May 6, 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-16072-P, REVISION 00, "IMPLEMENTATION OF ZIRCONIUM DIBORIDE BURNABLE ABSORBER COATINGS IN CE NUCLEAR POWER FUEL ASSEMBLY DESIGNS" (TAC NO. MB8721)

Dear Mr. Gresham:

On April 25, 2003, as supplemented by letters dated September 10, November 3, and December 5, 2003, and February 3, 2004, Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16072-P, Revision 00, "Implementation of Zirconium Diboride Burnable Absorber Coatings in CE Nuclear Power Fuel Assembly Designs," to the staff for review. On March 31, 2004, an NRC draft safety evaluation (SE) regarding our approval of WCAP-16702-P, Revision 00, was provided for your review and comments. By letter dated April 8, 2004, Westinghouse commented on the draft SE. The staff's disposition of Westinghouse's comments on the draft SE are discussed in the attachment to the final SE enclosed with this letter.

The staff has found that WCAP-16702-P, Revision 00, is acceptable for referencing in licensing applications for CE Nuclear Power designed pressurized water reactors to the extent specified and under the limitations delineated in the report and in the enclosed SE. The SE defines the basis for acceptance of the report.

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 an accepted version of this TR, including a non-proprietary version, within three months of receipt of this letter. The accepted version 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 in appendices historical review information, such as questions and accepted responses, draft SE comments, and original report pages that were replaced. The accepted version shall include a "-A" (designating accepted) following the report identification symbol.

If the NRC's criteria or regulations change so that its conclusions in this letter, that the TR is acceptable, is invalidated, Westinghouse and/or the licensees referencing the TR will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the TR without revision of the respective documentation.

Sincerely,

/RA/

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

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16072-P, REVISION 00,

"IMPLEMENTATION OF ZIRCONIUM DIBORIDE BURNABLE ABSORBER COATINGS

IN CE NUCLEAR POWER FUEL ASSEMBLY DESIGNS"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated April 25, 2003, as supplemented by letters dated September 10, November 3, and December 5, 2003, and February 3 and April 8, 2004, Westinghouse Electric Company (Westinghouse) requested review and approval of Topical Report (TR) WCAP-16072-P, Revision 00, "Implementation of Zirconium Diboride Burnable Absorber Coatings in CE Nuclear Power Fuel Assembly Designs." Zirconium diboride (ZrB_2) is coated onto the outer surface of the uranium dioxide (UO_2) fuel pellets prior to loading into the fuel rod cladding tubes rather than being mixed with the UO_2 directly as is done with other integral fuel burnable absorber (IFBA) materials. The large neutron absorption cross section of boron (B^{10}) holds down reactivity early in the cycle and permits longer full power operation. An advantage with ZrB_2 is that as the B^{10} neutron absorber depletes, no residual neutron absorber worth remains as is the case with erbium and gadolinium.

Westinghouse has considerable fabrication and operational experience with the ZrB_2 IFBA fuel designs within Westinghouse-designed pressurized-water reactors (PWRs). Approval of the TR would allow the ZrB_2 IFBA design in CE Nuclear Power (CE) 14x14 and 16x16 fuel assembly designs. In determining the acceptability of this TR, the staff reviewed four aspects of the ZrB_2 IFBA fuel implementation: (1) operating and fabricating experience, (2) fuel mechanical design, (3) safety analysis models and methods, and (4) design basis accident (DBA) radiological consequences.

2.0 REGULATORY EVALUATION

The use of ZrB_2 IFBA in Westinghouse fuel assembly designs was previously reviewed and approved as part of the VANTAGE5 fuel assembly TR, WCAP-10444, "Reference Core Report VANTAGE5 Fuel Assembly." Review of WCAP-16072-P focused on the potential impacts of extending this approved fuel design feature to CE 14x14 and 16x16 fuel assembly designs and their associated safety analysis methodologies.

Regulatory guidance for the review of fuel system designs and adherence to applicable General Design Criteria (GDC) is provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design."

In addition to review of the fuel system design and associated safety analysis methodologies, this safety evaluation (SE) addresses the impact of the proposed fuel design change on fission product inventory and transport assumptions used in DBA radiological consequence analyses. These assumptions form part of the bases of the DBA radiological consequences analyses performed to demonstrate compliance with:

- accident dose guidelines in Title 10 of the *Code of Federal Regulations* (10 CFR) 100.11, "Determination of exclusion area, low population zone, and population center distance," as supplemented by accident-specific criteria in Section 15, "Accident Analysis," of the SRP,
- accident dose criteria in 10 CFR 50.67, "Accident source term," as supplemented in Regulatory Position 4.4 of Regulatory Guide (RG) 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," and
- 10 CFR Part 50, Appendix A, GDC 19, "Control Room," as supplemented by Section 6.4, "Control Room Habitability System," of the SRP.

The current assumptions accepted by the staff, and to which the fission product inventory and transport for the proposed fuel design are to be compared, are provided in the regulatory guidance documents listed below. If there are no significant impacts on the previous assumptions, it can be reasonably determined that the prior analysis results continue to meet the regulatory requirements specified above.

