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Our ref: LTR-NRC-04-22

Attention: J. S. Wermiel, Chief
Reactor Systems Branch
Division of Systems Safety and Analysis

April 16, 2004

Subject: Part Response to NRC Request for Additional Information (RAI) on WCAP-15836-P, Revision 0, "Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1" (Proprietary/Non-Proprietary)

Dear Mr. Wermiel:

Enclosed are copies of the Proprietary and Non-Proprietary versions of the Part Response to NRC Request for Additional Information (RAI) on WCAP-15836-P, Revision 0, "Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1" (Proprietary/Non-Proprietary).

Also enclosed are:

1. One (1) copy of the Application for Withholding, AW-04-1816 with Proprietary Information Notice and Copyright Notice.

2. One (1) copy of Affidavit, AW-04-1816.

This submittal contains Westinghouse proprietary information of trade secrets, commercial or financial information which we consider privileged or confidential pursuant to 10 CFR Section 2.390. Therefore, it is requested that the Westinghouse proprietary information attached hereto be handled on a confidential basis and be withheld from public disclosure.

Correspondence with respect to any Application for Withholding should reference AW-04-18BB and should be addressed to James A. Gresham, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P. O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

James A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: F. M. Akstulewicz, NRR
P. Clifford, NRR
W. A. Macon Jr., NRR
E. S. Peyton, NRR

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Our ref: AW-04-1816

Attention: J. S. Wermiel, Chief
Reactor Systems Branch
Division of Systems Safety and Analysis

April 16, 2004

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: Part Response to NRC Request for Additional Information (RAI) on WCAP-15836-P, Revision 0, "Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1" (Proprietary)

Reference: Letter from James A. Gresham to J. S. Wermiel, LTR-NRC-04-22, dated April 16, 2004

Dear Mr. Wermiel:

The application for withholding is submitted by Westinghouse Electric Company LLC (Westinghouse) pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.390, Affidavit AW-04-1816 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-04-1816 and should be addressed to James A. Gresham, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P. O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

James A. Gresham, Manager
Regulatory Compliance and Plant Licensing

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared James A. Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse) and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

J A Gresham

James A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 16th day
of April, 2004.

Sharon L. Fiori

Notary Public

Notarial Seal
Sharon L. Fiori, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires January 29, 2007
Member, Pennsylvania Association Of Notaries

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC, a Delaware limited liability company (Westinghouse) and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked "Part Response to NRC Request for Additional Information (RAI) on WCAP-15836-P, Revision 0, 'Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1' (Proprietary/Non-Proprietary)," April 16, 2004, for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-04-22) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse is in response to a Request for Additional Information from the NRC staff.

This information is part of that which will enable Westinghouse to:

(a) Assist proper fuel performance of fuel operating in reactors.

(b) Assist customers to obtain license changes resulting from fuel performance modeling.

Further this information has substantial commercial value as follows:

(a) Westinghouse can use this fuel performance modeling capability to further enhance their licensing position over their competitors.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing the enclosed improved core thermal performance methodology.

Further the deponent sayeth not.

Proprietary Information Notice

Transmitted herewith are proprietary and non-proprietary versions of documents furnished to the NRC. In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

Copyright Notice

Part Response to NRC Request for Additional Information (RAI) on WCAP-15836-P, Revision 0, "Fuel Rod Design Methods for Boiling Water Reactors – Supplement 1"

Part 1

Partial Response to NRC Request for Additional Information (RAI) on WCAP-15836-P Rev. 0, Fuel Rod Design Methods for Boiling Water Reactors - Supplement 1

Part 1
Partial Response to NRC Request for Additional Information (RAI) on WCAP-15836-P Rev. 0, Fuel Rod Design Methods for Boiling Water Reactors - Supplement 1
STAV7.2

STAV7.2 RAI Number 7:

On page A-2, the equation for the burnup dependent term, b(u), in the fuel thermal conductivity equation is given in two forms with a burnup cutoff of 100 MWd/kgU for application of the two forms. On Page A-3, the document states that the burnup, u, for application of the function is in units of MWd/kgUO_2. If the first form of b(u) is applied using a burnup of 88 MWd/kgUO_2 (100MWd/kgU), the value of b(u) at 88 MWd/kgUO_2 is 0.14784. The second form of b(u), that will be used above 100 MWd/kgU (88 GWd/MTUO_2), provides a constant value of 0.15. This means that there will be a discontinuity in b(u) as a function of burnup at 88 MWd/kgUO_2. Is this interpretation of the burnup dependant term correct? It is noted that there would not be a discontinuity in b(u) if either the range of application for the first form was 100 MWd/kgUO_2, or if the units of local burnup, u, were in MWd/kgU.

Response 7:

The burnup units for the range of application of the two forms of b(u) in Equation (A.1-5) of WCAP-15836-P are MWd/kgUO_2. The MWd/kgU units cited in Equation (A.1-5) as the range of application represent an oversight. In addition, the statement that the units are MWd/kgU following the equations is incorrect. The quantity b(u) is continuous.

However, the dependency of fuel conductivity on burnup has been modified. The modifications will be described in Part 2 of these RAI responses and will be incorporated into WCAP-15836-P-A.

STAV7.2 RAI Number 8:

The equations for the fission gas diffusion constant may have an error. The only way to replicate Figure 2.1.5-3 for the effective diffusion constant as a function of temperature is to NOT multiply b by 1E-27 in Equation 2.1.5-23. Also, the units for "b" and for "g" in Equation 2.1.5-26 do not appear to be in meters.

