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Material Changes for SVEA-96 Optima2 Fuel Assemblies

Westinghouse

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Material Changes for SVEA-96 Optima2 Fuel Assemblies WCAP-15942-NP-A, Supplement 1

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1 SUMMARY AND CONCLUSIONS

1.1 SUMMARY

This Licensing Topical Report is a Supplement 1 to Reference 1.6, which contains the Westinghouse methodology for the fuel assembly and fuel rod mechanical evaluations identified in Section 4.2 of the Standard Review Plan, NUREG-0800 (Reference 1.4). [

]^{a,c} All other design features and materials of the Optima2 fuel design remain unchanged.

The numbering of sections, tables and figures in this document follows that of References 1.0 and 1.6 in order to assist the reader in relating this supplement to References 1.0 and 1.6.

The contents of this report can be summarized as follows:

1. [

   ]^{a,c}

2. [ ]^{a,c}

3. Planned inspections and aquisition of channel operating data.

4. [ ]^{a,c}

1.2 CONCLUSIONS

The information contained in this report in conjunction with References 1.0 and 1.6 supports the following conclusions:

1. The design bases identified are sufficient to assure that the requirements and guidelines identified in Section 4.2 of NUREG-0800 10CFR50, Appendix A and Section III of the ASME Code (Reference 1.3) will be satisfied, and

2. The improved mechanical behavior exhibited by lead test assemblies with [ ]^{a,c} channels demonstrates acceptability for design and licensing applications to a rod-average burnup of 62 MWd/kgU

NRC review and acceptance of this document for reference in licensing applications to a rod-average burnup of 62 MWd/kgU is requested.

[ ]^{a,c} is trademark property of Westinghouse Electric Company LLC

2 GENERAL DESCRIPTION

Section 2 is replaced with respect to Reference 1.0 to include a description of the SVEA-96 Optima2 assembly. Section 2 has been updated with [ ]a,c in Sub-sections 2.3 and (the new) 2.5.5. Furthermore, Sub-sections 2.2.1 and 2.2.2 have been updated to accommodate [ ]a,c. The remainder of Section 2 is unchanged with respect to Reference 1.6.

2.2.1 Top and Bottom Tie Plates

The top tie plate of each sub-bundle has an individual identification number engraved on the side. This feature is also used for administrative control purposes to assure the correct placement of the sub-bundle in the channel. [

]a,c

2.2.2 Standard Fuel Rods and Tie Rods

The top and bottom end plugs and also spacer capture heads may be manufactured [

]a,c

[

]a,c

[

]a,c

2.3 SVEA-96 OPTIMA2 FUEL CHANNEL

This section has been revised to add an alternative channel material to the existing Zircaloy-2 material. Also, the last paragraph has been added.

The fuel channel consists of a [ ]a,c inlet piece and a channel of Zircaloy or [ ]a,c. The inlet piece is composed of a transition piece and bottom support which can be equipped with an integrated debris filter and is bolted to the channel with four screws made of [ ]a,c material. The Zircaloy or [ ]a,c channel consists of an outer channel with a square cross section and an internal double-walled, cruciform structure, or "watercross," which forms channels for non-boiling water as shown in Figures 2-2 and 2-6.

The watercross structure is composed of a square central water channel and smaller water channels in each of the four wings as shown in Figure 2-2. The watercross structure, along with the outer channel walls, form four sub-channels in which the sub-bundles are positioned. A screw is welded to the top end of the cross which attaches the handle with the leaf spring to the fuel channel. The wall thicknesses of the outer channel and watercross are [ ]a,c, respectively.

[

]a,c

In addition to providing channels for non-boiling water, the integral watercross design results in improved dimensional stability leading to reduced bow and bulge of the channels.

The outer channel wall thickness is [

]a,c

The channel and inlet transition piece is designed to assure compatibility with the reactor internals as well as other fuel types in the core. The outer envelope of the SVEA-96 Optima2 channel and transition piece provide ample clearance for control rods and in-core instrumentation for the BWR/2 through BWR/6 reactor designs. The improved dimensional stability of the SVEA channel assures that ample clearances are maintained even at high burnups. The length of the assembly is compatible with the relative positions of the fuel support piece and upper core grid. The inlet transition piece matches the existing fuel support piece and has been designed to be compatible with existing refueling equipment. A detailed mechanical compatibility evaluation is performed as part of the standard design process for each application to assure mechanical compatibility.

SVEA channels were first introduced for reactor operation in 1981. An extensive inspection and measurement program has been performed on SVEA channels during the reactor refueling shutdowns. These inspections have verified that the SVEA channels behave as expected and have excellent dimensional stability.

