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10 CFR 50.90

RA-18-092

October 22, 2018

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Oyster Creek Nuclear Generating Station
Renewed Facility Operating License No. DPR-16
NRC Docket Nos. 50-219 and 72-15

Subject: License Amendment Request - Proposed Change of Effective and Implementation Dates of License Amendment No. 294, Oyster Creek Emergency Plan for Permanently Defueled Emergency Plan and Emergency Action Level Scheme

Reference:

1) Electronic Mail Capture from John Lamb (U.S. Nuclear Regulatory Commission) to David Helker (Exelon Generation Company, LLC), *"Oyster Creek Permanently Ceases Power Operations,"* dated September 17, 2018 (ML18263A163)
2) Letter from Michael P. Gallagher, Exelon Generation Company, LLC to U.S. Nuclear Regulatory Commission – *"Certification of Permanent Removal of Fuel from the Reactor Vessel for Oyster Creek Nuclear Generating Station,"* dated September 25, 2018 (ML18268A258)
3) Letter from U.S. Nuclear Regulatory Commission to Bryan C. Hanson (Exelon Generation Company, LLC) - *"Oyster Creek Nuclear Generating Station - Issuance of Amendment Re: Changes the Emergency Plan for Permanently Defueled Emergency Plan and Emergency Action Level Scheme (CAC NO. MG0160; EPID L-2017-LLA-0307),"* dated October 17, 2018 (ML18221A400)
4) Letter from U.S. Nuclear Regulatory Commission to Bryan C. Hanson (Exelon Generation Company, LLC) - *"Oyster Creek Nuclear Generating Station - Exemptions from Certain Emergency Planning Requirements and Related Safety Evaluation (CAC NO. MG0153; EPID L-2017-LLE-0020),"* dated October 16, 2018 (ML182220A980)
5) Letter from Michael P. Gallagher, (Exelon Generation Company, LLC) to U.S. Nuclear Regulatory Commission – *"Request for Exemptions from Portions of 10 CFR 50.47 and 10 CFR Part 50, Appendix E,"* dated August 22, 2017 (ML17234A082)

6) Letter from Michael P. Gallagher, (Exelon Generation Company, LLC) to U.S. Nuclear Regulatory Commission – *"Supplement to Request for Exemption from Portions of 10 CFR 50.47 and 10 CFR Part 50, Appendix E,"* dated March 8, 2018 (ML18067A087)

7) Letter from Michael P. Gallagher, Exelon Generation Company, LLC to U.S. Nuclear Regulatory Commission – *"Certification of Permanent Cessation of Power Operations for Oyster Creek Nuclear Generating Station,"* dated February 14, 2018 (ML18045A084)

Pursuant to 10 CFR 50.90, "Application for amendment of license or construction permit," Exelon Generation Company, LLC (Exelon) requests an amendment to Renewed Facility Operating License Number DPR-16 for Oyster Creek Nuclear Generating Station (OCNGS). The proposed amendment would revise the effective and implementation dates of License Amendment No. 294, Permanently Defueled Emergency Plan (PDEP) and Emergency Action Level (EAL) scheme for the permanently defueled condition. The proposed changes are being submitted to the U.S. Nuclear Regulatory Commission (NRC) for approval prior to implementation.

On September 17, 2018, OCNGS permanently ceased power operations (Reference 1). By letter dated September 25, 2018, (Reference 2), Exelon certified that all fuel had been permanently removed from the OCNGS reactor vessel and placed in the spent fuel pool (SFP).

On October 17, 2018, the NRC approved License Amendment No. 294, OCNGS PDEP and Permanently Defueled EAL Scheme (Reference 3). The PDEP and Permanently Defueled EAL scheme were predicated on approval of requests for Exemptions from portions of 10 CFR 50.47(b), 10 CFR 50.47(c)(2), and 10 CFR Part 50, Appendix E, Section IV, which were approved on October 16, 2018 (Reference 4).

The PDEP and Permanently Defueled EAL scheme were predicated on approval of requests for exemptions from portions of 10 CFR 50.47(b), 10 CFR 50.47(c)(2), and 10 CFR Part 50, Appendix E, Section IV, approved in Reference 4. The PDEP reduces the scope of offsite and onsite emergency planning commensurate with the permanently defueled condition.

The basis for the approval of the exemptions from offsite emergency preparedness (EP) requirements included a site-specific analysis that showed that the fuel stored in the SFP would not reach the zirconium ignition temperature in fewer than 10 hours from the time at which it was assumed a loss of both water and air cooling of the spent fuel (zirc-fire window). Exelon's site-specific analyses for OCNGS, as provided in Exelon's exemption request (Reference 5), showed that 12 months after permanent cessation of power operations, the spent fuel stored in the SFP will have decayed to the extent that the requested exemptions may be implemented at OCNGS.

Since the time of the submittal of the original adiabatic calculation in Reference 5, two key assumptions have been reconsidered based on actual conditions at the time of final shutdown. First, the fuel in the reactor at the time of the final shutdown (Cycle 26) was considered instead of projected next cycle fuel (Cycle 27). As provided in Reference 6, the conditions through the end of Cycle 26 result in less decay heat in its limiting bundle than the limiting bundle used from Cycle 27. Second, the masses of fuel bundle assembly hardware pieces, such as the channel box and tie plates are credited, which reduces the required decay time.

The revised adiabatic calculation provided in Attachment 2, factoring in these reconsidered assumptions, validates the response in Reference 6 and results in a reduced decay period of 9.38 months (285 days) for the zirc-fire window after the final reactor shut down. Significant conservatisms remain in the calculation.

Exelon is requesting that License Amendment No 294 (Reference 3) become effective 9.38 months (285 days) from the date of the permanent shut down of OCNGS on September 17, 2018 (Reference 1), as stated in the certification that OCNGS has been permanently shut down and defueled (Reference 2), which revises the amendment effective date to June 29, 2019.

License Amendment No. 294 is to become effective 12 months (365 days) following the permanent cessation of power operations and shall be implemented within 60 days of the effective date, but no later than March 28, 2021.

The description, technical and regulatory evaluation, significant hazards determination, and environmental considerations evaluation for the proposed amendment are contained in the Attachment 1. The revised bounding analysis is provided in Attachment 2.

The proposed change of the effective date for the PDEP and Permanently Defueled EAL scheme does not impact or change anything within the approved PDEP (Reference 3) other than the effective and implementation dates.

Exelon requests approval of the proposed license amendment by May 1, 2019, and an effective date of June 29, 2019. Exelon will implement this LAR within 30 days from the effective date; but no later than July 31, 2019. Approval by May 1, 2019, will provide Exelon the certainty in implementing change management for a significant reduction in site staffing.

The proposed change has been reviewed and approved by the station's Safety Review Committee in accordance with the requirements of the Exelon Decommissioning Quality Assurance Program.

In support of this license amendment request, Exelon has discussed the proposed change regarding the earlier implementation of the PDEP and Permanently Defueled EAL scheme with the New Jersey Bureau of Nuclear Engineering and local response organizations.

The proposed change has been evaluated in accordance with 10 CFR 50.91(a)(1) using criteria in 10 CFR 50.92(c), and Exelon has determined that this change involves no significant hazards consideration. Exelon has also determined that the proposed change satisfies the criteria for categorical exclusion in accordance with 10 CFR 51.22(c)(9) and does not require an environmental review. Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment is required.

No commitments to the NRC are made in this letter.

If you have any questions concerning this submittal, please contact Paul Bonnett at (610) 765-5264.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 22nd day of October 2018.

Respectfully,

Michael P. Gallagher
Vice President, License Renewal & Decommissioning
Exelon Generation Company, LLC

Attachment 1: Description and Evaluation of Proposed Changes

Attachment 2: Oyster Creek Nuclear Generating Station Zirconium Fire Analysis for Drained Spent Fuel Pool, C-1302-226-E310-457, Revision 1

cc: w/Attachment

Regional Administrator - NRC Region I
NRC Senior Resident Inspector - Oyster Creek Nuclear Generating Station
NRC Project Manager, NRR - Oyster Creek Nuclear Generating Station
Director, Bureau of Nuclear Engineering - New Jersey Department of Environmental Protection
Mayor of Lacey Township, Forked River, NJ

Attachment 1

Oyster Creek Nuclear Generation Station
Description and Evaluation of Proposed Changes

Attachment 1

License Amendment Request

Oyster Creek Nuclear Generating Station

Docket No. 50-219

EVALUATION OF PROPOSED CHANGES

Subject: **Proposed Change of Effective and Implementation Dates of License Amendment No. 294, Oyster Creek Emergency Plan for Permanently Defueled Emergency Plan and Emergency Action Level Scheme**

1.0 SUMMARY DESCRIPTION

Pursuant to 10 CFR 50.90, "Application for amendment of license or construction permit, "Exelon Generation Company, LLC (Exelon) requests an amendment to Renewed Facility Operating License Number DPR-16 for Oyster Creek Nuclear Generating Station (OCNGS). The proposed amendment would revise the effective and implementation dates of License Amendment No. 294, Permanently Defueled Emergency Plan (PDEP), Emergency Action Level (EAL) scheme for the permanently defueled condition, and associated Exemption from portions of 10 CFR 50.47(b), 10 CFR 50.47(c)(2), and 10 CFR Part 50, Appendix E, Section IV. The proposed changes are being submitted to the U.S. Nuclear Regulatory Commission (NRC) for approval prior to implementation.

The proposed change of the effective date for the PDEP, Permanently Defueled EAL scheme, and associated exemptions does not impact or change anything within the approved PDEP (Reference 5) or exemptions (Reference 6) other than the effective and implementation dates.

2.0 BACKGROUND

On January 7, 2011, Exelon informed the NRC that OCNGS will permanently cease power operations by December 31, 2019 (Reference 1). On February 2, 2018, Exelon announced that it planned to retire OCNGS no later than October 31, 2018 at the end of the current two-year operating cycle. Exelon informed the NRC of this change in Reference 2.

On September 17, 2018, OCNGS permanently ceased power operations (Reference 3). By letter dated September 25, 2018, (Reference 4), Exelon certified that all fuel had been permanently removed from the OCNGS reactor vessel and placed in the spent fuel pool (SFP).

On October 17, 2018, the NRC approved License Amendment No. 294, OCNGS PDEP and Permanently Defueled EAL Scheme (Reference 5). The PDEP and Permanently Defueled EAL scheme were predicated on approval of requests for Exemptions from portions of 10 CFR 50.47(b), 10 CFR 50.47(c)(2), and 10 CFR Part 50, Appendix E, Section IV, which were approved on October 16, 2018 (Reference 7).

License Amendment No. 294 becomes effective 12 months (365 days) following the permanent cessation of power operations and shall be implemented within 60 days of the effective date, but no later than March 28, 2021.

3.0 BASIS FOR PROPOSED CHANGES

The basis for the approval of the exemptions from offsite emergency preparedness (EP) requirements included a site-specific analysis that showed that the fuel stored in the SFP would not reach the zirconium ignition temperature in fewer than 10 hours from the time at which it was assumed a loss of both water and air cooling of the spent fuel. Exelon's site-specific analyses for OCNGS, as provided in Exelon's exemption request (Reference 7), showed that 12 months after permanent cessation of power operations, the spent fuel stored in the SFP will have decayed to the extent that the requested exemptions may be implemented at OCNGS.

Since the time of the submittal of the original adiabatic calculation in Reference 7, two key assumptions have been reconsidered based on actual conditions at the time of final shutdown. First, the fuel in the reactor at the time of the final shutdown (Cycle 26) was considered instead of projected next cycle fuel (Cycle 27). When the original calculation was submitted, OCNGS was scheduled to shut down no later than the end of December 2019 (Reference 1) and a refueling outage in October 2018 was scheduled to load fuel for Cycle 27. However, Exelon decided to reschedule the final shutdown to no later than October 31, 2018 (Reference 2), at the end of the current two-year operating cycle (Cycle 26). A revised adiabatic calculation (provided in Attachment 2) was performed that calculates new decay heat values and the required decay time based on the revised final shutdown date at OCNGS, which no longer includes Cycle 27, such that, Cycle 26 becomes the final and bounding reload.

Second, the masses of fuel bundle assembly hardware pieces, such as the channel box and tie plates are credited, which reduces the required decay time. The revised adiabatic calculation (provided in Attachment 2) factors in the reconsidered assumptions and the results indicate that the 12-month decay period originally predicted in Reference 7 may be reduced to 9.38 months (285 days) after the final reactor shut down.

Significant conservatisms remain in the calculation such as:

- Adiabatic heat up of the fuel bundle is utilized thus not accounting for the actual heat losses that would occur due to radiative and convective heat transfer to surrounding structures.
- The calculation assumed power level was at 100% up to when shutdown occurred. Reactor power level was 70% for 51 days prior to final shutdown. The reduced power level results in a reduction in the starting decay heat that would be present in the actual hottest fuel bundle.
- The specific heat for fuel assembly hardware pieces (stainless steel or Inconel) were assumed to be the lower specific heat of zircalloy. Actual fuel heat-up would be slower with actual materials.
- Starting temperature of the spent fuel pool was assumed to be 125°F instead of normal pool temperatures of less than 115°F. Lower temperature adds additional time to fuel heat-up.

The revised decay time is consistent with NRC's stated generic time for Boiling Water Reactors (BWRs) as documented in NUREG/CR-6451 BNL-NUREG-52498, "A Safety and Regulatory Assessment of Generic BWR and PWR [Pressurized Water Reactor] Permanently Shutdown Nuclear Power Plants" (Reference 8) and the Regulatory Basis document for "Regulatory Improvements for Power Reactors Transitioning to Decommissioning" (Reference 9). Oyster Creek is a lower power density plant than the BWR referenced in above documents; therefore, OCNGS would be expected to have a site-specific calculation that would be less than the generic required decay time.

Therefore, Exelon is requesting that the License Amendment No. 294 (Reference 5) become effective 9.38 months (285 days) from the date of the permanent shut down of OCNGS on September 17, 2018, as stated in the certification that OCNGS has been permanently shut down and defueled (Reference 4), which revises the amendment effective date to June 29, 2019.

4.0 TECHNICAL EVALUATION

As discussed above, based on actual conditions at the time of final shutdown, Exelon has revised the site-specific analysis that showed that the fuel stored in the SFP would not reach the zirconium ignition temperature in fewer than 10 hours from the time at which it was assumed a loss of both water and air cooling of the spent fuel based on reconsideration of two key assumptions. The revised analysis, "Oyster Creek Nuclear Generating Station Zirconium Fire Analysis for Drained Spent Fuel Pool" (Revision 1), is provided in Attachment 2.

5.0 REGULATORY EVALUATION

5.1 Applicable Regulatory Requirements and Guidance

Exelon intends to meet the applicable emergency regulatory requirements with the Exemptions approved in Reference 6 and license provisions approved in License Amendment No. 294 (Reference 5).

