AREVA

Realistic Thermal-Mechanical Fuel Rod Methodology For Boiling Water Reactors
Supplement 2: Mechanical Methods

BAW-10247NP-A
Supplement 2NP
Revision 0

Topical Report

April 2016

AREVA Inc.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

List of Tables

List of Figures

Nomenclature

Acronym	Definition
AOO	Anticipated Operational Occurrence
BOL	Beginning of Life
CFR	Code of Federal Regulations
DNB	Departure from Nucleate Boiling
EOL	End of Life
FMM	Fuel Management Manual
GDC	General Design Criteria
LTL	Lower Tolerance Limit
LTP	Lower Tie Plate
PIE	Post Irradiation Examination
QAP	Quality Assurance Program
RXA	Recrystallized Annealed
SRA	Stress-Relief Annealed
SRP	Standard Review Plan
UTL	Upper Tolerance Limit
UTP	Upper Tie Plate
Z4B™	AREVA Proprietary Zirconium Alloy
Zry-2	Zircaloy-2 Alloy
Zry-4	Zircaloy-4 Alloy

ABSTRACT

This supplement covers the balance of the BWR fuel mechanical methods which were not updated in the base topical report. The purpose of consolidating these miscellaneous mechanical methods into this supplement is to remove the existing ties to legacy methodology reports. This provides a well-defined licensing basis for BWR nuclear plants which have moved to AREVA's realistic fuel rod methodology.

As part of this consolidation effort, the most recent operating experience data is provided in order to update the correlations for fuel rod bow, fuel rod growth, and fuel assembly growth. This data supports raising the fuel assembly and fuel channel exposure limit to a value that will not restrict the fuel design from reaching the fuel rod exposure limit established in the base topical report.

1.0 INTRODUCTION

AREVA has been upgrading the entire suite of Boiling Water Reactor (BWR) fuel rod analysis methods to the RODEX4 realistic fuel rod thermal-mechanical methodology. This methodology includes peripheral mechanical methods which do not use any thermal-mechanical code such as RODEX4. This supplement is intended to clearly define the entire set of mechanical methods which are applicable to AREVA BWR fuel designs licensed with the RODEX4 methodology.

The thermal-mechanical fuel rod methods which were approved by the NRC in Reference 1 covered the bulk of the fuel rod evaluation requirements in Section 4.2 of the Standard Review Plan (SRP) (Reference 2). However, as noted in the last paragraph of Section 3.1.1 of Reference 1, a small selection of supplemental analysis methods are still based on approval of a topical report tied to legacy methods. AREVA intends to eliminate the need for this legacy reference with the approval of this supplement report. Not only does this provide more cohesive licensing documentation, it allows AREVA the opportunity to update the operating experience database based on our current knowledge of fuel rod performance.

This supplement does not introduce any changes to AREVA's existing BWR methodology other than updates to correlations derived from operating experience data. The described methods are consistent with the underlying methods supporting the design criteria approved for generic application in Reference 3. Recent operating experience data is provided for fuel rod bow, fuel rod growth, and fuel assembly growth; and the correlations are adjusted accordingly. This data is used to establish a fuel assembly exposure limit of [ ]. Since fuel channels are licensed for one fuel assembly lifetime, this represents an incremental increase in exposure for channels as well. This fuel assembly exposure limit is high enough to allow fuel rods to achieve the currently approved fuel rod exposure limit. The fuel rod exposure limit for the realistic fuel rod thermal-mechanical methodology has been established in Reference 1.

2.0 SUMMARY

This report describes the peripheral BWR mechanical methods within AREVA's realistic thermal-mechanical fuel rod methodology which had been included by reference in the base topical report (Section 3.1.1 of Reference 1). The legacy references are therefore superseded by this supplement; specifically

- EMF-85-74(P) Revision 0 Supplement 1(P)(A) and Supplement 2(P)(A), "RODEX2A (BWR) Fuel Rod Thermal-Mechanical Evaluation Model," Siemens Power Corporation, February 1998.

