TECHNICAL EVALUATION REPORT OF TOPICAL REPORT DPC-NE-2007 (DUKE POWER COMPANY FUEL RECONSTITUTION ANALYSIS METHODOLOGY)

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LIST OF ACRONYMS

AOO - Anticipated Operational Occurrence

ASME - American Society of Mechanical Engineers

BWFC - Babcock & Wilcox Fuel Company

CHF - Critical Heat Flux

DNB - Departure from Nucleate Boiling

DNBR - Departure from Nucleate Boiling Ratio

Duke - Duke Power Company

ECCS - Emergency Core Cooling System

GDC - General Design Criterion

LOCA - Loss of Coolant Accident

NRC - U.S. Nuclear Regulatory Commission

PCI - Pellet Cladding Interaction

PCT - Peak Cladding Temperature

PNL - Pacific Northwest Laboratory

RIA - Reactivity Insertion Accident

SAFDL - Specified Acceptable Fuel Design Limit

SRP - Standard Review Plan

SSE - Safe-Shutdown Earthquake

TER - Technical Evaluation Report

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1.0 INTRODUCTION

The routine operation and handling of fuel assemblies can damage individual fuel rods and assembly structures. The commercial nuclear industry has determined the reconstitution of these damaged fuel assemblies to be economical. In order to support customer needs and remain competitive, the fuel vendors have began to reconstitute and recage individual fuel assemblies. Recently, the U.S. Nuclear Regulatory Commission (NRC) has raised several issues with the fuel vendors concerning the application of reconstituted assemblies because the number of reconstituted assemblies has been increasing in the last few years (Reference 1).

In response to the NRC concerns, Duke Power Company (Duke) has submitted to the NRC, a topical report entitled "*Duke Power Company Fuel Reconstitution Analysis Methodology*", DPC-NE-2007 (Reference 2), for review and approval. The remainder of this report will refer to Duke Power Company as only Duke. Presented in Reference 2 is the information required to support the licensing basis for the implementation of reconstituted fuel assemblies in Duke plant reloads. This Technical Evaluation Report (TER) will only review the Duke proposed criteria and evaluation methodology for reconstituted assemblies using up to ten type 304 stainless steel or zircaloy solid replacement rods or one water hole (vacancy) per assembly quadrant, i.e., four per assembly. It is assumed throughout this review that the actual act of removing fuel rods and replacing them with solid rods in a fuel assembly does not stress the regular fuel assembly components beyond the assembly design tolerance limits. The submitted topical report compliments previously approved Duke reload design methodology, including DPC-NE-2001-A (Reference 3), DPC-NE-1002-A (Reference 4), and NFS-1001 (Reference 5). Duke is also proposing to replace damaged fuel rods with fuel rods containing natural UO_2 for reconstituted assemblies. The design and analysis methodology for fuel rods with natural UO_2 are covered under References 3, 4, and 5 for reload fuel. Therefore, this review has concentrated only on the use of solid replacement rods and vacancies in reconstituted assemblies.

Pacific Northwest Laboratory (PNL) has acted as a consultant to the NRC in this review. As a result of the NRC's staff and their PNL consultant's review of the topical report, a list of questions were sent by the NRC to Duke, requesting clarification of specific evaluation methodology and licensing analyses (Reference 6). Duke responded to those questions in Reference 7. Duke was further questioned in a May 9, 1995 conference call on two unresolved issues on the use of vacancies due to grid cell damage in their reconstituted assemblies. Specifically, the two issues were 1) the potential for fretting wear of rods adjacent to the damaged spacer cell/grid and 2) the impact on seismic-LOCA loading.

This review was based on those licensing requirements identified in Section 4.2 of the Standard Review Plan (SRP) (Reference 8). The objectives of this fuel system safety review, as described in Section 4.2 of the SRP, are to provide assurance that: 1) the fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs), 2) fuel system damage is never so severe as to prevent control rod insertion when it is required, 3) the number of fuel rod failures is not underestimated for postulated accidents, and 4) coolability is always maintained. A "not damaged" fuel system is defined as fuel rods that do not fail, fuel system dimensions that remain within operational tolerances, and functional capabilities that are not reduced below those assumed in the safety analysis. Objective 1, above, is consistent with General Design Criterion (GDC) 10 [10 Code of Federal Regulations (CFR) 50, Appendix A] (Reference 9), and the design limits that accomplish this are called specified acceptable fuel design limits (SAFDLs). "Fuel rod failure" means that the fuel rod leaks, and that the first fission product barrier (the cladding) has, consequently, been breached. Fuel rod failures must be accounted for in the dose analysis required by 10 CFR 100 (Reference 10) for postulated accidents. "Coolable geometry" means in general, that the fuel assembly retains its rod-bundle geometrical configuration with adequate coolant channels. This permits removal of residual heat even after a severe accident. The general requirements to maintain control rod insertability and core coolability appear repeatedly in the GDC (e.g., GDC 27 and 35). Specific coolability requirements for the loss-of-coolant accident (LOCA) are given in 10 CFR 50, Section 50.46.

