Westinghouse

Westinghouse Electric Company
Nuclear Services
1000 Westinghouse Drive
Cranberry Township, Pennsylvania 16066
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Direct tel: (412) 374-4643
Direct fax: (724) 720-0754
e-mail: greshaja@westinghouse.com

LTR-NRC-11-15, Rev.1

June 6, 2011

Subject: Response to the NRCs Request for Additional Information RE: Westinghouse Electric Company Topical Report WCAP-16182-P-A, Revision 1, "Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits" (TAC No. ME2630) (Proprietary/Non-Proprietary)

Enclosed are copies of the proprietary/non-proprietary versions of a report titled "Response to the NRC's Request for Additional Information RE: Westinghouse Electric Company Topical Report WCAP-16182-P-A, Revision 1, 'Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits'" provided for information only.

Also enclosed is:

1. One (1) copy of the Application for Withholding Proprietary Information from Public Disclosure, AW-11-3145 (Non-Proprietary), with Proprietary Information Notice and Copyright Notice.
2. One (1) copy of Affidavit (Non-Proprietary).

This submittal contains proprietary information of Westinghouse Electric Company LLC. In conformance with the requirements of 10 CFR Section 2.390, as amended, of the Commission's regulations, we are enclosing with this submittal an Application for Withholding Proprietary Information from Public Disclosure and an affidavit. The affidavit sets forth the basis on which the information identified as proprietary may be withheld from public disclosure by the Commission.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference AW-11-3145 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company LLC, Suite 428, 1000 Westinghouse Drive, Cranberry Township, Pennsylvania 16066.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance

Enclosures
cc: E. Lenning

T007
NRR

Westinghouse

Westinghouse Electric Company
Nuclear Services
1000 Westinghouse Drive
Cranberry Township, Pennsylvania 16066
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Direct tel: (412) 374-4643
Direct fax: (724) 720-0754
e-mail: greshaja@westinghouse.com

AW-11-3145

June 6, 2011

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-NRC-11-15, Rev.1, P-Attachment, "Response to the NRC's Request for Additional Information RE: Westinghouse Electric Company Topical Report WCAP-16182-P-A, Revision 1, 'Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits'" (Proprietary)

Reference: Letter from J. A. Gresham to Document Control Desk, LTR-NRC-11-15, Rev.1, dated June 6, 2011

The Application for Withholding Proprietary Information from Public Disclosure 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-11-3145 accompanies this Application for Withholding Proprietary Information from Public Disclosure, 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 the proprietary aspects of the application for withholding or the accompanying affidavit should reference AW-11-3145 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company LLC, Suite 428, 1000 Westinghouse Drive, Cranberry Township, Pennsylvania 16066.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance

Enclosures
cc: E. Lenning

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF BUTLER:

Before me, the undersigned authority, personally appeared J. 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, Manager
Regulatory Compliance

Sworn to and subscribed before me
this 6th day of June 2011

Renee' Giampole
Notary Public

COMMONWEALTH OF PENNSYLVANIA
NOTARIAL SEAL
Renee Giampole, Notary Public
Penn Township, Westmoreland County
My Commission Expires September 25, 2013

(1) I am Manager, Regulatory Compliance, in Nuclear Services, Westinghouse Electric Company LLC (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 rule making 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 Proprietary Information from Public Disclosure 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 that 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 in LTR-NRC-11-15, Rev.1 P-Attachment, "Response to the NRC's Request for Additional Information RE: Westinghouse Electric Company Topical Report WCAP-16182-P-A, Revision 1, 'Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits'" (Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter, LTR-NRC-11-15, Rev.1, and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse is that associated with the response to the NRC's request for additional information and may be used only for that purpose.

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

(a) Obtain NRC approval for revised design criteria which will allow for extended component life of the Westinghouse CR 99 BWR control rods.

(b) Meet NRC regulatory requirements in support of a Westinghouse product.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of the information to its customers for the purpose of further enhancing their licensing position over their competitors.

(b) Westinghouse can sell support and assist customers to obtain license changes.

(c) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

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 fuel design 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.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

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).

Response to the NRC's Request for Additional Information RE: Westinghouse Electric Company Topical Report WCAP-16182-P-A, Revision 1, "Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits" (Non-Proprietary)

June 2011

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, Pennsylvania 16066

RE: REQUEST FOR ADDITIONAL INFORMATION (RAI) BY THE OFFICE OF NUCLEAR REACTOR REGULATION FOR WCAP-16182-P-A, REVISION 1, "WESTINGHOUSE BOILING WATER REACTOR CONTROL ROD CR 99 LICENSING REPORT - UPDATE TO MECHANICAL DESIGN LIMITS" WESTINGHOUSE ELECTRIC COMPANY PROJECT NO. 700

RAI Question

1. The submittal has not provided helium release or swelling data, nor an adequate description of the data, the following questions request this data and information about this data.

a. Please provide the helium release data for the [ ]^{a,c} B_4C both graphically (on Figure 6-2 of submittal) and tabulated in terms of B_4C temperature and ^{10}B depletion (if the B_4C is different from natural ^{10}B provide the enrichment level).

b. Provide the swelling data for the [ ]^{a,c} B_4C tabulated in terms of B_4C temperature and ^{10}B depletion (if the B_4C is different from natural provide the ^{10}B enrichment level). [ ]^{a,c} Of primary interest for the swelling data is data with at least [ ]^{a,c} percent depletion of natural ^{10}B and greater.

c. If depletion is calculated for items a and b above define the analysis method. Also, denote if each of the release and swelling data are from BWR operation or from another reactor type defining the reactor type.

d. It is assumed that [ ]^{a,c} percent depletion is defined as being [ ]^{a,c} percent of the initial ^{10}B atoms have captured a neutron. Is this interpretation correct?