- XN-NF-75-32(P)(A) Supplements 1 through 4, "Computational Procedure for Evaluating Fuel Rod Bowing," Exxon Nuclear Company, October 1983. (Base document not approved.)

Approval of this supplement allows AREVA to remove these legacy topical reports when RODEX4 methods are used for licensing. New analyses based on RODEX4 methods will implement this supplement and the described methods. However, existing analyses based on RODEX4 methods and analyses based on older methodologies, such as RODEX2A, will not be updated after approval of this supplement.

The information provided in this supplement justifies a maximum fuel assembly exposure limit of [ ]. This is a small increase over the previously approved fuel assembly burnup limit in order to allow fuel rods to achieve the currently approved fuel rod exposure limit. Since fuel channels are licensed for one fuel assembly lifetime, this represents an incremental increase in exposure for channels as well. The fuel rod exposure limit for the realistic fuel rod thermal-mechanical methodology has been established in Reference 1.

A review of the design methodology indicates no changes are required in the existing approved methodology or design criteria. However, there are adjustments to the correlations for fuel rod bow, fuel rod growth, and fuel assembly growth due to the incorporation of recent operating experience data. Note that the fuel rod growth correlation presented in this supplement is based on the total axial rod growth measured in post-irradiation exams, and therefore does not affect the RODEX4 stress-free irradiation growth model in Reference 1.

The rod bow correlation is constructed from fuel rod-to-rod gap closure data measured on a broad selection of AREVA BWR fuel designs in varied operating environments. The rod-to-rod gap closure predicted as a function of fuel assembly exposure is used as an input to thermal limit evaluations (i.e. MCPR) for AREVA BWR fuel designs.

The BWR rod growth correlation is updated with the most recent data from AREVA's Zircaloy-2 stress-relief annealed (SRA) cladding, [

]. The BWR fuel assembly growth correlation is built from post-irradiation length measurement data taken from ATRIUM™[1] fuel assemblies. This model is applicable to all ATRIUM™ fuel assembly designs for which assembly growth is controlled by the water channel growth, including the ATRIUM™ 11 with Z4B™[2] water channels. The combination of the fuel rod and assembly growth correlations is used to define the maximum fuel rod length which will not interfere with the upper tie plate at end of life. This is the only mechanical method defined in this report which is limiting at end of life, and the growth databases support the maximum requested fuel assembly exposure limit.

1 ATRIUM is a trademark of AREVA Inc.
2 Z4B is a trademark of AREVA Inc.

3.0 APPLICABLE REGULATORY GUIDANCE

Regulatory guidance for the review of fuel system designs and adherence to applicable General Design Criteria is provided in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants”, Section 4.2, “Fuel System Design” (Reference 2). In accordance with the Standard Review Plan (SRP) Section 4.2, the objectives of the fuel system safety review are to provide assurance that:

- The fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs),
- Fuel system damage is never so severe as to prevent control rod insertion when it is required,
- The number of fuel rod failures is not underestimated for postulated accidents, and
- Fuel coolability is always maintained.

The mechanical methods covered in this supplement will be limited to those that establish the design bases for the acceptance criteria as provided in SRP Section 4.2 II.1.A, “Fuel System Damage”. These SRP acceptance criteria have been translated into specific requirements defined for AREVA BWR fuel designs in Reference 3. As shown in Table 3-1, only correlations supporting the fuel rod bow and axial growth methods have changed from previously approved methodology.

