September 12, 2001

Mr. Philip W. Richardson, Manager
Windsor Nuclear Licensing
Westinghouse Electric Company
2000 Day Hill Road
Windsor, CT 06095

SUBJECT: SAFETY EVALUATION OF TOPICAL REPORT CENPD-404-P, REVISION 0, "IMPLEMENTATION OF ZIRLO MATERIAL CLADDING IN CE NUCLEAR POWER FUEL ASSEMBLY DESIGNS" (TAC NO. MB1035)

Dear Mr. Richardson:

The NRC staff has completed its review of the subject topical report which was submitted by CE Nuclear Power LLC (CENP) by letter dated January 22, 2001, as supplemented by letters dated May 3, August 10 (two letters), and August 27, 2001. It should be noted that during the period between the submittal of this topical report (CENPD-404-P) and the issuance of this safety evaluation (SE), CENP the original submitting company has undergone an organizational change. CENP was a company owned by Westinghouse LLC (WEC). CENP has merged into WEC and no longer exists. Accordingly, references in the attached SE to the former name (e.g., CE Nuclear Power LLC or CENP) are understood to be equivalent to references to WEC. However, in order to differentiate between the parts of WEC, this SE uses CENP to refer to the part of WEC that formerly existed as CENP.

ZIRLO is a zirconium-based fuel rod cladding material which the NRC previously reviewed and approved for use by WEC, the ZIRLO developer. The intent of the current submittal was to obtain NRC review and approval to implement ZIRLO fuel rod cladding in CENP designed nuclear power plants. The subject topical report provides justification for applying NRC-approved ZIRLO properties and correlations in NRC-approved CENP design and licensing analysis methodologies.

The staff has found that CENPD-404-P, Revision 0, "Implementation of ZIRLO Cladding Material in CE Nuclear Power Fuel Assembly Designs" is acceptable for referencing in licensing applications for CE designed nuclear power plants to the extent specified and under the limitations delineated in the report and in the associated SE. The safety evaluation defines the basis for acceptance of the report.

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room for a period of ten (10) working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the SE is proprietary, please identify such information line by line and define the basis pursuant to the criteria of 10 CFR 2.790.

We do not intend to repeat our review of the matters described in the subject report, and found acceptable, when the report appears as a reference in license applications, except to ensure that the material presented applies to the specific plant involved. Our acceptance applies only to matters approved in the report.

In accordance with procedures established in NUREG-0390, the NRC requests that WEC publish accepted versions of the submittal, proprietary (-P) and non-proprietary (-NP), within 3 months of receipt of this letter. The accepted versions shall incorporate (1) this letter and the enclosed safety evaluation between the title page and the abstract, and (2) all requests for additional information from the staff and all associated responses, and (3) an "-A" (designating "accepted") following the report identification symbol.

Should our criteria or regulations change so that our conclusions as to the acceptability of the report are invalidated, WEC and/or the applicants referencing the topical report will be expected to revise and resubmit their respective documentation, or submit justification for the continued applicability of the topical report without revision of their respective documentation.

Sincerely,

/RA by Stephen Dembek for/

Stuart A. Richards, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 692

Enclosure: Safety Evaluation

cc w/encl: See next page

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*Memo transmitting Safety Evaluation

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT CENPD-404-P, REVISION 0,

"IMPLEMENTATION OF ZIRLO CLADDING MATERIAL IN CE NUCLEAR POWER FUEL ASSEMBLY DESIGNS"

PROJECT NO. 692

1.0 INTRODUCTION

By letter dated January 22, 2001, CE Nuclear Power LLC (CENP) submitted Topical Report CENPD-404-P Revision 0, "Implementation of ZIRLO Cladding Material in CE Nuclear Power Fuel Assembly Designs" (CENPD-404-P) (Reference 1), for review and approval by the U.S. Nuclear Regulatory Commission (NRC). Additional information was submitted by letters dated May 3, 2001, August 10, 2001 (two letters) and August 27, 2001 (References 2-5). ZIRLO is a zirconium-based fuel rod cladding material, which the NRC previously reviewed and approved (Reference 6) for use by Westinghouse Electric Company LLC (WEC), the ZIRLO developer. The intent of the current submittal was to obtain NRC review and approval to implement ZIRLO fuel rod cladding in CENP designed nuclear power plants. The NRC has previously reviewed and approved the various fuel design and licensing methodologies employed by CENP and the requested implementation of the ZIRLO fuel rod cladding will not change those or the manner in which they are used. The ZIRLO material properties and correlations will also remain unchanged, as will the CENP phenomenological models that the NRC previously reviewed and approved. Thus CENP submitted the subject topical report solely to provide justification for applying NRC-approved ZIRLO properties and correlations in NRC-approved CENP design and licensing analysis methodologies.

