LTR-NRC-35 NP-Attachment
TAC No. MC4592

Response to NRC Request for Additional Information on WCAP-15942-P, Rev. 0, "Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors Supplement 1 to CENP-287"

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1. Provide an explanation of the Westinghouse axial power shape methodology as applied in addressing the different fuel rod design criteria. Specifically, justify use of a single bounding power history for RIP, Strain and Fuel Temperature analyses, and multiple power shapes for the other criteria.

STAV7.2 is used with power histories for calculating performance relative to the following design criteria in Section 4.3.:

a. *Maximum fuel rod internal hot gas pressure*
b. *Maximum local cladding strain during AOOs*
c. *Maximum fuel centerline temperature (melting)*
d. *Accumulation of fatigue damage*

[

]a,c

2. Provide a more detailed explanation of the oxide thickness assumptions used in the safety analysis calculations. (LOCA)

The Westinghouse methodology for treating initial oxide thickness in the LOCA analyses recognizes that there are competing effects associated with the fuel rod heatup evaluation. A relatively [

][a,c] Therefore, the degree of conservatism or non-conservatism associated with cladding oxidation treatment can depend on the plant-specific system characteristics associated with the limiting LOCA.

Accordingly, Westinghouse performs [

][a,c] The subsequent establishment of LOCA limits are performed with the conservative treatment of initial cladding oxidation established with this process.

3. Provide the following information regarding hydrogen content: What AOO power level can be achieved at concentrations of 200 and 300 ppm H.

A ramp test has been performed within the OECD Studsvik Cladding Integrity Project (SCIP) using a segment from a [

][a,c] The average burnup of the ramped segment was above 60 MWd/kgU.

The conditioning was performed at [

][a,c]

Additional PCI ramp data is provided in RAI Response 25. It is noted that [

][a,c]

[

]^{a,c} The strain capability is discussed in RAI Response 4.

4. Provide the basis for the 500 ppm design limit mentioned in the topical report

The combined effect of irradiation and hydriding on the mechanical properties of Zircaloy has been investigated in several studies. It can be concluded that the yield strength increases with increasing fluence. The increase is rapid for low fluences (fast fluence < 0.5×10^{21} n/cm2, E ≥ 1 MeV), but very slow for higher fluence levels.

Westinghouse has, in co-operation with hot-cell facilities and utilities, performed mechanical testing of re-crystallization annealed (RXA) Zircaloy-2 fuel rod claddings and water rod tubing irradiated in boiling water reactors to evaluate the effect of hydrogen concentration on the mechanical properties. The considered materials have been irradiated in [

]^{a,c}

The burnup of the samples presented in the Figures 4-1 to 4-6 varies from [

]^{a,c} Uniform and total elongations shown in these figures are measured plastic strains only.

[

]^{a,c}

Hydride orientation and distribution also influence the ductility of the material. If a steep hydrogen concentration gradient exists [

]^{a,c} The water rod

tubes, on the other hand, have a uniform hydrogen distribution. The effect of the difference in hydrogen distribution can be observed in Figs. 4-1 to 4-6. As expected [

$]^{a,c}$

The chemical composition and the SPP distribution of the Zircaloy-2 channel material used by Westinghouse [

$]^{a,c}$ *to the regime where the hydrogen concentration significantly affects the essential mechanical properties of the Zircaloy channels.*

In summary, the hydrogen limit for BWR RXA Zircaloy-2 fuel rod cladding is [

$]^{a,c}$

a,b,c

Figure 4-1: Yield strength versus wall average hydrogen content

a,b,c

[ ]

Figure 4-2: Ultimate tensile strength versus wall average hydrogen content.

a,b,c

[ ]

Figure 4-3: Uniform elongation versus wall average hydrogen content

a,b,c

Figure 4-4: Uniform elongation versus wall average hydrogen content.

a,b,c

Figure 4-5: Total elongation versus wall average hydrogen content.

a,b,c

[

]

Figure 4-6: Total elongation detail versus wall average hydrogen content.

