NAC INTERNATIONAL	CALCULATION PACKAGE COVER SHEET	Calculation No: 71160-2025 NP Page 1

PROJECT NAME: NEWGEN	CLIENT: NAC International

CALCULATION TITLE:

NONPROPRIETARY

Fuel Assembly Structural Evaluation

PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

Perform a structural evaluation for the end drop of an intact fuel assembly for the fuel assembly inventory contained in this calculation. The end drop acceleration is limited to 48g's. The effect of the high burn up condition (60 GWD/MTU) of the fuel rod is taken into account

A side drop evaluation is performed for PWR assemblies with a missing grid allowing a maximum spacing of 60 inches.

Revision	Affected Pages	Revision Description	Name and Initials of Preparers & Checkers	Functional Manager Approval/Date
0	1-15 A1 – A4 B1 – B7	Initial Issue	Mike Yaksh Alan Lin	Mike Yaksh 8/05/07
1	1,2,3 B1-B8 C1-C13	Added side drop evaluation for PWR with a missing grid	Mike Yaksh *Mike Yaksh MY* Christine Wang *Christine Wang CXW*	Mike Yaksh *Mike Yaksh* *8/31/07*

INDEPENDENT DESIGN VERIFICATION CHECK SHEET

Calculation Number: 71160-2025 **Revision:** 1

Scope of Analysis File: Fuel assembly structural evaluation

Review Methodology: Check of Calculations: ✓
Alternate Analyses: ______
Other (explain): ______

Confirm that the Calculation Package Reviewed Includes:

1. Statement of Purpose .... ✓
2. Defined Method of Analysis .... ✓
3. Listing of Assumptions .... ✓
4. Detailed Analysis Record .... ✓
5. Statement of Conclusions / Recommendations (if applicable) .... ✓
6. References .... ✓

Step	Activities	Verification Yes	Verification No	Verification N/A	Comments
1	For the scope of the defined analysis: A. Are the required data input complete?	✓			
	1. Material Properties	✓			
	2. Geometry (Drawing Reference)	✓			
	3. Loading Source Term	✓			
	4. If a supporting analysis is required to define the load state, has it been defined?	✓			
	B. Are Boundary conditions acceptable?	✓			
2	Is the method of analysis adequate for the defined scope?	✓			
3	Is the worst case loading/configuration documented?	✓			
4	Are the acceptance criteria defined and complete?	✓			
5	Has all concurrent loading been considered?	✓			
6	Are analyses consistent with previous work for method and approach?	✓			
7	Are the records for input and output complete?	✓			
8	Has the computer output been verified?	✓			
9	Is traceability to verified software complete?	✓			
10	Is the statement of conclusions and recommendations complete and acceptable for the project and objectives of the defined purpose?	✓			
11	Are references complete?	✓			
12	Are results reasonable for purpose of calculation?	✓			
13	Has the cumulative effect of specified dimension tolerances on the fabrication/operation fit-up been addressed?			✓	See SP-111

Christine X. Wang / [signature] 8/30/07

Reviewer (Name/Signature) Date

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1.0 SYNOPSIS OF RESULTS

A structural evaluation is performed for the PWR and BWR fuel assembly for end drop conditions. The detailed evaluation is performed for the PWR which is shown to bound the BWR fuel rod.

The PWR and BWR fuel inventory was taken from Ref.1. The table below shows a sample of the fuel assemblies and contains the bounding conditions in terms of the minimum and maximum cross sectional moment of inertia.

PWR Fuel Assembly	Cladding Diameter (in)	Cladding Thickness (in)	Fuel Rod Pitch (in)	Gap between fuel assembly and fuel tube wall (in)
We 17x17	0.360	0.021	0.496	0.564
We 15x15	0.417	0.024	0.563	0.561
We 14x14	0.400	0.022	0.556	1.232
CE16x16	0.382	0.025	0.506	0.888
CE14x14	0.440	0.026 - 0.031	0.580	0.880
BW17x17	0.377	0.022	0.502	0.451
BW15x15	0.414	0.022	0.568	0.494

BWR Fuel Assembly	Cladding Diameter (in)	Cladding Thickness (in)
GE 7x7	0.563	0.032
GE 7x7	0.563	0.032
GE 8x8-2	0.483	0.032
GE 8x8-2	0.483	0.032
GE 8x8-4	0.484	0.032
GE 8x8-4	0.484	0.032
GE 9x9-2	0.441	0.028
GE 10x10-2	0.378	0.024

The PWR fuel assembly is considered to have a missing grid at the bounding location near the bottom end of the fuel assembly. The missing grid condition is simulated by considering the distance from the bottom of the fuel rod to the first grid to be 60 inches.