It should be noted that during the period between the submittal of this topical report (CENPD-404-P) and the issuance of this safety evaluation (SE), CENP the original submitting company has undergone an organizational change. CENP was a company owned by WEC. CENP has merged into WEC and no longer exists. Accordingly, references in this SE to the former name (e.g., CE Nuclear Power LLC or CENP) are understood to be equivalent to references to WEC. However, in order to differentiate between the parts of WEC, this SE uses CENP to refer to the part of WEC that formerly existed as CENP.

OPTIN, the Zircaloy-4 fuel cladding material that is currently used in CENP plants, is nearing its performance limits in high-duty applications. Since small amounts of oxide spalling have been observed on OPTIN clad fuel in CENP plants, a more robust cladding with respect to corrosion and dimensional stability is desired. Use of ZIRLO cladding has been widespread since its approval in 1991. No spallation has been observed on ZIRLO clad fuel, and the oxidation is significantly reduced compared to that with Zircaloy-4. Consequently, CENP plant licensees are interested in using ZIRLO-clad fuel to support more economic core designs and power uprates.

CENPD-404-P summarizes the ZIRLO material properties as they pertain to fuel rod cladding and provides an evaluation of these properties and the correlations that CENP intends to use in design and licensing analysis activities. CENPD-404-P also identifies the specific CENP topical reports that would be impacted by the implementation of ZIRLO cladding, and describes the substitutions that would be required as a result of the proposed ZIRLO implementation. In addition, CENPD-404-P provides the information needed to implement ZIRLO thereby precluding the need for CENP to revise and the NRC to review the dozen or more individual topical reports. As a result, those affected individual topical reports and the associated NRC SEs will remain the licensing basis for their subject methodologies, as modified by the implementation of the material properties described in CENPD-404-P. Nothing in any of the previously NRC-approved topical reports has been changed, with the exception of the linking of the information in one to the other for the purpose of gaining NRC approval for the use of ZIRLO-clad material in CENP designed fuel assemblies and the analysis of those fuel assemblies and the cores in which they reside.

Areas in which evaluations are performed include fuel performance, mechanical design, emergency core cooling system (ECCS) performance analysis (loss-of-coolant accident (LOCA)), non-LOCA transient analysis, and nuclear engineering (physics). Examples of these evaluations were performed to demonstrate that the impact on performance (thermal, mechanical, LOCA, non-LOCA, physics) was as expected and is generally small or negligible. In addition, since the ZIRLO cladding will be implemented in Zircaloy-4 cages with no changes to structural materials, CENPD-404-P provided a review of Westinghouse experience with ZIRLO cladding and Zircaloy-4 structural components to justify full batch implementation in CENP fuel design.

2.0 EVALUATION

Since the NRC staff previously reviewed and approved the use of ZIRLO cladding material, the review of CENPD-404-P focused on the applicable WEC ZIRLO experience, implementation in CENP plants, and issues that have arisen since the original ZIRLO approval in 1991. In the course of the review, the NRC staff held meetings and weekly teleconferences (June - August 2001) with WEC in order to expedite the review process. The staff asked many questions and requested clarifications and additional information in many areas. By letter dated August 10, 2001 (Reference 3), WEC provided its responses to the staff's requests. As part of its review the staff examined the following areas: fuel performance, mechanical design, ECCS performance analysis, non-LOCA transient analysis, and nuclear engineering. In addition, the staff focused its review on four specific areas, including (1) batch implementation without lead test assemblies, (2) the fuel rod fretting problems in WEC fuel that was previously manufactured for a CENP plant, (3) the use of Zircaloy-4 properties and correlations instead of measured ZIRLO properties and specifically ZIRLO correlations, and (4) questions regarding ductility of Zirconium 1 percent Niobium cladding.

2.1 Batch Implementation

Batch implementation of a new cladding material such as ZIRLO would normally be preceded by a series of lead test assemblies designed to demonstrate the performance of the cladding material. In this case, batch implementation without lead test assemblies was requested because of the extensive use of ZIRLO in WEC-designed reactors prior to this application and because CENP has had good fuel performance experience with advanced cladding alloys that are similar to ZIRLO. The WEC experience includes more than 1 million ZIRLO fuel rods in assemblies with ZIRLO and Zircaloy-4 optimized fuel assembly type spacer grids without incidence of leakers due to grid-to-rod fretting.

As the industry has moved toward greater plant operating efficiencies and the economic benefits derived from higher power ratings, extended burnups, and higher operating temperatures, the resulting harsher core environments have placed greater demands on the fuel. These aggressive fuel duty conditions include high fuel rod surface temperatures, with subcooled boiling and high power densities at longer residence times. With more demanding pressurized-water-reactor (PWR) fuel duties has come closer evaluation of the corrosion resistance of the fuel cladding. The OPTIN cladding is nearing its limits in terms of corrosion. High corrosion levels and some small areas of spallation have been observed on OPTIN fuel rods that are subjected to these demanding conditions. ZIRLO-clad fuel has operated in higher duty and more demanding conditions without excessive corrosion and no oxide spallation observed. The staff has reviewed the information and data provided on comparisons of corrosion, and agrees that ZIRLO is the superior material from a corrosion standpoint. Although ZIRLO is approved to burnup levels of 62 GWD/MTU for Westinghouse, CENPD-404-P requested approval to only 60 GWD/MTU for use in CENP plants in order to keep it consistent with the approved burnup level for CENP methodologies.