Answer

1a. The helium release data on which Equation 6.2 and Figure 6-2 of the Revision 1 topical are based, is provided in Table 1 below. Please note that Equation 6.2, Figure 6-2, and their associated References 18 and 19 have not been changed from the information previously submitted and approved by licensing topical report, WCAP-16182-P-A , Revision 0.

Helium release data was extracted from pellets irradiated in [ ]^{a,c}. The temperature in the pellets during irradiation was not measured, but a good estimation of the temperature in the pellets during irradiation is that it is similar to the normal pellet temperature in a CR 99 blade during operation, i.e., [ ]^{a,c} The helium gas release and pressure build-up determination are further explained in Reference 19 and additional information is also provided in the response to RAI questions 4 and 5.

Table 1. ^{10}B depletion and Helium release. Table 1 values are based on Reference 18, BUA 97-023, "Results from Post Irradiation Examination of Absorber Material Containing Boron Carbide", 1997 (proprietary).

[ ]^{a,c}

[ ]^{a,c}

Figure 1. Helium release as function of average ^{10}B depletion.

1b. Pellet swelling data is provided in Table 2 below. The data presented is extracted from pellets irradiated in [ ]^{a,c}. The temperature in the pellets during irradiation was not measured, but a good estimation of the temperature in the pellets during irradiation is that it is similar to normal pellet temperature in a CR 99 blade during operation, i.e., [ ]^{a,c} The presented swelling data is based on density measurements of the pellet after irradiation. Westinghouse uses the name [ ]^{a,c} in the RAI responses to illustrate that the origin of the data is a density measurement. The data is then converted into [ ]^{a,c}, which is representative of the change of the [ ]^{a,c} diameter.

The [ ]^{a,c} calculation is based on [ ]^{a,c} ^{10}B depletion which is a very conservative assumption of [ ]^{a,c} compared with measured data.

Table 2. ^{10}B depletion and **[** **]**^{a,c}

[ ] **a,c**

[ ] **a,c**

Figure 2. Linear swelling as function of average ^{10}B depletion.

1c. All test data are extracted from samples irradiated at **[** **]**^{a,c}. Flux monitoring performed by mass spectrometric analysis of the ratio of ^{10}B to ^{11}B for four samples confirmed the nominal ^{10}B depletion to be **[** **]**^{a,c}, Reference 18 (BUA 97-023).

1d. Yes. The equation defining the ^{10}B depletion is:

[ ] **a,c** **Equation 1**

where:

β is ^{10}B-depletion in %,
N_0 is the initial number of ^{10}B-atoms, and
N is the number of ^{10}B-atoms remaining.

Question

2. The following questions are related to how the gas pressure and swelling is calculated for B_4C [ ]^{a,c}.

a. Provide a copy of Reference 19, Westinghouse Atom Report BTA 03-118, G. Eriksson, Calculation Methodology in predicting Pressure Buildup and Swelling of HIP Boron Carbide Absorber in Westinghouse BWR Control Rod CR 99 for US Reactors with C-, D- and S-Lattice, 2003 (proprietary). This report is needed to understand how helium pressures and swelling are calculated.

b. Describe the assumptions made in determining the internal pressure buildup versus depletion (Eq. 6.6) for each lattice type (D, C, and S).

Answer

2a. Please note that Reference 19 of the Revision 1 submittal is the same Reference 19 (Westinghouse Atom Report BTA 03-118, G. Eriksson, "Calculation Methodology in predicting Pressure Buildup and Swelling of HIP Boron Carbide Absorber in Westinghouse BWR Control Rod CR 99 for US Reactors with C-, D- and S-Lattice") as previously reviewed and approved in CR 99 licensing topical report WCAP-16182-P-A, Revision 0.

Reference 19 is a proprietary report that includes both detailed specific instructions and calculations (i.e., a "CalcNote -like" document). This reference will be made available for staff review at their convenience at Westinghouse's Twinbrook office in Rockville, MD.

2b. The method and assumptions for calculating the internal pressure buildup are the same for all lattice types as described in Reference 19, BTA 03-118. The calculation is based on nominal geometrical data of the absorber blade and B_4C [ ]^{a,c}, including:

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

The [ ]^{a,c} of the [ ]^{a,c} due to irradiation is calculated based on assumption of the same [ ]^{a,c} in all directions. This means that the volume increases by [ ]^{a,c}.

In the calculation, the absorber blade is divided into four axial sections. The internal pressure buildup calculation is performed in each axial section and the results are summed up to get results for the whole absorber blade. Also, a conservative axial depletion profile is chosen based on Westinghouse experience.

