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Revision 1

Mechanical Design Evaluation for Kewaunee Cycle 23, Reloads KEW-19, KEW-18 and KEW-17 Fuel Assemblies

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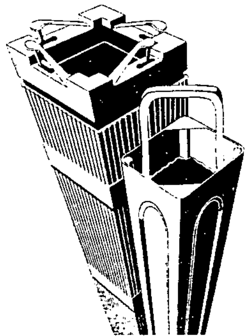

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Nature of Changes

Item	Paragraph or Page(s)	Description and Justification
1.	Throughout	Bracketed (Proprietary Version) or deleted (Non-proprietary version) selected text, tables and figures. Justification: Prepares proprietary and non-proprietary versions for WPSC to submit to NRC.

Contents

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Nomenclature

AOO	anticipated operational occurrences
ASME	American Society of Mechanical Engineers
BOL	beginning-of-life
CUF	cumulative usage factor
DNB	departure from nucleate boiling
EOL	end of life
HTP	high thermal performance
LHGR	linear heat generation rate
LOCA	loss-of-coolant-accident
LTP	lower tie plate
MDNBR	minimum departure from nucleate boiling ratio
NRC	U.S. Nuclear Regulatory Commission
PCI	pellet/clad interaction
SRP	Standard Review Plan
UTP	upper tie plate
WPSC	Wisconsin Public Service Corporation
P_m	primary membrane (stress category)
P_b	primary bending (stress category)
Q	secondary stress category

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1. Introduction

This report provides a design description and the results of supporting analyses applicable to the mechanical design of the Kewaunee Reload KEW-19 fuel assemblies. In addition, results are presented for the KEW-17 and KEW-18 fuel assemblies reinserted for Cycle 23. The mechanical design for the Kewaunee Reload KEW-19 is essentially the same mechanical design presented in topical reports EMF-94-178(P), *Mechanical Design Report for Kewaunee Lead Fuel Assemblies*,(1) and EMF-96-127, Revision 1, *Mechanical Design Evaluation for Kewaunee Reload KEW-18 Lead Fuel Assemblies*.(2)

In this document, the term "standard" (std) refers to the rod design with a cladding inner diameter of 0.364 inch and a pellet diameter of 0.3565 inch. Standard rods were used in the Reload 17 and Reload 18 standard assemblies. The term "heavy" (hvy) refers to the rod design having a cladding inner diameter of 0.374 inch and a pellet diameter of 0.367 inch. Heavy rods were used in the Reload 17 and Reload 18 lead assemblies, as well as in the Reload 19 assemblies.

2. Summary and Conclusions

Mechanical analyses of the Kewaunee Reload KEW-19 fuel design have been performed using U.S. Nuclear Regulatory Commission (NRC)-approved mechanical design analysis methodology(3,4) and the NRC-approved high thermal performance (HTP) fuel generic design report.(5) The results from the analyses demonstrate the mechanical criteria presented in the Reference 6 topical report are satisfied to the following maximum discharge exposures:

- 59 GWd/MTU assembly exposure
- 62 GWd/MTU rod exposure

Additionally, analyses have been performed to extend the allowable peak exposure of the standard design KEW-17 and KEW-18 fuel assemblies and fuel rods to 58 and 62 GWd/MTU, respectively, and of the heavy design KEW-17 and KEW-18 fuel assemblies and fuel rods to 59 and 62 GWd/MTU, respectively.

The analyses for the KEW-19 fuel design, the KEW-17 heavy fuel design, the KEW-18 fuel assembly design with the FUELGUARD™ [a]/HTP cage and standard fuel rod design, and the KEW-18 heavy fuel assembly design with the FUELGUARD™/HTP cage and the heavy fuel rod design were performed using peaking factor limits of $F_{\Delta H}^{T}$ of 1.70 and F_{Q}^{T} of 2.40 for normal operation and during anticipated operational occurrences (AOO). The analyses for the Reload KEW-17 standard fuel design were performed using peaking factor limits of $F_{\Delta H}^{T}$ of 1.55 and F_{Q}^{T} of 2.28 for normal operation and during AOO.

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[a] FUELGUARD is a trademark of Siemens.

