 4.05% through 5.0%. In order to meet the requirements of 10 CFR §71.55 and 10 CFR §71.57, the KENO models were specified with 100% water albedo on all four sides. Further discussion regarding the models can be found in Section 6.3 and in Section 6.6.

6.4.3 *Criticality Safety* Index

The number of packages that remain below the USL determines the *CSI* for criticality control. The number of packages to be transported at one time is set at 108. For normal conditions of transport, an array size of 8×9×8 (5N=540) was shown to remain subcritical. Under hypothetical accident conditions, an array size of 6×6×6 (2N=216) was also shown to remain subcritical. Thus, *CSI*=50/108=0.5.

6.5 Critical Benchmark Experiments

The results of this benchmark are used in the analysis of the TNF-XI containers. Two types of analysis is performed. One involves a payload of optimally moderated uranium oxide powder, and the other involves pellets or scraps of uranium oxide fuel. The input files for all benchmarks are taken from References [8] and [9]. The number of sampling histories is increased in all input files to reduce the statistical deviation associated with the Monte Carlo method. For the powder benchmark, cases that use the "multiregion" unit cell data are modified to "infinite homogeneous." The rod benchmark cases are modified to run the CSAS2X sequence and the fuel region is represented by a "mixture 500." This method generates cell-weighted cross sections in the XSDRNPM code to be used in the KENO calculation. These methods are selected to be consistent with the technique used to analyze the contents of the two packages.

An upper subcritical limit (USL) is determined as a function of several experimental variables. The values are then applied using Method 1 "confidence band with administrative margin", described in Section 4.1.1 of Reference [3]. The administrative margin is 0.05, and the confidence level $1-\gamma_1$ is 0.95. Excel spreadsheet functions and the ORNL program USLSTATS version1.3.7 are used to do the statistical analysis of the data.

6.5.1 Critical Experiment Characteristics

6.5.1.1 Description of Powder Cases

Critical experiments chosen to represent a UO_2 powder and water mixture include those that feature low enriched, homogeneous, and well-moderated systems without dissolved boron such as UF_2 solutions, and Uranium-paraffin mixtures. A total of 18 experiments were found to be sufficient for this benchmark, and are listed in Table 6-77.

Three independent variables were used in the analysis, enrichment, Hydrogen to fissile material ratio (H/X), and the average energy of the fission-causing neutron (AEF). Figures 6-64, 6-65, and 6-66 show the plots of each independent variable as a function of the k_{eff} value calculated in KENOVa. The USL value calculated from USLSTATS is also shown.

6.5.1.2 Description of Pellet Cases

Experiments chosen for the pellet scenario feature low enriched simple arrays with steel and/or water reflector walls in water without soluble boron. A total of 27 cases were used for the benchmark and are listed in Table 6-78. In addition to enrichment, H/X, and AEF, the volume ratio of water to fuel was also used as an independent variable. Figures 6-67 through 6-70 show

7.1.2 Loading the Payload into the TNF-XI

1. The uranium oxide payload will be contained in pails. Prior to the loading of the payload into the pails, visually verify that an undamaged boronated ring is correctly installed in each pail as shown in the drawings of Section 1.3.

   A maximum of three pails may be loaded into a single well and the contents shall not exceed 25 kg per pail of uranium oxide at a maximum enrichment of 5 % U235.
2. After loading the payload into each well, the primary lid shall be placed into the well and rotated to engage the bayonets.
3. Secure the primary lid locker for each primary lid.
4. Lower each upper plug into position and rotate to engage the bayonets.
5. Install the securing plate after all upper plugs are in place.
6. Install safety cover.

7.1.3 Final Package Preparations for Transport

1. Install the tamper-indicating seal.
2. *Not Used.*
3. Monitor external radiation for each package per 49CFR §173.441[1].
4. Determine the surface contamination levels for each TNF-XI package per 49CFR §173.443.
5. Determine the *criticality safety* index for the loaded TNF-XI package per 49 CFR §173.403.

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[1] Title 49, Code of Federal regulations Part 173 (49CFR 173), *Shippers – General Requirements for Shipments and Packagings*, 1-1-97 Edition

APPENDIX A.6
TNF-XI CRITICALITY EVALUATION

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APPENDIX A.6
TNF-XI CRITICALITY EVALUATION

The TNF-XI provides criticality control to meet the criticality performance requirements specified in Section 71.55 and 71.59 of 10 CFR Part 71. The criticality control design ensures that the effective multiplication factor (k_{eff}) of the contained fuel is no greater than an upper subcritical limit (USL) for the most reactive configuration. The USL includes a confidence band with an administrative safety margin of 0.05. The design has a criticality safety index (CSI) given in 10 CFR 71.59(b) as CSI = 50/"N". The number "N" is based on all of the following conditions being satisfied:

1. Five times "N" undamaged packages with nothing between the packages are subcritical.
2. Two times "N" damaged packages, if each package is subjected to the tests specified in 10 CFR 71.73 ("hypothetical accident conditions"), are subcritical with optimum interspersed hydrogenous moderation; and
3. The value of "N" cannot be less than 0.5.

A.6.1 DESCRIPTION OF CRITICALITY DESIGN

The design criteria for the TNF-XI require that the package remain subcritical under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) as defined 10 CFR Part 71.

A.6.1.1 Design Features

The TNF-XI package consists of a stainless steel outer shell and lid that encases a body of phenolic foam. Four individually sealed stainless steel inner wells/cavities are located in the body, containing three pails per well. The fuel is placed in polyethylene bags or plastic bags with hydrogen concentration less than polyethylene, which are placed inside stainless steel pails. Fuel may be in the form of UO_2 powder, pellets, or scrap. The maximum mass of polyethylene allowed in each cavity is 390 g. Criticality control is provided by a borated stainless steel sleeve in each pail and a boron containing resin (BORA) surrounding each well/cavity. Each well/cavity lid consists of layers of phenolic foam and aluminum honeycomb.

A.6.1.2 Summary Table of Criticality Evaluation

As required by 10 CFR Part 71.55(b), the TNX-XI is shown to be subcritical for the most reactive credible configuration and moderation by water to the most reactive credible extent. The cask is shown to be subcritical for five times "N" packages with void between packages and no in-leakage of water, as required by 10 CFR Part 71.59(a)(1). In addition, as required by 10 CFR Part 71.59(a)(2), two times "N" packages is shown to be subcritical with the fissile material in its most reactive configuration, optimum water moderation and close full water reflection consistent with its damaged condition.

Criticality calculations are performed for UO_2 powder, pellets and scrap pellets at enrichments of 4.05, 4.15, 4.25, 4.35, 4.45, 4.55, 4.65, 4.75, 4.85, 4.95, and 5.00 wt% U-235. The calculations determine k_{eff} with the CSAS5 control module of SCALE6 [1] for various configurations, including all uncertainties to assure criticality safety under all credible conditions.

The results of the evaluation demonstrate that the maximum expected k_{eff}, including statistical uncertainty, will be less than the USL determined from a statistical analysis of benchmark criticality experiments. The statistical analysis procedure includes a confidence band with an administrative safety margin of 0.05.

Table A.6-1 lists the bounding results for all conditions of transport for powder. The highest calculated k_{eff} for powder, including 2σ uncertainty, is an HAC array of TNF-XI packages containing UO_2 powder with an initial U-235 enrichment of 5.00 wt. % filled to a height of 44 cm. The maximum allowed initial enrichment is also listed in Table A.6-1. An 8x9x8 array was used for the NCT UO_2 powder array analyses and a 6x6x6 array for the HAC evaluations.

Table A.6-2 lists the bounding results for all conditions of transport for pellets and scrap. The highest calculated k_{eff} for pellets and scrap, including 2σ uncertainty, is an HAC array of TNF-XI packages containing UO_2 scrap with an initial U-235 enrichment of 4.45 wt. % filled to a height of 41.2 cm and a pitch of 0.8 cm. The maximum allowed initial enrichment is also listed in Table A.6-2. An 8x9x8 array was used for the NCT UO_2 pellet and scrap array analyses and a 6x6x6 array for the HAC evaluations.

These criticality calculations were performed with CSAS5 of SCALE6. For each case, the result includes (1) the KENO-calculated k_{KENO}, (2) the one sigma uncertainty $\square_{KENO}$, and (3) the final k_{eff}, which is equal to $k_{KENO} + 2\sigma_{KENO}$.

The criterion for sub-criticality is that

$$k_{KENO} + 2\sigma_{KENO} \leq USL,$$

where USL is the upper subcritical limit established by an analysis of benchmark criticality experiments. Two different USLs are developed for these analyses. From Section A.6.8.2, the minimum USL over the parameter range for UO_2 powder is 0.9388. The minimum USL over the parameter range for enriched UO_2 pellets and scrap is 0.9398. From Table A.6-2, for the most reactive case,

$$k_{KENO} + 2\sigma_{KENO} = 0.9364 + 2\ (0.0007) = 0.9379 \leq 0.9398.$$

A.6.1.3 Criticality Safety Index

The design has a CSI, given in 10 CFR 71.59(b) as CSI = 50/"N", of 0.5 for transport of UO_2 powder, pellets and scrap.

A.6.2 FISSILE MATERIAL CONTENTS

The TNF-XI package is capable of transporting UO_2 powder, pellets, and scrap up to a maximum enrichment of 5.00 wt % U-235. For each enrichment, the mass of UO_2 was varied to determine the maximum acceptable UO_2 mass limit. Table A.6-3 gives the UO_2 mass limits for the TNF-XI as a function of form (powder or pellet and scrap) and enrichment. For the pellet/scrap analysis, some of the mass limits are found to be slightly higher than the values given in Chapter 6. For these occurrences (4.25 wt %, 4.45 wt %, and 4.95 wt %), the mass limit from Chapter 6 is conservatively applied. It is expected that the fissile material will be divided evenly among the four cavities. Therefore, no cavity may exceed one quarter of the total UO_2 mass limit of the entire package.

A.6.3 GENERAL CONSIDERATIONS

The following subsections describe the physical models and materials of the TNF-XI packaging used for input to the CSAS5 module of SCALE6 to perform the criticality evaluation for UO_2 powder, pellets, and scrap. The models developed are for a single package and arrays of packages both for NCT and HAC.

A.6.3.1 Model Configuration

The TNF-XI model is based upon drawings in Section 1.3 of the SAR. An axially finite model of the normal geometry of the TNF-XI package is provided in Figure A.6-1. This figure shows the material constituent radial and axial dimensions. The model construct consists of four cavities inserted into the primary body of phenolic foam [[redacted]]. Each cavity is surrounded by BORA resin, which acts as a neutron absorber. At the bottom of each cavity is a borated stainless steel disk upon which a pail rests. Each pail is modeled as a sealed stainless steel can that contains the fuel/polyethylene/water mixture and is lined with borated stainless steel. For the NCT model, void is present between the pail and cavity wall and between the top of the pail and bottom of the lid. For conservatism, the pails in each cavity are pushed inward toward each other. The lid to each cavity consists of layers of phenolic foam [[redacted]], aluminum honeycomb, and [[redacted]]. The entire package is surrounded by a thin layer of stainless steel. Figures A.6-2 and A.6-3 show the NCT KENO model.

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An axially finite model of the damaged geometry (HAC) of the TNF-XI package is provided in Figure A.6-4. The effects of the certification test results are incorporated in the damaged model. The axial crush of the package was modeled as a 1.5 cm decrease in height. This is applied to the model construct by reducing the thickness of the bottom foam 1.5 cm. The side crush of the body results in a 2 cm reduction in this direction. This reduction was incorporated in the model by reducing each lateral face by 1 cm. Damage by a punch bar is modeled as a hole on one side, 3.9 cm deep and 15 cm in diameter. In addition, it is assumed that 2.7 cm of foam is consumed in fire on all surfaces and therefore is modeled as charred foam and that the top foam disk for each canister is also charred. One of the four cavity lids also has charred foam in the bottom disk. In the damaged model, the fuel lattice exists both inside and outside the pail, and void space within the package not containing the fuel lattice contains water.

A finite square lattice of packages is modeled for both the NCT and HAC. The NCT lattice is a 8x9x8 array and the HAC lattice is an array of 6x6x6 packages. The array of packages is surrounded by a water reflector (KENO water albedo). The package arrays are modeled as close fitting and virtually in contact to provide the most reactive array configuration.

Differences in the KENO model and the actual package are listed below:

- The criticality safety analysis model of the loaded TNF-XI package differs from the actual package in the allowance for water intrusion into the containment. The UO_2 mass and the water content are varied to optimally moderate the package. As the contents of the package have been demonstrated to remain 'dry' under hypothetical accident conditions, the optimal internal moderation treatment is a very large conservatism.
- By ignoring spatial effects, the TNF-XI undamaged and damaged arrays are modeled as close fitting and in virtual contact when in fact structure deformation and bowing would provide additional spacing between individual packages.
- The aluminum honeycomb in the top lid is modeled as solid aluminum with an accordingly reduced density for simplicity.
- The upper phenolic foam disk ([[redacted]]) in the lid is modeled as 0.4 cm thinner than actual and as charred [[redacted]] foam instead of [[redacted]] (for the damaged package). The difference in charred foam densities is negligible and the reduction in the disk thickness is conservative.

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- The contents in the actual package are contained within pails loaded into four compartments in the package. Each individual compartment contains three pails, each 20.5 cm high with a borated stainless steel liner 18.0 in height and 0.2 cm thick starting 2.5 cm from the bottom of each can. The three pails are modeled as a single can with a height of 61.2 cm with a borated stainless steel liner 53.7 cm in height starting 7.5 cm from the container bottom.
- The phenolic foam [[redacted]] in the bottom corner of the package is modeled as [[redacted]] for simplicity. Due primarily to the low density of the foam, the effects are negligible.
- The perforated aluminum disk is modeled as 3.0 cm thick, although the actual thickness is 1.5 cm. This difference is shown to be within the statistical uncertainty of the reactivity calculation methods employed.

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A.6.3.2 Material Properties

The material properties for the CSAS5 evaluations are taken directly from the SCALE6 standard compositions. The materials are summarized in Table A.6-4.

For powder, the fuel mixture (mixture #1) is a homogenized mixture of UO_2, polyethylene and water. The volume fractions are calculated based on the known mass of UO_2, polyethylene and the known volume (with variable height) occupied by the mixture. The density of the polyethylene is also varied from the nominal 0.92 g/cc to ensure that this parameter has negligible effect on the reactivity of the system within the range of 0.90 g/cc to 0.96 g/cc. Water (mixture #2) is used for the HAC analysis only.

For pellets and scrap, the fuel lattice (mixture #500) is a lattice of UO_2 (mixture #1) in a homogeneous mixture of water and polyethylene (mixture #2). The volume fractions of the moderator are calculated based on the known mass of polyethylene and the known volume (with variable height) occupied by the mixture. Water (mixture #11) is used for the HAC analysis only.

The other materials in the TNF-XI package are taken directly from the criticality analyses in Chapter 6. Stainless steel is the SCALE standard composition with nominal density. The BORA resin (material #4) has a density of 1.74 g/cc and the boron in the resin is natural boron. The B-10 is taken at 75% credit or 13.5 wt% (0.75*18).

The other boron containing material in the TNF-XI package is borated stainless steel (mixture #3) with 0.75 wt% natural boron.

Two phenolic foam compositions are utilized. [[redacted]] (mixture #5) at a density of 0.20 g/cc is the main foam modeled. [[redacted]] foam (mixture #6) at a density of 0.15 g/cc is modeled in the upper plugs. In the HAC model, the carbonized foam (mixture #7) is modeled as carbon with a density of 0.116 g/cc. Water is not added to the foam in the HAC model since it decreases reactivity by reducing the communication between packages in the array.