Response 8:

Figure 2.1.5-3 of WCAP-15836-P is correct, and Equation (2.1.5-23) is incorrect. Equation (2.1.5-23) should not contain the multiplier 1E-27. The units for "b" in Equation (2.1.5-23) and for "g" in Equation (2.1.5-26) are incorrect and should both be seconds^{-1}.

In addition, the correlation for the diffusion coefficient D2, just above Equation (2.1.5-21) is incorrect. It should not contain the constant R. The correlation was correctly substituted into Equation (2.1.5-20), however, obtaining Equation (2.1.5-21), which is also correct.

Modifications to the fission gas release model have been made which will impact the magnitude of "b" and "g". These modifications will be described in Part 2 of the RAI responses and will be incorporated into WCAP-15836-P-A.

STAV7.2 RAI Number 11:

How is the grain boundary sweeping model used to predict FGR? The grain boundary growth model is explained but how this is applied in calculating release is not explained. Please explain and provide an example.

Response 11:

The thermal fission gas release process in STAV7.2 is modeled by assuming that UO_2 (or $(U,Gd)O_2$) consists of spherical grains of equal size, i.e., by assuming the equivalent sphere model discussed in Section 2.1.5.2 of WCAP-15836-P. Fission gas release during grain growth is provided in detail in References 11-1 and 11-2.

In this model the fission product gases are produced at a rate β(t) in a grain of radius R(t), which is allowed to vary with time t due to the phenomenon of grain growth. The gases migrate to grain boundaries by diffusion with a diffusion coefficient D(t). The gas atoms reaching the boundary precipitate into intergranular bubbles with a local density of N(t) (number of gas atoms per unit area) and a grain boundary re-solution rate of $B(t)=b\lambda/2$, where b is the grain boundary re-solution frequency, and $\lambda/2$ is the re-solution distance from the grain face into the grain. The concentration of gas, C_λ, sustained at position λ, depends on how fast the gas can return by diffusion to the intergranular bubbles at the boundary.

The underlying physical assumption is that the grain boundary always behaves thermodynamically as a perfect sink, i.e., the rate of return of gas atoms to intergranular bubbles will be controlled by their diffusion within the matrix to the boundary as discussed in Reference 11-3. This rate is given by $2DC_\lambda/\lambda$. Hence the re-solved gas concentration can be determined from the equality:

$$2DC_\lambda/\lambda = bN \tag{1}$$

When the concentration of the gas atoms within grain boundaries reaches a certain threshold value, $N=N_s$, gas release will occur. The key relations needed to calculate and explain the release process can be summarized as follows.

The total amount of gas, G(t), per unit volume in a grain of radius R is calculated as

$$G(t) = \frac{3D(t)C(R,t)}{2RB} + \frac{3\int_0^R r^2 C(r,t)dr}{R^3} \tag{2}$$

where, C(r,t) is the concentration of gas at position r and time t in the grain. The first term on the right hand side of Equation (1) expresses the amount of gas residing in the grain boundary in equilibrium with the gas inside the grain, while the second term represents the amount of gas inside the grain whose distribution $C(r,t)$ is governed by the diffusion equation.

If no gas has been released, we have

$$G(t) = \int_0^t \beta(s)ds \tag{3}$$

Combining Equations (2) and (3), we can find the intergranular gas density N(t):

$$N(t)=\frac{2}{3}R\int_0^t \beta(s)ds-\frac{2\int_0^R r^2C(r,t)dr}{R^2} \tag{4}$$

where we used the relation $N(t)=D(t)C(R,t)/B(t)$. The gas concentration in the grain C(r,t) is determined by solving the diffusion equation in a spherical grain which is allowed to grow as discussed in Reference 11-2.

When the concentration of gas at the grain boundary reaches a certain level given by

$$C_{max}(t)=\frac{B(t)N_s(t)}{D(t)} \tag{5}$$

gas release will occur. The gas atom density per unit area of grain boundary at saturation, N_S, can be calculated through the gas equation of state. In the computations, it is assumed first that $C_{max}(t)$ is linear in t, and then upon grain saturation, only a fraction χ of the intergranular gas is released. This means that upon release, the concentration in the grain boundary will be dropped to a value of $(1-\chi)C_{max}$ as described in References 11-4 and 11-5.

Fission gas release is assumed to occur upon gas saturation in the grain boundaries. From Equations (4) and (5), the density of gas within the grain boundaries at saturation is

$$G_s=\frac{3}{2R}N_s \tag{6}$$

[

]^{a,c}:

[ ]^{a,c}

[

]^{a,c}

$$\left[\qquad\qquad\qquad\qquad \right]^{a,c} \qquad (7)$$

[

] a,c.

[

] a,c.

A concrete example using a variant of this model, but illustrating the principles, to calculate fission gas release as a function of temperature and time with the associated grain growth can be found in Reference 11-2.

References:

11-1 K. Forsberg, F. Lindström, A. R. Massih, "Modelling of some High Burnup Phenomena," IAEA-TECDOC-957, August 1997, IAEA, Vienna.

11-2 K. Forsberg, A. R. Massih, "Theory of Fission Gas Release with Grain Growth," SMiRT 16, Washington D.C., August 2001.

11-3 M. V. Speight, Nucl. Sci. Engrg., Vol. 37 (1969), pp. 180-185.

11-4 K. Forsberg and A. R. Massih, J. Nucl. Mater., Vol. 13 (1985), pp. 140-148.

11-5 K. Forsberg, A. R. Massih and K. Andersson, "Calculation of Fission Gas Migration in Nuclear Fuel with Re-solution Effect," Enlarge Halden Programme Group Meeting on Fuel Performance Experiments and Analysis, Sanderstølen, Norway, 2-7 March 1986.

STAV7.2 RAI Number 12:

How is the transient fission gas release applied? For example, what criteria turn the transient release on and what is used to turn it off?