5. **Provide a justification for the PH method (power history) used for the LOCA cases which do not require ramping to the TMOL limit.**

   The LOCA power history utilized in the example in Section 4.4.4 was selected to provide a clearly bounding power history, which would bound any realistic stored energy with which to initiate the postulated LOCA. It is recognized, however, that, while this power history is conservative, it does not provide a convenient means of confirming during plant operation that the core is being operated in accordance with the limiting power history assumed in the LOCA analysis.

   As discussed in Section 4.3.0, the Thermal Mechanical Operating Limit (TMOL) is provided to the plant operator in terms of a Linear Heat Generation Rate (LHGR) limit which [

   ]^{a,c} Of course, conformance with the conclusions of the LOCA analysis will continue to require operation with Average Planar Linear Heat Generation Rates (APLHGRs) less than the appropriate APLHGR limits.

   The conservative nature of the approach described above can be illustrated by comparing [

   ]^{a,c}

[

]a,c

This updated Figure 5-1, along with an updated description of the power history treatment for the LOCA analysis will be incorporated in the Approved version of WCAP-15942.

a,b,c

Figure 5-1 Pellet Centerline temperatures

a,b,c

[

]

Figure 5-2 Power histories

6. **Provide an explanation of how the liner is addressed in the calculations for the various fuel rod design criteria. Also, discuss how cladding collapse is evaluated for part length (PL) rods because the plenum is within a high flux region.**

[

]a,c

[

]^{a,c}

Figure 6-1 NCLO SVEA-96 Optima 2 Cladding without Liner

a,b,c

Figure 4.3.6-1 in WCAP-15942-P shows the [

]^{a,c}

Table 6-1 Collapse for Infinite Cladding Tubes a,b,c

[

]

Figure 6-2 Typical Athermal Fission Gas Release a,b,c

[

]

7. Clarify if WCAP-15942-P is seeking approval of a specific fuel assembly design in addition to a fuel mechanical design methodology and design criteria. Identify any plant mechanical compatibility related parameters that will need to change on a plant specific basis and the ranges of their variation. Discuss the continued applicability of the design criteria and methodology for each of the ranges of plant-specific design changes.

WCAP-15942 is a supplement to CENPD-287 describing the SVEA-96 Optima2 Reference fuel design as well as the design methodology for evaluating acceptability of the fuel design according to the design criteria identified in the Standard Review Plan. The SVEA-96 Optima2 fuel design has evolved from the SVEA-96 and 96+ products described in CENPD-287. Westinghouse is seeking approval of WCAP-15942 as defining the reference product description to be used by licensees as a reference document in license amendment requests and as defining the mechanical methodology Westinghouse will use to assess plant specific implementation applications relative to the General Design Criteria identified in the SRP. The report provides a complete specification of the mechanical design features of the fuel product [

]a,c

[

]^{a,c}

8. **Explain how the methodology described in WCAP-15492 will be applied to legacy Westinghouse BWR fuel designs and non-Westinghouse fuel designs. Explain how the methodology described in WCAP-15942, as well as WCAP-15836, will be applied to legacy Westinghouse BWR fuel designs and non-Westinghouse fuel designs.**

   WCAP-15836-P and WCAP-15942-P topical reports are equally applicable to the Westinghouse legacy fuel SVEA-64, SVEA-96/96+/100, SVEA-96 Optima, and the improved SVEA-96 Optima 2 fuel. [

   ]^{a,c}

[

]^{a,c}

9. **Will the crud buildup rate be an input variable, and if so, how will it be determined? What is the process that will be used in the standard fuel rod design analysis to ensure the effects of crud are included in the performance parameters and the potential plant response to chemistry control programs is accounted for?**

The coefficients affecting the crud build-up rate [

]^{a,c}

Figure 9-1 Predicted versus Measure Crud Thickness a,b,c

[

]

Compliance with an approved chemistry program [

]a,c

The mechanism for ensuring continued applicability of crud and corrosion models is discussed response to RAI 10.