Helium temperature is calculated by 2D finite element analysis.

Question

3. Describe how it is determined when a control rod has reached its maximum 10 percent worth decrease. Is this measured or calculated and what are the uncertainties? Page 6-7 states a maximum depletion of [ ]^{a,c} based on the maximum 10 percent decrease in rod worth while page 6-8 denotes a range between [ ]^{a,c}, please explain this difference.

Answer

3. Section 7.3.4, Physics Criterion 4 (PH-4), provides that "The Nuclear End-of-Life (NEOL) for a Westinghouse control rod is reached when its rod worth in any quarter segment decreases to 90% of the initial worth of an OEM control rod in the quarter segment." Thus, the 10% worth decrease at NEOL is reached when the control rod worth (RWD) of any quarter segment has decreased to a value corresponding to 90% of that for a fresh original equipment rod.

[ ]^{a,c} **Equation 2**

The ^{10}B depletion and control rod worth was calculated with the lattice code PHOENIX4 (Reference 26). The uncertainties of these calculations are small, estimated to be lower than 1%.

[ ]^{a,c}

In regards to the differences noted between pages 6-7 and 6-8, the Revision 1 topical report continues to follow the same organization and overall methodology as previously approved in WCAP-16182-P-A (Rev.0). As such, Section 6 describes the control rod Mechanical Evaluation, and all aspects of the Nuclear End-of-Life (NEOL) are treated in accordance with the Physics Evaluation described in Section 7.

Also as described in the Revision 1 topical, the criterion of a Mechanical End-of-Life (MEOL) that exceeds the Nuclear End-of-Life (NEOL) is considered to be met. Hence, the ^{10}B depletion limit "at the defined nuclear end of life (NEOL)" is used for the control rod mechanical evaluations that are described on pages 6-7 and 6-8.

Since the limiting load case consists of both scram force and load from the internal pressure that is a function of the ^{10}B depletion. The range of acceptable average ^{10}B depletion levels of [ ]^{a,c} reflects the different scram forces in the D-, C- and S-lattice reactors. The S-lattice reactors have the highest scram load, thus limiting the ^{10}B depletion to [ ]^{a,c}

Question

4. What is the operating temperature range of the B_4C in the CR 99 design at full power operation?

5. Please provide the primary stresses due to rod pressures at the blade outer wall, edge outer wall and ligament between holes. Of concern is whether creep of the 316 SS is significant at these locations.

Answer

4. & 5. The load that can trigger creep in the absorber blade is the internal Helium pressure, which is strongly dependent on depletion of the ^{10}B in the absorber [ ]^{a,c}. The variations of Helium pressure are shown in Figure 6-3 between [ ]^{a,c} (beginning of life) to [ ]^{a,c} (end of life). The primary membrane stress in the absorber blade locations for end of life and the temperature range at the absorber blade locations are given in Table 3 and Table 4 below.

Table 3. Calculated primary membrane stress in absorber blade at end of life, D- and S-lattice.

Position in absorber blade	Primary membrane stress (MPa)	Temperature Max/min (°C)
Outer wall	[ ]^{a,c}	[ ]^{a,c}
Outer edge	[ ]^{a,c}	[ ]^{a,c}
Ligament	[ ]^{a,c}	[ ]^{a,c}
B_4C		[ ]^{a,c} [ ]^{a,c}

Table 4. Calculated primary membrane stress in absorber blade at end of life, C-lattice.

Position in absorber blade	Primary membrane stress (MPa)	Temperature Max/min (°C)
Outer wall	[ ]^{a,c}	[ ]^{a,c}
Outer edge	[ ]^{a,c}	[ ]^{a,c}
Ligament	[ ]^{a,c}	[ ]^{a,c}
B_4C		[ ]^{a,c} [ ]^{a,c}

[

]^{a,c}

[

]^{a,c}

The measured long term steady state creep data for AISI 316L at a temperature of 550°C and higher are given in "Creep of the austenitic steel AISI 316L – Experiments and Models -", M. Rieth et. al. Forschongszentrum Karlsruhe GmbH, Karlsruhe (ISSN 09047-8620, urn:nbn:de:0005-070657). For the calculated stresses in the absorber blade, the creep strain rate is lower than 10^{-9}/hr at temperature 550°C. The creep rate is strongly temperature dependent and is therefore of no concern.

Question

6. Equation 6.21 is the criterion for maintaining the hole wall gap spacing [ ]^{a,c} Examination of this equation appears that this is for the gap spacing at hot full power operation including the effect of thermal expansion of the B_4C rod.

a. Is this understanding of the equation correct? If not correct, please provide a further explanation, particularly in relation to the concerns identified in items b and c below at the higher depletion levels requested.

b. No criterion was found to prevent gap closure [ ]^{a,c} This cycling [ ]^{a,c} could lead to fatigue fracture [ ]^{a,c} Shouldn't a criterion exist to prevent hard contact [ ]^{a,c} Please provide a justification for no criteria [ ]^{a,c}

c. The middle of page 6-16 quotes a larger minimum gap for cold conditions than that for hot conditions. Please provide an explanation on why the cold gap is larger even though the stainless steel expands a greater amount than the B_4C at hot conditions.