Response 12:

The transient fission gas release model is used to evaluate the impact of power ramps in a fuel rod power history. [

] a,c. In this way, the transient fission gas release model can be applied to the power ramp time steps in the rod power history intended to simulate, for example, power changes associated with Anticipated Operational Occurrences.

STAV7.2 RAI Number 14:

The STAV7.2 FGR model for $(U,GD)O_2$ fuel has reduced the diffusion coefficient compared to that for UO_2 because it is stated that the former has more microstructural vacancies than UO_2 fuel. The effect of diffusion coefficient on microstructural vacancies depends on the diffusion mechanism and many of the potential diffusion mechanisms increase with increasing vacancies. The exact mechanism for diffusion in $(U,GD)O_2$ fuel is not known so the effect is difficult to predict but as noted many of the mechanisms would predict an increase in diffusion with an increase in vacancies. It could be argued that the measured FGRs in $(U,GD)O_2$ fuel from steady-state operation are over-predicted using the diffusion coefficients from UO_2 fuel and the use of the reduced diffusion coefficients reduces this over-prediction. However, the steady-state database for $(U,GD)O_2$ fuel where thermal release is important is small with the measured FGR values lower than calculated for peak power conditions in commercial BWRs where the model will be applied. Also, the STAV7.2 transient FGR model for $(U,GD)O_2$ fuel over-predicts the power ramped $(U,GD)O_2$ FGR data (only data at approximately 34 GWd/MTU) in a similar manner to that predicted with the UO_2 transient FGR model. Please provide further justification for the reduction in the diffusion coefficient for $(U,GD)O_2$ fuel particularly considering that the FGR data for $(U,GD)O_2$ fuel do not achieve the desired application burnup.

Response 14:

Reduced diffusion of fission gas in $(U,Gd)O_2$ is supported by theoretical considerations and supported by experimental evidence obtained from gamma scans to justify a lower fission gas diffusion coefficient.

[

]^{a,c}.

[

]^{a,c}.

Detailed discussion of the theoretical and experimental justification was provided in CENPD-285-P-A, Appendix B. WCAP-15836-P now provides additional experimental data on fission gas release which Westinghouse believes is sufficient to demonstrate the lower diffusion of mobile fission gases in $(U,Gd)O_2$ fuel.

The combination of supporting theoretical considerations, experimental evidence [ ]^{a,c} for $(U,Gd)O_2$ rods is sufficient to justify a reduced diffusion coefficient.

References:

14-1 S. O. Andersson, et al, Proceedings of Symposium on Improvements in Water Rector Fuel Technology and Utilization, Stockholm, 15-19 September 1986, pp281-289. IAEA publications, Vienna (1987).

14-2 B. Grapengiesser, et al, Proceedings of ANS Topical Meeting on LWR Fuel Performance, April 17-29, 1988, Williamsburg, Virginia, pp31-40 (1988).

STAV7.2 RAI Number 15:

The equation for athermal gas release only seems to make sense if "F_{rim}" is multiplied by the volume fraction in the rim. This is also implied by the original reference (see Reference 2-6 in the submittal). The lower limit on the integral in the denominator in Equation 2.1.5-36 should be r_{inner} (= 0.0 for a solid pellet) not r_{rim} as shown; see Reference 2-6 in the submittal. Also, the discriminating burnup that establishes the whether F_{rim} is non-zero in Equation 2.1.5-37 is confusing. Is this burnup the radial node burnup of the rim (as implied) or is it the pellet average burnup? The use of radial node burnup of 45 or 54 GWd/tU for the rim does not make sense because a radial node burnup of ~ 70 GWd/tU for the rim is consistent with the data Reference 2-6. Please provide a better discussion of the burnup to be used to define the rim gas.

Response 15:

The observation regarding the lower limit of the integral in the denominator of Equation (2.1.5-36) is correct. The lower limit of the integral is r_{in}, where r_{in} is the pellet inner radius. This correction will be incorporated into WCAP-15836-P-A.

[

]^{a,c}.

[

]^{a,c}.

As discussed on pages 2-24 and 2-25 of WCAP-15836-P, the [

]^{a,c} was based on the work of Cunningham et. al. (Reference 2-27 of WCAP-15836-P) and Barner et. al. (Reference 2-28 of WCAP-15836-P). However, as discussed in Section 3.3.3.3 of WCAP-15836-P, the model parameter u_{rim} was [

]^{a,c}.

STAV7.2 RAI Number 17:

The cladding corrosion model assumes that there is no nodular corrosion in cladding currently fabricated by W-Atom due to fabrication improvements. Please provide the corrosion data that substantiates this claim. Also, please provide all of the uniform corrosion data versus burnup and also versus full power operation days (or hours) from the newer fabricated cladding. This information is valuable in determining the scatter in the corrosion data between different plants.

Response 17:

As noted in the Response to RAI 16, the values of A, B, and C in Table 2.2.5-1 of WCAP-15836-P are considered to be representative of the BWR cladding used in the qualification data base in Section 3 of WCAP-15836-P and were used for the code calibration in Section 3 of WCAP-15836-P. Specifically, the values of A, B, and C in Table 2.2.5-1 of WCAP-15836-P reflect the oxide thickness as a function of burnup [

][a,c].

[

][a,c].

[

][a,c].

The LK3 cladding is similar to LK1 with respect to [

][a,c].

[

]^{a,c}.

[

]^{a,c}.

It should be noted that a rod-average burnup of [

]^{a,c}.

