APPENDIX B

8X8 EXTENDED BURNUP

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B.1 INTRODUCTION

This appendix documents the mechanical design analyses performed to extend the assembly exposure limit of the WNP-2 8x8 fuel to 37,000 MWd/MTU. Reference is made to the NRC-approved document XN-NF-85-67(P)(A), Revision 1[9.2] which supported a fuel assembly exposure of 35,000 MWd/MTU for the 8x8 fuel design. The results of design calculations support the irradiation of the 8x8 fuel to the following exposure values:

Fuel Assembly	37,000 MWd/MTU
Fuel Rod	42,300 MWd/MTU
Peak Pellet	50,700 MWd/MTU
Planar Exposure	48,100 MWd/MTU

B.2 SUMMARY

The results of the design calculations performed to extend the 8x8 assembly exposure limit demonstrates full compliance with the design criteria.

B.2.1 Design Description Summary

The SNP 8x8 fuel design uses 62 fuel rods and two centrally located water rods, one of which functions as a spacer capture rod. Seven spacers maintain fuel rod spacing. The design uses a quick-removable upper tie plate design to facilitate fuel inspection and bundle reconstitution of irradiated assemblies.

The fuel rods are pressurized and utilize 0.035 inch thick Zircaloy-2 cladding. The rods contain either UO_2-Gd_2O_3 or UO_2 with a nominal density of 94.5% TD. Natural uranium axial fuel blankets are provided at the top and bottom of the fuel column for greater neutron economy.

B.2.2 <u>Design Analysis Summary</u>

The mechanical design analyses were performed to evaluate cladding steady-state strain and stress, transient strain and stress, fatigue damage, creep collapse, corrosion, hydrogen absorption, fuel rod internal pressure, differential fuel rod growth, and creep bow. The analyses justify irradiation to an assembly exposure of 37,000 MWd/MTU. The following summarizes the analysis results:

- The maximum end-of-life (EOL) steady-state cladding strain is calculated to be below the 1.0% design limit.
- Cladding steady-state stresses are calculated to be below the material strength limits.
- The cladding strain during anticipated operating occurrences (AOOs) does not exceed 1.0%.
- The maximum fuel rod internal rod pressure remains below the design limit.
- The fuel centerline temperature remains below the melting point during AOOs.
- The cladding fatigue usage factor is within the 0.67 design limit.
- Structural members have adequate strength to support handling and hydraulic loads.
- The cladding diameter reduction due to uniform creepdown, plus creep ovality at maximum densification, is less than the minimum initial gap. Compliance to this criterion prevents the formation of fuel column gaps and the possibility of creep collapse.
- Evaluations of assembly growth and differential fuel rod growths show that the design provides adequate clearances for compatibility with the fuel assembly channel. Also, there is adequate nominal engagement of the end caps in the upper tie plate and lower tie plate throughout the fuel design life.
- The initial fuel rod design spacing is anticipated to accommodate expected rod-to-rod gap closure throughout the fuel design life.
- The maximum EOL reduction in cladding thickness due to corrosion and the maximum concentration of hydrogen in the cladding are calculated to be well within the design limits.

- The fuel rod plenum spring and other miscellaneous components are shown to meet the respective design bases.
- The spacer spring meets all the design requirements and can accommodate the expected relaxation at the respective EOL exposures.

B.3 DESIGN ANALYSES

The design analyses for the 8x8 fuel were performed using the approved codes and methods in Reference 9.2. Design calculations were performed to extend the assembly exposure limit above that previously reported. Figure B3.1 is the LHGR limit used in the steady- state fuel rod performance evaluation. Figure B3.2 is the limit to protect against fuel damage during anticipated operational occurances (AOOs).

The design calculations assumed the following extended exposure values:

Fuel Assembly	37,000 MWd/MTU
Fuel Rod	42,300 MWd/MTU
Peak Pellet	50,700 MWd/MTU
Planar Exposure	48,100 MWd/MTU

These values are consistent with the peaking factors identified in Reference 9.2 and are conservative estimates of the exposures anticipated.

B.3.1 Fuel Rod Analyses

Fuel rod analyses were performed to verify adequate performance of the 8x8 fuel to a fuel rod exposure of 42,300 MWd/MTU and a peak pellet exposure of 50,700 MWd/MTU. The design power history used in Reference 9.2 was extended to these higher exposure values. The results of the analyses reported herein demonstrate compliance with the design criteria.

B.3.1.1 Maximum Cladding Strain During Steady-State Operation

The maximum cladding strain during steady-state operation is limited to < 1% to avoid ductile cladding fracture. The fuel rod analysis performed with RODEX2A indicates that at a 37,000 MWd/MTU assembly exposure the cladding strain is within the criteria.