Answer

6a. Yes, Equation 6.21 is applicable to full power and includes thermal expansion and swelling at the Mechanical End-of-Life (MEOL).

6b. "The rod is designed so that [ ]^{a,c} during rod lifetime," meaning unconditionally that [ ]^{a,c}. This criterion is not written as an equation but is stated in the sentence that immediately follows Equation 6.14.

6c. The minimum gap under cold conditions as stated in the Revision 1 topical report is not correct. The correct value is [ ]^{a,c} instead of [ ]^{a,c}. This value will be corrected in the final approved "A" version of the topical report.

Question

7. Please define an inspection program for the CR 99 including when the scope and depletion level at which inspections will take place. Because no deformation is expected due to B_4C swelling, define further inspection plans if deformation is observed from non-destructive examinations.

Answer

7. Westinghouse performs monitoring of leading control rods of its different designs with, at minimum, visual inspections. Additionally, Westinghouse has profilometry equipment that is used in pool-side examinations to measure and quantify the deformation of the blade wing, in the event that [ ]^{a,c} between the boron carbide and the stainless steel wall occurs.

CR 99 control rod blades of the earlier 2nd generation, which were designed with less volume to accommodate boron carbide swelling than the present 3rd generation design here under review, have been irradiated within a follow up program in the [ ]^{a,c} to exposures at the top node corresponding to end of life. These experiences correspond to [ ]^{a,c} cycles for a control rod operated in typical, power control in US reactors; i.e., for 2 three month periods during each 24 month cycle. These CR 99s have been inspected and profilometry have been performed. It has been shown that although local ^{10}B depletion [ ]^{a,c} has been reached and blade wing cracks have appeared, there is no loss of boron carbide absorber material. This demonstrates the improved defense in depth of the [ ]^{a,c} feature, besides the long time proven concept of horizontally drilled holes retaining the absorber material in case of crack appearance.

The 3rd generation CR 99 has a significantly increased free volume to accommodate [ ]^{a,c} of the absorber material. [ ]^{a,c} is avoided by design. Leading control rods of the 3rd generation CR 99 are operated in the BWR [ ]^{a,c}. These control rods have, this far, been operated deeply inserted for [ ]^{a,c}. Since the exposure rate in the [ ]^{a,c} reactors are comparatively higher than in US BWRs, [ ]^{a,c} thus far corresponds to more than [ ]^{a,c} 24 month cycles in power regulation in most US BWRs. These 3rd generation CR 99s have been visually inspected, showing the expected results of no defects. .

Additionally, the previously performed high burn up program on the 2nd generation CR 99 control rods has demonstrated the benefits with the [ ]^{a,c} design.

The 3rd generation CR 99 with the increased free volume can be considered proven for operation [ ]^{a,c} due to good operating experience from both 2nd generation CR 99 (in general) and 3rd generation CR 99 in the [ ]^{a,c}. Westinghouse, together with its customers, is continuing to track highly irradiated control rods to confirm the good behavior.

Question

8. Further description is needed for the finite element analysis (FEA) models used to demonstrate the stress limits are met for the CR 99 design.

a. Provide a list of all the FEA models referenced in WCAP-16182-P-A, Rev.1. For each model, briefly describe its purpose, loading conditions, model assumptions, and key results (such as stress results).

b. Confirm that all FEA modeling was done in ANSYS, or note any analyses that were performed utilizing some other general-purpose FEA code.

Answer

8. All finite element calculations are done using ANSYS. Descriptions of the models and assumptions are given in answers to question 10, where the model is explained parallel to the geometry. The following files are used:

C-Lattice files

- Mod3s.inp
  Build a 3D model of the absorber blade at a hole that is used to calculate mechanical stresses.

- Ldcase_x.inp
  Apply pressure load and scram load on the model. This file calls on Loading3dtol.inp that applies pressure loads on the geometry.

- Wall_area_strs.inp
  Calculate stress in the wall.

- Lig_area_strs.inp
  Calculate stress in ligament.

- Ltemp.sym,inp
  Build a 2D model of the absorber hole that is used to calculate temperatures in blade, absorber pins and Helium gas.

- Bound.inp
  Apply periodic boundary conditions on the 2D temperature model.

- Gstress.inp
  Convert temperature model into stress model, applying boundary conditions and calculates thermally induced stresses.

- C-Lattice-ANSYS-WB
  Model in ANSYS Work Bench 12.1 in which the blade at an absorber hole is analyzed. All load combinations are applied in the model.

- Handle C-Lattice US
  Model in ANSYS Work Bench 12.1 in which the handle is analyzed.

S- and D-Lattice files

- Mod3s.inp
  Build a 3D model of the absorber blade at a hole that is used to calculate mechanical stresses.

- Ldcase_x.inp
  Apply pressure load and scram load on the model for load case x. This file calls on Loading3dtol.inp that applies pressure loads on the geometry.

- Plstrs.mac
  Use paths to calculate stresses in wall and ligament.

- Ltemp.sym,inp
  Build a 2D model of the absorber hole that is used to calculate temperatures in blade, absorber pins and Helium gas.

- Bound.inp
  Apply periodic boundary conditions on the 2D temperature model.

