ATTACHMENT (10)

NONPROPRIETARY TRANSNUCLEAR, INC. CALCULATION, "END DROP STRUCTURAL EVALUATION OF CE 14X14 FUEL ASSEMBLY IN A 32P+ DSC," DOCUMENT NO. NUH32P+.0202, REVISION NO. 1

Non-proprietary Version

AREVA TRANSNUCLEAR INC.	Form 3.2-1 Calculation Cover Sheet TIP 3.2 (Revision 3)	Calculation No.:	NUH32P+.0202
		Revision No.:	1
		Page: 1 of 31	

DCR NO (if applicable) : NUH32P+ 002	PROJECT NAME: NUH32P+ Dry Fuel Storage Project for CCNPP
PROJECT NO: NUH32P+	CLIENT: CCNPP

Calculation Title: End Drop Structural Evaluation of CE 14x14 PWR Fuel Assembly in a 32P+ DSC

SUMMARY DESCRIPTION:

1) Calculation Summary

The purpose of this calculation is to verify the structural adequacy of the CE 14x14 fuel assembly Zircaloy clad fuel rods in a 32P+ DSC in the event of a transfer cask, top end drop accident.

2) Storage Media Description

1 CD (Rev.0), + 1DVD (Rev.1)

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

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

Software Utilized: ANSYS	**Version:** 8.1 and 10A1
Calculation is complete: Huan Li Originator Name and Signature:	Date: 12/05/08
Calculation has been checked for consistency, completeness and correctness: Raheel Haroon Checker Name and Signature:	12/05/08 Date:
Calculation is approved for use: PETER SHIH Project Engineer Name and Signature:	12/8/08 Date:

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REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISCS
0		Original	All	All
1	12/8/08	Four revisions are made as follows: 1. The initial bowing is changed to 0.015 in. consistent with NUREG 1864 and more recent end drop calculations; 2. The fuel cladding thickness is reduced by 0.00281 in. (125 microns thickness oxidation of the outer surface); 3. The methodology is modified (see section 3); 4. The new developed acceleration time histories are applied to the cask (see section 5.3).	1-24, 26	Added 1 DV D

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1. Purpose

The purpose of this calculation is to verify the structural adequacy of the CE 14x14 fuel assembly Zircaloy clad fuel rods in a 32P DSC in the event of a transfer cask, top or bottom end drop accident.

2. References

2.1. NUHOMS® 32P Dry Shielded Canister Design Specification, SP-0564C-R4.
2.2. ANSYS Computer Code and User's Manuals, Rev. 8.1.
2.3. Not Used
2.4. Not Used
2.5. Not used.
2.6. TN Calculation No. 972-179, Rev. 0, "TN-68 High Burnup Cladding Mechanical Properties".
2.7. T Sanders et al., "A Method for Determining the Spent-Fuel Contribution to Transport Cask Containment Requirements," Sandia Report SAND90-2406, Sandia National Laboratories, Albuquerque, NM, 1992.
2.8. Not Used
2.9. Not Used
2.10. "Nuhoms® -32P DSC Basket Details," Drawing 10950-30-07, Rev 5.
2.11. An Swam, L.F., Strasser A.A., Cook J.D., Burger J.M., "Behavior of Zircaloy-4 and Zirconium Linear Zircaloy-4 Cladding at High Burnup" Proceedings of the 1997 International Topical Meeting on LWR Fuel Performance, Portland, Oregon March 2-6, 1997.
2.12. Not Used
2.13. NUH32P+.0202, Rev. 0, "End Drop Structural Evaluation of CE 14x14 PWR Fuel Assembly in a 32P DSC"
2.14. Not Used
2.15. Adkins, Harold E. Jr., Brian J. Koeppel and David T. Tang, "Spent Nuclear Fuel Structural Response when Subject to an End Impact Accident," PVP2004-2804, San Diego, CA, July 25-29 2004.
2.16. NUREG-1864, "A Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant," USNRC, March, 2007.
2.17. Calvert Cliff Independent Spent Fuel Storage Installation, "Updated Safety Analysis Report", Rev. 17, Sept., 8th, 2008.

