Westinghouse Non-Proprietary Class 3

WCAP-16182-NP-A
Revision 0

March 2005

Westinghouse BWR Control Rod CR 99 Licensing Report

Westinghouse

WCAP-16182-NP-A
Revision 0

Westinghouse BWR Control Rod CR 99 Licensing Report

Prepared By:
George Hess
Richard Matheny
Bjorn Rebensdorff
Robert Sisk

Original Version: December 2003
Approved Version: March 2005

Verified:
*Richard Matheny
Fuel Business Manager

Approved:
*Robert Sisk, Manager
Fuel Engineering Licensing

***Official Record Electronically Approved in EDMS**

Westinghouse Electric Company LLC
4350 Northern Pike
Monroeville, PA 15146-2886

LEGAL NOTICE

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Section A

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

September 21, 2004

Mr. James A. Gresham, Manager
Regulatory and Licensing Engineering
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT WCAP-16182-P, "WESTINGHOUSE BWR CONTROL ROD CR 99 LICENSING REPORT" (TAC NO. MC1644)

Dear Mr. Gresham:

On December 16, 2003, the Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16182-P, "Westinghouse BWR Control Rod CR 99 Licensing Report," to the staff for review. On August 30, 2004, an NRC draft safety evaluation (SE) regarding our approval of the TR was provided for your review and comments. By e-mail dated September 10, 2004, Westinghouse stated that they had no comments on the draft SE.

The staff has found that WCAP-16182-P is acceptable for referencing in licensing applications for General Electric designed boiling water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that Westinghouse publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed SE between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain historical review information, such as questions and accepted responses, draft SE comments, and original TR pages that were replaced. The accepted version shall include a "-A" (designating accepted) following the TR identification symbol.

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SEP 28 2004

J. Gresham - 2 -

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Westinghouse and/or licensees referencing it will be expected to revise the TR appropriately or justify its continued applicability for subsequent referencing.

Sincerely,

Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure: Safety Evaluation

cc w/encl:
Mr. Gordon Bischoff, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16182-P, "WESTINGHOUSE BWR CONTROL ROD

CR 99 LICENSING REPORT"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated December 16, 2003 (Reference 1), the Westinghouse Electric Company LLC (Westinghouse), submitted Topical Report (TR) WCAP-16182-P, "Westinghouse BWR Control Rod CR 99 Licensing Report," to the NRC staff for review and approval. By letter dated May 19, 2004 (Reference 2), Westinghouse responded to a staff request for additional information (RAI).

The purpose of the TR is to present for licensing approval an improved boiling water reactor (BWR) control rod design (i.e., CR 99) along with a set of the design requirements used by Westinghouse to develop and evaluate BWR control rod designs for domestic use in BWRs in the United States.

The basic Westinghouse CR 99 control rod design has been in use for over 30 years in BWR reactors of all vendors. Currently, Westinghouse BWR control rod designs have been reviewed and approved for use in the domestic BWR designs supplied by the vendor General Electric (GE). Specifically, the Westinghouse CR 82 design has been approved for use in the D-Lattice (Reference 3), C-Lattice (Reference 4) and S-Lattice (Reference 5) BWRs. The improved CR 99 design is the same as the approved CR 82 design with the following changes:

- An improved neutron absorber material is used to replace the B_4C compacted powder and hafnium rodlets used in the CR 82 design.
- AISI 316L stainless steel material is used in the blade wings to replace the AISI 304L stainless steel used in the CR 82 design.

The TR gives a technical description of the Westinghouse CR 99 control rod design and provides the justification for the use of the CR 99 control rods in GE-designed BWRs. In addition, the TR also provided for staff review the formal design bases used by Westinghouse for the development and qualification of the CR 99 design. This set of design bases consists of general design requirements and a set of quantifiable and measurable acceptance criteria to ensure that the design requirements are met. These criteria address the materials, mechanical, physics, and operational performance requirements. The conformance methods used to verify that the CR 99 control rod design met these criteria are also identified. Westinghouse further states that this process will be used for the foreseeable future to make control rod design improvements, which will involve incremental changes from the basic design.

2.0 REGULATORY EVALUATION

The NRC's regulatory requirements for nuclear power plants are set forth in Title 10 of the *Code of Federal Regulations*, Part 50 (10 CFR Part 50), "Domestic Licensing of Production and Utilization Facilities." Appendix A of 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," provides the criteria to be met in licensing applications.

General Design Criterion (GDC) 27, "Combined Reactivity Control Systems," requires that the reactivity control system be designed with appropriate margin, and in conjunction with the emergency core cooling system, to be capable of controlling reactivity and cooling the core under post-accident conditions. GDC 28, "Reactivity Limits," requires that the control rod reactivity be maintained consistent with the plant safety analysis throughout its lifetime to provide sufficient control to shut down the core.

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design," defines the basis for the acceptance criteria for staff reviews. These criteria ensure compliance with GDC 27 and 28.

3.0 TECHNICAL EVALUATION

The staff's technical review of the CR 99 control rod design was based on Section 4.2 of the SRP. The review primarily considered the changes from the currently approved CR 82 design:

- An improved neutron absorber material to replace the B_4C powder and hafnium rodlets used in the CR 82 design.
- Use of AISI 316L stainless steel material in the blade wings to replace the AISI 304L stainless steel used in the CR 82 design.

The following sections address the review topics in the order that they are presented in WCAP-16182-P.

3.1 Design Requirements - Section 4

WCAP-16182-P presents the six general design requirements to be used for Westinghouse BWR control rods for use in GE-designed BWRs. Table 4-1 of the TR lists a matrix of the design requirements versus the applicable criteria used for the CR 99 evaluation. In response to the staff's RAI, Westinghouse provided a discussion of the relationship between these design requirements and applicable criteria both to the applicable SRP Section 4.2 review criteria and to the applicable 10 CFR Part 50 Appendix A GDCs. The RAI response also provided a pointer to the specific TR sections that disposition each requirement and criteria.

Specifically, SRP Section 4.2, Part I, "Areas of Review," requires the review to cover specific areas:

A. Design Bases
B. Description and Design Drawings
C. Design Evaluations
D. Testing, Inspection, and Surveillance Plans

Additionally, Appendix A of the SRP requires review of control rod insertability following a safe shutdown earthquake (SSE).

SRP Section 4.2, Part II, "Acceptance Criteria," specifies the review acceptance criteria for each review area.

The staff reviewed the CR 99 design requirements relative to the approved CR 82 design requirements and finds that they are essentially equal, although the methods used to demonstrate that the requirements are met are not the same. The staff also reviewed the TR with respect to completeness of the CR 99 design requirements in meeting the SRP criteria and finds that all applicable requirements are addressed either in specific sections of the TR or in the response to the staff's RAI.

The following subsections summarize the review areas and staff conclusions.

3.1.1 Design Bases

The staff reviewed the CR 99 design bases with respect to meeting the specified SRP criteria:

- Compliance with GDC 27 and 28
- Stress, strain and loading limits
- Cumulative number of strain fatigue cycles
- Dimensional changes regarding control rods
- Control rod reactivity must be maintained

Based on its review of the TR and the RAI responses, the staff has determined that the Westinghouse CR 99 control rod design bases meets the applicable criteria of the SRP and the requirements of the specified GDCs.

3.1.2 Description and Design Drawings

Outline drawings of the CR 99 design for D, C, and S-Lattice cores were provided in the RAI response. The staff finds that these meet the SRP criteria.

3.1.3 Design Evaluation

The staff reviewed the CR 99 design evaluation with respect to:

Prototype Testing - Control Rod Structural and Performance Test

Based on its review of the TR and the RAI responses, the staff has determined that the Westinghouse CR 99 control rod design evaluation meets the applicable criteria of the SRP.

3.1.4 Testing, Inspection, and Surveillance Plans

The staff reviewed the CR 99 testing, inspection and surveillance plans with respect to:

> Surveillance of control rods containing B_4C should be performed to ensure against reactivity loss.

Based on its review of the TR and the RAI responses, the staff has determined that the Westinghouse CR 99 design testing, inspection and surveillance plans meet the applicable criteria of the SRP.

3.1.5 SRP Appendix A

The staff reviewed the criteria of SRP Appendix A with respect to the CR 99 capability:

> Control rod insertability must be assured following an SSE

Based on its review of the TR and the RAI responses, the staff has determined that the Westinghouse CR 99 control rod design meets the applicable criteria of the SRP sections and the requirements of the specified GDCs.

3.2 Materials Evaluation - Section 5

Extensive control rod operating experience, supplemented by the inspections referenced in WCAP-16182-P, have shown an increased potential for control rod blade cracking for rods used in high duty locations in modern high capacity factor, extended operating cycle cores. High duty locations are typically found in control cell core reload core designs where individual control rods are deeply inserted for a significant fraction of the operating cycle. These control rods receive high doses of both thermal and fast neutrons in a short amount of time. The fast neutron dose is not measured by current core monitoring systems, but it is well known that fast neutron irradiation makes stainless steel more susceptible to irradiation assisted stress corrosion cracking.

The CR 99 use of an improved high density neutron absorber material, which is less sensitive to both powder densification and absorber swelling due to neutron absorption reactions, minimizes the possibility of absorber swelling causing contact with the surrounding stainless steel and contributing to stress. The CR 99 use of AISI 316L stainless steel, with its better resistance to fast neutron IASCC, also reduces the potential for control blade cracking.

The staff's review confirmed that the substitution of the two new materials is the only significant change between the approved CR 82 and the improved CR 99 designs.

Based on its review of the TR and the RAI responses, the staff has determined that the Westinghouse CR 99 control rod design materials evaluation meets the applicable criteria of the SRP.

3.3 Mechanical Evaluation - Section 6

The mechanical criteria to be met are the stress and fatigue limits contained in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III (ASME III), Division 1, Edition 2002.

The staff reviewed the CR 99 design mechanical evaluation with respect to meeting the SRP criteria.

The staff's review confirmed that the mechanical evaluation of the changes from the approved CR 82 design to the improved CR 99 design was adequately conducted and that the appropriate mechanical criteria were met.

3.4 Physics Evaluation - Section 7

The critical attributes for the CR 99 physics evaluation are:

- Total Rod Worth
- Shutdown Margin
- Low Power Range Monitor Detector Signal Change
- Nuclear End-of-Life

The staff reviewed the physics criteria and the methods used for confirmation that the criteria are met for the CR 99 design relative to the approved CR 82 design.

Based on its review of the TR and the RAI responses, the staff has determined that the Westinghouse CR 99 control rod design physics evaluation meets the applicable criteria of the SRP.

3.5 Operational Evaluation - Section 8

The critical attributes for the CR 99 operational evaluation are:

- Nominal wing thickness
- Maximum button thickness
- Maximum wing span
- Maximum velocity limiter diameter (with rollers installed)
- Total weight
- Overall length
- Velocity limiter/coupling design
- Handle design
- Envelope

The staff compared these CR 99 attributes with the values for the approved CR 82 design and finds they are equivalent.

Based on its review of the TR and the RAI responses, the staff has determined that the Westinghouse CR 99 control rod design operational evaluation meets the applicable criteria of the SRP.

4.0 CONCLUSION

The staff has reviewed WCAP-16182-P describing the improved Westinghouse CR 99 control rod design and has compared it to the currently approved CR 82 design. The staff finds that the incremental changes in using the improved neutron absorber and blade wing materials have been adequately evaluated and that the Westinghouse CR 99 design requirements and the resulting evaluations, as outlined in the TR and in the RAI responses, are consistent with the criteria of the SRP and the requirements of the applicable GDCs. Therefore, on the basis of the above review and justification, the staff concludes that the improved Westinghouse CR 99 control rod design is acceptable for use in BWRs in the United States.

The design requirements, criteria, and methodology described in the TR have also been reviewed and determined to be acceptable for use in making minor enhancements to the CR 99 control rod without further NRC review. The NRC staff is to be notified (for information only) of any changes in the materials or numerical limits as described in the TR.