5.2 Precedent

The proposed change revises the effective and implementation dates of License Amendment No. 294, OCNGS PDEP, Permanently Defueled EAL scheme (Reference 5), and Exemptions from portions of 10 CFR 50.47 and 10 CFR Part 50, Appendix E (Reference 6). Three similarly related license amendments involving changes to license amendment implementation due dates were approved in 2015 and 2004, and are listed below:

1. Limerick Generating Station, Unit 2 - Issuance of Exigent Amendment RE: Extend Implementation Period for Amendment No. 174- Leak Detection System Setpoint and Allowable Value Changes (TAC NO. MF5695), dated February 25, 2015 (ML150049A084).
2. Sequoyah Nuclear Plant Unit 1 (SQN) - Issuance of Emergency Amendment to Extend Implementation Period for License Amendment No. 294 (TAC NO. MC5041), dated November 9, 2004 (ML043130006).
3. Fort Calhoun Station, Unit No.1 - Issuance of Amendment (TAC No. MC1949), dated February 13, 2004 (ML040490383).

5.3 No Significant Hazards Consideration Determination

The proposed change would revise the effective and implementation dates of License Amendment No. 294, Oyster Creek Nuclear Generating Station (OCNGS) Permanently Defueled Emergency Plan (PDEP) and Emergency Action Level (EAL) scheme (Reference 5) [ML18221A400] and Exemptions from portions of 10 CFR 50.47 and 10 CFR Part 50, Appendix E (Reference 6) [ML182220A980]. Implementation of the previously approved PDEP, Permanently Shutdown EALs, and associated Exemptions are predicated on a site-specific analysis that showed that the fuel stored in the spent fuel pool (SFP) would not reach the zirconium ignition temperature in fewer than 10 hours from the time at which it was assumed a loss of both water and air cooling of the spent fuel at 12 months after the reactor had been shut down (zirc-fire window). The site-specific analysis has been revised to take into consideration actual conditions at the time of permanent shutdown that impact two key assumptions used in the original analysis. The revised site-specific analysis showed that the zirc-fire window may be revised to 9.38 months (285 days) after the reactor had been shutdown.

Pursuant to 10 CFR 50.92, Exelon has reviewed the proposed changes and concludes that the changes do not involve a significant hazards consideration because the proposed changes satisfy the criteria in 10 CFR 50.92(c). These criteria require that operation of the facility in accordance with the proposed amendment would not (1) involve a significant increase in the probability or consequences of an accident previously evaluated; (2) create the possibility of a new or different kind of accident from any accident previously evaluated; or (3) involve a significant reduction in a margin of safety.

The discussion below addresses each of these criteria and demonstrates that the proposed amendment does not constitute a significant hazard.

1. **Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?**

   Response: No

   The proposed change to the effective and implementation dates of License Amendment No. 294, OCNGS PDEP, Permanently Shutdown EAL scheme, and associated Exemptions at 9.38 months (285 days) does not impact the function of plant structures, systems, or components (SSCs). The proposed change does not affect accident initiators or precursors, nor does it alter design assumptions. The proposed change does not prevent the ability of the on-shift staff and emergency response organization (ERO) to perform their intended functions to mitigate the consequences of any accident or event that will be credible in the permanently defueled condition.

   The probability of occurrence of previously evaluated accidents is not increased, since most previously analyzed accidents can no longer occur and the probability of the few remaining credible accidents are unaffected by the proposed amendment.

   Therefore, the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. **Does the proposed amendment create the possibility of a new or different kind of accident from any accident previously evaluated?**

   Response: No

   The proposed change to effective and implementation dates for License Amendment No. 294, PDEP, Permanently Shutdown EAL scheme, and associated Exemptions at 9.38 months (285 days) is commensurate with the hazards associated with a permanently shutdown and defueled facility based on the updated site-specific analysis that showed the fuel stored in the SFP would not reach the zirconium ignition temperature in fewer than 10 hours from the time at which it was assumed a loss of both water and air cooling of the spent fuel. The proposed change does not involve installation of new equipment or modification of existing equipment, so that no new equipment failure modes are introduced. In addition, the proposed change does not result in a change to the way that the equipment or facility is operated so that no new or different kinds of accident initiators are created.

   Therefore, the proposed change does not create the possibility of a new or different kind of accident from any previously evaluated.

3. **Does the proposed amendment involve a significant reduction in a margin of safety?**

   Response: No

   Margin of safety is associated with confidence in the ability of the fission product barriers (i.e., fuel cladding, reactor coolant system pressure boundary, and containment structure) to limit the level of radiation dose to the public. The proposed change is associated with changing the effective and implementation dates of License Amendment No. 294, PDEP, Permanently Shutdown EAL scheme and associated Exemptions; it does not impact operation of the plant or its response to transients or accidents. The change does not affect the Technical Specifications. The proposed change does not involve a change in the method of plant operation, and no design bases accident analyses will be affected by the proposed changes. Safety analysis acceptance criteria are not affected by the proposed changes. The PDEP will continue to provide the necessary response staff with the appropriate guidance to protect the health and safety of the public.

Therefore, the proposed change does not involve a significant reduction in a margin of safety.

Based on the above, Exelon concludes that the proposed change presents no significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and, accordingly, a finding of "no significant hazards consideration" is justified.

5.4 Conclusion

In conclusion, based on the considerations discussed above: 1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, 2) such activities will be conducted in compliance with Commission's regulations, and 3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

6.0 ENVIRONMENTAL CONSIDERATIONS

This amendment request meets the eligibility criteria for categorical exclusion from environmental review set forth in 10 CFR 51.22(c)(9) as follows:

(i) **The amendment involves no significant hazards consideration.**

As described in Section 5.3 of this evaluation, the proposed changes involve no significant hazards consideration.

(ii) **There is no significant change in the types or significant increase in the amounts of any effluent that may be released offsite.**

The proposed changes do not involve any physical alterations to the plant configuration or any changes to the operation of the facility that could lead to a change in the type or amount of effluent release offsite.

(iii) **There is no significant increase in individual or cumulative occupational radiation exposure.**

The proposed changes do not involve any physical alterations to the plant configuration or any changes to the operation of the facility that could lead to a significant increase in individual or cumulative occupational radiation exposure.

Based on the above, Exelon concludes that the proposed change meets the eligibility criteria for categorical exclusion as set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the issuance of this amendment.

7.0 <u>REFERENCES</u>

1. Letter from Keith R. Jury, Exelon Generation Company, LLC to U.S. Nuclear Regulatory Commission - *"Permanent Cessation of Operations at Oyster Creek Nuclear Generating Station,"* dated January 7, 2011, (ML110070507)
2. Letter from Michael P. Gallagher, Exelon Generation Company, LLC to U.S. Nuclear Regulatory Commission – *"Certification of Permanent Cessation of Power Operations for Oyster Creek Nuclear Generating Station,"* dated February 14, 2018 (ML18045A084)
3. Electronic Mail Capture from John Lamb (U.S. Nuclear Regulatory Commission) to David Helker (Exelon Generation Company, LLC), *"Oyster Creek Permanently Ceases Power Operations,"* dated September 17, 2018 (ML18263A163)
4. Letter from Michael P. Gallagher, Exelon Generation Company, LLC to U.S. Nuclear Regulatory Commission – *"Certification of Permanent Removal of Fuel from the Reactor Vessel for Oyster Creek Nuclear Generating Station,"* dated September 25, 2018 (ML18268A258)
5. Letter from U.S. Nuclear Regulatory Commission to Bryan C. Hanson (Exelon Generation Company, LLC) - *"Oyster Creek Nuclear Generating Station - Issuance of Amendment Re: Changes the Emergency Plan for Permanently Defueled Emergency Plan and Emergency Action Level Scheme (CAC NO. MG0160; EPID L-2017-LLA-0307),"* dated October 17, 2018 (ML18221A400)
6. Letter from U.S. Nuclear Regulatory Commission to Bryan C. Hanson (Exelon Generation Company, LLC) - *"Oyster Creek Nuclear Generating Station - Exemptions from Certain Emergency Planning Requirements and Related Safety Evaluation (CAC NO. MG0153; EPID L-2017-LLE-0020),"* dated October 16, 2018 (ML18220A980)
7. Letter from Michael P. Gallagher, (Exelon Generation Company, LLC) to U.S. Nuclear Regulatory Commission – *"Request for Exemptions from Portions of 10 CFR 50.47 and 10 CFR Part 50, Appendix E,"* dated August 22, 2017 (ML17234A082)
8. U.S. Nuclear Regulatory Commission, NUREG/CR-6451 BNL-NUREG-52498, *"A Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants,"* dated August 1997 (ML082260098)
9. U.S. Nuclear Regulatory Commission, *"Regulatory Improvements for Power Reactors Transitioning to Decommissioning, Regulatory Basis Document"* dated November 20, 2017, NRC Docket ID: NRC-2017-0070, RIN Number: 3150-AJ59 (ML17215A010)

Attachment 2

Oyster Creek Nuclear Generation Station
Zirconium Fire Analysis for Drained Spent Fuel Pool,
C-1302-226-E310-457, Revision 1

Design Analysis				Last Page No.: [6] 41	
Analysis No.: [1]	C-1302-226-E310-457	Revision: [2]	1 Major ☒	Minor ☐	
Title: [3]	Oyster Creek Nuclear Generating Station Zirconium Fire Analysis for Drained Spent Fuel Pool				
EC/ECR No.: [4]	624353	Revision: [5]	0		

Station(s): [7]	OCNGS	Component(s): [14]	
Unit No.: [8]	1	N/A	
Discipline: [9]	MECH		
Descrip. Code/Keyword: [10]	N/A		
Safety/QA Class: [11]	NSR		
System Code: [12]	N/A		
Structure: [13]	SFP		

CONTROLLED DOCUMENT REFERENCES [15]

Document No.:	From/To	Document No.:	From/To
C-1302-226-E310-458, R0	From		
GEH-0000-0118-3544, R1	From		
DB-0011.03, R1	From		
26A7584, R0	From		

Is this Design Analysis Safeguards Information? [16] Yes ☐ No ☒ If yes, see SY-AA-101-106

Does this Design Analysis contain Unverified Assumptions? [17] Yes ☐ No ☒ If yes, ATI/AR#: ______

This Design Analysis SUPERCEDES: [18] **N/A** **in its entirety.**

Description of Revision (list changed pages when all pages of original analysis were not changed): [19]
Revision 1 calculates new decay heat values and the required decay time based on the revised final shutdown date at Oyster Creek, which will no longer have a Cycle 27 such that Cycle 26 becomes the final and bounding reload. Furthermore, the masses of assembly hardware pieces such as the channel box and tie plates are credited, which reduces the required decay time. This revision replaces all pages in the calculation.

	Print Name	Sign Name	Date
Preparer: [20]	Brian Froese	[signature]	6/5/2018

Method of Review: [21] **Detailed Review** ☒ **Alternate Calculations (attached)** ☐ **Testing** ☐

	Print Name	Sign Name	Date
Reviewer: [22]	Dwayne Blaylock	[signature]	6/5/2018

Review Notes: [23] Independent review ☒ Peer review ☐
This calculation has been independently reviewed per CC-AA-309 and CC-AA-309-1001. All comments have been satisfactorily incorporated.

(For External Analyses Only)

	Print Name	Sign Name	Date
External Approver: [24]	Guy Spikes	[signature]	6/5/2018
Exelon Reviewer: [25]	ROBERT CSILLAG	[signature]	7/17/18

Independent 3rd Party Review Reqd? [26] Yes ☐ No ☒

	Print Name	Sign Name	Date
Exelon Approver: [27]	Herbert Tritt	[signature]	7/21/18

Owner's Acceptance Review checklist for External Design Analysis

Page 1 of 3

Design Analysis No.: C-1302-226-E310-457 **Rev:** 1
Contract #: 00597114 **Release #:** 101

No	Question	Instructions and Guidance	Yes / No / N/A
1	Do assumptions have sufficient documented rationale?	All Assumptions should be stated in clear terms with enough justification to confirm that the assumption is conservative. For example, 1) the exact value of a particular parameter may not be known or that parameter may be known to vary over the range of conditions covered by the Calculation. It is appropriate to represent or bound the parameter with an assumed value. 2) The predicted performance of a specific piece of equipment in lieu of actual test data. It is appropriate to use the documented opinion/position of a recognized expert on that equipment to represent predicted equipment performance. Consideration should also be given as to any qualification testing that may be needed to validate the Assumptions. Ask yourself, would you provide more justification if you were performing this analysis? **If** yes, the rationale is likely incomplete.	☒ Yes ☐ No ☐ N/A
2	Are assumptions compatible with the way the plant is operated and with the licensing basis?	Ensure the documentation for source and rationale for the assumption supports the way the plant is currently or will be operated post change and they are not in conflict with any design parameters. If the Analysis purpose is to establish a new licensing basis, this question can be answered yes, if the assumption supports that new basis.	☒ Yes ☐ No ☐ N/A
3	Do all unverified assumptions have a tracking and closure mechanism in place?	**If** there are unverified assumptions without a tracking mechanism indicated, **then** create the tracking item either through an ATI or a work order attached to the implementing WO. Due dates for these actions need to support verification prior to the analysis becoming operational or the resultant plant change being op authorized.	☐ Yes ☐ No ☒ N/A
4	Do the design inputs have sufficient rationale?	The origin of the input, or the source should be identified and be readily retrievable within Exelon's documentation system. If not, then the source should be attached to the analysis. Ask yourself, would you provide more justification if you were performing this analysis? **If** yes, the rationale is likely incomplete.	☒ Yes ☐ No ☐ N/A
5	Are design inputs correct and reasonable with critical parameters identified, if appropriate?	The expectation is that an Exelon Engineer should be able to clearly understand which input parameters are critical to the outcome of the analysis. That is, what is the impact of a change in the parameter to the results of the analysis? If the impact is large, then that parameter is critical.	☒ Yes ☐ No ☐ N/A
6	Are design inputs compatible with the way the plant is operated and with the licensing basis?	Ensure the documentation for source and rationale for the inputs supports the way the plant is currently or will be operated post change and they are not in conflict with any design parameters.	☒ Yes ☐ No ☐ N/A

