FUEL MECHANICAL RELOAD ANALYSIS METHODOLOGY FOR MARK-BW FUEL

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MECHANICAL AND THERMAL HYDRAULICS ANALYSIS

ABSTRACT

This Technical Report describes Duke Power Company's Mechanical Reload Analysis Methodology for Mark-BW Fuel. For each reload cycle, mechanical analyses must be performed to ensure the fuel rod structural integrity, and to establish acceptable thermal and mechanical operating limits as specified by Section 4.2 of the NRC Standard Review Plan. This report describes these licensing analyses, and the methods utilized to ensure that the applicable NRC guidelines are met throughout the fuel's in-reactor lifetime.

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I. INTRODUCTION

This report describes Duke Power's Mechanical Reload Analysis Methodology for Mark-BW Fuel.

Each fuel cycle design requires that thorough fuel mechanical and thermal assessments be performed. A reload design utilizes fuel designs that are bound by previous fuel assembly design analyses. Occasionally, however, minor differences in the design will occur (such as a change in fuel density). These changes must then be assessed in regard to the following:

- Cladding creep collapse
- Cladding strain
- Cladding stress
- Fuel pin temperature
- Fuel pin pressure
- Vendor ECCS analysis interface criteria

Design analyses that envelope the operation of all current fuel designs have been completed by Duke Power, and reanalysis is normally not required for each fuel cycle design. Rather, a specific fuel cycle design is compared against the enveloping design analyses. The assessment must compare cladding and pellet designs against the pellet and cladding geometries and densities, etc., that have been considered in the enveloping design analyses. Further, the individual radial power histories during the fuel cycle (current and previous batches) must be compared against the generic radial power envelopes that have been used

in the design analyses. In most cases, the design analyses will envelope the fuel cycle design being considered and no reanalysis is required. However, in some cases, either the radial power history or fuel geometry may lie outside of the enveloping design analyses, thus requiring partial or full reanalysis. The following subsections describe the types of comparisons that must be made to justify a fuel cycle design without reanalysis and provides some detail concerning the types of analyses that must be performed if required by either the fuel cycle design or by changes in the fuel design itself.

Table 1 presents a summary of all types of fuel mechanical performance assessment criteria that are used to determine whether a fuel cycle design, the cladding, and the pellets are enveloped by existing analyses. As shown in Table 1, several of these analyses require either a comparison against a pin radial power versus burnup envelope or a comparison against an assembly radial power versus burnup envelope. Examples of these power history envelopes are presented in Figures 1 and 2. These envelopes change, as reanalysis is occasionally required, resulting in an expanded power history envelope.

II. CLADDING COLLAPSE

Cladding creepdown under the influence of external (system) pressure is a phenomenon that must be evaluated during each reload fuel cycle design to ensure that the most limiting fuel rod does not exceed the cladding collapse exposure limit. Cladding creep is a function of neutron flux, cladding temperature, applied stress, cladding thickness, and initial ovality. Acceptability of a fuel cycle design is demonstrated by comparing the power histories of all the fuel assemblies against the generic assembly power history similar to Figure 2. The generic power history must be completely enveloping to avoid reanalysis. Duke Power Company uses its own PDQ edit code to automatically perform this comparison for all fuel assemblies at each depletion step. Changes in pellet or cladding design are also assessed in a similar manner: direct comparison with the fuel rod geometries of Table 1 and reanalysis, if necessary.

The CROV[1] computer code calculates ovality changes in the fuel rod cladding due to thermal and irradiation creep and is used to perform the fuel rod creep collapse analysis when required. CROV predicts the conditions necessary for collapse and the resultant time to collapse. Conservative inputs to the CROV cladding collapse analysis include the use of minimum cladding wall thickness and maximum initial ovality (conservatively assumed to be uniformly oval), based on as-built records. Other conservatisms included are minimum prepressurization pressure and zero fission gas release. Internal pin pressure and cladding temperatures,

input to CROV, are calculated by TACO2[2] using a radial power history similar to that of Figure 2, and a set of axial power and exposure shapes similar to those in Table 2.

The conservative fuel rod geometry and conservative power history are used to predict the number of EFPH required for complete cladding collapse. To demonstrate acceptability, the maximum expected residence time of the cycle is compared against the EFPH required for complete collapse.

III. CLADDING STRAIN ANALYSIS

The diametral transient cladding strain is limited to a value equivalent to but not exceeding 1.0%.

A generic strain analysis has been completed by Duke using TACO2 to ensure that the strain criterion above is not exceeded. This is a bounding, generic analysis, that requires no reload assessments unless a design change occurs.