As previously stated, only the OPTIN cladding will be replaced with ZIRLO cladding. The structural material including the grids will continue to be Zircaloy-4. Also, because several factors contribute to grid-to-rod fretting, CENP evaluated the effect of using ZIRLO cladding in the CENP fuel designs by assessing the difference that would be expected in each contributing factor. On the basis of these results, CENPD-404-P stated that the implementation of ZIRLO cladding is expected to cause little if any change in the fretting wear. Given all of the variations in conditions, the best basis for comparing fretting behavior is the actual performance in reactors where the transition was already made to ZIRLO cladding without changing the structural material. CENPD-404-P provided data showing the WEC experience in which the fuel batches had ZIRLO cladding and no changes were made to the spacer grid or material. The staff reviewed the data provided, which showed considerable experience with ZIRLO cladding and Zircaloy-4 structural material without fretting failures. Operation without fretting failures after introduction of ZIRLO cladding in different designs provides confidence that there is no significant change in the failure margin with the introduction of ZIRLO.

WEC developed the concept of fuel duty index and later the modified fuel duty index. The fuel duty index model was briefly presented in CENPD-404-P, but the staff did not review that model as part of its review of the topical report. However, the staff acknowledges that the model appears to be a useful tool. The modified fuel duty index is dependent upon the time averaged oxide layer surface temperature, the total irradiation time, and the boiling rate. A plot of measured oxide thickness versus the modified fuel duty index for Westinghouse plants shows much better agreement than when oxide thickness is plotted versus burnup. The modified fuel duty index is also useful for plant-to-plant comparisons of how aggressive the fuel duty has been. Using this concept, CENP showed that the most aggressive CENP plants are well within the data base for the WEC plants.

Because of the improved corrosion and axial growth performance, the extensive experience with ZIRLO clad fuel in WEC plants, and the good fretting experience for several designs, the staff agrees that it is acceptable to approve ZIRLO cladding for use in CENP-designed plants on a batch basis. However, the fuel duty will be limited to that previously experienced by CENP-designed plants with some provision for adequate margin to accommodate variations in core design (e.g., cycle length, plant operating conditions, etc.) until data for actual ZIRLO performance has been obtained. This limitation will be addressed on a plant-specific basis when the use of ZIRLO is requested.

2.2 Fuel Rod Fretting Problems in WEC Fuel Previously Manufactured for a CENP-Designed Plant

WEC had supplied fuel for use in a CENP plant before CENPD-404-P was submitted. This fuel had a history of leaking fuel rods as a result of fretting in Cycles 14 through 18 at the Ft. Calhoun Plant. The staff requested that details of the root cause investigation of the Ft. Calhoun fuel fretting be provided. In response (Reference 2), a brief history of the fuel including a comparison of the fuel features, number of fuel rods and number of failures was provided. In addition, the modifications to the fuel assembly that were introduced were described. The WEC root cause investigation concluded that the Ft. Calhoun fuel failures were due to grid design not the ZIRLO cladding material. While the cladding material through the mechanical properties does play a role in grid-to-rod fretting (a different rod growth characteristic will affect how the cladding is exposed to the wearing surface of the grid support), the design of the grid is the dominant factor in determining whether fretting failures will occur. On the basis of its review of the material provided and examination of actual grid structures, the staff agrees that the root cause of the Ft. Calhoun fuel fretting failures was most likely the grid design. Furthermore, since the grid structure that will be used in future CENP fuel with ZIRLO cladding will be the CENP grid structure (not a WEC-designed grid structure), the staff considers that the issue of fuel rod fretting problems in WEC fuel previously manufactured for CENP plants has been adequately addressed.

