NON PROPRIETARY

AREVA TRANSNUCLEAR INC.	Form 3.2-1 Calculation Cover Sheet TIP 3.2 (Revision 3)	Calculation No.:	10421-024
		Revision No.:	2
		Page: 1 of 42	

DCR NO (if applicable) : DCR 10421-015 12/1/09	PROJECT NAME: TN-40 Transport
PROJECT NO: 10421	CLIENT: Transnuclear, Inc.

CALCULATION TITLE:

TN-40 CSAS25 Evaluation for Burnup Credit

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation performs a statistical evaluation of the Fresh UO_2 and MOX critical benchmark experiments. The USL functions for important geometry and material parameters are calculated using USLSTATS. Revision 1 of this calculation includes the Commercial Restart Critical (CRC) benchmarks in the USL evaluations. Revision 2 generates three more sets of USL.

2) Storage Media Description

Secure network server initially, then redundant tape backup.

If original issue, is licensing review per TIP 3.5 required? Not Applicable since it is a Revision

Yes ☐ **No** ☒ **(explain below)** **Licensing Review No.:**_____

This calculation is revised to provide a technical basis to the Transnuclear's response to the NRC RAI for the Part 71 license submittal for the TN-40 cask. Therefore, a licensing review (72.48) per TIP 3.5 is not applicable and is addressed in the DCR. The applicable licensing documents are listed in the Revision Summary page.

Software Utilized:	**Version:**
SCALE 4.4 PC (CSAS25 Module)	C00545MNYCP00
SCALE 5.0 Linux	C00725MNYCP01
USLSTATS (Limited Use Software)	1.4.2

Report is complete: Originator Name and Signature: David Lee *David Lee*	Date: July 6, 2009
Report has been checked for consistency, completeness and correctness: Checker Name and Signature: Michael Mason *Michael Mason*	Date: July 7, 2009
Report is approved for use: Project Engineer Name and Signature: S. R. STREUTKER *S. R. Streutker*	Date: 12/06/09

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REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISKS
0	08/07/2006	Initial Issue	ALL	1
1	08/29/2008	Include CRC benchmark results in the USL calculation	ALL as shown by rev bars	1
2	12/06/09	Three more sets of USL are generated. Computer program input and output are handled per Storage Media Description in Cover Sheet. Input and output of Revision 0 and 1 are moved to LaserFiche. The USL functions with CRC benchmarks calculated in Revision 1 are not applicable. The USL functions from Revision 2 shall be utilized.	ALL as shown by rev bars	0

Licensing Documents:

- Transnuclear application for Transportation License (Part 71) for the TN-40 Cask, dated June 29 2007, docketed under 71-9313.

This application is currently under review and this calculation is prepared to provide a technical justification to Transnuclear's response to the RAI #1 from the NRC.