Table 3-1 Methods Supporting the Standard Review Plan Criteria

1. Design Bases	Item	Topic	Assessment	Location in this Report
A. Fuel System Damage	i	Stress, strain, or loading limits	There is no change from the previously approved fuel rod cladding stress methodology as described in Section 3.4.3 of Reference 4. For structural components (not cladding), the methods are included in this supplement but there is also no change from previously approved methods.	Section 4.1.1
	ii	Fatigue	There is no change from the previously approved fuel rod cladding fatigue methodology as described in Reference 1. For structural components (not cladding), the methods are included in this supplement but there is also no change from previously approved methods.	Section 4.1.2
	iii	Fretting wear	The methodology for evaluating fretting is included in the supplement, but there is no change from previously approved methods.	Section 4.1.3
	iv	Oxidation, hydriding, crud	There is no change from the previously approved fuel rod cladding corrosion methodology as described in Reference 1. For structural components (not cladding), the methods are included in this supplement but there is also no change from previously approved methods.	Section 4.1.4
	v	Dimensional changes	Fuel rod bow and axial growth methods are included in the supplement with updated correlations based on recent data. Fuel channel bow and bulge methods are covered in References 5 and 6.	Section 4.1.5
	vi	Rod internal gas pressure	There is no change from the previously approved fuel rod internal pressure methodology as described in Reference 1.	This topic is not addressed in this supplement.
	vii	Assembly liftoff	The methodology for evaluating assembly liftoff is included in the supplement, but there is no change from previously approved methods.	Section 4.1.6
	viii	Control rod reactivity and insertability	Fuel channel bow and bulge methods are covered in References 5 and 6. The fuel channel methodology ensures control rod insertability.	This topic is not addressed in this supplement.

4.0 ANALYTICAL METHODOLOGY

4.1 *Mechanical Methods*

The methods described in this section cover the topics included in SRP Section 4.2 II.1.A for fuel system damage except those already addressed in the base topical report (Reference 1). These methods support AREVA's generic BWR fuel design criteria approved in Reference 3 throughout the design lifetime of the fuel and cover handling, normal operation and AOO conditions. The only changes to the previously approved BWR fuel mechanical methods are updates to fuel rod bow, fuel rod growth, and fuel assembly growth correlations.

4.1.1 Stress, strain or loading limits

The strength of the fuel assemblies and fuel rods is assured by evaluating the margin to conservative stress and deformation design limits under various shipping, handling and operational loads. The loads are applied to the fuel rod cladding, upper and lower tie plates, grid spacers, water channel (or tie rods) and connecting hardware, fuel assembly cage and springs where applicable. AREVA defines a maximum axial handling design load equivalent to [ ].

As described in Reference 3, AREVA uses Section III of the ASME Boiler and Pressure Vessel Code as guidance for establishing the acceptable stress, strain, or load criteria for assembly components and the corresponding analysis methods which may be used to evaluate those criteria. These methods include elastic and plastic analysis techniques as well as load rating from prototype testing. Analysis methods include use of conventional, open-literature equations, elasticity formulations, general purpose finite element stress analysis codes such as ANSYS, or testing.

The minimum specified yield and ultimate strength for unirradiated material are used in the analyses. This is a conservative assumption since strength will increase under irradiation. Since loads often stay the same or decrease over time, the beginning of life

(BOL) strength evaluations tend to be the most limiting. This is true even when the material loss due to oxidation that would be expected at end of life (EOL) is factored in. The oxide is either insignificant, as observed on stainless steel and nickel alloy components; or the oxide is on relatively thick components such as the Zircaloy water channel and fuel channel. Zircaloy fuel rod cladding is the only component with a specific EOL analysis requiring the assumed loss of material due to corrosion. However, even in this case the EOL analysis is not limiting due to the reduced loads at EOL.

While all load bearing fuel assembly components have some analysis or test to validate that criteria are met for the given design loads, a few of the components have standard evaluations as described below.

4.1.1.1 Fuel rod cladding

Various normal operation and AOO loads create stresses on the fuel rod cladding. Each individual stress is calculated at the inner and outer surfaces of the cladding at both the mid-span between spacer grids and at the spacer grid. The stresses at each location are then combined to determine the maximum stress intensities. The analysis is performed at BOL and EOL and at cold and hot conditions with unirradiated material strength. The stress analysis assumes maximum fuel rod power, minimum fill gas pressure, and the most conservative fuel rod geometry including a reduced wall thickness at EOL due to oxidation.