2.3 Use of Zircaloy-4 Properties and Correlations Instead of Measured ZIRLO Properties and Specifically ZIRLO Correlations

During the review of Section 4, "Fuel Performance," of CENPD-404-P, it became very clear to the staff that in most cases the cladding-related models and cladding material properties used were those of Zircaloy-4 or OPTIN not ZIRLO. CENP argued that the differences were small and the effects negligible. In some cases, ZIRLO measurements were available for comparison with the Zircaloy-4 data, but no actual ZIRLO data is available in other cases. This was the same approach that WEC used in the original application of ZIRLO (Reference 6). The staff questioned this approach extensively. The applicant provided additional information and justification for this approach. Where data was available, the staff compared the available data to assess whether the differences were in fact small, and attempted to evaluate the effect of the differences. The applicant provided additional information as regarding the magnitude of the effect. For instance with regard to thermal conductivity, the two equations that represent thermal conductivity vs. temperature for ZIRLO and Zircaloy-4 are identical in their functional form. Over the temperatures of interest for fuel performance (500°F to 700°F), the values of thermal conductivity are nearly identical. At an average clad temperature of 700°F, the difference in thermal conductivity would translate into less than a 5°F difference in fuel rod temperature. No thermal conductivity data was available for ZIRLO above 1300°F. The applicant argued that the ZIRLO value, if measured, would be slightly larger than the Zircaloy-4 value and, thus, would be conservative. The staff compared the Zircaloy-4 data for thermal conductivity in the 1300°F to 2200°F range with publicly available data for another Zirconium 1 percent niobium alloy, and found that there was little difference between the two.

The applicant made similar arguments and justifications for thermal expansion, modulus of elasticity, and Poisson's ratio. While this use of Zircaloy-4 or OPTIN properties instead of ZIRLO properties is not the preferred method of implementing the ZIRLO properties, the staff could not identify a safety significant effect related to its use.

2.4 Ductility of Zircaloy-4 and ZIRLO after High Temperature Oxidation in Steam

ZIRLO is a modification of Zircaloy-4 that includes a reduction in the tin and iron content, elimination of the chromium content and addition of 1 percent niobium. A technical paper by J. Bohmert, entitled "Embrittlement of ZrNb1 at Room Temperature After High-Temperature Oxidation in Steam Atmosphere" (Reference 7), raised questions about the validity of the 17 percent oxidation criterion for LOCA conditions for ZrNb1 fuel rod cladding. WEC uses this criterion for LOCA evaluations involving ZIRLO clad fuel. The NRC staff informed WEC about this paper and these questions. In response, WEC met with the NRC staff on February 26 and May 16, 2001, to discuss the subject and present data from testing on ZIRLO cladding. The staff requested the data from the testing and WEC provided a report documenting the results of the testing performed at its facilities to demonstrate the validity of the 17 percent oxidation criterion for ZIRLO cladding. The report described the tests performed, the high-temperature steam furnace used, the metallography, the ring compression tests, and the results.

The following major differences between the oxidation and embrittlement behavior of Zircaloy-4 and ZrNb1, as observed and reported in the work by Bohmert, were the basis for questioning the validity of the applicability of the 17 percent oxidation criterion for ZrNb1 cladding.

- The oxidation layer on the Zircaloy-4 specimens remained black and adherent while the ZrNb1 specimens had a heterogeneous appearance with multilayer oxide scales that tended to flake.

- There was a higher hydrogen uptake for the ZrNb1 specimens than for Zircaloy-4 specimens.

- There was a more rapid ductility reduction for the ZrNb1 specimens, leading to complete embrittlement at a small oxide layer thickness of ~ 5 percent.

The staff reviewed the WEC report, including the data and results presented. On the basis of that review, the staff agrees with the following conclusions.

- High temperature steam oxidation resulted in similar oxygen pickup in ZIRLO and Zircaloy-4 for a given oxide thickness.

- The stabilized alpha phase is harder than the prior-beta phase, which contains a lower oxygen concentration.

- Hydrogen pickup was low (<100 ppm) in both alloys following high temperature steam oxidation.

- Zircaloy-4 and ZIRLO show the same trends in ring compression tests at both room temperature and 275°F with both alloys surpassing the 10 percent criteria at 17 percent oxidation. (Relative displacements below 10 percent are considered brittle and displacements above 10 percent were classified as ductile or partially ductile.)

In addition, WEC reported that the oxides remained black and adherent for all ZIRLO as well as all Zircaloy-4 specimens.

On the basis of its review of the report and discussions with WEC, the staff agrees with WEC that the questions raised by the Bohmert paper about the validity of the 17 percent oxidation criteria for LOCA conditions for ZrNb1 fuel rod cladding do not apply to the ZIRLO cladding material. Thus, the staff concludes that the existing regulatory criteria regarding LOCAs specified in Title 10, Section 50.46, of the *Code of Federal Regulations* (10 CFR 50.46) continue to remain applicable for ZIRLO.

2.5 Fuel Performance Code

The CENP fuel performance code for reload designs and safety analyses, known as FATES3B, analyzes thermal and mechanical behavior of a fuel rod under steady-state and anticipated transient conditions. The code can be applied to uranium dioxide fuel (UO2), erbia bearing UO2 fuel, and gadolinia bearing fuel. However, the FATES3B code is rather old, and has not been updated since it was approved in 1992.