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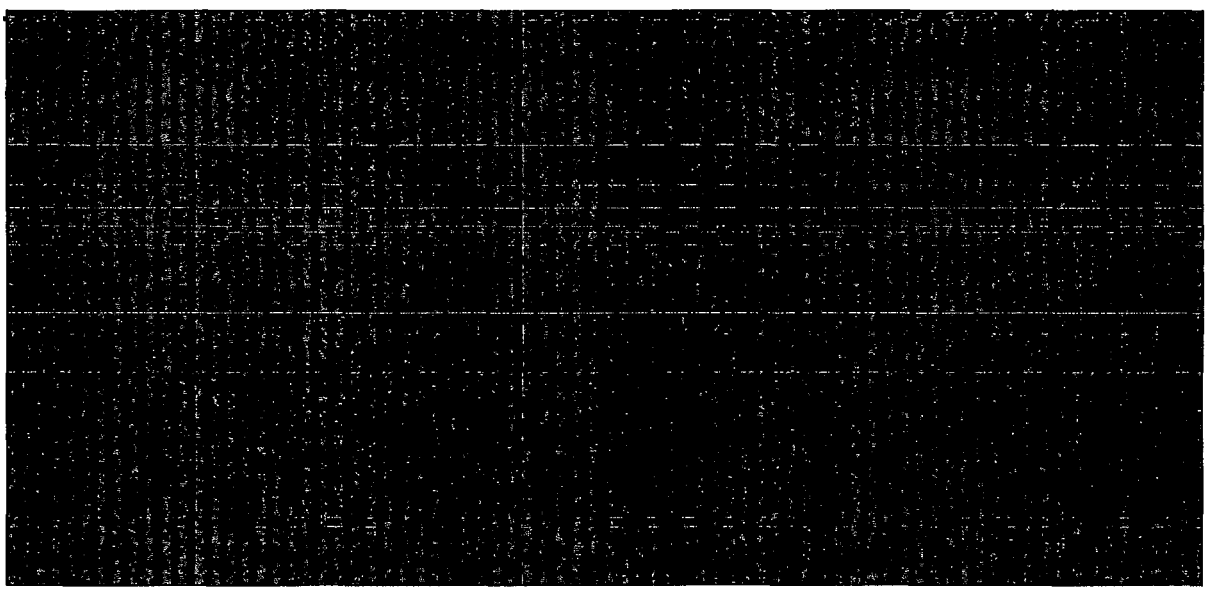
1.0 PURPOSE

The purpose of this calculation is to provide the basis for determining the Upper Subcritical Limit (USL) for the SCALE 4.4 PC CSAS25 control module with the 44 group cross section library (reference [6]). The basis described herein is applicable to Pressurized Water Reactor (PWR) fuel systems with credit for accumulated burnup. This document also includes guidelines for determining an appropriate USL for use with a criticality evaluation. The guidelines are based on guidance provided in reference [5].

Traditionally the benchmark analysis provided in this document was used to determine a calculational bias. The calculational bias accounted for the inherent bias associated with modeling methodology and the criticality code and cross section set used to perform criticality analysis. The USL includes a 0.05 Δk_{eff} administrative margin on k_{eff} in addition to the calculational bias.



1.1 Description of SCALE 4.4 Criticality Sequences

SCALE 4.4, reference [6], is an extensive computer package, which has many applications including cross section processing, criticality studies, and heat transfer analyses among others. The package is comprised of many functional modules, which can be run independent of each other. Control Modules were created to combine certain functional modules in order to make the input requirements less complex and shorter. For the purpose of this report, only four functional modules are used and one control module. This report verifies and validates the use of the Control Module CSAS25, which includes the three dimensional criticality code KENO-Va and the preprocessing codes BONAMI-S, NITAWL-II and XSDRNPM-S.

KENO Va, in conjunction with a suitable working library of nuclear cross section data, is used to calculate the multiplication factor, 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. KENO Va is capable of modeling complex geometries including facilities for handling arrays, arrays of arrays, and holes.

SCALE 4.4 is set up so that any number of cross-section libraries may be used with the preprocessing functional and control modules. For the purpose of this report, only the 44-group ENDF/B-V library is used to perform the benchmark calculations. Other cross-section sets are available, however their use is subject to the same requirements for benchmarking as the computer codes. Therefore, only the 44-group cross section set is validated herein.

The preprocessing codes used for this document are the functional modules BONAMI-S and NITAWL-II. They are consolidated into the control module CSAS25. BONAMI-S has the function of performing Bondarenko calculations for resonance self-shielding. The cross-sections and Bondarenko factor data are pulled from an AMPX master library. The output is placed into a master library as well. Dancoff approximations allow for different fuel lattice cell geometries. 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.

2.0 REFERENCES

1 E-20896, "Test Plan for Qualifying of the SCALE-4.4 Computer Program on the Transnuclear PC with Windows XP."

2 E-20897, "Test Report for Qualification of the SCALE-4.4 Computer Program on the Transnuclear PC with Windows XP."

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

4 U.S. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems" NUREG-1536, Published January 1997.

5 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.