3. Methodology

The methodology used in this calculation is based on References 2.7, 2.15 and 2.16, for the following:

- Transient dynamic analysis to evaluate the structural integrity of fuel cladding for accident end drop.
- Fuel cladding to basket wall contact modeled
- Fuel cladding is initially bowed
- Fuel cladding fails when total strain exceeds permissible strain of zircaloy

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In addition, the modification for the model is made and summarized as follows:

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The strain results are compared to the permissible strains for zircaloy under the dynamic loads of an end drop condition. A single fuel rod (with intermediate supports at grid spacer locations) is modeled at the center of the assembly for this analysis. The fuel rod to basket wall interface is modeled via contact elements.

Calvert Cliff's USAR [2.17, section 8.2.5.2] calculates the maximum deceleration of 51g for 80 inch end drop. Total strains in the fuel rod are calculated for loads ranging from 50% to 200% (25.5 g to 102 g) of the maximum calculated deceleration. This range bounds the loads for an 80 inch end drop.

Where plastic deformation is encountered, the deformed rods in the fuel grid may move further apart or may move closer together during an end drop. From a criticality perspective, expansion of the lattice increases neutron multiplication, and compression of the lattice reduces it. For evaluating the effects of the end drop on the criticality analysis, it is necessary to know, if plastic deformation could result in an increase in lattice sectional area. Since no plastic deformation results for the CE 14x14 STD fuel assembly, there is no reason to perform this analysis in this case.

4. Assumptions

The following assumptions are made to qualify and support the reported computational choices:

- The fuel pellets contained in the cladding tube are conservatively assumed not to contribute to axial or bending stiffness and the fuel pellet weight is assumed to be carried by the cladding tube.
- The maximum temperature in the fuel cladding cannot exceed 752 °F for normal operating conditions [2.1].
- Material properties of zircaloy-4 at 750 °F are conservatively used [2.6]. The yield stress value includes strain rate correction effects ($\dot{\varepsilon} = 0.5s^{-1}$).
- Since there is no data available for the shape of an irradiated fuel cladding, a conservative bowing initial condition is applied that assumes that all rods bow together and that all assume the shape of the lowest buckling mode of the rods.
- The fuel cladding thickness is reduced by 0.00281 inch to account for 125 microns thickness oxidation of the outer surface (See Appendix A for details). In order to calculate the actual thickness of the cladding needed to be reduced, the oxide thickness accumulation needed to be corrected. A Pilling-Bedworth factor of 1.75 [2.11, page 426] is used as follows:

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$$(125/1.75) \times 10^{-6} \times 39.372 = 0.00281 \text{ in.}$$

- The continuous beam model span lengths are taken from the fuel assembly tables in Appendix A. Some minor missing dimensions are approximated.
- A damping ratio of 5% is used to reduce undamped free vibration. This value is conservative considering that the cladding is filled with powder fuel, banging of adjacent claddings, and sliding along the basket walls.
- The end fittings are supported by the guide tubes in PWR fuel assemblies, their weight is not included in the analysis.
- Since internal pressure helps to stabilize the tubes in buckling, it is conservatively neglected.
- The fuel assembly is assumed to be centered in the fuel compartment, because random deflection of the alternate spans in opposite directions will tend to center the assembly regardless of its starting location.
- The gap between the fuel rod and the basket walls is calculated assuming that all rods deform identically. First, the outer rods contact the basket wall followed by additional deformation causing the next adjacent set of rods to seat and etc.
- A low strain hardening modulus of only 1% of the elastic modulus is used for the cladding material, which maximizes the plastic strain.
- Spacer grids provide lateral support only. They do not provide any rotational support and do not slide axially.
- [redacted]
- The stiffness and damping provided by the Plenum spring are conservatively neglected for the top end drop.

The following assumption is also made in addition to all assumptions above.

[redacted]

5. Computation

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5.1 Finite Element Model

[redacted]

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[redacted]

5.1.1 Contact

[redacted]

[redacted]

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5.1.2 Displacement Constraints

[redacted]

5.1.3 Material Properties

The following material properties are used for the fuel cladding (Zircaloy at 750 °F):

Young's Modulus, $E = 9.93 \times 10^6$ psi	Reference [2.6]
Tangent Modulus = 1% of E - low value used to maximize strain (conservative)	
Yield Strength, $S_y = 92{,}000$ psi	Reference [2.6]
Allowable Total Strain at Maximum Load = 1.5%	Reference [2.16]

The effective density for the fuel cladding (including the active fuel region) is calculated in the Table A-1. The fuel and cladding weight are combined and distributed over the cladding volume so that the fuel mass can be included without any credit for fuel stiffness.