CENP adopted ZIRLO cladding properties and correlations from WCAP-12610-P-A and added them to the FATES3B code. In a response to the staff's questions (Reference 3), CENP listed several thermal and mechanical properties of ZIRLO for use in FATES3B, including axial growth, creep, hardness, emissivity, hydride reorientation, modulus of elasticity, Poisson's ratio, thermal conductivity, and thermal expansion. However, as previously explained only two properties, axial growth and creep, were actually changed in the conversion to ZIRLO materials in FATES3B. The same values were used for both ZIRLO and Zircaloy-4 for the rest of the properties. CENP contended that the use of the Zircaloy-4 values for the rest of the properties did not represent a significant deviation from the original results of the FATES3B analyses. While this practice is quite unusual, the staff does not find any major discrepancy compared to the CENP results for these properties. In light of the increasing efforts by the industry to develop new cladding materials, the staff notes that this practice should not be used in the future, and future applicants will be expected to fully measure and develop the material properties of proposed new cladding alloys.

CENP stated that the FATES3B code performs numerous safety and licensing analyses. These analyses are typical safety and licensing analyses to qualify new fuel designs that use advanced cladding, and the previously approved methodologies remain unchanged.

2.6 Material Properties

As mentioned earlier, CENP has proposed to change only the axial growth and creep correlations of ZIRLO for FATES3B. According to the FATES3B code structure, the creep correlations have two parts. The first part is a nominal creep correlation for analyzing cladding creepdown under compressive reactor coolant system pressure during normal operations. The second part is the same creep correlation with an upper bound multiplier added for determining the maximum allowable internal rod pressure under the "no cladding liftoff" criterion when the rod pressure starts exceeding the coolant system pressure. For the axial growth and creep models in FATES3B, CENP employed approved correlations of ZIRLO material properties. Thus, the staff considers that the axial growth and creep models are acceptable for ZIRLO licensing applications.

2.6.1 Cladding Creepdown

The cladding creepdown model for ZIRLO was approved in the PAD 4.0 code and adopted in the FATES3B code. CENP verified the FATES3B results against the ZIRLO data with measured creepdown data from North Anna Unit 1. The results showed that the predicted diameters were in reasonable agreement with the measured diameters. Since the predictions are consistent with the observations, the staff concludes that the use of the ZIRLO creepdown model in FATES3B is acceptable for licensing applications.

2.6.2 No-Clad-Liftoff Creep

There are three criteria to be examined when a fuel vendor proposes to allow fuel rod internal pressure to exceed the system pressure. They are (1) no-clad-liftoff (NCLO), (2) no hydride reorientation, and (3) no departure from nucleate boiling (DNB) propagation. The NCLO criterion is designed to limit the fuel rod internal pressure, when exceeding the system pressure, so that the fuel remains in contact with the cladding. The intent of this design criterion is to prevent adverse effects on the fuel performance, such as increasing reactivity, which would occur if the fuel cladding gap reopens. The maximum allowable internal pressure achieved depends on the cladding creep rate, fuel swelling rate, and plant operational schemes. Since ZIRLO tends to have a lower creep rate than the Zircaloy-4, the use of ZIRLO cladding will result in higher internal pressure than the use of Zircaloy-4 cladding for a PWR fuel rod.

Cladding creep rates are slightly different under tensile or compressive stress states. Several investigators have observed that the tensile creep rate can be higher than the compressive creep rate. An increase in tensile creep over compressive creep would reduce the margin to the maximum allowable rod pressure. During the PAD 4.0 review, the staff asked WEC as to why there was no difference between tensile and compressive creep rates. WEC responded that, while there appeared to be a small difference in creep rates for the two stress states, it was within the uncertainty of the data-base and, therefore, there was no need to differentiate the creep rates for these two stress states. The staff reevaluated the data-base and agreed that there was considerable scatter in creep data, and very few comparisons are available between these two stress states to offer definitive conclusions. Furthermore, the staff noted that WEC had provided a relatively small creep database for ZIRLO. As a result of these discussions between the staff and WEC, WEC introduced additional conservatism into its creep model for the NCLO analysis. In addition, WEC committed to acquire more in-reactor creep data under both tensile and compressive stress conditions for ZIRLO material. Recently, WEC provided the staff with a detailed irradiation program for ZIRLO to fulfill this commitment.

CENP has adopted the WEC position in the NCLO analysis for the FATES3B code. As expected, the results showed that there were higher maximum rod pressures for ZIRLO than for Zircaloy-4 fuel rods. On the basis of the approved creep model and the commitment to acquire additional data, the staff considers that the creep model for the NCLO criterion is acceptable for FATES3B. In the event that new data emerges to show that the NCLO creep model requires modification, the NRC staff will review the model and CENP will be required to modify the NCLO creep model for FATES3B.