6 Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE: A Modular Code System for Performing Standardized Computer Analysis for

Licensing Evaluations for Workstations and Personal Computers," NUREG/CR-0200, Revision 6, ORNL/NUREG/CSD-2/V2/R6.

7 DeHart, M.D. and S. M. Bowman "Analysis of Fresh Fuel Critical Experiments Appropriate for Burnup Credit Validation," Oak Ridge National Laboratory, October 1999, ORNL/TM-12959.

8 E-16154, "Test Report for Qualification of the USLSTATS Computer Program Version 1.3.4 on Transnuclear's Pentium-based Desktop Computers."

9 Radulescu G, Mueller D. E. and J. C. Wagner, "Sensitivity and Uncertainty Analysis of Commercial Reactor Criticals for Burnup Credit," Oak Ridge National Laboratory, January 2008, ORNL/TM-2006-87, NUREG/CR-6951.

[redacted]

11 M. D. DeHart "SCALE-4 Analysis of Pressurized Water Reactor Critical Configurations: Volume 1 – Summary," Oak Ridge National Laboratory, March 1995, ORNL/TM-12294/V1.

12 Criticality Model, CAL-DS0-NU-0000003 REV 00A, Bechtel SAIC Company, Las Vegas, Nevada, 2004.

[redacted]

14 S. M. Bowman, W.C. Jordan, J. F. Mincey, C.V. Parks, and L. M. Petrie, "Experience with the SCALE Criticality Safety Cross-Section Libraries," Oak Ridge National Laboratory, NUREG/CR-6686, Published October 2000, ORNL/TM-1999/322.

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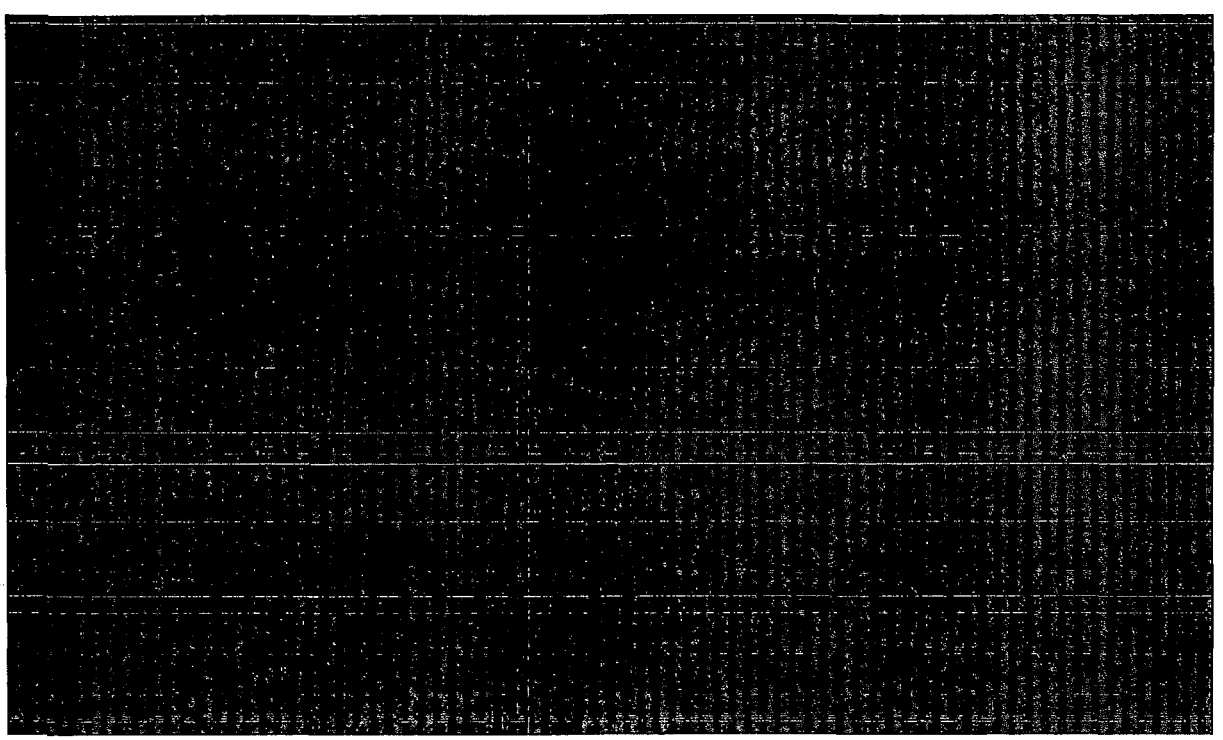
3.0 METHODOLOGY AND DESIGN INPUTS