Should reanalysis be required because of a significant change in the fuel rod design, Duke's generic strain analysis would be repeated using the same methodology. A description of the generic methodology follows:

Calculation of cladding strain is performed by utilizing the TACO2 Fuel Rod Analysis program. A very conservative local power ramp is first determined by considering a maximum local power change induced by a worst case core maneuvering scenario. The scenario involves the following, as appropriate: core power level changes, xenon transient, and control rod position changes. This worst case local power level change is then modeled in TACO2 to determine the maximum local fuel pellet thermal expansion. The cladding transient strain is calculated from the pellet expansion using the following equation:

$$\%\ \text{Strain} = \left[\frac{(\text{Pellet O.D.})_{\text{peak}} - (\text{Pellet O.D.})_{o}}{(\text{Pellet O.D.})_{o}} \right] \times 100 \leq 1.0\%$$

where (Pellet O.D.) peak = the maximum pellet O.D. at the local power peak, and $(\text{Pellet O.D.})_o$ = pellet O.D. prior to the ramp.

Pellet O.D. dimensions are used to calculate cladding strain because the strain itself is caused by pellet thermal expansion. There are three major conditions in this calculation that make it conservative. The first is the extreme power change that is used to simulate the worst case peaking. The second is that the pellet is assumed to be in hard contact at initiation of the ramp. This is a conservative assumption since the actual power scenario ramp is initiated from a very low power level and pellet/cladding contact is not expected to occur at this low linear heat rate. The third conservatism is that the pellet is non-compliant and that all of the pellet thermal expansion results directly in cladding strain.

IV. CLADDING STRESS ANALYSIS

The cladding stress analysis for a new fuel cycle design is similarly bounded by a conservative design analysis that uses Section III of the ASME Boiler and Pressure Vessel Code as a guide in clas fying the stresses into various categories, assigning appropriate limits to these categories, and combining these stresses to determine stress intensity. Each new fuel cycle design is assessed against the criteria stated in Table 1 to determine if reanalysis is required. The stress analysis is very conservative, and reanalysis should not be required for standard Mark BW reloads. However, an assessment is made for each reload design using the criteria of Table 1.

The fuel rod stress analysis considers those stresses that are not relaxed by small material deformation. This analysis complies with the following design criteria:

- The stress intensity value of the primary membrane stresses in the fuel rod cladding, which are not relieved by small material deformation of the cladding, shall not exceed the lesser of:

  (1) one-third of the specified minimum tensile strength at room temperature

  (2) one-third of the tensile strength at operating temperature

  (3) two-thirds of the specified minimum yield strength at room temperature

  (4) two-thirds of the yield strength at operating temperature

- The stress intensity value of the primary membrane plus secondary stresses in the fuel rod cladding, which are not relieved by small material deformation of the cladding, shall not exceed three times the lesser value of items 1-4 above.

In performing the stress analysis, all the loads were selected to represent the worst case loads and were then combined. This represents a conservative approach since they will not occur simultaneously. This insures that the worst case conditions for condition I and II events are satisfied. In addition, these input parameters were chosen so that they conservatively envelope all Mk-BW design conditions.

The primary membrane stresses result from the tensile/compressive pressure loading. Stresses resulting from creep ovalization are addressed in the creep collapse analysis.

The minimum internal fuel rod pressure at HZP conditions is combined with the maximum design system pressure during a transient to simulate the maximum pressure differential across the cladding, yielding the maximum compressive stress. The maximum tensile stress is generated at EOL when internal fuel rod pressure is conservatively higher than the atmospheric external pressure.

The worst case tensile/compressive pressure loads were combined with the other worst case loads. These are described below:

- The maximum grid loads will occur at BOL. During operation, the contact force will relax with time due to fuel rod creepdown and ovalization as well as grid spring relaxation.

- Conservative cladding dimensions with regard to stress.

- The maximum radial thermal stress will occur at the maximum rated power (power level corresponding to centerline fuel melt). This stress cannot physically occur at the same time the maximum pressure loading occurs, but is assumed to do so for conservatism. (Maximum cladding temperature gradient is combined with minimum pin pressure.)

- The ovality bending stresses are calculated at BOL conditions. A linear stress distribution is assumed. The creep collapse analysis calculates the stress increase with time and ovalization.

- Flow induced vibration, fuel rod bow, and differential fuel rod growth stresses are also addressed.

V. FUEL PIN PRESSURE ANALYSIS

The pin pressure analysis is assessed against the design basis analysis criteria and envelopes as indicated in Table 1. If any of the parameters of this table are violated, then a reanalysis is performed.

Pin pressure analysis is performed using TACO2. The rod is assumed to exhibit the burnup dependent set of axial power shapes similar to those shown in Table 2, with a pin power history similar to that presented in Figure 1. Incore fuel densification is minimized in this analysis to yield a smaller plenum volume and a maximum pin pressure history.