B.3.1.2 Maximum Cladding Stress During Steady-State Operation

Fuel rod cladding stresses during steady-state operation are calculated using linear elasticity theory. The design criteria is in accordance with the ASME pressure vessel code. Each individual stress is calculated inside and outside the cladding and at both midspan and spacer levels. The applicable stresses at each level are then combined to obtain the maximum stress intensities. The analysis is performed at beginning-of-life (BOL) and end-of-life (EOL) and at cold and hot conditions. The stress analysis assumes maximum fuel rod power, minimum fill gas pressure, and the most conservative fuel rod geometry.

The assumptions made in the analyses reported in Reference 9.2 have been reviewed to determine if additional calculations were required. The review indicated that the only input data affected by the increased exposure is the internal pressure. The internal pressure assumed at EOL is very conservative. The maximum pressure differential across the tube wall is obtained at BOL. The analyses in Reference 9.2 assumed that the rods at EOL had zero gas release. This conservative assumption leads to conservative stress which is also applicable to the 37,000 MWd/MTU assembly burnup. Consequently, the analysis results reported in Table 3.3 of Reference 9.2 are applicable.

B.3.1.3 Anticipated Operational Occurrences

Two criteria are imposed on the fuel rod to avoid fuel failure during power changes caused by AOOs. These criteria limit the cladding strain to less than 1% and maintain the maximum pellet temperature below melting. The AOOs are assumed to produce a maximum nodal power equal to those defined in Figure 3.4 of Reference 9.2. The analysis consists of calculating the cladding strain and fuel centerline temperature at the power levels defined in Figure 3.4 to verify compliance with the design criteria.

The calculations performed in support of Reference 9.2 were reviewed to determine if the higher exposure requires a reanalysis. Since the exposure at which the margin to the design criteria is the lowest is not at EOL, the results reported in support of Reference 9.2 are applicable.

B.3.1.4 Fuel Rod Internal Pressure

The fuel rod internal pressure is limited to 800 psi above system pressure[9.2]. However, if the internal pressure exceeds the system pressure, then the change in the pellet-cladding gap is calculated. The design criteria requires that the gap not open when the fuel rod power increases or when the power remains steady.

The analysis was extended to a fuel assembly exposure of 37,000 MWd/MTU, and the results indicate that the maximum rod internal pressure is less than 1835 psia, which is below the design criteria. However, since the internal pressure exceeded the system pressure, an evaluation of the gap was performed. This evaluation verified that the incremental pellet swelling with increased powers is greater than the incremental cladding creep, thus complying with the design criteria.

B.3.1.5 Fuel Pellet Centerline Temperature

The design criteria requires that fuel centerline temperature remain below the fuel melting point during operation. A fuel pellet centerline temperature analysis was performed using the methodology described in Reference 9.2 while applying the modified LHGR limit curve and higher exposure level. The results of the analysis indicated that the fuel pellet centerline temperature will remain below the fuel melting point. Therefore, the design criteria is met.

B.3.1.6 Fuel Rod Cladding Fatigue

Fuel assembly shuffling, reactor power maneuvering, and anticipated operational occurrences impose cyclic loading on the cladding. To assure that the fuel rod does not fail due to stress cyclic fatigue, a fatigue analysis is performed. The design criteria requires that the cumulative fatigue damage remain below 67%. To conservatively account for the

additional residence time associated with the higher exposure, the total number of cycles defined in Table 3.5 of Reference 9.2 was increased by over 15%. The maximum cumulative fatigue damage was below the 0.67 design criteria.

B.3.1.7 Cladding Collapse

Fuel failures due to cladding collapse have been observed in some PWR fuel rods designed and fabricated by other fuel vendors. No SNP fuel rod has ever failed due to this mechanism. The likelihood of a fuel rod failure due to cladding collapse in a BWR is very small due to the lower operating coolant pressure characteristics. Nevertheless, the fuel rods are analyzed to assure that fuel rod collapse will not occur. The design criteria requires that the pellet-cladding gap remains open during the pellet densification stage. This assures that axial gaps will not form in the pellet column. If axial gaps are not formed, the fuel rod cannot fail due to cladding collapse.

Since the pellet densifies at BOL, reverification of the design criteria was not required. Therefore, the results reported in Table 3.1 of Reference 9.2 are applicable.

