NON PROPRIETARY

AREVA TRANSNUCLEAR INC.	Form 3.2-1 Calculation Cover Sheet TIP 3.2 (Revision 3)	Calculation No.:	10421-023
		Revision No.:	2
		Page: 1 of 87	

DCR NO (If applicable) : 10421-013	PROJECT NAME: TN-40 Transport
PROJECT NO: 10421	CLIENT: NMC/Prairie Island

CALCULATION TITLE:

TN-40 SAS2H Evaluation for Burnup Credit

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation performs benchmarks of the isotopic content of burned fuel predicted by SAS2H with measurements for a select set of actinide and fission product isotopes. Isotopic correction factors are determined for use in subsequent criticality calculations that rely on credit of these actinide and fission products.

2) Storage Media Description

1 CD-ROM attached. All the runs and spreadsheets from all the SAS2H and CSAS25 benchmarks are included.

If original issue, is licensing review per TIP 3.5 required?

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: SCALE-PC	**Version:** 4.4
Calculation is complete: Michael Mason Originator Name and Signature: Michael Mason	Date: 8/28/08
Calculation has been checked for consistency, completeness and correctness: A. Prakash Checker Name and Signature: Prakash Narayanan	08/29/2008 Date:
Calculation is approved for use: Jayant Bondre for Steven Strentker Project Engineer Name and Signature:	8/29/2008 Date:

REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISKS
0	8/7/06	Initial Issue	all	1
1	6/26/07	Additional statistical and trending benchmarking is performed to develop new, conservative best estimate isotopic correction factors. This revision is documented in revised Appendix E. Other editorial and formatting changes are applied. Note the units of mg/g and Ci/gram were corrected to g/MTU and Ci/MTU, respectively.	all	1
2	08/29/2008	TMI benchmarks are added to the existing benchmarks and new best estimate factors for the isotopes are determined. Additionally, criticality analyses for all the benchmarks are performed. This revision is documented in Appendix F.	all	1

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

This calculation is used to validate the methodology for determining the isotopic content of burned fuel and the associated correction factors required to estimate the actinide and fission product content in PWR spent fuel for use in subsequent criticality calculations. Conservative estimates of the actinide and fissile isotopes are necessary to ensure that the criticality calculations are conservative.

2.0 REFERENCES

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

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

2.3 "Validation of the SCALE System for PWR Spent Fuel Isotopic Composition Analyses," ORNL/TM-12667, OW Hermann, SM Bowman, MC Brady, CV Parks, March 1995.

2.4 "An Extension of the Validation of SCALE (SAS2H) Isotopic Predictions for PWR Spent Fuel," ORNL/TM-13317, MD DeHart and OW Hermann, September 1996.

2.5 "Isotopic Analysis of High-Burnup PWR Spent Fuel Samples From the Takahama-3 Reactor," ORNL/TM-2001/259 (NUREG/CR-6798), CE Sanders and IC Gauld, January 2003.

2.6 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.

2.7 "Strategies for Application of Isotopic Uncertainties in Burnup Credit," NUREG/CR-6811, June 2003.

2.8 CAL-UDC-NU-000011 Rev A, , "Three Mile Island Unit 1 Radiochemical Assay Comparisons to SAS2H Calculations", Office of Civilian Radioactive Waste Management, U.S. Department of Energy, April 2002.

2.9 U.S. Nuclear Regulatory Commission, "Strategies for Application of Isotopic Uncertainties in Burnup-Credit," NUREG/CR-6811, Published June 2003, ORNL/TM-2001/257

3.0 METHODOLOGY, DESIGN INPUTS AND ASSUMPTIONS

The SAS2H (ORIGEN-S) module with the 44GROUPNDF5 cross section library of the SCALE 4.4 computer code system, reference [2.6], is used to calculate the actinide and fission product concentrations for the spent fuel. The validation of the SCALE system to predict the isotopic concentrations for the spent PWR fuel is documented in ORNL/TM-12667 (reference [2.3]), ORNL/TM-13317 (reference [2.4]) and ORNL/TM-2001/259 (reference [2.5]). The objective of these reports is to compare the measured isotopic composition to those obtained from SAS2H and subsequently, determine an acceptable, best-estimate scaling factors that can be utilized to scale the isotopic concentrations of the spent PWR fuel obtained from SCALE for use in burnup credit criticality analysis.

The SAS2H computer cases published in these reports are re-run in this calculation and the results are compared to those published therein. Differences between the results of these comparison calculations are documented to establish the isotopic scaling factors for use in burnup credit calculations.

The correction factor for each isotope based on comparison with measured data for the 44-group library is shown in reference [2.4]. A different version of the SCALE computer code was utilized in each of these reference documents. The difference between the results of the calculations and those documented in the reference documents should be small compared to the bias and uncertainty factors with the measured data. The minor differences between the versions of the code should not adversely impact the applicability of the correction and uncertainty factors presented for the same cross section set and methodology.