5.0 REFERENCES

1. Letter from B. F. Maurer (Westinghouse) to J. S. Wermiel (NRC), Submittal of WCAP-16182-P/WCAP-16182-NP, "Westinghouse BWR Control Rod CR99 Licensing Report," LTR-NRC-03-69, dated December 16, 2003. (Accession No. ML033530313)

2. Letter from J. A. Gresham (Westinghouse) to NRC, Transmittal of Proprietary Information regarding Responses to RAIs on WCAP-16182-P & NP, "Westinghouse BWR Control Rod CR 99 Licensing Report," LTR-NRC-04-31, dated May 19, 2004. (Accession No. ML041450258)

3. Letter from H. N. Berkow (NRC) to E. Tenerz (ASEA-ATOM), Subject: Acceptance for Referencing of Licensing Topical Report TR UR 85-225, "ASEA-ATOM Control Rods for US BWRs," dated February 20, 1986.

4. Letter from A. C. Thadani (NRC) to E. Tenerz (ASEA-ATOM), Subject: Acceptance as a Reference Document of Supplement 1 to Topical Report TR UR 85-225, "ASEA-ATOM Control Rods for US BWRs," dated May 5, 1988.

5. Letter from A. C. Thadani (NRC) to E. Ternez (ABB ATOM), Subject: Acceptance of Supplement 2 to Topical Report UR-85-225A, "ASEA-ATOM Control Rods for US BWRs as a Reference Document," dated August 8, 1989.

Principal Contributor: E. Kendrick, NRR/DSSA/SRXB-A

Date: September 21, 2004

Section B

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Direct tel: (412) 374-5036
Direct fax: (412) 374-4011
e-mail: galcm1js@westinghouse.com

Our ref: LTR-NRC-03-69

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

December 16, 2003

Subject: Submittal of WCAP-16182, "Westinghouse BWR Control Rod CR 99 Licensing Report" (Proprietary/Non-Proprietary), dated December 2003

Dear Mr. Wermiel:

Enclosed are copies of the Proprietary and Non-Proprietary versions of WCAP-16182-P, "Westinghouse BWR Control Rod CR 99 Licensing Report" (Proprietary), December 2003/ WCAP- 16182-NP, "Westinghouse BWR Control Rod CR 99 Licensing Report" (Nonproprietary), December 2003

Also enclosed are:

1. One (1) copy of the Application for Withholding, AW-03-1743 (Nonproprietary) with Proprietary Information Notice.
2. One (1) copy of Affidavit (Nonproprietary).

This information is being submitted by Westinghouse Electric Company LLC to obtain NRC approval to use the Westinghouse BWR CR 99 control rod design in US BWRs. Approval of the subject topical report is requested by September 30, 2004 to permit fabrication of CR 99 control rods to meet the installation schedules of various utilities, the earliest of which is Exelon's planned installation of the control rods in January 2005.

This submittal contains proprietary information of Westinghouse Electric Company, LLC. In conformance with the requirements of 10 CFR Section 2.790, as amended, of the Commission's regulations, we are enclosing with this submittal an Application for Withholding 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.

A BNFL Group company

Correspondence with respect to this affidavit or Application for Withholding should reference AW-03-1743 and should be addressed to the undersigned.

Very truly yours,

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: F. M. Akstulewicz/NRR
B. J. Benney/NRR
E. S. Peyton/NRR
U. Shoop/NRR
S. L. Wu/NRR

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Direct tel: (412) 374-5036
Direct fax: (412) 374-4011
e-mail: galem1js@westinghouse.com

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

Our ref: AW-03-1743

December 16, 2003

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-16182-P, "Westinghouse BWR Control Rod CR99 Licensing Report" (Proprietary)

Reference: Letter from B. F. Maurer to J. S. Wermiel, LTR-NRC-03-69, dated December 16, 2003

This Application for Withholding is submitted by Westinghouse Electric Company, LLC ("Westinghouse"), pursuant to the provisions of Paragraph (b) (1) of Section 2.790 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 2.790, Affidavit AW-03-1743 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 2.790 of the Commission's regulations.

Correspondence with respect to this Application for Withholding or the accompanying affidavit should reference AW-03-1743 and should be addressed to the undersigned.

Very truly yours,

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Enclosures

A BNFL Group company

AW-03-1743

AFFIDAVIT

STATE OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. W. Winters, 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. W. Winters, Manager
Product Engineering and Integration

Sworn to and subscribed
before me this 16th day
of December, 2003

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, Product Engineering and Integration, 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 the Westinghouse Electric Company LLC.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 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 the Westinghouse Electric Company LLC 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 2.790 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 constitute Westinghouse policy and provide 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 a 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 2.790, 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 WCAP-16182-P, "Westinghouse BWR Control Rod CR 99 Licensing Report" (Proprietary), December 2003, being transmitted by Westinghouse Electric Company letter (LTR-NRC-03-69) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk.

This information is part of that which will enable Westinghouse to provide CR99 design control rods for use in BWRs in the United States. This information has substantial commercial value in that it reveals distinguishing aspects of a BWR control rod design and its supporting analytical methodology and test data which was developed by Westinghouse, the application of which results in improved in-reactor control rod performance.

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 a similar product 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 an intensive Westinghouse effort and the expenditure of a considerable sum of money.

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 2.790 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 2.790(b)(1).

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EXECUTIVE SUMMARY

This report provides justification for use of Westinghouse CR 99 control rods in General Electric boiling water reactors (BWRs).

The important characteristics of the CR 99 design are the same as those of the CR 82 design previously approved by the NRC except for:

1. [ ]^{a,c}

2. Use of AISI 316L stainless steel material in the CR 99 blade wings instead of AISI 304 stainless steel.

The [ ]^{a,c} facilitates designing the control rod to avoid hard contact between absorber pins and the stainless steel blade wall, thereby reducing the likelihood of irradiation assisted stress corrosion cracking of the wall. AISI 316L stainless steel also exhibits superior resistance to irradiation assisted stress corrosion cracking compared to AISI 304 stainless steel.

This report presents design requirements for the CR 99 control rod. A set of quantifiable, measurable criteria are presented which, if met, ensure that the design requirements are met. The criteria address materials, mechanical, physics, and operational performance requirements. The methods used to verify that the CR 99 control rod design meets these criteria are identified.

The design requirements, criteria, and verification methods ensure that the CR 99 control rod will perform acceptably in General Electric BWRs.

1 PURPOSE

The purposes of this report are to:

1. Present a set of design requirements for Westinghouse BWR control rods to be used in General Electric (GE) BWRs. Given these design requirements, a set of measurable criteria is established which, if met, ensures that the design requirements are met. These design requirements and criteria together form a set of design bases for Westinghouse control rods for use in GE designed BWRs.

2. Evaluate the CR 99 design against the measurable criteria to ensure that the design meets the design bases for Westinghouse control rods for use in GE designed BWRs.

2 INTRODUCTION

2.1 BASIC WESTINGHOUSE DESIGN

The basic Westinghouse control rod design for which the Westinghouse experience base is applicable and for which this Licensing Topical Report is intended consists of a control rod which:

1. Has horizontal absorber holes drilled in solid stainless steel wings,

2. Uses guide pads (buttons) or no guide pads rather than the upper pins and rollers used in the Original Equipment Manufacturer's (OEM) control rods,

3. [ ]a,c

4. Has a velocity limiter,

5. Weighs less than the design weight for the control rod drive,

6. Has a handle the same as the one it is replacing, or has a core grid support which allows all four surrounding bundles to be removed without needing a blade guide to hold the control rod in place,

7. Has an initial worth within [ ]a,c of the initial worth of the control rod that it is replacing, and

8. Does not negatively impact the ability of the Core Monitoring System to monitor the core (i.e., [ ](a,c)).

2.2 LICENSING BACKGROUND

The initial design Westinghouse control rod, designated as CR 70, is described in Reference 1. This design contained only boron carbide (B_4C) as a neutron absorber. Due to the potential for B_4C swelling-induced cracking in the rod tip even when a control rod is fully withdrawn, subsequent designs have contained hafnium (which does not swell when irradiated) in the tips of the rods. The CR 70 design is no longer manufactured. Nevertheless, many of these rods have operated well, and are still in operation, in Swedish built Westinghouse reactors.

Reference 2 describes the next Westinghouse design, CR 82, for use in D-Lattice GE BWRs. This design contains hafnium in the top six inches of the rod, with a total rod worth within 5 percent of the original control rods. With the exception of the hafnium tip, it is essentially the same design as the rod described in Reference 1. Use of this rod design has been approved by the NRC in Reference 3.

Reference 4 discusses the use of the CR 82 design in C-Lattice GE BWRs. This design is similar to the D-Lattice rod design in concept, with differences in geometry and envelope dimensions due to differences in lattice designs. Use of this rod design has been approved by the NRC in Reference 5.

Reference 6 discusses: (1) a design (CR 85) that incorporates hafnium along the outer edge of the rod as well as in the top six inches as used in previous designs, and (2) use of Westinghouse control rods in BWR/6 reactors. NRC approval is documented in Reference 7.

With respect to important factors, the CR 99 design presented in this report is the same as the CR 82 design approved by the NRC in References 3, 5, and 7, with the following exceptions:

1. The [ ]a,c as absorber material in the CR 99 design instead of B_4C powder and hafnium rodlets used in the CR 82 design.

2. The use of AISI 316L stainless steel (SS) material in the blade wings of the CR 99 design instead of the AISI 304L SS used in the CR 82 design. This change of material is discussed in Reference 8.

2.3 CURRENT/FUTURE DEVELOPMENTS

Westinghouse's extensive experience with the basic Westinghouse control rod design encompasses more than 30 years in BWR reactors of all vendors. The basic design discussed in the previous section has proven to be an excellent design, and serves as the basis for future designs. Past improvements, as well as foreseeable future improvements, will involve incremental changes on the basic design such that the large experience base of proven design can be applied to any new design.

Control rod inspections (References 9 through 12) showed an increased potential for CR 82 control rod cracking for rods used in high duty (e.g., Control Cell Core) positions in the core. "High duty" is defined as a location where the control rod is deeply inserted into the core for a significant fraction of the cycle. Rods used in this manner receive high doses of thermal and fast neutrons in a short time when deeply inserted in the core. The fast neutron dose is not measured by current core monitoring systems since it does not lead directly to control rod ^{10}B depletion, but it is well known that fast neutron irradiation makes stainless steel susceptible to irradiation assisted stress corrosion cracking (IASCC).

Thus, an improved design designated CR 99 has been introduced to counteract the potential life shortening IASCC phenomenon. This design uses [ ]a,c as absorber material instead of B_4C powder and hafnium rodlets. AISI 316L SS is the blade wing material. AISI 316L SS has proven to be more resistant to IASCC than AISI 304L SS (Reference 8). This has been shown both in materials experiments and in control rod operation.

3 DEFINITIONS

3.1 CR 99

CR 99 is a control rod design whose critical attributes are presented in Sections 5 through 8 of this report. A large data base of operating experience shows that these rods meet the design requirements listed in Section 4.1 for Westinghouse control rods in GE BWRs.

3.2 CONFORMANCE METHODS

These are various methods by which it is possible to verify that the CR 99 design meets specific criteria. These methods include experience, testing, analyses, and inspection.

3.3 CRITERIA

Criteria are a set of quantifiable, measurable standards which, if met, ensure that the design requirements are met.

3.4 CRITICAL ATTRIBUTES

Critical attributes are those attributes (dimensions, materials, design values, etc.) which, if changed, have the potential to affect fit, form, or function of the control rod.

3.5 DESIGN REQUIREMENTS

Design requirements are a set of general guidelines for the design of Westinghouse control rods which, if met, ensure that Westinghouse control rods will operate as required in D-, C-, and S-Lattice GE BWRs.

4 DESIGN REQUIREMENTS

4.1 GENERAL

The general design requirements for Westinghouse BWR control rods to be used in GE BWRs are:

1. The control rod is compatible with the Control Rod Drive (CRD) system, coupling device, fuel, fuel channels, associated core internals, and rod handling equipment.

2. The control rod is designed such that rod worth and transient operation (e.g., scram and free fall velocity) are consistent with the plant safety analyses.

3. The control rod is designed with mechanical stability and materials such that scram capability is maintained throughout control rod life.

4. The control rod is designed such that currently used tools can monitor core power distribution and burn-up.

5. The control rod is designed such that total life cycle dose due to its use (activation product dose, direct dose, and disposal dose) is minimized.