In order to assure that the above stated objectives are met, and follow the format of Section 4.2 of the SRP, this review covers the following three major categories: 1) Fuel System Damage Mechanisms, which are most applicable to normal operation and AOOs, 2) Fuel Rod Failure Mechanisms, which apply to normal operation, AOOs, and postulated accidents, and 3) Fuel Coolability, which are applied to postulated accidents. Specific fuel damage or failure criteria are identified under each of these categories in Section 4.2 of the SRP. The Duke reconstitution analysis methodologies for solid replacement rods and vacancies are discussed in this TER under each fuel damage or failure mechanism listed in the SRP.

The purpose of the design bases and/or criteria is to provide limiting values that prevent fuel damage or failure with respect to each mechanism. Reviewed in this TER is the applicability of the design criteria, submitted in DPC-NE-2007 for employing reconstituted fuel assemblies, with up to ten solid stainless steel replacement rods in reactor reload designs. Reload design criteria have not changed from References 3, 4, and 5. The design criteria, along with certain definitions for fuel failure, constitute the SAFDLs required by GDC 10.

The Duke analysis methods assure that the design limits and, consequently, SAFDLs are met for a particular design application. Reviewed in this report is whether the NRC-approved design limits are met for the reconstituted fuel assemblies, using previously approved Duke criteria and analysis methods remains applicable to these assemblies. A description of a typical fuel assembly is briefly discussed in the following section (Section 2.0). The fuel damage and failure mechanisms are addressed in Sections 3.0 and 4.0, respectively, while fuel coolability is addressed in Section 5.0.

2.0 FUEL SYSTEM DESIGN

The fuel assembly consists of a square array of fuel rods, guide thimble tubes, and an instrumentation tube. These components are mechanically fastened together by grid assemblies, and top and bottom nozzles. The top nozzle is designed to allow for fuel assembly reconstitution. Fuel rods are supported at intervals along their length by grid springs and dimples contained within the grid assembly to maintain rod-to-rod spacing. The grid assembly consists of an egg-crate arrangement of interlocking straps that contain springs and dimples. Attached to the top nozzle are holddown springs, and spring clamps that keep the fuel assembly firmly seated on the lower core plate during normal plant operation.

The fuel rods consist of UO_2 pellets clad in Zircaloy tubing. The rod assembly is pressurized with helium, then plugged and seal welded at the ends to encapsulate the fuel. The solid replacement rod is a solid cylinder of type 304 stainless steel or zircaloy material. Both fuel and replacement rods are supported by the grid spring and dimples by frictional forces. The rod dimensions are set so that the replacement rod engages all spacer grid stops under all conditions. A clearance is maintained between the replacement rod and the top grillage under all conditions.

3.0 FUEL SYSTEM DAMAGE

The design criteria presented in this section should not be exceeded during normal operation including AOOs. The evaluation portion of each damage mechanism evaluates the analysis methods, and analyses used by Duke to demonstrate that the design criteria are not exceeded during normal operation including AOOs for the reconstituted fuel assembly design.

3.1 STRESS

Bases/Criteria - In keeping with the GDC 10 SAFDLs, fuel damage criteria for cladding stress should ensure that fuel system dimensions remain within operational tolerances and that functional capabilities are not reduced below those assumed in the safety analysis. The Duke design basis for fuel rod cladding stresses is that the fuel system will be functional and will not be damaged due to excessive stresses. These criteria are based on guidelines established in Section III of the American Society of Mechanical Engineers (ASME) Boiler Pressure Vessel Code (Reference 11). These criteria are consistent with the acceptance criteria established in Section 4.2 of the SRP and remain acceptable for reconstituted assemblies.