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The aluminum honeycomb (mixture #9) in the upper plugs is modeled as plain aluminum with a reduced density of 1.08 g/cc.

A.6.3.3 Computer Codes and Cross Section Libraries

The CSAS5 module of the SCALE6 code is used for the criticality analysis [1]. The 238groupndf5 cross section library is utilized with all cross sections at room temperature (293 or 300 K). The CSAS5 module uses the lattice cell option for the pellet/scrap analyses and the infinite homogenized fuel mixture option for the powder analyses. The NITAWL code is used to process the cross sections through the *parm=nitawl* card in the CSAS5 input.

All cases are run with at least 2000 neutrons per generation for 805 generations. The 1 sigma uncertainty is typically less than 0.001.

A.6.3.4 Lattice Cell Modeling for CSAS5

The pellet and scrap analysis utilizes a lattice cell configuration (**read celldata** card). The cell can be modeled as a cylindrical or spherical fuel pellet surrounded by a moderator. The cell is described by defining a radius for the fuel pellet and a cell (lattice) pitch with the moderator material identified. For the CSAS5 homogenized fuel calculation, a cell weighted cross section fuel mixture is created (**cellmix=500**) as a material input for the KENO V.a criticality calculation. For the homogenized fuel pellet/scrap analyses, a square lattice (**latticecell squa**) with cylindrical fuel, a triangular lattice (**latticecell trian**) with cylindrical fuel, and spherical fuel in a hexagonal lattice (**latticecell sphtriangp**) are evaluated.

For a given moderator to fuel volume ratio, V_m/V_f, the pitch and radius of the fuel is correlated. For NCT, the volume of the fuel lattice in the pail can be calculated as the cross sectional area of the pail times the height of the mixture minus the volume of the borated stainless steel (BSS) insert. The pail inner radius is 14.25 cm and the BSS insert is a 0.2 cm thick cylinder, located 7.5 cm above the bottom of the pail. For a given fuel lattice height measured from the bottom of the pail, H, the volume of the fuel lattice in the pail is:

$$V_T = \pi \cdot 14.25^2 \cdot 7.5 + \pi \cdot 14.05^2 \cdot (H - 7.5) \quad \text{Eq. 1}$$

In the HAC array analysis, the package cavities and pail are fully flooded with the fuel matrix occupying the full cross section (17.7 cm radius) of the cavity. The void space within the package not containing the fuel lattice contains water. As in the NCT models, the optimum moderation is determined by varying *H*. The volume fractions are calculated with the same methodology, except the mixture volume has to account for the volume around the bottom BSS plate (cavity pad 0.2 cm thick) and inside the cavity and around the pail:

Bottom of Pail Top of Pail Around BSS Plate Cavity Around Pail

$$V_T = \pi \cdot 14.25^2 \cdot 7.5 + \pi \cdot 14.05^2 \cdot (H - 7.5) + \pi \cdot (17.7^2 - 16.5^2) \cdot 0.2 + \pi \cdot (17.7^2 - 14.35^2) \cdot (H + 0.1)$$

Eq. 2

Since the volume occupied by the UO_2 and polyethylene, V_f and V_{poly} (cm^3), can easily be calculated from their masses, *M* (kg) and 390 g respectively, the remaining volume is filled by water, v_w. These values are calculated as follows:

$$V_f = \frac{1000 \cdot M}{4 \cdot 10.96}$$ Eq. 3

$$V_{poly} = \frac{390}{0.92}$$ Eq. 4

$$V_w = V_T - V_f - V_{poly}$$ Eq. 5

These values may then be used to calculate the polyethylene and water volume fractions for the moderator and the V_m/V_f ratio, where $V_m = V_w + V_{poly}$. For a square pitch lattice, the relation between pitch and radius is given by:

$$r = p\sqrt{\frac{1}{\pi\left(V_m/V_f + 1\right)}}$$ Eq. 6

where *r* is the radius of the fuel and *p* is the pitch. For a triangular pitch lattice, that relation is given by:

$$r = p\sqrt{\frac{\sqrt{3}}{2\pi\left(V_m/V_f + 1\right)}}$$ Eq. 7

The spherical lattice can be described as a rhombic dodecahedron containing a sphere [6]. The volume, V_s, of a unit is then given by:

$$V_s = \frac{\sqrt{2}}{2} p^3$$ Eq. 8

From this, the relation between pitch and radius can be derived as:

$$r = \frac{p}{2}\sqrt[3]{\frac{3\sqrt{2}}{\pi\left(V_m/V_f + 1\right)}} \quad \text{Eq. 9}$$

Fuel pellets are best represented by the square and triangular pitches lattice, while fuel scrap is best represented by the spherical-hexagonal lattice. The analysis utilizes the spherical-hexagonal lattice to bound both scrap and pellets since it is the most reactive configuration, as demonstrated in A.6.6.2.

A.6.3.5 Demonstration of Maximum Reactivity

This section describes the criticality analysis. The analyses are performed with the CSAS5 module of the SCALE6 system. A series of criticality calculations are performed for the TNF-XI packaging to determine the most reactive configurations for UO_2 powder and UO_2 pellets and scrap.

For the NCT analysis, both single package and array, the pails are conservatively allowed to fill with water and mix with the fuel to obtain the optimum level of moderation. Both the single package and array are closely reflected all around with 12" of full density water.

For the HAC array analysis, the pails and the inner cavity are conservatively allowed to fill with water and mix with the fuel to obtain the optimum level of moderation. The pail and cavity volume unoccupied by the fuel and water mixture is allowed to fill with full density water to provider further moderation and reflection. The array is closely reflected all around with 12" of full density water.

A.6.3.5.1 Bases and Assumptions

For the NCT analyses, the packaging geometry in accordance with the drawings shown in Chapter 1 is utilized with the exceptions as noted in Section 6.3.1. The results of the drop tests performed for the TNF-XI package documented in Chapter 2 demonstrate that the package does not undergo significant damage during HAC. The inner containment remains leak tight and the minimal local deformation of the outer container surface occurs. In order to bound this local deformation, a uniform reduction of 1.5 cm is applied to the height of the package and 2 cm is applied to sides of the package. By conservatively ignoring deformation and bowing, this reduces the separation distance between the packages in the array. Section A.6.3.1 addresses how the model treats additional conservatism under HAC due to a punch bar and charring. All calculations are performed using UO_2 fuel material without a burnable absorber like Gadolinia. Therefore, the results of these calculations are conservatively applied to fuel containing burnable absorbers.

The TNF-XI package is modeled with KENO V.a using the available geometry input. This option allows a model to be constructed that uses regular geometric shapes to define the material boundaries.

The following conservative assumptions are also incorporated into the criticality calculations:

1. The fuel (powder, pellet, and scrap) is modeled at 100% theoretical density.
2. Temperature is at 20°C (293K) or 27°C (300K), depending on the available data.
3. The maximum allowed 390 g of polyethylene is assumed for the fuel moderator mixture/cell.
4. The optimum moderator to fuel ratio is utilized by varying the fill height of the pail under NCT and the pail and cavity under HAC.
5. For pellets and scrap, the optimum pitch/radius combination is utilized.

A.6.4 EVALUATION OF SINGLE PACKAGE

Single package evaluations were performed for the TNF-XI package with UO_2 powder and scrap for NCT only. The TNF-XI package with UO_2 pellets is bounded by the scrap analysis.

A.6.4.1 Single Package with Powder Configuration

A single package analysis is performed for the NCT. Under NCT, the cavity interior and pail remain leak-tight. However, the pail is conservatively allowed to fill with water in the analysis, which forms a homogeneous mixture with the polyethylene bags and fuel. The package is closely reflected all around with 12" (30.48 cm) of full density water (water albedo).

The fuel mixture is modeled as a pure theoretical mixture of UO_2 powder (10.96 g/cm^3), polyethylene (0.92 g/cc), and water. The volume fraction of water is altered by varying the height, H, of the mixture while keeping the mass of the UO_2 constant. In this way optimum moderation is achieved.

The volume of the fuel, polyethylene, and water may be obtained from Equations 1 and 3 through 5. These volumes may then be used to calculate the volume fractions for the homogeneous mixture of fuel and moderator by dividing the volume of each component (UO_2, polyethylene, and water) by the total volume, V_T.

Evaluations are performed for UO_2 powder enrichments from 4.45 to 5.00 wt % U-235. For each enrichment, the fuel mixture height is varied from a full pail (61.2 cm) to 45 cm in height.

A.6.4.2 Single Package with Scrap Configuration

A single package analysis is performed for the NCT. Under NCT, the cavity interior and pail remain leak-tight. However, the pail is conservatively allowed to fill with water in the analysis, which forms a homogeneous mixture with the polyethylene bags. The package is closely reflected all around with 12" (30.48 cm) of full density water (water albedo).

The fuel lattice is modeled as spherical UO_2 pellets (10.96 g/cm^3) in a polyethylene (0.92 g/cc) and water mixture. The volume fraction of water is altered by varying the height of the mixture while keeping the mass of the UO_2 constant. In this way optimum moderation is achieved. Furthermore, the pitch and radius of the pellets is varied to determine the optimum combination.

The volume of the fuel, polyethylene, and water may be obtained from Equations 1 and 3 through 5. These volumes may then be used to calculate the volume fractions for the homogeneous moderator mixture of water and polyethylene by dividing the volume of each component by the sum of the water and polyethylene volumes (V_w and V_{poly}). For a given volume ratio of moderator to fuel, the pitch and radius are related as given in Equation 9 for a spherical lattice, which is demonstrated to be bounding for pellets and scrap in A.6.6.2.

The optimal fuel lattice height is first determined. This analysis is performed for 236 kg of UO_2 with 4.55 wt % U-235. Table A.6-5 displays the results and demonstrates that the package is most reactive when completely filled ($H = 61.2$ cm). While there may be some small variation in the optimal fill height for the various enrichments, the effect is small, as demonstrated by the HAC results in Section 0. Furthermore, there is ample margin between the maximum k_{eff} and the USL. Therefore, the single package analysis presented in Section A.6.4.3 is performed with maximally filled pails.

Evaluations are performed for UO_2 scrap enrichments from 4.05 to 5.00 wt % U-235. For each enrichment, the pitch is varied from 0.1 to 1.2 cm. If the results did not clearly demonstrate that the optimum pitch lied within that range, pitches from 1.3 to 2.0 cm were also considered.

A.6.4.3 Single Package Results

For the single package powder NCT evaluation, k_{eff} values are shown in Table A.6-6 through Table A.6-12 for the different powder enrichments. The bounding k_{eff} is for 4.95% enrichment with 238 kg UO_2 at a value of 0.8997.

For the single package pellet and scrap NCT evaluation, k_{eff} values are shown in Table A.6-13 through Table A.6-23 for the different powder enrichments. The bounding k_{eff} is for 4.95% enrichment with 204 kg UO_2 at a value of 0.9106.

A.6.5 EVALUATION OF PACKAGE ARRAY FOR NORMAL CONDITIONS OF TRANSPORTATION

Package array evaluations were performed for the TNF-XI package with UO_2 powder and scrap for NCT. The TNF-XI package with UO_2 pellets is bounded by the scrap analysis. The NCT array consists of an 8x9x8 lattice of packages.

A.6.5.1 NCT Package Array with Powder Configuration

The single package model described in Section A.6.4.1 is utilized as the basis for the NCT array evaluation. An 8x9x8 array of packages is modeled. The array of packages is closely reflected all around with 12" (30.48 cm) of full density water. However, there is nothing between the packages because they are in physical contact due to the cuboid geometry of the package. This array configuration is the most reactive because it allows the maximum "communication" between the packages.

As in the single packaging evaluation, the optimum moderation was determined by varying the fill height of the homogenized fuel and moderator mixture.

Evaluations are performed for UO_2 powder enrichments from 4.45 to 5.00 wt % U-235. For each enrichment, the fuel mixture height is varied from a full pail (61.2 cm) to 45 cm in height.

A.6.5.2 NCT Package Array with Scrap Configuration

The single package model described in Section A.6.4.2 is utilized as the basis for the NCT array evaluation. An 8x9x8 array of packages is modeled. The array of packages is closely reflected all around with 12" (30.48 cm) of full density water. However, there is nothing between the packages because they are in physical contact due to the cuboid geometry of the package. This array configuration is the most reactive because it allows the maximum "communication" between the packages.

As in the single packaging evaluation, the optimum moderation was determined by varying the fill height of the heterogeneous fuel and moderator mixture.

The optimal fuel lattice height is again determined. This analysis is performed for 236 kg of UO_2 with 4.55 wt % U-235. Table A.6-24 displays the results and demonstrates that the package is most reactive when completely filled ($H = 61.2$ cm). While there may be some small variation in the optimal fill height for the various enrichments, the effect is small, as demonstrated by the HAC results in Section A.6.6.3. Furthermore, there is ample margin between the maximum k_{eff} and the USL. Therefore, the single package analysis presented in Section A.6.5.3 is performed with maximally filled pails.

Since the most reactive configuration is with the pail completely filled, the system is likely undermoderated. Therefore, it is possible that a reduction in UO_2 mass may actually increase the reactivity. A range of masses were examined at 4.55 wt% U-235 with the pails completely filled to verify that this is not the case. The results shown in Figure A.6-5 clearly demonstrate that reactivity trends with UO_2 mass, almost linearly.

Evaluations are performed for UO_2 scrap enrichments from 4.05 to 5.00 wt % U-235. For each enrichment, the pitch is varied from 0.1 to 1.2 cm. If the results did not clearly demonstrate that the optimum pitch lied within that range, pitches from 1.3 to 2.0 cm were also considered.

A.6.5.3 NCT Package Array Results

For the NCT package array with powder evaluation, k_{eff} values are shown in Table A.6-25 through Table A.6-31 for the different powder enrichments. The bounding k_{eff} is for 5.00% enrichment with 232 kg UO_2 at a value of 0.9164.

For the NCT package array with pellet and scrap evaluation, k_{eff} values are shown in Table A.6-32 through Table A.6-42 for the different powder enrichments. The bounding k_{eff} is for 4.95% enrichment with 204 kg UO_2 at a value of 0.9267.

A.6.6 EVALUATION OF PACKAGE ARRAY FOR HYPOTHETICAL ACCIDENT CONDITIONS

Package array evaluations were performed for the TNF-XI package with UO_2 powder and scrap for HAC. The TNF-XI package with UO_2 pellets is bounded by the scrap analysis. The HAC array consists of a 6x6x6 lattice of packages.

The HAC geometry is similar to the NCT geometry. For HAC, the height of the package is decreased by reducing the thickness of the bottom foam by 1.5 cm to model the axial crush. The width of the package in the x and y directions is decreased by reducing the foam thickness by 1 cm on each side to model the side crush. A 15 cm diameter, 3.9 cm deep hole filled with water is included on one side to model the punch bar damage. In addition, it is assumed that 2.7 cm of foam is consumed in fire on all surfaces and therefore is modeled as charred foam and that the top foam disk for each canister is also charred. One of the four cavity lids also has charred foam in the bottom disk. In the damaged model, the fuel lattice exists both inside and outside the pail, and void space within the package not containing the fuel lattice contains water.