6. The design and manufacture of the control rod fulfill applicable codes and standards, including applicable parts of the ASME Boiler and Pressure Vessel Code.

Given the above design requirements, a set of measurable criteria is established which, if met, ensures that the design requirements are met. These criteria are given in Sections 5 through 8. Table 4-1 lists the design requirements along with their related criteria.

These criteria together with the design requirements form a set of design bases for Westinghouse BWR control rods for use in GE designed BWRs.

4.2 CONFORMANCE METHODS

Conformance to the acceptance criteria (and ultimately the design requirements) is ensured by at least one of the following methods:

1. Experience with identical or similar design(s)
2. Testing of prototypes, specific features, etc.
3. Analyses
4. Inspection

Of these conformance methods, experience is the preferred approach. The experience approach provides the most applicable, directly comparable method for verification of conformance to criteria. This is why, in general, design changes are made in small, incremental steps so that the experience base of previous designs remains valid and applicable to new designs.

Where the experience base does not exist or the time to obtain such a base is too long, testing of prototypes as well as specific control rod features may be undertaken. Analyses are used (1) to supplement testing, (2) to extend test results to other product lines or designs, or (3) in lieu of testing when testing is not practical or is prohibitively expensive, and the analytical tools available are known to give credible results.

Inspection is typically used to verify the first three methods rather than directly as a conformance method. Inspection allows for increasing the accuracy of analyses, verifying results of tests, and updating the experience base. Inspections may also lead to improved designs through detection of previously unknown or unanticipated problems that would not have been detected if inspections had not been done.

Table 4-1 Design Requirements/Criteria Matrix

Design Requirement	Applicable Criteria[1]
The control rod is compatible with the CRD system, coupling device, fuel, fuel channels, and rod handling equipment.	MA-2, 3 OP-1, 2, 3, 4
The control rod is designed such that rod worth and transient operation (e.g., scram and free fall velocity) are consistent with the plant safety analyses.	ME-3, 5 PH-1, 2, 3, 4 OP-2, 5, 6
The control rod is designed with mechanical stability and materials choices such that mechanical function is maintained throughout the life of the control rod.	MA-2 ME-1 through 5 OP-7, 8
The control rod is designed such that currently used tools can monitor core power distribution and burn-up.	PH-3, 4
The control rod is designed such that total life cycle dose due to its use (activation product dose, direct dose, and disposal dose) is minimized.	MA-1
The design and manufacture of the control rod fulfill applicable codes and standards, including applicable parts of the ASME Boiler and Pressure Vessel Code.	ME-2, 3

Notes:

1. Criteria Nomenclature is as follows:
   MA-xx Materials Criteria (See Section 5)
   ME-xx Mechanical Criteria (See Section 6)
   PH-xx Physics Criteria (See Section 7)
   OP-xx Operational Criteria (See Section 8)

5 MATERIALS EVALUATION

5.1 CRITICAL ATTRIBUTES

The critical attributes for materials related items are given in Table 5-1. The materials used in the CR 99 design are also included in the table.

5.2 CRITICAL ATTRIBUTES DISCUSSION

5.2.1 Rod Wing and Handle Material

Use of AISI 316L SS for the rod wing and handle is based on extensive in-reactor experience with the material. Better resistance to IASCC of AISI 316L SS has made it the preferred blade wing material (Reference 8). Since this material is in the reactor and subject to neutron activation, limits on cobalt concentration are set to minimize the release of cobalt to the primary coolant as well as minimize direct doses due to disposal.

5.2.2 Button and Roller Material

These components are subject to contact and are designed to slide or ride against other material. Thus the button and roller material must be wear resistant. Original equipment control rods in GE BWRs were made of material containing high cobalt concentrations (50% to 60%). While acceptable from the wear standpoint, they released unacceptable amounts of cobalt into the reactor coolant. An EPRI project identified a non-cobalt material, Inconel X-750, as an acceptable material for use in fabricating these components. This material has been the material of choice, with the specified limited cobalt content, for the CR 99 control rod. Extensive in-reactor experience, confirmed during post irradiation examinations, has shown this material to perform as required. During the last 10 years, AISI 316L SS has also been used in control rod buttons. Operational experience with this material is also very good.

Operational experience has also demonstrated that the control rods can be operated without a top button. No wear on any component, control rod or fuel channels, has occurred (Reference 13).

5.2.3 Absorbing Materials

Extensive in-reactor experience with boron carbide (B_4C) powder has been amassed on Westinghouse BWR control rods. In-pile measurements of helium gas pressure have confirmed the validity and conservatism of the helium release model used in the analyses.

With CR 99, Westinghouse has introduced [ ]^{a,c} This can be compared to the highest density of powder, about 70%, or standard sintering density of about 73%.

In a control rod with B_4C powder, the powder densifies during operation and also swells due to neutron absorption reactions. Westinghouse experience is that the competing effects of powder densification and swelling can result in the swelling powder contacting the surrounding stainless steel, possibly causing IASCC.

[

]a,c

Reference 14 describes the outline of the CR 99 control rod for an S-Lattice BWR6 reactor. CR 99 control rods have accumulated significant operating experience in GE BWRs.

5.2.4 Velocity Limiter

The design of the velocity limiter is very important to the control rod drop accident analysis. The design of this important component is discussed in Section 8 of this report. From a materials standpoint, the velocity limiter must be made from a material which can be readily cast, machined to final dimensions, and attached to the rod wings. Since it is in contact with primary coolant, cobalt content must also be controlled. The velocity limiter for the CR 99 is manufactured from cast AISI 304L SS.

Extensive in-reactor experience with all Westinghouse control rods has shown the acceptability of this material for the velocity limiter.

5.2.5 Coupling Socket

The design of the coupling socket is important to proper operation of the control rod. The design of this component is discussed in Section 8 of this report. The coupling socket must be made from a material which can be machined to final dimensions and has sufficient strength to keep the control rod coupled to the drive mechanism. The coupling socket is manufactured from Alloy X-750. Extensive in-reactor experience with this material has shown its acceptability for the coupling socket.

5.3 MATERIALS CRITERIA AND DISCUSSION

The following criteria are shown in Table 5-2 along with the conformance method(s) required to confirm that the criteria are met. CR 99 evaluation results are also provided.

5.3.1 Materials Criterion 1 (MA-1)

Criterion

No material shall be used which results in a larger total rod lifetime dose (direct + indirect) than does the material which it is to replace. If it does, compensatory measures must be implemented in some other material(s) to reduce total rod dose to meet this criterion.

Discussion

This criterion ensures that all Westinghouse control rod designs will have at least the same (relative to OEM rods) characteristics with respect to cobalt release during operation, dose received during replacement and preparation for disposal, and disposal-related radiological parameters (dose and curie content).

The investigation of dose impact of a new material may only involve verification that the new material contains less dose causing material (e.g., cobalt) than does the material which it is replacing. For less obvious materials changes, the investigation may require the use of the Westinghouse computer model BKM-CRUD (Reference 15) to determine the impact.

5.3.2 Materials Criterion 2 (MA-2)

Criterion

Rod wing material shall be better than or equal to original blade wing material (Type 304L stainless steel) with respect to stress corrosion cracking, particularly susceptibility to fast neutron IASCC.

Discussion

This criterion and its conformance methods ensure that only materials superior to those already in use are used for rod wings. Thus, it is possible to use past in-reactor experience as a conservative experience base for the new material.

As shown in Table 5-2, the conformance method required to confirm that a material is superior is testing and experience. Previous in-reactor experience with the proposed material and/or testing (e.g., in-pile material tests, autoclave tests, lead control rods, etc.) provides confidence that a material is superior, but the ultimate proof is long term use in its final form in control rods in the reactor. For this reason, the lead control rods containing critical components with new material need to be inspected to confirm results of pre-use testing and adequacy of the experience base.

5.3.3 Materials Criterion 3 (MA-3)

Criterion

Components shall be made of materials compatible with connected and interfacing materials and components.

Discussion

This criterion ensures that the design will be compatible with existing in-reactor materials.

Evaluation to confirm compliance with this criterion will ensure that materials related considerations (e.g., differences in thermal expansion, wear properties, etc.) do not create problems.

Table 5-1 Materials Related Critical Attributes for the CR 99 Design	
Materials Critical Attribute	**D, C, and S-Lattice Material or Value**
Rod Wing and Handle Material	AISI 316L SS
Cobalt Content	[ ]a,c
Impurities	[ ]a,c
Velocity Limiter Roller Material	Alloy X-750
Cobalt Content	[ ]a,c
Button Material	Alloy X-750, AISI 316L SS or No Button
Cobalt Content	[ ]a,c
Absorbing Materials	
Boron Carbide	[ ]a,c [ ]a,c Placed in holes drilled in stainless steel
Velocity Limiter	Cast AISI 304L SS
Cobalt Content	[ ]a,c
Coupling Socket	Alloy X-750
Cobalt Content	[ ]a,c

Table 5-2 Materials Criteria

Criterion	Conformance Method(s)[1]	D-, C- and S-Lattice CR 99
(MA-1) No material shall be used which results in a larger total rod lifetime dose (direct + indirect) than does the material which it is to replace. If it does, compensatory measures must be implemented in some other material(s) to reduce total rod dose to meet this criterion	Analyses	The materials chosen for CR 99 minimize Co. The two largest contributors to dose are the rollers/buttons (due to movement across other material) and the wings (largest surface). • With respect to the rollers/buttons, the materials chosen (Alloy X-750 and/or AISI 316L SS) have much less Co than the Stellite material in the original rods (see Section 5.2.2). • With respect to the wing material, the CR 99 has 1/3 of the surface area of the OEM blades. This, combined with a [ ]^{a,c} limit on Co, ensures that this criterion is met for CR 99. Based on the above, the CR99 rod meets this criterion.
(MA-2) Rod wing material shall be better than or equal to original blade wing material (AISI 304L SS) with respect to stress corrosion cracking, particularly susceptibility to fast neutron IASCC.	Experience Testing Inspection	Material testing as well as control rod operating experience have proven AISI 316L SS to be a better material than AISI 304L SS with respect to IASCC (Reference 8). On this basis, the CR99 rod meets this criterion.
(MA-3) Components shall be made of materials compatible with connected and interfacing materials and components.	Experience Testing Analyses	An extensive experience base has shown that the design meets this criterion, i.e., no problems with latching, normal rod movement, scram (as seen by rod insertion times within Technical Specification limits), or abnormal corrosion. On this basis, the CR99 rod meets this criterion.

Note:

1. See Section 4.2 for a discussion on Conformance Methods.

6 MECHANICAL EVALUATION

6.1 CRITICAL ATTRIBUTES

The critical attributes for mechanical related items are shown in Table 6-1. The attribute values for CR 99 are also included.

6.2 ATTRIBUTES DISCUSSION

6.2.1 Hole Diameter

Hole diameter directly impacts the wall thickness to the face of the blade. In conjunction with hole pitch, it impacts ligament thickness to the adjacent hole. In conjunction with hole pitch and hole depth, this parameter impacts total rod worth.

Thus, it can be seen that selection and control of this parameter are important to control rod design and in-reactor performance with respect to both mechanical and nuclear performance.

6.2.2 Hole Pitch

This parameter can affect ligament thickness between holes and total rod worth. Thus, while not as critical as hole diameter, hole pitch is still important to control rod performance.

6.2.3 Hole Depth

Hole depth is the primary parameter Westinghouse uses to control rod worth. Varying the hole depth can change the control rod worth of two otherwise identical control rods.

Due to the amount of stainless steel between the end of the hole and the inner edge of the control rod wing, and the lack of stress in that direction, differences in hole depths reasonably expected for any control rod designs for GE BWRs have little impact on mechanical performance.

6.2.4 Minimum Outer Wall Thickness

This parameter is important in stress analyses since any calculations done use this conservative value in determining stresses across the wall of the control rod.

During manufacture, control rods are inspected against this value to ensure that the analyses performed are valid. In general, actual values are greater than the specified minimum. Parameters which set this value include hole diameter, control rod blade wing thickness and manufacturing tolerances in the hole location.

6.2.5 Hole Ligament Thickness

This parameter is important in stress analyses done to determine stresses between holes. Parameters which set this value include hole diameter, hole pitch and manufacturing tolerances in the hole location.