3. Design Evaluation

3.1 *Mechanical Design*

The mechanical design for the Reload KEW-19 incorporates changes previously evaluated for and demonstrated in lead fuel assemblies loaded with Reloads 17 and 18. For mechanical analysis purposes, the fuel design is identical to the heavy lead assemblies supplied with the KEW-18 reload. This design has been incorporated with the neutronic design in a reload quantity which required an update to the fuel rod mechanical analyses to assure appropriate power histories were considered. Additionally, the fuel rod and fuel assembly peak discharge exposure has been increased to 62 GWd/MTU and 59 GWd/MTU, respectively, and peaking factor limits have been increased to $F^T_{\Delta H} = 1.70$ and $F^T_Q = 2.40$. References 1 and 2 remain applicable, as noted.

The following table summarizes the exposure limit and peaking factor increases for the previous reload and lead fuel assemblies:

	Peak Assembly Exposure, GWd/MTU	Peak Rod Exposure, GWd/MTU	$F^T_{\Delta H}$	F^T_Q
KEW-17 std	58	62	1.55	2.28
KEW-17 hvy	59	62	1.70	2.40
KEW-18 std	58	62	1.70	2.40
KEW-18 hvy	59	62	1.70	2.40
KEW-19	59	62	1.70	2.40

Mechanical analyses were performed to evaluate both the UO_2 and the NAF fuel rods contained in the assemblies to be loaded into Kewaunee Cycle 23 and the two fuel system designs represented by the FUELGUARD™/HTP cage and the standard design cage. The fuel rod calculations included a review and re-analysis of updated power histories for Cycle 23. Results of the analyses for the most limiting UO_2 and NAF rods and the fuel system design are presented in this report.

Table 3.1 shows the fuel assembly component attributes for the KEW-19 design. Attributes for the KEW-17 std, -17 hvy, -18 std, and -18 hvy designs can be found in the previous design reports.(1,2)

Table 3.2 summarizes the results from the design evaluations. These results include references to the appropriate criteria given in Section 3 of the design criteria topical report.(6) Table 3.3 lists the design duty cycles assumed in the fuel rod cladding fatigue analysis. Fuel rod and peak pellet power history inputs are shown in the following figures:

Figure	Case Description
3.1A/3.1B	KEW-17, -18 std UO_2 fuel rods
3.2A/3.2B	KEW-17 hvy, -18 hvy, -19 hvy UO_2 fuel rods
3.3A/3.3B	KEW-18 hvy NAF fuel rods, 4% gadolinia
3.4A/3.4B	KEW-19 NAF fuel rods, 4% gadolinia
3.5A/3.5B	KEW-19 NAF fuel rods, 8% gadolinia

The remaining figures contain results that correspond to criteria listed in Table 3.2. Appendix A contains applicable project-specific mechanical design criteria which were verified for Reload KEW-19.

3.2 *Thermal-Hydraulic Design*

Rod Bow Penalty

The impact of rod bowing on minimum departure from nucleate boiling ratio (MDNBR) and peak linear heat generation rate (LHGR) was evaluated using the SPC rod bow methodology (Reference 7). This evaluation shows that a rod bow penalty on MDNBR occurs for fuel assembly exposures in excess of about [ ] GWd/MTU. That is, there is no rod bow penalty for fuel assemblies with exposures less than the threshold value. The rod bow penalty on MDNBR as a function of assembly exposure is depicted in Figure 3.11. The rod bow penalty on MDNBR is applied to the affected assemblies as follows:

$$MDNBR_{bowed} = MDNBR_{non-bowed} \times (1 - \delta_B)$$

where $MDNBR_{bowed}$ is the rod bow penalized MDNBR as a function of exposure, $MDNBR_{non-bowed}$ is the MDNBR as a function of assembly exposure without a rod bow penalty, and $(1-\delta_B)$ is the rod bow penalty on MDNBR as a function of assembly exposure from Figure 3.11.

Similarly, the assembly exposure threshold for application of a rod bow penalty on peak LHGR is [ ] GWd/MTU. The rod bow penalty exposure thresholds described above, along with the DNBR penalty, are conservatively applicable to both the standard and heavy fuel designs.

Guide Tube Cooling

An evaluation was performed to demonstrate that the guide tube bypass flow is sufficient to cool control rods assuming increased radial peaking limits. The results of the evaluation confirmed that the bypass flow provides sufficient cooling.