- Gstress.inp
  Convert temperature model into stress model, applying boundary conditions and calculates thermally induced stresses.

- S-Lattice-ANSYS-WB
  Model in ANSYS Work Bench 12.1 in which the blade at an absorber hole is analyzed. All load combinations are applied in the model.

- Handle D-Lattice US
  Model in ANSYS Work Bench 12.1 in which the handle is analyzed.

Question

9. Provide a complete set of input and output files for each of the FEA models. As an alternative to providing input and output files for review in a written response, an on-site audit of the FEA calculations with full interactive access to the models and results for the reviewers could also achieve the same objective.

Answer

9. Westinghouse will make input and output files of the FEA analysis available for NRC staff review as part of an audit.

Question

10. The geometry of the CR 99 and the FEA modeling are not clear in the submittal.

a. Provide detailed drawings or sketches that describe the geometry of the control blade structure. The reviewers request drawings with enough geometry and annotation to explain the basic shape of the stainless steel components, including the geometry of the control rod blade central axis and control blade wing connection regions. One specific request is a horizontal cross section view through a control blade wing, with major dimensions and radii noted that are important in the stress analysis. Also, provide drawings or sketches that clarify the size, location, and orientation of the B_4C absorber relative to the control blade geometry.

b. Explain and justify the symmetry assumptions and the particular geometry used in the FEA models. Figure 6-4 appears to be a half-symmetry model of a single absorber hole, sectioned horizontally through a control blade wing. However, the original document (WCAP-16182, Rev. 0) indicates that [ ]^{a,c} so it is not clear which absorber hole was chosen for analysis or why it was chosen. [ ]^{a,c}

Answer

10a. Shown below are examples of CR 99 outline drawings, detailed sketches of a horizontal cross section, and the corresponding dimensions for CR 99 control rods with 7 mm and 8 mm blade wing thickness.

a,c

Figure 3. Outline drawing 7 mm blade wing thickness

a,c

Figure 4. Horizontal cross section 7 mm blade wing thickness

Table 5. Dimensions for 7 mm blade wing thickness

a,c

a,c

Figure 5. Outline drawing 8 mm blade wing thickness

a,c

Figure 6. Horizontal cross section 8 mm blade wing thickness

Table 6. Dimensions for 8 mm blade wing thickness

a,c

10b. Model of absorber blade:

The load on the absorber blade consists of two types:

1. Internal Helium pressure, which has the same magnitude in all holes for the absorber [ ]^{a,c} (communicating pressure vessel), and

2. Scram forces, which are assumed to result in constant acceleration in the control rod. This assumption makes it possible to scale the scram force in a cross section of the blade as a function of the total mass above the cross section.

The definition of these loads results in the conclusion that for a constant hole depth, the critical cross section is the one with the largest mass above the cross section. Any contribution to the cross section area by the shoulders at the central axis of the control rod is neglected.

If the number of hole depths in the blade layout are X, X number of possible critical cross sections can be identified. Every possible critical cross section is investigated by estimation of the primary membrane stress caused by internal Helium pressure and scram force. This estimation is calculated by:

[ ] **a,c** **Equation 3**

Where P_{He} is the internal Helium pressure, D the diameter of the hole, L the hole length and A_i the area of the cross section i. $F_{scram,i}$ is calculated by:

[ ] **a,c** **Equation 4**

Where F is the specified scram force at the coupling, M the mass of the control rod and M_i the mass above cross section i.

The cross section with largest P_m is identified as the critical cross section. This cross section is modeled and analyzed with the finite element system ANSYS.

Conservative geometry assumptions are used in the finite element model. Tolerances are chosen so that a minimum cross sectional area is used, with minimum blade thickness, maximum hole diameter and length, and maximum shoulder height. Minimum specified ligament thickness is used in the finite element model and the cross section through the ligament is constrained to constant axial deformation. The cross section through the absorber hole is constrained to zero axial deformation. These constraints are used because the critical load combination is scram force superimposed to internal Helium pressure.

Geometry of the CR 99 S-Lattice control rod:

Figure 7 and Figure 8 are shown in order to explain the finite element model used in the calculations of the absorber blade.