6.2.6 [

]^{a,c}

6.2.7 [

]^{a,c}

6.2.8 Moment of Inertia

Moment of inertia is important mainly with respect to seismic behavior and ability to insert during a seismic event.

6.2.9 Mass of the Complete Control Rod

This parameter, in conjunction with the mass of the control rod without the velocity limiter and socket, is important in determining axial stresses on the control rod during scrams.

6.2.10 Mass of the Control Rod without the Velocity Limiter and Socket

This parameter, in conjunction with the mass of the complete control rod, is important in determining axial stresses on the control rod during scrams.

6.2.11 Control Rod Design Temperature

The control rod design temperature is set by the design temperature of the plant reactor coolant. This value is far below any value that could substantially degrade (melt) the material in the control rod.

6.2.12 Control Rod Design Pressure

As with design temperature, design pressure is set by the design of the plant reactor coolant system. This value is used in determining the stresses across the hole walls due to differential pressures.

6.2.13 Handle Design

Westinghouse has manufactured control rods with both single and double handles. The safety function of the control rods does not depend on the handle design. However, the designs must be: (1) checked for compatibility with the rod handling equipment and (2) evaluated to ensure that the handle will be able to take the stresses due to normal loading and handling. Note that item (1) is addressed in Section 8, Operational Evaluation.

In general, the original control rods for D-Lattice plants were built with single handles, C-Lattice plants have a mix of single and double handle control rods, and S-Lattice plants have double handle control rods.

6.2.14 Materials Strength Properties

Values of the parameters listed below, which are related to the material used in the control rod, are used to determine whether calculated stress levels are within acceptable ranges.

- Young's Modulus, E
- Yield Strength, $Rp_{0.2}$
- Ultimate Strength, R_m
- Allowable Stress Limit, S_m – per Article III-2110(b) of ASME Boiler and Pressure Vessel Code, Section III is given by:

$$S_m = \text{Min}\{\ 2/3 \times Rp_{0.2}\ (20°C),\ 0.9 \times Rp_{0.2}\ (T°C),\ 1/3 \times R_m\ (20°C),\ 1/3 \times R_m\ (T°C)\ \}$$

The values of $Rp_{0.2}$ and R_m are the minimum values specified in the material specifications.

6.3 MECHANICAL CRITERIA AND DISCUSSION

Mechanical criteria to be met are stress and fatigue limits under differential static pressure, pressure cycling and scram load. Meeting criteria specified in this section assures that applicable codes and standards are met. Stresses as defined below are used in the evaluation.

General Primary Membrane Stress Intensity – P_m

This stress intensity is derived from the average value across the thickness of a section of the general primary stresses produced by design pressure and other specified design mechanical loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is S_m at the design temperature.

Local Membrane Stress Intensity – P_L

This stress intensity is derived from the average value across the thickness of a section of the local primary stresses produced by design pressure and other specified design mechanical loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is 1.5 S_m.

Primary Membrane (General or Local) Plus Primary Bending Stress Intensity – $P_m \pm P_b$ or $P_L \pm P_b$

This stress intensity is derived from the highest value across the thickness of a section of the general or local primary stresses plus primary bending stresses produced by design pressure and other specified design mechanical loads, but excluding all secondary and peak stresses. For solid rectangular sections, the allowable value of this stress intensity is 1.5 S_m.

The following criteria are shown in Table 6-2 along with the conformance method(s) that show the criteria are met.

6.3.1 Mechanical Criterion 1 (ME-1)

Criterion

Stresses on the Westinghouse control rod handle due to normal loading and handling shall not exceed allowable values anytime in life.

Discussion

This Criterion ensures that the control rod can be safely moved during receipt, initial installation, shuffling, removal, and preparation for disposal.

In the Westinghouse design, the support and the handle have been integrated with the control rod wings, which means that there is only one vertical weld where the two control rod wings are joined in the lifting handle.

During normal handling operations, the lifting handle is loaded with the weight of the control rod in air. In the stress analysis, this load is conservatively chosen as a concentrated force on the weld on the horizontal part of the handle. Figure 6-1 shows an example of the Finite Element Model of a double handled C-Lattice Westinghouse control rod. The applied force is assumed to be:

$$0.25 \times 2 \times \text{Control Rod Weight (in air)}$$

where:

0.25 = one fourth part of the handle (This value amounts to 0.5 for single handle designs)
2.0 = dynamic lifting factor (including a safety factor)

The maximum effective bending stress is then calculated on the horizontal part of the handle close to location of the applied load.

The maximum resulting effective stresses (P_m+P_b) must be lower than the corresponding allowable stresses. For the handle's material at 85°C, the allowable stress is $n \times 1.5\ S_m$, where n is the applicable welding factor according to Reference 16, Table NG 3352-1.

6.3.2 Mechanical Criterion 2 (ME-2)

Criterion

Stresses and fatigue in the Westinghouse control rod wings due to pressure differences (ΔP) across the walls shall not exceed allowable ASME values anytime in life.

Discussion

This criterion ensures that ASME Section III stress limits are met with the maximum outside to inside ΔP at beginning of life and maximum inside to outside ΔP at the end of life, throughout the complete lifetime of any Westinghouse control rod design.

6.3.2.1 Pressure Difference Determination

During reactor operation, the gas pressure in the control rod blades will increase with ^{10}B depletion from the initial filling gas pressure to the design pressure at EOL, and thus gradually change the differential pressure, ΔP, to its maximum across the walls of the blades. The differential pressure for which the blade stresses must be calculated is also a function of reactor temperature and system pressure.

Gas Pressure Buildup

[

]^{a,c}

Pressure Due to He Gas Remaining from Fabrication

[

]a,c

Total Gas Pressure Build-up

The total gas pressure in the blade is calculated according to:

$$P_{TOT} = P_{He} + P_{fill} \tag{6.4}$$

[

]a,c

Design Internal Rod Pressure

[

]a,c

[

]a,c

Total Differential Pressure

[

]a,c

6.3.2.2 Stress Determination

[

]^{a,c}

The highest stresses caused by this ΔP occur (1) in the ligaments between absorber holes, (2) in the outer wall of a blade adjacent to a section through an absorber hole and (3) in the control rod's outer edge, farthest from the centerline of the control rod. All stresses have sufficient margins to allowable stresses.

Due to the complicated geometry of the control rod, a three-dimensional FEM consisting of 20 node solid tetrahedral or brick elements is used. An example of this model is shown in Figure 6-4. In the model, all parameters are conservatively chosen. The calculations are carried out with the aid of a general purpose finite element computer program such as ANSYS (Reference 21). Calculated stresses are post processed by the FE program and linearized in accordance with the intent of the ASME code for the final evaluation.

The results of the stress computations are evaluated for each load case separately. The stress intensity limits are based on the S_m value and are summarized below (ASME Standard Section III, Division I, Article NB-3221 (Reference 16)).

Stresses due to Pressure Loads in the Control Rod Blade

[

]^{a,c}

<u>Blade Outer Wall Calculation</u>

[

]^{a,c}

<u>Edge Outer Wall Calculation</u>

[

]^{a,c}

Ligament Calculations

[

]a,c

All the calculated stresses at 300°C must be lower than the corresponding allowable stress limits discussed in Section 6.3.

6.3.2.3 Fatigue Calculation

During operation of the reactor, the gas pressure in the control rod blades will increase mainly due to helium release from the boron carbide, and thus gradually will change the pressure difference across the absorber hole walls. Furthermore, normal start-up and shutdown of the reactor results in more rapid variations of the differential pressure over the walls in the control rod blades.

Load cycling

[

]a,c

[

]^{a,c}

The alternating stresses are calculated as:

$$S_{alt} = K_t \frac{(P_L + P_b)}{2} \frac{E}{E_T} \quad (6.6)$$

[

]^{a,c}

6.3.3 Mechanical Criterion 3 (ME-3)

Criterion

Stresses and fatigue in Westinghouse control rods due to scram induced loads shall not exceed allowable values.

Discussion

This criterion ensures that ASME, Section III stress limits are met with any plant specific scram load throughout the lifetime of any Westinghouse control rod design.

6.3.3.1 Scram Load

Scram loads are given in Reference 22. During a reactor scram, the rods are hydraulically inserted in the reactor core and hydro-dynamically slowed at the end of the stroke. A scram load cycle is thus defined as a compressive scram force (acceleration) followed by a tensile scram force (deceleration). The maximum axial force in the velocity limiter and the socket occurs during the deceleration phase of the scram with cold reactor conditions, and assuming a failed buffer. This scram is considered a Level B load.

Scram of the reactor during the cold condition (85°C) is called cold scram, while reactor scram during normal reactor operation (300°C) is called hot scram. A "normal" scram at hot or cold conditions is considered a Level A load.

6.3.3.2 Forces and Stresses in the Velocity Limiter and the Socket

[

]^{a,c}

[

]^{a,c}

6.3.3.3 Fatigue Calculation in the Velocity Limiter and in the Socket

[

]^{a,c}

Membrane stresses (P_m) ensuing from tensile and compressive scram forces are calculated. The alternating stresses are calculated as:

$$S_{alt} = K_t P_m \frac{E}{E_T} \tag{6.7}$$

[

]^{a,c}

Finally, the cumulative usage factor, U is calculated by:

$$U = \frac{n_1}{N_1} + \frac{n_2}{N_2} \tag{6.8}$$

where:

n1, n2	=	number of cold and hot scrams ([ ]^{a,c}, respectively)
N_1, N_2	=	number of the cold and the hot scrams to failure, respectively

The total cumulative usage factor must be less than 1.0. [ ]^{a,c}

6.3.3.4 Combined Stress Determination in the Absorber Blade

It is assumed that a scram may occur at any time during reactor operation, that is, at both cold and hot conditions. Scram stresses occur in the blade wall in a section adjacent to an absorber hole, and thus must be superimposed on the pressure induced stresses for the operation condition analyzed.

Detailed Combined Stresses Analysis of the Control Rod Blade

[

]^{a,c}

[

]a,c

Blade Outer Wall Calculation

[

]a,c

Edge Outer Wall Calculation

The highest local primary membrane stress intensity (P_L) and local primary membrane plus bending stress intensity (P_L+P_b) across the thickness of the outer wall of the edge are calculated by the detailed FE analysis.

Ligament Calculations

The maximum stress intensity in a ligament is determined by the detailed FE analysis. This stress is the highest value across the thickness of a ligament of the local primary stress intensity (P_L) and local primary stress plus primary bending stress intensity (P_L+P_b).

[

]a,c

6.3.3.5 Fatigue Calculation for the Absorber Blade

The fatigue calculations are performed for the absorber blade under scram loads for both cold and hot scrams.

In the fatigue calculations, the following assumptions are made when calculating fatigue damage:

[

]^{a,c}

Finally, the cumulative usage factor, U, is calculated by equation (6.8):

$$U = \frac{n_1}{N_1} + \frac{n_2}{N_2}$$

where:

n1, n2 = number of cold and hot scrams ([ ]^{a,c}, respectively)
N1, N2 = number of cold and hot scrams to failure, respectively

The total cumulative usage factor must be less than 1.0. [
]^{a,c}

6.3.4 Mechanical Criterion 4 (ME-4)

Criterion

Calculated stresses in Westinghouse control rod wings due to [ ]^{a,c} shall not exceed values known to cause cracking.

Discussion

This criterion helps ensure that Westinghouse control rods reach end-of-life before the onset of cracking.

[

]^{a,c}

$$^{10}B + n \rightarrow 7Li + 4He + 2.8\ MeV$$

[

]a,c

6.3.4.1 [

]a,c

6.3.4.2 Differential Thermal Expansion

Thermal expansion is calculated from the information on the temperature field in the bodies involved. Thermal expansion proceeds according to the equation below.

[ ]a,c

[

]a,c

6.3.4.3 [

]a,c

Example

[

]a,c

[

]a,c

6.3.5 Mechanical Criterion 5 (ME-5)

Criterion

The Westinghouse control rod shall be capable of insertion into the core without structural damage in the presence of an oscillatory fuel (channel) deflection of [ ]^{a,c}.

Discussion

This criterion ensures that Westinghouse control rods are capable of insertion into the core in the unlikely event of relatively large earthquake induced oscillations of fuel channels (bundles). The rod must not be too stiff to adapt to the oscillating core during insertion.

