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LTR-NRC-12-48

June 21, 2012

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

Enclosed are the proprietary and non-proprietary versions of, "Response to the NRC's Request for Additional Information on WCAP-16182-P-A, Revision 1, 'Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits.'"

Also enclosed is:

1. One (1) copy of the Application for Withholding Proprietary Information from Public Disclosure, AW-12-3502 (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-12-3502, and should be addressed to J. A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, Suite 428, 1000 Westinghouse Drive, Cranberry Township, Pennsylvania 16066.

Very truly yours,

[signature] /for

J. A. Gresham, Manager
Regulatory Compliance

Enclosures

cc: E. Lenning
A. Mendiola

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NRR

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AW-12-3502

June 21, 2012

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-NRC-12-48 P-Attachment, "Response to the NRC's Request for Additional Information on 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-12-48, dated June 21, 2012

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 information 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-12-3502 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-12-3502, and should be addressed to J. A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, Suite 428, 1000 Westinghouse Drive, Cranberry Township, Pennsylvania 16066.

Very truly yours,

B. F. Maurer, Manager
ABWR Licensing

Enclosures

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF BUTLER:

Before me, the undersigned authority, personally appeared B. F. Maurer, 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:

B. F. Maurer, Manager
ABWR Licensing

Sworn to and subscribed before me
this 21st day of June 2012

Cynthia Olesky
Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Cynthia Olesky, Notary Public
Manor Boro, Westmoreland County
My Commission Expires July 16, 2014
Member, Pennsylvania Association of Notaries

(1) I am Manager, ABWR Licensing, 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-12-48 P-Attachment, "Response to the NRC's Request for Additional Information on 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-12-48, 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 Westinghouse's request for NRC approval of WCAP-16182-P-A, Revision 1, and may be used only for that purpose.

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

(a) Obtain NRC approval of WCAP-16182-P-A, Revision 1, "Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits."

(b) Extend the mechanical life time of Westinghouse BWR control blades.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of this information to its customers for the purpose of assisting in obtaining license changes.

(b) 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).

Copyright Notice

Response to NRC Request for Additional Information on WCAP-16182-P-A, Revision 1, "Westinghouse BWR Control Rod CR 99 Licensing Report - Update to Mechanical Design Limits" (Non-Proprietary)

June 2012

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

<u>Follow-up RAI-1, Follow-up to RAI-1a and RAI-11 on helium release and control rod pressure</u>

[ ]^{a,c} release data points have been provided to justify the helium release fraction as defined by Equation 6.2 of the submittal. This equation has very little conservatism in relation to the small amount of release data provided. Traditionally the NRC has required the pressures in fuel rods to be calculated from a 95/95 upper bound tolerance. The helium release calculated from Equation 6.2 is approximately a factor of [ ]^{a,c} than the 95/95 bounding value from the [ ]^{a,c} (assumes [ ]^{a,c} degrees of freedom) data provided. Please justify (based on data comparisons) why the rod pressures calculated for the CR-99 design are conservative particularly given the response to RAI-11 that suggests that the ideal gas law [ ]^{a,c} rod pressure for the CR-99 design and the use of [ ]^{a,c} for calculating initial void volume (response to RAI-2b). Also see RAI-17 below and RAI-18 that suggests the proposed B_4C pin swelling model is significantly lower than the traditional 95/95 upper bound that will not result in a 95/95 lower bound on void volume with ^{10}B depletion.

<u>Response to Follow-up RAI-1</u>

To justify the conservatism of the model presented in the topical report, Westinghouse performed a Monte Carlo analysis to determine the helium pressure in the Westinghouse CR99 control rod at a 95/95 upper bound tolerance. The analysis is based on an extended database of experimental measurements for fractional helium release and solid swelling as shown in Table 1-1.