Figure 3 presents an example of the results of an analysis of pin pressure versus burnup, performed by Duke Power Company, using TACO2. This analysis was performed for an extended burnup fuel cycle design, using a pin power history similar to Figure 1, and a set of axial power and exposure shapes similar to those in Table 2, for Reload Design purposes. To satisfy mechanical design criteria, pin pressure must be less than system pressure (2250 psia) throughout its design lifetime.

VI. LINEAR HEAT RATE CAPABILITY

Linear heat rate capability of all fuel rods in a reload batch is assessed by comparison against generic analysis criteria and envelopes of Table 1. Any rod whose geometry or power history falls outside of those criteria must be reanalyzed.

The Linear Heat Rate to Melt (LHRTM) analysis is performed using TACO2. This analysis assumes a conservative radial pin power history, similar to that of Figure 1, and a set of axial power and exposure shapes similar to those in Table 2. A variety of radial gaps and individual incore densification values are employed. All statistics are performed at the 95/95 level. In this analysis, a small axial segment of the fuel rod is spiked to high linear heat rates at each burnup step until centerline fuel melt occurs. The resulting heat rate required to reach centerline fuel melt at each burnup is then determined versus burnup for conservatively enveloping cases.

Figure 4 is an example plot of one fuel LHRTM versus burnup case for an extended burnup fuel cycle design. The TACO2 analyses, performed by Duke Power Company, used a pin power history similar to Figure 1, and a set of axial power and exposure shapes similar to those in Table 2. During a typical three cycle residence time, the minimum LHRTM occurs early in life due to fuel densification, but quickly increases due to the offsetting effects of cladding creepdown, pellet swelling, and fuel relocation. (No credit is taken for fuel restructuring in LHRTM analyses). Results of the minimum LHRTM analysis are used to ensure centerline fuel melt does not occur.

VII. ECCS ANALYSIS INTERFACE CRITERIA

Duke reviews each batch of fuel and the fuel cycle design for compatibility with the vendor's fuel rod thermal analysis inputs to the ECCS analysis. The "fuel rod thermal analysis" consists of volumetric average fuel temperature and pin internal pressure versus burnup. These thermal analyses are performed generically by the vendor to provide the fuel rod response during a LOCA. Duke's review of the "inputs" to the thermal analysis (items in Table 1), determine that the thermal analyses need not be repeated for the specific reload under evaluation.

Should the fuel rod thermal analysis inputs for a specific cycle lie outside the vendor's generic analysis, Duke will reperform the fuel rod thermal analysis on a batch specific basis to ensure that the results remain bounded by the results of the vendor's generic analysis. In the very unlikely event that the cycle specific thermal analysis results (fuel temperature and pin pressure) are more limiting than the vendor's generic analysis, either the fuel cycle design must be modified or the vendor must resolve the concern within the vendor's ECCS analysis. Responsibility for identification of incompatibility and resolution lies with Duke.

REFERENCES

1. Program to Determine In-Reactor Performance of B&W Fuels - Cladding Creep Collapse, BAW-10084, Rev. 2, Babcock & Wilcox, Lynchburg, Virginia, October 1978.

2. TACO2 - Fuel Pin Performance Analysis, BAW-10141PA, Rev. 1, Babcock & Wilcox, Lynchburg, Virginia, June 1983.

TABLE 1

FUEL MECHANCIAL PERFORMANCE ASSESSMENT CRITERIA

Analysis Category

TABLE 2

AXIAL POWER AND EXPOSURE SHAPES

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

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

October 15, 1990

Docket Nos. 50-369, 50-370,
50-413, and 50-414

Mr. H. B. Tucker, Vice President
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SUBJECT: SAFETY EVALUATION ON DPC-NE-2001, REVISION 1, "FUEL MECHANICAL RELOAD ANALYSIS METHODOLOGY FOR MARK-BW FUEL" (TAC 66581)

The Commission's staff has reviewed your Topical Report DPC-NE-2001, Revision 1, "Fuel Mechanical Reload Analysis for Mark-BW Fuel," dated January 1990 for application to reloads for the McGuire and Catawba Nuclear Stations. We find the report acceptable. A copy of our Safety Evaluation is enclosed. This completes our action under TAC No. 66581.

Sincerely,

Kahtan N. Jabbour

Kahtan N. Jabbour, Project Manager
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Enclosure:
As stated

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO DUKE POWER COMPANY TOPICAL REPORT DPC-NE-2001,

REVISION 1, "FUEL MECHANICAL RELOAD ANALYSIS

METHODOLOGY FOR MARK-BW FUEL"