[

]a,c

2.5 ADVANCED FEATURES

Details on [ ]a,c and channel bow performance have been added in (a new) Section 2.5.5, and Figure 2-15 has been updated with data on both Zircaloy and [ ]a,c. The remainder of the section and its subsections are unchanged relative to the corresponding section of Reference 1.6.

2.5.5 [ ]a,c Fuel Channels

Dimensional stability is one of the key factors in the development of channels for BWR fuel assemblies. [

]a,c

As identified in Section 1.1, this supplement defines the material compostion of [ ]a,c as:

[ ]a,b,c

[

]a,c

a,c

Figure 2-2 SVEA-96 Optima2 Fuel Assembly Cross Section

a,c

Figure 2-6 SVEA-96 Optima2 Channel

a,b.c

Figure 2-15 SVEA-10x10 Channel Bow Measurements in a Symmetric Lattice Plant

3 DESIGN CRITERIA

This section is unchanged relative to the corresponding section of Reference 1.6.

4 DESIGN METHODOLOGY AND APPLICATION

Section 4 remains unchanged relative to Reference 1.6 in all respects apart from the introduction of an alternative channel material. [ ]a,c mechanical properties as standard Zircaloy-2. Consequently, all assumptions and calculations concerning the fuel channel described in Reference 1.6 are valid also for [ ]a,c as the channel material. Table 4-1 has been updated with [ ]a,c data.

Mechanical Properties

The third, fourth and sixth paragraphs in this section have been updated with an alternative channel material. All other paragraphs are unchanged relative to Reference 1.6 and hence omitted in this document.

Typical properties for unirradiated [ ]a,c components currently used for the fuel assembly design evaluations are provided in Table 4-1.

[

]a,c

When unirradiated values are utilized for irradiated components, the effects of irradiation are treated conservatively. For example, conservative estimates of the increase in outer channel and watercross peak stresses associated with wall thinning due to corrosion are assumed. However, the yield and tensile strengths are expected to increase by factors of [

]a,c

Design Stress Intensities

Mechanical properties are conservatively the same for the alternative channel material, hence this section has been updated with [ ]a,c as an alternative channel material to Zircaloy.

Mechanical properties, such as those discussed in Table 4-1, are used to establish stress limits defined by the design bases for the design evaluations of the assembly and assembly components.

Stress limits are based on Reference 1.3. [

]a,c

The design stress intensity, S_m, for [

]a,c

The design stress intensity, Sm, [

]a,c

$Rp_{0.2}$ is the 0.2% offset yield strength. [

]a,c

The specified minimum tensile and yield strengths at material temperature are used unless specific data are available to support the use of less conservative values. For example, at the present time Westinghouse is utilizing [

]a,c

Sample design stress intensities, S_m, are shown in Table 4-1 and are derived in this manner and based on the mechanical properties which are also provided.

The fuel assembly structural component stresses under accident conditions are evaluated using the methods outlined in Appendix F Reference 1.3. The stress intensities (S_m) are defined in accordance with the rules described above for normal operating and anticipated operational transient conditions. [

]^{a,c}

These limits need not be satisfied at a specific location if it can be shown that the design loadings do not exceed two-thirds of the test collapse load determined in compliance with Section III of the Reference 1.3.

Unless otherwise stated, stress intensities are calculated with the Tresca criterion specified in the Reference 1.3:

$$S = \text{Maximum}\{|\sigma_1-\sigma_2|, |\sigma_1-\sigma_3|, |\sigma_2-\sigma_3|\}, \text{ where the } \sigma_i \text{ are the principal stresses.}$$

Under certain circumstances, which are identified in the text, stress intensities are calculated with the Von Mises criterion:

$$S = 1/\sqrt{2}\ \ [\,(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\,]^{1/2}$$

Design Loads

This section is unchanged relative to the corresponding section in Reference 1.6.

4.1 METHODOLOGY FOR EVALUATION OF GENERAL DESIGN CRITERIA

This section is unchanged relative to the corresponding section in Reference 1.6.

4.2 METHODOLOGY AND APPLICATION - FUEL ASSEMBLY COMPONENTS

This section is unchanged relative to the corresponding section in Reference 1.6.

4.2.1 Compatibility with Other Fuel Types and Reactor Internals

The conclusions regarding compatibility are unchanged relative to those of Reference 1.6. However, the following sections have been updated with information on [ ]^{a,c}; Methodology for Creep Deformation, Sample Application (general) and Sample Application for Channel Bulge and Channel Bow.