Attachment 2

Owner's Acceptance Review checklist for External Design Analysis

Page 2 of 3

Design Analysis No.: C-1302-226-E310-457 Rev: 1

No	Question	Instructions and Guidance	Yes / No / N/A
7	Are Engineering Judgments clearly documented and justified?	See Section 2.13 in CC-AA-309 for the attributes that are sufficient to justify Engineering Judgment. Ask yourself, would you provide more justification if you were performing this analysis? **If** yes, the rationale is likely incomplete.	☐ ☐ ☒
8	Are Engineering Judgments compatible with the way the plant is operated and with the licensing basis?	Ensure the justification for the engineering judgment supports the way the plant is currently or will be operated post change and is not in conflict with any design parameters. **If** the Analysis purpose is to establish a new licensing basis, **then** this question can be answered yes, if the judgment supports that new basis.	☐ ☐ ☒
9	Do the results and conclusions satisfy the purpose and objective of the Design Analysis?	Why was the analysis being performed? Does the stated purpose match the expectation from Exelon on the proposed application of the results? **If** yes, **then** the analysis meets the needs of the contract.	☒ ☐ ☐
10	Are the results and conclusions compatible with the way the plant is operated and with the licensing basis?	Make sure that the results support the UFSAR defined system design and operating conditions, or they support a proposed change to those conditions. If the analysis supports a change, are all of the other changing documents included on the cover sheet as impacted documents?	☒ ☐ ☐
11	Have any limitations on the use of the results been identified and transmitted to the appropriate organizations?	Does the analysis support a temporary condition or procedure change? Make sure that any other documents needing to be updated are included and clearly delineated in the design analysis. Make sure that the cover sheet includes the other documents where the results of this analysis provide the input.	☐ ☐ ☒
12	Have margin impacts been identified and documented appropriately for any negative impacts (Reference ER-AA-2007)?	Make sure that the impacts to margin are clearly shown within the body of the analysis. If the analysis results in reduced margins ensure that this has been appropriately dispositioned in the EC being used to issue the analysis.	☐ ☐ ☒
13	Does the Design Analysis include the applicable design basis documentation?	Are there sufficient documents included to support the sources of input, and other reference material that is not readily retrievable in Exelon controlled Documents?	☒ ☐ ☐
14	Have all affected design analyses been documented on the Affected Documents List (ADL) for the associated Configuration Change?	Determine if sufficient searches have been performed to identify any related analyses that need to be revised along with the base analysis. It may be necessary to perform some basic searches to validate this.	☒ ☐ ☐
15	Do the sources of inputs **and** analysis methodology used meet committed technical and regulatory requirements?	Compare any referenced codes and standards to the current design basis and ensure that any differences are reconciled. If the input sources **or** analysis methodology are based on an out-of-date methodology or code, additional reconciliation may be required if the site has since committed to a more recent code	☒ ☐ ☐

Attachment 2

Owner's Acceptance Review checklist for External Design Analysis

Page 3 of 3

Design Analysis No.: C-1302-226-E310-457 **Rev:** 1

No	Question	Instructions and Guidance	Yes / No / N/A
16	Have vendor supporting technical documents and references (including GE DRFs) been reviewed when necessary?	Based on the risk assessment performed during the pre-job brief for the analysis (per HU-AA-1212), ensure that sufficient reviews of any supporting documents not provided with the final analysis are performed.	☐ ☐ ☒
17	Do operational limits support assumptions and inputs?	Ensure the Tech Specs, Operating Procedures, etc. contain operational limits that support the analysis assumptions and inputs.	☐ ☐ ☒
18	List the critical characteristics of the product, and validate those critical characteristics.		

Create an SFMS entry as required by CC-AA-4008. SFMS Number: 62677

Exelon Reviewer Comments:
An HU-AA-1212 pre-job brief for owner's acceptance was held on 3/15/17 with the DEM and Exelon acceptance reviewer. The overall risk ranking was a '1,' therefore, existing in-process reviews are sufficient. An ITPR is not required. The brief did identify that additional technical expertise was required as allowed by CC-AA-103-1003 in the form of a review committee. Technical experts in Nuclear Fuels (Jill Fisher), Reactor Engineering (Jim Frank), Oyster Creek Emergency Plan (Jim Frank), and ORIGEN program SME (Greg Heasley) were utilized to support the Exelon owner's acceptance review. The Exelon acceptance reviewer (Robert Csillag) acted as chair of this committee and coordinated all Exelon reviews performed per CC-AA-103-1003, Attachment 2 and resolution of all comments.
Enercon was verified to be on the approved vendor list as an EOC per CC-AA-12, Attachment 1, therefore, a design review by Exelon is not required. Design qualifications were verified to be current for the Exelon owner's acceptance reviewer as was verification of being part of the ESP population.
Critical inputs and assumptions were scrutinized as was the veracity of the conclusions. Comments were supplied by the Exelon owner review committee. All comments were resolved to the satisfaction of the Exelon owner's review committee by the EOC.

Additional comment from ORIGEN Program SME Greg Heasley:
The method used in Attachment 2 to determine the decay heat used the bundle spec power. It was determined a Cycle 26 3rd burned bundle with higher power and exposure will produce approximately a 6% higher decay heat at 1 year. Due to the following conservatisms in the calculation, the zirc fire analysis performed herein is bounding: (1) No credit is taken for decay time between cycles, (2) stainless steel and Inconel in bundles are assumed to be Zirc-2, which has a considerably (>50%) lower specific heat, (3) conservatively assuming the pool starts at 125°F instead of 86°F (Section 5.6), and (4) conservatively not crediting the SFP rack material (Assumption 3.6) which has been demonstrated to reduce the cooling time by up to 50% in NRC-2015-0070-0224.

Contents

1.0 Purpose and Scope

The purpose of this calculation is to conservatively evaluate the length of time it takes for an uncovered spent fuel assembly in the spent fuel pool to reach the temperature where the zirconium cladding would fail. This analysis supports decommissioning of Oyster Creek Nuclear Generating Station (OCNGS). Specifically, this analysis will be used to reduce the emergency planning staff once the hottest fuel assembly decay time is sufficient and is demonstrated to reach 900°C in 10 hours which supports the requirements of ISG-02, Section 5, Item 2 (Ref. 9).

The number of hours it takes for the fuel to heat up (the heat-up time) is determined as a function of the decay time after shutdown. The heat load from GNF2 fuel used in this analysis is determined in Attachment 2. Note, the heat load was previously taken from Attachment 8 of Reference 1 in Revision 0 of this calculation.

2.0 Acceptance Criteria

There are no specific acceptance criteria for this analysis; however, SECY-99-168 (Ref. 8) suggests that "10 hours (is) sufficient time to take mitigative action" and that for BWRs, 2 years is expected to be the decay time needed to reach a 10 hour heat-up time from 30 °C to 900 °C. NUREG-1738 shows that a 10 hour heat up time for a BWR requires less than 2 years of cooling time (Ref. 7, Fig. 2-1).

NUREG/CR-6451 (Ref. 6) presents several studies discussing the maximum allowable temperature of zirconium cladding that will ensure that failure of the zirconium cladding will not occur. NUREG/CR-6451 states 565 °C (1049 °F) is the lowest temperature where incipient cladding failure might occur. Per NUREG-1738 (Ref. 7, pg. 3-7), 900°C (1652 °F) is the temperature where "runaway oxidation" (zirconium fire) is expected to occur. Therefore, the decay period to reach a 10 hour heat-up time from 30 °C (86 °F) to 900 °C is used as the acceptance criteria in this calculation. The decay period to reach a 10 hour heat-up time from 30 °C to 565 °C is also presented to show when cladding failure may occur.

NRC-2015-0070, Appendix A, Section 4.2.6 (Ref. 17) states that for BWRs a 10 month period for Level 1 (post-shutdown emergency planning) shall be used unless a site-specific analysis demonstrates a shorter time period is acceptable for reaching a cladding temperature of 900 °C within 10 hours.

3.0 Assumptions

3.1 The heat-up time is conservatively assumed to start when the spent fuel pool has been completely drained. This is conservative as the drain down time would increase the time to cladding failure.

3.2 Additional hardware materials made of stainless steel and Inconel X-750 are assumed to be zircaloy-2. This assumption is conservative since the specific heat capacity of zircaloy-2 is less than that of both stainless steel and Inconel X-750. For instance, at 300K (~70°F) the specific heat of zircaloy-2 is 0.28×10^{3} J/kg·K (Reference 4), stainless steel is 0.50×10^{3} J/kg·K (Reference 4), and

Inconel X-750 is 0.43×10^3 J/kg·K (0.103 Btu/lb·°F) (Reference 14). A lower specific heat capacity is conservative because it results in a shorter heat-up time.

3.3 OCNGS final cycle 26 will contain a full core of GNF2 fuel (Ref. 12); therefore, the analysis herein will only evaluate the heat up of GNF2 fuel assemblies and not any other assembly type in the spent fuel pool because the offloaded fuel directly after a cycle contains the assemblies with the highest decay heat (referred to as the hottest fuel assembly here-in).

3.4 The specific heat for uranium dioxide and the zircaloy-2 cladding are determined at a temperature of 500°F. A temperature of 500 °F is in the temperature range (approximately the midpoint of both ranges) for this analysis. From Reference 4, the specific heat slightly increases with an increase in temperatures; at higher temperatures, the uranium dioxide and zircaloy-2 would heat up more slowly. Thus, using a temperature at the midpoint for material properties is conservative with respect to the assembly heat-up. This temperature is used as representative of the full temperature range in this analysis.

3.5 This analysis conservatively assumes that there is no air cooling of the assemblies (i.e., adiabatic conditions): the flow paths that would provide natural circulation cooling are assumed to be blocked.

3.6 The fuel assembly material is assumed to start at a uniform temperature and heat up at uniform rate. While there are temperature gradients throughout the assemblies, these are small relative to the total heat up from 125 °F (Input 5.6) to either 1049 °F for cladding failure or 1652 °F for zirconium fire. Furthermore, this simplified approach is still conservative overall since convective and radiative heat transfer are not considered, nor is conduction to other structural materials such as the SFP racks.

3.7 Gadolinium, which is a burnable poison and can be used in some fuel rods (Reference 2), is conservatively not included in this evaluation.

4.0 References

1. C-1302-226-E310-458, Rev. 0, "Dose at Exclusion Area Boundary and Control Room Due to Shine from Drained Spent Fuel Pool During SAFSTOR".
2. TODI NF172795, Rev.0, "Transmit GNF2 Dimensional Data for Oyster Creek".
3. OCNGS Technical Specification 5.3.1, Amendment No. 223.
4. Glasstone and Sesonske, Nuclear Reactor Engineering, Van Nostrand Reinhold Company, 1981. (Attachment 1)
5. GEH-0000-0118-3544, Rev. 1, "GNF2 Fuel Design Cycle-Independent Analyses for Exelon Oyster Creek Generating Station".
6. NUREG/CR-6451, "A Safety and Regulatory Assessment of Generic BWR and PWR Permanently Shutdown Nuclear Power Plants", August 1997 (ML082260098).
7. NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants", February 2001 (ML010430066).
8. SECY-99-168, "Improving Decommissioning Regulations for Nuclear Power Plants", June 30, 1999 (ML992800087).

9. NSIR/DPR-ISG-02, "Emergency Planning Exemption Requests for Decommissioning Nuclear Power Plants", May 11, 2015.
10. ORNL/TM-2005/39, SCALE 6.1, User's Manual, June 2011.
11. Incropera & DeWitt, "Fundamentals of Heat and Mass Transfer", Third Edition, John Wiley & Sons, Inc., 1990
12. NF183597, Rev. 0, Oyster Creek Unit 1 Cycle 26 EOC Zirc Fire Calculation Inputs. (Attachment 3)
13. 26A7584, Rev. 0, GNF2 BWR/2-3 Fuel Bundle Weights (proprietary).
14. Inconel X-750 Technical Bulletin, Special Metals, <http://www.specialmetals.com/assets/smc/documents/alloys/inconel/inconel-alloy-x-750.pdf> (accessed 2/19/2018). (Attachment 4)
15. GNF2 Product Sheet, General Electrical, <https://nuclear.gepower.com/fuel-a-plant/products/gnf2-advantage> (accessed 2/20/2018). (Attachment 5)
16. DB-0011.03, Rev. 1, GNF2 Design Basis (proprietary).
17. NRC-2015-0070, Regulatory Improvements for Power Reactors Transitioning to Decommissioning, RIN Number 3150-AJ59, November 20, 2017.

5.0 Input Data

5.1 Zirconium Properties

The cladding for the GNF2 fuel is zircaloy-2 (Ref. 5). The specific heat of zircaloy-2 at 500°F (533 K) (Assumption 3.4) is 0.0761 Btu/ lbm-°F (Ref. 5, p. 89) and the density of zircaloy-2 is 6.56 g/cm^3 (409.53 lb/ft^3) (Ref. 10). The GNF2 channel is also zirconium alloy (Reference 15).

5.2 Uranium Properties

The specific heat of uranium dioxide at 500 °F (533 K) (Assumption 3.4) is 0.0683 Btu/ lbm-°F (Ref. 5, p. 89) and the density of uranium dioxide is 10.6 g/cm^3 (661.74 lb/ ft^3) (Ref. 5, p. 19).

5.3 Geometry for Limiting Assemblies

The table below shows the geometry inputs for the fuel assemblies used in this analysis. OCNGS's final cycle before decommissioning will contain a full core of GNF2 fuel (Assumption 3.3); therefore, the analysis herein will only evaluate the heat up of GNF2 fuel assemblies and not any other assembly type in the spent fuel pool because the offloaded fuel directly after a cycle is the hottest fuel assemblies in the pool. Table 1 contains fuel assembly input data for GNF2 fuel.

Table 1: Fuel Assembly Inputs for GNF2 Fuel

Number of Heated Rods	92 rods	Reference 5
Number of Water Rods	2 rods	Reference 5
Number of 2/3 Length Part Length Rod	8 rods	Reference 5
Number of 3/8 Length Part length Rod	6 rods	Reference 5
Length of 2/3 Part Length Rod	102 inches	Reference 2 and 5
Length of 3/8 Part Length Rod	54 inches	Reference 2 and 5
Uranium Pellet Diameter	0.3496 inches	Reference 2
Outer Diameter of Water Rods	0.980 inches	Reference 2
Inner Diameter of Water Rods	0.920 inches	Reference 2
Outer Diameter of Cladding	0.404 inches	Reference 2
Inner Diameter of Cladding	0.3567 inches	Reference 2
Heated Length of Rods	145.24 inches	Reference 2
Channel Width	5.283 inches	Reference 16
Channel Thickness	0.050 inches	Reference 16

5.4 Additional Hardware Masses

From Reference 13, the following additional hardware masses are also accounted for in calculating heat-up durations.

Table 2: Additional GNF2 Hardware Masses (Reference 13)

Component	Mass (lb)	Material
End plugs	5.66	Zircaloy-2
Upper tie plate, lower tie plate, lock tab washers and hex nuts, and retainer springs	19.92	Stainless Steel
Spacers and expansion springs	2.77	Alloy X-750 (Inconel)
Total	28.35	Modeled as Zircaloy-2 per Assumption 3.2

5.5 Heat Load

Attachment 2 determines the maximum heat load from a single fuel assembly, based on the information provided in Attachment 3. The assembly with the highest heat load will have the shortest heat-up time. The table showing the maximum fuel assembly heat generation rates for several years is in Attachment 2, Table A2-1.

The worst-case (hottest) bundle is one that was discharged at the end of Cycle 26 and has been cooling for nine months. From Table A2-1, it has a heat load of 1.091×10^{4} W/MTU. The maximum 0.181368 MTU/assembly value was derived from Cycle 26 data (Reference 12). The worst-case heat per assembly is calculated as follows:

$$Worst - case\ bundle\ heat\ load = \frac{1.091E + 04\ W}{MTU} \times \frac{0.181368\ MTU}{assembly} = 1979\ \frac{W}{assembly}$$

$$= 6752\ \frac{BTU/hr}{assembly}$$

The worst-case bundle heat load is determined at the remaining decay times (1 year, 1.25 years, 1.5 years, etc) using the same methodology.