- RG 1.4, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Pressurized Water Reactors"
- Safety Guide (SG) 25, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors"
- RG 1.77, "Assumptions Used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors"
- RG 1.183
- RG 1.195, "Methods and Assumptions for Evaluating Radiological Consequences of Design Basis Accidents at Light-Water Nuclear Power Reactors"
- SRP Section 15.0-1, "Radiological Consequence Analyses Using Alternative Source Term"
- SRP Section 15.3.3, "Reactor Coolant Pump Rotor Seizure"
- SRP Section 15.4.8, "Spectrum of Rod Ejection Accidents (PWR)," Appendix A

- SRP Section 15.6.5, "Loss-of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks Within the Reactor Coolant Pressure Boundary," Appendix A and Appendix B

3.0 TECHNICAL EVALUATION

The ZrB_2 IFBA fuel rod design consists of a ZrB_2 coating on the outer diameter of UO_2 fuel pellets over the center axial region of the fuel stack along with cutback regions (i.e., regions without ZrB_2 coating) on both ends of the fuel rod. Lower U^{235} enrichment fuel pellets may also be used in a portion of the cutback region. The cutback regions may consist of solid, annular, or a solid and annular fuel pellet combination. In determining the acceptability of this TR, the staff reviewed four aspects of the ZrB_2 IFBA fuel implementation: (1) operating and fabricating experience, (2) fuel mechanical design, (3) safety analysis models and methods, and (4) DBA radiological consequences.

3.1 Operating and Fabricating Experience

Since the approval of ZrB_2 IFBA in Westinghouse fuel assembly designs as part of the VANTAGE5 fuel design review, Westinghouse has accrued more than fifteen years of fabricating and operating experience. In its September 10, 2003, letter, Westinghouse provided details of the fabrication history of IFBA fuel rods. Westinghouse has fabricated a significant number of ZrB_2 IFBA fuel rods and these rods have irradiation experience in over 40 commercial nuclear plants. This historical database includes variations in B^{10} loading and variations in cutback regions (both solid and annular pellets). Westinghouse states that no fuel failures have been attributed to ZrB_2 IFBA fuel rod design in the substantial operational history within the Westinghouse fleet and at a CE-designed PWR (Fort Calhoun).

Westinghouse's letters dated September 10 and November 3, 2003, also identified post-irradiation examinations of ZrB_2 IFBA fuel rods. The post-irradiation examinations revealed no profilometry anomalies in the coated fuel pellet region, no chemical interaction between the coating and fuel rod cladding, no incipient cracks in the cladding inner diameter, no excessive fuel pellet cracking, nor any anomalies in the fuel structure. The ZrB_2 coating effectively remains in place throughout the service life of the fuel.

The substantial fabrication and operational databases along with the post-irradiation examinations demonstrate the reliability of ZrB_2 IFBA fuel rods. Based upon review of Westinghouse's ZrB_2 IFBA fuel experience, the staff finds no reason to anticipate fuel reliability problems with the implementation of ZrB_2 IFBA in CE fuel assembly designs.

3.2 Fuel Mechanical Design

The implementation of ZrB_2 IFBA fuel in CE fuel assembly designs will not necessitate any physical design changes to the fuel assemblies (fuel rod, spacer grid, support plates, etc.) nor changes to their materials. The ZrB_2 coating will slightly increase the fuel pellet diameter. In addition, to compensate for the helium production associated with the B^{10} depletion, the IFBA fuel design may employ annular fuel pellets (to provide additional void volume) and the initial helium fill gas pressure may be adjusted.

SRP Section 4.2.II.A defines fuel system damage and fuel rod failure mechanisms. Of these phenomena, the following are potentially impacted by the implementation of the ZrB_2 IFBA design in CE fuel assembly designs.

Fuel Rod Internal Pressure

Due to the no-clad-lift-off (NCLO) maximum pressure criterion established in CE TR CEN-372-P-A, "Fuel Rod Maximum Allowable Gas Pressure," the maximum predicted fuel rod internal pressures are constrained to prevent an outward clad creep rate that is in excess of the fuel radial growth rate anywhere locally along the entire active fuel length. Both ZrB_2 IFBA and non-IFBA fuel rods will continue to satisfy this fuel design limit.

Clad Stress

The NCLO pressure limit ensures that internal rod pressures are comparable between ZrB_2 IFBA and non-IFBA fuel rods. Since tensile cladding stresses are associated with internal fuel rod pressures, the tensile cladding stresses of the ZrB_2 IFBA fuel rods and the non-IFBA fuel rods will be comparable. Impacts of fill gas pressure on compressive cladding stresses are discussed below under cladding collapse.

Clad Strain

Westinghouse has evaluated the impact of rod internal pressure and the increased fuel pellet diameter for both the CE 14x14 and 16x16 fuel designs with the ZrB_2 IFBA fuel design. The approved FATES3B code is utilized to predict cladding strain as well as many other burnup dependent fuel performance parameters. The evaluations demonstrate that both fuel designs continue to satisfy the current cladding strain criteria.

Clad Fatigue

Westinghouse has evaluated the impact of rod internal pressure and the increased fuel pellet diameter for both the CE 14x14 and 16x16 fuel designs with the ZrB_2 IFBA fuel design. The approved FATES3B code is utilized to predict cladding strain during cyclic power maneuvers, core shutdowns, and anticipated operational occurrences (AOOs). The evaluations demonstrate that both fuel designs continue to satisfy the current cladding fatigue criteria.