3.1 Methodology

Criticality codes are verified by comparing benchmark calculations to actual critical benchmark experiments. The difference between the calculated reactivity and the experimental reactivity is referred to as calculational bias. This bias may be a function of system parameters such as fuel lattice separation, fuel enrichment, neutron absorber properties, reflector properties, or fuel/moderator volume ratio, or there may be no specific correlation with system parameters. The purpose of this computer code verification is to statistically determine the magnitude of the calculational bias and whether any such

dependencies exist so that they may be properly accounted for in licensing criticality analyses. The computer program USLSTATS V1.4.2 (limited use software per TIP 3.2) is utilized to determine an upper subcritical limit (USL) on k_{eff}. The NUREG/CR-6361 document, reference [5], describes and utilizes the USLSTATS program, Version 1.3.4, reference [8]. In addition, a test case from reference [10] is also utilized to compare the different versions of the USLSTATS program.

The USL Method 1 (USL-1), from reference [5] applies a statistical calculation of the bias and its uncertainty plus an administrative margin to the linear fit of results of the experimental benchmark data developed herein. The USL-1, as a function of independent variables energy of the average lethargy for fission, enrichment, water/fuel volume ratio, and rod pitch, are determined. The independent variables and k_{eff} are evaluated using a spread sheet (*Table 1*in Section 6) to determine which data set shows the best correlation (absolute value of the correlation coefficient "r" when a linear regression analysis is performed). An exact correlation between the k_{eff} and the independent variable would be indicated when $|r| = 1$. No correlation whatsoever would be indicated by $r=0$. The USL from the data set with the best correlation is used as the acceptance criteria for subsequent criticality evaluations. If no good correlation exists for any of the data sets, i.e., the correlation is essentially random, the lowest USL-1 will be used. USLSTATS is used to simplify the hand calculations to determine the most conservative USL-1. This methodology is also described in Section 4.1.3 of reference [5]. The SCALE-4.4 computer code system was run with the Windows-XP operating system. The verification and validation was performed in reference [1] and [2].



[redacted]

3.2 Design Inputs

The physical description for each critical benchmark experiment is provided in the applicable reference documents. All of the critical benchmark experiments are taken from references [5] and [7]. The $U0_2$ benchmarks are described in reference [5] and [7] and all of the PuO_2/UO_2 mixed oxide (MOX) critical benchmark experiments are described in reference [7].

The CRC benchmark results are obtained directly from Table 3.3 of reference [9]. The list of important parameters is shown in Table 3.2 of reference [9]. Additional information about the various CRC benchmarks is provided in the Yucca Mountain Criticality Calculation, reference [12].

The computer program USLSTATS Version 1.4.2 (similar to USLSTATS Version described in reference [5]) is used to determine an upper subcritical limit (USL) on k_{eff}. USL Method 1 (USL-1), from reference [5] applies a statistical calculation of the bias and its uncertainty plus an administrative margin to the linear fit of results of the experimental benchmark data developed herein. The basis for the administrative margin is reference [3] as discussed in Section 4 of this document.

[redacted]

3.3 Class of Problems

[redacted]

[redacted]

3.4 CSAS25 Control Module

CSAS25 is the only control module that is verified and validated in this document, which includes the criticality capabilities of KENO Va. The sequence of operations in CSAS25 is vital to perform resonance self-shielding and other calculations concerning the handling of the cross-sections. The sequence uses the Material Information Processor (MIP) which reads the standard composition data and other important data such as theoretical density. The MIP checks the preprocessing input data and creates binary input files that the functional modules access.