Table 1-1: Extended Database of Helium Release and Solid Swelling

	Number of data points WCAP-16182-P-A, Rev 1	Number of data points Extended database
Fractional Helium release	[ ]^{a,c}	[ ]^{a,c}
Solid swelling	[ ]^{a,c}	[ ]^{a,c}

Based on this extended database of measured fractional helium release and solid swelling, two models, a best estimate model and conservative model, for fractional helium release and for solid swelling were developed based on a minimization of a chi-square function.

Development of the mathematical models for solid swelling and fractional helium release

Mathematical optimization of parameter values against the database is used to calculate values for both a best estimate (BE), and 95/95 upper bound model (UB 95%). The functional form of the equations used to fit to the experimental data is presented in Table 1-2.

Table 1-2 Equations used to describe the fractional helium release and solid swelling in the Monte Carlo method

Model	Equation	Fitting Parameters	Comments
Fractional helium release	[		
Solid swelling			]a,c

Where:

[

]a,c

Both fractional helium release and solid swelling are assumed to be described by normal distributions. The constant bias used in the fractional helium release model makes it possible to formulate the normal distribution of the parameters with the mean value and standard deviation. The fitting parameter values are provided in Table 1-3.

Table 1-3 Calculated fitting parameter values for individual absorber pins

a,c

[

]

The solid swelling is more complicated and must be represented by a non-linear function. In this case the variation of the solid swelling is described by a normal distribution with a mean value of zero and standard deviation σ=1. The variation of the fitting parameter values as a function of the normal distribution are plotted in Figure 1-1 and approximations are given by the following equations:

a,c

[

]

The factor [ ]^{a,c} is used to achieve the UB 95% confidence level ([ ]^{a,c} points in database).

a,c

Figure 1-1 Fitting Parameter variation as a function of upper bound level measured as a function of a variation with mean value zero and standard deviation σ=1. Data points from mathematical optimization and the approximation of the variation, solid line. No confidence level bands are provided in the plots.

A comparison between the individual models and the measurement database are presented in Figures 1-2 and 1-3. The sample standard deviation is calculated as:

$$Sample\_stndard\_deviation = \frac{UB95\% - BE}{1.6449}$$

.

a,c

Figure 1-2 Fractional helium release models and database.

a,c

Figure 1-3 Models of solid swelling and database.

Method for calculation of the helium pressure

The method for calculating the helium pressure is based on the [

]^{a,c}

V is the free volume,

P is the internal gaspressure,

R is the universal gas constant, 8.314 J/mole, K

T is the absolute gas temperature, K

n is the number of released moles of internal gas

The helium pressure calculations are performed for each hole of the Westinghouse CR99 control rod. The equations developed to describe the fractional helium release and solid swelling of the Hot Isostatic Pressed (HIP) B_4C pins are described in the subsequent section.

Due to the non-linear relationship between fractional helium release, solid swelling and helium pressure in the [ ]^{a,c} a Monte Carlo simulation was performed to find the upper bound 95% helium pressure. The Monte Carlo simulation calculated the helium pressure 5000 times using a random normal distribution of fractional helium release and solid swelling as described in Table 1-3 and the equations of parameters D_1 and D_2 for each absorber pin, (95% confidence level).

Definition of two examples

The method for calculating the helium pressure presented in WCAP-16182-P-A, Rev 1 is compared with the Monte Carlo method presented above through the use of two examples of the helium pressure calculation. Critical geometries of the CR 99 blades wings used in the calculations are given Tables 1-4 and 1-5. The control rod geometry in Example 1 and Example 2 describes typical D- and S-Lattice CR99. Example 1 includes 36 empty holes at the top resulting in larger free volume in the control rod and thus lower helium pressure. These two examples show the upper and lower limit of the helium pressure in a D- and S-lattice control rod.

Table 1-4: Geometry definition Example 1

a,c

[ ]

Table 1-5: Geometry definition Example 2

a,c

[ ]

Comparison between the Monte Carlo method and WCAP-16182-P-A, Rev 1 method

The helium pressure is calculated for a control rod ^{10}B average depletion of [ ][a,c]. The depletion profile used in the example calculation is a profile known to generate the highest helium pressure for a given control rod average ^{10}B depletion. The average temperature of the helium gas is [ ][a,c].

