AREVA

February 15, 2017
E-47395

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

Subject: Application for Revision 9 to Certificate of Compliance No. 9301, Docket 71-9301, for the Model TNF-XI, Request for Additional Information, TAC Number 25158

References: [1] Letter from Huda Akhavannik (NRC) to Dr. Jayant Bondre (TN Americas LLC), Request for Additional Information for Review of the Model No. TNF-XI, January 12, 2017, Docket 71-9301, TAC Number 25158.

[2] Letter E-45372, October 13, 2016, from Jayant Bondre (TN) to NRC Document Control Desk, Application for Revision 9 to Certificate of Compliance No. 9301, Docket 71-9301, for the Model TNF-XI.

[3] Certificate of Compliance No. 9301; Docket 71-9301, TNF-XI, Revision 8, dated March 7, 2014.

This submittal provides responses to the request for additional information (RAI) forwarded by the NRC letter [1] referenced above.

This submittal contains the following enclosures:

- Enclosure 1 provides the RAIs and Responses. This enclosure is proprietary.
- Enclosure 2 provides the public version of Enclosure 1. This enclosure is non-proprietary.
- Enclosure 3 provides a description of each safety analysis report (SAR) proposed chapter and/or section proprietary marking change that resulted from a conference call and subsequent communications with the NRC regarding said markings.
- Enclosure 4 provides the changed pages only for TNF-XI SAR Revision 11B for Chapter 6, Appendix A.6, and Appendix B.6. This enclosure is proprietary.
- Enclosure 5 provides non-proprietary versions of the changed pages only for TNF-XI SAR Revision 11B for Chapter 6, Appendix A.6, and Appendix B.6. This enclosure is non-proprietary.
- Enclosure 6 provides an affidavit, in accordance with 10 CFR 2.390, specifically requesting that the proprietary information included in Enclosure 1 and Enclosure 4 of this submittal be withheld from public disclosure. That information may not be used for any purpose other than

NMSS01

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to support the review of the application for revision to the TNF-XI Certificate of Compliance (CoC). A non-proprietary version of Enclosure 1 is provided in Enclosure 2. A non-proprietary version of Enclosure 4 is provided in Enclosure 5

The changed areas in the SAR are marked as follows:

- New or changed pages show "Revision 11B" in the header.
- Changed areas are indicated using revision bars in the right-hand margin. Newly inserted or changed text is shown by italics and is gray shaded to distinguish them from the changes proposed in Revision 11A of the application.

TN Americas LLC respectfully requests that the NRC provide notification upon completion of the safety review, including the determination that no additional information is required for issuance of the CoC. This is to enable the prompt submittal of a consolidated Revision 12 to the TNF-XI SAR (both the proprietary and the non-proprietary versions), which will include all the changes that were completed during this application for revision.

TN Americas LLC respectfully requests that a review schedule be planned for Revision 9 of CoC 9301 TNF-XI Packaging to become effective on or before April 28, 2017 to support a future business need.

Should the NRC staff have any questions or require additional information to support the review of this application, please contact Mr. Glenn Mathues by telephone at 410-910-6538, or by e-mail at Glenn.Mathues@areva.com.

Sincerely,

Jayant Bondre
Chief Technical Officer

cc: Huda Akhavannik, U.S. Nuclear Regulatory Commission
- One electronic copy (computer disk) of this letter and Enclosures 1, 2, 4, and 6

M. Conroy, U.S. Department of Transportation
- This letter and Enclosure 2, via email

Enclosures:

1. RAIs and Responses (Proprietary Version)
2. RAIs and Responses (Non-Proprietary Version)
3. Listing and Description of Specific SAR Changes for Proprietary Markings
4. TNF-XI SAR, Revision 11B, Changed Pages Only, Chapter 6, Appendix A.6, and Appendix B.6 (Proprietary Version)
5. TNF-XI SAR, Revision 11B; Changed Pages Only, Chapter 6, Appendix A.6, and Appendix B.6 (Non-Proprietary Version)
6. Affidavit Pursuant to 10 CFR 2.390

AFFIDAVIT PURSUANT
TO 10 CFR 2.390

TN Americas LLC)
State of Maryland) SS.
County of Howard)