The oxide thickness in Figures 17-1 and 17-2 is plotted as a function of the integrated assembly energy density (MWd/kgU). Westinghouse has found this to be a convenient way of portraying oxide thickness data from different plants with different power densities and assembly designs that reflects the dependence of oxide buildup on metal/oxide surface heat flux and temperature. Consequently, Westinghouse does not routinely record oxide data in terms of cycle or core EFPH. While this information could be retrieved, it would require a significant effort and would, Westinghouse believes, be of limited usefulness.

Consequently, we have not provided the requested information as a function of EFPH.

Oxide thickness measurements are performed poolside using an eddy-current probe [

]^{a,c}.

[

]^{a,c}.

Reference:

17-1 CENPD-287-P-A, "ABB Fuel Assembly Mechanical Design Methodology for BWR Fuel," July 1996.

a, c

Figure 17-1 Average Oxide Thickness

a, c

Figure 17-2 Maximum Oxide Thickness

STAV7.2 RAI Number 18:

What value is used for crud conductivity (Section 2.2.5.3) in the code?

Response 18

The crud thermal conductivities for PWR and BWR fuel rods in STAV7.2 are the same as in Reference 18-1:

[ ]^{a,c}
[ ]^{a,c}

Reference:

18-1 CENPD-285-P-A, "Fuel Rod Design Methods for Boiling Water Reactors," July, 1996.

STAV7.2 RAI Number 19:

It appears that the cladding creep strain rate equation has an irradiation hardening term that (mathematically) is essentially a switch: It turns on with any finite (>1 day) exposure, and reduces the steady-state out-of-flux strain rate (i.e., the first term in Equation 2.2.3-2) by a factor of about 1.79. The second term in the equation (the neutron flux-enhanced creep) greatly dominates over the first, such that in nominal reactor-operating conditions (fast neutron flux = 4E17 n/m^2/s, hoop stress = 45 MPa, and cladding temperature = 570 K), the overall effect is only about a 2% relative reduction in the steady-state strain rate. Is this interpretation correct and the instant "step" function in strain rate with irradiation exposure correct?

Response 19:

The observation that the first term (in-reactor thermal steady-state creep) is dominated by the second term (steady-state neutron flux-enhanced creep) in Equation (2.2.3-2) of WCAP-15836-P is correct.

[

]^{a,c}. **Equations (2.2.3.2) through (2.2.3.5) must be substituted into Equation (2.2.3.1) to obtain the total creep strain.**

STAV7.2 RAI Number 20:

What are the applications of the cladding creep model? We do not recommend its application in the out-of-flux form at the very high stresses and temperatures encountered in storage cask handling. Will this creep equation be used for justifying fuel rod pressures greater than system pressure? When are the best estimate, the upper-bound and lower-bound creep models used respectively for licensing analyses?

Response 20:

The current applications of the cladding creep model can be categorized as follows:

1. **The cladding creep model is an integral part of STAV7.2. As such, the cladding creep model is used in all of the burnup-dependent reload licensing calculations described in Reference 20-1 for which STAV is used. It is applied to the inward and outward cladding creep.**
2. **As discussed in Reference 20-1, the creep correlation and upper bound uncertainty are used in the establishment of the limiting internal pressure at which pellet-clad lift-off is predicted to occur.**
3. **The creep correlation has been incorporated into COLLAPS-3.3D described in WCAP-15836-P.**

[

] a, c. However, the need for further benchmarking of the model for dry storage cask analyses would be considered prior to using it for this application.

The fuel rod internal pressure design criterion established in Reference 20-1 limits internal pressures to avoid more rapid outward creep of the cladding than the rate of radial thermal expansion of the pellet (i.e., the "No-Clad-Lift-Off (NCLO) criterion). Therefore, the Westinghouse methodology does require application of the cladding creep correlation for internal pressures greater than system pressure in STAV7.2. The application of the cladding creep correlation for NCLO evaluation is performed outside of STAV7.2.

As discussed in Reference 20-1, fuel rod reload licensing analyses utilize either bounding parameters or involve uncertainty analyses to assure at least 95% probability that a given design criterion is satisfied. A best estimate analysis in conjunction with an uncertainty analysis is preferred since its application generally provides a realistic estimate of the probability that the margin to the design criterion is conservatively predicted. In some cases, in which competing effects do not cause the response from a given parameter to be ambiguous, a bounding analysis can be applied. [

] a, c.

Reference:

20-1 WCAP-15942-P, "Westinghouse Fuel Assembly Mechanical Design Methodology for BWR Fuel," July 2004.

STAV7.2 RAI Number 21:

Measured and predicted creep values for a given fuel rod appear to be given as one value. However, most fuel rod diameter measurements contain several measured values at different circumferential and axial locations. Furthermore, a fuel performance code will calculate different amounts of cladding creepdown at different axial locations for any given point in time. Please explain how these measurements and predictions at different axial locations were broken into one measurement and prediction per rod. Note that any averaging of the measured and predicted values will wash out the actual variation in the data and predictions.

Response 21:

Cladding creep correlation predictions of measured creep strains are shown in the strain verification data of Tables C-9 through C-11 of WCAP-15836-P as one average prediction versus one measured value. The calculated and measured diameters are the average values over the middle 80% of the fuel rods.

The cladding creep correlation and uncertainty were formulated and calibrated outside of the STAV7.2 fuel performance code. The experimental calibration database consisted of individual measurements and predictions from well characterized tests. No average values were used. [

]^{a,c}. The data points shown in Figures 3.4-1 through 3.4-4 of WCAP-15836-P are for individual measurements. The fit between the correlation and measured data are good.