[

] The cladding stress analysis method has not changed from what was documented in Section 3.4.3 of Reference 4. The stress calculations use conventional, open-literature equations. A general purpose, finite element stress analysis code such as ANSYS may be used to calculate the stress due to spacer spring contact forces and the stress at the fuel rod end cap weld location.

4.1.1.2 Plenum spring

The internal fuel rod plenum spring provides an axial load on the fuel stack that is sufficient to assist in the closure of any gaps caused by handling, shipping, and densification. After fuel densification, the plenum spring has no functional requirements. Therefore, an EOL analysis is not required. The spring criteria are evaluated with coil spring handbook equations and validation testing.

4.1.1.3 Compression spring

The compression spring supports the upper tie plate (UTP) and fuel channel. The spring is evaluated with coil spring handbook equations and validation testing based on the deflection and specified spring force requirements. Irradiation-induced relaxation is taken into account to ensure the minimum compression spring force is greater than the combined weight for the UTP and fuel channel, including channel fastener hardware. Since the compression spring does not interact with the fuel rods, no evaluation is required for fuel rod buckling loads.

4.1.1.4 Seal spring

The lower tie plate (LTP) seal spring limits the bypass coolant leakage rate between the LTP and fuel channel. The seal spring accommodates the expected channel deformation while remaining in contact with the fuel channel. In addition, the seal spring must have adequate corrosion resistance and be able to withstand the operation stresses without yielding.

Flow testing is used to confirm acceptable bypass flow characteristics. The seal spring is designed with adequate deflection range for accommodating the maximum expected channel bulge while maintaining an acceptable leakage rate. Seal spring stresses are analyzed using a finite element method or handbook equations.

4.1.2 Strain fatigue

Fatigue of structural components is generally low because the cyclic loadings on the structural components typically have either a small number of cycles (i.e. reactor startup) or small amplitude (i.e. flow-induced vibration). Cyclic loading associated with relatively large changes in power can cause cumulative damage which may eventually lead to fatigue failure. The O'Donnell and Langer fatigue curves are used in the analysis of Zircaloy components (Reference 7). These fatigue curves incorporate the NRC recommended "2 or 20" safety factor. This safety factor reduces the stress amplitude by a factor of two or reduces the number of cycles by a factor of twenty, whichever is more conservative. The fatigue curves provide the maximum allowed number of cyclic loadings for each stress amplitude. The fatigue usage factor is the number of expected cycles divided by the number of allowed cycles. The total cumulative usage factor is the sum of the individual usage factors for each duty cycle.

4.1.3 Fretting wear

Fretting wear is a concern for the fuel rod cladding. Fretting wear may occur on the fuel cladding surfaces in contact with the spacer grids if there is a reduction in grid spacer spring loads in combination with small amplitude, flow induced, vibratory forces.

[

]

[

].

4.1.4 Oxidation, hydriding, and crud

Because of the low amount of corrosion on fuel assembly structural components,

[

].

Oxidation, hydriding, and crud are the greatest at EOL. However, the effects of corrosion are not limiting at EOL. Design analyses have shown that irradiation increases material strength more than wall thinning due to oxidation reduces strength on fuel assembly structural components; [

].

4.1.5 Dimensional changes

The dimensions of fuel assembly components will change during irradiation which has the potential to affect safety margins. As detailed in the SRP, the thermal-hydraulic safety limits could be affected by rod bow. This includes the rod bow which would occur if the differential irradiation growth between the fuel rod and fuel assembly was enough to cause interference between the rod and upper tie plate. Fuel channel deformation due to bow and bulge is also a concern as it can affect control blade insertability if there is too much interference between the channel and blade. The topics of rod bow and axial growth are covered below. Fuel channel deformation is covered in References 5 and 6. AREVA uses empirical models to determine the expected bow and growth.