I, Jayant Bondre, depose and say that I am Chief Technology Officer of TN Americas LLC, duly authorized to execute this affidavit, and have reviewed or caused to have reviewed the information that 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 meets the provisions of paragraph (a)(4) of Section 2.390 of the Commission's regulations. The information is contained in Enclosures 1 and 4, as listed below:

- Enclosure 1 - Portions of the RAIs and Responses
- Enclosure 4 - Portions of Chapter 6, Appendix A.6, and Appendix B.6 for the TNF-XI Safety Analysis Report (SAR), Revision 11B

These documents have been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by TN Americas LLC in designating information as 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 portions of the RAIs and responses and portions TNF-XI SAR associated with the application submittal, all related to the design of the TNF-XI package, which are owned and have been held in confidence by TN Americas LLC.

2) The information is of a type customarily held in confidence by TN Americas LLC, and not customarily disclosed to the public. TN Americas LLC 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 TN Americas LLC, because the information is related to the design and analysis of the TNF-XI transportation package, the application of which provides a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with TN Americas LLC, take marketing or other actions to improve their product's position, or impair the position of TN Americas LLC's product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

Further the deponent sayeth not.

Jayant Bondre
Chief Technology Officer, TN Americas LLC

Subscribed and sworn before me this 15th day of February 2017.

Notary Public

My Commission Expires 10 / 16 / 19

RONDA JONES
NOTARY PUBLIC STATE OF MARYLAND
My Commission Expires October 16, 2019

Enclosure 2 to E-47395

RAIs and Responses
(Non-Proprietary Version)

CHAPTER 2 – Structural Evaluation

2.0 Materials

RAI 2-1

Provide the basis that pyrophoricity is prevented with Content 7.

Content 7 has scrap, and residues of incinerator ashes or earth, sand and residues from dissolution. Additionally, the aluminum impurity level is up to 5000 ppm in the uranium oxide powder. ASTM C753 limits 300 ppm of aluminum impurity. As the scrap is less than sub-mm (or scrap spherule radius of 0.10 cm) in size and may include aluminum, it is unclear whether the scrap is well inerted without moisture or oxygen to prevent potential pyrophoricity. Additionally, the applicant conservatively assumed in qualification at normal conditions that the mass loss of Bora resin is due to water evaporation. The applicant should justify that any water generated due to degradation of Bora resin or plastic bags will not react with powdered metals in the content, which may result in pyrophoric conditions.

This information is needed to determine compliance with the requirements of 10 CFR 71.43(d).

Response to RAI 2-1

Aluminum metal present in the residues before incineration is in the form of sheet metal that is around 35 μm thick. Because the incineration temperature is around 800 °C, it is considered that the total amount of aluminum present in the residues will occur in the form of oxides. The very small thickness of the aluminum material is favorable to the complete oxidation of the material. Therefore, the risk of pyrophoricity is excluded for the content number 7.

As shown in the figure below, the presence of Bora resin outside the containment system is evidence that water evaporation coming from the Bora resin cannot be directly in contact with the powdered metals.

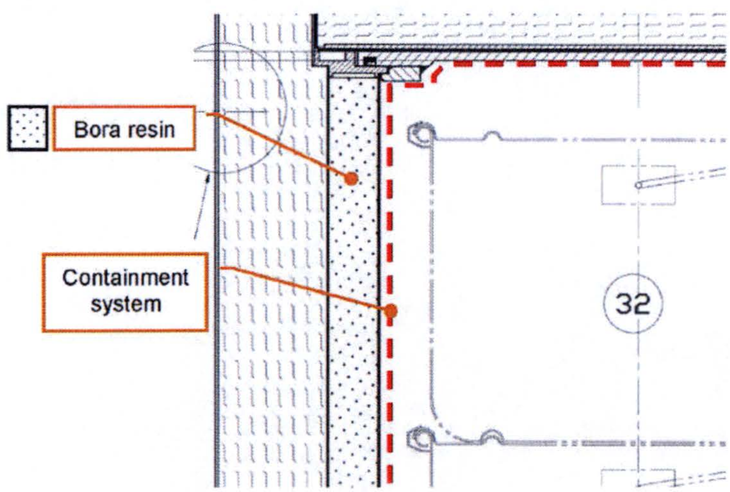

Figure 2-1
Packaging View Showing Bora Resin

In Chapter 3 of the Safety Analysis Report (SAR), it is demonstrated that the maximum temperature of the pails, and then of the plastic bags (accident conditions), is 100 °C (assessment in a penalizing way). Therefore, neither gas emissions coming from the plastic bag in accident conditions, nor subsequent pyrophoric conditions, are expected.