Clad Collapse

Using approved methods including the CEPAN computer code, Westinghouse has evaluated the impact of rod internal pressure and the increased fuel pellet diameter for both the CE 14x14 and 16x16 fuel designs with the ZrB_2 IFBA fuel design. The evaluations demonstrate that both fuel designs continue to satisfy the current cladding collapse criteria in the active fuel region.

The Westinghouse evaluation of cladding collapse in the plenum region of the rods demonstrates that cladding collapse would not occur if the radial support offered to the cladding by the plenum spring was factored into the calculation. The staff had a concern with credit for radial support offered by the plenum spring since this was a deviation from established methodology (e.g., CENPD-404-P-A, "Implementation of ZIRLO Material Cladding in CE Nuclear Power Fuel Assembly Designs"), and not part of the design basis for this component.

In its December 5, 2003, letter, Westinghouse stated that no indication of cladding collapse in the plenum region has been observed in their considerable operating experience with ZrB_2 IFBA fuel rods. In addition, Westinghouse provided the results of autoclave tests (at elevated temperatures and pressures) on a variety of fuel rod designs with both zircaloy-4 and ZIRLO™ clad material. These autoclave tests and supporting ovality measurements demonstrate that clad collapse is essentially terminated upon hard cladding-to-spring contact. Furthermore, Westinghouse states that future autoclave tests will be performed, when needed, to verify adequate plenum spring support for CE fuel designs. Based upon operating experience, supporting autoclave tests, and a commitment to validate adequate plenum spring support in future applications, the staff finds it acceptable to credit the plenum spring for cladding collapse evaluations in the plenum region.

<u>Clad Oxidation and Hydriding</u>

Clad reaction rates and the associated degree of oxidation and hydriding will not be significantly impacted by the implementation of ZrB_2 IFBA fuel designs. However, an increase in rod internal pressure has the potential to promote radially-oriented hydride precipitates during plant cool down. In its February 3, 2004 letter, Westinghouse stated that the tensile stresses and peak temperatures for operation at NCLO conditions were concluded to be well below the magnitudes that might result in adverse hydride reorientation. In their response, Westinghouse also stated:

> It is the intention to address adverse hydride reorientation for conditions where the plant will recover and restart (Condition I & II). It is not intended to address reorientation for events where restart is not possible without further evaluation of fuel system damage (Condition III & IV events).

Since clad hydride reorientation was not addressed for these events, the staff has instituted a condition requiring that this issue be evaluated prior to restart following a Condition III or IV event.

<u>Pellet/Cladding Interaction</u>

Current criteria on cladding strain and fuel melting will continue to apply to ZrB_2 IFBA fuel design. Furthermore, Westinghouse has demonstrated via post-irradiation examinations of ZrB_2 IFBA fuel irradiated at the BR-3 reactor and the NRU reactor that no chemical reaction occurs between the ZrB_2 coating and its transmutation products and the cladding and that there is no adverse impact on the performance of the fuel rod.

Fuel Rod Ballooning and Bursting

During normal operations, the NCLO maximum pressure criterion (established in CEN-372-P-A) constrains fuel rod internal pressures to prevent an outward clad creep rate that is in excess of the fuel radial growth rate anywhere locally along the entire active fuel length. Both ZrB_2 IFBA and non-ZrB_2 fuel rods will continue to satisfy this fuel design limit.

During AOOs and postulated transients, fuel rods with elevated clad temperatures may experience outward clad creep even below the NCLO criteria. This phenomena raises concerns about excessive rod ballooning affecting neighboring fuel rods and even rod bursting.

The staff had concerns with the surge in rod internal pressure exhibited by the ZrB_2 fuel rods (depicted in Figures 4.2-3 and 4.2-4 of the TR) which increases the likelihood that rod internal pressure would exceed system pressure during the first operating cycle. In its September 10 and November 3, 2003, and February 3, 2004, letters, Westinghouse stated that predicted rod internal pressures were higher than expected due to the conservative models. However, Westinghouse would not commit to ensuring that rod internal pressures remained less than system pressures during the rod’s first cycle.

With the rapid build-up of rod internal pressure associated with ZrB_2, the likelihood of a single fuel rod exhibiting rod internal pressure (in excess of system pressure) concurrent with a rod power close to the peak pin is significantly increased. As a result, the probability of a fuel rod with rod internal pressure in excess of system pressure experiencing departure from nucleate boiling (DNB) induced elevated clad temperatures (during Condition III or IV non-loss-of-coolant accident (LOCA) events) is dramatically increased. The staff had concerns that the implementation of ZrB_2 would promote rod ballooning and even rod burst during these conditions.

In its September 10 and November 3, 2003, and February 3, 2004, letters, Westinghouse stated that clad burst was an acceptable mechanism and would be credited for terminating rod ballooning during ZrB_2 applications. In addition, Westinghouse also stated that an allowable rod burst philosophy was "implicitly recognized" in CEN-372-P-A. The staff does not agree with these assertions. Although fuel rod bursting is an acceptable phenomena explicitly recognized during lower probability LOCA and implicitly recognized during lower probability non-LOCA events (e.g., control element assembly ejection), the staff had concerns with extending fuel rod burst to all events that experience elevated clad temperatures. Furthermore, the staff had concerns that allowing clad burst would encourage the development of future clad materials which lack sufficient creep properties and reduce the defense-in-depth found in the existing licensing basis for the fission product barrier.