CENP examined the presence of hydrides and the potential for hydride reorientation as a result of operations with rod internal pressure in excess of the system pressure. CENP determined that plant operation with ZIRLO will be similar to operation with Zircaloy-4, thus, the potential for stress induced hydride reorientation did not change with the use of ZIRLO material from the previous analysis and conclusions based on the Zircaloy-4 material. CENP also reviewed the DNB propagation analysis. High temperature creep and rupture properties of ZIRLO have been incorporated into the approved analysis. A comparison of high temperature creep and rupture of ZIRLO with Zircaloy-4 indicated that ZIRLO was less likely than Zircaloy-4 to initiate DNB propagation. The staff has reviewed these creep and rupture properties, and accepted them in the approved WCAP-12610-P-A. Therefore, the staff concludes that there are no differences between ZIRLO and Zircaloy-4 with regard to hydride reorientation and the DNB propagation analyses.

2.6.3 Rod Axial Growth

Fuel rod axial growth occurs during reactor operations as a result of fast neutron irradiation. WEC has obtained new data from irradiation history and improved the growth correlation for ZIRLO. The improved correlation was approved in the PAD 4.0 code. CENP adopted this approved correlation in the FATES3B code. The FATES3B results of axial growth were consistent with the PAD 4.0 data-base. Thus, the staff considers that the rod axial growth model is acceptable for FATES3B.

2.7 Fuel Thermal-Mechanical Analysis

The use of ZIRLO cladding for fuel rod designs will potentially affect the overall thermal-mechanical analyses. CENP reviewed and summarized those analyses that may be affected by the cladding change. The thermal-mechanical analyses involved not only FATES3B code, but also other approved computer codes. For these computer codes, CENP has implemented the necessary cladding properties for ZIRLO.

2.7.1 Power-to-Melt Analysis

CENP performed power-to-melt analyses using the FATES3B code for 14x14 and 16x16 fuel designs. The results showed that the limiting power-to-melt conditions occurred at the beginning of life, and that the trend consistently decreases toward the end of life. These results were typical for Zircaloy-4 as well as ZIRLO. Therefore, the staff considers that the power-to-melt analyses are acceptable for CENP 14x14 and 16x16 fuel designs.

2.7.2 Creep Collapse

If axial gaps exist between fuel pellets during operations, the cladding could creep inward as a result of higher coolant system pressure and cause the fuel rod to collapse and fail prematurely. The potential for creep collapse usually occurs early in life. In order to prevent this from occurring, the fuel rods are usually pre-pressurized with helium to certain pressure in order to reduce the chance of creep collapse.

CENP had an approved code, CEPAN, to predict the cladding collapse in conjunction with inputs from FATES3B code. CENP has implemented the approved creep correlations for the CEPAN code. The CENP analysis will ensure that no creep collapse occurs for ZIRLO fuel rods. Based on the approved creep correlation and methodology, the staff concludes that the creep collapse analysis is acceptable for ZIRLO.

2.7.3 Assembly Growth and Shoulder Gap

The fuel assembly, like the fuel rods, will grow axially under irradiation conditions. The clearance between the fuel rods and the upper end fitting is called a shoulder gap. If this clearance diminishes, the fuel rods will start contacting the upper end fitting, and fuel rod bowing will occur. Fuel rod bowing can induce some DNB penalties. Therefore, maintaining an adequate shoulder gap through the fuel lifetime is important for fuel mechanical designs. CENP has an approved computer code known as SIGREEP to predict assembly growth and shoulder gap changes.

The assembly axial growth is mainly controlled by the growth of the guide tubes. For CENP 14x14 and 16x16 fuel designs, the guide tubes continue to be made of Zircaloy-4. Thus, the use of ZIRLO cladding does not affect the SIGREEP analysis. CENP analysis will ensure that adequate shoulder gaps are maintained for ZIRLO fuel. Thus the staff accepts the CENP shoulder gap assessment.

2.7.4 Rod Internal Pressure

The fuel rod internal pressure has been used as one of the calibration parameters to ensure that the analytical tools are sufficiently conservative so that the rod pressures are not underestimated. The FATES3B code was used to calculate rod pressures under different operating conditions. The operating conditions that are considered include the peak linear heat generation rate (LHGR), the nominal LHGR, and the peak LHGR with transient conditions. In all cases, the code consistently predicted higher rod pressures for the ZIRLO fuel than for the Zircaloy-4 fuel for 14x14 and 16x16 fuel designs. Since the FATES3B code used the same thermal conductivity correlation for ZIRLO and Zircaloy-4, the staff considers that the rod pressure analysis is conservative for ZIRLO fuel, and therefore is acceptable.

2.7.5 Fuel Centerline Temperature

The fuel centerline temperature is another calibration parameter like rod internal pressure. With the same philosophy, the fuel performance code must conservatively predict the fuel centerline temperatures. CENP uses the FATES3B code for fuel temperature calculations in limiting operating conditions. The results of CENP calculations showed that the code consistently predicted slightly higher fuel temperatures for the ZIRLO fuel than for the Zircaloy-4 fuel at hottest axial locations for 14x14 and 16x16 fuel designs. Since the FATES3B code has enough conservatism built in for the Zircaloy-4 fuel temperature analysis, and the ZIRLO results are even more conservative, the staff considers that the fuel temperature analysis is acceptable for ZIRLO.