Seismic behavior in terms of insertion time in an oscillating core is essentially determined by the specific bending stiffness and moment of inertia (MOI) of the control rod. The bending stiffness is a function of the blade span, the blade thickness, hole diameter and pitch. Other factors that affect the bending stiffness are the presence of hafnium pins.

Acceptable seismic behavior of the Westinghouse CR 85 control rod design [ ]^{a,c} and its capability to withstand seismic forces have been verified in Toshiba laboratory tests under simulated earthquake conditions (Reference 23). The seismic condition was simulated by oscillating the center of the four surrounding fuel channels. In addition, a misalignment between components was also introduced. Scram insertion time was measured for different channel deflection amplitudes, up to [ ]^{a,b,c}. The tests were performed at full operating pressure and temperature. Test results are shown in Figures 6-6 and 6-7 for BWR 2/3/4/5 which present time to 90% insertion as a function of channel deflection amplitude. Figure 6-8 shows test results for BWR-6 which presents time to 75% insertion as a function of channel deflection amplitude. As Figures 6-6 to 6-8 indicate, the Westinghouse control rod blade inserts for mid-span deflections according to Table 6-2.

Inspection of the control rod after the seismic test showed that there was no functional damage and no large deformation. This demonstrates that the control rod can withstand even extremely strong seismic forces.

The Westinghouse base design of control rod blades with drilled holes in solid plates implies a consistent rod stiffness in the beam mode. That is, the expected seismic behavior is the same for rods for the C-, D- and S-Lattices. [ ]^{a,c}

[ ]^{a,c}

[ ]^{a,c}

Table 6-1 Mechanical Related Critical Attributes for CR 99 Designs

Mechanical Critical Attribute	D–Lattice CR 99 Value or Range	C–Lattice CR 99 Value or Range	S–Lattice CR 99 Value or Range

a,c

Table 6-1 Mechanical Related Critical Attributes for CR 99 Designs (cont.)

Mechanical Critical Attribute	D–Lattice CR 99 Value or Range	C–Lattice CR 99 Value or Range	S–Lattice CR 99 Value or Range
Material strength properties T = 20°C Young's modulus, E Yield strength, $Rp_{0.2}$ Ultimate strength, R_m			
Material strength properties T = 85°C Young's modulus, E Yield strength, $Rp_{0.2}$ Ultimate strength, R_m Allowable Stress, S_m			
Material strength properties T = 300°C Young's modulus, E Yield strength, $Rp_{0.2}$ Ultimate strength, R_m Allowable Stress, S_m			

a,c

Table 6-2 Mechanical Related Critical Attributes for CR 99 Designs				
Criterion	Conformance Method(s)[1]	D-Lattice Reference 24	C-Lattice Reference 24	S-Lattice Reference 24
(ME-1) Section 6.3.1 Handle: Max effective stress (P_m+P_b) n = 0.65 for double handle n = 1.0 for single handle	Analyses (meets criteria)			
(ME-2) Section 6.3.2 Control Rod Blade Wings: Primary Membrane Stress Intensity (P_m), Local Membrane stress Intensity (P_L) and Local Membrane plus Primary Bending Stress Intensity (P_L+P_b) Cycles to Failure, CF > 200	Analyses (meets criteria)			
(ME-3) Section 6.3.3 Velocity Limiter and Socket: Primary Membrane Stress Intensity (P_m) at cold (85°C) and hot (300°C) conditions Fatigue usage factor U < 1 Control Rod Blade Wings: Primary Membrane Stress Intensity (P_m) at cold (85°C) and hot (300°C) conditions Local Membrane stress Intensity (P_L), and Local Membrane plus Primary Bending Stress Intensity (P_L+P_b) at 85°C and 300°C Fatigue usage factor U < 1	Analyses (meets criteria)			

a,c

Table 6-2 (cont.) Mechanical Related Critical Attributes for CR 99 Designs

a,c

Criterion	Conformance Method(s)[1]	D-Lattice Reference 24	C-Lattice Reference 24	S-Lattice Reference 24
(ME-4) Section 6.3.4 B_4C pin to hole wall gap: Initial gap wide enough to prevent hard contact due to swelling before EOL	Analyses (meets criteria)			
(ME-5) Section 6.3.5 Control rod insertion into the core during a seismic event without structural damage with an oscillary fuel (channel) deflection of [ ]a,c	Analyses, Test (meets criteria)			

Note:

1. See Section 4.2 for a discussion on Conformance Methods.

a,c

Figure 6-1 FEM Model of Handle

a,c

Figure 6-2 Helium Release vs ^{10}B Depletion

a,c

Figure 6-3 Design Pressure Curve

a,c

Figure 6-4 FE Model of a Section of the Blade Wing Structure

a,c

Figure 6-5 Blade Wing Sections in the Scram and Pressure Force Induced Stress Evaluation

a,b,c

Figure 6-6 Seismic Scram Insertion Test, D-Lattice

a,b,c

Figure 6-7 Seismic Scram Insertion Test, C-Lattice

a,b,c

Figure 6-8 Seismic Scram Insertion Test, S-Lattice

7 PHYSICS EVALUTION

7.1 CRITICAL ATTRIBUTES

The critical attributes for physics related items are given in Table 7-1. The values for the CR 99 control rod are also included in the table.

7.2 ATTRIBUTES DISCUSSION

7.2.1 Total Rod Worth

Rod worth calculations have been typically done using the PHOENIX code (Reference 26) to allow comparison of Westinghouse control rod worth to the worth of the rod it is replacing at various conditions simulating a range of reactor conditions. Results of these calculations are then used to confirm nuclear compatibility with the core.

PHOENIX single bundle calculations are made at three different conditions simulating various shutdown conditions:

1. Cold, clean critical - corresponding to the limiting shutdown condition,
2. Hot-Full power, zero void - corresponding to a location near the core inlet, and
3. Hot-Full power, 50% void - corresponding to the top of the core.

[

]a,c

For multiple absorber control rods, the calculations are done for each different absorber zone separately. The total control rod worth difference between the Westinghouse control rod and the replaced rod is then a weighted sum of the various zones. The weighting factors describe the axial power distributions and depend on the type of control rod and on the shutdown conditions, cold clean or hot.

The differences between Westinghouse control rods and the replaced rod using the above procedure vary only slightly for any lattice type control rod design as a function of fuel burn-up and fuel type.

7.2.2 Shutdown Margin (SDM)

In general, shutdown margin follows rod worth, i.e., higher worth translates to more shutdown margin. Westinghouse experience has shown the following to be a good estimate of the impact rod worth has on shutdown margin at limiting cold conditions:

[ ]a,c

where:

Δ SDM is the change in SDM, relative to an original equipment manufacturer's (OEM) rod
$\Delta\ k_{COLD}$ is the PHOENIX single bundle cold clean rod worth of the OEM rod

$$\Delta k = \frac{k_{\infty}^{\text{with CR}} - k_{\infty}^{\text{without CR}}}{k_{\infty}^{\text{without CR}}} (\%)$$

and RWD is the relative rod worth difference between the Westinghouse control rod and the rod it is replacing

$$RWD = \frac{\Delta k(\text{West}) - \Delta k(\text{OEM})}{\Delta k(\text{OEM})} \cdot 100(\%)$$

[

]a,c

For multiple absorber control rods, total SDM is a weighted sum of the various zones. [ ]a,c For an example of a CR 99 absorber material outline, see Reference 14. The total SDM change would be (Reference 28):

[ ]a,c

where:

$\Delta\ SDM_{Total}$ is the total change in shutdown margin and

$\Delta\ SDM_{Top}$, $\Delta\ SDM_{Mid}$ and $\Delta\ SDM_{Bot}$ are the shutdown margin changes in the top, mid and bottom zones respectively.

W_{Top}, WMid, and W_{Bot} are weighting factors that describe the axial flux distribution, as discussed in Section 7.2.1 above.

As with the calculation of total rod worth, there is only a slight ΔSDM dependence on fuel burn-up and fuel type.

7.2.3 LPRM Detector Signal Change

This calculation, which indicates the power distribution effect relative to the replaced rod, is also done using the PHOENIX code. Results of this calculation are used to ensure nuclear compatibility and negligible effect on the core monitoring system.

7.2.4 Nuclear End-of-Life (NEOL)

Many of the reload analyses performed, and core monitoring codes used in plants, assume that all control rods are new, full strength OEM control rods. For this assumption to remain valid for replacement rods, differences in replacement rod initial worth and allowable depletion relative to the OEM rods must be limited. Replacement rod initial worths of 95% to 105% of OEM initial worth, and allowable control rod depletion of 10% loss in reactivity from initial OEM rod worth, have been the historical limits for GE BWRs. Calculation of Westinghouse BWR control rod worth reduction is done using the PHOENIX/XYBDRY method described in Reference 27.

References 28-30 show calculated NEOL's for Westinghouse BWR CR 99 control rods based on the defined limit of 10% loss in reactivity from initial OEM rods.

7.3 PHYSICS CRITERIA AND DISCUSSION

The following criteria are shown in Table 7-2 along with the conformance method(s) required to confirm that the Criteria are met. CR 99 evaluation results are also shown.

7.3.1 Physics Criterion 1 (PH-1)

Criterion

Total Westinghouse control rod initial worth shall be within [ ]^{a,c} of the initial worth of the control rod it is replacing.

Discussion

This criterion helps ensure that any Westinghouse control rod design has nuclear compatibility with other rods in the core as well as helping to ensure that calculations performed by the installed core monitoring system remain valid. In addition, this criterion ensures that in-reactor response of the rod will be indistinguishable from the rod it replaces.

Results of calculations done for a specific lattice type control rod design vary only slightly as a function of burn-up and fuel type. Thus, calculations done at the time of initial design of a Westinghouse control rod for installation in a representative core will remain valid for the life of the rod and are valid for other similar lattice type cores.

7.3.2 Physics Criterion 2 (PH-2)

Criterion

The effect on shutdown margin due to the use of a Westinghouse control rod shall be such that:

$$SDM_{Westinghouse} \geq [\quad]^{a,c}\ SDM_{Replaced}$$

Discussion

This criterion helps ensure that core monitoring and reload related calculations, which are done assuming an OEM control rod is installed, remain valid.

As discussed in Section 7.2.2, results of calculations done for a specific lattice type control rod design vary only slightly as a function of burn-up and fuel type.

7.3.3 Physics Criterion 3 (PH-3)

Criterion

The difference seen by an LPRM detector due to the use of a Westinghouse control rod relative to the use of the replaced rod in the same location shall be less than or equal to [ ]^{a,c}.

Discussion

This criterion helps ensure that the calculations done by the core monitoring system remain valid as well as ensuring that local power distribution uncertainties are not significantly increased.

7.3.4 Physics Criterion 4 (PH-4)

Criterion

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.

Discussion

This criterion helps ensure that core monitoring and reload related calculations which are done assuming a fresh, OEM control rod is installed remain valid. A value of 90% of initial worth of an OEM rod in any quarter segment has been historically used for this limit in GE BWRs.

Use of a Westinghouse control rod past this historical limit is acceptable as long as the control rod worth is explicitly monitored in appropriate reload and core monitoring codes, mechanical limits for the projected longer life are investigated, and appropriate inspections are carried out after the Westinghouse control rod exceeds the 10% reactivity loss threshold. For such use, end of life for the Westinghouse control rod would occur when either of the following occurs:

- The worth of the rod decreases to the point where fuel costs are negatively impacted (i.e., loading pattern cannot be optimized due to the decreased worth of the rod), or
- A visual inspection detects an unacceptable crack.