To avoid these issues, the staff has instituted a condition to preclude fuel clad burst during Condition I, II, and III events. For Condition IV non-LOCA events which predict clad burst, the potential impacts of fuel rod ballooning and bursting need to be specifically addressed with regard to coolable geometry, reactor coolant system (RCS) pressure, and radiological source term.

In conclusion, the staff recognizes fuel rod ballooning as a fuel coolability concern which must be addressed for all categories of events. Further, the staff recognizes fuel rod burst as a distinctive fuel failure mechanism which must also be addressed. Although both DNB-related clad failure and fuel rod burst involve elevated clad temperatures, the failure mechanisms are driven by different phenomena. As a result, fuel rod burst must be assessed independent of DNB-related clad failure.

Based upon review of the fuel system damage and fuel rod failure mechanisms, the staff finds the fuel mechanical design aspect of implementing the ZrB_2 IFBA design in CE fuel assembly designs acceptable subject to the limitations and conditions described in Section 4.0.

3.3 Safety Analysis Models and Methods

Changes in the fuel rod design introduced by the implementation of ZrB_2 IFBA design may include: (1) ZrB_2 coating on the fuel pellets in the central axial region of the fuel stack, (2) axial cutback regions with lower U^{235} enrichment, (3) axial cutback regions with annular pellets, and (4) an adjusted helium fill gas pressure. This section addresses the potential impact of these changes on safety analysis models and methods.

Core Physics

The neutron cross-sections and reaction rates of B^{10} have been modeled extensively with the currently approved Westinghouse core physics codes. PHOENIX-P and ANC are already licensed as the primary neutronic models for all Westinghouse reloads, most of which contain ZrB_2 IFBA fuel designs. Westinghouse has benchmarked DIT-ROCS to PHOENIX-ANC on plants containing erbia, gadolinia, and ZrB_2 IFBAs and has produced results that are essentially the same. Based upon Westinghouse's experience modeling boron and the equivalency of the computer codes, the staff finds the use of DIT-ROCS acceptable for the implementation of the ZrB_2 IFBA design in CE fuel assembly designs.

As a result of the rapid depletion of B^{10} in the ZrB_2 IFBA fuel design, peak soluble boron concentration may occur after beginning of cycle (BOC). As a consequence, peak positive moderator temperature coefficient (MTC) may occur later than BOC. Plant technical specifications (TS) surveillance requirements (SR) (e.g., Standard TS SRs 3.1.3.1 and 3.1.3.2) dictate MTC measurements to validate the physics predictions and ensure that plant operations remain within TS limits. The staff had concerns that current plant procedures for meeting these surveillance requirements may be inadequate based on an increasing trend in MTC at BOC.

In its December 5, 2003 letter, Westinghouse stated that they would recommend that the MTC SR be modified if several conditions existed. The staff believes that their concerns warrant an SE condition as opposed to a vendor's recommendation. As a result, the staff has instituted a condition requiring that licensees confirm that the peak positive hot full power (HFP) MTC is within the TS limits at the highest RCS soluble boron concentration predicted during full power operation. The peak positive HFP MTC shall be derived by adjusting the measured MTC at HFP BOC conditions to the maximum HFP soluble boron concentration expected during the cycle. Plant procedures used to perform MTC surveillance should be updated to reflect the calculated peak positive HFP MTC along with ZrB_2 IFBA's distinctive trend in RCS critical boron concentration.

Manufacturing tolerances associated with ZrB_2 IFBA fuel (e.g., B^{10} loading and axial cutback region variations) will impact detailed core physics predictions. In its September 10, 2003, letter, Westinghouse stated that these tolerances would be conservatively applied within local power peaking and stored energy calculations. The staff finds the application of these manufacturing tolerances acceptable.

Fuel Performance

In the TR and its September 10, 2003, letter, Westinghouse provided details of the FATES3B model and its application for ZrB_2 IFBA. The FATES3B models, including annular fuel pellets, have already been reviewed and approved by the staff. These models have been extensively benchmarked to experimental data, much of which contained annular fuel pellets.

Helium is generated as a result of the depletion of B^{10} in the ZrB_2 coating. Along with other fission gases, helium contributes to increased rod internal pressure. Updates to FATES3B for the implementation of ZrB_2 IFBA include B^{10} depletion and helium release equations. Westinghouse has benchmarked these new models to those already approved in the PAD fuel performance code and to detailed core physics depletions. The results show good agreement.

Based upon the information presented in the TR and in response to requests for additional information (RAIs), the staff finds the modified FATES3B models and their application acceptable for the implementation of the ZrB_2 IFBA design in CE fuel assembly designs.