A.6.6.1 HAC Package Array with Powder Configuration

The HAC package array model is similar to the NCT package array described in Section A.6.5.1. However, the geometry of the package is adjusted to account for the effects of the certification test results as described in Section A.6.3.1. Also, the homogenized fuel and moderator mixture is allowed to fill both the pails and the inner cavities, rather than just the pails as in the NCT evaluation. A 6x6x6 array of packages is modeled. The array of packages is closely reflected all around with 12" (30.48 cm) of full density water. However, there is nothing between the packages because they are in physical contact due to the cuboid geometry of the package. This array configuration is the most reactive because it allows the maximum "communication" between the packages.

The volume of the fuel, polyethylene, and water may be obtained from Equations 2 and 3 through 5. These volumes may then be used to calculate the volume fractions for the homogeneous mixture of fuel and moderator by dividing the volume of each component (UO_2, polyethylene, and water) by the total volume, V_T. The remaining volume of the pails and cavities is filled with full density water.

Evaluations are performed for UO_2 powder enrichments from 4.45 to 5.00 wt % U-235. For each enrichment, the fuel mixture height is varied from 50 cm to 40 cm in height.

A study was also performed to ensure that varying polyethylene densities would not significantly affect the reactivity of the system. The TNF-XI under HAC with 232 kg of UO_2 at 5.00 wt % U-235 was examined for this purpose since it was the most reactive enrichment/mass combination. The results are presented in Table A.6-64 and clearly demonstrate that minor variations in polyethylene density have a negligible effect on the reactivity of the system. This analysis was only carried out for powder since the homogenous system is more sensitive to the moderator properties than the heterogeneous system.

A.6.6.2 HAC Package Array with Scrap Configuration

The HAC package array model is similar to the NCT package array described in Section A.6.5.1. However, the geometry of the package is adjusted to account for the effects of the certification test results as described in Section A.6.3.1. Also, the heterogeneous fuel and moderator mixture is allowed to fill both the pails and the inner cavities, rather than just the pails as in the NCT evaluation. A 6x6x6 array of packages is modeled. The array of packages is closely reflected all around with 12" (30.48 cm) of full density water. However, there is nothing between the packages because they are in physical contact due to the cuboid geometry of the package. This array configuration is the most reactive because it allows the maximum "communication" between the packages.

The volume of the fuel, polyethylene, and water may be obtained from Equations 2 and 3 through 5. These volumes may then be used to calculate the volume fractions for the homogeneous moderator mixture of water and polyethylene by dividing the volume of each component by the sum of the water and polyethylene volumes (V_w and V_{poly}).

For a given volume ratio of moderator to fuel, the pitch and radius are related as given in Equations 6, 7, and 9 for a square pitch lattice, triangular pitch lattice, and spherical lattice, respectively. These three lattice types were evaluated to determine which is the most reactive. To ensure that the most reactive configuration was captured, the each lattice was evaluated at three different fill heights and at pitches varied from 0.1 to 1.2 cm for each fill height. The results presented in Tables A.6-43 through A.6-45 demonstrate that the spherical lattice is bounding for both pellets and scrap. For brevity, only the most reactive pitch is listed from fill heights that are less than optimal.

As in the NCT analysis, a range of masses were examined at 4.55 wt% U-235 with the pails filled to 41.2 cm to verify that a decrease in UO_2 mass does not result in an increase in reactivity. The results shown in Figure A.6-6 clearly demonstrate that reactivity trends with UO_2 mass, almost linearly.

Evaluations are performed for UO_2 scrap enrichments from 4.05 to 5.00 wt % U-235. For each enrichment, various fill heights are analyzed. For each enrichment and fill height combination, the pitch is varied from 0.1 to 1.2 cm. For brevity, only the results for the most reactive pitch are listed from fill heights that are less than optimal.

A.6.6.3 HAC Package Array Results

For the HAC package array with powder evaluation, k_{eff} values are shown in Table A.6-46 through Table A.6-52 for the different powder enrichments. The bounding k_{eff} is for 5.00% enrichment with 232 kg UO_2 at a value of 0.9352.

For the HAC package array with pellet and scrap evaluation, k_{eff} values are shown in Table A.6-53 through Table A.6-63 for the different powder enrichments. The bounding k_{eff} is for 4.95% enrichment with 204 kg UO_2 at a value of 0.9378.

A.6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

Not applicable to the TNF-XI.

A.6.7.1 Air Transport Configuration

Not applicable to the TNF-XI.

A.6.7.2 Air Transport Results

Not applicable to the TNF-XI.

A.6.8 BENCHMARK EVALUATIONS

The criticality safety analysis of the TNF-XI packaging uses the CSAS5 module of the SCALE6 system of codes. The CSAS5 control module allows simplified data input to the functional modules BONAMI, NITAWL, and KENO V.a. These modules process the required cross-section data and calculate the k_{eff} of the system. BONAMI performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-S applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. Finally, KENO V.a calculates the effective neutron multiplication (k_{eff}) of a 3-D system. The benchmark calculations performed for this module are described herein. The methodology employed is based on the guidance provided in reference [5].

The analysis presented herein uses the fresh fuel in the form of low enriched UO_2 powder and pellets/ scrap for criticality analysis. The analysis employs the 238-group ENDF/B-V cross-section library because it has a small bias and is appropriate for low enriched hydrogen moderated systems. An upper subcritical limit (USL-1) is determined for both powder and pellet evaluation using the results of these benchmark calculations.

The parameters that are independent variables of USL functions are U-235 enrichment, energy of average lethargy of fission (EALF) and hydrogen-to-fissile ratio (H/X).

Eighteen critical experiments [3] are selected for the UO_2 powder USL evaluation. The material and geometrical characteristics of these criticality experiments are summarized in Table A.6-65. The critical experiments, the calculated results and their U-235 enrichment and H/X values are listed in Table A.6-66.

Twenty-three critical experiments are selected for the UO_2 pellet USL evaluation. All of the 23 critical experiments are part of the NUREG/CR-6361 critical experiments [2]. The experiments are square lattice containing UO_2, H_2O and aluminum. The fifteen P3602 experiments have steel reflecting walls. The material and geometrical characteristics of these criticality experiments are summarized in Table A.6-67. The critical experiments, the calculated results and their U-235 enrichment and H/X values are listed in Table A.6-68.

A.6.8.1 Applicability of Benchmark Experiments

The pertinent parameters for each experiment are included in Tables A.6-66 and A.6-68 along with the results of each run. The best linear correlation is observed for the powder experiments enrichment with a correlation of -0.78. All other parameters show much lower correlation ratios indicating no real correlation. All parameters were evaluated for trends and to determine the most conservative USL using the USLSTATS 6 Program [4].

In addition, the sufficiency of the number of experiments used for the pellet and powder analyses benchmarking is also determined herein. The 18 experiments chosen for powder benchmarking are the most representative critical benchmarks. Additional experiments are available from the International Handbook of Evaluated Criticality Safety Benchmark Experiments but most of these experiments are based on Uranyl Nitrate solutions with an enrichment of 10.0 wt. % U-235. Therefore, only these 18 experiments were employed as powder benchmarks. The test of normalcy performed by the USLSTATS program indicates that the benchmark data is normal.

The 23 experiments chosen for pellet benchmarking are sufficient from a 95% probability, 95% statistical confidence level (95/95 basis) since one needs 20 experiments for this purpose. However, these experiments are also selected because they represent those set of experiments that adequately represent the system being evaluated – fuel pins (or pellets) in an array without the presence of poison material or soluble poison. The USLSTATS program employed herein also indicates that the benchmark data is normal.

The upper subcritical limit (USL) is calculated in accordance to NUREG/CR-6361 [2]. USL Method 1 (USL-1) applies a statistical calculation of the bias and its uncertainty plus an administrative margin (0.05) to the linear fit of results of the experimental benchmark data. Results from the USL evaluation are presented in Table A.6-69 for UO_2 powder and Table A.6-70 for UO_2 pellets.

The criticality evaluation used the same cross section set, fuel materials and similar material/geometry options that were used in the benchmark calculations.

A.6.8.2 Bias Determination

It is clear from the USL functions shown in Table A.6-69 that the USL for enrichment is the limiting USL for the UO_2 powder evaluations. The powder USL is 0.9388.

For pellets and scrap, it is not as obvious which parameter is limiting. Therefore, the limiting value for each parameter is determined and the corresponding USL is calculated from the USL functions in Table A.6-70. The results are presented in Table A.6-71. The lowest USL value is obtained for the H/X trending parameter. This corresponds to the HAC cases with 196 kg UO_2 enriched to 5.00 wt% U-235 and a fill height of 41.2 cm. The pellet USL is 0.9398.

A.6.9 REFERENCES

1. SCALE6: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers, Oak Ridge National Laboratory, Radiation Shielding Information Center Code Package CCC-750, February 2009.

2. U.S. Nuclear Regulatory Commission, "Criticality Benchmark Guide for Light-Water-Reactor fuel in Transportation and Storage Packages," NUREG/CR-6361, Published March 1997, ORNL/TM-13211.

3. Oak Ridge National Laboratory, "Validation of KENO V.a Comparison with Critical Experiments," ORNL/CSD/TM-238, December 1986.

4. USLSTATS: A Utility to Calculate Upper Subcritical Limits for Criticality Safety Applications, Version 6, Oak Ridge National Laboratory, January 26, 2009.

5. U.S. Nuclear Regulatory Commission, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," NUREG/CR-5661, Published April 1997, ORNL/TM-11936.

6. ORNL/TM-2005/39, Version 6, Vol. II, Section F17, "KENO-VI: A General Quadratic Version of the KENO Program", January 2009.

A.6.10 APPENDICES

A.6.10.1 Example Powder Input Listing

This input represents the most reactive powder case of 232 kg of UO_2 with 5.00 wt % enrichment. This input models the 6x6x6 HAC array with a fill height of 44 cm.

Proprietary information withheld pursuant to 10 CFR 2.390.

Proprietary information on pages A.6-16 to A.6-18 withheld pursuant to 10 CFR 2.390.

Proprietary information withheld pursuant to 10 CFR 2.390.

A.6.10.2 Example Pellet/Scrap Input Listing

This input represents the most reactive pellet/scrap case of 204 kg of UO_2 with 4.95 wt % enrichment. This input models the 6x6x6 HAC array with a fill height of 41.2 cm and a pitch of 0.6 cm.

Proprietary information withheld pursuant to 10 CFR 2.390.

Proprietary information on pages A.6-20 to A.6-23 withheld pursuant to 10 CFR 2.390.

Table A.6-1 Summary of Criticality Results for Powder

Normal Conditions of Transport (NCT)		
	Single	8x9x8 Array
Case	k_{eff}	k_{eff}
5.00 wt% U-235 – 232kg UO_2	0.8993	0.9164
4.95 wt% U-235 – 238 kg UO_2	0.8997	0.9157
4.85 wt% U-235 – 248 kg UO_2	0.8981	0.9143
4.75 wt% U-235 – 259 kg UO_2	0.8964	0.9122
4.65 wt% U-235 – 271 kg UO_2	0.8927	0.9084
4.55 wt% U-235 – 286 kg UO_2	0.8916	0.9072
4.45 wt% U-235 – 300 kg UO_2	0.8870	0.9028
Hypothetical Accident Conditions (HAC)		
	Single	6x6x6 Array
Case	k_{eff}	k_{eff}
5.00 wt% U-235 – 232kg UO_2	-	0.9352
4.95 wt% U-235 – 238 kg UO_2	-	0.9352
4.85 wt% U-235 – 248 kg UO_2	-	0.9345
4.75 wt% U-235 – 259 kg UO_2	-	0.9341
4.65 wt% U-235 – 271 kg UO_2	-	0.9344
4.55 wt% U-235 – 286 kg UO_2	-	0.9341
4.45 wt% U-235 – 300 kg UO_2	-	0.9335

Table A.6-2 Summary of Criticality Results for Pellets and Scrap

Normal Conditions of Transport (NCT)		
	Single	8x9x8 Array
Case	k_{eff}	k_{eff}
5.00 wt% U-235 – 196 kg UO_2	0.90975	0.92540
4.95 wt% U-235 – 204 kg UO_2	0.91059	0.92666
4.85 wt% U-235 – 208 kg UO_2	0.90834	0.92518
4.75 wt% U-235 – 216 kg UO_2	0.90902	0.92510
4.65 wt% U-235 – 224 kg UO_2	0.90695	0.92380
4.55 wt% U-235 – 236 kg UO_2	0.90622	0.92378
4.45 wt% U-235 – 248 kg UO_2	0.90696	0.92354
4.35 wt% U-235 – 256 kg UO_2	0.90493	0.92137
4.25 wt% U-235 – 272 kg UO_2	0.90418	0.92007
4.15 wt% U-235 – 284 kg UO_2	0.90165	0.91836
4.05 wt% U-235 – 300 kg UO_2	0.90075	0.91742
Hypothetical Accident Conditions (HAC)		
	Single	6x6x6 Array
Case	k_{eff}	k_{eff}
5.00 wt% U-235 – 196 kg UO_2	-	0.93503
4.95 wt% U-235 – 204 kg UO_2	-	0.93782
4.85 wt% U-235 – 208 kg UO_2	-	0.93594
4.75 wt% U-235 – 216 kg UO_2	-	0.93654
4.65 wt% U-235 – 224 kg UO_2	-	0.93488
4.55 wt% U-235 – 236 kg UO_2	-	0.93617
4.45 wt% U-235 – 248 kg UO_2	-	0.93788
4.35 wt% U-235 – 256 kg UO_2	-	0.93618
4.25 wt% U-235 – 272 kg UO_2	-	0.93744
4.15 wt% U-235 – 284 kg UO_2	-	0.93690
4.05 wt% U-235 – 300 kg UO_2	-	0.93741

Table A.6-3 TNF-XI Allowable UO_2 Masses

Max ^{235}U Enrichment (weight percent)	**Homogenous UO_2 Powder Maximum Loading (kg)**	**Heterogeneous UO_2 Material (Pellet and Scrap) Maximum Loading (kg)**
≤ 4.05	300	300
4.15		284
4.25		271
4.35		256
4.45		247
4.55	286	236
4.65	271	224
4.75	259	216
4.85	248	208
4.95	238	202
5.0	232	196

Table A.6-4 KENO Mixture Numbers

Mixture Number	**Powder**	**Pellets and Scrap**
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Trade Secret

Table A.6-5 Optimal Fill Height for NCT Single Package with Scrap with 236 kg UO_2, 4.55 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
41.2	3.7711	1.1	0.87919	0.00055	0.88029
46.2	4.3471	1.1	0.89343	0.00048	0.89439
51.2	4.9231	1.2	0.90137	0.00049	0.90235
56.2	5.4991	0.9	0.90491	0.00048	0.90587
61.2	**6.0752**	**0.9**	**0.90520**	**0.00051**	**0.90622**

Table A.6-6 Single NCT TNF-XI with 232 kg UO_2 Powder, 5.00 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	0.8955	0.0007	0.8969
60	**0.8977**	**0.0008**	**0.8993**
59	0.8957	0.0007	0.8971
58	0.8976	0.0006	0.8988
57	0.8950	0.0007	0.8964
55	0.8936	0.0007	0.8950
53	0.8912	0.0007	0.8926
51	0.8875	0.0007	0.8889
49	0.8851	0.0007	0.8865
47	0.8795	0.0007	0.8810
45	0.8753	0.0007	0.8767

Table A.6-7 Single NCT TNF-XI with 238 kg UO_2 Powder, 4.95 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.8983**	**0.0007**	**0.8997**
60	0.8960	0.0008	0.8975
59	0.8956	0.0008	0.8972
58	0.8951	0.0007	0.8964
57	0.8943	0.0007	0.8957
55	0.8927	0.0007	0.8940
53	0.8893	0.0007	0.8907
51	0.8863	0.0007	0.8877
49	0.8820	0.0007	0.8834
47	0.8770	0.0008	0.8786
45	0.8721	0.0008	0.8736