TNF-XI SAR Impact:

No changes as a result of this question.

RAI 2-2

Confirm that flammable gases generated from potential thermolysis or radiolysis of Content 7 (e.g., Bora resin or plastic bags) will not compromise package safety.

In previous amendments, the applicant conducted thermal analysis of materials (e.g., Bora resin or plastic bags) and demonstrated materials (water) loss was minimal. The staff reviewed the analyses and concludes that the amount of flammable gases due to material loss is not a safety concern. For the current amendment, the applicant needs to confirm materials (water) loss for Content 7.

This information is needed to determine compliance with the requirements of 10 CFR 71.43(d).

Response to RAI 2-2

Radiolysis

Considering the spectrum of the maximum radioactive content given in the SAR, it is determined that the thermal power per cavity for 75 kg of fissile material is around 2 mW, and that it is conservatively considered that, in one pail, power will be lower than 1 mW. Therefore, given the very low power, generation of flammable gases due to radiolysis phenomenon is not expected.

Thermolysis

As described in the SAR Chapter 1, content number 7 is made of uranium oxides mixed with residues consisting of either incinerator ashes, or sand and residues from dissolution.

Concerning the "incinerator ashes" residues, the temperature of incineration of around 800 °C is evidence that thermolysis of the content is not expected, even in accident conditions. The temperature that the content reaches is less than 100 °C. Therefore, no generation of gas is expected.

Concerning the content made of sand and residues from dissolution, the constitution of these components is not subjected to thermolysis for a temperature of 100 °C.

Regarding the plastic bags, as explained in the Response to RAI 2-1, it is demonstrated in SAR Chapter 3 that the maximum temperature of the pails, and then of the plastic bags (accident conditions) is 100 °C (assessment in a penalizing way). Therefore, thermolysis of the plastic bags is not expected. Moreover, it is emphasized that the auto-ignition temperature of the material used for the plastic bag is above 300 °C. Therefore, there is no risk of flammable gas production due to thermolysis of the plastic bags.

In the same manner, it is demonstrated in SAR Chapter 3 that the maximal Bora temperature remains below the criterion of 150 °C. Therefore, thermolysis of the Bora resin is not expected. As shown on Figure 2-1, the presence of Bora resin outside the containment system is evidence that gas coming from the Bora resin cannot be directly in contact with the content.

TNF-XI SAR Impact:

No changes as a result of this question.

CHAPTER 6 - CRITICALITY EVALUATION

6.0 Criticality

RAI 6-1

Clarify if [ ] is the intended content. If so, determine the combined quantity limits on fissile material and [ ] that meet the criticality safety requirements of 10 CFR 71.55 and 71.59.

In Section B.6.3.5 of the Safety Analyses Report (SAR), the applicant states, "[i]n addition, [ ] are evaluated in order to identify the most reactive reflector." In the same section, the applicant also states that [ ] is the most reactive in-cavity reflector material. However, the proposed revision of the CoC does not mention [ ] and merely states: "presence of material containing more hydrogen than polyethylene is not allowed." In addition, no [ ] -containing benchmarks were included in the previous bias determination described in Section A.6.8 of the SAR. Based on the information in the proposed CoC and the SAR, the staff is unable to determine whether [ ] is an intended content or not. The applicant needs to provide the following: clarification whether [ ] is the intended content and provide criticality safety analyses for this content consistent with the [ ] and fissile material composition and quantity; determine a USL for [ ] moderated and reflected systems with additional, applicable benchmark evaluations; and demonstrate that the package maximum reactivity containing this content meets the regulatory requirements for criticality safety.