4.1.5.1 Rod bow

Differential expansion between the fuel rods, as well as lateral thermal and flux gradients can lead to lateral creep bow of the rods in the spans between spacer grids. This lateral creep bow alters the pitch between the rods and may affect the peaking and local heat transfer. Therefore, AREVA has developed a correlation for predicting BWR fuel rod-to-rod gap closure as a function of assembly burnup for use in the thermal-hydraulic safety analyses. Data shows that [ ] and is provided in Appendix A. This observation, combined with the fact that [ ]. The rod bow correlation has been updated and is provided in Appendix A.

4.1.5.2 Axial irradiation growth

AREVA sizes the fuel assembly components to have clearances or engagements which are sufficient to accommodate differential growth through EOL. There are a handful of interfaces which change due to axial irradiation growth such as the engagement between channel springs on adjacent assemblies, engagement of the fuel channel with the seal spring, engagement of the fuel rods in the spacer grids, and clearance between the fuel rod and the upper tie plate. ([

]). While all of these evaluations are considered during design, only the loss of clearance between the fuel rod and the upper tie plate has the potential to affect safety margins since interference may cause additional rod bow and lead to fuel rod failures.

To evaluate the minimum EOL clearance between the fuel rod and tie plates it is necessary to determine correlations for the fuel rod growth and the fuel assembly growth derived from post-irradiation length measurements. The initial nominal clearance between the fuel rod and upper tie plate can then be reduced by an accounting of fabrication tolerances and uncertainty in the growth correlations. This determines the design margin for growth.

EOL calculations are limiting, and data has been provided which covers the maximum fuel assembly exposure limit. The fuel rod growth and fuel assembly growth correlations have been updated in Appendices B and C, respectively, including an upper bound for the fuel rod growth and a lower bound for the fuel assembly growth. Note that the fuel rod growth correlation presented in this supplement is based on the total axial growth measured in post-irradiation exams which includes both stress-free growth and stress-induced growth. Only stress-free irradiation growth data is used to support the growth model in RODEX4 (Reference 1). Therefore, this new growth correlation has no impact on the RODEX4 stress-free irradiation growth model.

4.1.6 Assembly liftoff

AREVA requires that the fuel assembly not levitate due to hydraulic loads during normal operation and AOO conditions. The criterion covers both cold and hot conditions and uses the Technical Specification limits on flow.

The net axial force acting on the fuel assembly is calculated by adding the loads from gravity, hydraulic resistance from coolant flow, difference in fluid flow entrance and exit momentum, and buoyancy. The component pressure drop coefficients are determined from flow testing. The calculated net force is confirmed to be in the downward direction, indicating no assembly liftoff. Maximum hot channel conditions are used in the calculation because the greater two-phase flow losses produce higher uplift force. At higher exposures, the lower reactivity results in lower two-phase pressure drop. This will result in a smaller overall lift force such that high exposure fuel assemblies are non-limiting.

Analyses to date indicate a large margin to assembly liftoff under normal operating conditions and AOO. Therefore, fuel liftoff in BWRs under normal operating conditions and AOO is considered to be of no concern.

5.0 UPDATE PROCESS

AREVA plans to continue to acquire rod bow and growth data on irradiated BWR fuel designs. As post-irradiation examination data are obtained, the AREVA PIE database will be expanded. Periodically, the models shown in the appendices will be reviewed against the growing database. If the data support a modification to these models, the internal AREVA design change process will be followed. This change process includes documentation and justification of the change and evaluation of the impact on future design analyses. Any changes to the models will be maintained in an internal AREVA document. A summary of any updates made to the models will be provided to the NRC in a letter for information only, unless the change exceeds the threshold required for submittal. The threshold for submittal of the growth and bow correlations is an increase of the correlation tolerance limits by one standard deviation.

