NAC INTERNATIONAL	**CALCULATION PACKAGE COVER SHEET**	Calculation No: **71160-2026-NP** Page **1**

PROJECT NAME: **NEWGEN**	CLIENT: **NAC International**

CALCULATION TITLE: NONPROPRIETARY

Fuel Assembly Structural Evaluation for the Storage End Drop Condition

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 developed due to a 24-inch end drop accident condition of the storage cask of the UMS and MAGNASTOR systems. The effect of the high burn up condition (60 GWD/MTU) of the fuel rod is taken into account

This calculation considers the bounding conditions for both MAGNASTOR and the NAC UMS storage systems.

Revision	Affected Pages	Revision Description	Name and Initials of Preparers & Checkers	Functional Manager Approval/Date
0	1-30 A1 – A3 B1 – B12	Initial Issue	Mike Yaksh Mike Yaksh MY S. Alan Lin SAL Alan	Mike Yaksh Mike Yaksh 11/30/07

INDEPENDENT DESIGN VERIFICATION CHECK SHEET

Calculation Number: 71160-2026 **Revision:** 0

Scope of Analysis File: Fuel assembly structural evaluation for the Storage End Drop Condition

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	No	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

S. Alan Lin / [signature] 11/29/07

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 the 24-inch end drop condition of the storage cask. The detailed evaluation is performed for the PWR which is shown to bound the evaluation of the BWR fuel assembly.

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 missing grids 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 rods with a bounding bow
The analyses consider the bounding conditions for the MAGNASTOR and the UMS.

The minimum factor of safety determined for the bounding end drop condition is 1.86.

2.0 PURPOSE

The purpose of this calculation is to perform an evaluation for the PWR and BWR fuel assembly for a 24-inch end drop condition of the storage cask.

3.0 METHOD OF ANALYSIS

For the end drop evaluation a transient evaluation is performed using LS-DYNA. The fuel rod model corresponds to the PWR fuel assemblies and incorporates a bounding bow

4.0 DESIGN INPUT AND ASSUMPTIONS

4.1 Design Input

The following design input is used for the PWR 17x17 fuel rod evaluation (Reference 1) which considers the cross section with the smallest cross sectional moment:

The following design input is used for the PWR 14x14 fuel rod evaluation (Reference 1) which considers the cross section with the smallest cross sectional moment:

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

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

Five (5) LS-DYNA models are considered for the 24-inch cask end drop conditions.

Case 5 is used to confirm that the acceleration associated with the 24-inch end drop of the UMS system provides bounding stresses.

Case	Fuel Assembly	Lowest grid spacing (inch)	Acceleration definition for 24-inch cask end drop
1	14×14	60*	UMS
2	14×14	33	UMS
3	17×17	60*	UMS
4	17×17	33	UMS
5	17×17	60*	MAGNASTOR

* The 60-inch spacing corresponds to the fuel rod configuration with two missing grids at the bottom of the fuel assembly

The acceleration time history data are shown below.

Time (sec)	**UMS Acceleration (in/sec^2)**	**Time (sec)**	**MAGNASTOR Acceleration (in/sec^2)**
0.000	0.	0.000	0.
0.008	773.	0.00115	10508.
0.012	17002.	0.00159	11153.
0.0124	17388.	0.0041	8571.
0.0128	17002.	0.0078	9862
0.02	0.	0.0117	8805.
		0.0153	1057.
		0.024	1057.
		0.0275	0

The maximum shear stress result from LS-DYNA is factored by two to determine the maximum stress intensity. The maximum stress intensity in the fuel clad for each of the cases is shown in Figures 5-5 through 5-14. These figures also show the location of the maximum stresses.

The table below contains the maximum stress intensity for the five cases.

Maximum Stress Intensity for the Five LS-DYNA Analyses

Case	Maximum Stress Intensity (ksi)	Factor of safety against yield strength
1	25.4	3.08
2	21.8	3.59
3	41.9	1.86
4	34.7	2.25
5	22.0	3.54

The case using the 60-inch spacing in conjunction with the minimal cross-section (Case 3) is identified as the bounding case. All stresses were shown to be less than the yield strength.

The results confirm that high burnup PWR fuel with a maximum distance of 60 inches from bottom to the first grid will remain structurally adequate for the storage 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

$$L/r \;=\; \frac{33}{0.5\times\sqrt{((0.360-2\times0.0047)/2)^2+(0.318/2)^2}} = 279$$

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-DYNA Input file
1	pf146ab55.mac	FUELBUCKLING_PF146A_BL_B55.DYN
2	pf146d55.mac	FUELBUCKLING_PF146D_BL_B55.DYN
3	pf176ab55mac	FUELBUCKLING_PF176A_BL_B.DYN
4	pf176d55.mac	FUELBUCKLING_PF176D_BL_B.DYN
5	pf176ab55mac	FUELBUCKLING_PF176A_BL_B_MAG.DYN

Figures 5-1 through 5-14 on pages 15 through 28 are proprietary and, therefore, have been deleted.

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 for the storage condition for both the MAGNASTOR and the UMS design. The minimum safety factor for the fuel rod due to bending is 1.86 (See Table of Maximum Stress Intensity for the Five LS-DYNA Analyses in Section 5.1) against the yield strength which confirms that the fuel rod will maintain its integrity and will remain intact during the 24-inch storage cask end drop accident.

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

790-081 REV. 11, PWR Fuel Tube, Captivated Boral, NAC UMS

5.

6.

7.

8.

9.

10.

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: 71160-2026 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: 11/29/07

Checked by: [signature] / S. Alan Lin Date: 11/29/07

Case	ANSYS Input	ANSYS Output	Date of Run
1	pf146ab55.mac	pf146ab55.db	11/21/07
2	pf146d55.mac	pf146d55.db	11/21/07
3	pf176ab55mac	pf176ab55.db	11/21/07
4	pf176d55.mac	pf176d55..db	11/21/07
5	pf176ab55mac	pf176ab55.db	11/21/07

COMPUTER OUTPUT COVER SHEET

Project Name: MAGNASTOR

Project Number: 71160

File Number (Input File): See Table Below

Calculation Number: 71160-2026 Rev. 0

Title of Analysis: LS-DYNA analyses of the PWR fuel for the storage cask end drop

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: 11/29/07

Checked by: S. Alan Liu / S. Alan Liu Date: 11/29/07

Case	LS-DYNA MAIN INPUT FILE	D3PLOT file (1)	Date of D3PLOT file (1)
1	FUELBUCKLING_PF146A_BL_B55.DYN	d3plot90	11/28/07
2	FUELBUCKLING_PF146D_BL_B55.DYN	d3plot90	11/28/07
3	FUELBUCKLING_PF176A_BL_B.DYN	d3plot134	11/28/07
4	FUELBUCKLING_PF176D_BL_B.DYN	d3plot134	11/28/07
5	FUELBUCKLING_PF176A_BL_B_MAG.DYN	d3plot101	11/28/07

(1) This is the last D3PLOT file generated

Appendix B

ANSYS/LS-DYNA Input / Output Files on Disk

Pages B2 through B12 are proprietary and, therefore, have been deleted.