This information is necessary to determine compliance with 10 CFR 71.55(b), 71.55(d), 71.55(e), and 71.59.

Response to RAI 6-1

[ ] is not an intended content. The authorized quantity of uranium is fixed at 5 kg and a maximum 5 wt% enrichment in U-235. This mass limit results in a calculated k_{eff} that provides a significantly larger subcritical margin than the minimum specified by the upper subcritical limit (USL). Appendix B.6 of the SAR describes the expected material mixed with the uranium for content number 7 and is as follows:

> The residue incinerator ashes consist of mainly silica, alumina, aluminosilicates, metal oxides, phosphates, aluminum metal, charred wood and charred plastic in undefined part. The earth, sand and dissolved residues consist of mainly silica, alumina, titania, iron oxide and aluminosilicate. Other organic or inorganic compounds may be present in the form of traces.

Only CH_2 is considered as a moderator material because it is the most penalizing moderator of the credible materials and chemical elements in the content. Any moderators that are more effective than CH_2 are not present in sufficient quantities to have a significant effect on the reactivity of the mixture. For example, pure carbon (graphite) is a more effective moderator than CH_2, but it has to be present in quantities greater than the specified impurity level to be more effective than the unrestricted quantity of CH_2. Uranium-bearing materials may be comingled or mixed with any non-fissile materials having moderator effectiveness no greater than CH_2. More effective moderators are excluded or restricted to impurity limits that are known to have an effect no greater than an unrestricted quantity of CH_2.

The sensitivity study done using different reflector materials is not intended to define a limit on the mass of uranium-bearing material. The sensitivity study is only intended to demonstrate the effectiveness of different effective reflector materials [ ] A USL for [ ] moderated or reflected system is not calculated, because [ ] in the form of metal or oxide is not present in content number 7. The calculation of a [ ] reflected system serves only to show the effect on the subcritical margin. The sensitivity study shows that a large margin of safety, relative to uncertainty in the reflector material, is provided by the 5 kg uranium mass limit.

Moderation or reflection may be provided by any of the credible materials in the contents without exceeding the USL. [ ] is not a credible moderator or reflector material. Uranium-bearing materials may be mixed with other non-fissile materials, with the exception of [ ] or hydrogenous materials enriched in deuterium. Materials that are a more effective moderator than CH_2, or that contain a hydrogen density greater than CH_2 are excluded from the allowed contents, except for any allowance provided by specific impurity limits.

TNF-XI SAR Impact:

No changes as a result of this question.

Enclosure 3 to E-47395

Listing and Description of Specific SAR Changes for Proprietary Markings

Listing and Description of Specific SAR Changes for Proprietary Markings

During communications with the NRC regarding the request for additional information (RAI) questions, the NRC Project Manager and the Criticality Reviewer discussed with TN Americas LLC (TN) several details regarding proprietary markings in specific sections and tables within the TNF-XI safety analysis report. Accordingly, TN is including these changes as part of the RAI response package.

Table 6-4, Section 6.3 (and other locations in Chapter 6 and A.6);

For the locations in Chapter 6 where the phenolic foam model type is listed, the appropriate type number has been added. These changes are on pages 6-3, 6-4, 6-7, and 6-10, and on page A.6-4.

Section A.6.3.4

This section has been revised to reflect that the dimensions are the only items that are proprietary. These are on pages A.6-5 and A.6-6. Page A.6-7 has been revised to be non-proprietary.

Table A.6-4

For the locations on Table A.6-4, (Page A.6-26) where the phenolic foam model type is listed, the appropriate mixture number has been added and the foam model type has been removed.

Section B.6.3.1

This section has been revised to remove the proprietary markings. This change is on page B.6-2.

Section B. 6.3.4

This section has been revised to remove the proprietary markings. This change is on page B.6-3.