The update process ensures that design margins are maintained, and it ensures compliance with any limitations specified in the NRC's Safety Evaluation Report. If the updates are outside of the NRC's Safety Evaluation Report limitations, then one of the following actions will be taken:

- No credit taken for the update, or
- Update documented for NRC review and approval.

The bow and growth correlations provided in the appendices are based on an extensive database covering several fuel designs operating in many different reactors. There is not expected to be a significant change in any of these correlations unless a significantly different material or fuel design is introduced. In such as case, the lead assembly process would be followed prior to reload supply to justify continued use of these correlations.

6.0 QUALITY ASSURANCE PROGRAM

Licensees and vendors use a variety of methods to evaluate the thermal, mechanical, and materials design of the fuel system. The NRC staff reviews these methods to ensure that they provide a realistic or conservative result and that they adhere to the requirements of the Code of Federal Regulations (CFR) and General Design Criteria (GDC). Regulations, which are applicable to thermal, mechanical and material design of the fuel system, are found in 10 CFR 50.46; GDC 10, 27 and 35; 10 CFR 50 Appendix K; and 10 CFR 100. Additionally, because the result of the transient and accident analysis methods are important to the safety of the nuclear power plants, these methods must be maintained under a quality assurance program (QAP) which meets the criteria set for in 10 CFR 50 Appendix B. The AREVA QAP is documented in Reference 8.

The AREVA QAP covers the procedures for design control, document control, software configuration control and testing, and error identification and corrective actions used in the development and maintenance of the evaluation model. The program also ensures adequate training of personnel involved with code development and maintenance, as well as those who perform the analyses.

7.0 REFERENCES

1. BAW-10247PA Revision 0, “Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors”, AREVA NP, February 2008.

2. USNRC Standard Review Plan, Section 4.2 “Fuel System Design”, NUREG-0800, Revision 3, March 2007.

3. ANF-89-98(P)(A) Revision 1 and Supplement 1, “Generic Mechanical Design Criteria for BWR Fuel Designs”, Advanced Nuclear Fuels Corporation, May 1995.

4. ANF-88-152(P)(A) with Amendment 1 and Supplement 1, “Generic Mechanical Design for Advanced Nuclear Fuels 9x9-5 BWR Reload Fuel,” Advanced Nuclear Fuels Corporation, August 1990.

5. EMF-93-177(P)(A) Revision 1, “Mechanical Design for BWR Fuel Channels,” Framatome ANP, August 2005.

6. EMF-93-177P-A Revision 1 Supplement 1P-A Revision 0, “Mechanical Design for BWR Fuel Channels, Supplement 1: Advanced Methods for New Channel Designs,” AREVA NP Inc., September 2013.

7. W. J. O’Donnell and B. F. Langer, “Fatigue Design Basis for Zircaloy Components,” Nuclear Science and Engineering, Volume 20, Number 1, September 1964.

8. FMM Revision 6, AREVA Mining Front –End Business Group Fuel Management Manual, effective December 2015.

APPENDIX A BWR FUEL ROD BOW CORRELATION

Introduction

AREVA has gathered post-irradiation rod-to-rod gap closure measurements from a variety of BWR fuel designs as shown in Figure A-1. Both the absolute and the percent gap closure data for all measured AREVA BWR designs (7x7, 8x8, 9x9, and 10x10) reveal [

] This new correlation will provide a bounding estimation of fuel rod-to-rod gap closure that will be used for all current and future AREVA BWR fuel designs in the United States.

Measurement Description

AREVA has conducted PIE campaigns both in the U.S. and in Europe to collect fuel rod-to-rod gap measurements. The fuel rod-to-rod gap database includes AREVA's legacy designs with 7x7, 8x8, and 9x9 rod arrays which are no longer in operation, and also the ATRIUM™-10 design still in use today.