Evaluation - Fuel assembly reconstitution does not directly impact the cladding stress generated in the remaining fuel rods of the fuel assembly. However, as fuel rods are replaced by solid rods or vacancies, there is a small increase in the core average linear heat generation rate (LHGR).[a] In addition, there may be a small increase in the LHGR of fuel rods directly adjacent to solid replacement rods or vacancies. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved fuel performance models. The impact of using solid replacement rods or vacancies in reconstituted assemblies is evaluated as part of this cycle specific design process. The cladding stresses generated in fuel rods adjacent to the solid replacement rods or vacancies will be evaluated on a case-by-case basis based on the analysis of LHGRs. Consequently, PNL concludes that fuel assembly reconstitution with solid replacements or vacancies is acceptable in regards to the analysis methodology for determining cladding stress.

3.2 STRAIN

Bases/Criteria - The Duke design criterion for fuel rod cladding strain specifies that maximum uniform hoop strain (elastic plus plastic) shall not exceed 1%. This criterion is intended to preclude excessive cladding deformation from normal operation and AOOs. This is the same criterion for cladding

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(a) To maintain total core heat generation upon replacement of fuel rods by replacement rods, the remaining fuel rods must operate at a higher linear heat generation rate.

strain that is used in Section 4.2 of the SRP and, therefore, remains acceptable for reconstituted assemblies.

Evaluation - As fuel rods are replaced by solid rods or vacancies, there is a small increase in the core average LHGR. In addition, there may be a small increase in the LHGR of fuel rods directly adjacent to solid replacement rods or vacancies. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved fuel performance models. The impact of using solid replacement rods or vacancies in reconstituted assemblies is evaluated as part of this cycle specific design process. The cladding strains in fuel rods adjacent to the solid replacement rods or vacancies will be evaluated based on the increase in LHGRs. Therefore, introduction of solid replacement rods or vacancies will be evaluated on a case-by-case basis to determine their impact on cladding strains in a fuel assembly. Consequently, PNL concludes that fuel assembly reconstitution with solid replacements or vacancies is acceptable in regards to the analysis methodology for determining cladding strain.

3.3 STRAIN FATIGUE

Bases/Criteria - The Duke design criterion for cladding strain fatigue specifies that the cumulative fatigue factor be less than 0.9, when a minimum safety factor of 2 on the stress amplitude or a minimum safety factor of 20 on the number of cycles (which ever is the most conservative), is imposed as per the O'Donnell and Langer design curve (Reference 12) for fatigue usage. This criterion is conservative in relation to that described in Section 4.2 of the SRP and remains acceptable for reconstituted assemblies.

Evaluation - Fuel assembly reconstitution does not significantly impact the cladding fatigue generated in the remaining fuel rods of the fuel assembly. However, as fuel rods are replaced by solid rods or vacancies, there is a small increase in the core average LHGR. In addition, there may be a small increase in the LHGR of fuel rods directly adjacent to solid replacement rods or vacancies. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved fuel performance models. The impact of using solid replacement rods or vacancies in reconstituted assemblies is evaluated as part of this cycle specific design process, taking into account changes in the linear heat generation rate of the adjacent fuel rods. Consequently, introduction of solid replacement rods or vacancies will be evaluated on a case-by-case basis. Therefore, PNL concludes that fuel assembly reconstitution is acceptable in regards to the analysis methodology for determining cladding strain fatigue.

3.4 FRETTING WEAR

Bases/Criteria - Fretting wear is a concern for fuel, burnable poison rods, and guide tubes. Fretting or wear may occur on the fuel and/or burnable poison cladding surfaces in contact with the spacer grids, if there is a reduction in grid spacing loads in combination with flow induced vibratory forces. The Duke design criterion for fretting wear specifies that the assembly design shall provide sufficient support to limit rod vibration and fretting wear. This criterion is consistent with Section 4.2 of the SRP and remains acceptable for reconstituted assemblies.

Evaluation - Operation of a reconstituted fuel assembly does not directly impact the rod fretting wear as long as the reconstituted assembly does not have significant spacer damage. Duke was questioned about when vacancies would be left in an assembly for reconstitution (Reference 6). Duke responded (Reference 7) that a vacancy would only be left in a reconstituted assembly, if the spacer grid cell were damaged enough such that placing a solid replacement rod could possibly lead to subsequent failures in adjacent fuel rods. However, there remains the following question or issue. If the spacer grid cell is damaged enough that placing a solid rod in this cell could lead to additional failures, how can it be determined that leaving the cell vacant will not also lead to additional failures? The ability to predict fretting behavior of a damaged grid is very difficult at best for two reasons. First, spacer grid fretting is predicted from prototypic spacer designed flow tests, and there are no fretting tests for a similarly damaged grid to demonstrate acceptable behavior. Second, the extent of damage in a previously irradiated assembly spacer cell is difficult to assess from remote viewing devices. Therefore, PNL recommends that the use of vacancies in reconstituted fuel assemblies should not be approved on a generic basis due to grid spacer fretting concerns. If in the future Duke has a specific application where they feel a vacancy is warranted it may be submitted to NRC for approval on a case-by-case basis along with justification that design criteria will be met including the fretting wear criterion. This justification should include information on the extent of spacer damage in the vacant grid cell and adjacent cells along with an evaluation of the impact on grid fretting.