DUKE POWER COMPANY

CATAWBA NUCLEAR STATION, UNITS 1 AND 2

DOCKET NOS. 50-413 AND 50-414

AND MCGUIRE NUCLEAR STATION, UNITS 1 AND 2

DOCKET NOS. 50-369 AND 50-370

1.0 INTRODUCTION

By letter dated January 22, 1990, from H. B. Tucker, Duke Power Company, to NRC, the licensee requested that the NRC review a topical report, "Fuel Mechanical Reload Analysis Methodology for Mark-BW Fuel," (DPC-NE-2001) Revision 1, dated January 1990, for McGuire and Catawba reload applications. The methodology described in DPC-NE-2001, Rev. 1, has been approved previously for B&W-designed Oconee reload applications. The licensee intends to use the same methodology for Mark-BW fuel in Westinghouse-designed McGuire and Catawba. The Mark-BW fuel design was approved in Topical Report BAW-10172P. Mark-BW fuel is very similar to the currently B&W-designed Mark B and Mark C fuel. Report DPC-NE-2001, Rev. 1, addresses such analyses as cladding stress and strain, cladding collapse, fuel centerline temperature, rod pressure, and Emergency Core Cooling System (ECCS) initial conditions. All the analyses are performed using the previously approved TACO2 and CROV codes. The licensee has determined that the use of the described methodology for Mark-BW fuel does not create any safety concern, nor require any Technical Specification changes, nor involve any unreviewed safety questions for Catawba and McGuire. Our evaluation follows.

2.0 EVALUATION

2.1 Cladding Collapse

If axial gaps in the fuel pellet column were to occur due to densification, the cladding would have the potential of collapsing into a gap, i.e., flattening. Because of the large local strains that would result from collapse, the cladding is assumed to fail. The licensee used the CROV and TACO2 computer codes to analyze the likelihood of cladding collapse for Mark-BW fuel. Since the CROV and TACO2 computer codes have been approved previously for this analysis, we conclude

that the licensee's methodology of analyzing cladding collapse is acceptable for Mark-BW fuel in McGuire and Catawba reload applications.

2.2 Cladding Strain

The licensee cladding strain criterion is limited to 1% strain during normal operation and transients. The staff has previously approved the criterion. The licensee analyzed the maximum strain using the TACO2 code to determine that 1% strain limit is not exceeded. The method is similar to those methods used by B&W and had been approved by the staff. We therefore consider that the licensee cladding strain analysis is acceptable for Mark-BW fuel in McGuire and Catawba reload applications.

2.3 Cladding Stress

The licensee cladding stress criterion is based on the ASME Code which is acceptable to the staff. The licensee stress analysis methodology is based on the approved B&W methodology to calculate the maximum stress to assure that it remains below the allowable stress. We, thus, consider that the licensee cladding stress analysis is acceptable for Mark-BW fuel in McGuire and Catawba reload applications.

2.4 Rod Pressure

The licensee rod pressure criterion is that the rod pressure shall remain below the system pressure throughout the design lifetime. This criterion is consistent with the staff Standard Review Plan (SRP) criterion and is approved by the staff. To calculate the maximum rod pressure, the licensee used the TACO2 code to predict the gas pressure buildup. Since the TACO2 is an approved code, we conclude that the licensee's rod pressure calculation is acceptable for Mark-BW fuel in McGuire and Catawba reload applications.

2.5 Fuel Centerline Temperature

To assure that a fuel rod does not fail by overheating, the conservative criterion provided by the SRP is that the fuel centerline temperature should not reach the fuel melting point during normal operation and transients. To analyze the melting possibility, the licensee performed maximum linear heat generation rate (LHGR) calculations using the approved TACO2 code to determine the power-to-melt bounding curve. Fuel melting is prevented by maintaining the operating power below the power-to-melt curve. This method is consistent with previously approved B&W analytical methods. We therefore consider that the licensee fuel centerline temperature calculation is acceptable for Mark-BW fuel in McGuire and Catawba reload applications.

2.6 ECCS Initial Conditions

The TACO2 code can also be used to calculate initial conditions such as rod pressure, densification, stored energy, and fuel cladding gap for the ECCS analysis. The staff has previously approved the use of TACO2 for establishing ECCS

initial conditions. We thus consider that the licensee's use of TACO2 to determine ECCS initial conditions is acceptable for Mark-BW fuel in McGuire and Catawba reload applications.

3.0 CONCLUSIONS

We have reviewed the licensee's submittal concerning the use of methodology described in DPC-NE-2001, Rev. 1, for Mark-BW fuel reloads in McGuire and Catawba. Based on the use of previously approved analytical methods and the approved TACO2 and CROV codes, and the similarity between Mark-BW and Mark B and Mark C fuel, we conclude that the DPC-NE-2001, Rev. 1, report is acceptable for Mark-BW fuel licensing applications in McGuire and Catawba. We also determine that there are no unreviewed safety questions and no need of Technical Specification changes for McGuire and Catawba. This approval is limited to the use of the TACO2 code. If, in the future, the licensee decides to use the newer approved code, TACO3, the staff requires the licensee to demonstrate its proficiency in using the TACO3 code.

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Dated: October 15, 1990

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