[

]^{a,c}

[

]^{a,c}

For determination of stresses due to helium release with consequent pressure build-up, actual ^{10}B depletion is used. The correlation between ^{10}B depletion and helium release is specified as a function of actual depletion. In Section 6.3.2, an average value of [

]^{a,c}

Table 7-1 Physical Related Critical Attributes for CR 99 Designs

a,c

Physical Critical Attribute	D–Lattice CR 99 Value or Range	C–Lattice CR 99 Value or Range	S–Lattice CR 99 Value or Range
Total rod worth relative to replaced rod			
Shutdown margin relative to replaced rod			
LPRM detector signal change relative to replaced rod			
Nuclear End of L (10% worth decrease from OEM value) Top quarter segment 2nd and 3rd quarter segments Bottom quarter segment			

Table 7-2 Physics Criteria		
Criterion	Conformance Method(s)[1]	CR 99, D-, C- and S-Lattice Valuation Results
(PH-1) Total Westinghouse control rod initial worth shall be within [ ]^{a,c} of the initial worth of the control rod it is replacing.	Analyses	See Table 7.1 (meets Criterion)
(PH-2) The effect on shutdown margin due to the use of a Westinghouse control rod shall be such that: $SDM_{Westinghouse} \geq$ [ ]^{a,c} $SDM_{Replaced}$	Analyses	See Table 7.1 (meets Criterion)
(PH-3) The difference seen by an LPRM detector due to the use of a Westinghouse control rod relative to the use of the replaced rod in the same location shall be less than or equal to [ ]^{a,c}.	Analyses	See Table 7.1 (meets Criterion)
(PH-4) 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 rod quarter segment.	Analyses	See Table 7.1 (meets Criterion)

Note:

1. See Section 4.2 for a discussion on Conformance Methods.

8 OPERATIONAL EVALUATION

8.1 CRITICAL ATTRIBUTES

The critical attributes for operational related items are given in Table 8-1. The attribute values used for the CR 99 are also included in the table.

8.2 ATTRIBUTES DISCUSSION

8.2.1 Nominal Wing Thickness

The most important dimensional parameter with respect to compatibility with fuel and fuel channels is the control rod envelope discussed in Section 8.2.9 below. However, nominal wing thickness is also an important parameter that should be examined for different rod designs.

8.2.2 Maximum Button Thickness

Along with the envelope dimensions, this parameter is important with respect to fuel and channel compatibility. The button is the feature which touches the adjacent fuel channels, helping to keep the control rod centered in the gap between the fuel assemblies.

The CR 99 control rod can also be delivered with no button (Reference 13).

8.2.3 Maximum Wing Span

Maximum wing span is important to compatibility of the rod with core internals and CRD components (e.g., fit through the fuel support piece and fit in the guide tube).

8.2.4 Maximum Velocity Limiter Diameter (With Rollers Installed)

This parameter is important in ensuring compatibility with the CRD system, in particular the guide tube. The rollers on the end of the velocity limiter ride against the inside of the guide tube. The maximum diameter of the velocity limiter with the rollers installed must be such that the rod can travel freely up and down in the guide tube without binding.

8.2.5 Total Weight

Total weight for a control rod must be less than that for which the CRD system was designed.

8.2.6 Overall Length

Overall length is important with respect to interfacing with the CRD system and core internals.

8.2.7 Velocity Limiter/Coupling Design

The design of the velocity limiter is important with respect to the free fall velocity assumed in the Control Rod Drop Accident.

Coupling (socket) design is important since this component provides the control rod interface with the CRD system.

8.2.8 Handle Design

Westinghouse has manufactured control rods with both single and double handles. To ensure compatibility with the rod handling equipment, the handle design of the Westinghouse control rod should be checked against the design of the replaced rod.

In general, the original rods for D-Lattice plants were built with single handles, C-Lattice plants have a mix of single and double handle rods, and S-Lattice plants have double handle rods.The control rods can also be delivered with a core grid support, which allows all four surrounding bundles to be removed without needing a blade guide to hold the control rod in place, provided that the control rod is fully inserted. This means that the handle will be extended up to 2.8 in. (72 mm). When the rod is completely inserted, the support will extend into the core grid. When the rod is completely withdrawn, the handle will experience additional neutron fluence compared with the standard handle. This additional fluence does not limit the use of the rod since the handle is not stressed during operation.

8.2.9 Envelope

The envelope figure for a Westinghouse control rod shows the maximum thickness of the blade as well as the maximum allowed twist and bow along the full length of the control rod.

This envelope is checked for every control rod along its full length in a full length test fixture as part of the manufacturing process.

This envelope is important in determining proper rod interface with fuel, fuel channels, and other core internals.

8.3 OPERATIONAL CRITERIA AND DISCUSSION

The following criteria are shown in Table 8-2 along with the conformance method(s) required to confirm that the criteria are met. CR 99 evaluation results are also shown.

8.3.1 Operational Criterion 1 (OP-1)

Criterion

The Westinghouse control rod socket shall be compatible with the existing CRD coupling device (spud).

Discussion

A good coupling design ensures that (1) the control rod can be coupled to the drive when initially installed, (2) the control rod will remain coupled during operation, and (3) the control rod can be uncoupled when the rod is to be shuffled or removed.

8.3.2 Operational Criterion 2 (OP-2)

Criterion

The Westinghouse control rod weight shall be similar to the nominal weight of the OEM rod.

Discussion

The control rod can not significantly exceed the nominal weight of the OEM rod due to considerations of scram capability, scram times and free fall (rod drop) characteristics. However the control rod shall not be significantly below the weight of the OEM rod due to settling capability, which depends on the weight of the control rod to cause it to settle into its final position during normal insertion and withdrawal.

8.3.3 Operational Criterion 3 (OP-3)

Criterion

The Westinghouse control rod shall be compatible with existing fuel, fuel channels, and core internals.

Discussion

This criterion is important to ensure that normal operation and scram capability are not impacted, i.e., the control rod will not damage surrounding fuel channels, and will fit in the core.

8.3.4 Operational Criterion 4 (OP-4)

Criterion

The Westinghouse control rod shall be compatible with control rod handling equipment.

Discussion

This criterion would only be of concern in cases where the Westinghouse control rod handle design is different from that which it is replacing. Examples would be providing a double handled rod for a plant originally supplied with single handled rods or supplying rods with extended handles.

Compatibility with rod handling equipment is not a safety issue but, nevertheless, must be investigated to ensure that the handling equipment can move, install, and remove the control rods.

8.3.5 Operational Criterion 5 (OP-5)

Criterion

The Westinghouse control rod free fall velocity shall be consistent with the design basis velocity.

Discussion

This criterion (along with OP-2) ensures that any Westinghouse control rod design is consistent with the control rod free fall assumptions in the plant's Safety Analysis for the Control Rod Drop Accident.

The velocity limiter design for the CR 99 is identical to the design of the OEM control rods. This, in combination with control rod weights less than those assumed in the design of the CRD system, ensures that the CR 99 meets Criterion OP-5.

In addition, free fall velocity tests of Westinghouse control rods have been performed (Reference 32) that show that Westinghouse control rods meet this criterion.

8.3.6 Operational Criterion 6 (OP-6)

Criterion

The Westinghouse control rod shall not adversely affect scram times and settling capability in the reactor.

Discussion

In conjunction with OP-2, this criterion ensures that scram times will be consistent with those assumed in the plant's Safety Analyses. In addition, it ensures that any Westinghouse control rod design also settles normally when withdrawn or inserted which, while not a direct safety concern, is a necessary operational consideration.

8.3.7 Operational Criterion 7 (OP-7)

Criterion

Flow-induced vibration of the Westinghouse control rods shall not cause detrimental fretting of the rod or fuel channels.

Discussion

The criterion ensures that control rod vibration, which may be induced by coolant flow in guide tubes and/or in the core, does not have any adverse effect on the control rod or on adjacent fuel channels.

The Westinghouse control rod is designed to have similar clearances to guide tubes and fuel channels as the original control rod. As a result, flow velocities and flow patterns, and thus also rod vibrations, will not be significantly changed. In addition, interfacing surfaces between the control rod and channel are designed to have sufficiently large contact area to avoid fretting.

8.3.8 Operational Criterion 8 (OP-8)

Criterion

Mechanical End-of-Life (MEOL) for all new Westinghouse control rod designs should be greater than or equal to the Nuclear End-of-Life (NEOL).

Discussion

This criterion is set as a design goal. Nevertheless, historical in-reactor experience has shown that there is a possibility of unexpected cracking due to B_4C swelling, material cold work, IASCC, etc. In reality, a crack in a Westinghouse control rod has no impact on the safety function of the rod. Rather, the concern is with eventual wash-out of boron carbide, resulting in unmonitored control rod worth reduction. Hot cell examinations and neutron radiography in reactor pools have shown that the loss of B_4C in Westinghouse control rods with B_4C powder (e.g., CR 70) through leaching and washout is very limited in adjacent uncracked holes during the course of one or even several operating cycles. [

]^{a,c}

Westinghouse has a policy to follow lead control rods of each design to high burn ups by performing inspections. From these inspections, guidelines for operation and the need for further inspections of the various designs are formulated.

A lead CR 99 control rod has been operated in the Swedish Oskarshamn 3 BWR to almost 5 snvt, and then inspected with an acceptable result, i.e., no cracking. Furthermore, the margin for swelling has been increased in later CR 99 control rods, which is also the case for CR 99 rods that will be provided for US plants. Thus, the criterion of a MEOL that exceeds the NEOL is considered to be met.

Table 8-1 Operational Related Critical Attributes for CR 99 Designs

Operational Critical Attribute	D–Lattice CR 99 Value	C–Lattice CR 99 Value	S–Lattice CR 99 Value
Nominal wing thickness			
Maximum button thickness			
Maximum wing span			
Maximum velocity limiter diameter (with rollers installed)			
Nominal weight			
Overall length			
Velocity limiter/coupling (socket) design			
Handle design			
Envelope			

a,c

Table 8-2 Operational Criteria			
Criterion	**Conformance Methods(s)[1]**	**CR 99 C-Lattice Evaluation Results**	**CR 99 D- and S-Lattice Evaluation Results**
(OP-1) The Westinghouse control rod socket shall be compatible with the existing CRD coupling device (spud).	Experience Testing	Extensive data base of experience has shown that the design meets this criterion, i.e., the control rod couples with the spud, does not decouple inadvertently, and can be removed without problems. (meets criterion)	Extensive data base of experience has shown that the design meets this criterion, i.e. the control rod couples with the spud, does not decouple inadvertently, and can be removed without problems. (meets criterion)
(OP-2) The Westinghouse control rod weight shall be similar to nominal weight of OEM blades.	Testing Analysis	[ ]^{a,c} (meets criterion)	[ ]^{a,c} (meets criterion)
(OP-3) The Westinghouse control rod shall be compatible with existing fuel, fuel channels, and core internals.	Experience Testing Analysis	Extensive data base of experience has shown that the design meets this criterion, i.e., does not impact normal operation and scram times, does not damage surrounding fuel channels, and fits in the core internals. (meets criterion)	Extensive data base of experience has shown that the design meets this criterion, i.e. does not impact normal and scram times, does not damage surrounding fuel channels, and fits with the core internals. (meets criterion)
(OP-4) The Westinghouse control rod shall be compatible with control rod handling equipment.	Experience	Extensive data base of experience has shown that the design meets this criterion, i.e., all utilities installing the CR 99 design have been able to handle the rods without difficulty. (meets criterion)	Extensive data base of experience has shown that the design meets this criterion, i.e., all utilities installing the CR 99 design have been able to handle the rods without difficulty. (meets criterion)
(OP-5) The Westinghouse control rod free fall velocity shall be consistent with the design basis velocity.	Experience Testing	[ ]^{a,c} (meets criterion)	[ ]^{a,c} (meets criterion)

Table 8-2 Operational Criteria (cont.)			
Criterion	**Conformance Methods(s)[1]**	**CR 99 C-Lattice Evaluation Results**	**CR 99 D- and S-Lattice Evaluation Results**
(OP-6) The Westinghouse control rod shall not adversely affect scram times and settling capability in the reactor	Experience Testing Analysis	Extensive data base 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. (meets criterion)	Extensive data base 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. (meets criterion)
(OP-7) Flow-induced vibration of the Westinghouse control rods shall not cause detrimental fretting of the rod or fuel channels.	Experience Analysis	Extensive data base of experience has shown that the design meets this criterion, i.e., no fretting or wear on the control rods or fuel have been seen during examination. (meets criterion)	Extensive data base of experience has shown that the design meets this criterion, i.e., no fretting or wear on the control rods or fuel have been seen during examination. (meets criterion)
(OP-8) Mechanical End-of-Life (MEOL) for all new Westinghouse control rod designs shall be greater than or equal to the Nuclear End-of-Life (NEOL).	Inspection Analysis	See Section 8.3.8 (meets criterion)	See Section 8.3.8 (meets criterion)
Note: 1. See Section 4.2 for a discussion on Conformance Methods.			

a,c

Figure 8-1 Control Rod Tolerance Envelope D-Lattice, Base Design

a,c

Figure 8-2 Control Rod Tolerance Envelope C-Lattice, Base Design

a,c

Figure 8-3 Control Rod Tolerance Envelope S-Lattice, Base Design

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30. Westinghouse Atom Report BTF 03-202, Nuclear Design Characteristics of Westinghouse Atom Control Rod CR 99 for BWR4/5 C-Lattice Reactors, October 2003 (proprietary).