a,c

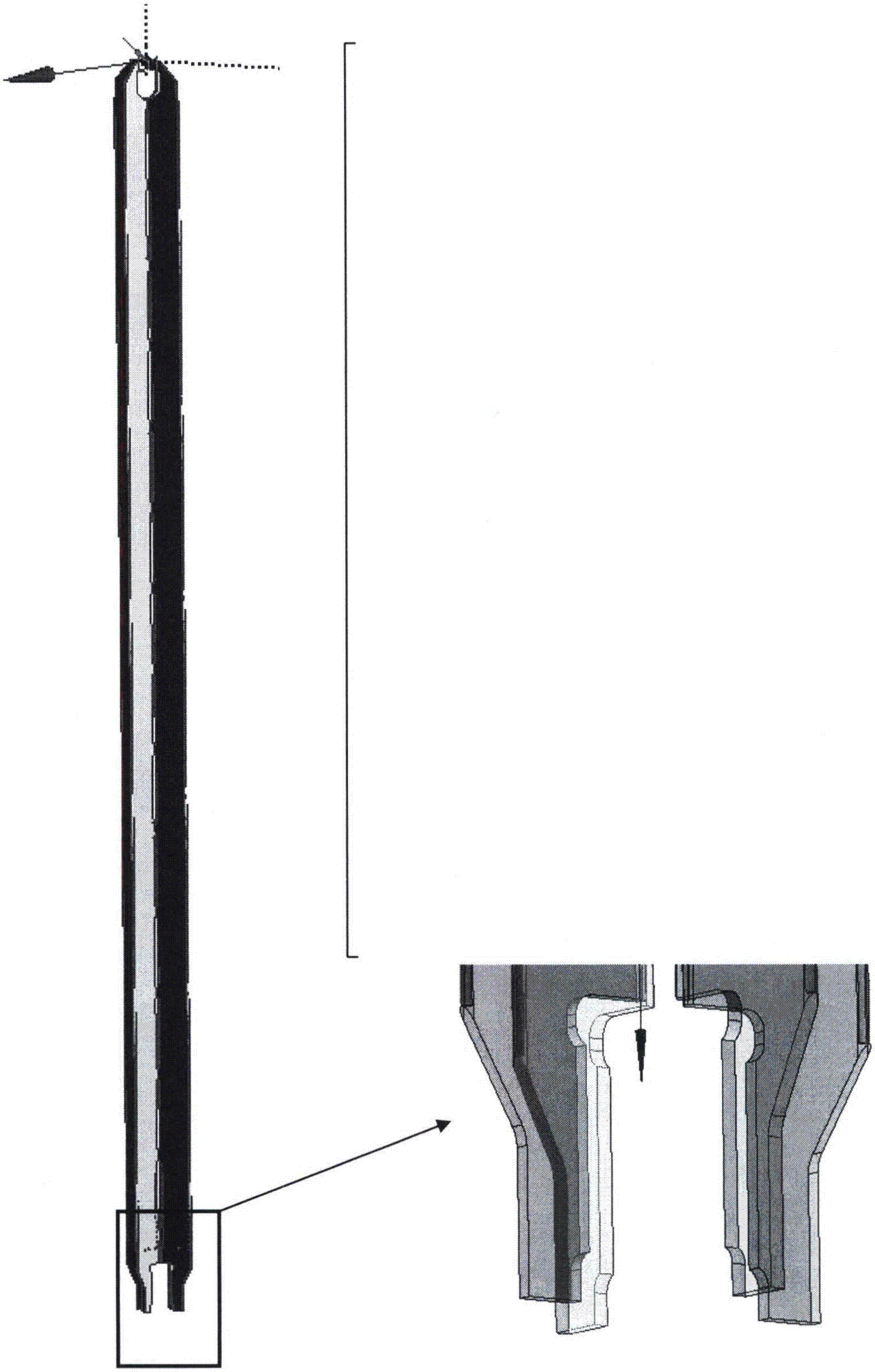
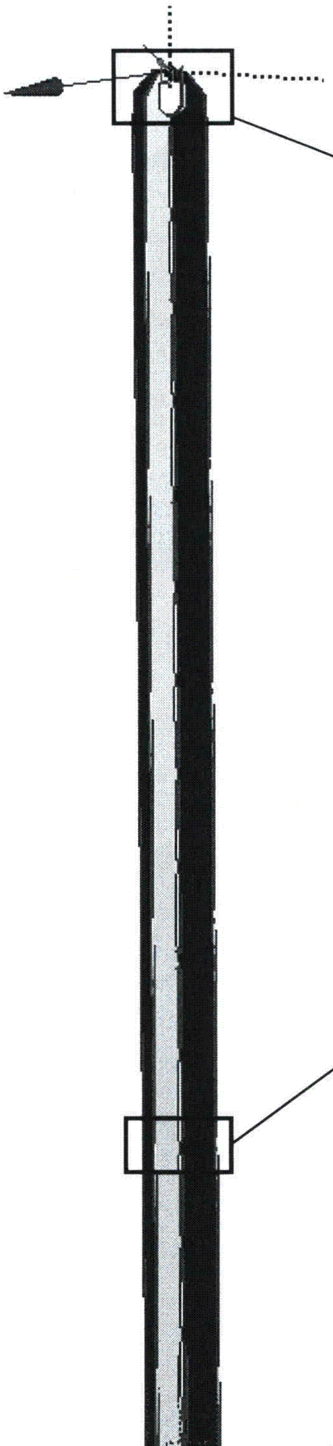
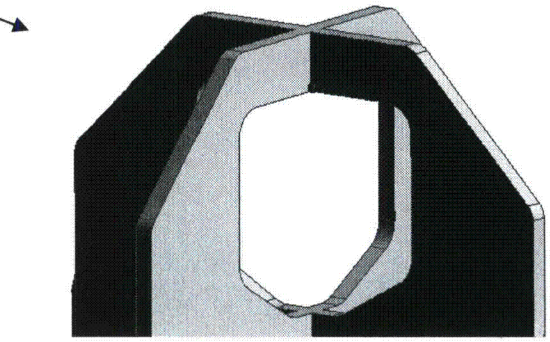


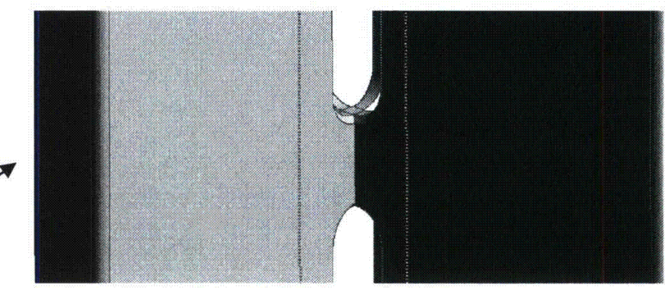
Figure 7. Finite element model used for the absorber blade stress calculations.