Also, Figures 4.2-1, 4.2-6, 4.2-14a and 4.2-14b have been updated with data on [ ]^{a,c} channels.

The updated Figure 4.2-1 shows that the upper limit for channel growth remains unchanged when using [ ]a,c as the channel material.

The updated Figure 4.2-6 shows that channel bow data for [ ]a,c channels are well within the experience of Zircaloy-2 and Zircaloy-4 channels.

The updated Figures 4.2-14a and 4.2-14b show a similar or possibly reduced oxidation behavior, compared to Zircaloy-2 and Zircaloy-4.

There is currently no PIE data on hydriding of [ ]a,c, but the data on low channel growth supports a low hydriding of [ ]a,c.

In conclusion – with identical mechanical properties, decreased channel bow and decreased oxide thickness, the assumptions and methodology in this section remain valid also for [ ]a,c channels.

Methodology

This section is unchanged relative to the corresponding section of Reference 1.6.

Creep Deformation

[

]a,c

[

]a,c

Channel Bow

This section is unchanged relative to the corresponding section of Reference 1.6.

Sample Application

This section contains an example of the methodology for evaluating compatibility in a mixed core by evaluating the SVEA-96 Optima2 assembly in a C-lattice in a BWR/6 type plant equipped with 3810 mm (150-inch) active fuel. The resident fuel to which the SVEA-96 Optima2 fuel must be compatible is referred to as the "non-SVEA" fuel assembly.

1. Geometrical Compatibility with Other Fuel Types in the Core

[

]a,c

[

]a,c

Evaluation for the four design conditions for relative axial growth of the non-SVEA assembly and the SVEA-96 Optima2 assembly for this case can be summarized as follows:

SVEA-96 Optima2 at BOL / Non-SVEA Assembly at BOL

This section is unchanged relative to the corresponding section of Reference 1.6.

SVEA-96 Optima2 at BOL / Non-SVEA Assembly at EOL

This section is unchanged relative to the corresponding section of Reference 1.6.

SVEA-96 Optima2 at EOL / Non-SVEA Assembly at BOL

This section is unchanged relative to the corresponding section of Reference 1.6.

SVEA-96 Optima2 at EOL / Non-SVEA Assembly at EOL

This section is unchanged relative to the corresponding section of Reference 1.6.

2. Geometrical Compatibility with Control Rods and Detectors

This section is unchanged relative to the corresponding section of Reference 1.6.

Channel Bulge

The following example illustrates the impact of channel bulge due to the pressure differential across the channel to a bundle burnup [ ]a,c

The SVEA channel has very favorable creep properties. The support of the channel walls by the watercross reduces creep deformation and stresses associated with deformation. [

]a,c

[

]a,c Consequently, the calculations and assumptions described below are still valid as conservative.

Since the correlation has [

]a,c

Application of the creep model described above demonstrates that for the SVEA-96 Optima2 channel the combination of the axial variations of [

]a,c

[

]a,c

a,c

[

]a,c

a,b,c

[

]a,c

Channel Bow

[

]a,c

[

]a,c

[

]a,c

Furthermore, the experience with SVEA fuel and reduced control rod gaps in Westinghouse reactors is very extensive and no case of control rod maneuverability problems due to the SVEA fuel have been indicated or reported. Therefore, it is concluded that SVEA-96 Optima2 fuel in C- and D-lattice BWR reactors will not pose a risk of jeopardizing control rod maneuverability.

The SVEA-96 Optima2 channel could bow sufficiently to contact an instrument guide tube. However, the relatively flexible SVEA channel will not damage the instrument guide tube, and operational experience to date has not indicated that channel bow adversely affects the operation of the in-core instrumentation.

Therefore, these examples demonstrate the compatibility of the SVEA-96 Optima2 assembly with control rods and detectors in symmetric and asymmetric lattice plants. Similar compatibility evaluations are performed for each new plant application.

3. Geometrical Compatibility with Other Core Components

This section is unchanged relative to the corresponding section of Reference 1.6.

4. Geometric Compatibility with Storage Facilities

This section is unchanged relative to the corresponding section of Reference 1.6.

4.2.2 Geometric Changes in the Assembly During Operation

This section is unchanged relative to the corresponding section of Reference 1.6.

4.2.3 Transport and Handling Loads

This section is unchanged relative to the corresponding section of Reference 1.6.

4.2.4 Hydraulic Lifting Loads During Normal Operation and AOOs

This section is unchanged relative to the corresponding section of Reference 1.6.