The verification data for a number of commercial PWR and BWR fuel rods were obtained from profilometry performed at poolside. Verification data is compared to STAV7.2 predictions. It is noted that pre-characterization was not usually performed for the rods in the verification database. Consequently, the accuracy of the measured strains is subject to uncertainty and an average for each rod compared to an average for the creepdown predicted from STAV7.2 is consistent with the expected accuracy. Since nominal initial diameters are assumed for the verification data, axial strain distributions may also be somewhat systematically biased. However, some typical examples are provided in Figures 21-1, 21-2, and 21-3 for two BWR rods and one PWR rod from Tables C-9 and C-11, respectively to demonstrate the comparisons. Examples of the range of prediction versus measured are represented in these figures. Note that these comparisons in Figures 21-1 through 21-3 are from the original version of STAV7.2 documented in WCAP-15836-P. The original data are provided herein because it is judged that the modifications to STAV7.2 will have an insignificant impact on these comparisons.

BWR Studsvik data of Table C-10 (S268/S269) [

]^{a,c}. Irradiation was performed in the Studsvik R-2 research reactor between 1976 and 1979. The S268/S269 irradiation experiment was performed to investigate rod internal fill gas pressure effects on fuel rod behavior.

[

]^{a,c}.

[

] [a,c].

Table 21-1

[ ] a, c

[

] [a,c].

[

] [a,c]. Predicted and measured values of creepdown are presented in Table C-10.

Averaging of the verification data has no impact on the cladding creep correlation or uncertainty.

a, c

Figure 21-1
A comparison of between STAV7.2 prediction and profilometry measurement, for BWR B2e5, rod 10624-H8. [

]a,c.

a, c

Figure 21-2
A Comparison Between Prediction and Profilometry Measurement for PWR Zion Rod 665. (Note the calculated creep strain at the ends and in the middle of rod in this case due to the pellet cladding contact as discussed in Section 3.4.2.3 of WCAP-15836-P. Creepdown recovery is predicted to occur in the middle of the rod where hoop stress becomes tensile. The data are taken from one of the average PWR data comparison from Table C-11.)

a, c

Figure 21-3

A Comparison Between Prediction and Profilometry Measurements for BWR B2e5 Rod 10580-A6. [ ]a, c.

STAV7.2 RAI Number 22:

The report in Section 2.2.6 states that the modeling of hydriding in STAV7.2 (for high burnup applications) does not impact other calculations. The report further states that hydriding in W-Atom designs will be acceptable in terms of design performance. However, recent RIA tests performed on BWR rods in NSRR suggest that the BWR rod ductility drops significantly at burnups above 57 GWd/MTU and hydrogen levels above 150 – 200 ppm. In addition, power ramp testing of high burnup rods (at 60 GWd/MTU) in JMTR with hold times of several minutes also demonstrated brittle failure at hydrogen levels near 200 ppm (Hayashi et al). Please discuss the above and how the lack of hydride modeling in STAV 7.2 is acceptable considering the JMTR data from Hayashi et al.

Response 22:

The Westinghouse statement from Section 2.2.6 is intended to convey that hydriding predicted within STAV7.2 will have no impact on other STAV7.2 calculations. As discussed in Reference 22-1, the STAV7.2 code is used to assess the impact on fuel rod performance during normal operations and Anticipated Operational Occurrences (AOO's). It is not used to establish the dynamic response and fuel rod mechanical margin to failure or fuel dispersal during postulated Reactivity Insertion Accidents such as the BWR Control Rod Drop Accident (CRDA's). As discussed in Reference 22-2, this CRDA event is treated in an appropriate systems code capable of predicting the very rapid core reactivity and power increases and nuclear feedback mechanisms characteristic of this event. The licensing analysis described in Reference 22-2 results in establishing peak pellet enthalpies during the event which are compared with accepted enthalpy limits for fuel dispersal and fuel rod failure currently provided in NUREG-0800. It is Westinghouse's understanding that effects of degradation in cladding ductility, as a function of burnup and potential for brittle fracture during a postulated CRDA, will be accommodated, if necessary, in revisions to these limits on an industry basis.

As noted in the RAI, the tests discussed in Reference 22-3 involved conditions representative of a BWR CRDA but not representative of normal operation or AOOs. For example, comparison of Figures 2 and 5 of Reference 22-3 indicates that the highest burnup fuel rod which failed required an essentially instantaneous ramp from about 8 to about 40 kW/m in a fuel rod whose average burnup was in excess of 60 MWd/kgU. This type of ramp in such a highly burned rod might be credible in a CRDA, but would not be credible in an AOO or under normal conditions. Consequently, the tests described in Reference 22-3 are not considered relevant to the STAV7.2 code within the framework of the Westinghouse reload licensing analysis methodology.

The fourteen tests on BWR-type fuel rods, conducted in the NSRR facility, were performed in stagnant water (25 °C and 0.1 MPa) conditions and at pulse widths that ranged from 4.3-7.3 msec. These test conditions are not representative of commercial BWRs even at accident conditions. Furthermore, the JMTR test rods experienced an irradiation environment that is inconsistent with LWR conditions and thus are also not representative.

References:

22-1 WCAP-15942-P, "Westinghouse Fuel Assembly Mechanical Design Methodology for BWR Fuel," July 2004.

22-2 CENPD-284-P-A, "Control Rod Drop Accident Analysis Methodology for Boiling Water Reactors: Summary and Qualification," July 1996.

22-3 Hayashi et. al., "Outside-in Failure of High Burnup BWR Segment Rods Caused by Power Ramp Tests," ENS TopFuel 2003, March 16 – 19, 2003, Wurzburg, Germany.