10. **Different values for the constants A, B, and C, in the corrosion model for LK2 and LK3 are provided. It was earlier stated that these constants could be adjusted based on alloy and water chemistry. How will these constants be determined for SVEA-96 Optima2, and will they change for each reactor based on water chemistry? Describe the fuel surveillance plan for collecting poolside data used to update these constants.**

    As discussed in RAI 16 for WCAP-15836-P, the values of [

    ]a,c

[

]^{a,c}

11. **What LTA programs with SVEA-96 Optima2 are currently in progress or planned in US reactors? What PIE measurements will be made on SVEA-96 Optima2 once assemblies start to be discharged?**

LTA and Lead Region Program

The SVEA-100, 96, 96+, Optima and Optima2 fuel designs are a closely related fuel product family of incremental, evolutionary product feature changes. Shortly after introduction of the [

]^{a,c} Table 11-1 provides the irradiation experience of the Westinghouse SVEA 10x10 fuel product line by plant and year of introduction, including LTAs and regions. Table 11-2 provides an expansion and update of Table 7-1 in the topical report, describing plant internals configuration and fuel management employed by the plant.

The experience basis supporting the Westinghouse mechanical methodology and the Optima2 product for rod burnups up to 62 MWd/kgU is provided through a number of lead test assemblies and test fuel rods of different product types. Material properties data has been provided by high burnup experience of the SVEA-96 product, which includes [

]^{a,c}

Table 11-3 provides a mapping between the fuel criteria and the experience database for the Westinghouse SVEA fuel justifying the Optima2 fuel product to a burnup level of 62MWd/kgU. Provided for each critical design criteria is [

]^{a,c}

Validation of Experience to US Plants

The majority of Westinghouse BWR fuel experience lies with [

]^{a,c}

[

]^a,c These results demonstrate that key plant parameter ranges that drive fuel performance considerations lie within the Westinghouse fuel experience base for all US plants. As noted in Section 8 of WCAP-15942, Westinghouse fuel experience has been excellent, with no PCI induced fuel failures in lined fuel and fuel failures dominated by debris-induced fretting.

Planned Optima2 Fuel Surveillance in the US

Optima2 is considered to be a proven design based on the extensive experience base described above, which includes plants operating at maximum duties equivalent to the US BWRs. The operating [

]^a,c

An indication of the variability in [

]^a,c

Table 11-1 LTA and Region Experience Summary for SVEA 10x10 Fuel Products

a,b,c

Table 11-2 Fuel Management Summary for Westinghouse BWR Fuel Users

a,b,c

a,b,c

Table11-3 Irradiation Experience Database for SVEA Fuel

Table 11-4
Hot channel exit void fractions for various plant types

a,b,c

Table 11-5
Peak-to-average LHGR Ratios as a function of cycle exposure

a,b,c

Figure 11-1
Power Rating Comparison Between Westinghouse Fueled Plants and US Plants

a,b,c

Figure 11-2
Bundle Rating Comparison Between Westinghouse Fueled Plants and US Plants

a,b,c

Figure 11-3
LHGR Comparison Between Westinghouse Fueled Plants and US Plants

a,b,c

Figure 11-4
Bundle Flow Comparison Between Westinghouse Fueled Plants and US Plants

a,b,c

Figure 11-5
Core Exit Enthalpy Comparison Between Westinghouse Fueled Plants and US Plants

a,b,c

[

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12. How is maximum stored energy calculated for LOCA initialization? What parameters are used from STAV7.2 for input to CHACHA for LOCA analyses? Has it been confirmed that the CHACHA calculations of Hgap and temperature reproduce the Hgap and temperature at LOCA conditions calculated by STAV7.2?

<u>Maximum Stored Energy</u>

Maximum stored energy calculated for LOCA initialization with models in [

]^{a,c}

[

][a,c] *These comparisons are shown in the following figures.*

Fuel centerline temperature (C)

a,b,c

[

]

Fuel average temperature (C)

a,b,c

[ ]

Gap heat transfer coefficient (W/m2/K)

a,b,c

[ ]