5.2 Transient Damping

[redacted]

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[redacted]

5.3 Body Force Loading

[redacted]

5.4 Initial Conditions

[redacted]

5.5 Finite Element Analysis

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[redacted]

6. Discussion of Results

[redacted]

The maximum axial strains for the fuel rod are summarized in Table 2 for various force functions (see Figure 3). The analyses show that there is no plastic deformation taken place for all the cases. Figures 4 - 11 show the lateral displacement time history at middle of the top three spans and the total maximum axial strain time history of the worst location for each loading condition.

7. Conclusion

From the above results, for the top end drop of the single Combustion Engineering 14x14 STD spent fuel rod, the maximum total strain (elastic + plastic) is well within experimentally derived failure criteria of

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Reference [16]. There is no plastic deformation found in this analysis. It can be concluded that the CE 14x14 fuel assembly cladding will not fail in the event of an end drop accident. Since there is no permanent deformation of the fuel rod, criticality is not affected.

8. ANSYS Files

All runs use ANSYS Release 10 SP1 on the Linux Cluster System. The files pertinent to this report are summarized in table 3 (in DVD also).

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Table A- 1

PWR Fuel Assembly Data - Concluded

Notes:

(1) Includes 0.002811 in. reduction in cladding thickness to account for oxidation. Ref. 1, below

(2) Source: Ref. 2, below

(3) $\rho = [(OD^2_{orig} - ID^2) / (OD^2 - ID^2)] \times \rho_{orig}$ --- $\rho_{orig} = 0.234$, Ref. 3, below

(4) $\rho = \rho_{cladding} + \rho_{fuel} * [OD^2_{fuel\ pellet} / (OD^2 - ID^2)]$ --- $\rho_{fuel} = 0.382$, Ref. 4, below

Ref. 1 Van Swam, L.F., Strasser, A.A., Cook, J.D. and Burger, J.M., 1997, "Behavior of Zircalloy-4 and Zirconium Liner Zircalloy-4 Cladding at High Burnup," pp 421-431, Proceedings of the 1997 International Topical Meeting on LWR Fuel Performance, Portland, Oregon, ANS, LaGrange Park, Illinois.

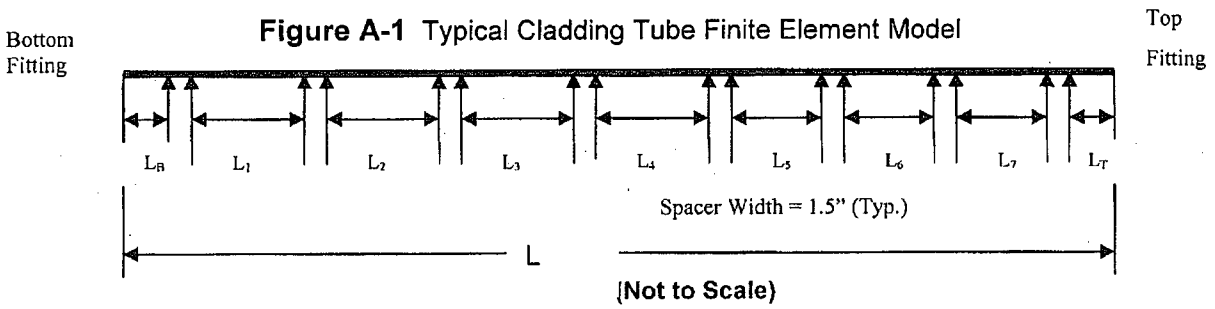
The fuel cladding thickness is reduced by 125 microns (62.5 microns thickness oxidation at inner and at the outer surfaces). The Pilling-Bedworth factor of 1.75, for Zircaloy cladding, is applied and the maximum reduction in cladding thickness is calculated, as: (125/1.75) μm x 39.37e-6 in/μm = 0.002811 in

Ref. 2 DOE/RW-0184, Vol. 3 of 6, "Characteristics of Spent Fuel, High Level Lste and other Radioactive Lstes which require Long Term Isolation – Physical Descriptions of LWR Fuel Assemblies, U.S. DOE, December, 1987.