The results of the comparison between the Monte Carlo method and the WCAP method are shown in Table 1-6. Additionally, Figure 1-4 provides the distribution of results from the Monte Carlo calculations. The method presented in WCAP-16182-P-A, Rev 1 calculates higher helium pressures than the Monte Carlo method. The conclusion of the example calculations is that the method presented in WCAP-16182-P-A, Rev 1 is very conservative when compared to a Monte Carlo method at a 95/95 level.

Table 1-6 Comparison of calculated helium pressure

	Method WCAP-16182-P-A, Rev. 1	Monte Carlo Method (95/95)	Difference
Example 1	[		
Example 2			] a,c

a,c

Figure 1-4 Helium pressure variation from Monte Carlo simulation. At left Example 1 and at right Example 2.

Follow-Up RAI-2

The recent paper by G. Ledberger, P. Seltborg and B. Rebensdorft "Mechanical Performance of the Westinghouse BWR CR 99 Control Rod at High Depletion Levels", presented at the 2011 Water Reactor Fuel Performance Meeting in Changdu, China notes that cracking has been observed in the Generation 2 CR 99 design. The subject topical report states that the Generation 3 CR 99 was a redesign of Generation 2 to provide additional volume to prevent contact between the B_4C pins and the blade wall. There are three concerns associated with the analyses presented in the current submittal for the Generation 3 CR 99 design:

1) **The analysis of gap size appears to be based on the same upper bound B_4C pin swelling model used for Generation 2 design that resulted in gap closure and cracking,**

2) **See Item 3 below that suggests the upper bound swelling model does not meet the traditional 95/95 upper bound traditionally used for licensing analyses, and**

3) **The depletion limit for Generation 3 appears to be in terms of average ^{10}B depletion [ ]^{a,c} while the paper notes that peak local ^{10}B depletion can be considerably higher than the average resulting in peak swelling significantly higher than the average depletion level. This paper further notes that cracking first appeared in the locations of peak depletion. Please explain why a limit should not be established for a peak depletion level in the CR 99 Generation 3 control rod in addition to an average depletion. Did the peak depletion locations in Generation 2 [ ]^{a,c} ^{10}B depletion?**

Also, from this paper it appears that free (non-constrained) swelling has been measured in the KKL pins but this swelling data has not been discussed in this submittal, please discuss this data in relation to the relevance to this submittal.

Response to Follow-up RAI-2

The solid swelling model is used for CR 99 Generation 2 and 3 when analyzing the pin to blade gap. In WCAP-16182-P-A, Rev 1 a [ ]^{a,c} (Eq. 6.12 and 6.13). The data in Figure 1-3 shows that this is a very conservative assumption. This criterion is used to verify that a 100% density boron carbide pin cannot grow into contact with the blade.

However, as boron is self-shielding, the boron carbide pins have a diametrical depletion profile with the highest depletion at the surfaces and the lowest depletion at the center. This means that the solid pin swelling follows the same profile, i.e., the outer surface of the pins have higher solid swelling compared with the inner parts. This solid swelling profile results in compressive tangential stress at the surface and tensile stress in the inner part of the pins. When critical compressive stress at the surface is reached, a small part of the material near the surface will spall off, leading to porosity in the pin close to the surface. This process will continue inward to the pin center as the ^{10}B depletion increases. Due to the porosity development during the ^{10}B depletion, the outer layer of the pin will grow faster compared with the inner part of the pin. However, the porosity reduces the pin stiffness, so when the pin comes in contact with the blade wing, it is soft contact and the contact force that develops is small. The gap between the absorber pins and the blade wing hole wall is designed so that the soft contact and the resulting blade wing swelling do not lead to any deterioration of the mechanical performance of the control rods.