3.1 Design Inputs

The design inputs for this calculation are the SAS2H computer cases from reference [2.3], [2.4], [2.5] and [2.8].

3.1.1 SAS2H Input Files

Input decks for the SAS2H calculations were extracted from Appendix A of reference [2.3], Appendix B of reference [2.4] and Appendix A of reference [2.5]. The 41 cases were executed with the Transnuclear validated and verified (reference [2.1] and [2.2]) version of SCALE 4.4. The reference [2.5] document lists only three SAS2H input files compared to the 16 benchmark comparisons performed as part of the report. These three cases are considered representative and are utilized in these calculations to extend the validity of these benchmark comparisons. The case names are listed in Table 3-1 and the input files are provided on the attached disk.

In Revision 2, all the Takahama benchmarks with SAS2H are evaluated. Input files for the TMI and Takahama benchmarks (Appendix F) are prepared from data presented in reference [2.8] and [2.5], respectively.

Table 3-1. SAS2H Input Files

Case Titles	Input File
Calvert Cliffs Assembly D047 Rod MKP109, 27.35 GWd/MTU	D04727.IN
Calvert Cliffs Assembly D047 Rod MKP109, 37.12 GWd/MTU	D04737.IN
Calvert Cliffs Assembly D047 Rod MKP109, 44.34 GWd/MTU	D04744.IN
Calvert Cliffs Assembly D101 Rod MLA.98, 18.68 GWd/MTU	D10118.IN
Calvert Cliffs Assembly D101 Rod MLA.98, 26.62 GWd/MTU	D10126.IN
Calvert Cliffs Assembly D101 Rod MLA.98, 33.17 GWd/MTU	D10133.IN
Calvert Cliffs Assembly BT03 Rod NBD107, 31.40 GWd/MTU	BT0331.IN
Calvert Cliffs Assembly BT03 Rod NBD107, 37.27 GWd/MTU	BT0337.IN
Calvert Cliffs Assembly BT03 Rod NBD107, 46.46 GWd/MTU	BT0346.IN
H. B. Robinson Assembly B05 Rod N-9, 16.02 GWd/MTU	B0516.IN
H. B. Robinson Assembly B05 Rod N-9, 23.81 GWd/MTU	B0523.IN
H. B. Robinson Assembly B05 Rod N-9, 28.47 GWd/MTU	B0528.IN
H. B. Robinson Assembly B05 Rod N-9, 31.66 GWd/MTU	B0531.IN
Obrigheim (KWO) Assembly 170 Batch 94, 25.93 GWd/MTU	17025.IN
Obrigheim (KWO) Assembly 172 Batch 92, 26.54 GWd/MTU	17226.IN
Obrigheim (KWO) Assembly 176 Batch 91, 27.99 GWd/MTU	17627.IN
Obrigheim (KWO) Assembly 168 Batch 86, 28.40 GWd/MTU	16828.IN
Obrigheim (KWO) Assembly 171 Batch 89, 29.04 GWd/MTU	17129.IN
Obrigheim (KWO) Assembly 176 Batch 90, 29.52 GWd/MTU	17629.IN
Assembly D01, Rod G9, with a Burnup of 30.720 GWd/MTU	d01g931.IN
Assembly D01, Rod G10, with a Burnup of 30.510 GWd/MTU	d01g1030.IN
Assembly D01, Rod H9, with a Burnup of 31.560 GWd/MTU	d01h931.IN
Assembly D04, Rod G9, with a Burnup of 31.260 GWd/MTU	d04g931.IN
Assembly D04, Rod G10, with a Burnup of 31.310 GWd/MTU	d04g1031.IN
Assembly 509-104, Rod M11, Axial Level 7, with a Burnup of 12.042 GWd/MTU	m1107.IN
Assembly 509-032, Rod E11, Axial Level 4, with a Burnup of 15.377 GWd/MTU	e1104.IN
Assembly 509-032, Rod E11, Axial Level 7, with a Burnup of 15.898 GWd/MTU	e1107.IN
Assembly 509-032, Rod E11, Axial Level 9, with a Burnup of 11.529 GWd/MTU	e1109.IN
Assembly 509-069, Rod E11, Axial Level 1, with a Burnup of 12.859 GWd/MTU	e1101.IN
Assembly 509-069, Rod E11, Axial Level 2, with a Burnup of 20.602 GWd/MTU	e1102.IN
Assembly 509-069, Rod E11, Axial Level 4, with a Burnup of 23.718 GWd/MTU	e1104b.IN
Assembly 509-069, Rod E11, Axial Level 7, with a Burnup of 24.304 GWd/MTU	e1107b.IN
Assembly 509-069, Rod L5, Axial Level 4, with a Burnup of 24.330 GWd/MTU	l504.IN
Assembly 509-069, Rod E5, Axial Level 7, with a Burnup of 24.548 GWd/MTU	e507.IN
Assembly 509-069, Rod L11, Axial Level 4, with a Burnup of 23.928 GWd/MTU	l1104.IN
Assembly 509-069, Rod L11, Axial Level 7, with a Burnup of 24.362 GWd/MTU	l1107.IN
Assembly 509-069, Rod E5, Axial Level 4, with a Burnup of 23.867 GWd/MTU	e504.IN
Assembly 509-069, Rod L5, Axial Level 7, with a Burnup of 24.313 GWd/MTU	l507.IN
Takahama 3 PWR, SF95-4, Rod a-q, with a Burnup of 36.69 GWd/MTU	Sf95-4.in
Takahama 3 PWR, SF96-3, Rod c-m, with a Burnup of 28.20 GWd/MTU	Sf96-3.in
Takahama 3 PWR, SF97-2, Rod i-q, with a Burnup of 30.73 GWd/MTU	Sf97-2.in