STAV7.2 RAI Number 23:

Please provide example stored energy calculations and rod pressure calculations used for LOCA input for a typical ABB design where a UO_2 fuel rod is limiting. Also please provide example end-of-life rod pressure, fuel melting and cladding strain analyses using the licensing methods described for these analyses when a UO_2 fuel rod is limiting. Please provide similar analyses when a $(U,GD)O_2$ fuel rod is limiting using licensing methods. Please provide the input values used for the above analyses including the linear heat generation rates and axial profiles versus time. Please provide output values for each calculation including fission gas release, rod pressure, gap conductance, gap size, gas composition, fuel stored energy, fuel centerline, surface temperature for the peak axial node. The output should also include the rod fission gas release and internal pressures. The best estimate as well as upper bound values used for licensing analyses should be provided as well as the adjustments to the input and modeling parameters for each of these predictions. In addition for the cladding strain analysis, the elastic and plastic hoop should be provided at the peak axial node as well as total axial elastic and plastic strains for the rod.

Response 23:

Westinghouse will submit a supplement to Reference 23-1 providing any required changes to the Westinghouse BWR fuel assembly and fuel rod methodologies required to support the application of STAV7.2. In addition, sample calculations illustrating the methodology using STAV7.2 and supporting a rod average burnup of 62 MWd/kgU will be provided. These sample calculations will include the analyses requested in this RAI.

Reference:

23-1 CENPD-287-P-A, "ABB Fuel Assembly Mechanical Design Methodology for BWR Fuel," July 1996.

STAV7.2 RAI Number 24:

It is stated that the TUBRNP sub-code is used to generate $U0_2$ pellet radial power and burnup profiles as burnup progresses. This sub-code accounts for the build-in of Pu isotopes preferentially near the edge of the pellet due to resonance capture by U^{238} (in the epithermal neutron energy range) and subsequent transmutation to Pu, and the consequent edge-peaked radial distributions that develop. It is unclear whether the same phenomena are accounted for with respect to Gadolinia-$U0_2$ pellets. Although some gadolinium isotopes have very high thermal cross-sections, it is expected that the resonance capture leading to Pu buildup will still occur, and certainly will accrue as the high cross-section gadolinium isotopes burn out. Appendix B in Reference 1-1 implies that this is the case, but it is not explicitly stated. Please confirm whether the effects of plutonium edge-peaked buildup are accounted for in the radial power and burnup profiles calculated for gadolinia-$U0_2$ pellets.

Response 24:

TUBRNP for UO_2 is replaced by a similar code BURAS for gadolinia-UO_2 fuel. BURAS is described in Reference 24-1, in Section 2.1.2.3 and in Appendix B. It is also described in Reference 24-2. The BURAS code accounts for the build-up of Pu isotopes, radial power distributions, and burnup distributions similar to TUBRNP.

References:

24-1 CENPD-285-P-A, "Fuel Rod Design Methods for Boiling Water Reactors," July 1996.

24-2 A. Massih, S. Persson, and Z. Weiss, "Modelling of $(U,Gd)O_2$ Fuel Behavior in Boiling Water Reactors," J. Nucl. Mater., Vol. 188, pp. 323-330, (1992).

STAV7.2 RAI Number 25:

The submittal suggests that the code is intended to be used only for BWR applications, from this it could be implied that the only cladding properties applied will be those from recrystallized Zr-2 cladding types. Is this interpretation correct? The equations for cladding corrosion appear to imply that there are several W-CE cladding types used for BWR applications. Please provide the differences (fabrication and composition) of those cladding types used for current and future fuel reloads and, also, those types that are still in operating plants. What creep and axial growth data are available that demonstrate these different cladding types have similar creep and growth characteristics? What is the fluence range for this data?

Response 25:

Yes, the interpretation is correct. STAV7.2 will only be used for BWR applications in the U.S. and Westinghouse is only requesting approval for that purpose.

Current BWR cladding types to be used in the U.S. are included in WCAP-15836-P. Future cladding types would be expected to be submitted to the NRC for appropriate review only when Westinghouse implements a plan to use them.

Cladding properties, irradiation behavior models and correlations for PWR fuel are required in order to model the entire database for STAV7.2. Westinghouse has no intention of introducing PWR cladding types into BWRs. Corrosion for PWR cladding types is intended to only model the average thermal effects of waterside corrosion on fuel performance. Similarly, creep and growth characteristics are required for the PWR data, which Westinghouse believes helps demonstrate the capability and accuracy for licensing applications to BWR fuel.

VIK-3

VIK-3 RAI Number 1:

The spring supports are assumed to be rigid in the vibration analysis (Section 4.1.7); however, the springs are not rigid. It is not obvious whether this assumption adds conservatism to the rod bending stress analysis. Please discuss the impact of a rigid support versus a non-rigid support in the flow induced bending analysis and provide examples. The analysis also assumes the fuel is not connected to the cladding but is an independent mass. This assumption is valid at low burnups but at moderate to high burnups the fuel and cladding are in contact adding stiffness to the fuel rod. Please discuss the impact of fuel cladding contact on the flow induced bending stresses.

Response 1:

Paidoussis' model for vibration amplitude under fully clamped end conditions, i.e., rigid lateral and rotational supports, have been validated against experimental data on boiling water reactor for the 10x10 fuel design. Thus, the rigid model is verified as the appropriate boundary conditions in this case.

Westinghouse performed an evaluation of flow induced vibration for the 10x10 fuel design in 1992. [

]^{a,c}. Results were compared to predictions using correlations available in the literature. These correlations were two versions of Paidoussis' model (with and without rod pitch as a parameter), Reference 1-1, Chen's correlation, Reference 1-2, and Reavis' correlation, Reference 1-3. Test amplitudes generally gave the best agreement with the Paidoussis model with pitch included. Thus, it was concluded that this model was adequate for design analysis.

[

]^{a,c}.