Fuel Centerline Melt

An analysis was performed to evaluate the LHGR at which fuel centerline melting would occur for the KEW-19 fuel design, including the effect of the 4 and 8 wt% gadolinia-bearing fuel rods. The resulting fuel centerline melt LHGR limit was calculated to be [ ] kW/ft for UO_2 rods which precludes centerline melt on either UO_2 or gadolinia rods. That is, fuel centerline melting will be precluded for peak LHGRs up to the fuel centerline melt LHGR limit.

Table 3.1 KEW-19 Fuel Assembly and Component Description

Characteristic	Material	Value
Fuel assembly		
Fuel assembly pitch, inch		7.803
Array		14x14
Number of fuel rods		179
Number of non-fueled elements		
Guide tubes	Zircaloy-4	16
Instrument tube	Zircaloy-4	1
Overall length, inch		159.71
Spacers		
Number of spacers		
Bimetallic	Zr-4 structure with Inconel 718 springs	2
HTP	Zircaloy-4	5
Spacer grid		
Envelope (Bimetallic), inch		7.763
Envelope (HTP), inch		7.761
Fuel rod pitch, inch		0.556
Fuel rod-to-rod spacing, inch		0.132
Lower tie plate envelope, inch (FUELGUARD)	Stainless steel	7.761
Upper tie plate envelope, inch	Stainless steel	7.761
Holddown springs	Inconel 718	
Instrument tube	Zircaloy-4	
Outside diameter, inch		0.424
Inside diameter, inch		0.374

Table 3.1 KEW-19 Fuel Assembly and Component Description (Continued)

Characteristic	Material	Value
Fuel rod		
Cladding	Zircaloy-4	
Cladding outside diameter, inch		0.424
Cladding inside diameter, inch		0.374
Fuel column	UO_2 or UO_2/Gd_2O_3	
Pellet diameter, inch		0.367
Active fuel length, inch		144.0
Density, % of theoretical		95.35
Fill gas pressure, psia	Helium	[ ]
Plenum spring	Inconel X-750	
Overall length, inch		152.07

Table 3.2 Design Evaluation Results

Criteria Section(5)	Description	Criteria	Results or Disposition
3.2	**Fuel Rod Criteria**		
3.2.1	Internal hydriding	Hydrogen content in components shall be controlled to a minimum level during manufacture to limit internal hydriding.	Controlled by manufacturing specifications and verified by QC inspection.
3.2.2	Cladding collapse	Sufficient beginning-of-life (BOL) cold radial gap, plenum spring force and fuel rod internal pressure to prevent axial gap formation and Pellet/Clad Interaction (PCI) during densification.	Radial gap $>$ 0.0 inch [ ]. Plenum spring design ensures positive downward force and fuel rod internal pressure maintains radial gap [ ].
3.2.3	Overheating of cladding	95/95 confidence that fuel rods do not experience DNB during steady state or AOO.	Verified in SRP Chapter 15 analyses performed by Wisconsin Public Service Corporation (WPSC).
3.2.4	Overheating of fuel pellets	No centerline melting during normal operation and AOO.	Centerline temperature $<$ melting during AOO (steady-state operation is bounded by AOO). See Figures 3.6 through 3.8. This analysis does not correspond to the safety analysis performed by WPSC.
3.2.5	Stress and Strain Limits		
	Pellet/ cladding interaction	Cladding strain $<$ 1% ($<$ [ ]% at pellet burnups greater than [ ] GWd/MTU) and no fuel melting.	Transient strain margin, %: UO_2 Hvy Rod = [ ] NAF Hvy Rod = [ ] UO_2 Std Rod = [ ] Steady-state strain %: UO_2 Hvy Rod = [ ] NAF Hvy Rod = [ ] UO_2 Std Rod = [ ] (See 3.2.4 above for fuel temperatures.)
	Cladding stress	ASME Section III, Appendix III, Article III-2000, in combination with the specified 0.2% offset yield strength and ultimate strength of Zircaloy.	P_m margin = [ ] $P_m + P_b$ margin = [ ] P + Q margin = [ ]

Table 3.2 Design Evaluation Results (Continued)