The data for the preprocessing is controlled entirely by the MIP. It requires data to specify the cross-section library, the composition of each mixture, and the geometry of the fuel unit cell. For our purposes, the compositions of the mixtures are specified by either some percentage of theoretical atom density, by atomic density (atoms/barn-cm) or by selecting the material from the choices provided in the MIP list of standard materials. The temperature of the mixture may also be specified. The fuel lattice cell region is identified by a certain geometric pitch, which is the spacing between two adjacent fuel rods (e.g. square pitch), the mixtures associated with the fuel, clad, and gap regions, and the dimensions of those regions. The data is entered as free form, which allows input in an unstructured style.

4.0 ASSUMPTIONS AND CONSERVATISMS

4.1 Assumptions

[redacted]

4.2 Conservatism

The Upper Subcritical Limit, which is calculated for CSAS25 and the 44-group cross section library, includes 0.05 Δk_{eff} administrative margin. NUREG/CR-5661, reference [3], states that "The NRC currently regards 0.05 Δk_{eff} as the minimum administrative margin of subcriticality that should be considered for transportation packages." This is also consistent with the margin presented in NUREG-1536, reference [4].

5.0 ANALYSIS

5.1 Computations

[redacted]

[redacted]

6.0 RESULTS, CONCLUSIONS AND RECOMMENDATIONS

6.1 CSAS25 Results

[redacted]

6.2 USLSTATS Results

[redacted]

6.3 Conclusions

[redacted]

[redacted]

6.4 Guidelines for Determining an appropriate USL

[redacted]

Table 1: CSAS25 Results

[redacted]

Table 1: CSAS25 Results

(continued)

[redacted]

Table 1: CSAS25 Results

(continued)

[redacted]

Table 1: CSAS25 Results

(continued)

[redacted]

Table 1: CSAS25 Results

(concluded)

[redacted]

Table 2: USLSTATS Results

[redacted]

7.0 APPENDIX A

7.1 CSAS25 File Listing

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

7.2 USLSTATS File Listing

[redacted]

[redacted]

[redacted]

7.3 Output Echo of USLSTATS Output Files

[redacted]

[redacted]

[redacted]

[redacted]

7.4 First Alternate USL Targeting SCALE-4.4

[redacted]

Table 3: First Alternate USL for SCALE-4.4

[redacted]

The version of SCALE and cross section library used to generate K_{EFF} input to the first alternate USL are illustrated below.

	Critical Experiments	
	BOL	*CRC*
SCALE Version	*4.4*	*5.0*
Cross Section Library	*44-group*	*238-group*