3.1.2 Fuel Assembly Data

The fuel design information is identified in reference [2.3], [2.4], [2.5], and [2.8]. This data is incorporated into the SAS2H input decks. A summary of the basic fuel information is shown in Table 3-2 (from Table 2 in reference [2.3], Table 1 in reference [2.4] and Table 5 in reference [2.5]). Basic fuel information for the TMI fuel is shown in Table 2, Appendix F.

Table 3-2. Basic Fuel Assembly Parameters

Pressurized water reactor	Test assembly (ATM No.)	Enrichment (wt% ^{235}U)	Axial location (cm)	Burnup (GWd/MTU)	Cooling Time (days)
Calvert Cliffs Unit 1	D047 (ATM-104)	3.038	13.20 27.70 165.22	27.35 37.12 44.34	1870
Calvert Cliffs Unit 1	D101 (ATM-103)	2.72	8.90 24.30 161.70	18.68 26.62 33.17	2374
Calvert Cliffs Unit 1	BT03 (ATM-106)	2.453	11.28 19.92 161.21	31.40 37.27 46.46	2447
H. B. Robinson Unit 2	B05 (ATM-101)	2.561	11 26 199 226	16.02 23.81 28.47 31.66	3936 3936 3631 3631
Obrigheim	170	3.13	Assembly Average	25.93	0
Obrigheim	172	3.13	Assembly Average	26.54	0
Obrigheim	176 batch 91	3.13	Assembly Average	27.99	0
Obrigheim	168	3.13	Assembly Average	28.40	0
Obrigheim	176, batch 90	3.13	Assembly Average	29.52	0
Trino Vercelles	509-104: M11	3.897	79.2	12.042	10
Trino Vercelles	509-032: E11	3.13	158.5 79.2 26.4	15.377 15.898 11.529	10
Trino Vercelles	509-069: E11	3.13	237.7 211.3 158.5 79.2	12.859 20.602 23.718 24.304	10
Trino Vercelles	509-069: E5	3.13	158.5 79.2	23.867 24.548	10
Trino Vercelles	509-069: L11	3.13	158.5 79.2 158.5 79.2	23.928 24.362 24.330 24.313	10
Turkey Point Unit 3	D01: G9 : G10 : H9	2.556	167.6 167.0 167.0	30.72 30.51 31.56	927
Turkey Point Unit 3	D04: G9 :G10	2.556	167.6 167.0	31.26 31.31	927
Takahama-3 (SF95-4)	A-Q	4.11	216.1	36.69	0
Takahama-3 (SF96-3)	C-M	2.63	85.6	28.20	0
Takahama-3 (SF97-2)	I-Q	4.11	35.0	30.73	0

3.1.3 Acceptance Criteria

There are no specific acceptance criteria for this calculation. This calculation performs a benchmark comparison of the results obtained from two different version of the SCALE code package in order to utilize the isotopic correction factors in subsequent burnup credit analyses.

3.2 Analysis

The SAS2H module of the SCALE 4.4 computer code system with the 44 Group ENDF/B-V library was utilized to determine the isotopic and/or radioactive concentrations to perform the benchmark comparisons. The input files listed in Table 3-1 were utilized for this purpose. All the inputs and outputs are listed in Appendix A and included in the attached CD.