Table A.6-8 Single NCT TNF-XI with 248 kg UO_2 Powder, 4.85 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.8966**	**0.0008**	**0.8982**
60	0.8937	0.0007	0.8950
59	0.8943	0.0008	0.8959
58	0.8926	0.0006	0.8939
57	0.8913	0.0008	0.8929
55	0.8904	0.0007	0.8918
53	0.8866	0.0007	0.8880
51	0.8834	0.0007	0.8849
49	0.8801	0.0006	0.8814
47	0.8728	0.0007	0.8742
45	0.8667	0.0008	0.8682

Table A.6-9 Single NCT TNF-XI with 259 kg UO_2 Powder, 4.75 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.8949**	**0.0007**	**0.8963**
60	0.8931	0.0007	0.8945
59	0.8915	0.0007	0.8929
58	0.8902	0.0008	0.8918
57	0.8888	0.0008	0.8903
55	0.8851	0.0007	0.8866
53	0.8837	0.0007	0.8851
51	0.8789	0.0007	0.8803
49	0.8764	0.0008	0.8780
47	0.8698	0.0007	0.8712
45	0.8626	0.0007	0.8641

Table A.6-10 Single NCT TNF-XI with 271 kg UO_2 Powder, 4.65 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	0.8911	0.0008	0.8927
60	0.8897	0.0007	0.8912
59	0.8893	0.0007	0.8906
58	0.8874	0.0008	0.8891
57	0.8866	0.0007	0.8880
55	0.8844	0.0007	0.8858
53	0.8794	0.0008	0.8810
51	0.8767	0.0008	0.8784
49	0.8708	0.0007	0.8722
47	0.8658	0.0007	0.8671
45	0.8586	0.0007	0.8600

Table A.6-11 Single NCT TNF-XI with 286 kg UO_2 Powder, 4.55 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.8901**	**0.0007**	**0.8917**
60	0.8870	0.0007	0.8884
59	0.8853	0.0007	0.8868
58	0.8843	0.0008	0.8859
57	0.8835	0.0007	0.8849
55	0.8804	0.0007	0.8818
53	0.8761	0.0007	0.8775
51	0.8705	0.0007	0.8719
49	0.8653	0.0008	0.8669
47	0.8590	0.0007	0.8604
45	0.8514	0.0007	0.8527

Table A.6-12 Single NCT TNF-XI with 300 kg UO_2 Powder, 4.45 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.8856**	**0.0007**	**0.8870**
60	0.8840	0.0007	0.8854
59	0.8818	0.0008	0.8834
58	0.8816	0.0007	0.8830
57	0.8794	0.0008	0.8810
55	0.8752	0.0010	0.8772
53	0.8706	0.0007	0.8720
51	0.8667	0.0007	0.8680
49	0.8613	0.0007	0.8628
47	0.8529	0.0007	0.8543
45	0.8461	0.0008	0.8477

Table A.6-13 Single NCT TNF-XI with 196 kg UO_2 Scrap, 5.00 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.89959	0.00074	0.90107
0.2	0.90290	0.00074	0.90438
0.3	0.90609	0.00073	0.90755
0.4	0.90540	0.00070	0.90680
0.5	**0.90837**	**0.00069**	**0.90975**
0.6	0.90774	0.00067	0.90908
0.7	0.90712	0.00073	0.90858
0.8	0.90558	0.00062	0.90682
0.9	0.90454	0.00082	0.90618
1.0	0.90352	0.00077	0.90506
1.1	0.90186	0.00075	0.90336
1.2	0.90055	0.00068	0.90191

1) $V_m/V_f = 7.5191$

Table A.6-14 Single NCT TNF-XI with 204 kg UO_2 Scrap, 4.95 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.89997	0.00070	0.90137
0.2	0.90415	0.00077	0.90569
0.3	0.90573	0.00070	0.90713
0.4	0.90724	0.00073	0.90870
0.5	0.90792	0.00067	0.90926
0.6	0.90804	0.00065	0.90934
0.7	0.90931	0.00064	0.91059
0.8	**0.90923**	**0.00068**	**0.91059**
0.9	0.90768	0.00078	0.90924
1.0	0.90741	0.00070	0.90881
1.1	0.90609	0.00070	0.90749
1.2	0.90350	0.00068	0.90486

1) $V_m/V_f = 7.1850$

Table A.6-15 Single NCT TNF-XI with 208 kg UO_2 Scrap, 4.85 wt % U-235[1]

Pitch (cm)	**k_{keno}**	**σ_{keno}**	**k_{eff}**
0.1	0.89862	0.00075	0.90012
0.2	0.90172	0.00070	0.90312
0.3	0.90226	0.00067	0.90360
0.4	0.90573	0.00066	0.90705
0.5	0.90627	0.00071	0.90769
0.6	**0.90680**	**0.00077**	**0.90834**
0.7	0.90617	0.00070	0.90757
0.8	0.90529	0.00070	0.90669
0.9	0.90593	0.00081	0.90755
1.0	0.90587	0.00076	0.90739
1.1	0.90381	0.00070	0.90521
1.2	0.90306	0.00075	0.90456

1) $V_m/V_f = 7.0276$

Table A.6-16 Single NCT TNF-XI with 216 kg UO_2 Scrap, 4.75 wt % U-235[1]

Pitch (cm)	**k_{keno}**	**σ_{keno}**	**k_{eff}**
0.1	0.89837	0.00064	0.89965
0.2	0.89943	0.00076	0.90095
0.3	0.90254	0.00070	0.90394
0.4	0.90441	0.00073	0.90587
0.5	0.90513	0.00086	0.90685
0.6	0.90517	0.00082	0.90681
0.7	0.90755	0.00069	0.90893
0.8	**0.90756**	**0.00073**	**0.90902**
0.9	0.90520	0.00075	0.90670
1.0	0.90457	0.00076	0.90609
1.1	0.90359	0.00073	0.90505
1.2	0.90168	0.00072	0.90312

1) $V_m/V_f = 6.7303$

Table A.6-17 Single NCT TNF-XI with 224 kg UO_2 Scrap, 4.65 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.89555	0.00066	0.89687
0.2	0.89834	0.00074	0.89982
0.3	0.90083	0.00079	0.90241
0.4	0.90250	0.00066	0.90382
0.5	0.90474	0.00075	0.90624
0.6	0.90483	0.00063	0.90609
0.7	**0.90551**	**0.00072**	**0.90695**
0.8	0.90443	0.00070	0.90583
0.9	0.90455	0.00064	0.90583
1.0	0.90303	0.00073	0.90449
1.1	0.90252	0.00071	0.90394
1.2	0.90175	0.00078	0.90331

1) $V_m/V_f = 6.4542$

Table A.6-18 Single NCT TNF-XI with 236 kg UO_2 Scrap, 4.55 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.89566	0.00056	0.89678
0.2	0.89790	0.00048	0.89886
0.3	0.90097	0.00051	0.90199
0.4	0.90253	0.00050	0.90353
0.5	0.90365	0.00052	0.90469
0.6	0.90504	0.00050	0.90604
0.7	0.90528	0.00046	0.90620
0.8	0.90514	0.00049	0.90612
0.9	**0.90520**	**0.00051**	**0.90622**
1.0	0.90510	0.00050	0.90610
1.1	0.90358	0.00046	0.90450
1.2	0.90323	0.00055	0.90433

1) $V_m/V_f = 6.0752$

Table A.6-19 Single NCT TNF-XI with 248 kg UO_2 Scrap, 4.45 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.89264	0.00068	0.89400
0.2	0.89668	0.00073	0.89814
0.3	0.89969	0.00081	0.90131
0.4	0.90212	0.00084	0.90380
0.5	0.90271	0.00078	0.90427
0.6	0.90516	0.00069	0.90654
0.7	0.90528	0.00066	0.90660
0.8	**0.90544**	**0.00076**	**0.90696**
0.9	0.90505	0.00071	0.90647
1.0	0.90518	0.00069	0.90656
1.1	0.90324	0.00071	0.90466
1.2	0.90461	0.00071	0.90603

1) $V_m/V_f = 5.7328$

Table A.6-20 Single NCT TNF-XI with 256 kg UO_2 Scrap, 4.35 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.88965	0.00064	0.89093
0.2	0.89327	0.00072	0.89471
0.3	0.89610	0.00068	0.89746
0.4	0.89969	0.00086	0.90141
0.5	0.90016	0.00069	0.90154
0.6	0.90063	0.00074	0.90211
0.7	**0.90363**	**0.00065**	**0.90493**
0.8	0.90314	0.00070	0.90454
0.9	0.90223	0.00070	0.90363
1.0	0.90251	0.00076	0.90403
1.1	0.90124	0.00068	0.90260
1.2	0.90013	0.00067	0.90147

1) $V_m/V_f = 5.5224$

Table A.6-21 Single NCT TNF-XI with 272 kg UO_2 Scrap, 4.25 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.88624	0.00075	0.88774
0.2	0.89125	0.00080	0.89285
0.3	0.89365	0.00072	0.89509
0.4	0.89531	0.00068	0.89667
0.5	0.89910	0.00082	0.90074
0.6	0.90127	0.00063	0.90253
0.7	0.90200	0.00069	0.90338
0.8	**0.90274**	**0.00072**	**0.90418**
0.9	0.90236	0.00071	0.90378
1.0	0.90223	0.00071	0.90365
1.1	0.90235	0.00070	0.90375
1.2	0.90097	0.00069	0.90235

1) $V_m/V_f = 5.1387$

Table A.6-22 Single NCT TNF-XI with 284 kg UO_2 Scrap, 4.15 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.88578	0.00071	0.88720
0.2	0.88738	0.00082	0.88902
0.3	0.89128	0.00071	0.89270
0.4	0.89345	0.00071	0.89487
0.5	0.89679	0.00073	0.89825
0.6	0.89781	0.00068	0.89917
0.7	0.90013	0.00070	0.90153
0.8	0.89971	0.00065	0.90101
0.9	0.89937	0.00069	0.90075
1.0	0.89896	0.00071	0.90038
1.1	0.89956	0.00071	0.90098
1.2	**0.90017**	**0.00074**	**0.90165**
1.3	0.89971	0.00082	0.90135
1.4	0.89922	0.00067	0.90056
1.5	0.89616	0.00077	0.89770
1.6	0.89642	0.00069	0.89780
1.7	0.89517	0.00065	0.89647
1.8	0.89382	0.00069	0.89520
1.9	0.89131	0.00070	0.89271
2.0	0.89023	0.00069	0.89161

1) $V_m/V_f = 4.8794$

Table A.6-23 Single NCT TNF-XI with 300 kg UO_2 Scrap, 4.05 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.87983	0.00071	0.88125
0.2	0.88491	0.00078	0.88647
0.3	0.88767	0.00070	0.88907
0.4	0.89064	0.00072	0.89208
0.5	0.89522	0.00066	0.89654
0.6	0.89581	0.00079	0.89739
0.7	0.89680	0.00066	0.89812
0.8	0.89761	0.00074	0.89909
0.9	0.89800	0.00070	0.89940
1.0	**0.89941**	**0.00067**	**0.90075**
1.1	0.89763	0.00069	0.89901
1.2	0.89800	0.00083	0.89966
1.3	0.89828	0.00071	0.89970
1.4	0.89854	0.00073	0.90000
1.5	0.89700	0.00072	0.89844
1.6	0.89599	0.00070	0.89739
1.7	0.89544	0.00071	0.89686
1.8	0.89447	0.00082	0.89611
1.9	0.89263	0.00074	0.89411
2.0	0.89006	0.00069	0.89144

1) $V_m/V_f = 4.5658$

Table A.6-24 Optimal Fill Height for NCT Package Array with Scrap[1]

Fill Height (cm)	V_m/V_f	Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
41.2	3.7711	1.1	0.89347	0.00048	0.89443
46.2	4.3471	1.1	0.90875	0.00048	0.90971
51.2	4.9231	0.8	0.91655	0.00050	0.91755
56.2	5.4991	1.1	0.92038	0.00050	0.92138
61.2	**6.0752**	**0.7**	**0.92268**	**0.00055**	**0.92378**

1) 236 kg UO_2, 4.55 wt % U-235

Table A.6-25 NCT TNF-XI Package Array with 232 kg UO_2 Powder, 5.00 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.9150**	**0.0007**	**0.9164**
60	0.9123	0.0007	0.9138
59	0.9118	0.0008	0.9134
58	0.9126	0.0007	0.9141
57	0.9107	0.0008	0.9122
55	0.9098	0.0007	0.9112
53	0.9067	0.0008	0.9082
51	0.9039	0.0007	0.9052
49	0.9003	0.0007	0.9018
47	0.8935	0.0007	0.8950
45	0.8882	0.0007	0.8897

Table A.6-26 NCT TNF-XI Package Array with 238 kg UO_2 Powder, 4.95 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	0.9137	0.0007	0.9151
60	**0.9143**	**0.0007**	**0.9157**
59	0.9123	0.0007	0.9136
58	0.9108	0.0008	0.9124
57	0.9086	0.0007	0.9099
55	0.9089	0.0007	0.9103
53	0.9070	0.0009	0.9087
51	0.9014	0.0007	0.9028
49	0.8972	0.0009	0.8989
47	0.8909	0.0007	0.8923
45	0.8860	0.0007	0.8874

Table A.6-27 NCT TNF-XI Package Array with 248 kg UO_2 Powder, 4.85 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.9128**	**0.0007**	**0.9142**
60	0.9100	0.0007	0.9113
59	0.9100	0.0008	0.9116
58	0.9099	0.0007	0.9112
57	0.9068	0.0007	0.9081
55	0.9060	0.0006	0.9072
53	0.9031	0.0007	0.9044
51	0.8983	0.0008	0.8999
49	0.8940	0.0007	0.8954
47	0.8882	0.0007	0.8896
45	0.8824	0.0007	0.8839

Table A.6-28 NCT TNF-XI Package Array with 259 kg UO_2 Powder, 4.75 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.9107**	**0.0008**	**0.9123**
60	0.9093	0.0007	0.9106
59	0.9094	0.0008	0.9110
58	0.9062	0.0008	0.9077
57	0.9047	0.0008	0.9062
55	0.9026	0.0007	0.9039
53	0.8989	0.0007	0.9003
51	0.8951	0.0007	0.8965
49	0.8909	0.0007	0.8922
47	0.8843	0.0008	0.8860
45	0.8779	0.0007	0.8793

Table A.6-29 NCT TNF-XI Package Array with 271 kg UO_2 Powder, 4.65 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.9069**	**0.0007**	**0.9083**
60	0.9066	0.0007	0.9080
59	0.9045	0.0007	0.9058
58	0.9026	0.0007	0.9039
57	0.9016	0.0007	0.9030
55	0.9004	0.0008	0.9020
53	0.8962	0.0007	0.8975
51	0.8913	0.0007	0.8927
49	0.8846	0.0007	0.8860
47	0.8797	0.0007	0.8811
45	0.8721	0.0007	0.8735

Table A.6-30 NCT TNF-XI Package Array with 286 kg UO_2 Powder, 4.55 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.9055**	**0.0008**	**0.9071**
60	0.9039	0.0007	0.9054
59	0.9033	0.0006	0.9045
58	0.9015	0.0007	0.9029
57	0.8998	0.0008	0.9013
55	0.8953	0.0007	0.8967
53	0.8928	0.0008	0.8944
51	0.8866	0.0007	0.8879
49	0.8830	0.0007	0.8845
47	0.8735	0.0008	0.8750
45	0.8675	0.0007	0.8690