A transient evaluation was performed for the PWR fuel rod for a maximum bowed condition of 1.23 inch. The minimum safety factor determined for the bounding end drop condition is 2.00.

2.0 PURPOSE

The purpose of this Calculation is to perform an evaluation of the end drop condition for the fuel assembly.

3.0 METHOD OF ANALYSIS

For the end drop evaluation a transient evaluation is performed using LS-DYNA.

4.0 DESIGN INPUT AND ASSUMPTIONS

4.1 Design Input

The following design input is used for the PWR fuel rod evaluation (Reference 1):

The following design input is used for the BWR fuel rod evaluation (Reference 1):

Clad and pellet properties:

	Modulus of Elasticity (10^6 psi)	Density (lb/in^3)
Rod Clad	10.47 (Ref. 5)	0.237 (Ref. 2)
Fuel pellet	13 (Ref. 3)	0.396 (Ref. 3)

Dimensions for the PWR basket tube: (maximum slot opening is 8.86 inches) Ref. 4

4.2 Assumptions/Design Considerations

5.0 ANALYSIS DETAILS

Transient analyses using LS-DYNA are performed to evaluate the transient response in the end drop for the PWR fuel rods.

5.1 End Drop Analysis of the PWR fuel rod

In the end drop orientation, the fuel rods are laterally restrained by the grids and come into contact with the fuel assembly base. As opposed to employing a straight fuel assembly in the evaluation with all the grids present, the fuel assembly is considered to have a maximum possible bow with or without a missing grid (the configuration still meets the acceptable configuration for undamaged fuel). The evaluation of the PWR fuel rod is based on the following representative samples of PWR fuel assemblies:

PWR Fuel Assembly	Cladding Diameter (in)	Cladding Thickness (in)	Fuel Rod Pitch (in)	Gap between fuel assembly and fuel tube wall (in)
We 17x17	0.360	0.021	0.496	0.564
We 15x15	0.417	0.024	0.563	0.561
We 14x14	0.400	0.022	0.556	1.232
CE16x16	0.382	0.025	0.506	0.888
CE14x14	0.440	0.026 - 0.031	0.580	0.880
BW17x17	0.377	0.022	0.502	0.451
BW15x15	0.414	0.022	0.568	0.494

Four (4) LS-DYNA models are considered which incorporate the bow of 1.23 inch. These cases envelope the range of the cross sectional moments for the PWR fuel rods and the grid spacing at the bottom of the fuel assembly as summarized in the following Table.

Case	Lowest grid spacing (inch)	Cross sectional moment of Inertia	Fuel rod OD (inch)	Fuel Clad thickness (w/o oxide effect) (inch)
1	60	Minimum	0.36	0.021
2	33	Minimum	0.36	0.021
3	25	Minimum	0.36	0.021
4	60	Maximum	0.44	0.031

This acceleration time history is shown below. The velocity associated with this acceleration is 527 in/sec or greater.

Time (sec)	Acceleration (in/sec^2)
0.000	0.
0.01	10384
0.02	13846
0.036	18461
0.038	15384
0.045	1923
0.05	0

The maximum stress intensity at the mid-span of the lowest span of the fuel rod is shown for each case in the table below. The temperature of the fuel at the bottom end of the basket is bounded by 752°F (400°C) and the static yield strength for irradiated ziracloy at 752°F is 69.6 ksi (Reference 5).

Case	Maximum Stress Intensity (ksi) at mid-span of lowest grid spacing	Factor of safety against yield strength
1	22.8	3.05
2	34.8	2.00
3	17.0	4.09
4	15.2	4.58

The case using the 33-inch spacing in conjunction with the minimal cross section (Case 2) is identified as the bounding case.

In comparing case 4 to cases 1 and 2, the effect of the maximum cross sectional moment (the ratio of the maximum cross sectional moment to the minimal cross sectional moment is approximately 2.7) indicates that the cross sectional moment has more influence than the grid spacing on the maximum stress.