Enclosure 5 to E-47395

TNF-XI SAR, Revision 11B; Changed Pages Only, Chapter 6, Appendix A.6, and Appendix B.6 (Non-Proprietary Version)

NON-PROPRIETARY

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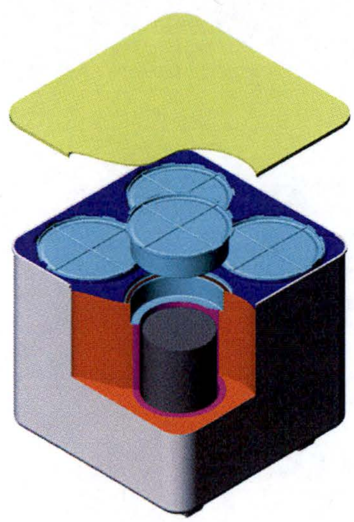
TNF-XI Package



SAFETY ANALYSIS REPORT

Docket Number 71-9301

Revision 11B
February 2017

TN Americas LLC
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Revision Log

Rev. No.	Date	Description
0	7/2002	Original Issue for CoC Revision 0
1	1/2002	Various Changes CoC Revision 0
2	2/2002	Various Changes CoC Revision 0
3	4/2002	Various Changes CoC Revision 0
4	7/2003	Application for CoC Revision 5
5	5/2011	Various Changes for CoC Revision 5
6	10/2011	Various Changes for CoC Revision 5
7	12/2011	Various Changes for CoC Revision 5
8	1/2012	Various Changes for CoC Revision 5
9	7/2013	Application for CoC Revision 6
10	11/2013	Various Changes for CoC Revision 6
11	12/2014	Application for CoC Revision 8
11A	8/2016	Application for CoC Revision 9 Revised pages as follows: SAR pages 1-1 through 1-10, 6-1 through 6-136, A.6-i through A.6-iii, A.6-5 through A.6-7, A.6-65, 7-2, 7-4, 8-1 through 8-12, 8.3.A-i, 8.4.B-i, and 8.5.C-i New pages as follows: Proprietary Information Notice Revision Log SAR pages B.6-i, B.6-ii, B.6-1 through B.6-19
11B	2/2017	Application for CoC Revision 9 Revised pages as follows: Proprietary Information Notice Revision Log SAR pages 6-3, 6-4, 6-7, 6-10, A.6-4, A.6-5, A.6-6, A.6-7, A.6-26, B.6-2, B.6-3

Table 6-4. Material Specifications for the TNF-XI Shipping Package

Material	Density (g/cm³)	Constituent	Atomic Density KENO-Va (atoms/b-cm)
UO_2	≤10.96	^{235}U	variable
		^{238}U	variable
		O	variable
Water	1.00	H	6.67692E-02
		O	3.33846E-02
Borated Stainless Steel	7.85	B10	6.37374E-04
		B11	2.64080E-03
		C	3.12795E-04
		Si	1.67060E-03
		P	6.81655E-05
		Cr	1.71450E-02
		Mn	1.70808E-03
		Fe	5.74468E-02
		Ni	7.59507E-03
BORA Resin	[		]
Phenolic Foam [ ] *(Type 1)*			
Phenolic Foam [ ] *(Type 3)*			
Charred *Phenolic Foam (Type 1)* [ ] (accident model only)			]
Aluminum Honeycomb	1.08	Al	2.41048E-02
Stainless Steel 304	7.94	C	3.18772E-04
		Si	1.70252E-03
		P	6.94680E-05
		Cr	1.74726E-02
		Mn	1.74071E-03
		Fe	5.85446E-02
		Ni	7.74020E-03

6.3 Model Specification

6.3.1 Description of the KENO-Va Calculational Models

An axially finite model of the normal geometry of the TNF-XI package is provided in Figure 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 [ ] (Type 1) using the hole function in KENO. 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 pails rests. Each pail is modeled as a sealed stainless steel can that contains the fuel/water mixture and is lined with borated stainless steel. Void is present between the pail and canister wall., and between the top of the pail and bottom of the lid. The lid to each cavity consists of layers of phenolic foam [ ] (Type 3), aluminum honeycomb, and [ ] *(Type 1)*. The entire package is surrounded by a thin layer of stainless steel. The single package model is then placed in an array.