31. ABB Report UR 87-102 Rev. 1, "ASEA-ATOM Control Rods for BWR 2/3/4/5/6 Service Limit Recommendations," April 15, 1987 (proprietary).

32. Westinghouse Atom Report, BTA 02-154, L Plobeck, Test of Westinghouse atom Control Rods for BWR Dropping Speed, Oct. 2002 (proprietary).

Section C

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Direct tel: (412) 374-4643
Direct fax: (412) 374-4011
e-mail: greshaja@westinghouse.com

Our ref: LTR-NRC-04-31

May 19, 2004

TRANSMITTAL OF PROPRIETARY INFORMATION

Enclosed are:

1. 1 proprietary copy and 1 nonproprietary copy of Responses to RAIs on WCAP-16182-P & NP, "Westinghouse BWR Control Rod CR 99 Licensing Report"

Also enclosed is:

1. One (1) copy of the Application for Withholding, AW-04-1839 (Nonproprietary) with Proprietary Information Notice.
2. One (1) copy of Affidavit (Nonproprietary).

This information is being submitted by Westinghouse Electric Company LLC in response to the NRC's Request for Additional Information regarding WCAP-16182-P & NP.

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 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 affidavit or Application for Withholding should reference AW-04-1839 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: W. Macon
E. Peyton

A BNFL Group company

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230 0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Direct tel: (412) 374-4643
Direct fax: (412) 374-4011
e-mail: greshaja@westinghouse.com

Our ref: AW-04-1839

May 19, 2004

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: Responses to RAIs on WCAP-16182-P & NP, "Westinghouse BWR Control Rod CR 99 Licensing Report" (Proprietary)

Reference: Email from Mr. W. Macon (NRC) to Mr. R. Sisk (Westinghouse) "WCAP-16182 - CR 99 - RAIs," dated 4/19/04

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-04-1839 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-04-1839 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: W. Macon
E. Peyton

A BNFL Group company

AW-04-1839

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

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 and Plant Licensing

Sworn to and subscribed
before me this 19th day
of May, 2004

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 (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" 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 Responses to RAIs on WCAP-16182-P & NP, "Westinghouse BWR Control Rod CR 99 Licensing Report" (Proprietary), being transmitted by Westinghouse letter (LTR-NRC-04-31) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted for use by Westinghouse is expected to be applicable in other licensee submittals in response to certain NRC requirements for justification of the use of the CR 99 control rods.

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

(a) Provide CR 99 control rods to Licensees.

(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 similar information to its customers for purposes of supplying CR 99 control rods to BWR Licensees.

(b) Westinghouse can sell support and defense of the use of CR 99 control rods.

(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 services 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).

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Request for Additional Information
WCAP-16182-P/NP
Westinghouse BWR Control Rod CR 99 Licensing Report

1. **LTR Table 4-1 lists a matrix of the Design Requirements versus the Applicable Criteria used for the CR 99 evaluation. How do these requirements/criteria relate to the licensing requirements of SRP Section 4.2 and to the design requirements used for the approved CR 82 design?**

According to SRP Section 4.2.I, the review is to cover the following specific areas: (A) Design Bases, (B) Description and Design Drawings, (C) Design Evaluation, and (D) Testing, Inspection, and Surveillance Plans. In addition, Appendix A to the SRP requires control rod insertability following a Safe Shutdown Earthquake. Each of these, as required in Section 4.2.II generically for control rods, is discussed separately below as they apply to the CR 99 Westinghouse BWR Control Rod design.

Design Bases (SRP 4.2.II.A)
General Design Criteria 27 (and 28) – [

]^{a,c} This ensures (1) that there is sufficient reactivity throughout its lifetime to meet Criteria 27 in the same way as the OEM rods do and (2) reactivity limits associated with the OEM rod worth are met (Criteria 28). This holds for both the CR 99 and CR 82 designs. Specifically: see LTR Sections 4.1.1, 4.1.2, 4.1.3, 4.1.4, 7.2.1 through 7.2.4, 7.3.1 through 7.3.4, 8.2.5, 8.2.7, 8.3.5, and 8.3.6.

The CR 99 design meets the specified criteria for D, C, and S Lattice in US GE BWR's.

Stress, strain, and loading limits for the CR 99 control rods (SRP 4.2.II.A.1(a)) and cumulative number of strain fatigue cycles (SRP 4.2.II.A.1(b)) - Chapter 6 in the LTR discusses these items. The control rod is evaluated according to ASME Section III. Specifically: see LTR Sections 4.1.6, 5.2.1, 5.3.2, and 6.3.

The CR 99 design meets the requirements of these sections of the SRP for D, C, and S Lattice in US GE BWR's.

Dimensional changes regarding control rods (SRP 4.2.II.A.1(e)) - The same basic design has been operated for more than 30 years, including the approved CR 82. The control rods have been shown not to undergo any dimensional changes under operation. The CR 99 has this same basic design with the stainless steel sheets mounted together to form a cruciform shaped rod. From the outside, the CR 99 looks identical to the approved CR 82. This experience base is directly applicable to the CR 99. Specifically: see LTR Sections 4.1.1, 4.1.2, 4.1.3 5.3.3, 6.3.5, 8.2, and 8.3.1 through 8.3.7.

The CR 99 design meets the requirements of this section of the SRP for D, C, and S Lattice in US GE BWR's.

Control rod reactivity must be maintained (SRP 4.2.II.A.1(h)) - The control rods are designed such that rod worth is consistent with the plant safety analysis. [

]^{a,c} Surveillance that reactivity loss does not occur due to B_4C wash out has been performed by visual inspections and neutron radiography measurements. It has been shown that the basic concept of the Westinghouse BWR control rods, with the horizontally drilled absorber holes, retains boron carbide powder even in the case of cracking.

Regarding CR 99, the performance is considered to be even better since the [ ]^{a,c} are more inert than the powder. [ ]^{a,c}. Specifically: see LTR Sections 4.1.2, 4.1.4, 5.2.3, 7.2.1, 7.2.4, 7.3.1, 7.3.4, and 8.3.8. Also see the response to Question 16.

The CR 99 design meets the requirements of this section of the SRP for D, C, and S Lattice US GE BWR's.

Description and Design Drawings (SRP 4.2.II.B)

Outline drawings of CR 99 for D, C, and S Lattices are enclosed.

Design Evaluation (SRP 4.2.II.C)

Prototype Testing - Control Rod Structural and Performance Test (SRP 4.2.II.C.2) - The basic design of Westinghouse BWR control rods has been operated for more than 30 years, including the approved CR 82. The CR 99 has this same basic design with the stainless steel sheets mounted together to form an cruciform shaped rod. From the outside, the CR 99 looks identical to the approved CR 82. The absorber material is contained in horizontally drilled absorber holes – B_4C powder for the CR 82 and [ ]^{a,c} for the CR 99. A CR 99 has already been operated to the NEOL in the Oskarshamn 3 BWR in Sweden, with additional CR 99's currently in operation in the BWR6 Leibstadt, Forsmark 3, Isar, Oskarshamn 3, and KRB-II. The operational evaluation of the CR 99 is discussed in LTR Chapter 8.

The CR 99 design meets the requirements of this section of the SRP for D, C, and S Lattice in US GE BWR's.

Testing, Inspection, and Surveillance Plans (SRP 4.2.II.D)

Surveillance of control rods containing B_4C should be performed to ensure against reactivity loss - *Since the early 1980's, surveillances (visual inspections and neutron radiography* measurements), have been conducted which have demonstrated that reactivity loss does not occur due to B_4C wash out. It has been shown that the basic concept of the Westinghouse BWR control rods, with the horizontally drilled absorber holes, retains boron carbide powder even in the case of cracking. Regarding CR 99, the performance is considered to be even better since the [ ]^{a,c} are more inert than the powder. [ ]^{a,c}

A CR 99 has already been operated to the NEOL in the Oskarshamn 3 BWR in Sweden, with other CR 99's currently in operation in Leibstadt, Forsmark 3, Isar, Oskarshamn 3, and KRB-II. Lead control rods of this design have been, and will continue to be inspected to ensure that no cracking occurs prior to NEOL.

It is expected that the European experience will continue to lead the US in terms of burn-up, with all lead rod inspections there. In particular, a set of CR 99's delivered to Leibstadt are undergoing an extensive surveillance program, consisting of:

- Pre-characterization of the control rods, including blade profile measurements - completed
- Multi-cycle burn-up to reach moderate exposure (2-3 cycles) – on-going
- Visual and blade profile measurements to NEOL
- The blade profile measurements will allow us to verify that there is no hard contact between the [ ]^{a,c} and the wing material at NEOL. No hard contact means no swelling induced stresses are created, which is historically what leads to cracking in Westinghouse BWR control rods prior to NEOL.
- This verification will confirm that Operational Criteria 8 (LTR Section 8.3.8), mechanical end of life greater than nuclear end of life, is met.

The CR 99 design meets the requirements of this section of the SRP for D, C, and S Lattice US GE BWR's. Thus, there is no expectation of Westinghouse recommended inspections (lead use or normal operation) for US BWR's.

Appendix A

Control Rod insertability must be assured following a Safe Shutdown Earthquake (SSE) (SRP 4.2, Appendix A, section D.2(b)) – This section was written to ensure that any new fuel design would retain sufficient integrity following a SSE to allow control rod insertability. Nevertheless, when a new control rod design is introduced, this issue needs to be addressed going the other way, i.e., can the new control rod design survive the SSE with the existing fuel design?

This is discussed in Section 6.3.5 of the LTR and the response to Question 8.

The CR 99 design meets the requirements of this section of the SRP for D, C, and S Lattice in US GE BWR's.

Design Requirements relative to the approved CR 82 – The design requirements for the CR 99 are identical to the approved CR 82, although some of the methods and methodologies to show how they are met are not identical. See the answer to this question, as well as the other questions contained in this RIA for more insight into this. It should be noted here that Westinghouse plans to submit a LTR in the near future which updates and collates the information for the licensed CR 82 (which we now call the CR 82M-1) in a format identical to that presented in this LTR for the CR 99.

2. **In LTR Section 5.2.3 and Table 5-1, it is stated that the [proprietary] absorber material provides a higher effective density of the absorber. What is the nominal absorber "stack" density and the tolerances, or lower limit, to be achieved?**

The nominal density of the absorber material is [ ]^{a,c} There is no specified lower value for density. This is not necessary in that:

- [

  ]^{a,c}
- There is also a requirement on total absorber weight in a wing (weight after absorber is added – weight before added) which ensures that the correct amount of B_4C is added.

Additionally, the density is monitored to control the manufacturing process by our sub-supplier.

3. In LTR Table 5-1, values are given for materials related critical attributes for the CR 99 design. What are the equivalent values for the approved CR 82 materials?