2.7.6 Swelling and Rupture

The ZIRLO swelling and rupture model is described in the approved WCAP-12610-P-A (Reference 6). This model, developed according to the NUREG-0630 methodology, is a correlation of rupture strain versus rupture temperature that conservatively bounds the ZIRLO data. CENP implemented this model in its large- and small-break LOCA (LBLOCA and SBLOCA) evaluation models. The assembly flow blockage as a result of rupture strains was also approved in WCAP-12610-P-A. The flow blockage model was only applied for the LBLOCA analysis. Based on the approved models in WCAP-12610-P-A, the staff concludes that the swelling and rupture model and assembly flow blockage model are acceptable for ZIRLO applications.

2.7.7 LOCA Initial Conditions

The FATES3B code provides the initial conditions, including fuel temperature and rod pressure, for LOCA analysis. These initial conditions were derived under bounding axial and radial power histories, coupled with transient characteristics for UO2 fuel and erbia-bearing fuel. CENP provided the peak pellet volume-averaged fuel temperatures for 14x14 and 16x16 fuel designs. The results showed that the limiting conditions for a LOCA occurred at the beginning of life (BOL) for ZIRLO fuel. This observation is consistent with the traditional conclusion that the LOCA is limited at BOL for Zircaloy-4 clad fuel. CENP concluded that the ZIRLO clad fuel temperatures were similar to the Zircaloy-4 clad fuel temperatures to the end of life.

The staff recognizes the possibility that the limiting LOCA initial conditions may shift from BOL toward the middle of life (MOL) under aggressive operating schemes. If this situation occurs, WEC will re-analyze the impact on 10 CFR 50.46 requirements for ZIRLO fuel design. Based on the approved methodology of the FATES3B code and the similarity between ZIRLO and Zircaloy-4 clad fuel temperatures, the staff concludes that the LOCA initial conditions are acceptable for ZIRLO applications.

2.8 CENPD-404-P LOCA Analysis Methods

Section 6.0 of CENPD-404-P and a "roadmap" provided at the NRC/CENP February 8, 2001, meeting describe how CENP's SBLOCA and LBLOCA analysis methodologies account for ZIRLO fuel in performing licensing-basis calculations. The documents indicate that the LOCA methodologies would generally be applied in the same way as described in WCAP-12610-P-A and its Appendices F and G to perform analyses that account for ZIRLO fuel using WEC's LOCA methodologies.

WCAP-12610, Appendices F and G, dealing with LBLOCA and SBLOCA, were reviewed and approved by the NRC. The review of Appendices F and G primarily focused on the effect of ZIRLO on mixed-core LOCA analyses, and whether a separate mixed-core penalty would be needed for LOCA analyses. The review revealed that for Zircaloy-4 and ZIRLO fuels of like features (geometry, including spacers, flow mixing vanes, cladding surface texture, etc.), a mixed-core penalty need not be added for each/either fuel. In representing ZIRLO, use of the Baker-Just equation (and any other Appendix K-specified treatment) was granted, but only after WEC had provided justification that it (they) conservatively represented ZIRLO. This was done to avoid an unnecessary conflict with Appendix K, which would have resulted in a need to issue an exemption from elements of Appendix K to reference that regulation in showing compliance.

Given the similarity between ZIRLO and Zircaloy-4, the staff found that for Zircaloy-4 and ZIRLO fuels of like features (geometry, including spacers, flow mixing vanes, cladding surface texture, etc.), a mixed-core penalty need not be added for each/either fuel. However, the SE did not remove the obligation to evaluate each type of cladding separately using the fuel heatup model.

CENP proposes to represent ZIRLO fuel by assuming some ZIRLO-specific properties and some properties that are specific to Zircaloy-4 in the LOCA analyses. The list of substituted properties varies between SBLOCA and LBLOCA analyses, between various stages of the LOCA events, and between the various models that comprise the LOCA methodologies. CENP stated that the substitution of Zircaloy-4 properties for ZIRLO properties was justified because either the specific calculational model does not use the specific property, the properties of the two materials were close enough to be interchangeable, or the impact of the substitution on calculated peak cladding temperature (PCT) was negligible. CENP provided information to support the substitutions using its LOCA methodologies and constituent models as they are presently configured and codified.

On the basis of its review of the information provided, the staff concludes that, while the properties of Zircaloy-4 are not strictly the properties of ZIRLO, the proposed substitution is acceptable using the present CENP methodologies as CENP asserts and justifies. However, this finding applies only to the present CENP LOCA methodologies and constituent models as they are presently configured and codified. Changes to the LOCA methodologies and models could affect the relative PCT impact between the substituted properties and the ZIRLO-specific properties. If the CENP LOCA methodologies and/or constituent models are changed in the future, documentation supporting the change(s) should include justification of the continued applicability of the methodology or model to ZIRLO.