Phenolic foam [ ] (Type 2) is used in the corners of the package. For simplicity, it is modeled as [ ] *(Type 1)* in KENO. Also, for simplicity the phenolic foam [ ] *(Type 3)* in the top disk is modeled as [ ] *(Type 1)* in KENO. Impacts on the reactivity as a result of these minor simplifications are within the statistical uncertainty of the methods used.

An axially finite model of the damaged geometry of the TNF-XI package is provided in Figure 6-2. 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 canister lids also has charred foam in the bottom disk. In the damaged model, the fuel/water mixture exists both inside and outside the pail, and void space with the package not containing the fuel/water mixture contains water.

The model is considered conservative for the following reasons:

- Only 75% credit is taken for the B-10 in the chemical composition of the BORA resin and for all the borated stainless steel material.
- The most reactive pail position (all pails pushed to the center of the package) is utilized.
- Fuel is optimally moderated with water in both the normal and accident geometry scenarios. Heterogeneous material is modeled as cylinders of solid UO_2 of optimum diameter in an optimum rectangular lattice.
- The TNF-XI undamaged and package arrays are modeled as close fitting and in virtual contact when in fact deformation and bowing would provide additional (x-y) and axial (x-z) center-top-center spacing between individual packages, especially in an accident condition.

6.3.2 Materials

Figures 6-3 and 6-4 show the material assignments for the normal case. Figures 6-5 and 6-6 show the material assignments for the accident case. The color coding for these figures is provided in Table 6-5.

Table 6-5. Material Mapping

KENO Material No.	Description	Color
0	Void	Black
1	Fuel/water	Grey
2	Water	Dark Blue
3	Borated Stainless Steel	Light blue
4	BORA Resin	Green
5	Phenolic foam [ ] *(Type 1)*	Yellow
6	Phenolic foam [ ] *(Type 3)*	Red
7	Charred [ ] *(Type 1)*	Purple
8	Not Used	NA
9	Aluminum honeycomb	Pink
10	Stainless steel 304	Blue

The UO_2 mixture (fuel) material specifications used in the TNF-XI criticality safety demonstrations are dependent upon the case being modeled. The treatment of the fueled region is limited to the following parametric studies:

1. Undamaged array of homogeneous mixtures of UO_2 powder and water
2. Damaged array of homogeneous mixtures of UO_2 powder and water
3. Single container cases for homogenous fuel mixtures
4. Undamaged array of heterogeneous UO_2
5. Damaged array of heterogeneous UO_2
6. Single container cases for heterogeneous fuel mixtures

In the first set of cases, the $UO_2 + H_2O$ mixture is modeled as a pure theoretical mixture of UO_2 powder (10.96 g/cm^3) and water. 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 for the fully reflected undamaged and damaged array is achieved.

In the second set of cases, the heterogeneous UO_2 is modeled as a series of water moderated cylindrical rods. The volume fraction of water inside the package is altered by varying the diameter of the fuel, the pitch, and the stack height. In this way optimum moderation for the fully reflected undamaged and damaged array is achieved. Note that in the heterogeneous cases, fuel pellets are not explicitly modeled in the three-dimensional KENO model. Rather, XSDRN is used to generate cell-averaged cross sections for the given heterogeneous unit cell and these cell-averaged cross sections are utilized in the KENO model.

6.3.3 Models – Actual Package Differences

- 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 fuel region is modeled with variable UO_2 mass and variable H_2O content. 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 (x-y) and axial (x-z) center-top-center spacing between individual packages.
- The aluminum honeycomb in the top lid is modeled as solid aluminum with a reduced density for simplicity.
- The upper phenolic foam disk [ ] *(Type 3)* in the lid is modeled as 0.4 cm thinner than actual and as charred [ ] *(Type 1)* foam instead of [ ] *(Type 3)* (for the damaged package). The difference in charred foam densities is negligible and the reduction in the disk thickness is conservative.
- 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 61.5 cm with a borated stainless steel liner 54.0 cm in height starting 7.5 cm from the container bottom.
- The phenolic foam [ ] *(Type 2)* in the bottom corner of the package is modeled as [ ] *(Type 1)* for simplicity.
- The perforated aluminum disk is modeled as 3.0 cm thick, although the actual thickness is 1.5 cm. This difference is demonstrated to be within the statistical uncertainty of the methods employed.