Another possible concern is the slight decrease in the weight of a reconstituted assembly when solid replacement rods are used because they are slightly lighter than fuel rods. This is not expected to affect fretting wear. This is because the replacement rods do not affect the assembly pressure drops nor flow distribution (see Section 4.4), and have dimensions similar to a fuel rod. Thus, PNL concludes that fuel assembly reconstitution with solid replacement rods is acceptable in regards to the analysis methodology for determining fretting wear. As noted above, generic approval is not recommended for the use of vacancies in reconstituted assemblies, due to grid spacer fretting concerns from damaged grids.

3.5 OXIDATION AND CRUD BUILDUP

Bases/Criteria - Section 4.2 of the SRP identifies cladding oxidation and crud buildup as potential fuel system damage mechanisms. The SRP does not establish specific limits on cladding oxidation and crud buildup but does specify that their effects be accounted for in the thermal and mechanical analyses performed for the fuel. Cladding oxidation and crud are not affected by the use of solid replacement rods. Consequently, these criteria remain acceptable for reconstituted assemblies.

Evaluation - Fuel assembly reconstitution does not directly impact the cladding oxidation and crud buildup generated on the remaining fuel rods of the fuel assembly. As fuel rods are replaced by solid rods, there is a small increase in the core average linear heat generation rate. In addition, there may be a small increase in the linear heat generation rate of fuel rods directly adjacent to solid replacement rods or vacancies. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved fuel performance models. The impact of using solid replacement rods or vacancies in reconstituted assemblies on cladding oxidation and crud buildup, is evaluated as part of this cycle specific design process. The impact of cladding oxidation and crud buildup in fuel thermal and mechanical performance analyses are evaluated by Duke when solid replacement rods are introduced in reconstituted assemblies. Consequently, PNL concludes that fuel assembly reconstitution with solid replacements is acceptable in regards to the analysis methodology for cladding oxidation and crud buildup.

3.6 ROD BOWING

Bases/Criteria - Fuel and burnable poison rod bowing is a phenomenon that alters the design-pitch dimensions between adjacent rods. Fuel rod bowing affects local nuclear power peaking and the local heat transfer to the coolant. Rather than place design limits on the amount of bowing that is permitted, the effects of bowing are included in the departure for nucleate boiling ratio (DNBR) analysis by a DNBR penalty, when rod bow is greater than a predetermined amount. This approach is consistent with Section 4.2 of the SRP and remains acceptable for reconstituted assemblies.

Evaluation - Rod bowing has been found to be dependent on the distance between grid spacers, the rod moment of inertia, and flux distribution. The design characteristics will not change with the addition of solid replacement rods or vacancies, but the flux distribution will change in the immediate vicinity of the replacement rods or vacancies. This flux distribution is not expected to be significantly different than what currently exists for a fuel rod adjacent to a guide tube. Reconstituted fuel assemblies will have rod bow characteristics that are similar to normal fuel assemblies. PNL concludes that fuel assembly reconstitution with solid replacements rods is acceptable in regards to the analysis methodology used to determine rod bow.

3.7 AXIAL GROWTH

Bases/Criteria - The Duke design basis for axial growth specifies that adequate clearance be maintained between the rod ends, and the top and bottom nozzles to accommodate the differences in the growth of fuel rods and the growth of the fuel assembly. For assembly growth, Duke has a design basis that specifies axial clearance between core plates and the bottom and top assembly nozzles, that should allow sufficient margin for fuel assembly irradiation growth during the assembly lifetime. These criteria are consistent with Section 4.2 of the SRP and remain acceptable for reconstituted assemblies.

Evaluation - Duke provides an initial fuel rod-to-nozzle growth gap in their fuel assembly plant applications to allow for differential irradiation growth, and thermal expansion between the fuel rod cladding and the fuel assembly guide thimble tubes. The minimum gap required to allow for the irradiation growth and thermal expansion to preclude interference during operation is based on the assumption of worst case (maximum) fuel rod, and fuel assembly growth combined with worst case (minimum) fabrication tolerances. For solid stainless steel rods the concern is not the closing up of this gap (the concern with fuel rods and solid Zircaloy rods), but that the rods will remain engaged with the upper and lower tie plates with increasing burnup. The Zircaloy guide tubes and fuel rods grow at a significantly greater rate than the solid stainless steel rods that experience little or no growth with irradiation. Since stainless steel has a greater thermal expansion coefficient than Zircaloy, the disengagement of the solid rods becomes greatest at end-of-life (EOL) during cold conditions.