Table A.6-31 NCT TNF-XI Package Array with 300 kg UO_2 Powder, 4.45 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
61.2	**0.9011**	**0.0009**	**0.9029**
60	0.9014	0.0007	0.9027
59	0.8989	0.0008	0.9004
58	0.8977	0.0008	0.8993
57	0.8952	0.0007	0.8965
55	0.8905	0.0008	0.8921
53	0.8864	0.0007	0.8879
51	0.8819	0.0007	0.8834
49	0.8752	0.0008	0.8768
47	0.8687	0.0008	0.8702
45	0.8617	0.0008	0.8632

Table A.6-32 NCT TNF-XI Package Array with 196 kg UO_2 Scrap, 5.00 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.91575	0.00075	0.91725
0.2	0.91728	0.00066	0.91860
0.3	0.91909	0.00076	0.92061
0.4	0.92060	0.00078	0.92216
0.5	**0.92412**	**0.00064**	**0.92540**
0.6	0.92374	0.00066	0.92506
0.7	0.92364	0.00073	0.92510
0.8	0.92300	0.00075	0.92450
0.9	0.92103	0.00075	0.92253
1.0	0.91889	0.00069	0.92027
1.1	0.91818	0.00069	0.91956
1.2	0.91624	0.00063	0.91750

1) $V_m/V_f = 7.5191$

Table A.6-33 NCT TNF-XI Package Array with 204 kg UO_2 Scrap, 4.95 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.91784	0.00064	0.91912
0.2	0.91899	0.00075	0.92049
0.3	0.92306	0.00074	0.92454
0.4	0.92325	0.00069	0.92463
0.5	0.92364	0.00074	0.92512
0.6	**0.92530**	**0.00068**	**0.92666**
0.7	0.92434	0.00070	0.92574
0.8	0.92416	0.00071	0.92558
0.9	0.92499	0.00078	0.92655
1.0	0.92187	0.00067	0.92321
1.1	0.92241	0.00071	0.92383
1.2	0.91991	0.00068	0.92127

1) $V_m/V_f = 7.1850$

Table A.6-34 NCT TNF-XI Package Array with 208 kg UO_2 Scrap, 4.85 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.91442	0.00070	0.91582
0.2	0.91842	0.00063	0.91968
0.3	0.91934	0.00079	0.92092
0.4	0.92226	0.00069	0.92364
0.5	0.92186	0.00064	0.92314
0.6	0.92347	0.00065	0.92477
0.7	0.92357	0.00065	0.92487
0.8	**0.92366**	**0.00076**	**0.92518**
0.9	0.92317	0.00071	0.92459
1.0	0.92048	0.00068	0.92184
1.1	0.92007	0.00074	0.92155
1.2	0.91831	0.00075	0.91981

1) $V_m/V_f = 7.0276$

Table A.6-35 NCT TNF-XI Package Array with 216 kg UO_2 Scrap, 4.75 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.91290	0.00065	0.91420
0.2	0.91577	0.00069	0.91715
0.3	0.92000	0.00067	0.92134
0.4	0.92008	0.00065	0.92138
0.5	0.92117	0.00072	0.92261
0.6	**0.92356**	**0.00077**	**0.92510**
0.7	0.92257	0.00061	0.92379
0.8	0.92195	0.00073	0.92341
0.9	0.92133	0.00065	0.92263
1.0	0.92068	0.00067	0.92202
1.1	0.91874	0.00075	0.92024
1.2	0.91724	0.00068	0.91860

1) $V_m/V_f = 6.7303$

Table A.6-36 NCT TNF-XI Package Array with 224 kg UO_2 Scrap, 4.65 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.91024	0.00072	0.91168
0.2	0.91439	0.00077	0.91593
0.3	0.91629	0.00072	0.91773
0.4	0.91846	0.00060	0.91966
0.5	0.91995	0.00065	0.92125
0.6	0.92152	0.00075	0.92302
0.7	**0.92248**	**0.00066**	**0.92380**
0.8	0.91980	0.00064	0.92108
0.9	0.92201	0.00071	0.92343
1.0	0.92035	0.00068	0.92171
1.1	0.91914	0.00067	0.92048
1.2	0.91622	0.00059	0.91740

1) $V_m/V_f = 6.4542$

Table A.6-37 NCT TNF-XI Package Array with 236 kg UO_2 Scrap, 4.55 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.91054	0.00049	0.91152
0.2	0.91401	0.00052	0.91505
0.3	0.91596	0.00047	0.91690
0.4	0.91912	0.00047	0.92006
0.5	0.91926	0.00052	0.92030
0.6	0.92173	0.00046	0.92265
0.7	**0.92268**	**0.00055**	**0.92378**
0.8	0.92202	0.00046	0.92294
0.9	0.92161	0.00045	0.92251
1.0	0.92184	0.00046	0.92276
1.1	0.92047	0.00046	0.92139
1.2	0.91889	0.00047	0.91983

1) $V_m/V_f = 6.0752$

Table A.6-38 NCT TNF-XI Package Array with 248 kg UO_2 Scrap, 4.45 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.90886	0.00066	0.91018
0.2	0.91217	0.00069	0.91355
0.3	0.91428	0.00068	0.91564
0.4	0.91895	0.00082	0.92059
0.5	0.91824	0.00069	0.91962
0.6	0.91986	0.00071	0.92128
0.7	0.92214	0.00069	0.92352
0.8	**0.92206**	**0.00074**	**0.92354**
0.9	0.92160	0.00074	0.92308
1.0	0.92040	0.00068	0.92176
1.1	0.92061	0.00069	0.92199
1.2	0.92018	0.00067	0.92152

1) $V_m/V_f = 5.7328$

Table A.6-39 NCT TNF-XI Package Array with 256 kg UO_2 Scrap, 4.35 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.90585	0.00050	0.90685
0.2	0.90943	0.00044	0.91031
0.3	0.91184	0.00049	0.91282
0.4	0.91391	0.00051	0.91493
0.5	0.91692	0.00047	0.91786
0.6	0.91779	0.00055	0.91889
0.7	0.91942	0.00050	0.92042
0.8	0.91965	0.00067	0.92099
0.9	0.91929	0.00069	0.92067
1.0	**0.92015**	**0.00061**	**0.92137**
1.1	0.91887	0.00068	0.92023
1.2	0.91686	0.00068	0.91822
1.3	0.91638	0.00069	0.91776
1.4	0.91436	0.00064	0.91564
1.5	0.91505	0.00073	0.91651
1.6	0.91172	0.00069	0.91310
1.7	0.91145	0.00068	0.91281
1.8	0.90995	0.00065	0.91125
1.9	0.90620	0.00067	0.90754
2.0	0.90485	0.00067	0.90619

1) $V_m/V_f = 5.5224$

Table A.6-40 NCT TNF-XI Package Array with 272 kg UO_2 Scrap, 4.25 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.90348	0.00058	0.90464
0.2	0.90764	0.00053	0.90870
0.3	0.91050	0.00047	0.91144
0.4	0.91255	0.00047	0.91349
0.5	0.91599	0.00049	0.91697
0.6	0.91633	0.00051	0.91735
0.7	0.91827	0.00057	0.91941
0.8	0.91883	0.00051	0.91985
0.9	**0.91911**	**0.00048**	**0.92007**
1.0	0.91831	0.00056	0.91943
1.1	0.91908	0.00049	0.92006
1.2	0.91837	0.00051	0.91939
1.3	0.91720	0.00067	0.91854
1.4	0.91689	0.00065	0.91819
1.5	0.91458	0.00075	0.91608
1.6	0.91369	0.00068	0.91505
1.7	0.91263	0.00075	0.91413
1.8	0.90945	0.00069	0.91083
1.9	0.90900	0.00080	0.91060
2.0	0.90656	0.00068	0.90792

1) $V_m/V_f = 5.1387$

Table A.6-41 NCT TNF-XI Package Array with 284 kg UO_2 Scrap, 4.15 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.90108	0.00053	0.90214
0.2	0.90402	0.00048	0.90498
0.3	0.90780	0.00047	0.90874
0.4	0.91041	0.00055	0.91151
0.5	0.91164	0.00060	0.91284
0.6	0.91427	0.00050	0.91527
0.7	0.91630	0.00042	0.91714
0.8	0.91604	0.00051	0.91706
0.9	0.91623	0.00056	0.91735
1.0	**0.91732**	**0.00052**	**0.91836**
1.1	0.91719	0.00046	0.91811
1.2	0.91654	0.00052	0.91758
1.3	0.91565	0.00075	0.91715
1.4	0.91540	0.00066	0.91672
1.5	0.91128	0.00068	0.91264
1.6	0.91376	0.00067	0.91510
1.7	0.91080	0.00066	0.91212
1.8	0.91120	0.00074	0.91268
1.9	0.90910	0.00064	0.91038
2.0	0.90565	0.00067	0.90699

1) $V_m/V_f = 4.8794$

Table A.6-42 NCT TNF-XI Package Array with 300 kg UO_2 Scrap, 4.05 wt % U-235[1]

Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
0.1	0.89740	0.00058	0.89856
0.2	0.90135	0.00056	0.90247
0.3	0.90450	0.00047	0.90544
0.4	0.90688	0.00048	0.90784
0.5	0.90925	0.00047	0.91019
0.6	0.91221	0.00049	0.91319
0.7	0.91234	0.00054	0.91342
0.8	0.91517	0.00048	0.91613
0.9	0.91441	0.00051	0.91543
1.0	**0.91650**	**0.00046**	**0.91742**
1.1	0.91629	0.00045	0.91719
1.2	0.91533	0.00046	0.91625
1.3	0.91493	0.00069	0.91631
1.4	0.91371	0.00076	0.91523
1.5	0.91558	0.00072	0.91702
1.6	0.91259	0.00076	0.91411
1.7	0.91113	0.00075	0.91263
1.8	0.90992	0.00074	0.91140
1.9	0.90675	0.00067	0.90809
2.0	0.90774	0.00063	0.90900

1) $V_m/V_f = 4.5658$

Table A.6-43 Square Pitch Lattice for HAC Package Array[1]

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	5.4744	0.6	0.93050	0.00070	0.93190
41.2	6.3637	0.1	0.92356	0.00080	0.92516
		0.2	0.92521	0.00058	0.92637
		0.3	0.92980	0.00072	0.93124
		0.4	0.93232	0.00067	0.93366
		0.5	0.93318	0.00069	0.93456
		0.6	**0.93353**	**0.00074**	**0.93501**
		0.7	0.93250	0.00069	0.93388
		0.8	0.93109	0.00067	0.93243
		0.9	0.92999	0.00065	0.93129
		1.0	0.92889	0.00074	0.93037
		1.1	0.92626	0.00075	0.92776
		1.2	0.92399	0.00085	0.92569
46.2	7.2530	0.6	0.93165	0.00061	0.93287

1) 236 kg UO_2 Scrap with 4.55 wt % U-235

Table A.6-44 Triangular Pitch Lattice for HAC Package Array[1]

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	5.4744	0.7	0.92962	0.00073	0.93108
41.2	6.3637	0.1	0.92035	0.00073	0.92181
		0.2	0.92498	0.00070	0.92638
		0.3	0.92875	0.00071	0.93017
		0.4	0.93057	0.00069	0.93195
		0.5	0.93255	0.00071	0.93397
		0.6	0.93143	0.00064	0.93271
		0.7	**0.93391**	**0.00074**	**0.93539**
		0.8	0.93223	0.00084	0.93391
		0.9	0.93006	0.00070	0.93146
		1.0	0.93080	0.00073	0.93226
		1.1	0.92804	0.00066	0.92936
		1.2	0.92664	0.00066	0.92796
46.2	7.2530	0.7	0.93135	0.00067	0.93269

1) 236 kg UO_2 Scrap with 4.55 wt % U-235

Table A.6-45 Spherical Lattice for HAC Package Array[1]

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	$\mathbf{k_{keno}}$	σ_{keno}	$\mathbf{k_{eff}}$
36.2	5.4744	1.1	0.93343	0.00083	0.93509
41.2	6.3637	0.1	0.92535	0.00072	0.92679
		0.2	0.92895	0.00081	0.93057
		0.3	0.93073	0.00069	0.93211
		0.4	0.93132	0.00073	0.93278
		0.5	0.93380	0.00068	0.93516
		0.6	0.93466	0.00070	0.93606
		0.7	**0.93477**	**0.00070**	**0.93617**
		0.8	0.93427	0.00064	0.93555
		0.9	0.93380	0.00069	0.93518
		1.0	0.93292	0.00083	0.93458
		1.1	0.93188	0.00062	0.93312
		1.2	0.93091	0.00073	0.93237
46.2	7.2530	0.5	0.93298	0.00073	0.93444

1) 236 kg UO_2 Scrap with 4.55 wt % U-235

Table A.6-46 HAC TNF-XI Package Array with 232 kg UO_2 Powder, 5.00 wt % U-235

Fill Height (cm)	$\mathbf{k_{keno}}$	σ_{keno}	$\mathbf{k_{eff}}$
50	0.9284	0.0007	0.9298
49	0.9309	0.0008	0.9324
48	0.9313	0.0007	0.9327
47	0.9320	0.0008	0.9335
46	0.9314	0.0008	0.9330
45	0.9302	0.0007	0.9316
44	**0.9339**	**0.0007**	**0.9352**
43	0.9325	0.0007	0.9338
42	0.9309	0.0008	0.9324
41	0.9300	0.0007	0.9313
40	0.9293	0.0007	0.9307

Table A.6-47 HAC TNF-XI Package Array with 238 kg UO_2 Powder, 4.95 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
50	0.9302	0.0008	0.9317
49	0.9327	0.0007	0.9341
48	0.9312	0.0007	0.9325
47	0.9317	0.0007	0.9331
46	**0.9328**	**0.0006**	**0.9341**
45	0.9325	0.0007	0.9339
44	0.9312	0.0007	0.9326
43	0.9312	0.0008	0.9328
42	0.9306	0.0007	0.9320
41	0.9310	0.0008	0.9325
40	0.9299	0.0007	0.9313

Table A.6-48 HAC TNF-XI Package Array with 248 kg UO_2 Powder, 4.85 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
50	0.9310	0.0008	0.9325
49	0.9306	0.0007	0.9321
48	0.9317	0.0007	0.9330
47	**0.9332**	**0.0007**	**0.9345**
46	0.9316	0.0007	0.9331
45	0.9330	0.0007	0.9344
44	0.9320	0.0007	0.9333
43	0.9310	0.0008	0.9325
42	0.9303	0.0007	0.9317
41	0.9303	0.0007	0.9317
40	0.9275	0.0007	0.9289

Table A.6-49 HAC TNF-XI Package Array with 259 kg UO_2 Powder, 4.75 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
50	0.9312	0.0008	0.9327
49	0.9305	0.0008	0.9322
48	**0.9327**	**0.0007**	**0.9341**
47	0.9311	0.0007	0.9326
46	0.9317	0.0009	0.9336
45	0.9322	0.0007	0.9337
44	0.9309	0.0007	0.9323
43	0.9289	0.0007	0.9303
42	0.9288	0.0007	0.9303
41	0.9278	0.0008	0.9294
40	0.9254	0.0008	0.9269