The design strategy with CR 99 has been to accommodate the local depletion peaks by the optimized design of the absorber pins (e.g. adjusted pin diameter and tapered ends), which is possible with the high-density pins that can be manufactured with a desired geometrical shape (in contrast to standard boron carbide powder). The radial depletion peaks at the blade wing edges (Fig. 8, Ref. 2-1) are managed by the tapered ends. For the top zone, the possible axial depletion peak (Fig. 6, Ref. 2-1) is managed by the reduced pin diameter in the top [ ][a,c] for Generation 2 CR 99). This means that the leading swelling will occur in the [ ][a,c] (Fig. 10, Ref. 2-1) and, [ ][a,c], (Fig. 9, Ref. 2-1). At these locations, the depletion is very similar to the calculated node average depletion given by the nodal code simulator.

The operating conditions that the CR 99 control rods experienced in the KKL reactor were extraordinarily demanding (e.g. high power density, no low-enriched core bottom section), in particular for the control rod top, which caused the strong axial depletion peak shown in Fig. 6 (Ref. 2-1) (~80% for the top hole as an average and 100% at the radial edge of it, Fig 8, Ref. 2-1). The effects of this on the blade swelling can also be seen in Fig. 9, which shows that the swelling of the top hole is actually higher than anywhere else. In US BWRs, under normal operating conditions, this very strong axial depletion peak will not occur and the 100% local depletion will not be reached within the licensed operating range (i.e. Nuclear End of Life (NEOL)). Hence, the local depletion peaks (radial and possibly minor axial peaks) are well accommodated by the CR 99 design and only the node average ^{10}B depletion needs to be tracked.

The Top Fuel paper (Ref. 2-1) addresses and assesses the appearance and the probability of Irradiation Assisted Stress Corrosion Cracking (IASCC). However, the IASCC cracks that were detected on the KKL rods and analyzed were minor and very limited in extent and appearance. There were no open cracks and and no boron leakage from any of the rods, despite the very high depletion levels and the fact that the 7 cycle rod had been operating in regulating mode with IASCC cracks for more than one cycle. These inspection results show that, under normal operating conditions (i.e. without the extreme axial depletion peak achieved in KKL), CR 99 can operate well beyond NEOL without any impact on the nuclear or mechanical performance.

Moreover, as explained in Ref. 2-1, the irradiation of the CR 99 rods to the high depletion levels reached in KKL was part of a well-planned and controlled evaluation program. The main objective of the program was to prove the robust behavior of CR 99, i.e. the full resistance to mechanical degradation and boron leakage at very high depletion levels and under operation with IASCC cracks. Hence, a limited number of minor IASCC cracks were expected to occur within the planned evaluation program and were successfully proven to have no impact on the safety function of the control rods.

References:

2-1 G. Ledergerber, P. Seltborg and B. Rebensdorff, "Mechanical Performance of the Westinghouse BWR CR 99 Control Rod at High Depletion Levels," 2011 Water Reactor Fuel Performance Meeting, Chengdu, China, September 11-14, 2011.

Follow-up RAI-3, Follow up to RAI-1b:

[ ]a,c swelling data have been provided to justify the B_4C swelling as defined by Equation 6.12 of the submittal. A 95/95 upper bound based on the [ ]a,c data points (assuming [ ]a,c degrees of freedom) is over a factor of [ ]a,c than the value applied in Equation 6.12. Therefore, the bounding Equation 6.12 provides a significantly lower bound than the traditional 95/95 bound of the data used in licensing analyses; please discuss why this is acceptable.

Response to Follow-up RAI-3:

As discussed in the response to Follow-Up RAI-2, a [
]a,c (Eq. 6.12 and 6.13 in the topical). The data presented in Figure 1-3 show that this is a very conservative assumption. Additionally, this is shown to be conservative for significantly more data in the response to Follow-up RAI-1. Therefore, it is acceptable to use Equation 6.12 to calculate the B_4C swelling.

<u>**Follow-up RAI-4, Follow up to RAI-7:**</u>

In light of the small amount of helium release and swelling data provided and the cracking problems with the Generation 2 CR 99 design, the initial response appears inadequate. Please provide more comprehensive inspection and surveillance program or elaborate the reason otherwise.