Safety Analysis

For emergency core cooling system (ECCS) performance analyses, ZrB_2 IFBA fuel is represented via normal code input. ZrB_2 IFBA fuel characteristics are also input through interfaces with core physics and fuel performance models. However, in the ECCS performance models, solid fuel pellet models will be used to represent annular fuel pellets in the axial cutback regions. Westinghouse provided the results in the TR of demonstration analyses which establish that this modeling approach yielded conservative peak clad temperatures (PCT) and maximum cladding oxidation results. Based upon the conservative results, the staff finds this modeling approach acceptable.

Large break LOCA and small break LOCA demonstration analyses reported by Westinghouse reveal that aspects of ZrB_2 IFBA fuel designs, especially the impacts of rod internal pressure, have the potential to produce significant changes in the calculated results. The staff inquired about the plant-specific implementation analyses which would be necessitated by ZrB_2 IFBA fuel designs. In its December 5, 2003, letter, Westinghouse stated that determination of whether a full-blown LOCA analysis was required would be made via the normal reload design process and that the acceptance criteria and reporting criteria in 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," would be met. The staff finds this approach acceptable.

For non-LOCA safety analyses, the main challenge of the implementation of ZrB_2 IFBA fuel designs is the influence of the cutback regions on power distributions. Fuel pellets in the axial cutback regions at the top and bottom of the fuel stack will not be coated with ZrB_2 and may contain a lower U^{235} enrichment and consist of solid or annular pellets. Westinghouse evaluations of ZrB_2 IFBA fuel designs credit lower power peaking in these cutback regions such that these regions will never be limiting. As a result, plant-specific core design guidelines or cycle-specific calculations need to be used to verify that required power margins in the axial cutback regions are maintained within safety analysis limitations.

3.4 DBA Radiological Consequences

The staff review of the Westinghouse regulatory and technical evaluations contained in the TR revealed that they did not address the impact of the proposed fuel design change on assumptions used in DBA radiological consequences that relate to the inventory and transport of core fission products. Westinghouse responded in its September 10, 2003, letter to the staff's RAI specifically addressing this topic.

The staff's approach to this review was to establish that the changes proposed by Westinghouse would not adversely affect assumptions used in the DBA radiological consequences analyses. If this determination can be made, re-analysis of the affected events by applicants who reference this TR would not be necessary. The findings of this SE are based on the descriptions of the Westinghouse evaluations and other supporting information docketed by Westinghouse. During its review of the proposed fuel changes, the staff identified several possible impacts warranting evaluation and resolution.

Impact of the ZrB_2 Coating on the Source Term

The staff used the source term data provided in NUREG-1465, "Accident Source Terms Light-Water Nuclear Power Plants," for comparison rather than the earlier TID14844, "Calculation of Distance Factors for Power and Test Reactor Sites," since the NUREG-1465 data are more closely derived from observed phenomena than were the data in TID14844. The deterministic source terms in TID14844 are insensitive to the issues at hand. Numerous licensees have applied for and obtained authorization to use the source terms contained in NUREG-1465. The staff has determined that if the proposed changes can be shown to have minimal impact on the NUREG-1465 source term data then the same conclusion would also apply to the TID14844 data.

In response, Westinghouse states that the amount of fission products in the fuel rod gap is controlled by the temperatures of the inner regions of the pellets rather than the surface of the pellets. As such, the thin ZrB_2 coating is not expected to have a significant impact on the magnitude and mix of fission products in the fuel rod gap region given the relative cross-sectional dimensions of the fuel pellet and the coating. For accidents that progress beyond the release of gap activity, Westinghouse states that it is not credible that the ZrB_2 coating could significantly increase the magnitude and mix of fission products already projected to be released by NUREG-1465. The staff agrees that it is reasonable to assume that the ZrB_2 coating would not significantly effect the magnitude and mix of fission products and the timing of their release projected by NUREG-1465 for core melts associated with the early in-vessel release phase. The staff notes that the release assumptions provided in NUREG-1465 were based on sequences of severe accidents that involved substantial core damage. The mass of the added ZrB_2 coating is inconsequential in comparison to the mass of the other fuel and core constituents that would be involved in a core melt.

Westinghouse states that the mass of the ZrB_2 coating is small in comparison to the mass of metallic zirconium in the fuel pellets and fuel rod cladding. Also, the mass of cesium in the fuel matrix is on the order of ten times greater than the mass of radioiodine present. Thus, chemical reactions leading to cesium iodide are predominant. Westinghouse concludes that the added ZrB_2 will not affect the assumed chemical and physical form of released radioiodines. Westinghouse also stated that if the iodine were to combine with the slightly increased mass of zirconium to form zirconium iodide, there would not be significant impact on postulated doses since zirconium iodide, like cesium iodide, is an aerosol which is readily mitigated by natural processes and mitigation system operation. Based upon its consideration of the above information the staff has determined that there is reasonable assurance that the ZrB_2 coating will not impact existing source term assumptions.