The handle is of standard design, with single or double handles, and evaluated separate. The double handle design is shown.



Shoulders are welded, forming a control rod of four absorber blades. Scram force and/or internal Helium pressure give neglectible stresses in the shoulders.



The weld between absorber blade and velocity limiter is evaluated for scram forces. This is done by calculating the primary membrane stress as

[ ]**a,c** **Equation 5**

Where A_{weld} is the cross sectional area of the full penetration weld between the absorber blade and the velocity limiter.

Figure 8. Finite element model used for the handle stress calculations.

Question

11. Discuss the degree to which helium adheres to the ideal gas law in the anticipated temperature and pressure range. Estimate the potential variation between the calculated pressures based on ideal gas and realistic pressures, and demonstrate that the control blade stress evaluations are not sensitive to this potential variation.

Answer

11. The ideal gas law is written as:

$$P \cdot V = n \cdot R \cdot T \qquad \textbf{Equation 6}$$

Van der Waals' modification of the ideal gas law is a more realistic gas law and is written as:

$$\left(P + a\frac{n^2}{V^2}\right)(V - n \cdot b) = n \cdot R \cdot T \qquad \textbf{Equation 7}$$

Where the constants take the values a= 3.46×10^{-3} Pa m^6/mol^2 and b=23.71×10^{-6} m^3/mol for Helium gas.

The pressure, *P*, is calculated for C- and D-/S-Lattice with van der Waals' equation. The number of moles of Helium, *n*, and free volume, *V*, is the same as used in the pressure calculation with the ideal gas law. The results are presented in Table 7 below.

Table 7. Comparison between ideal gas law and van der Waals' gas law

Lattice	P (MPa) Ideal gas law	Moles Helium	Free volume (m^3)	Temperature (°K)	P (MPa) Van der Waals eq.
C	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}
D and S	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}

These calculations are based on a very conservative assumption of [ ]^{a,c} ^{10}B depletion. [ ]^{a,c} A more realistic Helium pressure based on van der Waals' equation and measured [ ]^{a,c} is presented in Table 8.

Table 8. Helium pressure based on [ ]^{a,c} ^{10}B depletion

Lattice	Moles Helium	Free volume (m^3)	Temperature (°K)	P (MPa) Van der Waals eq.
C	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}
D and S	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}	[ ]^{a,c}

The conclusion is that the Helium pressure calculation based on [ ]^{a,c} ^{10}B depletion and ideal gas law results is a conservative estimation of the Helium pressure. Westinghouse concludes that the calculated design Helium pressures presented in the topical report are conservative.

Question

12. The following relates to satisfying Mechanical Criterion 5 (ME-5, Section 6.4.5). Both Rev. 0 and Rev. 1 of WCAP-16182-P note that control rod insertion during a seismic event is a function of control rod moment of inertia (MOI) and bending stiffness.

a. Precisely define control rod moment of inertia (MOI) as it is used as the figure of merit for ME-5. The actual cross-sectional area moment of inertia of the control rod varies along its length, so it is not clear how a control rod can be classified with a single moment of inertia value. Is this an average MOI taken along the full length of the control rod, how is it calculated? Does this MOI represent the control rod at room temperature or operating conditions?

b. No mention is made on whether the bending stiffness has changed and if so what is the degree of change. Provide a discussion on changes in the bending stiffness. How is the bending stiffness determined for the CR 85 and revised CR 99 to determine their relative stiffness differences? Provide a discussion on whether the increased stress levels in the wing in the revised CR 99 impact bending stiffness.

Answer

12. The moment of inertia (MOI) is a geometrical property of a cross section. For a cross section of arbitrary shape the definition is:

$$I = \int_A l^2 dA$$

where l is the length from the axis of interest to the infinitesimal area element. In classic beam bending problems the MOI is used in the calculation of the stress as:

$$\sigma = \frac{M}{I} t$$

where t is the distance from the neutral axis of the beam to the point where the stress is calculated and M is the applied moment.

The control rod moment of inertia (MOI) is calculated for the active zone of the control rod in which the holes for [ ]^{a,c} are placed. This zone covers most of the blade length. The MOI for this section determines the bending stiffness of the control rod. Sections outside this zone have minor influence on the bending stiffness.

The control rod is exposed to thermal cycling from 85°C to approximately 300°C. The CTE for stainless steel 316L is approximately 16×10^{-6} -/°C which means that the thermal strain during the cycle is 0.34%. This means that the width of the control rod blade typically change from 250 mm to 250.8 mm which has negligible influence on the MOI.