These results confirm that high burnup PWR fuel with one missing grid will remain undamaged for design basis cask end drop load conditions.

5.2 End Drop Analysis of the BWR fuel rod

The evaluation of the BWR fuel rod is based on the following representative sample of BWR fuel rods from Ref.1:

Fuel Assembly	Cladding Diameter (in)	Cladding Thickness (in)
GE 7x7	0.563	0.032
GE 7x7	0.563	0.032
GE 8x8-2	0.483	0.032
GE 8x8-2	0.483	0.032
GE 8x8-4	0.484	0.032
GE 8x8-4	0.484	0.032
GE 9x9-2	0.441	0.028
GE 10x10-2	0.378	0.024

The location of the lateral constraints in the BWR fuel are: 0.00 in, 22.88 in, 43.03 in, 63.18 in, 83.33 in, 103.48 in, 122.3 in, 143.78 in, and 163.42 in.

For the PWR fuel rod (with all grids and with the 120 micron thickness reduction) the largest ratio of unsupported length (L) to radius of gyration of the cladding cross section (r) is

$$L/r = \frac{33}{0.5 \times \sqrt{((0.360 - 2 \times 0.0047)/2)^2 + (0.318/2)^2}} = 279$$

The ratio (L/r) for a BWR fuel rod (with the 125 micron thickness reduction for high burnup fuel) is

$$L/r = \frac{22.88}{0.5\times\sqrt{((0.378-2\times0.0049)/2)^2+(0.330/2)^2}} = 185$$

The analysis presented in Section 5.1 is bounding for both PWR and BWR fuel rods, because the (L/r) for the PWR fuel rod is larger than the (L/r) for the BWR fuel rod. Therefore, no further evaluation of the BWR fuel rod is required.

5.3 Input / Output Files

The names of ANSYS macros to generate the models and the LS-DYNA files to perform the LS-DYNA analyses are shown below. The output cover sheets are contained in Appendix A. Listing of the ANSYS macros and LS-DYNA files contained on the compact disk is shown in Appendix B.

Case	ANSYS Macro	LS-DYAN Input file
1	posroda.mac	fuelrodbuckling_6a.dyn
2	posrodb.mac	fuelrodbuckling_6b.dyn
3	posrodf.mac	fuelrodbuckling_6f.dyn
4	posrodd.mac	fuelrodbuckling_6d.dyn

6.0 SUMMARY OF RESULTS/CONCLUSIONS

The end drop evaluation of the PWR and BWR fuel assemblies contained in Ref. 1 is performed using bounding parameters. The bounding load condition for the evaluation is the end drop orientation using a maximum acceleration of 48g's. The minimum safety factor for the fuel rod due to bending is 2.0 against the yield strength which confirms that the fuel rod will maintain its integrity and will remain intact during the end drop event.

7.0 REFERENCES

1.

2.

3.

4. NAC Drawings:
71160-051 REV. 7, FUEL TUBE ASSEMBLY, TYPE 1, 37 ELEMENT PWR, NEWGEN (as modified by DCR 71160-051-7A)
71160-052 REV. 6, FUEL TUBE ASSEMBLY, TYPE 2, 37 ELEMENT PWR, NEWGEN (as modified by DCR 71160-052-6A)
71160-053 REV. 6, FUEL TUBE ASSEMBLY, TYPE 3, 37 ELEMENT PWR, NEWGEN (as modified by DCR 71160-053-6A)
71160-054 REV. 6, FUEL TUBE ASSEMBLY, TYPE 4, 37 ELEMENT PWR, NEWGEN (as modified by DCR 71160-054-6A)
71160-055 REV. 6, FUEL TUBE ASSEMBLY, TYPE 5, 37 ELEMENT PWR, NEWGEN

5.

Figures 1, 2 & 3 on pages 13, 14 & 15 are proprietary and, therefore, have been deleted.

APPENDIX A

ANSYS and LS-DYNA Output

COMPUTER OUTPUT COVER SHEET

Project Name: MAGNASTOR

Project Number: 71160

File Number (Input File): See Table Below

Calculation Number: 71160-2025 Rev. 0

Title of Analysis: ANSYS analyses for the PWR fuel rod – Initial Bow

Program: ANSYS **Version:** 10.0 **Originator:** ANSYS, Inc.