Impact of Increased Helium Gas Pressure

With regard to the potential impact of increased helium gas pressure in the fuel pins on analysis assumptions regarding iodine scavenging by the spent fuel pool or reactor cavity, Westinghouse provided information that concludes that although there would be increased helium production in the fuel, it is not anticipated that the maximum internal fuel rod pressure for the ZrB_2 coated fuel would exceed the current design levels for CE plants. Westinghouse stated that the annular fuel pellets added to the fuel rods provide additional volume to contain the increased gas production. Also, cycle-specific core design constraints prevent current design pressures from being exceeded. In support of their conclusion, Westinghouse described an evaluation based on WCAP-7518-L, "Radiological Consequences of a Fuel Handling Accident," for fuel rod pressures of 1200 psig and 1500 psig. This evaluation determined that the iodine decontamination factors would be 580 and 473, respectively. The staff considered the methodology of WCAP-7518-L when it published SG 25. SG 25 provided a decontamination factor of 133 for fuel rod pressures up to 1200 psig. Westinghouse concluded that the factor provided in SG 25 would remain conservative. Based upon its consideration of the above information, the staff has determined that there is reasonable assurance that fuel rod design pressures of up to 1500 psig will not invalidate analysis assumptions related to iodine decontamination. The staff has also determined that this conclusion remains valid for the decontamination factor of 200 provided in RG 1.183 and RG 1.195, which supercede SG 25 for alternative source terms and TID14844 source terms, respectively.

Impact of the Annular Pellets on Fuel Gap Inventory

Westinghouse states that the potential impact of the annular pellets on fuel gap inventory will be small, as the fission product diffusion from within fuel grains and release from the grain boundaries will be the same for annular fuel pellets as for solid fuel pellets. Fission gas generation in the annular pellet would be proportionately larger at the same linear heat rate as for a solid pellet. The annular pellets constitute only about 10 percent of the active fuel length, typically the top and bottom 5 percent. In these regions of the core, the core power is lower and the linear heat generation rate is lower, resulting in lower pellet temperatures. Since the generation of fission products and the diffusion of fission products is proportional to temperature, there would be fewer fission products released to the fuel rod gap from the annular pellets. Westinghouse states that these differences were taken into account in the FATES3B fission gas analyses reported in the TR. Based upon its consideration of the above information, the staff has determined that there is reasonable assurance that the annular pellets will not significantly affect the fuel rod gap inventory.

Since these evaluations demonstrated that the changes did not have a significant impact on the DBA analysis assumptions, no dose calculations were necessary and none were performed.

4.0 CONDITIONS AND LIMITATIONS

Licensees referencing this TR to implement ZrB_2 IFBA in CE 14x14 and 16x16 fuel assembly designs must ensure compliance with the following conditions and limitations:

1. A license amendment is required to add this TR to the Core Operating Limits Report analytical methods listed in the licensee's TS.

2. Plant-specific core design guidelines or cycle-specific calculations shall be used to verify that required power margins in the axial cutback regions are maintained within safety analysis limitations.

3. Plant TS SRs on MTC validate the physics predictions and ensure that plant operations remain within allowable limits. In addition to current SRs, licensees shall confirm that the peak positive HFP MTC is within the TS limits at the highest RCS soluble boron concentration predicted during full power operation. The peak positive HFP MTC shall be derived by adjusting the measured MTC at HFP BOC conditions to the maximum HFP soluble boron concentration expected during the cycle. In order to ensure a conservative adjustment, a direct measurement of MTC is required at the highest RCS soluble boron concentration predicted during full power operation. This direct measurement is only required for the first application of ZrB_2 IFBA in a CE 14x14 or 16x16 fuel assembly design. During the first cycle implementation, Westinghouse shall provide the staff with a letter containing the following information:

    i. Measured HFP BOC MTC (TS SR),

    ii. Measured HFP MTC at highest RCS soluble boron concentration,

    iii. Calculated HFP MTC at highest RCS soluble boron concentration, and

    iv. Demonstrated accuracy of the calculated HFP MTC within current analytical uncertainties.

    In addition, plant procedures used to perform MTC surveillances shall be updated, where appropriate, to reflect the calculated peak positive HFP MTC along with ZrB_2 IFBA's distinctive trend in RCS critical boron concentration.

4. Prior to startup following a Condition III or IV event, licensees must evaluate clad hydriding to ensure that hydrides have not precipitated in the radial direction (in accordance with Section 3.2 of this SE).

5. CEN-372-P-A constraints and limitations with regard to rod internal pressure and DNB propagation must continue to be met. In addition, licensees must ensure that the following two conditions are satisfied:

   a. For Condition I (normal), Condition II (moderate frequency), and Condition III (infrequent) events, fuel cladding burst must be precluded for ZrB_2 IFBA fuel rods. Using models and methods approved for CE fuel designs, licensees must demonstrate that the total calculated stress remains below cladding burst stress at the cladding temperatures experienced during any potential Condition II or Condition III event. Within the confines of the plant's licensing basis, licensees must evaluate all Condition II events in combination with any credible, single active failure to ensure that fuel rod burst is precluded.

   b. For Condition IV non-LOCA events which predict clad burst, the potential impacts of fuel rod ballooning and bursting need to be specifically addressed with regard to coolable geometry, RCS pressure, and radiological source term.

5.0 CONCLUSION

The staff reviewed the effects of the proposed changes using the appropriate fuel design requirements of SRP Section 4.2 and 10 CFR Part 50, Appendix A, GDC and found that the TR provided reasonable assurance under both normal and accident conditions that CE fuel assembly designs implementing the ZrB_2 IFBA design would be able to safely operate and comply with NRC regulations.