Fuel rod-to-rod gap measurements are typically taken at each span between spacer grids (usually 8 spans) and at each fuel rod-to-rod gap. In addition, measurements can be taken when the tool is inserted and withdrawn, for two measurements of every gap.

For example, there are 120 fuel rod-to-rod gaps in a 9x9 assembly with a central water channel. Therefore, in this particular assembly, there could be up to 1920 measurements if two measurements per gap are recorded. For the ATRIUM™-10 family of fuel designs, there are 156 fuel rod-to-rod gaps which could lead to a total of up to 2496 measurements for the entire bundle if two measurements per gap are recorded.

[

]

Visual Inspections

When fuel rod-to-rod gap measurements are not taken, fuel rods are typically visually inspected for any signs of abnormal bow behavior. The ATRIUM™ 11, currently supplied as lead test assemblies, is also well-represented by the database as shown in recent visual examinations. [

] These inspections confirm that ATRIUM™ 11 is performing similar to past operating experience in 7x7, 8x8, 9x9, and 10x10 designs.

Table A-1 ATRIUM™ 11 Leads Visual Inspections

[

]

Correlation Development

[

]

[

] To include additional conservatism, the obtained 95/95 UTL function is multiplied by a 1.2 factor. This 1.2 factor was previously suggested in Section 2.5 of Reference A-2 to account for changes in rod bow at hot operating conditions with respect to the cold conditions where the measurements are taken.

[

]

[

]

Table A-2 BWR Fuel Rod Bow Equation

[

]

Summary

The comparison between the fuel rod bow correlation and the AREVA BWR rod-to-rod gap closure database is presented in Figure A-1. The chart contains the 95/95 UTL percent gap closure data per span for AREVA BWR fuel assembly designs, including 7x7, 8x8, 9x9, and ATRIUM™-10. The double yellow line represents the correlation as described by Equation A-4.

Visual exams on ATRIUM™ 11 have not revealed any unusual fuel rod bow behavior

[

] Therefore, ATRIUM™ 11 has been shown to have minimal rod bow which can be conservatively bound with the new rod-to-rod gap closure correlation.

AREVA will continue to monitor the mechanical performance of its fuel designs, including ATRIUM 11 leads in the U.S. and in Europe. In addition to visual examinations where rod bow behavior is specifically addressed, fuel rods are routinely visually inspected when possible during PIE campaigns to identify unusual trends in rod bow behavior that may require additional measurements to characterize the performance.

[

]

Figure A-1 BWR Fuel Rod Bow Correlation

APPENDIX A REFERENCES

A-1 Factors for One-Sided Tolerance Limits and For Variables Sampling Plans, D. B. Owen. Sandia Corporation Monograph (SRC-607), March 1963.

A-2 Memorandum from D. F. Ross and D. G. Eisenhut, NRC, to D. B. Vassallo and K. R. Goller, Subject: Revised Interim Safety Evaluation Report on the Effects of Fuel Rod Bowing on Thermal Margin Calculations for Light Water Reactors, dated February 16, 1977.

APPENDIX B BWR FUEL ROD GROWTH CORRELATION

Introduction

The fuel rod growth correlation was most recently approved in 1998 using Zircaloy-2 (Zry-2) Stress Relief Annealed (SRA) growth data obtained from post irradiation examination (PIE) campaigns. This correlation has been updated to include the Zry-2 SRA rod growth data obtained from PIE campaigns since 1998.

Measurement Description

Figure B-1 shows the fuel rod growth correlation containing the data presented in the rod growth correlation from 1998, the data in open blue markers, as well as the new data collected since 1998, the closed red markers. The data include fuel rods from 7x7, 8x8, 9x9 and 10x10 arrays (ATRIUM™-10). [

]

Correlation Development

The fuel rod growth data (expressed as percent of active fuel length) versus assembly average burnup is shown in Figure B-1. [

]

[

]

Table B-1 BWR Fuel Rod Growth Equation

[

]

[

]

Summary

The results of the fuel rod growth linear correlation are summarized in Table B-1. The maximum fuel assembly exposure level represented by the data is [

] Based on the data and similarity in manufacturing processes, the BWR rod growth correlation is fully applicable to AREVA BWR fuel rod designs with SRA Zry-2 cladding.