For reconstituted assemblies with solid stainless steel rods, Duke utilizes the upper tolerance growth curves for fuel assembly growth, worst case tolerances, and assumes no solid stainless steel rod growth in order to demonstrate that these solid rods remain engaged at cold conditions at their burnup limit. PNL concludes that the Duke analysis methodology for fuel assembly reconstitution with solid replacement rods is conservative and, therefore, acceptable in regards to axial growth.

3.8 ROD INTERNAL PRESSURE

Bases/Criteria - The Duke design basis for rod internal pressure specifies that the fuel system will remain below nominal system pressure during normal operation and AOOs. This design basis may change based on the recent NRC approval for the Babcock and Wilcox Fuel Company (BWFC) fuel designs to exceed nominal system pressure (Reference 13). The Duke application of reconstituted assemblies does not impact either rod pressure criterion.

Either criterion is applicable to reconstituted assemblies, as long as the methods in Reference 13 are found to be applicable to Duke applications.

Evaluation - As fuel rods are replaced by solid rods or vacancies, there is a small increase in the core average linear heat generation rate. In addition, there may be a small increase in the linear heat generation rate of fuel rods directly adjacent to solid replacement rods or vacancies. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved fuel performance models. The impact of using solid replacement rods in reconstituted assemblies on rod internal pressure is evaluated as part of this cycle specific design process. The solid replacement rods in a reconstituted assembly are not affected by rod internal pressure. PNL concludes that fuel assembly reconstitution with solid replacement rods is acceptable in regards to the analysis methodology for determining rod internal pressure.

3.9 ASSEMBLY LIFTOFF

Bases/Criteria - Section 4.2 of the SRP calls for the fuel assembly holddown capability (wet weight and spring forces) to exceed worst case hydraulic loads for normal operation and AOOs. The Duke design criterion for assembly liftoff specifies that the holddown spring system shall be capable of maintaining fuel assembly contact with the lower support plate during Condition I and II events. PNL concludes that this is consistent with the SRP guidelines and, therefore, remains acceptable for use with reconstituted fuel assemblies.

Evaluation - The fuel assembly liftoff forces are a function of primary coolant flow, spring forces, and assembly dimensional changes. The only change incurred by the addition of solid replacement rods is in assembly weight because there are no changes in assembly dimensions. Replacement rods have the same outside diameters and design configurations as a fuel rod. These rods also displace essentially the same volume of coolant. However, the weight of a replacement rod is less than a fuel rod by a small amount. The lower weight of a replacement rod results in a small increase in the net upward force on the fuel assembly.

The use of vacancies in an assembly makes a larger impact on assembly liftoff because of the reduced weight in the assembly. There is a small increase in flow around the vacancy, but the overall change in assembly flow should be small. This will most likely be more than compensated for by the friction losses due to the vacant cell. Hence, Dukes assumption that the change in lift force is only due to a reduction in fuel assembly weight is valid.

The total net upward force due to lift and buoyancy forces for a typical fuel assembly is designed to be within the minimum available holddown spring force at hot full power and cold zero power conditions. The Duke liftoff analysis methodology for reconstituted assemblies takes into account the weight changes due to solid replacement rods. Consequently, PNL concludes that the Duke analysis methodology for fuel assembly liftoff fuel is acceptable.

4.0 FUEL ROD FAILURE

In the following paragraphs, fuel rod failure thresholds and analysis methods for the failure mechanisms listed in the SRP will be reviewed. When the failure thresholds are applied to normal operation including AOOs, they are used as limits (and hence SAFDLs) since fuel failure under those conditions should not occur according to the traditional conservative interpretation of the GDC 10. When these thresholds are used for postulated accidents, fuel failures are permitted, but they must be accounted for in the dose assessments required by 10 CFR 100. The basis or reason for establishing these failure thresholds is thus established by GDC 10 and Part 100. Only the threshold values and the analysis methods used to assure that they are met are reviewed below.

4.1 HYDRIDING

Bases/Criteria - Internal hydriding as a cladding failure mechanism is precluded by controlling the level of hydrogen impurities in the fuel during fabrication. External hydriding can occur due to waterside corrosion. The use of solid replacement rods does not impact internal or external hydriding criteria. Therefore, the existing criteria for fuel rods remains valid.