4.0 ASSUMPTIONS

[redacted]

5.0 COMPUTATION

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6.0 RESULTS AND CONCLUSIONS

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7.0 APPENDICES

7.1 APPENDIX A – LISTING OF COMPUTER FILES

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7.2 APPENDIX B – ISOTOPIC COMPARISONS FROM ORNL/TM-12667

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7.3 APPENDIX C – ISOTOPIC COMPARISONS FROM ORNL/TM-13317

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7.4 APPENDIX D – ISOTOPIC COMPARISONS FROM ORNL/TM-2001/259

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7.5 APPENDIX E – BEST ESTIMATE CORRECTION FACTORS

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7.6 APPENDIX F – TMI BENCHMARKS and REVISED BEST ESTIMATE FACTORS

Additional benchmark data from TMI fuel experiments (B&W 15x15) have been selected to be included in this benchmarking evaluation. The TMI information includes measured isotopic data from four rods in two different fuel assemblies. Multiple samples were taken from along the axial length of the rods which provided both measured concentrations and SAS2H calculated concentrations for various burnups. In addition to providing additional data points for the best estimate evaluation, the TMI benchmarks provide information for several of the fission product isotopes for which the other benchmarks provide very little if any data, i.e. Mo-95, Ru-101, Rh-103 and Ag-109.

Reference [2.8] provides the physical parameters for the fuel rods along with the calculated and measured isotopic concentrations. Information on the samples is provided in Table 1 below.

Table 1 Fuel Sample Characteristic Parameters [2.8 Table 1]

Assembly	Rod Number	Sample ID	Axial Location (in)	Initial Enrichment (wt% U-235)	Measured Burnup (GWD/MTU)
NJ05YU	H6	TMI A2	29.4	4.00	50.6
NJ05YU	H6	TMI B2	45.3	4.00	50.1
NJ05YU	H6	TMI C1	92.7	4.00	50.2
NJ05YU	H6	TMI C3	61.5	4.00	51.3
NJ05YU	H6	TMI D2	126.8	4.00	44.4
NJ05YU	H6	TMI A1B	15.25	4.00	44.8
NJ05YU	H6	TMI B1B	61.4	4.00	54.5
NJ05YU	H6	TMI B3J	30.32	4.00	53.0
NJ05YU	H6	TMI C2B	76.62	4.00	52.6
NJ05YU	H6	TMI D1A2	103.11	4.00	55.7
NJ05YU	H6	TMI D1A4	115.11	4.00	50.5
NJ070G	O1	O1S1	15.5	4.65	25.8
NJ070G	O1	O1S2	77.6	4.65	29.9
NJ070G	O1	O1S3	109.5	4.65	26.7
NJ070G	O12	O12S4	15.5	4.65	23.7
NJ070G	O12	O12S5	77.6	4.65	26.5
NJ070G	O12	O12S6	109.5	4.65	24.0
NJ070G	O13	O13S7	15.5	4.65	22.8
NJ070G	O13	O13S8	77.6	4.65	26.3

The days considered for downtimes [2.8] are 1529 days for samples O1S2, O12S5, O13S7, and O13S8; downtime of 1298 days for samples O1S1, O1S3, O12S4, and O12S6; downtime of 1103 days for samples TMI A2, B2, C1, C3, and D2: and a

downtime of 1711 days for samples TMI A1B, B1B, B3J, C2B, D1A2, and D1A4. Fuel assembly geometry and material information is shown in Table 2 below.

Table 2 Fuel Assembly Geometry and Material Information

Fuel Assembly Identification	NJ05YU	NJ070G
Fuel Assembly Data		
Lattice	15x15	15x15
Number of fuel rods	208	208
Number of guide tubes	16	16
Number of Instrument tubes	1	1
Latttice Pitch (cm)	1.4427	1.4427
Fuel Rod Data		
Clad OD (cm)	1.0922	1.0922
Clad ID (cm)	0.95758	0.95758
Fuel Rod length (cm)	391.5664	391.5664
Fill gas	He	He
Cladding Material	Zircaloy-4	Zircaloy-4
Fuel Pellet Data		
Diameter (cm)	0.9362	0.9398
Active fuel length (cm)	360.172	357.124
Wt% U-235	4.00	4.65/.19 (Gd)[1]
Pellet Composition		
U-234 (wt% heavy metal)	0.040	0.045
U-235 (wt% heavy metal)	4.013	4.657
U-236 (wt% heavy metal)	<0.001	<0.001
U-238 (wt% heavy metal)	95.947	95.298
Burnable Poison Rod Data		
Absorber diameter (cm)	0.8636	0.8636
Cladding outer diameter (cm)	1.0922	1.0922
Cladding inner diameter (cm)	0.9144	0.9144
Pellet density (g/cc)	3.7	3.7
Pellet material	Al_2O_3-B_4C	Al_2O_3-B_4C
Wt% B_4C	1.7	2.1
Cladding material	Zircaloy-4	Zircaloy-4

1. Four of the fuel rods contain 2.0 wt% Gd_2O_3 with 4.19 wt% U-235

Table 7 in the published reference provides the moderator density for each sample during depletion. Based on his density, a corresponding temperature was determined using a best fit curve from previous analyses. As in the other SAS2H analyses, a Path B model is utilized. The Path B model parameters are created using the same methodology as that employed in the TN-40 SAS2H analyses.

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