6.3.4 Package Arrays

Two basic package array model constructs are included in this evaluation – damaged and undamaged for both homogeneous UO_2 powder and heterogeneous UO_2 material. Single package models are also developed, although the results of the single package are bounded by the array results.

- 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 ([ ] *(mixture #6)* in the lid is modeled as 0.4 cm thinner than actual and as charred [ ] *(mixture #5)* foam instead of [ ] *(mixture #6)* (for the damaged package). The difference in charred foam densities is negligible and the reduction in the disk thickness is conservative.
- 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 [ ] in the bottom corner of the package is modeled as [ ] *(mixture #5)* 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.

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 powder scrap, the fuel mixture includes impurities, as defined in ASTM C753 [7] or, conservatively, as aluminum and carbon not exceeding 5,000 ppm and 10,000 ppm, respectively.*

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. **[ ]** (mixture #5) at a density of 0.20 g/cc is the main foam modeled. **[ ]** 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.

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 **[ ]** cm and the BSS insert is a **[ ]** cm thick cylinder, located **[ ]** 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:

[ ] Eq. 1

In the HAC array analysis, the package cavities and pail are fully flooded with the fuel matrix occupying the full cross section ([ ] 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 [ ] cm thick) and inside the cavity and around the pail:

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

[ ]

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:

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

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

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

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:

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

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

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

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:

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

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.

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

Max ^{235}U Enrichment (wt. percent)	Homogeneous UO_2 Powder *and Powder Scrap*[1] 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

1- Powder scrap defined as powder with impurities such as aluminum and carbon not exceeding 5,000 ppm and 10,000 ppm, respectively.

Table A.6-4 KENO Mixture Numbers

Mixture Number	Powder	Pellets and Scrap
1	Fuel/Polyethylene\Water	Fuel
2	Water	Polyethylene/Water
3	Borated Stainless Steel	Borated Stainless Steel
4	BORA Resin	BORA Resin
5	Phenolic Foam *(mixture #5)*	Phenolic Foam *(mixture #5)*
6	Phenolic Foam *(mixture #6)*	Phenolic Foam *(mixture #6)*
7	Charred *(mixture #5)*	Charred *(mixture #5)*
8	Not Used	Not Used
9	Aluminum Honeycomb	Aluminum Honeycomb
10	Stainless Steel 304	Stainless Steel 304
11	-	Water
500	-	Fuel/Moderator Lattice

The residue incinerator ashes consist of mainly silica, alumina, aluminosilicates, metal oxides, phosphates, aluminum metal, charred wood and charred plastic in undefined part. The earth, sand and dissolved residues consist of mainly silica, alumina, titania, iron oxide and aluminosilicate. Other organic or inorganic compounds may be present in the form of traces. The residues are chemically stable, contain no liquid and are compatible with the material of the pails (steel).

The authorized quantity of uranium is limited to 5 kg per cavity. The authorized quantity of uranium oxides and residues is limited to 75 kg per cavity.

The radioactive material may be put in plastic bags made with a material more hydrogenated than water and less than or equal to polyethylene. The mass of those plastic bags is not limited. The operating temperature of the plastic bag must be equal or greater than 100 °C (in steady-state conditions). The material of the plastic bags must be compatible with the residues.

B.6.3 GENERAL CONSIDERATIONS

B.6.3.1 Model Configuration

The TNF-XI model is based upon drawings shown in Chapter 1 of the SAR. The TNF-XI package model construct consists of four cavities inserted into the primary body of phenolic foam. The detailed description of the TNF-XI model configuration is provided in Appendix A.6, Section A.6.3.1. The simplified packaging model consists of a single cylindrical cavity wrapped by a layer of BORA resin which is enclosed between two cylindrical steel walls, as illustrated in Figure B.6-1. The radioactive material is placed in the cylindrical cavity surrounded by reflector material as shown in Figure B.6-2. The simplified TNF-XI package model is chosen to cover the study for isolated package and for infinite array of packages. In the same way, the simplified model is chosen to cover all mechanical and thermal damages resulting from the regulatory test corresponding to the normal conditions of transport (NCT) combined with the regulatory tests corresponding to the accident conditions of transport (HAC), as described in Appendix A.6.