<u>**Response to Follow-up RAI-4:**</u>

As discussed in the response to Follow-up RAI-2, one of the major advantages of Westinghouse control rods is that an IASCC crack in the blade wing is not a problem. An IASCC crack does not lead to loss of boron carbide and thus the nuclear performance is not impacted. This was clearly displayed in the high depletion program of CR 99 in KKL.

Westinghouse has a very extensive and rigorous inspection program for the BWR control rod blades (CRBs). This inspection program has been developed and refined during the last forty years of Westinghouse CRB manufacturing history. The BWR reactor core environment is very similar worldwide: similar thermal neutron flux, similar coolant temperatures, and similar core pressures. Therefore the robustness of the inspection program is dependent primarily on the particular core CRB operating strategies. The inspection programs are mainly performed in Europe because the CRB operating environment is more challenging than in the US. Most of the BWR reactors in Europe operate one year cycles, with the control blades continuously inserted during the cycle, i.e. no periodic control rod swaps like in the US. Some plants are operated with fuel bundles that are not equipped with natural uranium blankets in the bottom of the bundle. The high enrichment at the bottom of the bundle will result in higher neutron flux exposure on the top of the CRB even when the CRB is withdrawn from the core. The more challenging CRB operating mode in European reactors enables Westinghouse to achieve crucial data and experience much faster than an equivalent program in the US.

Thus, with the objective to achieve maximum information and conservatism in data acquired, Westinghouse is always aiming to study lead rods in the most demanding BWRs. The high depletion program of the 2nd generation CR 99 control rods was launched in the Swiss Leibstadt BWR/6 reactor (KKL) since it is the BWR that is operated with the highest core power density in the world, does not contain natural uranium blankets in the fuel, operates with long control rod insertion times and is thus a more challenging environment for control rods than the BWRs operating in the US. Furthermore, as also mentioned in the response to Follow-up RAI-2, the KKL program aimed at showing the IASCC threshold of the 2nd generation CR 99 control rod and the operation to this very high local depletion, was intentional. Thus the appearance of cracks in this aggressive KKL program is not regarded as a generic cracking problem for CRB in normal operation in the US.

The profilometry inspection program at KKL, documented in Reference 4-1, generated about [ ]a,c measurement data points that also have been compared with very detailed Monte Carlo (MCNP) calculations. Profilometry has earlier been performed on four highly irradiated CR 99 from the 1st generation. Today Westinghouse, consequently, has an extensive database on the irradiation induced behavior of HIP boron carbide pins. Through the profilometry programs, Westinghouse has quantified the material behavior as a function of neutron exposure. [ ]a,c Thus the material behavior is known and Westinghouse will continue to follow leading rods, in BWRs

operating the 3rd generation CR 99, by performing visual inspections on an annual or semi-annual basis in these reactors.

Table 4-1 shows the leading rods of the 3rd generation CR 99 that are regularly inspected to confirm the good performance of CR 99.

Table 4-1: Leading rod of 3rd Generation CR 99

Reactor	Current level of % ^{10}B depletion with inspection	Predicted year to reach NEOL
[		]a,c

In the response to Follow-up RAI-1, it is shown that Westinghouse is using an extensive database, considering helium release and boron carbide pin swelling. Much of the information is gained from the hot cell PIE programs that Westinghouse has performed on their control rods.

Westinghouse has selected the most demanding and challenging BWR cores to demonstrate new features in their control rods. While these cores are not located in the US, the experiences gained from these cores encompass the operating modes that exist in US BWRs. The extensive programs that have been performed by Westinghouse and its customers, especially the KKL program, have generated a large data base, showing, in detail, the performance of the special feature of CR 99, the Hot Isostatic Pressed boron carbide pin, when operated to the [ ]a,c A US inspection program for demonstrating the 3rd generation CR 99 is not expected to provide any new information or to extend this knowledge and is therefore viewed as unnecessary.