4.2.5 Assembly Stress and Strain During Normal Operation and AOOs

This section is unchanged relative to the corresponding section of Reference 1.6.

4.2.6 Fatigue of Assembly Components

This section is unchanged relative to the corresponding section of Reference 1.6.

4.2.7 Fretting Wear of Assembly Components

This section is unchanged relative to the corresponding section of Reference 1.6.

4.2.8 Corrosion of Assembly Components

Methodology

This section is unchanged relative to the corresponding section of Reference 1.6.

Sample Application

Based on industry data and Westinghouse experience with the component materials used in the SVEA-96 Optima2 design (Section 5.2.2), the SVEA-96 Optima2 assembly components for which the potential for corrosion must be specifically addressed are:

[

]a,c

[

]a,c A summary of the operating experience and recent inspections are provided in Section 7.

Corrosion of the fuel rod cladding is addressed separately in Section 4.3.5. [

]a,c

[

]a,c

Assembly component corrosion is also maintained at a low level to keep the contribution to coolant activity by the assembly at a level which is as low as reasonably achievable. A related program to meet this goal is utilization of low-cobalt material. Westinghouse has maintained an ongoing program over the past 35 years to minimize cobalt concentration in core components, including fuel assembly components, as a means of reducing personnel exposures.

Particular emphasis has been placed on reducing cobalt concentrations in those components which represent relatively large potential sources of cobalt to the coolant. As a result, cobalt concentrations in Westinghouse fuel assembly components are maintained at a relatively low level as shown in the following table.

[ ]a,c

4.2.9 Hydriding of Zirconium Assembly Components other than Fuel Rods

Methodology

The methodology for treating fuel rod cladding hydriding is addressed in Section 4.3.4. The methodology for treatment of hydriding in the remaining Zirconium based assembly components is provided in this section.

[ ]a,c

The following measures are taken to minimize the impact of hydriding and to support the evaluation of its effect on structural assembly components for assemblies of Westinghouse design:

[ ]a,c

[

]a,c

Evaluation of the potential for hydriding of Zircaloy in non-Westinghouse fuel is based on test data and post irradiation examination results for that fuel provided by the utility or the fuel vendor.

Sample Application

[

]a,c

[

]a,c

a,c

[

]

[

]a,c

Table 4-1 Typical Fuel Assembly Material Properties a,c

a,b,c

[ ]

Figure 4.2-1 SVEA Channel Growth

a,b,c

[ ]

Figure 4.2-5 SVEA-64 Channel Creep Deformation

a,b,c

[ ]

Figure 4.2-6 SVEA-10X10 Channel Bow Measurements in Asymmetric Lattice Plants

a,b,c

[ ]

Figure 4.2-14a Maximum SVEA Channel Oxide Thickness

a,b,c

[ ]

Figure 4.2-14b Average SVEA Channel Oxide Thickness

4.3 METHODOLOGY AND APPLICATION – FUEL RODS

This section is unchanged relative to the corresponding section of Reference 1.6.

4.4 STEADY-STATE INITIALIZATION OF TRANSIENT AND ACCIDENT ANALYSES

This section is unchanged relative to the corresponding section of Reference 1.6.

5 TECHNICAL DATA

This section is unchanged relative to the corresponding section in Reference 1.6.

5.1 FUEL RODS

This section is unchanged relative to the corresponding section in Reference 1.6.

5.2 FUEL ASSEMBLY DATA

Section 5.2.2 has been updated relative to Reference 1.6 with [ ][a,c] *as the channel material. All other sub-sections remain unchanged.*

5.2.2 Fuel Assembly Materials

a,c

[ ]

a,c

[ ]

6 CODE DESCRIPTION

This section is unchanged relative to the corresponding section of Reference 1.6.

7 OPERATING EXPERIENCE

This section has been updated with a description of Westinghouse's history with [ ]a,c as the channel material in test assemblies, as described in Section 7.1. Table 7-2 has been added, describing [ ]a,c channel deliveries. Section 7.2.2.4 and Section 7.4.3 have been added to describe experience with [ ]a,c channels and inspections of [ ]a,c channels, respectively. Table 7-3 has been added, including reactor power data for two additional reactors that have received [ ]a,c channels, not previously described in Reference 1.6. Table-7-4 has been added, showing ongoing inspection plans for [ ]a,c lead assemblies. The remainder of Section 7 is unchanged relative to Reference 1.6.