The staff also reviewed the Westinghouse regulatory and technical evaluations related to the impact of the proposed fuel design change on the fission product inventory and transport assumptions used in DBA radiological consequence analyses. The staff finds the Westinghouse evaluations persuasive and supportive of the conclusion that the proposed fuel design will not significantly impact the fission product inventory and transport assumptions established in existing regulatory guidance and incorporated in current licensing basis analyses. The staff finds, with reasonable assurance, that should a design basis accident involving fuel of the proposed design occur, the radiological consequences will continue to comply with the applicable criteria identified in Section 2.0 of this SE. Therefore, the proposed fuel design is acceptable with regard to the radiological consequences of postulated design basis accidents.

Based upon its review of this TR, the staff finds WCAP-16072-P, Revision 00, acceptable. Licensees referencing this TR will need to comply with the conditions and limitations listed in Section 4.0 above.

Attachment: Resolution of Comments

Principal Contributors: S. LaVie
P. Clifford

Date: May 6, 2004

RESOLUTION OF COMMENTS

ON DRAFT SAFETY EVALUATION FOR TOPICAL REPORT WCAP-16072-P, REVISION 00,

"IMPLEMENTATION OF ZIRCONIUM DIBORIDE BURNABLE ABSORBER COATINGS

IN CE NUCLEAR POWER FUEL ASSEMBLY DESIGNS"

By letter dated April 8, 2004, Westinghouse provided comments on the draft safety evaluation (SE) for WCAP-16072-P, Revision 00, "Implementation of Zirconium Diboride Burnable Absorber Coatings in CE Nuclear Power Fuel Assembly Designs." The following is the staff's resolution of those comments.

1. Westinghouse Comment: Line 111, page 3, Section 3.1, "Operating and Fabricating Experience," first paragraph, last sentence – "Westinghouse claims that no ..."

   Westinghouse Proposed Resolution: "Westinghouse stated that no ..."

   NRC Action: The comment was fully adopted into the final SE.

2. Westinghouse Comment: Line 133-134, page 3, Section 3.2, "Fuel Mechanical Design," first paragraph – last sentence contained information that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: "... fuel design may employ annular fuel pellets (to provide void volume)."

   NRC Action: Last sentence now reads, "... and the initial helium fill gas pressure may be adjusted."

3. Westinghouse Comment: Line 147, page 4, Section 3.2, "Fuel Mechanical Design," "Fuel Rod Internal Pressure" – last sentence contained information that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: Delete last sentence.

   NRC Action: The comment was fully adopted into the final SE.

4. Westinghouse Comment: Lines 155-156, page 4, Section 3.2, "Fuel Mechanical Design," "Clad Stress" – last sentence contained information that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: "Impacts of a fill gas pressure on comprehensive cladding stresses are discussed below under cladding collapse."

   NRC Action: The comment was fully adopted into the final SE.

5. Westinghouse Comment: Line 168, page 4, Section 3.2, "Fuel Mechanical Design," "Clad Fatigue" – first sentence contained information that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: "Westinghouse has evaluated the impact of rod internal pressure and the increased fuel pellet diameter for both the 14x14 and 16x16 CE fuel designs with Zr B2 IFBA fuel design."

   NRC Action: The comment was adopted into the final SE.

6. Westinghouse Comment: Line 177, page 4, Section 3.2, "Fuel Mechanical Design," "Clad Collapse" – first sentence contained information that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: "... Westinghouse has evaluated the impact of rod internal pressure and the increased fuel pellet diameter for both ..."

   NRC Action: The comment was fully adopted into the final SE.

7. Westinghouse Comment: Lines 208-210, page 5, Section 3.2, "Fuel Mechanical Design," "Clad Oxidation and Hydriding" – last sentence reads "Since clad hydride reorientation was not addressed for these events, the staff has instituted a condition requiring that this issue be evaluated prior to restart following a Condition III or IV event."

   Westinghouse Proposed Resolution: Delete this sentence.

   NRC Action: The staff changed the text to clarify their position. Per telephone conferences on April 21 and April 22, 2004, the staff agreed to clarify the wording of lines 206-208 to read "Westinghouse also stated: It is the intention to address adverse hydride reorientation for conditions where the plant will recover and restart (Condition I & II). It is not intended to address reorientation for events where restart is not possible without further evaluation of fuel system damage (Condition III & IV events.)"

8. Westinghouse Comment: Lines 227-263, page 6, Section 3.2, "Fuel Mechanical Design," "Fuel Rod Ballooning and Bursting" – second, third, fourth, fifth and sixth paragraphs contained information that Westinghouse requested to be clarified.

   Westinghouse Proposed Resolution: Significant rewording of these paragraphs was proposed.

   NRC Action: Original paragraphs retained. To clarify the staff's position, a new paragraph was inserted between the original fifth and sixth paragraphs: "In conclusion, the staff recognizes fuel rod ballooning as a fuel coolability concern which must be addressed for all categories of events. Further, the staff recognizes fuel rod burst as a distinctive fuel failure mechanism which must also be addressed. Although both DNB-related clad failure and fuel rod burst involve elevated clad temperatures, the failure mechanisms are driven by different phenomena. As a result, fuel rod burst must be assessed independent of DNB-related clad failure."