Criteria Section(5)	Description	Criteria	Results or Disposition
3.2	**Fuel Rod Criteria (Continued)**		
3.2.6	Cladding rupture	Not underestimated during loss-of-coolant-accident (LOCA) and used in determination of 10 CFR 50.46 criteria.	Accepted model in Appendix K evaluation. This analysis is an integral part of the plant specific large-break LOCA evaluation.
3.2.7	Fuel rod mechanical fracturing	ASME Section III, Appendix F.	Unchanged. Same material and assembly characteristics as co-resident fuel that meets criteria. Also, see 3.4 of this table.
3.2.8	Fuel densification and swelling	Sections 3.2.2, 3.2.4, 3.2.5, & 3.3.7	Models included in NRC accepted fuel performance codes.
3.3	**Fuel System Criteria**		
3.3.1	Stress, strain and loading limits on assembly components. (See 3.3.9 for handling and 3.4 for accident conditions.)		
	Spacer grid	Lateral load < load limit	Unchanged. See 3.4 of this table.
	Upper and lower tie plates	Limiting loads occur during handling and postulated accidents.	Unchanged. See 3.3.9 and 3.4 of this table.
	Cladding and guide tubes	ASME Section III, Appendix III, Article III-2000, in combination with the specified 0.2% offset yield strength and ultimate strength of Zircaloy.	The analyses supporting Reference 1 remain applicable. Also, see 3.2.5 of this table.
3.3.2	Fatigue	Cumulative usage factor (CUF) < [ ]	CUF: UO_2 Hvy Rod = [ ] NAF Hvy Rod = [ ] UO_2 Std Rod = [ ] (See Table 3.3 for typical duty cycles)

Table 3.2 Design Evaluation Results (Continued)

Criteria Section(5)	Description	Criteria	Results or Disposition
3.3	**Fuel System Criteria (Continued)**		
3.3.3	Fretting wear	No fuel rod failures due to fretting wear.	Unchanged. See Reference 1.
3.3.4	Oxidation, hydriding, and crud buildup	Acceptable maximum oxide thickness. Effects of oxidation and crud to be included in thermal and mechanical fuel rod analyses. Stress analysis to include metal loss due to oxidation.	Peak local oxide less than [ ] microns. KEW-18 Leads and KEW-19 limiting. See Figure 3.9. Approved fuel rod performance code accounts for oxidation and crud buildup. Metal loss accounted for in cladding stress analysis.
3.3.5	Rod bow	Lateral displacement of the fuel rods shall not be of sufficient magnitude to impact thermal margins.	NRC accepted model used to compute impact for transient analyses. See Section 3.2.
3.3.6	Axial Irradiation Growth		
	Fuel rod	Clearance remains between fuel rod and UTP/LTP at end of life (EOL).	Minimum clearance of [ ] inch at EOL hot conditions.
	Fuel assembly	The fuel assembly length shall not exceed the minimum space between upper and lower core plates in the cold condition at EOL.	Clearance exists at EOL under cold conditions.
3.3.7	Rod internal pressure	Acceptable maximum internal rod pressure. Gap does not open during steady state or increasing power.	Maximum internal rod pressure less than [ ] psi (system pressure plus [ ] psi). KEW-18 Leads limiting for both UO_2 and NAF. See Figure 3.10. Gap criteria are satisfied.

Table 3.2 Design Evaluation Results (Continued)

Criteria Section[5]	Description	Criteria	Results or Disposition
3.3	**Fuel System Criteria (Continued)**		
3.3.8	Assembly liftoff during normal operation (including AOOs)	No liftoff from core lower support.	At the limiting flow of 206900 gpm (140°F), the heavy HTP assembly has [ ] lbf of holddown; the standard HTP has [ ] lbf of holddown, and the standard BM has [ ] lbf of holddown.
3.3.9	Fuel assembly handling	Assembly withstands [ ] times weight as static force.	The analyses supporting Reference 1 remain applicable.
3.4	**Fuel Coolability**		
	Structural deformations	Maintain coolable geometry and ability to insert control rods. SRP 4.2, App. A and ASME Section III, App. F.	Unchanged. See Reference 1.
3.4.1	Cladding embrittlement	Include in LOCA analysis.	Verified in the safety analysis performed by WPSC.
3.4.2	Violent expulsion of fuel	<280 cal/g hottest axial deposition.	Verified in plant/cycle transient analyses.
3.4.3	Fuel ballooning	Consider impact on flow blockage in LOCA analysis.	Verified in the large-break LOCA evaluation performed by WPSC.