7.1 HISTORY

The following is added to this section:

In 2004, the first test assemblies with [ ]a,c channel material were delivered to [ ]a,c In total, [ ]a,c assemblies with [ ]a,c channels have been delivered to different customers for plants between 12 and 24 month cycles. Westinghouse has received orders for approximately the same number of test assemblies from a number of European and American customers and [ ]a,c of SVEA-96 Optima2 with [ ]a,c channels.

The remainder of Section 7.1 is unchanged relative to Reference 1.6

7.2 EXPERIENCE

Sub-section 7.2.2.4 has been added. The remaining sub-sections of Section 7.2 are unchanged relative to Reference 1.6.

7.2.1 SVEA-64

This section remains unchanged relative to Reference 1.6.

7.2.2 SVEA 10x10 fuel

A description of [ ]a,c channel deliveries is added in Sub-section 7.2.2.4. A summary of [ ]a,c channel deliveries is shown in Table 7-2. The remainder of this section remains unchanged relative to Reference 1.6.

7.2.2.4 SVEA-96 Optima/SVEA-96 Optima2 with [ ]a,c channels

The first lead test assemblies with [ ]a,c channels were delivered to [ ]a,c Since then, [ ]a,c channel test assemblies have been delivered to [ ]a,c

Table 7-2 [ ]a,c Channel Deliveries as of July 2010 a,c

The ten leading assemblies in [ ]a,c have achieved an assembly average burnup of [ ]a,c MWd/kgU.

Validation of Experience to US Plants

The majority of Westinghouse BWR experience lies with [ ]a,c. Recent significant experience also exists in four U.S. plants with reload quantities of SVEA-96 Optima2 fuel. Table 7-3 shows the core thermal power ratings as well as power generated in each bundle of those European plants that have contained SVEA-96 Optima2 fuel assemblies with [ ]a,c channels and select U.S. plants. Other key BWR fuel duty related parameters such as linear heat generation rate, hydraulic forces and and core exit enthalpies are not applicable to the behavior of the channel.

Given the equivalence of the channel material used in previous SVEA-96 Optima2 fuel designs and the coverage of BWR plant parameters, the experience gained in channel growth, bowing and oxidation from European reactors is representative also for U.S. reactors.

Table 7-3: Operating Parameters for Plants with SVEA-96 Optima2 Fuel Assemblies a,c

[ ] a,c

7.3 FUEL RELIABILITY

This section, including sub-sections, remains unchanged relative to Reference 1.6.

7.4 INSPECTIONS

Sub-section 7.4.3 has been added to describe inspection of [ ]a,c channels. The remainder of this section remains unchanged relative to Reference 1.6.

7.4.3 SVEA 10x10 Fuel with [ ]a,c channels

A number of inspections have been performed on the test assemblies delivered according to Table 7-2. All channels have been inspected at least once, apart from the channels delivered to [ ]a,c All inspected channels have performed as expected, displaying improved growth, channel bow and oxidation relative to Zircaloy-2 and Zircaloy-4.

Plans for future inspections on these lead assemblies are shown in Table 7-4. Westinghouse also intends to perform inspections on future deliveries (including full reloads) of [ ]a,c channels in order to increase the database and monitor channel behavior.

Table 7-4 [ ]a,c Channel Inspection Plans a,c

8 PROTOTYPE TESTING

This section is unchanged relative to the corresponding sections of Reference 1.6.

9 TESTING, INSPECTION, AND SURVEILLANCE PLANS

This section is unchanged relative to the corresponding sections of Reference 1.6.

10 REFERENCES

1.0 "Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors," Westinghouse Report CENPD-287-P-A (proprietary), CENPD-287-NP-A (non-proprietary), July 1996.

1.2 "Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1," Westinghouse Report WCAP-15836-P (proprietary), WCAP-15836-NP (non-proprietary), June 2002 and RAI responses to this report dated April 2004 and July 2004. (WCAP-15836-P is a supplement to CENPD-285-P-A. As such, it does not repeat the information in CENPD-285-P-A, but refers the reader to the appropriate sections in CENPD-285-P-A.)

1.3 ASME Boiler and Pressure Vessel Code, Section III.

1.4 "Fuel System Design," U.S. NRC Standard Review Plan Section 4.2, NUREG-0800, Rev. 2, July 1981.

1.6 "Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors, Supplement 1 to CENP-287" Westinghouse report WCAP-15942-P-A (proprietary), WCAP-15942-NP-A (non-proprietary), March 2006

4.7 MATPRO Revision 11-Version 2, "A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behaviour," NUREG/CR-0497, Tree-1280.