Table A.6-50 HAC TNF-XI Package Array with 271 kg UO_2 Powder, 4.65 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
50	0.9308	0.0006	0.9320
49	0.9306	0.0007	0.9320
48	0.9323	0.0008	0.9338
47	0.9314	0.0008	0.9329
46	**0.9330**	**0.0007**	**0.9344**
45	0.9306	0.0007	0.9320
44	0.9292	0.0007	0.9306
43	0.9309	0.0007	0.9323
42	0.9285	0.0008	0.9301
41	0.9262	0.0008	0.9277
40	0.9250	0.0008	0.9267

Table A.6-51 HAC TNF-XI Package Array with 286 kg UO_2 Powder, 4.55 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
50	0.9325	0.0007	0.9339
49	0.9322	0.0007	0.9336
48	0.9323	0.0007	0.9336
47	**0.9327**	**0.0007**	**0.9341**
46	0.9314	0.0007	0.9328
45	0.9309	0.0008	0.9325
44	0.9303	0.0007	0.9318
43	0.9269	0.0008	0.9285
42	0.9264	0.0007	0.9278
41	0.9253	0.0008	0.9268
40	0.9238	0.0007	0.9252

Table A.6-52 HAC TNF-XI Package Array with 300 kg UO_2 Powder, 4.45 wt % U-235

Fill Height (cm)	k_{keno}	σ_{keno}	k_{eff}
53	0.9319	0.0007	0.9333
52	0.9309	0.0008	0.9325
51	**0.9320**	**0.0008**	**0.9335**
50	0.9316	0.0007	0.9330
49	0.9314	0.0007	0.9328
48	0.9306	0.0006	0.9319
47	0.9311	0.0006	0.9323
46	0.9305	0.0007	0.9319
45	0.9289	0.0007	0.9303
44	0.9279	0.0007	0.9293
43	0.9252	0.0007	0.9267

Table A.6-53 HAC TNF-XI Package Array with 196 kg UO_2 Scrap, 5.00 wt % U-235

Fill Height (cm)	V_m/V_f	Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
36.2	6.7957	0.6	0.93349	0.00077	0.93503
41.2	7.8665	0.1	0.92641	0.00072	0.92785
		0.2	0.92931	0.00063	0.93057
		0.3	0.93215	0.00077	0.93369
		0.4	0.93283	0.00070	0.93423
		0.5	0.93246	0.00075	0.93396
		0.6	**0.93357**	**0.00073**	**0.93503**
		0.7	0.93264	0.00067	0.93398
		0.8	0.92954	0.00073	0.93100
		0.9	0.92864	0.00073	0.93010
		1.0	0.92742	0.00071	0.92884
		1.1	0.92637	0.00063	0.92763
		1.2	0.92413	0.00066	0.92545
46.2	8.9373	0.5	0.92889	0.00070	0.93029

Table A.6-54 HAC TNF-XI Package Array with 204 kg UO_2 Scrap, 4.95 wt % U-235

Fill Height (cm)	V_m/V_f	Pitch (cm)	k_{keno}	σ_{keno}	k_{eff}
36.2	6.4900	0.7	0.93590	0.00065	0.93720
41.2	7.5188	0.1	0.92990	0.00064	0.93118
		0.2	0.93163	0.00069	0.93301
		0.3	0.93469	0.00068	0.93605
		0.4	0.93506	0.00076	0.93658
		0.5	0.93560	0.00083	0.93726
		0.6	**0.93626**	**0.00078**	**0.93782**
		0.7	0.93395	0.00072	0.93539
		0.8	0.93425	0.00090	0.93605
		0.9	0.93189	0.00076	0.93341
		1.0	0.93264	0.00068	0.93400
		1.1	0.92991	0.00073	0.93137
		1.2	0.92895	0.00079	0.93053
46.2	8.5476	0.3	0.93232	0.00082	0.93396

Table A.6-55 HAC TNF-XI Package Array with 208 kg UO_2 Scrap, 4.85 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	6.3459	0.7	0.93355	0.00076	0.93507
41.2	7.3550	0.1	0.92416	0.00071	0.92558
		0.2	0.93005	0.00065	0.93135
		0.3	0.93163	0.0007	0.93303
		0.4	0.93342	0.00077	0.93496
		0.5	0.93402	0.00076	0.93554
		0.6	**0.93438**	**0.00078**	**0.93594**
		0.7	0.93344	0.00065	0.93474
		0.8	0.93187	0.00071	0.93329
		0.9	0.9312	0.0007	0.93260
		1.0	0.92967	0.00075	0.93117
		1.1	0.9285	0.00078	0.93006
		1.2	0.92743	0.00068	0.92879
46.2	8.3640	0.4	0.92986	0.00076	0.93138

Table A.6-56 HAC TNF-XI Package Array with 216 kg UO_2 Scrap, 4.75 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	6.0739	0.8	0.93186	0.00073	0.93332
41.2	7.0455	0.1	0.92766	0.00073	0.92912
		0.2	0.92990	0.00075	0.93140
		0.3	0.93014	0.00065	0.93144
		0.4	0.93316	0.00061	0.93438
		0.5	0.93446	0.00077	0.93600
		0.6	0.93356	0.00076	0.93508
		0.7	**0.93518**	**0.00068**	**0.93654**
		0.8	0.93310	0.00069	0.93448
		0.9	0.93199	0.00069	0.93337
		1.0	0.93028	0.00067	0.93162
		1.1	0.92981	0.00074	0.93129
		1.2	0.92752	0.00067	0.92886
46.2	8.0172	0.5	0.93051	0.00071	0.93193

Table A.6-57 HAC TNF-XI Package Array with 224 kg UO_2 Scrap, 4.65 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	5.8212	0.9	0.93193	0.00076	0.93345
41.2	6.7582	0.1	0.92480	0.00072	0.92624
		0.2	0.92702	0.00073	0.92848
		0.3	0.93074	0.00069	0.93212
		0.4	0.93169	0.00072	0.93313
		0.5	0.93293	0.00075	0.93443
		0.6	0.93219	0.00068	0.93355
		0.7	**0.93306**	**0.00091**	**0.93488**
		0.8	0.93256	0.00068	0.93392
		0.9	0.93323	0.00077	0.93477
		1.0	0.93160	0.00070	0.93300
		1.1	0.92891	0.00065	0.93021
		1.2	0.92914	0.00067	0.93048
46.2	7.6951	0.5	0.93174	0.00068	0.93310

Table A.6-58 HAC TNF-XI Package Array with 236 kg UO_2 Scrap, 4.55 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	5.4744	1.1	0.93343	0.00083	0.93509
41.2	6.3637	0.1	0.92535	0.00072	0.92679
		0.2	0.92895	0.00081	0.93057
		0.3	0.93073	0.00069	0.93211
		0.4	0.93132	0.00073	0.93278
		0.5	0.93380	0.00068	0.93516
		0.6	0.93466	0.00070	0.93606
		0.7	**0.93477**	**0.00070**	**0.93617**
		0.8	0.93427	0.00064	0.93555
		0.9	0.93380	0.00069	0.93518
		1.0	0.93292	0.00083	0.93458
		1.1	0.93188	0.00062	0.93312
		1.2	0.93091	0.00073	0.93237
46.2	7.2530	0.5	0.93298	0.00073	0.93444

Table A.6-59 HAC TNF-XI Package Array with 248 kg UO_2 Scrap, 4.45 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	5.1611	0.7	0.93126	0.00076	0.93278
41.2	6.0074	0.1	0.92430	0.00074	0.92578
		0.2	0.92911	0.00061	0.93033
		0.3	0.93214	0.00064	0.93342
		0.4	0.93234	0.00063	0.93360
		0.5	0.93419	0.00069	0.93557
		0.6	0.93558	0.00071	0.93700
		0.7	0.93552	0.00066	0.93684
		0.8	**0.93640**	**0.00074**	**0.93788**
		0.9	0.93484	0.00079	0.93642
		1.0	0.93245	0.00074	0.93393
		1.1	0.93357	0.00066	0.93489
		1.2	0.93326	0.00064	0.93454
46.2	6.8537	0.6	0.93483	0.00068	0.93619

Table A.6-60 HAC TNF-XI Package Array with 256 kg UO_2 Scrap, 4.35 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
36.2	4.9686	0.6	0.92804	0.00079	0.92962
41.2	5.7884	0.1	0.92142	0.00072	0.92286
		0.2	0.92565	0.00076	0.92717
		0.3	0.92887	0.00068	0.93023
		0.4	0.92979	0.00071	0.93121
		0.5	0.93271	0.00075	0.93421
		0.6	0.93410	0.00070	0.93550
		0.7	0.93436	0.00072	0.93580
		0.8	0.93420	0.00071	0.93562
		0.9	0.93456	0.00071	0.93598
		1.0	**0.93476**	**0.00071**	**0.93618**
		1.1	0.93306	0.00069	0.93444
		1.2	0.93116	0.00066	0.93248
46.2	6.6082	0.6	0.93381	0.00085	0.93551

Table A.6-61 HAC TNF-XI Package Array with 272 kg UO_2 Scrap, 4.25 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
41.2	5.3891	0.8	0.93537	0.00071	0.93679
46.2	6.1607	0.1	0.92543	0.00068	0.92679
		0.2	0.92756	0.00079	0.92914
		0.3	0.93094	0.00069	0.93232
		0.4	0.93387	0.00071	0.93529
		0.5	0.93423	0.00064	0.93551
		0.6	0.93485	0.00069	0.93623
		0.7	**0.93606**	**0.00069**	**0.93744**
		0.8	0.93453	0.00064	0.93581
		0.9	0.93415	0.00075	0.93565
		1.0	0.93342	0.00073	0.93488
		1.1	0.93136	0.00075	0.93286
		1.2	0.93266	0.00070	0.93406
51.2	6.9323	0.6	0.93235	0.00071	0.93377

Table A.6-62 HAC TNF-XI Package Array with 284 kg UO_2 Scrap, 4.15 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
41.2	5.1191	0.9	0.93381	0.00063	0.93507
46.2	5.8581	0.1	0.92375	0.00075	0.92525
		0.2	0.92652	0.00062	0.92776
		0.3	0.92930	0.00072	0.93074
		0.4	0.93306	0.00067	0.93440
		0.5	0.93426	0.00071	0.93568
		0.6	0.93414	0.00071	0.93556
		0.7	**0.93540**	**0.00075**	**0.93690**
		0.8	0.93519	0.00067	0.93653
		0.9	0.93472	0.00069	0.93610
		1.0	0.93524	0.00071	0.93666
		1.1	0.93399	0.00072	0.93543
		1.2	0.93094	0.00075	0.93244
51.2	6.5971	0.7	0.93300	0.00070	0.93440

Table A.6-63 HAC TNF-XI Package Array with 300 kg UO_2 Scrap, 4.05 wt % U-235

Fill Height (cm)	V_m/V_f	**Pitch (cm)**	k_{keno}	σ_{keno}	k_{eff}
41.2	4.7928	1.1	0.93398	0.00076	0.93550
46.2	5.4924	0.1	0.92273	0.00064	0.92401
		0.2	0.92639	0.00064	0.92767
		0.3	0.92813	0.00074	0.92961
		0.4	0.93138	0.00062	0.93262
		0.5	0.93300	0.00066	0.93432
		0.6	0.93245	0.00075	0.93395
		0.7	0.93441	0.00070	0.93581
		0.8	0.93503	0.00069	0.93641
		0.9	**0.93587**	**0.00077**	**0.93741**
		1.0	0.93486	0.00073	0.93632
		1.1	0.93523	0.00064	0.93651
		1.2	0.93332	0.00068	0.93468
51.2	6.1920	0.7	0.93489	0.00076	0.93641

Table A.6-64 Polyethylene Density Sensitivity Study under HAC with 232 kg UO_2 Powder, 5.00 wt % U-235

Fill Height (cm)	**k_{keno}**	**σ_{keno}**	**k_{eff}**
Polyethylene Density 0.90 g/cc			
50	0.9303	0.0008	0.9319
49	0.9288	0.0007	0.9302
48	0.9305	0.0008	0.9321
47	0.9313	0.0009	0.9330
46	0.9315	0.0009	0.9332
45	0.9307	0.0008	0.9323
44	**0.9337**	**0.0007**	**0.9350**
43	0.9310	0.0007	0.9324
42	0.9320	0.0008	0.9335
41	0.9309	0.0007	0.9323
40	0.9301	0.0007	0.9314
Polyethylene Density 0.94 g/cc			
50	0.9276	0.0007	0.9290
49	0.9300	0.0007	0.9313
48	0.9316	0.0007	0.9330
47	0.9313	0.0008	0.9328
46	0.9312	0.0006	0.9325
45	0.9312	0.0007	0.9326
44	0.9317	0.0008	0.9333
43	**0.9317**	**0.0008**	**0.9334**
42	0.9296	0.0007	0.9310
41	0.9295	0.0007	0.9309
40	0.9291	0.0007	0.9305
Polyethylene Density 0.96 g/cc			
50	0.9292	0.0007	0.9306
49	0.9286	0.0007	0.9300
48	0.9312	0.0007	0.9326
47	0.9293	0.0008	0.9309
46	0.9308	0.0007	0.9322
45	0.9309	0.0008	0.9325
44	**0.9326**	**0.0008**	**0.9342**
43	0.9324	0.0007	0.9339
42	0.9314	0.0009	0.9332
41	0.9294	0.0007	0.9308
40	0.9291	0.0007	0.9306

Table A.6-65 Description of Criticality Experiments for UO_2 Powder

Case ID	**Material Composition**	**Geometry**
CAA35	UO_2F_2 solution	H_2O reflected, SS cylinder
CAA36	UO_2F_2 solution	H_2O reflected, aluminum box
CAA37	UO_2F_2 solution	H_2O reflected, SS cylinder
CAA38	UO_2F_2 solution	H_2O reflected, aluminum sphere
CAA39	UO_2F_2 solution	H_2O reflected, SS cylinder
CAS11	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS13	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS15	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS16	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS17	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS19	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS21	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS22	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS23	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS24	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS25	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS29	Homogeneous U(3)F_4 and paraffin	Reflected rectangular parallelepiped
CAS34	U(4.98)O_2F_2 solution	Reflected rectangular parallelepiped

Table A.6-66 Benchmark Results for Powder Experiments

No.	**Experiment ID**	**U-235 Enrichment in wt%**	**H/X**	**EALF**	**k_{keno}**	**σ**
1	CAA35	4.89	524.0000	0.0515	1.0007	0.0010
2	CAA36	4.89	524.0000	0.0503	1.0043	0.0008
3	CAA37	4.89	734.0000	0.0436	1.0018	0.0008
4	CAA38	4.89	991.0000	0.0378	0.9972	0.0007
5	CAA39	4.89	994.0000	0.0392	0.9991	0.0008
6	CAS11	2.00	195.2000	0.2053	0.9988	0.0009
7	CAS13	2.00	293.6000	0.1210	1.0035	0.0009
8	CAS15	2.00	406.3000	0.0875	1.0013	0.0008
9	CAS16	2.00	495.9000	0.0742	0.9995	0.0008
10	CAS17	2.00	613.6000	0.0637	0.9987	0.0008
11	CAS19	2.00	971.7000	0.0495	0.9942	0.0007
12	CAS21	3.00	133.4000	0.2424	1.0098	0.0009
13	CAS22	3.00	133.4000	0.2429	1.0092	0.0010
14	CAS23	3.00	133.4000	0.2427	1.0099	0.0010
15	CAS24	3.00	133.4000	0.2421	1.0121	0.0008
16	CAS25	3.00	133.4000	0.2420	1.0101	0.0009
17	CAS29	3.00	276.9000	0.0958	1.0131	0.0009
18	CAS34	4.98	488.0000	0.0566	1.0008	0.0008
	Correlation	-0.07	-0.78	0.71		