5.6 Water Temperature

The starting temperature for the heat-up analysis is taken as a uniform 125 °F (51 °C). The temperature of 125 °F (51 °C) is the maximum initial pool temperature at or near the surface (Ref. 3). SECY-99-168 (Ref. 8) and NUREG-1738 (Ref. 7) both set the starting water temperature at 30 °C (86 °F), so setting the initial temperature to the maximum pool temperature is conservative.

6.0 Identification of Computer Codes

The ORIGEN-ARP module of the SCALE 6.1 code package is used to calculate new decay heat values in Attachment 2 of this calculation. This revised model is based on the existing ORIGEN-ARP models developed as part of C-1302-226-E310-458 (Reference 1). Further discussion on the use and application of this software is contained within C-1302-226-E310-458.

7.0 Method of Analysis

This analysis determines the heat-up time of the fuel assembly using the thermal capacity of materials. As discussed in Assumption 3.6, this simplified approach is both reasonable and conservative given the overall temperature range and not accounting for convective or radiative heat transfer in the analysis.

Equation 7-1 (Ref. 11, Ch. 8):

$$\dot{q} = m \times c_p \times \frac{\Delta T}{t}$$

$$m = \rho \times V$$

Where:

$\dot{q}$ is the heat generation rate in BTU/hr
m is the mass of material in lb
ρ is the density of the material in lb/ft^3
V is the volume of the material in ft^3
c_p is the specific heat in BTU/lb- °F
ΔT is the temperature increase in °F
t is the heat-up time in hr

For this analysis, there are two materials that are considered: the uranium dioxide fuel pellets and zircaloy-2. Zircaloy-2 comprises the cladding, the water tubes, channel, and the additional hardware (Assumption 3.2), all of which are also being heated. Under adiabatic conditions, zircaloy-2 and the uranium dioxide are modeled as heating up at the same rate, so the $\frac{\Delta T}{t}$ will be the same for both materials.

Equation 7-2:

$$\dot{q} = \frac{\Delta T}{t} \times \left(\rho_u \times V_u \times c_{p,u} + \rho_z \times V_z \times c_{p,z} + m_z \times c_{p,z}\right)$$

Where:

X_u signifies the property is for uranium dioxide
X_z signifies the property is for zirconium
m_z signifies any additional hardware modeled as zirconium

This calculation seeks the heat-up time, so Equation 7-2 is solved for t.

Equation 7-3:

$$t = \frac{\Delta T}{\dot{q}} \times \left(\rho_u \times V_u \times c_{p,u} + \rho_z \times V_z \times c_{p,z} + m_z \times c_{p,z}\right)$$

The volume of uranium is given below.

Equation 7-4:

$$V_u = \left(\left(\pi \times \frac{{D_p}^2}{4}\right) N_{FL} \times L_{FL}\right) + \left(\left(\pi \times \frac{{D_p}^2}{4}\right) N_{\left(\frac{2}{3}\right)} \times L_{\left(\frac{2}{3}\right)}\right) + \left(\left(\pi \times \frac{{D_p}^2}{4}\right) N_{\left(\frac{3}{8}\right)} \times L_{\left(\frac{3}{8}\right)}\right)$$

Where:

D_p is the diameter of the uranium pellet in ft
N_{FL} is the number of full length heated rods
L_{FL} is the heated length of the full length rods in ft
$N_{\left(\frac{2}{3}\right)}$ is the number of 2/3 length heated rods
$L_{\left(\frac{2}{3}\right)}$ is the heated length of 2/3 length rods in ft
$N_{\left(\frac{3}{8}\right)}$ is the number of 3/8 length heated rods
$L_{\left(\frac{3}{8}\right)}$ is the heated length of 3/8 length rods in ft

The volume of zircaloy-2 along the heated portion of rods, water rods, and channel are given below. The length of the cladding, water rods, and channel that are heated are conservatively modeled as being the same as the heated length of uranium dioxide. In reality, they are longer than the length of the uranium dioxide pellets.

Equation 7-5:

$$V_{z,cl} = \left(\left(\pi \times \frac{D_{c,o}^{2} - D_{c,i}^{2}}{4}\right) N_{FL} \times L_{FL}\right) + \left(\left(\pi \times \frac{D_{c,o}^{2} - D_{c,i}^{2}}{4}\right) N_{\left(\frac{2}{3}\right)} \times L_{\left(\frac{2}{3}\right)}\right) + \left(\left(\pi \times \frac{D_{c,o}^{2} - D_{c,i}^{2}}{4}\right) N_{\left(\frac{3}{8}\right)} \times L_{\left(\frac{3}{8}\right)}\right)$$

Where:

$V_{z,cl}$ is the volume of zircaloy-2 in the cladding of heated tubes
$D_{c,o}$ is the outer diameter of the cladding
$D_{c,i}$ is the inner diameter of the cladding

Equation 7-6:

$$V_{z,wr} = \left(\pi \times \frac{D_{w,o}^{2} - D_{w,i}^{2}}{4}\right) N_{wr} \times L_{FL}$$

Where:

$V_{z,wr}$ is the volume of zircaloy-2 in the water rods
$D_{w,o}$ is the outer diameter of the water rods
$D_{w,i}$ is the inner diameter of the water rods
N_{wr} is the number of water rods

Equation 7-7:

$$V_{z,ch} = W_{ch} \times th_{ch} \times L_{FL} \times 4$$

Where:

$V_{z,ch}$ is the volume of zircaloy-2 in the channel
W_{ch} is the channel width
th_{ch} is the minimum channel thickness

Equation 7-8:

$$V_z = V_{z,cl} + V_{z,wr} + V_{z,ch}$$

The temperature increase (ΔT) for this analysis is taken to be from the initial temperature of the pool, 125°F (51 °C) (Input 5.6), to the zirconium cladding failure temperatures of interest, 1049°F (565°C) and 1652°F (900°C) (Acceptance Criteria, Section 2).

The heat-up time is calculated as a function of the decay time for each of the times in Attachment 2. The hottest assembly source term methodology is described in Attachment 2.

8.0 Numeric Analysis

The volume of Uranium Dioxide in the hottest fuel assembly is determined below using Equation 7-4:

$$V_u = \left(\left(\pi \times \frac{(\frac{0.3496\ in}{12\ in/ft})^2}{4}\right) 78\ rods \times \frac{145.24\ in}{12\ in/ft}\right) + \left(\left(\pi \times \frac{(\frac{0.3496\ in}{12\ in/ft})^2}{4}\right) 8\ rods \times \frac{102\ in}{12\ in/ft}\right) + \left(\left(\pi \times \frac{(\frac{0.3496\ in}{12\ in/ft})^2}{4}\right) 6\ rods \times \frac{54\ in}{12\ in/ft}\right) = 0.693\ ft^3$$

The volume of zircaloy-2 in the cladding is determined below using Equation 7-5:

$$V_{z,cl} = \left(\left(\pi \times \frac{(\frac{0.404\ in}{12\ in/ft})^2 - (\frac{0.3567\ in}{12\ in/ft})^2}{4}\right) 78\ rods \times \frac{145.24\ in}{12\ in/ft}\right) + \left(\left(\pi \times \frac{(\frac{0.404\ in}{12\ in/ft})^2 - (\frac{0.3567\ in}{12\ in/ft})^2}{4}\right) 8\ rods \times \frac{102\ in}{12\ in/ft}\right) + \left(\left(\pi \times \frac{(\frac{0.404\ in}{12\ in/ft})^2 - (\frac{0.3567\ in}{12\ in/ft})^2}{4}\right) 6\ rods \times \frac{54\ in}{12\ in/ft}\right) = 0.204 ft^3$$

The volume of zircaloy-2 in the water rods is determined below using Equation 7-6.

$$V_{z,wr} = \left(\pi \times \frac{(\frac{0.980\ in}{12\ in/ft})^2 - (\frac{0.920\ in}{12\ in/ft})^2}{4}\right) 2\ rods \times \frac{145.24\ in}{12\ in/ft} = 0.015\ ft^3$$

The volume of zircaloy-2 in the channel is determined below using Equation 7-7.

$$V_{z,ch} = \frac{5.283\ in}{12\ in/ft} \times \frac{0.05\ in}{12\ in/ft} \times \frac{145.24\ in}{12\ in/ft} \times 4 = 0.089\ ft^3$$

The total zircaloy-2 volume is then determined below from Equation 7-8:

$$V_z = 0.204\ ft^3 + 0.015\ ft^3 + 0.089\ ft^3 = 0.308\ ft^3$$

The heat-up time is then determined for end temperatures of 565°C (1049°F) and 900°C (1652°F) using the maximum bundle heat load at different decay times with Equation 7-3. The heat-up time to 1049°F for the nine-month decay maximum bundle (Section 5.5) is shown below; the heat-up for the remaining decay times is solved in the same exact manner (i.e., changing the heat load and keeping the remaining inputs constant) and the results are reported in Section 9. Note, as-presented values may differ slightly due to rounding in Excel.

$$t = \frac{(1049°F - 125°F)}{6752\ BTU/hr}\Big(661.74\frac{lb}{ft^3} \times 0.693\ ft^3 \times 0.0683\frac{BTU}{lbm - °F} + 409.53\frac{lb}{ft^3} \times 0.308\ ft^3 \times 0.0761\frac{BTU}{lbm - °F} + 28.35 lb \times 0.0761\frac{BTU}{lbm - °F}\Big) = 5.89\ hours$$

9.0 Results and Conclusions

The results are shown in Table 3.

Table 3: Results

End Temperature (°C, °F)	Decay Time (years)	Heat-Up Time (hours)
565, 1049	0.75	5.89
565, 1049	1	7.13
565, 1049	1.25	8.34
565, 1049	1.5	9.56
565, 1049	2	12.09
565, 1049	3	17.28
900, 1652	0.75	9.74
900, 1652	1	11.78
900, 1652	1.25	13.78
900, 1652	1.5	15.81
900, 1652	2	19.98
900, 1652	3	28.56

The 10 hour heat-up time to a temperature of 565°C (1049 °F), which is when cladding failure is expected, occurs just after 1.5 years. The 10 hour heat-up time to a temperature of 900°C (1652°F), which is when zirconium fire is expected, occurs at a decay time of 9.38 months (0.78 years). This was conservatively calculated by interpolating between the nine month (0.75 year) and one year times. This aligns with the 10 month decay time for Emergency Planning Level 1 determined in NRC-2015-0070 (Ref. 17).
Figure 1 below shows the heat-up time vs decay time for both temperatures of interest.

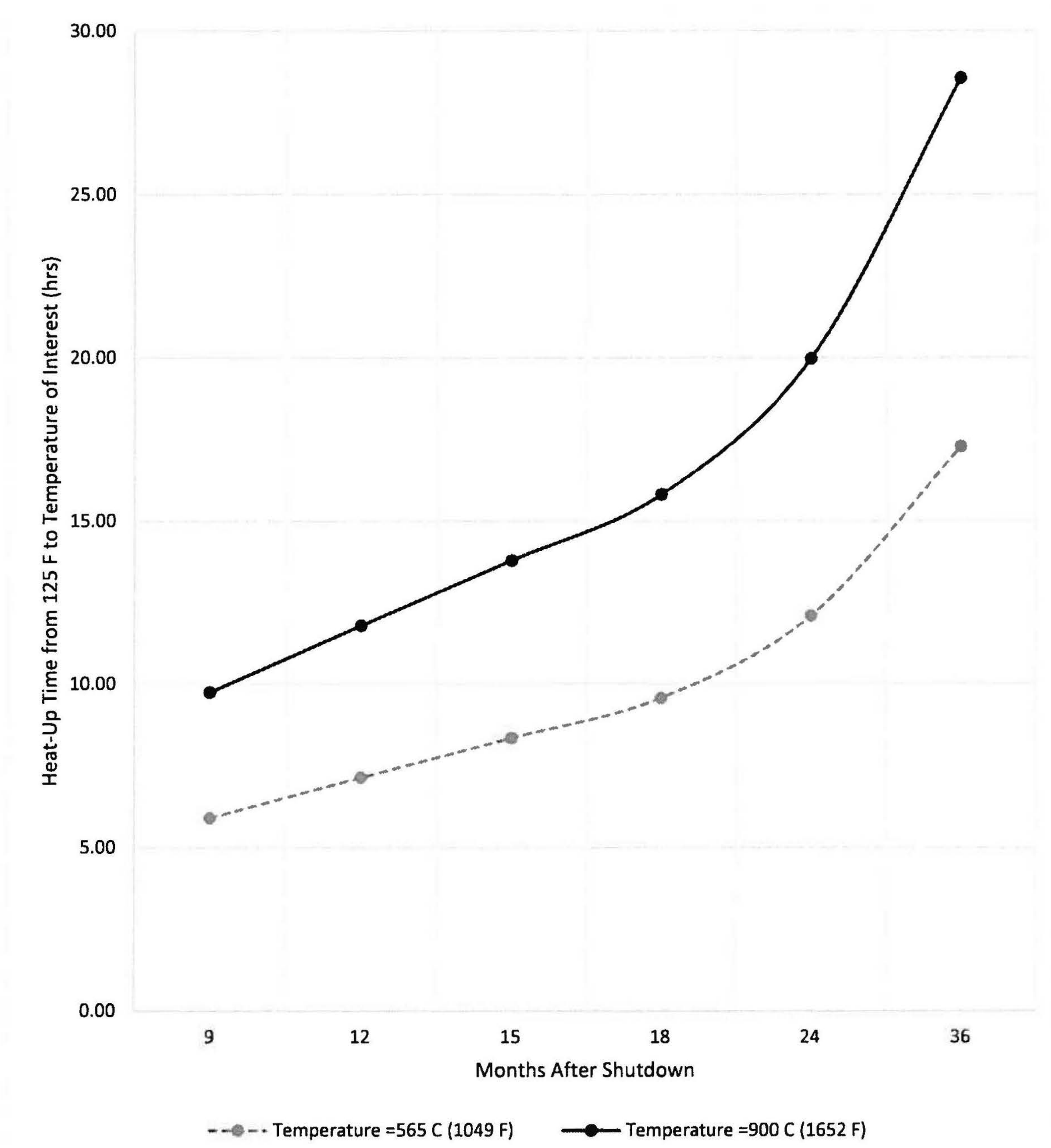

Figure 1: Heat-Up Time vs. Decay Time

TABLE A.6 PHYSICAL PROPERTIES OF SOME REACTOR MATERIALS
(Average values for preliminary calculations only; not to be used for design purposes.)