2.9 Non-LOCA Accidents

The effect on non-LOCA accidents of changing from OPTIN to ZIRLO depends on the difference in thermophysical properties of OPTIN and ZIRLO. Except for the phase change temperature shift on the specific heat versus temperature relationship, the properties are essentially identical. Thus, for the non-LOCA accident analyses in which the clad temperature does not exceed 1380°F, the use of ZIRLO cladding will have no effect on the analysis because there is no difference in the input parameters. A review of the non-LOCA licensing basis analyses concluded that only one non-LOCA licensing basis analysis (the control element assembly (CEA) ejection) resulted in clad temperatures that were predicted to reach 1380°F.

Approximately 24 existing CEA ejection cases were repeated using the ZIRLO specific heat properties to determine the impact of using ZIRLO. The results from the ZIRLO cases remained within approximately ±10 cal/gm of the results for OPTIN in all cases. The following criteria used to ensure that fuel dispersal into the coolant, gross lattice distortion and severe shock waves do not occur are:

- The average fuel pellet energy at the hot spot remains below 200cal/gm as calculated by a point kinetics synthesis method.

- Fuel centerline temperature is limited to less than the incipient melting temperature of the fuel.

- Peak RCS pressure is less than that which would cause clad stresses to exceed the faulted condition stress limits.

The staff believes that the first criterion listed above is nonconservative in light of test data from foreign test reactors on reactivity-initiated accidents. CENP has addressed this issue in a response to a staff question (Reference 3). The point kinetics calculation is extremely conservative in that it overestimates the core average power excursion and highly overestimates the hot spot power excursion compared to a more detailed three-dimensional (3-D) calculation. Using bounding values and uncertainties, a 3-D space-time method produces results less than 100 cal/gm. The staff considers this acceptable because the probability of control element assembly ejection accidents is low, and the 3-D calculation still contains considerable conservatism. It should be noted that for some CENP plants, DNB is used an alternative fuel failure criteria. The staff finds this acceptable.

2.10 Nuclear Engineering

The change in the cladding material from OPTIN to ZIRLO will have a negligible effect on nuclear performance since the primary change in physics properties is a small increase in neutron absorption attributable to the addition of niobium. An increase in neutron absorption of this magnitude has no effect on nuclear performance. Thus, no modifications were made to the nuclear engineering methodologies or computer codes. This is the same approach that was used for the previous application of ZIRLO. The staff agrees that the change would be negligible and, thus, finds this approach acceptable.

3.0 CONCLUSIONS

On the basis of the evaluation discussed above, the staff concludes that it is acceptable for WEC to use ZIRLO as the cladding material for CENP-designed plants subject to the following conditions to which WEC has agreed (Reference 5):

(1) The corrosion limit, as predicted by the best-estimate model will remain below 100 microns for all locations of the fuel.

(2) All the conditions listed in the SEs for all the CENPD methodologies used for ZIRLO fuel analysis will continue to be met, except that the use of ZIRLO cladding in addition to Zircaloy-4 cladding is now approved.

(3) All CENP methodologies will be used only within the range for which ZIRLO data was acceptable and for which the verifications discussed in CENPD-404-P and responses to requests for additional information were performed.

(4) Until data is available demonstrating the performance of ZIRLO cladding in CENP designed plants, the fuel duty will be limited for each CENP designed plant with some provision for adequate margin to account for variations in core design (e.g., cycle length, plant operating conditions, etc.). Details of this condition will be addressed on a plant specific basis during the approval to use ZIRLO in a specific plant.

(5) The burnup limit for this approval is 60 MWD/MTU.

4.0 REFERENCES

1. Letter from Philip W. Richardson, CE Nuclear Power LLC to NRC Document Control Desk, January 22, 2001.

2. Letter from Philip W. Richardson, Westinghouse Electric Company LLC to NRC Document Control Desk, May 3, 2001.

3. Letter from Philip W. Richardson, Westinghouse Electric Company LLC to NRC Document Control Desk, August 10, 2001.

4. Letter from Philip W. Richardson, Westinghouse Electric Company LLC (LD-2001-0046, Revision 0) to John S. Cushing, NRC, August 10, 2001.

5. Letter from Philip W. Richardson, Westinghouse Electric Company LLC to NRC Document Control Desk, August 27, 2001.

6. WCAP-12610-P-A, "Vantage+ Fuel Assembly Reference Core Report," April 1995.

7. Nuclear Engineering and Design, Volume 147, No. 1, Page 53, Comparative Studies on High-Temperature Corrosion of ZrNb1 and Zircaloy-4.

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