Evaluation - As fuel rods are replaced by inert rods, there is a small increase in the core average linear heat generation rate of the remaining fuel rods. In addition, there may be a slight increase in the linear heat generation rate of fuel rods directly adjacent to solid replacement rods, or vacancies which could increase cladding waterside corrosion by a small amount. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved fuel performance models. The impact of using solid replacement rods or vacancies in reconstituted assemblies on rod corrosion is evaluated as part of this cycle specific design process. Because the solid replacement rods are not significantly affected by hydriding, and because external hydriding due to waterside corrosion is included in Duke analysis methodology, PNL concludes that fuel assembly reconstitution is acceptable with regard to hydriding.

4.2 CLADDING COLLAPSE

Bases/Criteria - If axial gaps in the fuel pellet column were to occur due to fuel densification, the potential would exist for the cladding to collapse into a gap. Because of the large local strains that would result from collapse, the cladding is then assumed to fail. The Duke design criterion specifies that cladding collapse is precluded during the fuel rod design lifetime. This design basis is the same as that in Section 4.2 of the SRP and remains acceptable for reconstituted assemblies.

Evaluation - The cladding collapse criterion is not applicable to the solid replacement rods. As fuel rods are replaced by solid rods, there is a small increase in the core average linear heat generation rate. In addition, there may be a slight increase in the linear heat generation rate of fuel rods directly adjacent to solid replacement rods or vacancies. This could result in a small decrease in the time to creep collapse. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved fuel performance models. The impact of using solid replacement rods in reconstituted assemblies on cladding collapse is evaluated as part of the cycle specific design process, taking into account changes in the linear heat generation rate of the fuel rods. PNL concludes that fuel assembly reconstitution with solid replacement rods is acceptable with regard to the analysis methodology used to determine cladding collapse.

4.3 OVERHEATING OF CLADDING

Bases/Criteria - The Duke design limit for the prevention of fuel failures due to overheating specifies at least a 95% probability at a 95% confidence level and that departure from nucleate boiling (DNB) will not occur on a fuel rod having the minimum DNBR during normal operation and AOOs. This design limit is consistent with the thermal margin criterion of Section 4.2 of the SRP, and thus remains acceptable for application to reconstituted fuel assemblies.

Evaluation - Fuel rod reconstitution using solid replacement rods and vacancies affects predictions of DNB in hot channels due to changes in local power, and resultant changes in the distribution of enthalpy and coolant flow in the fuel assembly. Duke uses two critical heat flux (CHF) correlations BWC and BWCMV for their Mark B and BW designs, respectively, to calculate critical power and minimum DNBR. The major issue is whether these correlations are applicable to the reconstituted assembly applications proposed by Duke. Duke has presented CHF data for their Mark BW fuel assembly design. This data demonstrates that their CHF correlation BWCMV provides a reasonably conservative prediction of critical power for test bundles with one cold rod, three cold rods, and one vacancy per test bundle. The test bundles simulate a quarter of the assembly. Examination of the CHF data does show that the critical bundle power is lowered for those bundles with either three cold rods in a row or one vacancy per test bundle. However, it appears that the BWCMV correlation provides a satisfactory prediction of critical power in these cases. It should be noted that the prediction of one vacancy rod was slightly less conservative than for the other test cases but, it is acceptable because it is small and within the error of the data.

Duke also presents calculational results using their BWC and BWCMV correlations for their Mark B and BW designs, respectively, for the cases of a regular assembly, one cold rod, three cold rods, and one vacancy. These results demonstrate that the BWC correlation predicts similar behavior as the BWCMV correlation for the regular assembly, one cold rod, three cold rods, and one vacancy. Duke has shown that for these particular cold rod, vacancy geometries, and assumed radial power distributions that the MDNBR is either similar to or equal to the MDNBR of the regular assembly. However, these calculations do not cover all possible geometries and radial power distributions.

Therefore, both the BWCMV and BWC correlations are found to be acceptable for application to reconstituted assemblies with the limitations on geometry presented in Reference 2. However, the above calculations with these CHF correlations do not cover all possible geometries and radial power distributions. Thus, PNL recommends that Duke perform calculations of MDNBR using the appropriate CHF correlation for each reconstituted assembly application using actual geometries and power distributions.