Reference:

4-1. G. Ledergerber, P. Seltborg and B. Rebensdorff "Mechanical Performance of the Westinghouse BWR CR 99 Control Rod at High Depletion Levels," 2011 Water Reactor Fuel Performance Meeting, Chengdu, China, September 11-14, 2011

Follow-up to RAI-5, Follow up to RAI-8:

Was the control blade evaluated for bending loads, such as a seismic channel bow load case? If evaluated please discuss, if not please provide justification why the bending loads were not considered.

Response to Follow-up RAI-5:

No, Westinghouse does not evaluate bending loads.

Mechanical Criterion 5 (ME-5) states that the control rod should be capable of insertion into the core without structural damage in the presence of an oscillatory core. Westinghouse's intention with this criterion is that the control rod worth should not be affected by an oscillatory core. When the control rod is inserted into the core the boron carbide should geometrically be located at designed positions so that the reactivity of the control rod is as designed and, consequently, safe shut down of the reactor is guaranteed.

The amplitude of the oscillation during Level D Safe Shutdown Earthquake (SSE) is [ ]^{a,c} maximum calculated for Westinghouse SVEA-96 Optima 2 channels.

During a seismic event the core starts to vibrate and channels are designed to withstand the resulting forces. Due to the weight differences between the fuel and the control rod, the deformation in the core is transferred into the control rod when inserted into an oscillating core. Thus, the deformation of the control rod is restricted by the core deformation and is classified as a secondary stress.

[ ]^{a,c} The average bending strain in an absorber blade at [ ]^{a,c} in the middle of the control rod was calculated and applied as a linear varying deformation over a representative section of the absorber part of the blade wing, half of a hole and ligament, see Figure 5-2.

Unirradiated material data based on the material specification was used in the calculation. The assumption of fresh material is conservative because neutron fluence will rapidly harden the material leading to less maximum straining of the material in the absorber wing. The elastic-plastic material behavior is modeled based on min specified values of $R_{p0.2}$ and R_m in Table 7-1 in Follow-up RAI-7, and [ ]^{a,c}

[ ]^{a,c}

[ ]^{a,c}

[ ]^{a,c}

Figure 5-1 Plastic data for fresh material used in the collapse analysis

In the evaluation it was stated that the control rod will meet all design and operating criteria after the combination of an Operational Basis Earthquake (OBE), Level B with amplitude defined as half of the SSE amplitude, followed by a SSE. According to NUREG-0800 Standard Review Plan 3.7.3 5 OBE events with [ ]^{a,c} strain cycles each are assumed to occur during the lifetime of the nuclear power plant. One OBE can therefore be evaluated for [ ]^{a,c} Ten [ ]^{a,c} is also used in the load definition of the SSE. Fatigue data contained in Reference 5-1 was used in the evaluation.

Maximum local total equivalent strain was calculated to [ ]^{a,c} in case of SSE, see Figure 5-3. The result in Figure 5-3 also shows that maximum local strain decreases to low values towards the control rod centre. Fatigue evaluation shows that usage factor [ ]^{a,c} The usage factor is less than 1 and therefore no fatigue damage will evolve due to earthquake conditions, ensuring that structural integrity and insertability is maintained.

Table 5-1 Results from fatigue assessment of OBE and SSE.

		Fresh material			Irradiated material		
	CR deformation [mm]	Stress amplitude $E \cdot \varepsilon_{tot}$ [MPa]	Nf	Usage	Stress amplitude $E \cdot \varepsilon_{tot}$ [MPa]	Nf	Usage
OBE	[						
SSE							][a,c]

Scram insertion tests show that the stiffer CR85 can be inserted in the core without structural damage in the outer surface of the control rod blade during seismic oscillation of the core with amplitudes up to [ ][a,c]. Figures 6-6 to 6-8 in WCAP-16182-P-A, Rev 1 show the scram time for three different control rod blades. The deformation of the control rod is given by the core oscillation and therefore the average straining of the CR85 [ ][a,c] and CR 99 [ ][a,c] will be identical. The very small difference in hole dimensions will have very small influence on local straining and any scram tests during earthquake conditions valid for CR 85 remain valid for the CR 99.