Ref. 3 UCID – 21246, "Dynamic Input Effects on Spent Fuel Assemblies," Lawrence Livermore National Laboratory, October 20, 1987.

Ref. 4 SCALE NUREG/CR-0200, Vol 3, Rev. 5 (Table M8.2)

Figure A-1 Typical Cladding Tube Finite Element Model



(Not to Scale)

See Table A-1 for continuous beam span lengths

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APPENDIX B - Modal Analysis of the CE 14x14 Fuel Cladding

B-1 Introduction

ANSYS modal analyses of the Combustion Engineering (CE) 14x14 Std fuel cladding is conducted to determine the lateral and axial natural frequencies. These frequencies are used to estimate the structural damping and integration time step size limitations for computing the dynamic response of tube during cask end drop.

B-2 Modal Analyses

A single fuel cladding is modeled using PIPE16 (elastic strain only) elements. The finite element grid, boundary conditions and material properties are described in section 5 of this calculation. The grid and boundary conditions are shown in Figure B-1. Separate modal analyses are conducted for lateral and axial vibrations and the master degree-of-freedom of each is shown in Figures B-2 and B-3, respectively.

B-3 Integration Time Step

The integration time step should be small enough to obtain an accurate dynamic response. As recommended by ANSYS [Structural Analysis Guide, Section 5.10.1, 2.2],

ITS (Integration Time Step), Axial = 1/(20f) = 1/(20 x 82.7) = 0.0006 second

ITS (Integration Time Step), Lateral = 1/(20f) = 1/(20 x 32.9) = 0.0304 second

The initial time step is, therefore, is limited to 0.0006 sec to maintain accuracy and stability of the transient dynamic solution. A conservative initial time step of 0.00001 seconds is applied to ensure an accurate start and ANSYS automatic time stepping is used to maintain solution accuracy.

B-4 Structural Damping

In a fuel assembly, the cladding is closely packed and the rods will interact to damp any free vibration of the assembly. For this analysis we assume 5% frequency independent damping of the stiffness to account for these frictional effects. In Ansys, frequency compensated damping is expressed as Beta Damping [2.2, Section 15.3] and is calculated as shown below

$\beta = 2\xi / \omega$ [2.2, Eq.(15-23)]

Where, ξ is the damping factor and ω is the angular frequency expressed as 2π x (lowest modal frequency of a fuel rod) since displacement and stress are maximized at the lowest frequency mode. Therefore,

$\beta = 0.05 / (\pi \times 32.9) = 4.84E\text{-}04$

For the analyses of this computation, to ensure that over-damping of transient models doesn't occur, the frequency is approximately doubled and applied as 60 Hz, yielding:

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$\beta = 0.05 / (\pi \times 60) = 2.65E\text{-}04$

B-4 Results

- **Lateral Vibration Modal Analysis Results:**

The lateral natural frequencies for first five modes of vibration are listed below. The deformed shape for the first mode is shown in Figure B-4.

Mode No.	Lateral Frequency (Hz.)
1	32.9
2	36.7
3	42.5
4	49.8
5	57.8

- **Axial Vibration Modal Analysis Results:**

The axial natural frequencies for first five modes of vibration are listed below. The deformed shape for the first mode is shown in Figure B-5.

Mode No.	Axial Frequency (Hz.)
1	82.7
2	180.6
3	320.9
4	364.5
5	534.4

B-6 Ansys Files

This analysis was performed using ANSYS 8.1 on a PC with window XP. The Ansys files pertinent to this report exist on the accompanying CD as Follows:

Axial Modal Analysis

ce14x14std_axial_modal.db, ce14x14std_axial_modal.rst,
ce14x14std_axial_modal.inp, ce14x14std_axial_modal.out, ce14x14std_axial_modal.err

Lateral Modal Analysis

ce14x14std_lateral_modal.db, ce14x14std_lateral_modal.rst,
ce14x14std_lateral_modal.inp, ce14x14std_lateral_modal.out, ce14x14std_lateral_modal.err

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