Fuel centerline temperature (C)

a,b,c

Fuel average temperature (C)

a,b,c

Gap heat transfer coefficient (W/m2/K) a,b,c

The comparisons in the figures above confirm that the [

]^{a,c}

13. **On Page 4-23, referring to Figure 4.2-11, there is no relaxation data at higher fluence than $3x10^{25}$ n/m², yet the curve has been extrapolated out to $14x10^{25}$ n/m² and conclusions are drawn in the text based on this extrapolation. How can this extrapolation be justified? If a linear fit was applied to the data, an equally good fit to this data could be obtained with significantly lower spring force predicted at high fluence. How can it be assured that flow vibration tests are bounding if they assume a small force still exists in springs when it is not clear what the force is or if there is any force remaining? Describe how the flow testing addressed the potential for "resonant response" over the range of primary coolant flow levels.**

The functional form chosen for the fit is based on [

]^{a,c}

[

]^{a,c}

14. The topical report mentions a creep model used for internal over-pressurization of the channel that have been verified against channel bulge data for SVEA-64 channels up to 45 GWd/MTU. A discussion is needed on why this data is applicable to SVEA-96 Optima2 channels, e.g., the range of stress levels experience in US plants and the stress levels in the bulge data from SVEA-64 channels. This discussion should also address applicability of the creep model to SVEA-96 Optima2 channels up to 55 GWd/MTU assembly burnup in US plants.

The lifetime average [

]^{a,c}

[

]a,c

[

]a,c

Figure 14-1
Measured 10x10 SVEA Relative Zry-2 Channel Bulge in a European BWR/6

a,b,c

[ ]

Figure 14-2
Measured Average 10x10 SVEA Relative Zry-2 Channel Bulge in a European BWR/6

a,b,c

Figure 14-3
Predicted Zry-2 Channel Bulge in a European BWR/6

a,b,c

Table 14-1
Bottom end outer channel wall pressure drops at 100% power and flow

a,b,c

[

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15. The calculation of interference between channel and control blade, as discussed on page 4-15, appears to be done with a 1σ uncertainty. A 2σ uncertainty increases this interference significantly. A C-lattice appears to have a 2.5 mm interference while for an asymmetric lattice, the 2σ uncertainty results in a 6 to 7 mm interference. Why is this satisfactory? Extrapolation of C lattice data to D lattice data up to 55 GWd/MTU needs further justification.

Control rod insertion and withdrawal considerations have both safety and economic aspects. Control rod insertability is a safety requirement and minimum requirements for insertion time are in the plant technical specifications. Control rod insertability is verified prior to startup and periodic surveillance checks are performed during the cycle in accordance with technical specification requirements. In BWR plants, the maximum insertion force delivered through the scram mechanism is much higher than the frictional force associated with fuel channel bow. The forces generated for normal SCRAM insertion are the same for all the BWR plant types at about 42700N per drive mechanism. Westinghouse suggests setting the design criteria for allowed channel bow on the basis of the [

]^{a,c}

This criteria is confirmed on a plant specific basis for SVEA fuel by [

]^{a,c}

[

]^{a,c}

[

]^{a,c}

[

] a,c

Table 15-1
Control Rod Gaps with SVEA fuel

a,b,c

Figure 15-1
Zry-4 Channel Bow in Symmetric Lattices

a,b,c

Figure 15-2
Measured Control Blade Insertion Times

a,b,c

[ ]

Figure 15-3
Statistical Representation of Liebstadt Zry-4 Channel Bow Database

a,b,c

Figure 15-4
Zry-4 Channel Bow in Asymmetric Lattices

a,b,c

Figure 15-5
Zry-2 Channel Bow in Symmetric Lattices

a,b,c

Figure 15-6
Zry-2 Channel Bow in Asymmetric Lattices

a,b,c

[

]

16. Not used.

17. Is there a difference in irradiation growth between spacer rods, fuel rods and tie rods?

There is no detectable difference in the growth per unit length between these different rod types. We have observed [

]a,c

Figure 17-1 10x10 Fuel Rod Growth Database a,b,c

As shown in this figure, there is no apparent growth bias between full length rods, tie rods and spacer capture rods.