To make the comparison clear the materials of the approved CR 82 is inserted in this modification of table 5.1 in the LTR.

a, c

4. **In LTR Table 5-2, materials criteria are provided, along with the conformance method and the evaluation results for the CR 99 design. What are the equivalent criteria/results for the approved CR 82 design?**

To make the comparison clear the approved CR 82 is inserted in this modification of table 5.2 in the LTR.

a, c

5. **LTR Table 6-1 provides the critical mechanical evaluation attributes/values for the CR 99 design. What are the equivalent values for the approved CR 82 design?**

The equivalent values of the approved CR 82 are shown in this modification of table 6.1 from the LTR. For this comparison, values for D-lattice CR 99 and CR 82 are shown to demonstrate the similarity of the rods. Results from comparison of C- and S-lattice rods lead to the same conclusions. D-lattice is chosen since the initial licensing work of the CR 82 describes rods for D-lattice.

a, c

a, c

[ ]

6. **LTR Section 6 provides an extensive overview of the mechanical evaluation process used for the CR 99 design. It would be helpful to the staff if a summary of the significant differences between this process and the mechanical evaluation analyses performed for the approved CR 82 design could be provided. Changes in methodology should be flagged, with citations to the appropriate references if not included in the LTR.**

There are no major changes in the structural part of the CR 99 control rod compared with the CR 82 control rod. The principle of a control rod with a cruciform absorber section, formed by four solid stainless steel sheets, which are welded together at the center, has been unchanged over the years. The absorber material resides in horizontally drilled holes in both types of rods. [

]^{a,c}

Since the 1980's, when the CR 82 was licensed by the NRC, fuel operation has generally underwent up-grading in power. Specific thermal loads have increased and demands on burn-up and life time have increased for both fuel and control rods. Despite the existence of these factors, Westinghouse has been able to continue to meet the additional demands by improvements in material, design and careful analysis.

In the course of applying to the Standard Review Plan (SRP), ASME III Code is employed for stress and fatigue evaluation. The basic underlying methodology concerning the use of ASME criteria in the evaluation has, in principle, been unchanged over the years. Nevertheless, the mechanical calculation methods used have been continuously improved. Finite Element Analyses (FEA) is now fully employed in the stress analyses as well as in thermal analyses of the absorber blade, with dimensional tolerances strictly implemented in the most conservative way.

Computer codes used for stress and temperature calculations have varied over the years. For CR 82 the 3D Finite Element (FE) code EUFEMI was used for the stress analysis and the 2D FE code ALEXANDER was used for temperature calculations. Today, ANSYS 7.1 is used for both thermal and stress analysis. [

]^{a,c}

The design pressure and temperature is set by the design of the plant reactor coolant system; whereas the internal pressure is determined by the He-gas release from the absorber and the system temperature effect on that gas. Design pressure, as it relates to control rod design, consists of (1) a maximum system pressure the control rod can be expected to experience and (2) a pressure difference across the holes (? P) used in the stress calculations.

The maximum system pressure expected during operation is specified as [
]^{a,c} The control rod can be expected to survive much higher absolute pressure[
]^{a,c}, but reactor vessel capability precludes this value from being reached. [ ]^{a,c}

Total ? P and its use in stress calculations are described in Section 6.3.2.1 of the LTR. [

]a,c See the table in the answer to Question 7.

As discussed in Section 6.3.2.1 of the LTR, the ? P varies over control rod lifetime and with reactor pressure/temperature. At BOL, external pressure exceeds internal pressure, while at EOL (the limiting case), internal pressure exceeds external pressure. [

]a,c

It should be noted that an analysis of the load-case with internal overpressure only results in an allowable differential pressure on the order of [ ]a,c However, dynamic (scram) loads must also be added to the stresses caused by the ? P, lowering the calculated margin to the stress limits at a design ? P of [ ]a,c

In order to prevent any confusion regarding design pressure, we are submitting an Addendum to Table 6-1 (page 6-18) of the LTR to specify both design pressure values.

Experience shows (as can be expected from the above discussion) that premature failure of Westinghouse BWR Control Rods is caused by stress corrosion cracking ensuing from B_4C swelling rather than by the gas pressure. [

]a,c The methodology for calculation of the design margins is discussed in LTR section 6.3.4.3.

7. **LTR Section 6 provides design and calculated values from the CR 99 mechanical design evaluation. Please provide, where possible, the equivalent values used for the approved CR 82 design, or explain why a direct comparison is not applicable.**

Calculated design values, that is stresses and strains ensuing from internal gas pressure build-up for the CR 99 design and CR 82 design in combination with operation (scram) induced loads, in both cases, comply with the ASME criteria cited in the LTR.

Stress analysis comparison of CR 99/CR 82 a, c

a, c

8. LTR Section 6.3.5 discusses seismic behavior for the Westinghouse CR 85 control rod design. Please provide a summary of the design differences between the approved CR 82 design and the tested CR 85 design.

a, c

Seismic tests of CR 85 control rods in Japan has shown that the control rods behave satisfactory in terms of insertion time.

For the CR 82 a bending stiffness (N/mm) was reported whereas for the CR 99 the moment of inertia (mm^4) has been calculated. The moment of inertia for CR 85, based on old calculations, was also mentioned in the LTR. The bending stiffness in terms of moment of inertia for CR 82 and CR 99 is estimated to be equal due to almost identical geometry (blade thickness, pitch, hole diameter and depth).

9. LTR Table 7-1 provides the critical physics related attributes for the CR 99 control rod. What are the equivalent values for the approved CR 82 design?

The equivalent values of the approved CR 82 are shown in this modification of Table 7.1 from the LTR. For this comparison, values for D-lattice CR 99 and CR 82 are shown to demonstrate the similarity of the rods. Results from comparison of C- and S-lattice rods lead to the same conclusions. D-lattice is chosen since the initial licensing work of the CR 82 describes rods for D-lattice.

a, c

[ ]

10. LTR Section 7 discusses the use of the PHOENIX code for determining the control rod worth attributes and the effect on the LPRM detector signal for the CR 99 control rod. Please describe the code model used for the approved CR 82 control rod evaluation and the effect of using a different model.

PHOENIX (NRC reviewed and approved in NRC Topical Report BR 91-402-P-A) is a two-dimensional transport theory and depletion code used for evaluation of the neutronic behavior of individual pins as well as whole fuel assemblies with and without control rods. In addition quadruple assembly configurations may be treated by PHOENIX. PHOENIX is also Westinghouse standard computer program for BWR to calculate reactivity quantities, fuel assembly power distributions and homogenized neutron cross-sections for input to the Westinghouse 3D-core simulator.

For CR 99 and CR 82, the same code model, PHOENIX, has been used for all nuclear physics calculation. New versions of PHOENIX and libraries have been introduced since the CR 82 was approved. However, this will not significantly influence the control rod calculations results.

11. LTR Section 7.2.4 discusses the use of the PHOENIX/XYBDRY method (Ref. 27) for control rod nuclear lifetime calculations and cites three references (Refs. 28-30) to show the calculated nuclear end-of-life values (NEOL's) for the CR 99 rods. Please provide these references or a detailed discussion of the method and the calculated results. Also describe the methods and results used for the approved CR 82 rods.

References 27 – 30 are enclosed. As mentioned in the answer to Question 10, the same model (PHOENIX) was used for both CR 82 and CR 99. The BWR control rod worth and worth depletion calculations are handled with the Westinghouse code package XYBDRY/PHOENIX. It consists of the following:

XYBDRY- Used for detailed depletion and resonance self-shielding calculation on the control rod and for detailed calculation of control rod boundary conditions and response properties with regard to interaction between absorber pins as well as surrounding materials.

PHOENIX- Westinghouse standard code for BWR lattice calculations.

For CR 99 and CR 82 the same code model, XYBDRY/PHOENIX, has also been used for the nuclear lifetime calculations. New versions of XYBDRY/PHOENIX and libraries have been introduced since the CR 82 was approved. However, this does not significantly influence the control rod calculations results.

The nuclear end-of-lifes (NEOL) for both CR 82 and CR 99 are based on the historical limits for GE BWRs, [ ][a,c] Thus the reactivity worth reduction for CR 99 or CR 82 will only decrease during control rod depletion to the level allowed for the OEM. This means that the criteria for the determination of the NEOL is consistent among CR 99, CR 82, and the OEM rods.

15 of 22

12. LTR Table 7-2 provides the physics criteria and evaluation results for the CR 99 rods. What are the equivalent criteria/results used for the approved CR 82 rods?

To make the comparison clear the approved CR 82 is inserted in this modification of Table 7.2 in the LTR.

a, c

[ ]

13. **LTR Section 7.3.4 discusses the applicability of the "historical" value of 90% of the initial rod worth, due to absorber depletion, as the basis for the NEOL limit. Also discussed is the use of explicit control rod worth representation in reload and core monitoring codes to extend the use of Westinghouse control rods beyond the historical limit. The use of visual inspections to verify acceptable mechanical performance is listed.**

    How is the effect of using different reload methodologies and different core monitoring codes accounted for in determining the physics criterion conformance? How does this contrast with the methodology used for the approved CR 82 rod evaluations?

    Westinghouse BWR control rods of different types, including CR82 and CR 99, have been applied in several countries with different reload methodologies and different fuel types. They are inserted in GE and KWU D, C, S-lattice BWRs as well as Westinghouse BWRs. As shown by a number of nuclear design calculations, the reactivity worth and its decrease during control rod depletion is quite insensitive to fuel type, and fuel depletion for a certain reactor type. The combined experience for these reactors show that no special effect regarding different reload methodologies are needed for the Westinghouse control rods.

    With respect to core supervision, the concept of matching reactivity worth for CR82, CR 99 and OEM is sufficient to secure that the impact of the control rods on the core is treated sufficiently well, even regarding the aspect of depleting control rods. A separate set of lattice parameters for the different control rods in a reactor is therefore only necessary if the OEM are exchanged with control rods with more than 5% higher reactivity worth. Also the positive experiences for such high-worth control rods in different reactors with different core monitoring systems support the fact that OEM, CR 82 and CR99 can be treated well by different core monitoring systems.

14. LTR Table 8-1 gives the critical operational related attributes and values for the CR 99 control rod. What are the equivalent attributes/values for the approved CR 82 rod?

The equivalent values of the approved CR 82 are shown in this modification of Table 8.1 from the LTR. For this comparison, values for D-lattice CR 99 and CR 82 are shown to demonstrate the similarity of the rods. Results from comparison of C- and S-lattice rods lead to the same conclusions. D-lattice is chosen since the initial licensing work of the CR 82 describes rods for D-lattice.

a, c

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15. LTR Table 8-2 shows the operational criteria and CR 99 evaluation results. What criteria/methods and evaluation results were used for the approved CR 82 rod evaluations?

The equivalent evaluation results of the approved CR 82 are shown in this modification of table 8.2 from the LTR. For this comparison, values for D-lattice CR 99 and CR 82 are shown to demonstrate the similarity of the rods. Results from comparison of C- and S-lattice rods lead to the same conclusions. D-lattice is chosen since the initial licensing work of the CR 82 describes rods for D-lattice.

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15. Continued

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15. Continued

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16. LTR Section 8.3.8 discusses the mechanical end-of-life (MEOL) design goal of greater than or equal to the NEOL for new control rod designs. Please discuss the formal Westinghouse policy to follow lead control rods of each design to high burnups by performing inspections. This is related to the Section 7.3.4 statement on use of visual inspections. What is the current process for formulating guidelines for operation and further inspections for the CR 99 rods and is this different from the approved CR 82 process?

Westinghouse has always followed a policy regarding BWR control rod blades that states that operating guidelines are based on visual inspections on leading blades of each type. That strategy was used for the CR 82 and the same strategy is also used to formulate operating guidelines for the CR 99. As mentioned in the LTR a CR 99 was inspected in Oskarshamn 3 in the summer of 2003 at the NEOL and was found to be intact. This inspection has verified the potential of the CR 99 control rod.

Westinghouse, together with the BWR6 Kernkraftwerk Leibstadt (KKL) in Switzerland, will perform an extensive surveillance program on a set of CR 99's delivered to Leibstadt, consisting of:

- Pre-characterization of the control rods, including blade profile measurements - completed
- Multi-cycle burn-up to reach moderate exposure (2-3 cycles) – on-going
- Visual and blade profile measurements to NEOL
- [

]a,c

This verification will confirm that Operational Criteria 8 (LTR Section 8.3.8), mechanical end of life greater than nuclear end of life, is met. Thus, there is no expectation of Westinghouse recommended inspections (lead use or normal operation) for US BWR's. Nevertheless, should this program identify a need to do inspections prior to NEOL, this recommendation will be passed on to utilities, as has been done for previous designs.

The process described above for CR 99 is no different than used for the CR 82. Lead blades were monitored, crack thresholds were determined (when less than NEOL), and inspection recommendations provided to utilities.

The enclosures provided with the Class 2 RAIs are considered proprietary and are not included in this Class 3 version.