Any additional rigidity will reduce the amplitude and lower the stress.

References:

1-1 M. P. Paidousssis, "Fluidelastic Vibration of Cylinder Arrays in Axial and Cross Flow: State of the Art," Journal of Sound and Vibration, Vol. 76(3), pp. 329-360, (1981).

1-2 Y. N. Chen, "Flow-induced Vibrations in Tube Bundle Heat Exchanges with cross and parallel flow," Flow-induced Vibration in Heat Exchanges, Editor D. D. Reiff, ASME, New York (1970).

1-3 J. R. Reavis, "Vibration Correlation for Maximum Fuel-Element Displacement in Parallel Turbulent Flow," Nuclear Science and Engineering, Vol. 38, pp. 63-69 (1969).

VIK-3 RAI Number 2:

The contact shear stresses are noted to be neglected in Section 4.1.11. Does this mean that axial loading due to PCMI is neglected and, if not, is a friction coefficient assumed for this analysis?

Response 2:

The purpose of the added Section 4.1.11 is to account for the added load in the calculation of hoop stress where appropriate.

The clad design stress calculation in VIK-3 assumes frictionless pellet-clad contact and applies the normal (compressive) contact stress, as determined by STAV7.2 according to Section 2.2.2.2, as additional load component to the hoop stress.

VIK-3 RAI Number 3:

A finite element model is used to determine thermal gradients and stresses at the bottom end plug (Section 4.2.2). The accuracy of this modeling is dependent on a number of parameters (e.g., mesh and finite element type). Please provide a better description of the finite element model for the end plug. In addition, a stress concentration factor is used to derive the localized stresses at the end plug. Please provide a description of how this stress concentration factor was chosen.

Response 3:

The TAMFEP (Thermal And Mechanical Finite Element Program) code is used within the VIK-3 code to determine the end-plug weld stress according to classical steady state finite element methods. TAMFEP is an extension of the DLEARN educational finite element code developed by T.J.R. Hughes, The Finite Element Method, Prentice Hall, 1987. [

][a, c]. The calculated temperatures, heat fluxes, displacements and stresses of the individual element types have been validated against ANSYS 5.3 using PLANE55 and PLANE42 finite element types. Excellent correlation was found.

A typical end-plug weld finite element mesh used by the TAMFEP code is shown in Figure 3-1 below. The same geometric mesh is used for both the thermal and stress analysis. Note that a section of the pellet stack is modeled. The mesh uses three elements across the thickness of the clad and in the area of interest at the end-plug weld the element aspect ratio is no greater than 2.5. The finite element type, used in both kinds of analyses, is an axi-symmetric 4 node rectangular element. Note that in the stress analysis both the thermal and internal rod pressure loads are considered. The material properties (thermal conductivity, Youngs modulus and Poisson ratio) are considered to be functions of temperature.

The calculated temperatures and stresses of a typical end-plug model have also been validated against ANSYS. The maximum difference in temperature and stress were found to be within 1%. When comparing to the original finite difference model of the end-plug used in VIK-2 a maximum difference of 10% was found. It is Westinghouse's engineering judgement that for the end-plug model the finite element results are more accurate than the finite difference results.

[

][a, c]. This is the same value as used by the VIK-2 code, see Section 4.2.2 of CENPD-285-P-A.

The stress concentration factor derived from an examination of stress concentration factors for an assumed discontinuity groove around the entire circumference is typically between 1.4 and 1.5. [

]^{a,c}.