In addition, a wider range of [

]^{a,c}

Figure 17-2 Differential Tie Rod Growth a,b,c

18. **How are the power factors for design (DM) and maneuverability (MF) applied in conjunction with RMS power uncertainties?**

The power factor (QFACT), the Design Multiplier, and the Maneuvering Factor are [

]^{a,c}

19. **Please provide rod bow data to substantiate the claim that fuel rod bow is not a problem to 55 GWd/MTU assembly average burnup for SVEA 96 fuel designs.**

As discussed in Section 4.3.10, the potential for fuel rod bowing is minimized by the design features of assembly. The use of [

]^{a,c}

[

]a,c

20. PNNL has noted that the RMS upper bound fission gas release predictions only bound 91% of the 231 data points in the BWR calibration and verification databases. PNNL expected the RMS upper bound prediction to bound 95% of the data. Why is this satisfactory, particularly when it is the high release rods that are underpredicted? See Figure 20-1, which shows that the [

]a,c

a,b,c

[

]

Figure 20-1: RMS upper bound predicted minus measured fission gas release predictions from BWR calibration and verification databases.

[

]a,c

[

] a,c

a,b,c

Figure 20-2 BWR Calibration Upper Bound Fission Gas Release

[

]

Figure 20-3
BWR Verification Upper Bound Fission Gas Release

a,b,c

[ ]

Figure 20-4
BWR SVEA-64 8x8 Upper Bound Fission Gas Release

a,b,c

[ ]

21. Please provide a calculation for the maximum strain for a case with an AOO at 50 GWd/MTU similar to what was provided for the RIP analysis

A cladding maximum strain analysis was performed applying a [

]^{a,c}

Table 21-1
Summary of Total Transient Strains for AOOS

a,b,c

Figure 21-1 Total Transient Strain Due to AOO at 50 MWd/kgU a,b,c

22. Please provide a calculation for the fuel melt analysis for a case with an AOO at 50 GWd/MTU similar to what was provided for the RIP analysis

A fuel centerline temperature analysis was performed applying a [

]^{a,c}

[

]a,c

Table 22-1
Summary of Nominal Centerline Temperatures for AOOs

a,b,c

Figure 22-1 Fuel Nominal Centerline Temperature

a,b,c

23. Please provide example gap conductance calculations for best estimate, lower bound, and upper bound used for transient and LOCA analyses. For example, provide an example for each type of calculation i.e., a best estimate, lower bound (input to LOCA) and upper bound (input to MCPR).

Figure 23-1 shows [

]a,c

[

]^{a,c}

a,b,c

Figure 23-1
Bounding Gap Heat Transfer Coefficients

24. Page 4-2 discusses the effect of fluence on yield strength. It states that the yield stress and ultimate tensile strength reach their saturation after only a few months of full power operation. This is contrary to the yield stress model used in STAV7.2, which does not model saturation until around 8x1025 n/m².

The discussion of the effect of fluence on the strength of Zircaloy will be replaced with the following paragraph:

[

]a,c

25. Provide the test data justifying the PCI related operating restrictions for lined and un-lined fuel described in Section 4.3.11.

Conditions leading to potential PCI induced fuel failures have been highly studied and can be generally avoided by appropriate use of some or all of the following means:

[

]a,c

Westinghouse has not had any PCI failures in ZrSn-liner fuel - either 8x8 or 10x10 – and only one suspected case in 10x10-fuel without liner. This has been the result of recommended operating restrictions and, for about the last 15 years, adoption of fuel with liner. Most plants that have introduced fuel with liner have not eliminated operating restrictions, but only relaxed those areas that provide significant economic benefit.

PCI-rules for non-liner fuel
The first remedy against PCI failures was the operating restrictions or conditioning procedures, first introduced in the seventies. The key principle is determined by [

]a,c

[

]a,c

The rules have been very effective in eliminating the PCI failures but [

]a,c

Published ramp test data comparing lined and unlined fuel is extensive and well reported in the literature. In addition, Westinghouse also has an extensive database. The non-liner fuel data can be conservatively described by a normal distribution with the mean value [

]a,c

Ramp data for fuel with [

]a,c

The ramp test results are summarized in the Figure 25-1 below.

Several liner materials have been tested as shown in Figure 25-1. [

]a,c

a,b,c

Figure-25-1 Ramp Rate Test Results

[

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