The MOI is calculated in accordance with beam theory. An equivalent thickness of the blade is calculated for a solid blade, which results in the same bending stiffness as the absorber blade. The equivalent thickness is calculated according to:

[ ]a,c **Equation 8**

[ ]a,c **Equation 9**

t Absorber blade thickness
d diameter of hole
p pitch between holes
t_{eq} equivalent thickness
C Parameter that is calibrated against test results

A three point bending test of Japanese control rods very similar to C-, D- and S-Lattice is used to calibrate the parameter C. This calculation is performed for the reference control rods CR 85 and the control rods for C-, D- and S-Lattice. The calculated MOI depends on the layout of the control rod, but typical results are given in Table 9 below.

Table 9. Typical calculated MOI for CR 99 and comparison with reference control rod CR 85.

Lattice type	CR 99 MOI	CR 85 MOI
C- Lattice	[ ]a,c	[ ]a,c
D-Lattice	[ ]a,c	[ ]a,c
S-Lattice	[ ]a,c	[ ]a,c

The increased stress level in CR 99 control rods depends mainly on higher allowed Helium pressure. The influence of Helium pressure on bending stiffness is low and therefore negligible.

Question

13. For Operational Criteria 2, describe the range of acceptable deviation from the nominal weight. Also describe the basis for this range.

Answer

13. The weight of Westinghouse Sweden Engineering control rods are limited to the same maximum level as the OEM (Original Equipment Manufacturer) control rods. Maximum weights are defined for the control rods to the D-, C-, and S-lattice reactors.

The nominal weight is due to the design with blade wings in solid stainless steel close to the max allowed weight. The nominal weight differs slightly relative to the maximum weight for the different control rods. The highest difference corresponds to 3.5% of the nominal weight. The minimum weight, which is basically defined by the geometrical dimensional requirements, is related to the nominal weight by a maximum difference of 2.5%. Thus the range of acceptable deviation from the nominal weight is +3.5% to -2.5%.

Question

14. For Operational Criteria 1, 3, 4, 6, and 7, explain in more detail how the CR 99 control blade relates to the extensive database of experience. For example, OP-6 states "Extensive database of experience has shown that the design meets this criterion, i.e., scram times for Westinghouse control rods are within the experience base (and meet Technical Specification times) of the reactors into which they have been installed." It is assumed that this statement is not referring to direct experience with CR 99 C-, D-, and S- lattice blades, but rather the CR 99 blades are comparable to other successful designs that comprise the extensive database. Provide a discussion of the differences in the most relevant past designs with CR 99 along with the number of blades irradiated, their maximum length of time in-reactor, and depletion level.

Answer

14. The first Westinghouse BWR control rods were installed in US BWRs in the mid-1980s. Many of these control rods are still in operation thus demonstrating the performance and compatibility of these designs for over 25 years.

Since then more than 1500 Westinghouse BWR control rods have been operated in US reactors of D-, C- and S-lattice types. Furthermore, another 200 Westinghouse BWR control rods have been operated in reactors built by GE outside of the US. All these control rods, irrespective of type CR 99, CR 82M-1, etc., have had the same outer dimensions and geometry within the groups of D-, C- and S-lattice reactors. The difference between the types is mainly defined by the cross sectional outline of the absorber material inside the blade wings. Thus for the reviewed CR 99, compatibility with operation in GE BWR reactors is proven by the large amount of successfully operated control rods.

Question

15. Justify the new design stress limit defined in Section 6.3.1, considering the change to [ ]^{a,c}

This appears to be a less conservative stress limit than the one based [ ]^{a,c} and previously approved in WCAP-16182-P-A, Rev. 0. Explain the need for two separate definitions of Sm in this document and explain how the two are implemented.

Answer

15. The [ ]^{a,c} (Section 6.3.2 in WCAP-16182-P-A, Revision 1) is intended to be used for hand calculation of areas where Westinghouse knows from experience that the margin is large. Hand calculation is less accurate than results from finite element calculation and Westinghouse therefore uses larger margins in those calculations. For consistency with previous design requirements, the limits previously approved in Revision 0 of the CR 99 licensing topical report are also retained as an alternative that may be used with the more conservative maximum shear stress theory (Tresca). The idea being that the current licensing analyses of various control rod handle designs and the standard part of the control rod below the absorber zone should remain valid.

The [ ]^{a,c} (Section 6.3.1 in WCAP-16182-P-A, Revision 1) is intended to be used in combination with finite element calculations. This criterion is written based on knowledge of results from collapse analysis of the absorber blade according to [ ]^{a,c} and the [ ]^{a,c}.

[ ]^{a,c} and defines the allowable stress for primary membrane stress to:

[ ]^{a,c} **Equation 10**

[ ]^{a,c} The proposed definition of [ ]^{a,c} limit in WCAP-16182-P-A, Revision 1, is more conservative than [ ]^{a,c}.

Collapse analyses of the absorber blade based on models similar to the model shown in WCAP-16182-P-A, Revision 1, Figure 6-4 typically show that a load combination of internal pressure and scram loads results in margin similar to that predicted by the proposed [ ]^{a,c}. These collapse analyses are based on [ ]^{a,c}, which is known to agree well with observed plastic behavior of steels.