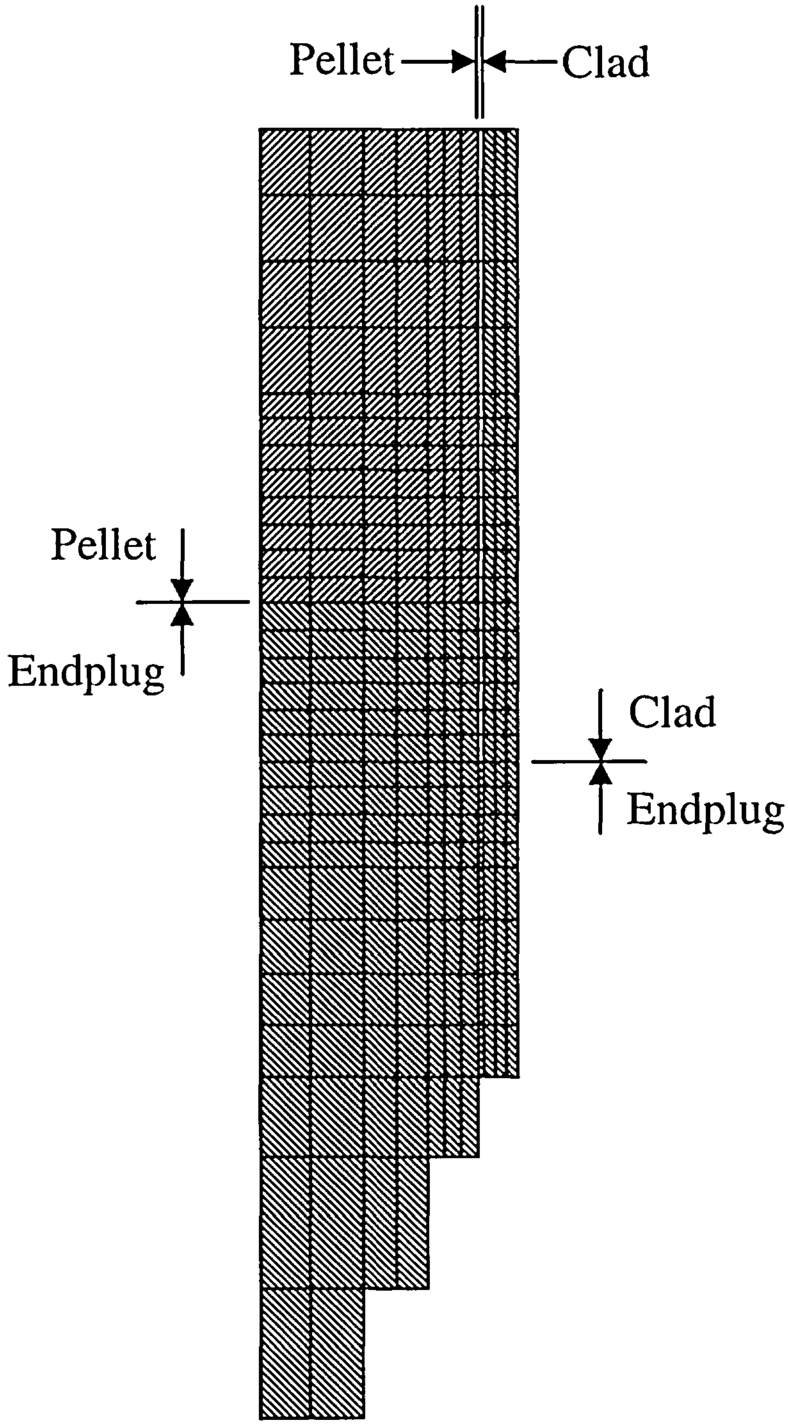

Figure 3-1
Finite Element Mesh used by the TAMFEP Code

VIK-3 RAI Number 4:

The spring force relaxation is calculated in Section 4.1.6 but does not appear to be used in the flow induced vibration or other stress calculations. Is this interpretation correct?

Response 4:

Yes, the interpretation is correct. The spring force relaxation is only used in the conservative calculation of the stress due to axial force from the internal and external springs. It is a component of the total stress as calculated from the list of stress components of Table 4-1 of WCAP-15836-P.

It is assumed that the axial spring force is an independent axial loading and therefore does not impact the stress due to flow induced vibration or other loadings on the clad.

Conservative values for the spring forces are used and it is ensured that the top plate is in equilibrium, i.e., the tie rod has a negative external force and the other (normal and spacer capture) rods have a positive external force, see sample of VIK-3 input.

Note that using the load scale factors described in Table 4-1 the effective stress due to the superposition of oscillating and non-oscillating loads are maximized.

COLLAPS3.3D

COLLAPS3.3D RAI Number 1:

As noted in Question 21 of the STAV7.2 RAIs, the creep model used in STAV7.2 and COLLAPS3.3D appears to be compared to only one average creep diametral measurement per rod for the commercial fuel rods and only one measurement per rod per time step for the Studsvik test rods (Tables C-9 and C-10). For the commercial rods several measurements over the length of each rod should have been performed. Please provide the burnup/fluence level and a comparison of the measured creep diameter change, the STAV7.2/COLLAPS3.3D predicted creep cladding diameter change along the axial position of each rod. If several hundred measurements were made for each rod please average the measurements over a small length, e.g., 6 inches, and provide these values compared to the predicted values.

Response 1:

Response 21 of the STAV7.2 RAIs provides a discussion of the verification data and examples of the requested information.

The cladding creep correlation and uncertainty was calibrated to well characterized individual data measurements. Verification data is not generally pre-characterized. Consequently, each rod may be systematically biased in an unknown direction and amount. Thus, individual measurements in these rods are not as useful as average measurements for the purpose of benchmarking the creep correlation.

COLLAPS3.3D RAI Number 2:

Please provide background information on the Studesvik test rods in Table C-10 such as rod length, fast flux, clad temperatures, stresses and the number of diameter measurements per rod per time step. Please provide comparisons of predicted change in cladding diameters from STAV7.2/COLLAPS3.3D to the measured change in cladding diameters at regular intervals along the length of these rods.

Response 2:

A general discussion of the Studsvik test rods for Table C-10 can be found in Section C.1.2 Studsvik R-2 BWR Irradiation Experiment S268/S269.

Additional requested background information has been extracted. The additional information is provided in the STAV7.2 Response 21. It is noted, however, that the BWR Studsvik rods are short rodlets [

] a,c.

Measured and calculated relative diametral changes are compared in the response to STAV RAI 21.

COLLAPS3.3D RAI Number 3:

The background information on the collapse data (e.g., cladding type, geometry, initial ovality, hoop stresses, etc) in Table 7-1 used to verify and qualify the COLLAPS3.3D model is not provided. Please provide the EPRI NP-3966 document that discusses this data or other applicable documentation that describes this data.

Response 3:

This finite gap analysis is intended to verify the concept of pellet support for various axial gaps by normalizing the predicted collapse time to the measured collapse time for the case with the largest axial gap and smallest collapse time. The increasing conservatism for decreasing gaps demonstrates that the prediction of collapse for finite axial gaps will be conservative. In addition, no instances of clad collapse in the fueled region of BWR fuel has ever been observed.

Background information for Table 7-1 of WCAP-15836-P is provided below.

[ ] a, c

COLLAPS3.3D RAI Number 4:

Please provide examples of how the finite gap length will be determined between pellets in the finite length cladding collapse analysis. The finite length will most likely be determined from the fuel densification but the location of pellet hang-up and other considerations are important in determining the axial gap length.

Response 4:

Measurements of axial gap distribution in Westinghouse BWR fuel rod designs have not been made. Consequently, a conservative estimate of the maximum length of an axial gap will be made.

[

] a,c.

Cladding collapse at the maximum gap lengths will be evaluated at operating conditions existing at the various axial positions.