Computer Manufacturer / Operating System: DELL Optiplex GX620/ Windows XP

Computer Identification / NAC Number: 00-12-3F-C7-FB-F4 / NAC1550

Hardware Verified: YES [X] NO [ ] (if no, calculation is preliminary)

Computer Verification Report Number: EA913-1020-006 Rev. 0 5/3/2006

Output File / Title of Case: See Table Below

Date of Run: See Table Below

Prepared by: Mike Yaksh / Mike Yaksh Date: 8/5/07

Checked by: Alan Liu / Alan Liu Date: 8/5/07

Case	ANSYS Input	ANSYS Output	Date of Run
1	posroda.mac	posroda.db	8/4/07
2	posrodb.mac	posrodb.db	8/4/07
3	posrodc.mac	posrodc.db	8/4/07
4	posrodf.mac	posrodf.db	8/4/07

COMPUTER OUTPUT COVER SHEET

Project Name: MAGNASTOR

Project Number: 71160

File Number (Input File): See Table Below

Calculation Number: 71160-2025 Rev. 0

Title of Analysis: LS-DYNA analyses of the PWR fuel rod enddrop

Program: LS-DYNA **Version:** 970 **Originator:** LSTC Inc.

Computer Manufacturer / Operating System: AMD Opteron / Professional X64 Edition Version 2003

Computer Identification / NAC Number: 00-11-25-1E-44-18 / NAC1533

Hardware Verified: YES [X] NO [ ] (if no, calculation is preliminary)

Computer Verification Report Number: EA913-1030-123 Rev. 0

Output File / Title of Case: See Table Below

Date of Run: See Table Below

Prepared by: Mike Yaksh, Mike Yaksh Date: 8/5/07

Checked by: Alan Liu Alan Liu Date: 8/5/07

Case	LS-DYNA MAIN INPUT FILE	D3PLOT file (1)	Date of D3PLOT file (1)
2	FUELRODBUCKLING_6B.DYN	d3plot49	8/04/07
4	FUELRODBUCKLING_6C.DYN	d3plot48	8/05/07

(1) This is the last D3PLOT file generated

COMPUTER OUTPUT COVER SHEET

Project Name: MAGNASTOR

Project Number: 71160

File Number (Input File): See Table Below

Calculation Number: 71160-2025 Rev. 0

Title of Analysis: LS-DYNA analyses of the PWR fuel rod enddrop

Program: LS-DYNA **Version:** 970 **Originator:** LSTC Inc.

Computer Manufacturer / Operating System: AMD Opteron / Professional X64 Edition Version 2003

Computer Identification / NAC Number: 00-11-25-1E-44-08 / NAC1534

Hardware Verified: YES [X] NO [ ] (if no, calculation is preliminary)

Computer Verification Report Number: EA913-1030-124 Rev. 0

Output File / Title of Case: See Table Below

Date of Run: See Table Below

Prepared by: Mike Yaksh [signature] Date: 8/5/07

Checked by: Alan Lin [signature] Date: 8/5/07

Case	LS-DYNA MAIN INPUT FILE	D3PLOT file (1)	Date of D3PLOT file (1)
1	FUELRODBUCKLING_6A.DYN	d3plot49	8/04/07
3	FUELRODBUCKLING_6F.DYN	d3plot49	8/05/07

(1) This is the last D3PLOT file generated

Appendix B

ANSYS/LS-DYNA Input / Output Files on Disk

Pages B2 through B8 are proprietary and, therefore, have been deleted.

APPENDIX C

Evaluation of Side Drop for a PWR with a Missing Grid

C.1 SYNOPSIS OF RESULTS

A structural evaluation is performed for the PWR fuel assembly with a missing grid of up to 60 inches for a 60g side drop condition. The yield strength is the stress allowable. The minimum margin of safety (M.S.) is computed to be +0.45.

Case	Maximum Stress (ksi)	M.S Against Yield Strength
CE14×14	37.1	+0.88
WE15×15	48.1	+0.45
WE17×17	46.3	+0.50

This confirms that the PWR fuel rod with a missing grid subject to high burn up conditions will remain intact for a side drop condition, which bounds the tip-over accident condition.

C.2 PURPOSE

The purpose of this Appendix is to perform an evaluation of the side drop condition for the PWR fuel assembly with a missing grid.

C.3 METHOD OF ANALYSIS

For the side drop evaluation a static evaluation is performed using ANSYS with a lateral load of 60g's.