7.5 Second Alternate USL targeting SCALE-4.4

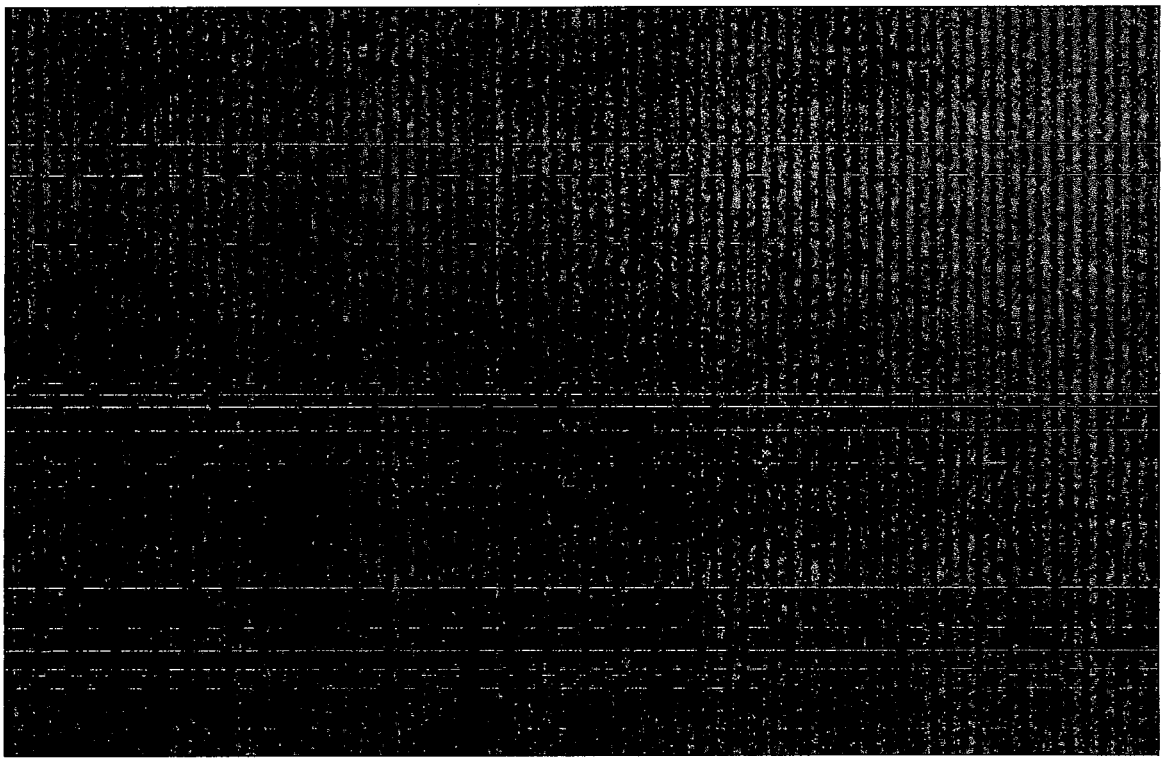


Table 4: Second Alternate USL for SCALE-4.4

Parameter	*Range of applicability*	*ALL-Experiment USL-1 Formula*
Energy of the Average Lethargy for Fission (EALF)	*0.083 – 1.39*	*0.9427 + (-3.0241E-03)*X (X > 0.20691)* *0.9421 (X <= 0.20691)*
U-235 Enrichment in wt%	*2.35 – 5.74*	*0.9389 + (7.3145E-04)*X (X < 4.5697)* *0.9422 (X >= 4.5697)*
H_2O/Fuel Volume Ratio	*0.38 – 10.8*	*0.9387 + (9.2625E-04)*X (X < 2.6949)* *0.9412 (X >= 2.6949)*
Rod Pitch in cm	*1.10 – 2.64*	*0.9330 + (5.2634E-03)*X (X < 1.8164)* *0.9425 (X >= 1.8164)*

The version of SCALE and cross section library used to generate K_{EFF} input to the first alternate USL are illustrated below.

	Critical Experiments	
	BOL	*CRC*
SCALE Version	*4.4*	*5.0*
Cross Section Library	*44-group*	*44-group*

7.6 USL targeting SCALE-5.0

[redacted]

[redacted]

The version of SCALE and cross section library used to generate K_{EFF} input to the USL for SCALE 5.0are illustrated below.

	Critical Experiments	
	BOL	*CRC*
SCALE Version	*5.0*	*5.0*
Cross Section Library	*44-group*	*44-group*

Table 5: USL for SCALE-5.0

[redacted]

Table 6: SCALE-5.0 K_{EFF} – BOL Critical Experiment with 44-Group

[redacted]

Table 6: SCALE-5.0 K_{EFF} – BOL Critical Experiment with 44-Group

[redacted]

Table 6: SCALE-5.0 K_{EFF} – BOL Critical Experiment with 44-Group

[redacted]

Table 7: SCALE 5.0 Input and Output for Fresh Fuel Runs

[redacted]

Table 7: SCALE 5.0 Input and Output for Fresh Fuel Runs

[redacted]

Table 7: SCALE 5.0 Input and Output for Fresh Fuel Runs

[redacted]