Table 3.3 Design Duty Cycles for Cyclic Fatigue Evaluation

Type of Load Variation	Analyzed Power Level (% of Full Power)		Number per Reactor Cycle
	High	Low	
Shutdowns from 100% Power to Cold Conditions (including refueling shutdown)	125	0 (Cold)	2
Shutdowns from 100% Power to Hot Conditions	125	0 (Hot)	3
Scrams	125	0 (Hot)	9
Load Follow to 40% Power	125	20	90
Valve Testing to 50% Power	125	30	9
Step Load Reduction to 5% Power	125	0 (Hot)	3
Step Load Reduction to 30% Power	125	10	3
Step Load Reduction to 80% Power	125	60	78

Figure 3.1A Power History Inputs, Rod Average Power

Figure 3.1B Power History Inputs, Peak Pellet LHGR

Figure 3.2A Power History Inputs, Rod Average Power

Figure 3.2B Power History Inputs, Peak Pellet LHGR

Figure 3.3A Power History Inputs, Rod Average Power

Figure 3.3B Power History Inputs, Peak Pellet LHGR

Figure 3.4A Power History Inputs, Rod Average Power

Figure 3.4B Power History Inputs, Peak Pellet LHGR

Figure 3.5A Power History Inputs, Rod Average Power

Figure 3.5B Power History Inputs, Peak Pellet LHGR

Figure 3.6 AOO Fuel Centerline Temperatures

Figure 3.7 AOO Fuel Centerline Temperatures

Figure 3.8 AOO Fuel Centerline Temperatures

Figure 3.9 Fuel Rod Maximum Corrosion

Figure 3.10 Fuel Rod Internal Gas Pressure

Figure 3.11 MDN8R Rod Bow Penalty for the KEW-19 Fuel Design

4. References

1. *Mechanical Design Report for Kewaunee Lead Fuel Assemblies*, EMF-94-178(P), Siemens Power Corporation - Nuclear Division, September 1994.

2. *Mechanical Design Evaluation for Kewaunee Reload KEW-18 Lead Fuel Assemblies*, EMF-96-127(P), Revision 1, Siemens Power Corporation - Nuclear Division, September 1996.

3. *Qualification of Exxon Nuclear Fuel for Extended Burnup*, XN-NF-82-06(P)(A) Revision 1 and Supplements 2, 4 & 5, Exxon Nuclear Company, October 1986.

4. *Qualification of Advanced Nuclear Fuels' PWR Design Methodology for Rod Burnups of 62 GWd/MTU*, ANF-88-133(P)(A) and Supplement 1, Advanced Nuclear Fuels Corporation, December 1991.

5. *Generic Mechanical Design Report High Thermal Performance Spacer and Intermediate Flow Mixer*, ANF-88-060(P)(A) and Supplement 1, Advanced Nuclear Fuels Corporation, March 1991.

6. *Generic Mechanical Design Criteria for PWR Fuel Designs*, EMF-92-116(P), Siemens Power Corporation - Nuclear Division, July 1992.

7. *Computational Procedure for Evaluating Fuel Rod Bowing*, XN-75-32(P)(A) Supplements 1 through 4, Exxon Nuclear Company, October 1983. (Base document not approved.)

Appendix A - Project-Specific Mechanical Design Criteria

Criteria	Disposition
Spacer centerline located within 0.25 inch of the BOL spacer centerline locations on existing fuel assemblies.	Verified for KEW-19
The diagonal dimension of an assembly at any cross-section shall be less than 10.870 inches.	Verified for KEW-19
The placement of the fuel column shall be compatible with prior fuel designs and the position of the fully inserted RCCA rodlets in the fuel assembly guide tubes.	This criterion, as previously stated, is overly specific. The criterion has been restated to maintain the intent without reliance on specific dimensions. [ ].
The enrichment of the gadolinia-bearing rods shall be such that the power of a gadolinia-bearing fuel rod will at no time be the highest in the reactor core.	Verified for KEW-19

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Criteria	Disposition
The cooling holes shall be designed to assure that the maximum scram time (time of signal initiation to entry of control rods into the dashpot region) specified in the reactor Technical Specifications is met.	Verified for KEW-19
The damping function shall be such that the control rod assembly spring shall not be deflected more than 0.75 inch beyond the preloaded condition during a scram.	Verified for KEW-19