The conclusion is that strain cycling of the control rod will not affect the control rod worth and the control rod is therefore verified for earthquake conditions.

a,c

Figure 5-2 Control rod bending is applied as a linear varying prescribed deformation over a detailed geometrical model including hole and ligament. [ ]^{a,c} corresponds to SSE. Conservative geometrical tolerances were used in the model and calculations.

a,c

Figure 5-3 Strain amplitude in control rod absorber blade in case of [ ]^{a,c} in the middle of the control rod (SSE condition).

References:

5-1. ASME Boiler and Pressure Vessel Code, 2010 ASME III Appendices Table I-9.2

Follow-up RAI-6, Follow up to RAI-12:

(1) Mechanical Criterion 5 requires the control rod be insertable into the core without structural damage during a certain specified oscillatory fuel channel deflection. Does this analysis take into account possible creep strains in the control rods that could affect insertion?

(2) The proof of insertion appears to be that the CR-99 rod is more compatible than the CR-85 rod, and the CR-85 rod was found to be acceptably insertable during testing. However, the CR-99 appears to be operating at a higher stress state and insertion stresses could increase with rod compatibility, leading to a more potentially damaging mechanism for the CR-99. How does the requirement of no structural damage address this concern?

Response to Follow-up RAI-6:

(1) No, this analysis does not take into account possible creep strains in the control rods. As was discussed in the original response to RAI-12, the increased stress level in CR99 is due mainly to the higher Helium pressure limit. However, the influence of Helium pressure on creep strains is low and is therefore negligible.

(2) Westinghouse considers the requirement of no structural damage to be met as long as the control rod can be inserted into the core without loss of boron carbide. The mechanical integrity is viewed to be acceptable provided that there is no loss of rod worth as a result of IASCC. Additional verification of the mechanical integrity for the CR 99 Generation 3 at higher stress states is discussed in the response to RAI-5 of this document.

Follow-up RAI-7, Follow up to RAI-15

What is the allowable design limit (Sm) value for stainless steel used in the CR-99 evaluation? What is the difference in Sm values using [ ]a,c stress criteria? Also justify the reduced stress conversion factor for the fatigue calculation (Equation 6.7) from that provided in Reference 2.

Response to Follow-up RAI-7:

Allowable design limits are based on internal Westinghouse material specifications, which are used when ordering material for use in manufacturing control rods. All of the material lots delivered to Westinghouse are tested in order to verify that the material specification is fulfilled. Min material data are given in Table 7-1.

The [ ]a,c design limits are not identical. The allowable [ ]a,c design limit (finite element calculations) is calculated according to:

[ ]a,c

This method can be compared with the ASME definition of Sm (analytical calculations):

[ ]a,c

and with the KTA 3103 (standard for shut down systems) definition:

[ ]a,c

where RT is room temperature and T is actual temperature. Comparison of [ ]a,c derivation of S_m shows that the [ ]a,c equation is conservative compared with KTA 3103.

Table 7-1 Material data for fresh stainless steel AISI 316L. Bold numbers are taken directly from material specification, other scaled based on these numbers and knowledge of typical dependence of temperature for austenitic stainless steels.

[ ]a,c

Equation 6.7 in the topical report is used to calculate current stress state for any condition during lifetime. Fatigue assessment is based on stress range as defined in Equation 6.8 of the topical. This stress range is calculated as maximum possible between end of life conditions and beginning of life conditions.

Follow-up RAI-8, Follow up to RAI-8

Do stresses in the structural finite element models exceed the elastic range? If so, is plastic material behavior modeled? If plastic is modeled please provide a description of the model.

Response to Follow-up RAI-8:

All structural analyses are done based on linear elastic assumption. [ ][a,c] Local stress concentration is controlled so that no ratcheting takes place due to load cycling, Pm+Pb+Q<3*Sm. Controlling the local stress concentration ensures that an initial plastic response leads to a pure elastic cycling.