Material	Temperature (K)	Density (kg/m³)	Coefficient of Linear Thermal Expansion* (per K × 10⁶)	Specific Heat (J/kg·K × 10⁻³)	Thermal Conductivity (W/m·K)	Ultimate Tensile Strength (MPa)	Yield Strength or Compressive Strength (C) (MPa)	Young's Modulus (10⁹ Pa)	Poisson's Ratio
Graphite (average nuclear grade)	300	1700	–	0.71	156	13.8	58 (C)	–	–
	500		3.6†	1.75	118	15.9	–	9.0	–
	800	–	5.0†	1.67	73	17.2	–	–	–
	1400	–	6.3†	1.88	36	19.3	–	–	–
	2500	–	8.5†	–	31	27.6	–	–	–
Steel, carbon (A 533-B)	300	7860	–	0.50	52	550	340	207	0.28
	600	–	10.2	0.59	45	530	280	182	–
	750	–	10.4	0.63	38	450	240	172	–
	800	–	10.4	0.67	35	390	200	169	–
Steel, stainless (type 347)	300	7950	–	0.50	14	520	210	–	–
	500	7860	16.9	0.52	17	420	–	173	0.30
	700	7710	17.4	0.55	20	400	150	166	0.31
	800	–	18.5	0.57	22	390	–	157	0.32
Uranium carbide (UC)	300	13,620	–	0.15	–	–	372 (C)	214	–
	600	–	–	–	23	–	–	–	–
	1250	–	10.3	–	23	–	–	–	–
Uranium dioxide	300	10,980	–	0.23	8.0	–	960 (C)	183	–
	500	–	9.0	0.28	6.1	–	–	–	–
	800	–	10.1	0.30	4.1	–	–	165	–
	1100	–	–	0.31	2.6	–	–	–	–
	1400	–	12.8	0.32	2.2	–	–	–	–
	2300	–	–	0.42	2.3	–	–	–	–
Zircaloy-2	300	6560	–	0.28	12.7	490	300	95	0.43
	500	–	–	0.31	15.2	280	170	90	0.28
	600	–	6.5	0.33	16.5	210	117	78	–
	800	–	–	0.35	18.9	–	–	–	–
	1000	–	–	0.37	21.6	–	–	–	–

*Average values from 20°C to indicated temperatures.
†Average of longitudinal and transverse properties.

Decay Heat Calculation

The revised decay heat run is based on the Cycle 26 maximum burnup (48762.3 MWd/MTU), minimum enrichment (3.43%), and maximum MTU (0.181368 MTU/Assy) from Reference 12. Using the same 560 assemblies in the core, power level of 1930 MWt, and GNF2 fuel from Reference 1, the new bounding bundle power level is calculated below:

$$Bounding\ Avg.\ Power\ Level = 1930\ MWt \times \frac{1\ core}{560\ assemblies} \times \frac{1}{0.181368 \frac{MTU}{assembly}} = 19.0024\ MWt/MTU$$

This results in a total irradiation period calculated as

$$Irradiation\ Period = \frac{48762.3 \frac{MWd}{MTU}}{19.0024 \frac{MWt}{MTU}} = 2566.11\ days$$

These values are used to update the ORIGEN-ARP decay heat model from Reference 1 and the revised input file is included in Attachment 6 of this calculation. Table A8-2 from Attachment 8 of Reference 1 is recreated below using this Cycle 26 fuel information and accounts for the additional assembly hardware mass. This also includes a 9-month (0.75 year) time step due to the increased margin from using this cycle.

Table A2-1: Decay Heat Source Terms from ORIGEN-ARP

Decay Time	0.75 Year Decay (W/MTU)	1 Year Decay (W/MTU)	1.25 Year Decay (W/MTU)	1.5 Year Decay (W/MTU)	2 Year Decay (W/MTU)	3 Year Decay (W/MTU)	5 Year Decay (W/MTU)
Cycle 26, max. burnup, min. enrichment, max. MTU	1.091E+04	9.018E+03	7.707E+03	6.721E+03	5.318E+03	3.720E+03	2.454E+03

NUCLEAR FEELS

TRANSMITTAL OF DESIGN INFORMATION

☐ SAFETY RELATED ☒ NON-SAFETY RELATED ☐ REGULATORY RELATED	Originating Organization ☒ Nuclear Fuels ☐ Other (specify) ________	NF ID# NF183597 Revision 0 SRRS # 3A.130 Page 1 of 18

Subject: Oyster Creek Unit 1 Cycle 26 EOC Zirc Fire Calculation Inputs

Station: Oyster Creek Unit: 1 Cycle: 26 Generic: N/A

To: Dwayne Blaylock (Enercon) EC/ECR#: N/A

Ferheen Qureshi	[signature]	2/16/2018
Prepared by	Signature	Date
Robert Potter	[signature]	2/16/2018
Reviewed by	Signature	Date
Armando Johnson	[signature]	16FEB18
Approved by	Signature	Date

Status of Information: ☒ Verified ☐ Unverified ☐ Engineering Judgment

Action Tracking # for Method and Schedule of Verification for Unverified DESIGN INFORMATION: N/A

Purpose of Information:

Provides inputs to Enercon calculation for "Oyster Creek Nuclear Generating Station Zirconium Fire Analysis for Drained Spent Fuel Pool" assuming a shutdown date of October 1st, 2018.

Description of Information/Basis:

This package provides information necessary to revise the "Oyster Creek Nuclear Generating Station Zirconium Fire Analysis for Drained Spent Fuel Pool" which was previously based on the final operating cycle 27 fuel data. With Exelon decision to shut down Oyster Creek after cycle 26, the calculation is being revised to determine the potential reduction in acceptable decay time for the limiting bundle for the cycle 26 core. The information generated assumes a shutdown date of October 1st, 2018.

The following information is included as attachments in this TODI:

1. Attachment 1: Oyster Creek Cycle 26 Fuel Bundle Inventory
2. Attachment 2: Oyster Creek Cycle 26 Fuel Bundle Identification Array
3. Attachment 3: Oyster Creek Cycle 26 Fuel IAT Map
4. Attachment 4: Oyster Creek Cycle 26 Fuel Bundle Exposure, Uranium Mass, & Enrichment

Source of Information (References):

1. Oyster Creek Unit 1 Cycle 26 Core Loading Plan Rev. 3
2. Disk6:[Readonly.OC.C26.Project.zircfire]OC1C26D_OC_02-12-18.WRP

Supplemental Distribution:	E - Mail: Robert Csillag Armando Johnson Brian Froese NCS Controlled Documents Distribution	Hard Copy: None.

ATTACHMENT 1: Oyster Creek Cycle 26 Fuel Bundle Inventory

BUNDLE TYPE	NO.	FUEL BUNDLE DESCRIPTION	CHANNEL MATERIAL	CYCLE LOADED	BATCH ID RANGE
6	48	GNF2-P10DG2B370-16GZ-100T2-145-T6-3356	ZR2RX	23	JYN413-JYN460
7	12	GNF2-P10DG2B369-16GZ-100T2-145-T6-3357-LTD	ZR2RX	23	JYN501-JYN516
8	32	GNF2-P10DG2B370-16GZ-100T2-145-T6-4137	ZR2RX	24	JYX370-JYX401
9	16	GNF2-P10DG2B372-14GZ-100T2-145-T6-4138	ZR4RX	24	JYX426-JYX441
10	16	GNF2-P10DG2B370-15GZ-100T2-145-T6-3355	ZR2RX	23	JYN381-JYN404
11	40	GNF2-P10DG2B371-14GZ-100T2-145-T6-4300	ZR2RX	25	YLD792-YLD831
12	24	GNF2-P10DG2B371-16GZ-100T2-145-T6-4301	ZR2RX	25	YLD856-YLD879
13	16	GNF2-P10DG2B370-16GZ-100T2-145-T6-3356	ZR4RX	23	JYN461-JYN476
14	16	GNF2-P10DG2B369-16GZ-100T2-145-T6-3357-LTD	ZR4RX	23	JYN525-JYN540
15	24	GNF2-P10DG2B372-14GZ-100T2-145-T6-4138	ZR2RX	24	JYX402-JYX425
17	48	GNF2-P10DG2B371-14GZ-100T2-145-T6-4136	ZR4RX	24	JYX322-JYX369
20	32	GNF2-P10DG2B371-14GZ-100T2-145-T6-4136	ZR2RX	24	JYX290-JYX321
21	24	GNF2-P10DG2B369-16GZ-100T2-145-T6-4303	ZR2RX	25	YLD888-YLD911
22	24	GNF2-P10DG2B371-14GZ-100T2-145-T6-4300	ZR4RX	25	YLD832-YLD855
23	8	GNF2-P10DG2B371-16GZ-100T2-145-T6-4301	ZR4RX	25	YLD880-YLD887
24	32	GNF2-P10DG2B369-16GZ-100T2-145-T6-4303	ZR4RX	25	YLD912-YLD943
25	8	GNF2-P10DG2B370-12GZ-100T2-145-T6-4437	ZR2RX	26	YLL555-YLL562
26	56	GNF2-P10DG2B346-13GZ-100T2-145-T6-4435-LTD	ZR2RX	26	YLL423-YLL478
27	44	GNF2-P10DG2B343-14GZ-100T2-145-T6-4436-LTD	ZR2RX	26	YLL479-YLL522
28	8	GNF2-P10DG2B346-13GZ-100T2-145-T6-4435-LTD	ZR4RX	26	YLL415-YLL422
29	32	GNF2-P10DG2B370-12GZ-100T2-145-T6-4437	ZR4RX	26	YLL523-YLL554
SUM =	560				

ATTACHMENT 2: Oyster Creek Cycle 26 Fuel Bundle Identification Array

J/I (PANAC)	1	2	3	4	5	6	7	8	9	10	11	12	13	
1									JYN462	JYN509	JYN454	JYN382	JYN445	52
2								JYN438	JYN469	JYX323	YLD929	YLD937	YLD873	50
3					JYN534	JYN413	JYN422	JYN398	YLD905	YLD825	YLD809	YLD913	JYX363	48
4				JYN501	JYN430	JYN502	YLD921	YLD849	JYX379	YLD880	JYX402	YLD817	YLD793	46
5			JYN533	JYN429	JYX386	YLD865	YLD897	YLD833	YLD857	YLL432	YLL500	YLL508	YLL416	44
6			JYN414	JYN529	YLD864	JYX338	YLD801	JYX299	YLL492	JYX307	YLL440	JYX427	JYX347	42
7			JYN421	YLD920	YLD896	YLD800	YLL479	YLL484	YLD841	YLL556	JYX291	YLL540	YLD889	40
8		JYN437	JYN397	YLD848	YLD832	JYX298	YLL483	JYX419	YLL424	JYX435	YLL532	JYX395	YLL516	38
9	JYN461	JYN470	YLD904	JYX378	YLD856	YLL491	YLD840	YLL423	JYX354	YLL524	JYX411	YLL456	JYX315	36
10	JYN525	JYX322	YLD824	YLD881	YLL431	JYX306	YLL555	JYX434	YLL523	JYX339	YLL448	JYX370	YLL548	34
11	JYN453	YLD928	YLD808	JYX403	YLL499	YLL439	JYX290	YLL531	JYX410	YLL447	JYX387	YLL464	JYX330	32
12	JYN381	YLD936	YLD912	YLD816	YLL507	JYX426	YLL539	JYX394	YLL455	JYX371	YLL463	JYX355	YLL472	30
13	JYN446	YLD872	JYX362	YLD792	YLL415	JYX346	YLD888	YLL515	JYX314	YLL547	JYX331	YLL471	JYX418	28
14	JYN451	YLD879	JYX369	YLD799	YLL422	JYX353	YLD895	YLL522	JYX321	YLL554	JYX336	YLL478	JYX425	26
15	JYN388	YLD943	YLD919	YLD823	YLL514	JYX433	YLL546	JYX401	YLL462	JYX376	YLL470	JYX360	YLL477	24
16	JYN460	YLD935	YLD815	JYX408	YLL506	YLL446	JYX297	YLL538	JYX417	YLL454	JYX392	YLL469	JYX337	22
17	JYN528	JYX329	YLD831	YLD886	YLL438	JYX313	YLL562	JYX441	YLL530	JYX344	YLL453	JYX377	YLL553	20
18	JYN468	JYN475	YLD911	JYX385	YLD863	YLL498	YLD847	YLL430	JYX361	YLL529	JYX416	YLL461	JYX320	18
19		JYN444	JYN404	YLD855	YLD839	JYX305	YLL490	JYX424	YLL429	JYX440	YLL537	JYX400	YLL521	16
20			JYN428	YLD927	YLD903	YLD807	YLL482	YLL489	YLD846	YLL561	JYX296	YLL545	YLD894	14
21			JYN419	JYN532	YLD871	JYX345	YLD806	JYX304	YLL497	JYX312	YLL445	JYX432	JYX352	12
22			JYN540	JYN436	JYX393	YLD870	YLD902	YLD838	YLD862	YLL437	YLL505	YLL513	YLL421	10
23				JYN508	JYN435	JYN507	YLD926	YLD854	JYX384	YLD887	JYX409	YLD822	YLD798	8
24					JYN539	JYN420	JYN427	JYN403	YLD910	YLD830	YLD814	YLD918	JYX368	6
25								JYN443	JYN476	JYX328	YLD934	YLD942	YLD878	4
26									JYN467	JYN516	JYN459	JYN387	JYN452	2
	1	3	5	7	9	11	13	15	17	19	21	23	25	X/Y (SITE)

J/I (PANAC)	14	15	16	17	18	19	20	21	22	23	24	25	26	
1	JYN448	JYN383	JYN455	JYN512	JYN463									52
2	YLD874	YLD938	YLD930	JYX324	JYN472	JYN439								50
3	JYX364	YLD914	YLD810	YLD826	YLD906	JYN399	JYN423	JYN416	JYN535					48
4	YLD794	YLD818	JYX405	YLD883	JYX380	YLD850	YLD922	JYN503	JYN431	JYN504				46
5	YLL417	YLL509	YLL501	YLL433	YLD858	YLD834	YLD898	YLD866	JYX389	JYN432	JYN536			44
6	JYX348	JYX428	YLL441	JYX308	YLL493	JYX300	YLD802	JYX341	YLD867	JYN530	JYN415			42
7	YLD890	YLL541	JYX292	YLL557	YLD842	YLL485	YLL480	YLD803	YLD899	YLD923	JYN424			40
8	YLL517	JYX396	YLL533	JYX436	YLL425	JYX420	YLL486	JYX301	YLD835	YLD851	JYN400	JYN440		38
9	JYX316	YLL457	JYX412	YLL525	JYX357	YLL426	YLD843	YLL494	YLD859	JYX381	YLD907	JYN471	JYN464	36
10	YLL549	JYX373	YLL449	JYX340	YLL526	JYX437	YLL558	JYX309	YLL434	YLD882	YLD827	JYX325	JYN526	34
11	JYX333	YLL465	JYX388	YLL450	JYX413	YLL534	JYX293	YLL442	YLL502	JYX404	YLD811	YLD931	JYN456	32
12	YLL473	JYX356	YLL466	JYX372	YLL458	JYX397	YLL542	JYX429	YLL510	YLD819	YLD915	YLD939	JYN384	30
13	JYX421	YLL474	JYX332	YLL550	JYX317	YLL518	YLD891	JYX349	YLL418	YLD795	JYX365	YLD875	JYN447	28
14	JYX422	YLL475	JYX335	YLL551	JYX318	YLL519	YLD892	JYX350	YLL419	YLD796	JYX366	YLD876	JYN450	26
15	YLL476	JYX359	YLL467	JYX375	YLL459	JYX398	YLL543	JYX430	YLL511	YLD820	YLD916	YLD940	JYN385	24
16	JYX334	YLL468	JYX391	YLL451	JYX414	YLL535	JYX294	YLL443	YLL503	JYX407	YLD812	YLD932	JYN457	22
17	YLL552	JYX374	YLL452	JYX343	YLL527	JYX438	YLL559	JYX310	YLL435	YLD885	YLD828	JYX326	JYN527	20
18	JYX319	YLL460	JYX415	YLL528	JYX358	YLL427	YLD844	YLL495	YLD860	JYX382	YLD908	JYN474	JYN465	18
19	YLL520	JYX399	YLL536	JYX439	YLL428	JYX423	YLL487	JYX302	YLD836	YLD852	JYN401	JYN441		16
20	YLD893	YLL544	JYX295	YLL560	YLD845	YLL488	YLL481	YLD804	YLD900	YLD924	JYN425			14
21	JYX351	JYX431	YLL444	JYX311	YLL496	JYX303	YLD805	JYX342	YLD868	JYN531	JYN418			12
22	YLL420	YLL512	YLL504	YLL436	YLD861	YLD837	YLD901	YLD869	JYX390	JYN433	JYN537			10
23	YLD797	YLD821	JYX406	YLD884	JYX383	YLD853	YLD925	JYN506	JYN434	JYN505				8
24	JYX367	YLD917	YLD813	YLD829	YLD909	JYN402	JYN426	JYN417	JYN538					6
25	YLD877	YLD941	YLD933	JYX327	JYN473	JYN442								4
26	JYN449	JYN386	JYN458	JYN513	JYN466									2
	27	29	31	33	35	37	39	41	43	45	47	49	51	X/Y (SITE)