Table A.6-67 Description of Criticality Experiments for UO_2 Pellets

Case ID	**Material Composition**	**Geometry**
bw1484sl	UO_2, H_2O, aluminum	Square lattice
epru65	UO_2, H_2O, aluminum, lead	Square lattice
epru75	UO_2, H_2O, aluminum	
p2438slg	UO_2, H_2O, aluminum	Square lattice
p2827slg	UO_2, H_2O, aluminum	Square lattice
p3314slg	UO_2, H_2O, aluminum	Square lattice
p3602n11	UO_2, H_2O, aluminum, steel	Square lattice, steel reflecting walls
p3602n12		
p3602n13		
p3602n14		
p3602n21		
p3602n22		
p3602n31		
p3602n32		
p3602n33		
p3602n34		
p3602n35		
p3602n36		
p3602n41		
p3602n42		
p3602n43		
p3926sl1	UO_2, H_2O, aluminum	Square lattice
p3926sl2	UO_2, H_2O, aluminum	

Table A.6-68 Benchmark Results for Pellet Experiments

No.	**Experiment ID**	**U-235 Enrichment in wt%**	**H/X**	**EALF**	k_{keno}	σ
1	bw1484sl	2.46	216.1000	0.1418	0.9925	0.0008
2	epru65	2.35	163.6000	0.2616	0.9937	0.0009
3	epru75	2.35	329.4000	0.1158	0.9965	0.0009
4	p2438slg	2.35	398.7000	0.0976	0.9968	0.0008
5	p2827slg	2.35	398.7000	0.0976	0.9940	0.0008
6	p3314slg	4.31	105.4000	0.2375	0.9952	0.0011
7	p3602n11	2.35	218.6000	0.1840	0.9954	0.0009
8	p3602n12	2.35	218.6000	0.1775	0.9993	0.0009
9	p3602n13	2.35	218.6000	0.1714	0.9993	0.0009
10	p3602n14	2.35	218.6000	0.1654	0.9963	0.0009
11	p3602n21	2.35	398.7000	0.0975	0.9985	0.0009
12	p3602n22	2.35	398.7000	0.1004	0.9993	0.0009
13	p3602n31	4.31	105.4000	0.3211	1.0028	0.0010
14	p3602n32	4.31	105.4000	0.3083	1.0023	0.0009
15	p3602n33	4.31	105.4000	0.2977	1.0038	0.0010
16	p3602n34	4.31	105.4000	0.2918	1.0013	0.0010
17	p3602n35	4.31	105.4000	0.2864	0.9988	0.0009
18	p3602n36	4.31	105.4000	0.2811	0.9975	0.0010
19	p3602n41	4.31	256.1000	0.1253	1.0067	0.0009
20	p3602n42	4.31	256.1000	0.1188	1.0023	0.0009
21	p3602n43	4.31	256.1000	0.1152	1.0007	0.0008
22	p3926sl1	2.35	218.6000	0.1638	0.9924	0.0009
23	p3926sl2	4.31	105.4000	0.2812	0.9941	0.0010
Correlation		0.57	-0.14	0.16		

Table A.6-69 USL Functions for UO_2 Powder

Parameter	**Application Range**	**USL Function**	
EALF in eV	[0.0378, 0.2429]	0.9399 + 4.7091e-02 * X	X < 0.04594
		0.9420	X >= 0.04594
U-235 Enrichment in wt%	[2.00, 4.98]	0.9388	
H/X	[133.40, 994.00]	0.9529 – 1.4560e-05 * X	X > 698.76
		0.9427	X <= 698.76

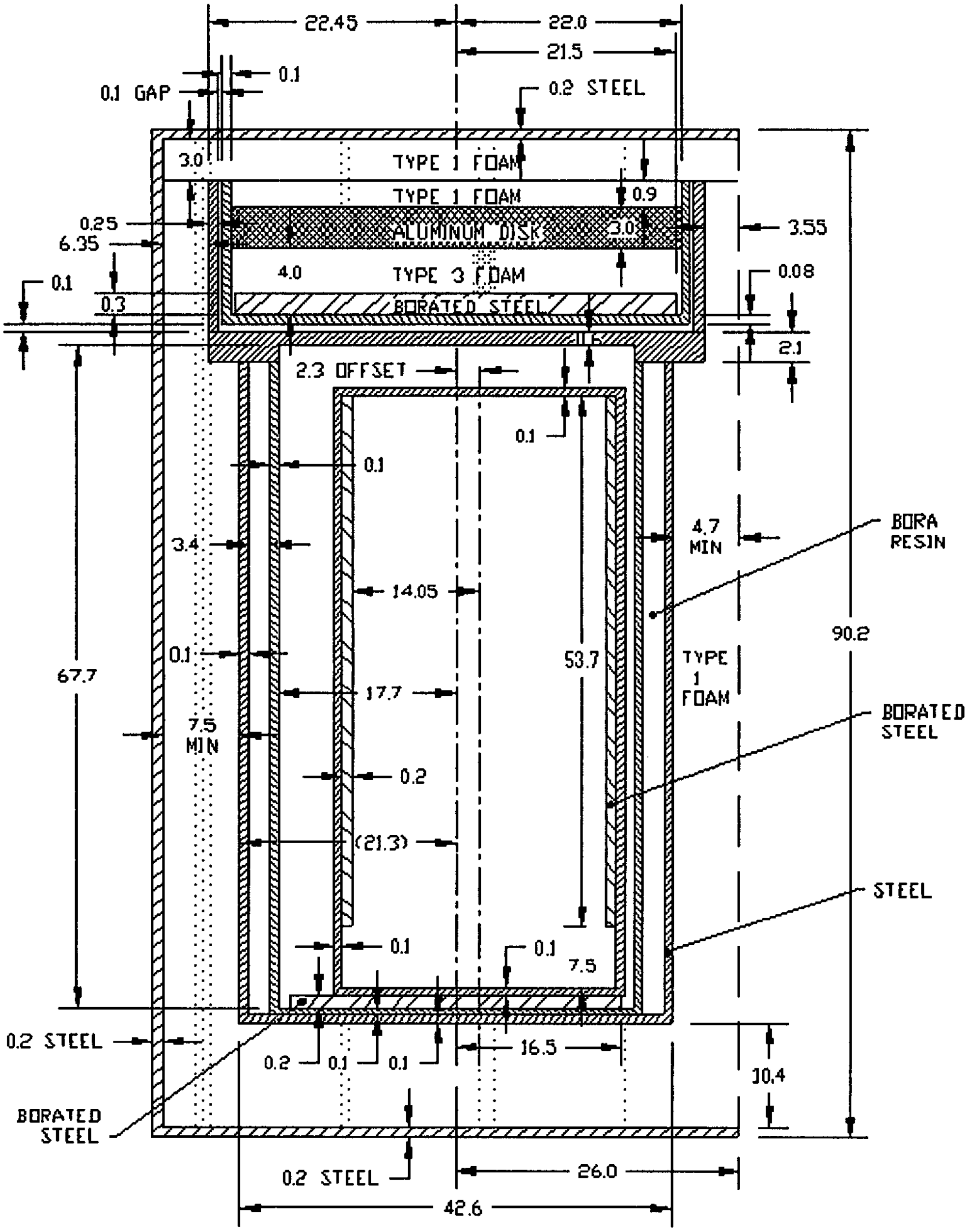
Table A.6-70 USL Functions for UO_2 Pellets

Parameter	**Application Range**	**USL Function**	
EALF in eV	[0.0975, 0.3211]	0.9394 + 7.6453e-03 * X	
U-235 Enrichment in wt%	[2.35, 4.31]	0.9350 + 2.2017e-03* X	X < 4.0920
		0.9440	X >= 4.0920
H/X	[105.40, 398.70]	0.9419 – 5.0469e-06 * X	

Table A.6-71 USL Analysis for UO_2 Pellets

Parameter	**Limiting Value**	**USL**
EALF in eV	6.61476E-2[1]	0.9399
U-235 Enrichment in wt%	4.05	0.9439
H/X	425[2]	0.9398

1) HAC with 196 kg of 5.00 wt % U-235, fill height of 41.2 cm (V_m/V_f= 7.8665), 0.1 cm pitch
2) HAC with 196 kg of 5.00 wt % U-235, fill height of 41.2 cm (V_m/V_f= 7.8665), all pitches



ALL DIMENSIONS ARE IN CENTIMETERS

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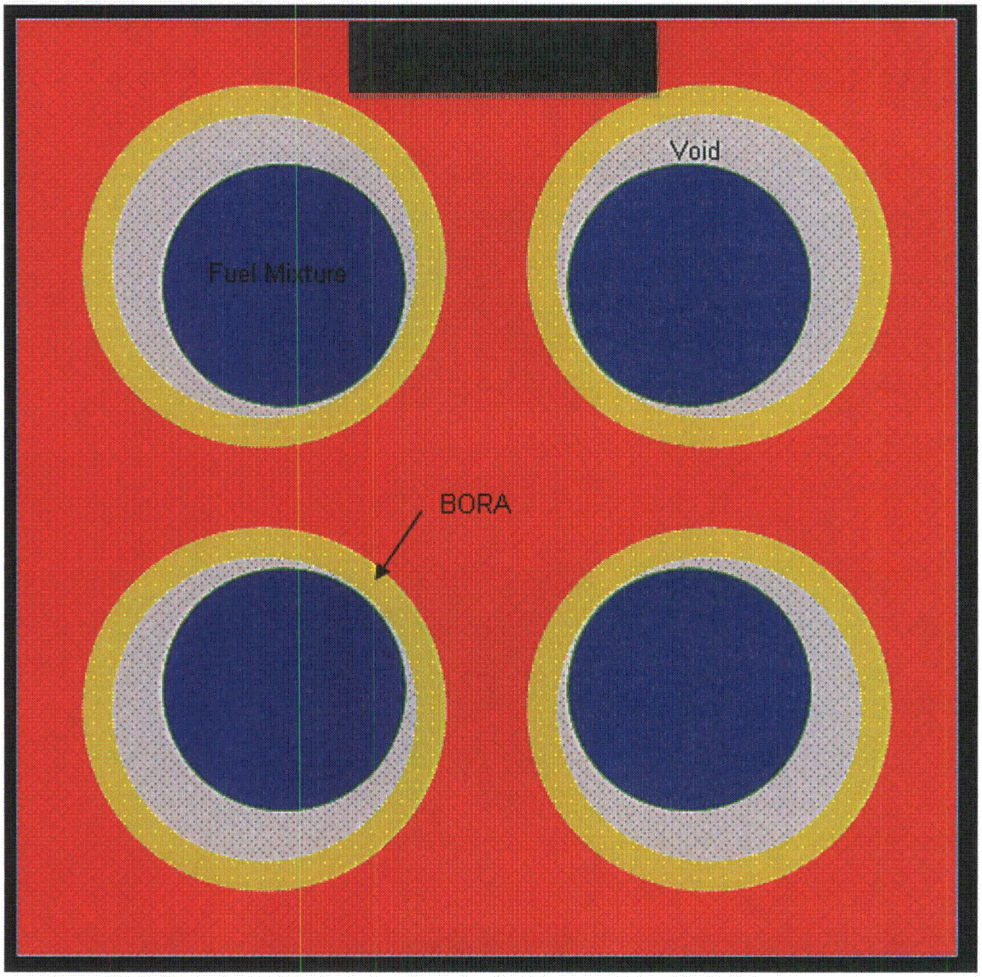
Trade Secret

Figure A.6-1 TNF-XI NCT KENO Model Dimensions



[redacted]