C.4 DESIGN INPUT AND ASSUMPTIONS

C.4.1 Design input

The fuel rod dimension and material properties used in this Appendix are taken from Section 4 of the main body of this calculation.

C.4.2 Assumptions/Design Considerations

C.5 ANALYSIS DETAILS

Static analyses using ANSYS are performed to evaluate the response in the side drop for the PWR fuel rods with a missing grid, of which the maximum spacing is 60 inches. The analyzed bounding fuel rod length of 60.0 inches envelopes all fuel types and includes the condition with a missing support grid in the fuel assembly. This configuration is evaluated for a 60g side drop. During a side drop, the maximum deflection of a fuel rod is based on the fuel rod spacing of the fuel assembly. Assuming a 17×17 array

, the maximum fuel rod deflection, including the 120 micron oxide layer, is:

Case	Rod diameter (inches)	Clad thickness (inches)	Cross sectional Area (A) (in^2)	Cross sectional moment (I) (in^4) 10^{-4}	Z (in^3) 10^{-3}	Span (inches) Ref. 2 [page]
CE14×14	0.440	0.031	0.0334	6.854	3.18	16.8[2A-64]
WE15×15	0.417	0.024	0.0197	2.723	2.20	26.2 [2A-322]
WE17×17	0.360	0.0205	0.0163	2.289	1.33	20.6[2A-346]

ANSYS is used to perform a static analysis with a lateral loading of 60g.

C.5.2 Input / Output Files

The names of ANSYS macros to generate the models and to perform the static analyses are shown below. The table also contains the summary file showing the maximum stress in the beam elements (parameter name STR_MX). The output cover sheets are contained in Section C.6. Listing of the ANSYS macros contained on the compact disk is shown in C.7

Case	Fuel	ANSYS Macro (*.mac)	ANSYS Summary file (*.sum)
1	CE14×14	posrCE_E,,60*	posrCE_E
2	WE15×15	posrWE_Y,,60*	posrWE_Y
3	WE17×17	posrWE_z,,60*	posrWE_z

* The second argument is the acceleration (g)

C.6 SUMMARY OF RESULTS/CONCLUSIONS

The side drop evaluation of the PWR fuel assemblies contained in Ref. 1 is performed using a bounding 60 inch spacing for the missing grid. The bounding load condition for the evaluation is the side drop orientation using a maximum acceleration of 60g's. The safety factors for the fuel rod due to the lateral loading is shown in the Table below.

Case	**Maximum Stress (ksi)**	**M.S Against Yield Strength**
CE14×14	37.1	+0.88
WE15×15	48.1	+0.45
WE17×17	46.3	+0.50

The yield strength is the stress allowable. The minimum margin of safety (M.S.) is computed to be +0.45 which confirms that the fuel rod will maintain its integrity and will remain intact during the end drop event.

Figure C-1.

C.7 COMPUTER OUTPUT COVER SHEET

Project Name: Magnastor

Project Number: 71160

File Number (Input File): See Table Below

Calculation Number: 71160-2025 Rev. 1

Title of Analysis: ANSYS analyses for the PWR fuel rod – Side drop with a missing grid

Program: ANSYS **Version:** 10.0 **Originator:** ANSYS, Inc.

Computer Manufacturer / Operating System: DELL Optiplex GX620/ Windows XP

Computer Identification / NAC Number: 00-12-3F-C7-FB-F4 / NAC1550

Hardware Verified: YES [X] NO [ ] (if no, calculation is preliminary)

Computer Verification Report Number: EA913-1020-006 Rev. 0 5/3/2006

Output File / Title of Case: See Table Below

Date of Run: See Table Below

Prepared by: Mike Yaksh Mike Yaksh Date: 8/30/07

Checked by: Christine X. Wang Christine X. Wang Date: 8/30/07

Case	Fuel	ANSYS Macro (*.mac)	ANSYS Summary file (*.sum)	Date of Run
1	CE14×14	posrCE_E	posrCE_E	8/28/07
2	WE15×15	posrWE_Y	posrWE_Y	8/29/07
3	WE17×17	posrWE_z	posrWE_z	8/28/07

C.8, Listing of ANSYS Macros, on pages C7 through C13 is proprietary and, therefore, has been deleted.

C.8 Listing of ANSYS Macros