ATTACHMENT 3: Oyster Creek Cycle 26 Fuel IAT Map

J/I	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
1									13	7	6	10	6	6	10	6	7	13									52
2								6	13	17	24	24	12	12	24	24	17	13	6								50
3					14	6	6	10	21	11	11	24	17	17	24	11	11	21	10	6	6	14					48
4				7	6	7	24	22	8	23	15	11	11	11	11	15	23	8	22	24	7	6	7				46
5			14	6	8	12	21	22	12	26	27	27	28	28	27	27	26	12	22	21	12	8	6	14			44
6			6	14	12	17	11	20	27	20	26	9	17	17	9	26	20	27	20	11	17	12	14	6			42
7			6	24	21	11	27	27	22	25	20	29	21	21	29	20	25	22	27	27	11	21	24	6			40
8		6	10	22	22	20	27	15	26	9	29	8	27	27	8	29	9	26	15	27	20	22	22	10	6		38
9	13	13	21	8	12	27	22	26	17	29	15	26	20	20	26	15	29	17	26	22	27	12	8	21	13	13	36
10	14	17	11	23	26	20	25	9	29	17	26	8	29	29	8	26	17	29	9	25	20	26	23	11	17	14	34
11	6	24	11	15	27	26	20	29	15	26	8	26	17	17	26	8	26	15	29	20	26	27	15	11	24	6	32
12	10	24	24	11	27	9	29	8	26	8	26	17	26	26	17	26	8	26	8	29	9	27	11	24	24	10	30
13	6	12	17	11	28	17	21	27	20	29	17	26	15	15	26	17	29	20	27	21	17	28	11	17	12	6	28
14	6	12	17	11	28	17	21	27	20	29	17	26	15	15	26	17	29	20	27	21	17	28	11	17	12	6	26
15	10	24	24	11	27	9	29	8	26	8	26	17	26	26	17	26	8	26	8	29	9	27	11	24	24	10	24
16	6	24	11	15	27	26	20	29	15	26	8	26	17	17	26	8	26	15	29	20	26	27	15	11	24	6	22
17	14	17	11	23	26	20	25	9	29	17	26	8	29	29	8	26	17	29	9	25	20	26	23	11	17	14	20
18	13	13	21	8	12	27	22	26	17	29	15	26	20	20	26	15	29	17	26	22	27	12	8	21	13	13	18
19		6	10	22	22	20	27	15	26	9	29	8	27	27	8	29	9	26	15	27	20	22	22	10	6		16
20			6	24	21	11	27	27	22	25	20	29	21	21	29	20	25	22	27	27	11	21	24	6			14
21			6	14	12	17	11	20	27	20	26	9	17	17	9	26	20	27	20	11	17	12	14	6			12
22			14	6	8	12	21	22	12	26	27	27	28	28	27	27	26	12	22	21	12	8	6	14			10
23				7	6	7	24	22	8	23	15	11	11	11	11	15	23	8	22	24	7	6	7				8
24					14	6	6	10	21	11	11	24	17	17	24	11	11	21	10	6	6	14					6
25								6	13	17	24	24	12	12	24	24	17	13	6								4
26									13	7	6	10	6	6	10	6	7	13									2
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	

ATTACHMENT 4: Oyster Creek Cycle 26 Fuel Bundle Exposure, Uranium Mass, & Enrichment

Bundle Serial ID	Bundle Type (IAT)	EOC Bundle Exp (GWd/MT)	Initial Weight (MT)	Initial Enrich (fraction)
JYN461	13	46.7913	0.180885	0.037016
JYN525	14	47.0963	0.180771	0.036880
JYN453	6	47.0508	0.180840	0.037038
JYN381	10	47.5784	0.180944	0.037066
JYN446	6	48.3574	0.180928	0.037036
JYN451	6	48.4346	0.180956	0.036993
JYN388	10	47.6153	0.180856	0.037038
JYN460	6	47.0528	0.180856	0.037001
JYN528	14	47.2909	0.180918	0.036880
JYN468	13	46.8265	0.180816	0.036971
JYN437	6	47.1013	0.180940	0.037017
JYN470	13	45.9430	0.180771	0.036983
JYX322	17	35.2095	0.181064	0.037105
YLD928	24	27.9412	0.180415	0.036866
YLD936	24	27.4603	0.180413	0.036864
YLD872	12	28.1927	0.180246	0.037090
YLD879	12	28.1668	0.180377	0.037078
YLD943	24	27.4484	0.180419	0.036864
YLD935	24	27.9199	0.180438	0.036856
JYX329	17	35.2612	0.181013	0.037096
JYN475	13	46.0372	0.180897	0.036996
JYN444	6	47.1046	0.180924	0.037018
JYN533	14	47.6656	0.181162	0.036891
JYN414	6	45.8782	0.180841	0.037004
JYN421	6	48.7544	0.180808	0.036971
JYN397	10	44.9803	0.180819	0.037039
YLD904	21	28.2190	0.180318	0.036853
YLD824	11	28.7219	0.180544	0.037086
YLD808	11	31.0810	0.180407	0.037103
YLD912	24	31.6330	0.180307	0.036856
JYX362	17	43.1786	0.180983	0.037061
JYX369	17	43.2291	0.180955	0.037072
YLD919	24	31.6384	0.180394	0.036872
YLD815	11	31.0659	0.180434	0.037088
YLD831	11	28.6980	0.180544	0.037080
YLD911	21	28.1943	0.180311	0.036851
JYN404	10	44.9880	0.180895	0.037045
JYN428	6	48.7623	0.180855	0.037046
JYN419	6	45.9307	0.180967	0.037029

JYN540	14	47.7202	0.181000	0.036878
JYN501	7	47.3498	0.180795	0.036899
JYN429	6	44.6650	0.180914	0.036991
JYN529	14	42.2695	0.180882	0.036876
YLD920	24	27.4228	0.180421	0.036866
YLD848	22	29.2999	0.180549	0.037109
JYX378	8	44.8288	0.180675	0.036927
YLD881	23	31.2113	0.180360	0.037077
JYX403	15	46.9403	0.180663	0.037160
YLD816	11	32.7881	0.180477	0.037103
YLD792	11	32.6462	0.180476	0.037100
YLD799	11	32.6869	0.180409	0.037105
YLD823	11	32.7571	0.180571	0.037092
JYX408	15	46.9685	0.180746	0.037182
YLD886	23	31.2930	0.180373	0.037080
JYX385	8	44.8688	0.180675	0.036957
YLD855	22	29.2650	0.180620	0.037115
YLD927	24	27.4035	0.180413	0.036868
JYN532	14	42.2820	0.181096	0.036895
JYN436	6	44.6691	0.180912	0.037004
JYN508	7	47.3109	0.180898	0.036878
JYN534	14	47.6497	0.181186	0.036883
JYN430	6	44.4073	0.180948	0.037021
JYX386	8	40.1257	0.180689	0.036950
YLD864	12	28.3874	0.180331	0.037081
YLD896	21	30.6601	0.180305	0.036862
YLD832	22	31.8674	0.180541	0.037099
YLD856	12	31.5925	0.180333	0.037083
YLL431	26	16.8696	0.180710	0.034588
YLL499	27	17.8470	0.180610	0.034378
YLL507	27	17.9508	0.180526	0.034361
YLL415	28	17.0129	0.180802	0.034558
YLL422	28	17.0061	0.180803	0.034594
YLL514	27	17.9331	0.180491	0.034370
YLL506	27	17.8062	0.180729	0.034359
YLL438	26	16.8367	0.180738	0.034586
YLD863	12	31.6397	0.180358	0.037075
YLD839	22	31.8582	0.180528	0.037116
YLD903	21	30.6213	0.180325	0.036856
YLD871	12	28.3465	0.180335	0.037092
JYX393	8	40.1549	0.180567	0.036945
JYN435	6	44.6145	0.180910	0.037006
JYN539	14	47.7421	0.180974	0.036871
JYN413	6	45.9948	0.180756	0.037000

JYN502	7	44.9950	0.180802	0.036895
YLD865	12	28.3737	0.180349	0.037085
JYX338	17	41.8157	0.181108	0.037098
YLD800	11	32.7274	0.180516	0.037084
JYX298	20	45.6360	0.181269	0.037053
YLL491	27	17.0019	0.180551	0.034387
JYX306	20	44.1676	0.181211	0.037062
YLL439	26	18.5264	0.180697	0.034572
JYX426	9	44.7833	0.180649	0.037184
JYX346	17	44.4934	0.181069	0.037058
JYX353	17	44.5266	0.180972	0.037066
JYX433	9	44.7559	0.180754	0.037186
YLL446	26	18.4791	0.180800	0.034561
JYX313	20	44.1772	0.181120	0.037089
YLL498	27	16.9705	0.180516	0.034372
JYX305	20	45.6561	0.181209	0.037069
YLD807	11	32.7196	0.180492	0.037087
JYX345	17	41.8993	0.180865	0.037066
YLD870	12	28.3263	0.180307	0.037088
JYN507	7	45.0657	0.180806	0.036880
JYN420	6	45.9565	0.180962	0.037014
JYN422	6	48.6226	0.180838	0.036993
YLD921	24	27.4097	0.180460	0.036868
YLD897	21	30.6819	0.180310	0.036861
YLD801	11	32.7223	0.180507	0.037085
YLL479	27	17.0117	0.180544	0.034372
YLL483	27	17.7602	0.180552	0.034368
YLD840	22	34.4626	0.180564	0.037114
YLL555	25	18.8889	0.180792	0.036976
JYX290	20	43.2128	0.181331	0.037106
YLL539	29	18.1641	0.180677	0.036984
YLD888	21	34.7157	0.180372	0.036860
YLD895	21	34.7338	0.180292	0.036853
YLL546	29	18.0942	0.180766	0.036963
JYX297	20	43.2096	0.181285	0.037071
YLL562	25	18.8547	0.180759	0.036995
YLD847	22	34.4445	0.180537	0.037117
YLL490	27	17.7204	0.180425	0.034404
YLL482	27	16.9472	0.180531	0.034374
YLD806	11	32.7282	0.180412	0.037103
YLD902	21	30.6202	0.180246	0.036860
YLD926	24	27.3851	0.180371	0.036867
JYN427	6	48.7491	0.180854	0.037044
JYN438	6	46.7672	0.180935	0.037015

JYN398	10	44.8150	0.180889	0.037028
YLD849	22	29.3201	0.180606	0.037108
YLD833	22	31.6552	0.180518	0.037099
JYX299	20	45.6437	0.181246	0.037045
YLL484	27	17.7907	0.180577	0.034372
JYX419	15	48.2107	0.180746	0.037178
YLL423	26	18.6980	0.180753	0.034604
JYX434	9	43.2434	0.180742	0.037213
YLL531	29	18.1953	0.180699	0.036989
JYX394	8	42.7113	0.180557	0.036936
YLL515	27	18.4323	0.180536	0.034359
YLL522	27	18.4274	0.180438	0.034361
JYX401	8	42.7385	0.180634	0.036955
YLL538	29	18.1391	0.180677	0.036960
JYX441	9	43.2669	0.180616	0.037193
YLL430	26	18.6839	0.180659	0.034566
JYX424	15	48.2397	0.180634	0.037186
YLL489	27	17.7201	0.180444	0.034403
JYX304	20	45.6197	0.181183	0.037072
YLD838	22	31.8546	0.180477	0.037107
YLD854	22	29.2622	0.180618	0.037121
JYN403	10	44.9218	0.180869	0.037058
JYN443	6	47.1285	0.180906	0.036992
JYN462	13	46.8231	0.180805	0.037003
JYN469	13	45.7639	0.180774	0.036986
YLD905	21	28.2960	0.180282	0.036846
JYX379	8	44.7244	0.180721	0.036964
YLD857	12	31.5714	0.180313	0.037083
YLL492	27	17.0837	0.180564	0.034390
YLD841	22	34.3358	0.180563	0.037118
YLL424	26	18.7500	0.180762	0.034604
JYX354	17	42.4193	0.180987	0.037075
YLL523	29	17.1289	0.180726	0.036985
JYX410	15	45.3287	0.180792	0.037177
YLL455	26	18.4172	0.180728	0.034558
JYX314	20	46.8374	0.180960	0.037070
JYX321	20	46.8404	0.180927	0.037078
YLL462	26	18.3917	0.180710	0.034554
JYX417	15	45.3668	0.180656	0.037160
YLL530	29	17.2251	0.180674	0.036995
JYX361	17	42.4970	0.180940	0.037069
YLL429	26	18.6871	0.180687	0.034572
YLD846	22	34.4469	0.180528	0.037123
YLL497	27	16.9617	0.180648	0.034371