4.4 OVERHEATING OF FUEL PELLETS

Bases/Criteria - As a second method of avoiding cladding failure due to overheating, Duke precludes centerline pellet melting during normal operation and AOOs. This design limit is the same as given in the SRP and has been approved for application in Duke designs. Duke has placed a temperature limit on fuel melting at extended fuel burnups that is considered to be conservative. Therefore, PNL concludes that BWFC's design limit for fuel melting remains acceptable for application to reconstituted fuel assemblies.

Evaluation - As fuel rods are replaced by inert rods, there is a small increase in the core average linear heat generation rate which could slightly increase fuel pellet temperatures. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved Duke fuel performance models. The impact of using solid replacement rods in reconstituted assemblies on fuel pellet temperature is evaluated as part of this cycle specific design process. Since the analysis methods used by Duke to determine fuel temperatures remain applicable to reconstituted assemblies, PNL concludes that they are acceptable for application in regards to overheating of fuel pellets.

4.5 PELLET/CLADDING INTERACTION

Bases/Criteria - As indicated in Section 4.2 of the SRP, there are no generally applicable criteria for pellet cladding interaction (PCI) failure. However, two acceptance criteria of limited application are presented in the SRP for PCI: 1) less than 1% transient induced cladding strain, and 2) no centerline fuel melting. Both of these limits have been adopted by Duke for use in evaluating their fuel designs and have been approved by the NRC. PNL concludes that these remain acceptable for application to reconstituted fuel assemblies.

Evaluation - There is no chance for PCI to occur in solid replacement rods, and the use of solid replacement rods will not cause PCI to significantly increase in the remaining fuel rods of the assembly. Also, since the issues of cladding strain and fuel pellet melting were satisfactorily addressed in Sections 3.2 and 4.4, respectively, PNL concludes that fuel assembly reconstitution with solid replacement rods is acceptable in regards to the analysis methodology used to determine pellet/cladding interaction.

4.6 CLADDING RUPTURE

Bases/Criteria - There are no specific design limits associated with cladding rupture other than the 10 CFR 50, Appendix K (Reference 14) requirements that the incidence of rupture not be underestimated. Duke uses a rupture temperature correlation consistent with NUREG-0630 guidance (Reference 15). PNL concludes that Duke has adequately addressed the criteria for cladding rupture in reconstituted assemblies.

Evaluation - Cladding rupture will not occur in solid replacement rods. The model used for cladding rupture remains applicable to the remaining fuel rods in the assembly. PNL concludes that fuel assembly reconstitution with solid replacement rods is acceptable in regards to the analysis methodology used to determine cladding rupture.

4.7 FUEL ROD MECHANICAL FRACTURING

Bases/Criteria - The term "mechanical fracture" refers to a fuel rod defect that is caused by externally applied forces such as hydraulic loads or loads derived from core-plate motion. These loads are bounded by the loads of a Safe-Shutdown Earthquake (SSE) and Loss-of-Coolant Accident (LOCA), and the mechanical fracturing analysis is usually done as a part of the SSE-LOCA loads analysis (see Section 5.4 of this TER).

Evaluation - The discussion of the SSE-LOCA loading analysis is given in Section 5.4 of this TER.

5.0 FUEL COOLABILITY

For postulated accidents in which severe fuel damage might occur, core coolability must be maintained as required by several GDCs (e.g., GDC 27 and 35). In the following paragraphs, limits and methods used to assure that coolability is maintained are discussed for the severe damage mechanisms listed in the SRP.

5.1 FRAGMENTATION OF EMBRITTLED CLADDING

Bases/Criteria - The most severe occurrence of cladding oxidation and possible fragmentation during a postulated accident is the result of a LOCA. In order to reduce the effects of cladding oxidation during LOCA, Duke uses a limiting criteria of 2200°F on peak cladding temperature (PCT), and a limit of 17% on maximum cladding oxidation as prescribed in 10 CFR 50.46. These criteria are consistent with the SRP criteria. PNL concludes that these criteria are also applicable to the reconstituted assemblies.

Evaluation - Duke will evaluate the impact of fuel reconstitution on LOCA in a similar way to that discussed for Cladding Overheating in Section 4.3. BWFC will take into consideration the exact configuration of reconstituted rods and assemblies, to determine their impact on local power distributions near the reconstituted rods and assemblies, and also the core wide power changes. These local and core power distributions will be used to assess their impact on flow, enthalpy, and stored energy in the LOCA analysis on a cycle specific basis.