B.3.1.8 Fuel Rod Spacing

Rod-to-rod and rod-to-channel spacing must not affect the assembly thermal performance. Thermal limits are not affected if the minimum rod-to-rod spacing is greater than 0.090 inch. The analysis performed in Reference 9.2 to calculate the maximum fuel rod bow was evaluated for applicability at higher exposures. The correlation used by SNP to calculate fuel rod bow is exposure dependent. A small incremental increase in rod bow is calculated to occur between 35,000 MWd/MTU and 37,000 MWd/MTU. The maximum fuel rod channel closure at 37,000 MWd/MTU provides ample margin to the channel closure that could affect the assembly thermal performance.

B.3.1.9 Cladding Corrosion and Hydrogen Concentration

The SNP design criteria is to maintain the metal loss due to corrosion to less than 0.002 in. Hydrogen absorption is limited to less than 500 ppm. Using the methodology in Reference 9.2, an analysis was performed using a bundle exposure limit of 37,000 MWd/MTU

MWd/MTU and the modified LHGR limit curve. The results of the analyses indicated that at the increased exposure and modified LHGR limit, the cladding corrosion and hydrogen absorption will remain well below the design criteria.

B.3.2 Fuel Assembly Analyses

The performance of the fuel assembly at 37,000 MWd/MTU was evaluated.

B.3.2.1 Structural Strength

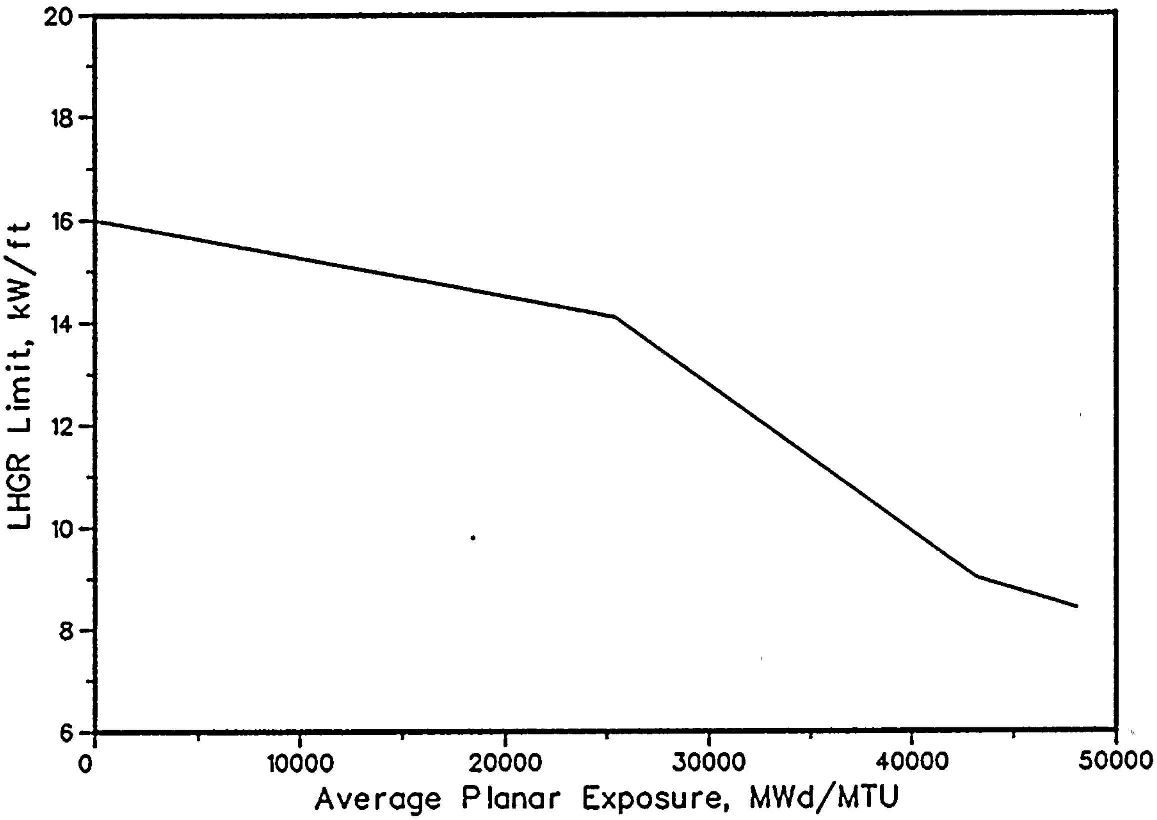
The structural strength of tie plates, locking mechanism, and tie rods is not decreased with exposure. Therefore, the analysis and test results previously reported in Reference 9.2 are applicable..