Trade Secret

Figure A.6-2 TNF-XI NCT KENO Model Cross-Section

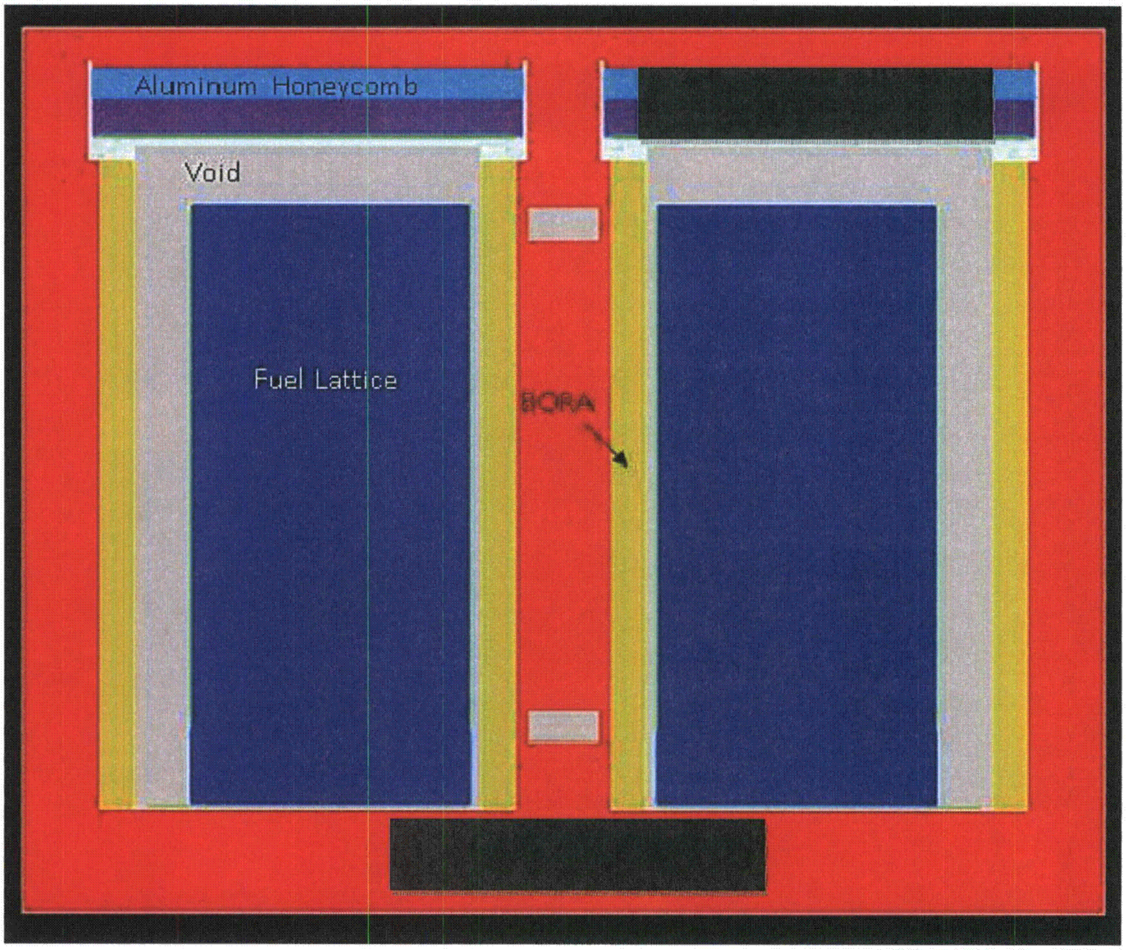


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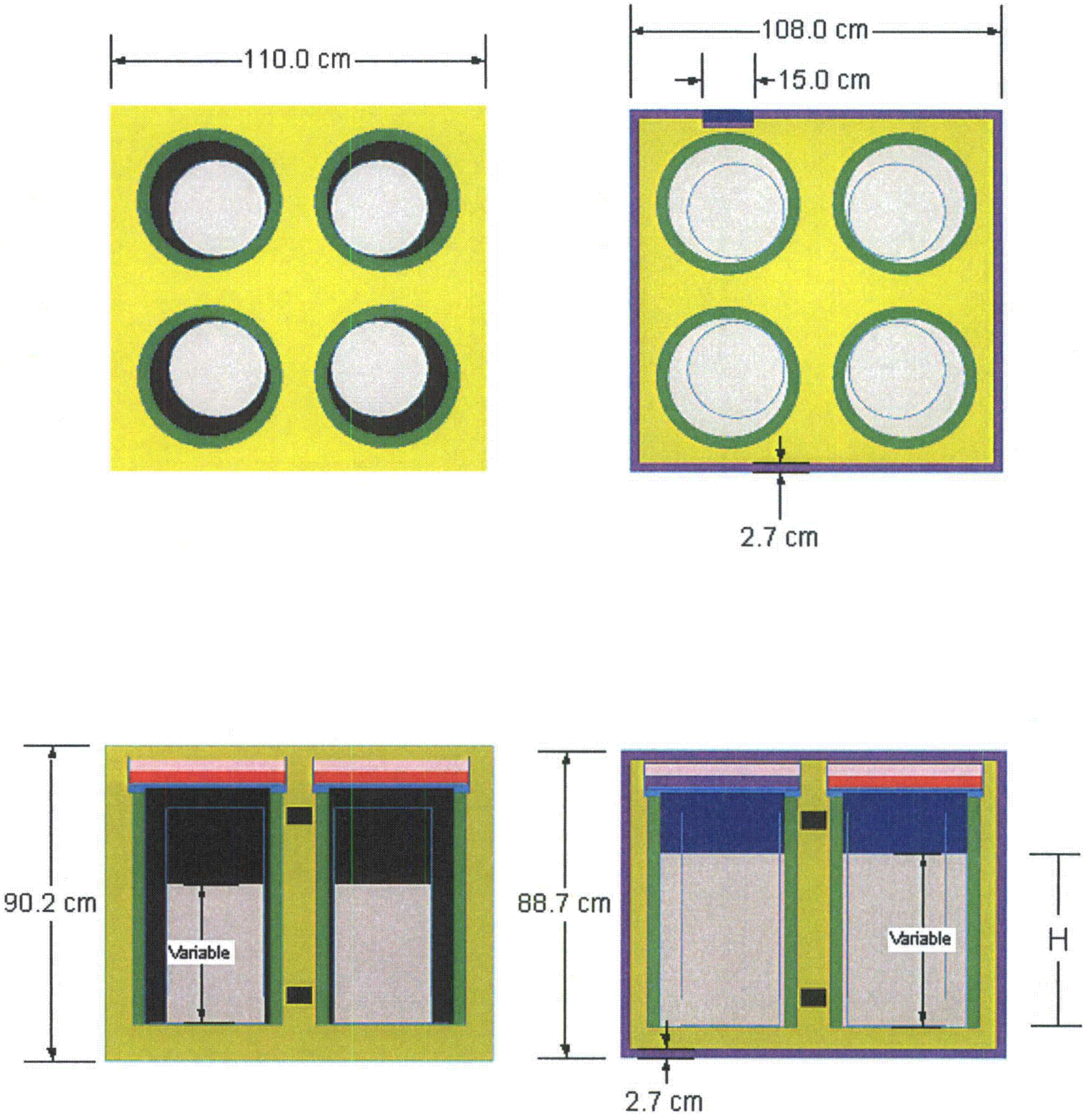
Figure A.6-3 TNF-XI NCT KENO Model Axial View



Normal Geometry

Damaged Geometry

Figure A.6-4 TNF-XI HAC KENO Model Dimensions

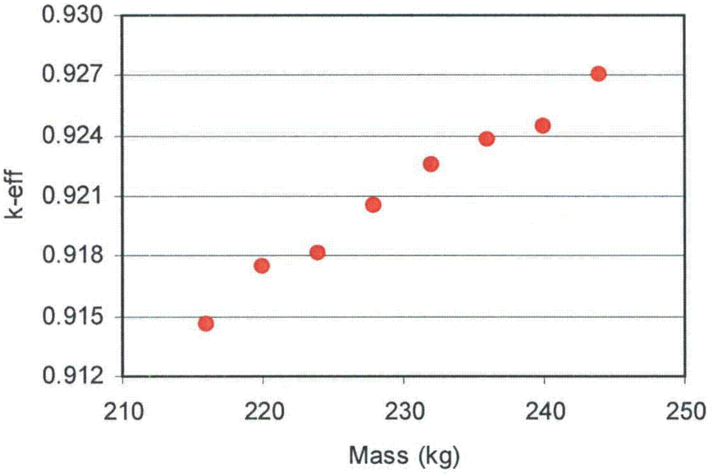


Figure A.6-5 Mass Sensitivity for NCT Array (4.55 wt% U-235, 61.2 cm Fill Height)

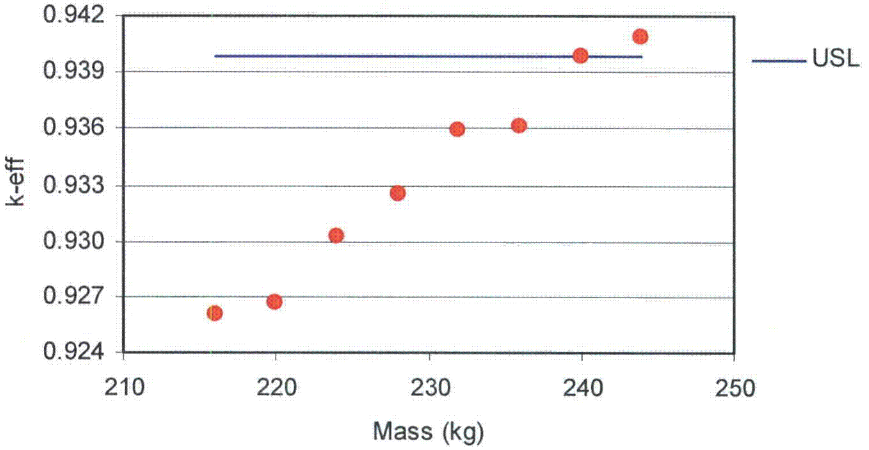


Figure A.6-6 Mass Sensitivity for HAC Array (4.55 wt% U-235, 41.2 cm Fill Height)

Enclosure 7 to TN E-31428

Listing of Computer Files Contained in Enclosure 8

Listing of Computer Files Contained in Enclosure 8

Disk ID No. (size)	**Discipline**	**Folder Name**	**File Series (topics)**	**Number of files**
Enclosure 8 CD (1 of 1) (6.52 MB)	**Criticality**	001-usl	• The input and output files of the USLSTATS runs for powder and pellet	14
		002-powder	• The input and output of the SCALE 6 238-group calculation for powder.	4
		003-pellet-scrap	• The input and output of the SCALE 6 238-group calculation for pellet/scrap.	4

Enclosure 9 to TN E-31428

CoC Marked up for Proposed Changes related to Application for Revision 5 to CoC 9301

Justifications for the CoC proposed changes:

Change	Page No.	Justification
Change Revision Number to 5	All pages	Update of the application
Change Package Identification number to USA/9301/AF-96	All pages	Application upgrades the designator to AF-96
Add subsection (i) to Paragraph 5.(b)(1)	Page 2	The change is required to distinguish between limitation for content with and without PE bags.
Change ASTM C996-96 to ASTM C996-96.	Page 2	Update the requirement to the latest applicable code
Add subsection (i) to Paragraph 5.(b)(1)	Page 3	The change is required to distinguish between limitation for content with and without PE bags.
Change "Pellet" to "Material (Pellet and Scrap) in 3rd column of the table on page 3	Page 3	This change makes the CoC consistent with Table 6-1 of the SAR.
Add Insert 1	Page 3	The change is required to add the requirements for content when using PE bags.
Add subsection (i) and (ii) to Paragraph 5.(b)(2) and add Insert 2	Page 3	The change is required to clarify requirements for the content without PE bags and to add the requirements for content when using PE bags.

The proposed changes are provided as markups in the next six pages.

NRC FORM 618
(8-2000)
10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE		PAGES
9301	~~4~~ 5	71-9301	USA/9301/AF-8~~5~~ 96	1	OF	4

2. PREAMBLE

a. This certificate is issued to certify that the package (packaging and contents) described in Item 5 below meets the applicable safety standards set forth in Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material."

b. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. THIS CERTIFICATE IS ISSUED ON THE BASIS OF A SAFETY ANALYSIS REPORT OF THE PACKAGE DESIGN OR APPLICATION

a. ISSUED TO *(Name and Address)*

Transnuclear, Inc.
7135 Minstrel Way
Columbia, MD 21045

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

Packaging Technology, Inc., application dated July 24, 2002, as supplemented.

4. CONDITIONS

This certificate is conditional upon fulfilling the requirements of 10 CFR Part 71, as applicable, and the conditions specified below.

5.

(a) Packaging

(1) Model No.: TNF-XI

(2) Description

A shipping container for unirradiated enriched forms of homogenous and heterogeneous uranium oxides. The packaging body is a parallelepiped and is approximately 44 inches x 44 inches x 37 inches. The package contents are enclosed in pails which each have a borated stainless steel ring. Three pails are stacked inside four inner wells of the packaging body. Each inner well is closed by a primary lid and an upper plug.

The packaging body is constructed of an outer stainless steel envelope which is 0.08 inches thick. The space between the outer shell and the inner wells is filled with fire-retardant, open cell phenolic foam.

The four inner wells each have an inside diameter of 14 inches and height of 27 inches. The inner wells are constructed of (1) and outer shell of stainless steel sheet 0.04 inches thick, with a diameter of 17 inches, (2) and inner shell of stainless steel sheet 0.04 inches thick with a diameter of 14 inches, and (3) a flat bottom of 0.04 inch thick stainless steel sheet with a 0.08 inch thick borated stainless steel plate glued to it. A molded annular layer of neutron-poison BORA resin is inserted between the inner and outer steel shells of the inner well.

Each upper plug consists of two thermal insulating disks of phenolic foam, with an internal stiffener disk made of aluminum alloy. The upper plug assembly is encapsulated inside a 0.03 inch thick stainless steel envelope.

NRC FORM 618 (8-2000) 10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF COMPLIANCE FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATE NUMBER 9301	b. REVISION NUMBER ~~4~~ 5	c. DOCKET NUMBER 71-9031	d. PACKAGE IDENTIFICATION NUMBER USA/9301/AF-~~85~~ 96	PAGE 2 OF PAGES 4

5.(a) (2) Description (continued)

The four primary lids closing off the inner wells are stainless steel circular plates 0.2 inches thick on the center part, and 0.4 inches thick on the periphery. Four bayonet teeth are welded to the primary lid to lock in the well flanges. A primary lid locker is located between the well flange and the primary lid to prevent the rotation of the primary lid during transport. The primary lid and the inner well are sealed by an elastomer gasket set in a rectangular groove machined on the inner face of the primary lid.

The approximate dimensions and weights of the package are as follows:

Inner well inside diameter	14 inches
Overall package dimensions	
Width	44 inches
Length	44 inches
Height	41 inches
Maximum weight of contents in any pail	25 kg
Maximum content weight	300 kg
Maximum package weight (including contents)	1050 kg

(3) Drawings

The packaging is constructed in accordance with the Packaging Technology, Inc., Drawing No. 10799-SAR, Rev. 3, Sheets 1 through 7.

(b) Contents

(1) Type and form of material

10

(i) Uranium oxide pellets, powder, and scrap meeting the requirements of Enriched Commercial Grade Uranium, as defined in ASTM C996-~~96~~. U_3O_8 or $UO_{x,\ x>2}$ are authorized provided that the equivalent UO_2 mass is less than the limits specified below:

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CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATE NUMBER 9301	b. REVISION NUMBER ~~4~~ 5	c. DOCKET NUMBER 71-9301	d. PACKAGE IDENTIFICATION NUMBER USA/9301/AF-~~85~~ 96	PAGE 3 OF PAGES 4

5.(b)(1) (i) Type and Form of Material (continued)

Max ^{235}U Enrichment (weight percent)	Homogenous UO_2 Powder Maximum Loading (kg)	Heterogeneous UO_2 ~~Pellet~~ Material (Pellet and Scrap) Maximum Loading (kg)
≤4.05	300	300
4.1	300	293
4.15	300	287
4.25	300	271
4.35	300	259
4.45	300	247
4.55	294	238
4.65	281	228
4.75	265	219
4.85	255	208
4.95	244	202
5.0	239	197

INSERT 1

(2) Maximum quantity of material per package

(i) For the contents described in 5.(b)(1)(i)

No more than 25 kg of contents per pail. No more than 300 kg of contents per package.

INSERT 2

(c) Criticality Safety Index: 0.5

6. Transport by air is not authorized.

7. In addition to the requirements of Subpart G of 10 CFR Part 71:

(a) The package shall be prepared for shipment and operated in accordance with the operating procedures in Chapter 7 of the application, as supplemented;

(b) The package must by acceptance tested and maintained in accordance with the Acceptance Tests and Maintenance Program in Chapter 8 of the application, as supplemented; and,

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CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE / PAGES
9301	~~4~~ 5	71-9031	USA/9301/AF-~~85~~ 96	4 OF 4

(c) Prior to each shipment, the stainless steel components of the packaging must be visually inspected. Packagings in which stainless steel components show pitting corrosion, cracking, or pinholes are not authorized for transport.

8. The packaging authorized by this certificate is hereby approved for use under the general license provision of 10 CFR 71.71.

9. Expiration date: August 31, 2013.

provided by Packaging Technology, Inc.

REFERENCES

Packaging Technology, Inc., application dated July 24, 2002.

Supplements dated: October 29, 2002; March 7, April 3, May 6, June 26, July 21, 2003; November 26, 2007; and August 6, 2008.

Supplements provided by Transnuclear, Inc. dated: September 7, 2011

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

Kimberly J. Hardin

Eric J. Benner, Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Date: ~~September 12, 2008.~~ TBD

INSERT 1 to mark-up of the CoC 9301, Rev. 5:

(ii) Uranium oxide pellets, powder, and scrap meeting the requirements of Enriched Commercial Grade Uranium, as defined in ASTM C996-10. U_3O_8 or $UO_{x,\ x>2}$ are authorized provided that the equivalent UO_2 mass is less than the limits specified below:

Max ^{235}U Enrichment (weight percent)	**Homogenous UO_2 Powder Maximum Loading (kg)**	**Heterogeneous UO_2 Material (Pellet and Scrap) Maximum Loading (kg)**
≤ 4.05	300	300
4.15		284
4.25		271
4.35		256
4.45		247
4.55	286	236
4.65	271	224
4.75	259	216
4.85	248	208
4.95	238	202
5.0	232	196

INSERT 2 to mark-up of the CoC 9301, Rev. 5

Presence of hydrogenated materials (with a hydrogen concentration less than hydrogen concentration in water) or water inside cavities and pails is allowed.

The presence of materials containing more hydrogen than water is not allowed in the package.

(ii) For the contents described in 5.(b)91)(ii), no more than 25 kg of contents per pail. No more than 300 kg of contents per package. In each pail, the contents can be put in a polyethylene bag (CH_2) or in a bag made of a material with a hydrogen concentration less than that of polyethylene. The maximum hydrogen content of the bags within each cavity is a mass of 56 g H, which is equivalent to a maximum mass of 390 g polyethylene, considering all sources of hydrogenous material within each cavity.

The presence of materials containing more hydrogen than polyethylene is not allowed in the package.