5.2 VIOLENT EXPULSION OF FUEL

Bases/Criteria - In a severe Reactivity Insertion A.accident (RIA), such as a control rod ejection accident, large and rapid deposition of energy in the fuel could result in melting, fragmentation, and dispersal of fuel. The mechanical action associated with fuel dispersal might be sufficient to destroy the fuel cladding and rod bundle geometry and provide significant pressure pulses in the primary system. To limit the effects of an RIA event, Regulatory Guide 1.77 recommends that the radially-averaged energy deposition at the hottest axial location be restricted to less than 280 cal/g.

The Duke design criterion for this event is identical to that in Regulatory Guide 1.77, such that the peak fuel enthalpy for the hottest axial fuel rod location shall not exceed 280 cal/g. The reconstitution of fuel assemblies does not impact the fuel enthalpy limit. Therefore, PNL concludes that Duke design limits for fuel dispersal are acceptable for reconstituted fuel assemblies.

Evaluation - The Duke reload analysis methods for RIA events takes into consideration the changes due to reconstitution. PNL concludes that the analysis methodology remains acceptable for application to reconstituted fuel assemblies with solid replacement rods.

5.3 CLADDING BALLOONING

Bases/Criteria - Fuel cladding will balloon (swell) under certain combinations of temperature, heating rate, and stress during a LOCA. There are no specific design limits associated with cladding ballooning, other than the 10 CFR 50 Appendix K requirement, stating that the degree of swelling not be underestimated.

Evaluation - The cladding ballooning model and flow blockage model used by Duke are directly coupled to the cladding rupture temperature model for the LOCA-emergency core cooling system (ECCS) analysis. These models have previously been approved by the NRC, and are considered to be conservative for a reconstituted assembly. As part of the Duke reload design methods discussed in References 3, 4, and 5 cycle specific fuel rod design evaluations are performed using NRC approved Duke fuel performance models. The impact of using solid replacement rods in reconstituted assemblies on cladding ballooning is evaluated as part of this cycle specific design process. Therefore, PNL concludes that Duke has adequately addressed the issue of cladding ballooning, and that these models remain acceptable for application to fuel assembly reconstitution with solid replacement rods.

5.4 FUEL ASSEMBLY STRUCTURAL DAMAGE FROM EXTERNAL FORCES

Bases/Criteria - Earthquakes and postulated pipe breaks in the reactor coolant system would result in external forces on the fuel assembly. Appendix A to SRP Section 4.2 states that the fuel system coolable geometry shall be maintained, and damage should not be so severe as to prevent control rod insertion during seismic and LOCA events. The Duke design basis specifies that the fuel assembly will maintain a geometry that is capable of being cooled under the worst case design accident, and that no interference between control rods and thimble tubes will occur during a safe shutdown earthquake. This is consistent with the SRP and, therefore, remains acceptable for reconstituted assemblies.

Evaluation - Duke has performed a LOCA-seismic analysis to determine how solid replacement rods change the fuel assembly structural response to LOCA-seismic loadings. Reconstituted fuel assemblies have a slightly reduced weight. The structural stiffness is increased when solid replacement rods are used. This results in a shift of the natural frequencies of the reconstituted assembly. Thus, the total energy required to excite and deflect a reconstituted assembly is different from a normal assembly. Also, solid replacement rods do not significantly affect the grid dynamic properties. Therefore, the use of solid replacement rods is acceptable for seismic-LOCA analyses.

The approved seismic and LOCA loading methodologies all assume a full fuel assembly of fuel rods and guide tubes. The approval of these methodologies does not apply to the use of vacancies in an assembly. The use of vacancies will alter the dynamic response of an assembly due to changes in the physical characteristics and material properties. Therefore, based on the approved methodologies of qualifying a fuel assembly with no vacancies, the use of vacancies in reconstituted assemblies is not acceptable for seismic and LOCA analysis for Duke Power Company.

6.0 CONCLUSIONS

PNL has reviewed the Duke mechanical and thermal hydraulic analysis criteria and methods for reconstituted fuel assemblies as presented in Sections 1.0, 2.0, 4.0, 5.0 and 6.0 of Reference 1. This review has been conducted in accordance with Section 4.2 of the SRP. PNL concludes that the reconstitution methodology as described in Reference 1 is acceptable for core reload analysis licensing applications for solid replacement rods with the following restrictions: 1) no more than ten solid rods per assembly, 2) no more than 3 solid rods in a row, and 3) cycle specific reload analyses must include the exact configuration and case location of reconstituted rods and assemblies including power distributions.

This approval does not provide generic approval for the use of vacancies in reconstituted assemblies because of concerns with fretting wear and seismic-LOCA loads as discussed in Sections 3.4 and 5.4 of this report.

7.0 REFERENCES

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