YLD862	12	31.6431	0.180319	0.037071
JYX384	8	44.8613	0.180668	0.036974
YLD910	21	28.1812	0.180339	0.036845
JYN476	13	46.0016	0.180996	0.036985
JYN467	13	46.8525	0.180784	0.036988
JYN509	7	45.8381	0.180834	0.036886
JYX323	17	34.5627	0.181008	0.037085
YLD825	11	28.7401	0.180503	0.037088
YLD880	23	31.3415	0.180345	0.037076
YLL432	26	16.9735	0.180626	0.034585
JYX307	20	44.0520	0.181211	0.037057
YLL556	25	19.0264	0.180757	0.036966
JYX435	9	42.8704	0.180732	0.037200
YLL524	29	17.1724	0.180727	0.036984
JYX339	17	44.0875	0.180968	0.037070
YLL447	26	18.4052	0.180799	0.034578
JYX371	8	48.0557	0.180648	0.036922
YLL547	29	17.7631	0.180717	0.036968
YLL554	29	17.7460	0.180784	0.036964
JYX376	8	48.1056	0.180609	0.036942
YLL454	26	18.3937	0.180723	0.034578
JYX344	17	44.5069	0.180964	0.037083
YLL529	29	17.2271	0.180733	0.036992
JYX440	9	43.2925	0.180499	0.037174
YLL561	25	18.8723	0.180753	0.036973
JYX312	20	44.1475	0.181152	0.037066
YLL437	26	16.8377	0.180739	0.034582
YLD887	23	31.2919	0.180362	0.037081
YLD830	11	28.6645	0.180542	0.037104
JYX328	17	35.2568	0.181036	0.037069
JYN516	7	45.8050	0.180858	0.036857
JYN454	6	47.0448	0.180882	0.036991
YLD929	24	28.0211	0.180444	0.036863
YLD809	11	31.0860	0.180415	0.037107
JYX402	15	47.0036	0.180705	0.037185
YLL500	27	17.9618	0.180560	0.034370
YLL440	26	18.6669	0.180683	0.034574
JYX291	20	42.4912	0.181339	0.037101
YLL532	29	18.3131	0.180738	0.036981
JYX411	15	45.3085	0.180718	0.037179
YLL448	26	18.4315	0.180792	0.034587
JYX387	8	46.4990	0.180674	0.036947
YLL463	26	18.7416	0.180821	0.034582
JYX331	17	47.1711	0.181025	0.037069

JYX336	17	47.2424	0.180949	0.037064
YLL470	26	18.7059	0.180779	0.034580
JYX392	8	46.6144	0.180578	0.036949
YLL453	26	18.4077	0.180657	0.034578
JYX416	15	45.3017	0.180679	0.037195
YLL537	29	18.1883	0.180713	0.036968
JYX296	20	43.2442	0.181311	0.037095
YLL445	26	18.5003	0.180737	0.034573
YLL505	27	17.8178	0.180638	0.034357
JYX409	15	46.9826	0.180703	0.037185
YLD814	11	31.0527	0.180490	0.037082
YLD934	24	27.9165	0.180399	0.036848
JYN459	6	47.0484	0.180923	0.036991
JYN382	10	46.9554	0.180962	0.037068
YLD937	24	27.5554	0.180422	0.036869
YLD913	24	31.5841	0.180291	0.036860
YLD817	11	32.8022	0.180478	0.037084
YLL508	27	18.0691	0.180422	0.034351
JYX427	9	44.7431	0.180643	0.037156
YLL540	29	18.2964	0.180649	0.036988
JYX395	8	42.6552	0.180591	0.036923
YLL456	26	18.4910	0.180643	0.034560
JYX370	8	48.0884	0.180629	0.036913
YLL464	26	18.7501	0.180867	0.034577
JYX355	17	43.3861	0.181006	0.037067
YLL471	26	18.7088	0.180769	0.034560
YLL478	26	18.6844	0.180825	0.034607
JYX360	17	43.7634	0.180909	0.037068
YLL469	26	18.7096	0.180749	0.034575
JYX377	8	48.0993	0.180655	0.036959
YLL461	26	18.4082	0.180708	0.034558
JYX400	8	42.7886	0.180687	0.036956
YLL545	29	18.1485	0.180701	0.036973
JYX432	9	44.7015	0.180798	0.037184
YLL513	27	17.9274	0.180527	0.034363
YLD822	11	32.7394	0.180595	0.037097
YLD918	24	31.6334	0.180379	0.036859
YLD942	24	27.4512	0.180423	0.036860
JYN387	10	47.5847	0.180846	0.037057
JYN445	6	48.3269	0.180967	0.037031
YLD873	12	28.2644	0.180264	0.037090
JYX363	17	42.7492	0.181054	0.037051
YLD793	11	32.4134	0.180525	0.037097
YLL416	28	17.1023	0.180812	0.034562

JYX347	17	44.3304	0.181120	0.037031
YLD889	21	34.7511	0.180342	0.036858
YLL516	27	18.5141	0.180549	0.034369
JYX315	20	46.8702	0.180989	0.037079
YLL548	29	17.7942	0.180808	0.036948
JYX330	17	47.2091	0.180996	0.037083
YLL472	26	18.7158	0.180790	0.034576
JYX418	15	48.0746	0.180694	0.037180
JYX425	15	48.0784	0.180665	0.037191
YLL477	26	18.6809	0.180790	0.034597
JYX337	17	47.2216	0.181034	0.037070
YLL553	29	17.7512	0.180746	0.036965
JYX320	20	46.8314	0.180990	0.037084
YLL521	27	18.4269	0.180489	0.034362
YLD894	21	34.7344	0.180304	0.036848
JYX352	17	44.5040	0.180959	0.037074
YLL421	28	16.9910	0.180755	0.034594
YLD798	11	32.6632	0.180446	0.037104
JYX368	17	43.1878	0.181014	0.037076
YLD878	12	28.1661	0.180345	0.037066
JYN452	6	48.3690	0.180966	0.036985
JYN448	6	48.3978	0.180843	0.037034
YLD874	12	28.2375	0.180317	0.037078
JYX364	17	43.2605	0.181011	0.037059
YLD794	11	32.7562	0.180468	0.037109
YLL417	28	17.0808	0.180749	0.034561
JYX348	17	44.5129	0.181164	0.037020
YLD890	21	34.8123	0.180336	0.036860
YLL517	27	18.4960	0.180505	0.034357
JYX316	20	46.8684	0.180989	0.037067
YLL549	29	17.7924	0.180742	0.036960
JYX333	17	47.2210	0.181061	0.037049
YLL473	26	18.7018	0.180810	0.034581
JYX421	15	48.0658	0.180603	0.037143
JYX422	15	48.0469	0.180635	0.037179
YLL476	26	18.6873	0.180755	0.034599
JYX334	17	47.0472	0.181031	0.037054
YLL552	29	17.7518	0.180725	0.036963
JYX319	20	46.8249	0.180969	0.037072
YLL520	27	18.4231	0.180463	0.034349
YLD893	21	34.6975	0.180340	0.036848
JYX351	17	44.4371	0.180959	0.037084
YLL420	28	16.9791	0.180733	0.034574
YLD797	11	32.6599	0.180435	0.037107

JYX367	17	43.1568	0.181045	0.037069
YLD877	12	28.1457	0.180312	0.037075
JYN449	6	48.3112	0.180957	0.037037
JYN383	10	47.5977	0.180914	0.037077
YLD938	24	27.5089	0.180329	0.036871
YLD914	24	31.6962	0.180338	0.036861
YLD818	11	32.8089	0.180482	0.037089
YLL509	27	18.0018	0.180406	0.034336
JYX428	9	44.7523	0.180712	0.037201
YLL541	29	18.2076	0.180639	0.037003
JYX396	8	42.8235	0.180594	0.036896
YLL457	26	18.4536	0.180680	0.034567
JYX373	8	48.1220	0.180583	0.036919
YLL465	26	18.7294	0.180829	0.034587
JYX356	17	43.7423	0.181017	0.037071
YLL474	26	18.6939	0.180777	0.034586
YLL475	26	18.6875	0.180800	0.034594
JYX359	17	43.7380	0.180934	0.037052
YLL468	26	18.6991	0.180806	0.034569
JYX374	8	48.0115	0.180621	0.036930
YLL460	26	18.3819	0.180741	0.034559
JYX399	8	42.7855	0.180630	0.036907
YLL544	29	18.1251	0.180696	0.036967
JYX431	9	44.6190	0.180738	0.037192
YLL512	27	17.8707	0.180410	0.034356
YLD821	11	32.6995	0.180610	0.037108
YLD917	24	31.6061	0.180427	0.036878
YLD941	24	27.4427	0.180426	0.036848
JYN386	10	47.5723	0.180909	0.037058
JYN455	6	47.0339	0.180919	0.036984
YLD930	24	27.9346	0.180489	0.036863
YLD810	11	31.0987	0.180436	0.037102
JYX405	15	46.9953	0.180721	0.037163
YLL501	27	17.8793	0.180466	0.034363
YLL441	26	18.5476	0.180714	0.034580
JYX292	20	43.2692	0.181318	0.037115
YLL533	29	18.2307	0.180659	0.036998
JYX412	15	45.3158	0.180765	0.037183
YLL449	26	18.4280	0.180772	0.034579
JYX388	8	46.6409	0.180589	0.036940
YLL466	26	18.7212	0.180838	0.034580
JYX332	17	47.2195	0.181029	0.037055
JYX335	17	47.0755	0.180952	0.037060
YLL467	26	18.7044	0.180788	0.034572

JYX391	8	46.5964	0.180592	0.036922
YLL452	26	18.3581	0.180660	0.034589
JYX415	15	45.2568	0.180713	0.037184
YLL536	29	18.1471	0.180720	0.036970
JYX295	20	43.2028	0.181321	0.037104
YLL444	26	18.4263	0.180718	0.034560
YLL504	27	17.7479	0.180588	0.034356
JYX406	15	46.8755	0.180684	0.037191
YLD813	11	31.0278	0.180493	0.037094
YLD933	24	27.8927	0.180406	0.036851
JYN458	6	47.0372	0.180886	0.037003
JYN512	7	45.7916	0.180877	0.036862
JYX324	17	35.2609	0.181041	0.037065
YLD826	11	28.6710	0.180531	0.037085
YLD883	23	31.3223	0.180373	0.037083
YLL433	26	16.8806	0.180627	0.034592
JYX308	20	44.1635	0.181117	0.037075
YLL557	25	18.9065	0.180757	0.036958
JYX436	9	43.3048	0.180640	0.037212
YLL525	29	17.2571	0.180737	0.036989
JYX340	17	44.5228	0.180962	0.037067
YLL450	26	18.4234	0.180752	0.034581
JYX372	8	48.1106	0.180625	0.036917
YLL550	29	17.7642	0.180748	0.036970
YLL551	29	17.7581	0.180747	0.036962
JYX375	8	48.0181	0.180657	0.036935
YLL451	26	18.3540	0.180732	0.034600
JYX343	17	44.3587	0.181029	0.037070
YLL528	29	17.0527	0.180758	0.036986
JYX439	9	43.2361	0.180529	0.037175
YLL560	25	18.8327	0.180763	0.036964
JYX311	20	44.0779	0.181150	0.037063
YLL436	26	16.8077	0.180734	0.034591
YLD884	23	31.2685	0.180417	0.037076
YLD829	11	28.6426	0.180575	0.037090
JYX327	17	35.2392	0.181012	0.037071
JYN513	7	45.7883	0.180879	0.036867
JYN463	13	46.8103	0.180816	0.037006
JYN472	13	45.9928	0.181008	0.036994
YLD906	21	28.2038	0.180346	0.036840
JYX380	8	44.8599	0.180709	0.036939
YLD858	12	31.6743	0.180343	0.037085
YLL493	27	16.9937	0.180595	0.034385
YLD842	22	34.4793	0.180567	0.037113

YLL425	26	18.7117	0.180753	0.034596
JYX357	17	42.4961	0.180966	0.037068
YLL526	29	17.2488	0.180785	0.036974
JYX413	15	45.3457	0.180808	0.037170
YLL458	26	18.4295	0.180717	0.034573
JYX317	20	46.8162	0.180992	0.037070
JYX318	20	46.8097	0.180985	0.037091
YLL459	26	18.3910	0.180769	0.034568
JYX414	15	45.3003	0.180693	0.037183
YLL527	29	17.0653	0.180669	0.036993
JYX358	17	42.3661	0.180895	0.037060
YLL428	26	18.6294	0.180682	0.034570
YLD845	22	34.4104	0.180518	0.037122
YLL496	27	16.9414	0.180641	0.034380
YLD861	12	31.6380	0.180315	0.037074
JYX383	8	44.8345	0.180717	0.036972
YLD909	21	28.1736	0.180342	0.036852
JYN473	13	45.9266	0.181026	0.036991
JYN466	13	46.7703	0.180825	0.036975
JYN439	6	47.0967	0.180960	0.037018
JYN399	10	44.9100	0.180857	0.037010
YLD850	22	29.2860	0.180587	0.037108
YLD834	22	31.8787	0.180523	0.037107
JYX300	20	45.6347	0.181261	0.037057
YLL485	27	17.7360	0.180559	0.034376
JYX420	15	48.2466	0.180704	0.037185
YLL426	26	18.7104	0.180755	0.034599
JYX437	9	43.2896	0.180639	0.037202
YLL534	29	18.2155	0.180700	0.036982
JYX397	8	42.7712	0.180673	0.036915
YLL518	27	18.4564	0.180441	0.034353
YLL519	27	18.4400	0.180521	0.034352
JYX398	8	42.7589	0.180643	0.036921
YLL535	29	18.1630	0.180689	0.036972
JYX438	9	43.2414	0.180577	0.037184
YLL427	26	18.6321	0.180701	0.034568
JYX423	15	48.1949	0.180695	0.037164
YLL488	27	17.7090	0.180394	0.034408
JYX303	20	45.5877	0.181226	0.037057
YLD837	22	31.8420	0.180497	0.037106
YLD853	22	29.2584	0.180556	0.037141
JYN402	10	44.9178	0.180862	0.037042
JYN442	6	47.0997	0.180881	0.036994
JYN423	6	48.7261	0.180866	0.037011

YLD922	24	27.4071	0.180369	0.036875
YLD898	21	30.6300	0.180332	0.036860
YLD802	11	32.7473	0.180475	0.037084
YLL480	27	16.9752	0.180507	0.034375
YLL486	27	17.7359	0.180582	0.034382
YLD843	22	34.4743	0.180556	0.037109
YLL558	25	18.9016	0.180755	0.036966
JYX293	20	43.2147	0.181368	0.037108
YLL542	29	18.1733	0.180714	0.036992
YLD891	21	34.7475	0.180372	0.036850
YLD892	21	34.7241	0.180326	0.036849
YLL543	29	18.1533	0.180693	0.036984
JYX294	20	43.2177	0.181326	0.037108
YLL559	25	18.8529	0.180735	0.036978
YLD844	22	34.4300	0.180538	0.037110
YLL487	27	17.7127	0.180421	0.034398
YLL481	27	16.9480	0.180509	0.034369
YLD805	11	32.6698	0.180456	0.037097
YLD901	21	30.6160	0.180272	0.036848
YLD925	24	27.3493	0.180410	0.036864
JYN426	6	48.7193	0.180869	0.037023
JYN416	6	45.9160	0.180940	0.036989
JYN503	7	45.0245	0.180789	0.036892
YLD866	12	28.3478	0.180322	0.037082
JYX341	17	41.8646	0.181001	0.037059
YLD803	11	32.7547	0.180450	0.037089
JYX301	20	45.6097	0.181253	0.037065
YLL494	27	16.9922	0.180614	0.034378
JYX309	20	44.1749	0.181156	0.037071
YLL442	26	18.5303	0.180724	0.034580
JYX429	9	44.7575	0.180783	0.037199
JYX349	17	44.4822	0.181147	0.037037
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JYX430	9	44.7614	0.180712	0.037188
YLL443	26	18.5050	0.180713	0.034579
JYX310	20	44.1491	0.181169	0.037075
YLL495	27	16.9514	0.180650	0.034379
JYX302	20	45.5589	0.181238	0.037040
YLD804	11	32.6742	0.180482	0.037089
JYX342	17	41.8461	0.181063	0.037080
YLD869	12	28.2802	0.180322	0.037089
JYN506	7	45.0556	0.180823	0.036877
JYN417	6	45.9172	0.180947	0.036982
JYN535	14	47.6703	0.181174	0.036881