9. Westinghouse Comment: Line 274, page 7, Section 3.3, "Safety Analysis Models and Methods" – Item 4 contained information that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: "... (4) initial helium fill gas pressure."

   NRC Action: The comment was adopted into the final SE as "... (4) an adjusted helium fill gas pressure."

10. Westinghouse Comment: Lines 297-301, page 7, Section 3.3, "Safety Analysis Models and Methods," "Core Physics" – second paragraph, last two sentences read "Further, until licensees have experienced several cycles of an increasing trend in RCS soluble boron concentration, a direct measurement of MTC is prudent. As a result, the staff has instituted a condition requiring that licensees confirm by direct measurement that the peak positive MTC is within the TS limits at the highest RCS soluble boron concentration predicted during Mode 1 operation."

    Westinghouse Proposed Resolution: Delete these two sentences or change the wording with a proposed rewrite.

    NRC Action: Per telephone conferences on April 21 and April 22, 2004, the staff agreed to clarify this paragraph with the wording as it appears in the final SE.

11. Westinghouse Comment: Lines 322-324, page 8, Section 3.3, "Safety Analysis Models and Methods," "Fuel Performance" – third paragraph contained information that Westinghouse considered proprietary.

    Westinghouse Proposed Resolution: Delete this paragraph.

    NRC Action: The comment was fully adopted into the final SE.

12. Westinghouse Comment: Lines 326-330, page 8, Section 3.3, "Safety Analysis Models and Methods," "Fuel Performance" – fourth paragraph contained information that Westinghouse considered proprietary.

    Westinghouse Proposed Resolution: Delete this paragraph.

    NRC Action: The comment was fully adopted into the final SE.

13. Westinghouse Comment: Lines 472-475, page 11, Section 4.0, "Conditions and Limitations" – third bullet reads, "Plant TSs SRs on MTC validate the pyhisics predictions and ensure that plant operations remain within allowable limits. In addition to current SRs, licensees shall confirm by direct measurement that the peak positive MTC is within the TS limits at the highest RCS soluble boron concentration predicted during Mode 1 operations."

Westinghouse Proposed Resolution: Delete this item or change the wording with a proposed rewrite.

NRC Action: Per telephone conferences on April 21 and April 22, 2004, the staff agreed to clarify this item with the wording as it appears in the final SE.

14. Westinghouse Comment: Lines 477-478, page 11, Section 4.0, "Conditions and Limitations" – fourth bullet reads "Prior to startup following a Condition III or IV event, licensees must evaluate clad hydriding to ensure that hydrides have not precipitated in the radial direction."

    Westinghouse Proposed Resolution: Delete this item.

    NRC Action: Original item retained, with reference to Section 3.2 of the SE.

15. Westinghouse Comment: Lines 480-481, page 11, Section 4.0, "Conditions and Limitations" – fifth bullet reads "CEN-372-P-A constraints and limitations with regard to rod internal pressure, hydride reorientation, and DNB propagation must continue to be met."

    Westinghouse Proposed Resolution: "CEN-372-P-A constraints and limitations with regard to rod internal pressure and DNB propagation must continue to be met."

    NRC Action: The comment was fully adopted into the final SE.

16. Westinghouse Comment: Lines 481-482, page 11, Section 4.0, "Conditions and Limitations" – fifth bullet reads "In addition, licensees must ensure that the following two conditions are satisfied:"

    Westinghouse Proposed Resolution: "In addition, when addressing DNB propagation, licensees must ensure that the following two conditions are satisfied:"

    NRC Action: Original wording retained.

17. Westinghouse Comment: Lines 484-494, page 11, Section 4.0, "Conditions and Limitations" – fifth bullet, Item a reads "For Condition I (normal), Condition II (moderate frequency), and Condition III (infrequent) events, fuel cladding burst must be precluded for all fuel types. Using current models and methods approved for CE fuel designs, licensees must demonstrate that the total calculated stress remains below cladding burst stress at the cladding temperatures experienced during any potential Condition II or Condition III event. To ensure that fuel rod burst is precluded, licensees must evaluate all Condition II events in combination with any credible, single active failure. The selection of limiting single failure shall include a loss of offsite power (LOAC). Unless the staff has previously approved a time delay for a LOAC following turbine trip for this category of event, the timing of the LOAC shall be coincident with reactor trip breakers open."

Westinghouse Proposed Resolution: "For Condition I (normal), Condition II (moderate frequency), and Condition III (infrequent) events, fuel cladding burst must be precluded for CE ZrB_2 rods using currently approved creep and rupture models approved for CE fuel designs."

NRC Action: The comment was partially adopted into the final SE. Per telephone conferences on April 21 and April 22, 2004, the staff agreed to clarify this item with the wording as it appears in the final SE.

18. Westinghouse Comment: Lines 496-498, page 11, Section 4.0, "Conditions and Limitations" – fifth bullet, Item b reads "For Condition IV non-LOCA events which predict clad burst, the potential impacts of fuel rod ballooning and bursting need to be specifically addressed with regard to coolable geometry, RCS pressure, and radiological source term."

Westinghouse Proposed Resolution: Delete this statement.

NRC Action: Original wording retained.