B.3.2.2 Spacer Spring

SNP data indicates that spacer spring relaxation occurs with irradiation. However, the relaxation rate tends to decrease with increased exposure and saturate at higher exposure. In addition, the spacer spring remains in contact with the fuel rod, thus preventing the formation of gaps. Increased exposure does not have a significant effect on spacer spring performance. PWR spacers of essentially the same fuel rod cell design have been irradiated to exposures as high as 50,000 MWd/MTU without experiencing degradation of the spacer performance. The spacer spring design is therefore concluded to be acceptable at assembly exposures up to 37,000 MWd/MTU.

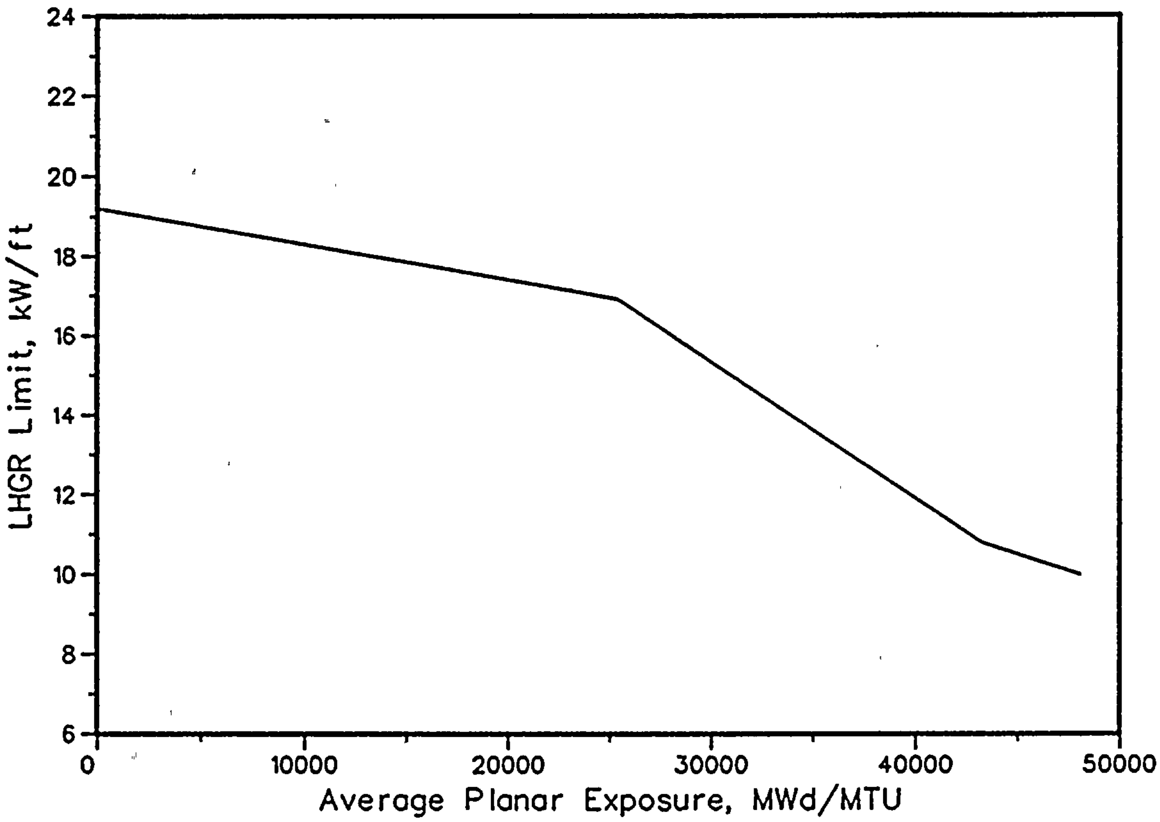
B.3.2.3 Assembly Growth

Assembly growth was determined by evaluating differential growth between standard fuel rods and tie rods. The evaluation was based on data obtained on SNP fuel growth extrapolated to 37,000 MWd/MTU. Additionally, an evaluation of channel engagement with the lower tie plate seal as a function of irradiation exposure was performed. The calculations indicate that sufficient channel and end cap engagement was present to EOL.



EXP	LHGR
0.0	16.0
25,400	14.1
43,200	9.0
48,100	8.4

FIGURE B3.1 LINEAR HEAT GENERATION RATE (LHGR) LIMIT
VERSUS AVERAGE PLANAR EXPOSURE, SNP 8X8 FUEL



EXP	LHGR
0.0	19.2
25,400	16.9
43,200	10.8
48,100	9.98

FIGURE B3.2 PROTECTION AGAINST FUEL FAILURE LIMIT DURING AOO'S