JYN431	6	44.5828	0.180945	0.037012
JYX389	8	40.1566	0.180608	0.036949
YLD867	12	28.3649	0.180351	0.037084
YLD899	21	30.6292	0.180307	0.036852
YLD835	22	31.8857	0.180497	0.037111
YLD859	12	31.6737	0.180329	0.037080
YLL434	26	16.8676	0.180702	0.034601
YLL502	27	17.8634	0.180458	0.034369
YLL510	27	17.9597	0.180495	0.034359
YLL418	28	17.0242	0.180762	0.034563
YLL419	28	17.0262	0.180703	0.034568
YLL511	27	17.9546	0.180438	0.034353
YLL503	27	17.8463	0.180460	0.034349
YLL435	26	16.8405	0.180712	0.034594
YLD860	12	31.6518	0.180340	0.037085
YLD836	22	31.8715	0.180499	0.037096
YLD900	21	30.6251	0.180262	0.036852
YLD868	12	28.3021	0.180349	0.037082
JYX390	8	39.9972	0.180603	0.036909
JYN434	6	44.5889	0.180987	0.036996
JYN538	14	47.7226	0.180958	0.036875
JYN504	7	47.3102	0.180779	0.036899
JYN432	6	44.6346	0.180945	0.037014
JYN530	14	42.2638	0.180996	0.036877
YLD923	24	27.4076	0.180420	0.036869
YLD851	22	29.2723	0.180559	0.037121
JYX381	8	44.8622	0.180691	0.036968
YLD882	23	31.3245	0.180365	0.037075
JYX404	15	46.9712	0.180730	0.037173
YLD819	11	32.7664	0.180514	0.037088
YLD795	11	32.6858	0.180485	0.037105
YLD796	11	32.6929	0.180470	0.037108
YLD820	11	32.7636	0.180488	0.037097
JYX407	15	46.9106	0.180726	0.037188
YLD885	23	31.3014	0.180370	0.037078
JYX382	8	44.8372	0.180726	0.036972
YLD852	22	29.2669	0.180540	0.037136
YLD924	24	27.3770	0.180412	0.036874
JYN531	14	42.2964	0.181041	0.036893
JYN433	6	44.6610	0.180908	0.037005
JYN505	7	47.2923	0.180866	0.036894
JYN536	14	47.6667	0.181143	0.036882
JYN415	6	45.8819	0.180959	0.036975
JYN424	6	48.7400	0.180833	0.037010

JYN400	10	44.9677	0.180851	0.037031
YLD907	21	28.2041	0.180342	0.036837
YLD827	11	28.6941	0.180541	0.037080
YLD811	11	31.0758	0.180423	0.037099
YLD915	24	31.6537	0.180397	0.036867
JYX365	17	43.1952	0.181066	0.037053
JYX366	17	43.1893	0.181021	0.037073
YLD916	24	31.6504	0.180346	0.036874
YLD812	11	31.0636	0.180428	0.037095
YLD828	11	28.6772	0.180623	0.037076
YLD908	21	28.1917	0.180347	0.036839
JYN401	10	44.9956	0.180849	0.037018
JYN425	6	48.7368	0.180848	0.037003
JYN418	6	45.9167	0.180939	0.036985
JYN537	14	47.6608	0.181130	0.036881
JYN440	6	47.0781	0.180946	0.037011
JYN471	13	46.0108	0.180827	0.036995
JYX325	17	35.2221	0.181070	0.037052
YLD931	24	27.9411	0.180382	0.036866
YLD939	24	27.4667	0.180338	0.036862
YLD875	12	28.1804	0.180317	0.037076
YLD876	12	28.1532	0.180328	0.037068
YLD940	24	27.4606	0.180331	0.036848
YLD932	24	27.9084	0.180444	0.036863
JYX326	17	35.2539	0.181016	0.037083
JYN474	13	45.9665	0.181023	0.036987
JYN441	6	47.0884	0.180976	0.036991
JYN464	13	46.7866	0.180853	0.036991
JYN526	14	47.2833	0.180833	0.036874
JYN456	6	46.9741	0.180960	0.037002
JYN384	10	47.5578	0.180923	0.037067
JYN447	6	48.3915	0.180952	0.037039
JYN450	6	48.4297	0.180908	0.037020
JYN385	10	47.5995	0.180850	0.037069
JYN457	6	46.9889	0.180900	0.037000
JYN527	14	47.1677	0.180921	0.036880
JYN465	13	46.7419	0.180897	0.036987

INCONEL® alloy X-750 (UNS N07750/W. Nr. 2.4669) is a precipitation-hardenable nickel-chromium alloy used for its corrosion and oxidation resistance and high strength at temperatures to 1300°F. Although much of the effect of precipitation hardening is lost with increasing temperature over 1300°F, heat-treated material has useful strength up to 1800°F. Alloy X-750 also has excellent properties down to cryogenic termperatures. Composition is shown in Table 1.

The economics of INCONEL alloy X-750 coupled with its availability in all standard mill forms has resulted in applications in a wide variety of industrial fields. In gas turbines, it is used for rotor blades and wheels, bolts, and other structural members. INCONEL alloy X-750 is used extensively in rocket-engine thrust chambers. Airframe applications include thrust reversers and hot-air ducting systems. Large pressure vessels are formed from INCONEL alloy X-750. Other applications are heat-treating fixtures, forming tools, extrusion dies, and test machine grips. For springs and fasteners, INCONEL alloy X-750 is used from sub-zero to 1200°F.

Depending on the application and the properties desired, various heat treatments are employed. For service above 1100°F, particularly where loads are to be sustained for long times, optimum properties are achieved by solution treating (2100°F) plus stabilization treating (1550°F) plus precipitation treating (1300°F). For service below 1100°F, the alloy may be strengthened by precipitation treating after hot or cold working or by precipitation treating after equalizing or solution treating. A furnace-cooling treatment is also used to develop optimum properties for some applications.

The various heat treatments and the properties developed are described under the section on Mechanical Properties.

Property values in this bulletin – the results of extensive testing – are typical of the alloy but, unless shown as limiting, should not be used as specification values.

Publication No. SMC-067

Table 1 - Limiting Chemical Composition, %

Nickel (plus Cobalt)	70.00 min.
Chromium	14.0-17.0
Iron	5.0-9.0
Titanium	2.25-2.75
Aluminum	0.40-1.00
Niobium (plus Tantalum)	0.70-1.20
Manganese	1.00 max.
Silicon	0.50 max.
Sulfur	0.01 max.
Copper	0.50 max.
Carbon	0.08 max.
Cobalt[1]	1.00 max

[1]Determination not required for routine acceptance.

Physical Constants and Thermal Properties

Some physical constants and thermal properties of INCONEL alloy X-750 are given in Tables 2 and 3.

Values for thermal expansion, thermal conductivity, specific heat, and diffusivity are from Lucks and Deem and electrical resistivity from tests conducted at Lehigh University.

Effects of temperature on modulus of elasticity and additional data on resistivity are in Tables 4 and 5. More modulus values can be found in the section on Mechanical Properties.

Table 2 – Physical Constants

Density, lb/in³	0.299
g/cm³	8.28
Melting Range, °F	2540-2600
°C	1393-1427
Curie Temperature, °F	
As hot-rolled	-225
Triple-heat-treated (2100°F/2 hr, A.C.,+1500°F /24 hr, A.C., + 1300°F/20 hr, A.C.)	-193
Magnetic Permeability, 70°F, 200H	
As Hot-Rolled	1.0020
Triple-heat-treated (2100°F/2 hr, A.C.,+1500°F /24 hr, A.C., + 1300°F/20 hr, A.C.)	1.0035
Emissivity, oxidized surface	
600°F	0.895
2000°F	0.925
Linear Contraction during Precipitation Treatment (1300°F/20 hr), in/in	
Hot-Rolled	0.00044
20% Cold-Rolled	0.00052
Annealed	0.00026

INCONEL® alloy X-750

Table 3 - Thermal Properties[a]

Temperature, °F	Mean Linear Expansion, in./in./°F x 10^{-6} from 70° F to Temperature Shown	Thermal Conductivity, Btu/in./hr/sq ft/°F	Specific Heat Btu/lb/°F	Diffusivity, sq ft/hr	Electrical Resistivity, ohm/circ mil/ft
-250	6.5	67	0.073	0.150	-
-200	6.6	70	0.080	0.143	-
-100	6.7	74	0.090	0.135	-
70	-	83	0.103	0.132	731
200	7.0	89	0.109	0.133	739
400	7.2	98	0.116	0.140	746
600	7.5	109	0.120	0.148	761
800	7.8	120	0.125	0.158	771
1000	8.1	131	0.130	0.169	783
1200	8.4	143	0.137	0.173	786
1400	8.8	154	0.151	0.172	775
1600	9.3	164	0.171	0.164	761
1800	9.8	-	-	-	-

[a] Material heat-treated 2100°F/3 hr, A.C., + 1550°F/24 hr, A.C., + 1300°F/20 hr, A.C.

Table 4 - Effect of Heat Treatment on Room-Temperature Resistivity of Hot-Rolled Bar

Heat Treatment	Resistivity, ohm/circ mil/ft
As hot-rolled	759
2000°F/1 hr, A.C.	763
2100°F/1 hr, A.C.+1500°F/24 hr, A.C.+ 1300°F/20 hr, A.C.	724
1800°F/1 hr, A.C.+1350°F/8 hr,F.C. to 1150°F, hold at 1150°F for total time of 18 hr, A.C.	739

Table 5 - Modulus of Elasticity

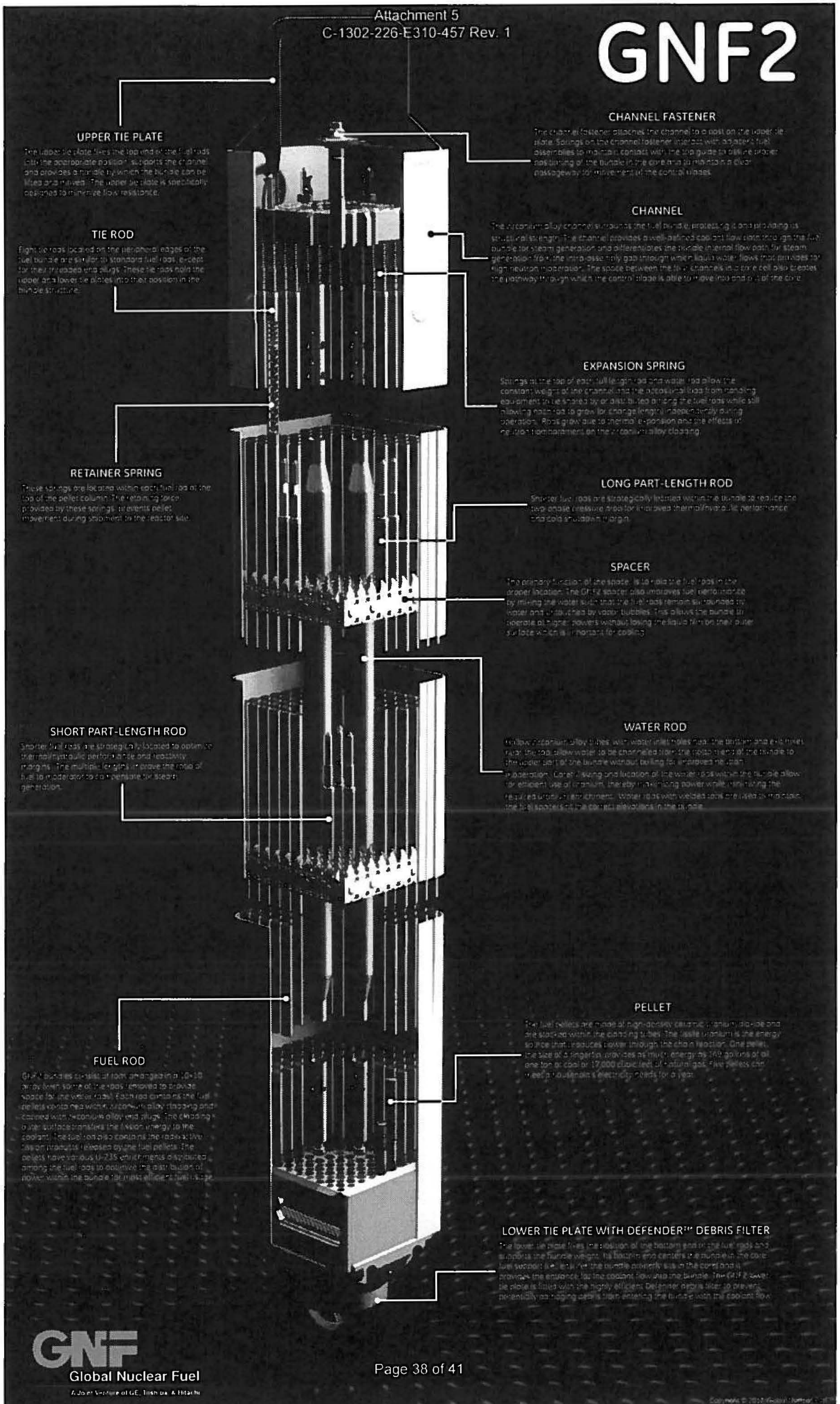
Temperature, °F	Modulus of Elasticity, 10^3 ksi		
	Tension		Torsion
	Static	Dynamic	Static
80[a]	31.0	31.0	11.0
500	28.7	29.1	10.2
1000	25.0	26.7	9.0
1200	23.0	25.5	8.1
1350	21.0	24.4	-
1500	18.5	23.2	-
1600	-	22.1	-
1800	-	20.0	-

[a] Poisson's ratio = 0.29

Mechanical Properties

INCONEL alloy X-750 may be given any one of a variety of heat treatments. Each develops special properties and puts the product form in the best condition for its intended application. In all conditions, alloy X-750 is resistant to oxidation up to 1800°F. The most often used heat treatments have been incorporated by the Society of Automotive Engineers in their AMS specifications* for various product forms. The heat treatments, specifications, and product forms are summarized in Table 6.

*AMS specifications are subject to revision. The ones referenced in this publication were current when it was released. Publisher is the Society of Automotive Engineers, Inc.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UPPER TIE PLATE
CHANNEL FASTENER
CHANNEL
TIE ROD
EXPANSION SPRING
RETAINER SPRING
LONG PART-LENGTH ROD
SPACER
SHORT PART-LENGTH ROD
WATER ROD
PELLET
FUEL ROD
LOWER TIE PLATE WITH DEFENDER™ DEBRIS FILTER
GNF
Global Nuclear Fuel

C26Max.inp

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65$$
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