A sensitivity study is performed to compare the simplified packaging model against four full packaging models; single and array cases under NCT and HAC. Three full packaging models are selected from Appendix A.6, Table A.6-2; the single package under NCT with 5.00 wt. % ^{235}U, the 8x9x8 package array under NCT with 5.00 wt. % ^{235}U, and the 6x6x6 package array under HAC with 5.00 wt. % ^{235}U. The fourth full packaging model is for a single package under HAC, which is derived from the above 6x6x6 package array under HAC. For the comparison purpose, the single and array cases with 5.00 wt. % ^{235}U are selected from Appendix A.6, Table A.6-2, the two array models are converted into an infinite array and the simplified model has an identical fissile material configuration and quantity as the HAC model (Appendix A.6, Table A.6-2). The results are for comparison purpose and are not intended to be compared with the USL. The sensitivity study results are given in Table B.6-4, which show that simplified packaging model has the highest k_{eff} value. Therefore, the simplified packaging model bounds the single package and the infinite array of packages under NCT and HAC.

B.6.3.2 Material Properties

As shown in Table B.6-2, seven material compositions (mixtures) are used in the Content 7 criticality evaluation model. The material properties of the first six mixtures are identical to those used in Appendix A.6. Mixture Number 7 is the material used as the in-cavity reflector in the simplified TNF-XI model. For Mixture Number 7, nine materials are used in the sensitivity study to determine the optimal in-cavity reflector material. The compositions of three reflector materials (polyethylene, water and stainless steel) are identical to those used in Appendix A.6. The compositions of the remaining six reflector materials are specified in Table B.6-3.

B.6.3.3 Computer Codes and Cross Section Library

The computer codes and neutron cross section library used in the Content 7 evaluation are described in Appendix A.6, Section A.6.3.3.

B.6.3.4 Lattice Cell Modeling for CSAS5

Content 7 consists of uranium oxides in the form of powder and scrap, which are stored in plastic bags along with residues specified in Section B.6.2. Appendix A.6, Table A.6-3 shows that the scrap is more reactive then the powder. Therefore, the criticality evaluation for Content 7 considers the scrap only. In the SCALE lattice cell calculation, the residues are ignored and the scrap are treated as a spherule, homogenized with the plastic bag material, and then arranged in a spherical-hexagonal lattice as described in Appendix A.6, Section A.6.3.4. The spherical-hexagonal lattice can be described as a rhombic dodecahedron containing sphere. The moderation primarily depends on the scrap spherule size and the amount of plastic bag material. The moderator to fuel volume ratio (V_m/V_f), the scrap spherule pitch (P) and the spherule radius (r_f) are related in Equation 9 given in Appendix A.6, Section A.6.3.4, which is reproduced below,

$$r_f = \frac{P}{2}\sqrt[3]{\frac{3\sqrt{2}}{\pi\left(V_m/V_f+1\right)}} \qquad \text{Eq. 1}$$

The total volume of the fissile mixture (V_T) depends on the volume of UO_2 scrap and plastic material. The total volume of fissile mixture (V_T) is the product of number of spherules (N) and volume of each unit fragments ($V=V_f+V_m$), given by:

$$V_T = N \times V \qquad \text{Eq. 2}$$

The volume of the moderator (V_m) in the unit fragment can be estimated by knowing the moderator to fuel volume ratio (V_m/V_f) and scrap spherule volume (V_f). The scrap spherule volume and moderator volume will change depending on the scrap spherule radius.

The number (N) of scrap spherules depends on the mass of scrap spherule and the total mass of radioactive material. The mass (m) of scrap spherule is calculated using scrap spherule volume (V_f) and density (ρ) of UO_2 (10.96 g/cc). The equation is given by:

$$m = \rho \times V_f \qquad \text{Eq. 3}$$

The total volume of the fissile mixture (V_T) and the scrap spherule pitch (P) varies depending on the scrap spherule radius (r_f) and the moderator to fuel volume ratio (V_m/V_f).