[

]

Figure B-1 BWR Fuel Rod Growth Correlation for SRA Cladding

[

]

Figure B-2 UO2 and Chromia-doped Fuel Rod Growth in BWR Reactor C22 with RXA Cladding

APPENDIX B REFERENCES

B-1 Factors for One-Sided Tolerance Limits and For Variables Sampling Plans, D. B. Owen. Sandia Corporation Monograph (SRC-607), March 1963.

APPENDIX C BWR FUEL ASSEMBLY GROWTH CORRELATION

Introduction

This appendix provides an assembly growth correlation to be applied for the evaluation of AREVA BWR fuel assemblies where the axial growth is controlled by a central water channel made from a zirconium alloy. The new correlation is based on ATRIUM™ type fuel assembly growth data only, and excludes designs with load bearing tie rods as well as the European bundle in basket designs. The database includes water channels made from both Zircaloy-4 (Zry-4) and Z4B™ materials.

Measurement Description

Figure C-1 only includes growth data from ATRIUM™-10 assemblies, solid green data points, and ATRIUM™ 11 assemblies, open orange data points, made from Zry-4 and Z4B™ water channels, excluding designs with load bearing tie rods and the European bundle in basket design. [

]

Correlation Development

The fuel assembly growth data (expressed as percent of active fuel length) versus assembly average burnup is shown in Figure C-1. [

]

[

]

Table C-1 BWR Fuel Assembly Growth Correlation

[

]

[

]

Summary

The results of the fuel assembly growth correlation are summarized in Table C-1. The maximum assembly exposure level represented by the data is [ ] Based on the data and similarity in manufacturing processes, the BWR fuel assembly growth correlation is fully applicable to ATRIUM™ type fuel assembly designs, including ATRIUM™ 11, with water channels made from Zry-4 and Z4B™. This correlation does not apply to load bearing tie rod designs or the European bundle in basket design.

[

]

Figure C-1 BWR Fuel Assembly Growth Correlation

APPENDIX C REFERENCES

C-1 Factors for One-Sided Tolerance Limits and For Variables Sampling Plans, D. B. Owen. Sandia Corporation Monograph (SRC-607), March 1963.

TR Prioritization Scheme			
Title: BAW-10247P-A Supplement 2P Revision 0, "Realistic Thermal-Mechanical Fuel Rod Methodology For Boiling Water Reactors Supplement 2: Mechanical Methods"			
Expect submitting FY	**TAC**	**PM**	**Today's Date:4/29/2016**
Technical Review Division(s)		**Technical Review Branch(s)**	
Factors	**Select the Criteria That the TR satisfies**	**Points can be Assigned for Each Criteria**	**Assigned Points**
TR Classification (Select one only)	Resolve Generic Safety Issue (GSI)	6	2
	Emergent NRC Technical Issue	3	
	New technology improves safety	2	
	TR Revision reflecting current requirements or analytical methods.	2	
	Standard TR	1	
TR Applicability (Select one only)	Potential industry-wide applications	3	2
	Potentially applicable to entire groups of licensees.	2	
	Intended for only partial groups of licensees.	1	
TR Implementation Certainty (Select one only)	Industry-wide Implementation expected	3	1
	Expected implementation by an entire group of licensees (BWROG, PWROG, BWRVIP, etc.) who sponsored the TR.	2	
	Docketed intent by U.S. plant(s) but no formal LAR schedule yet	1	
	No US plants have indicated strong intent on docket to implement yet.	0	
Tie to a LAR (Select if applicable)	A SE is requested by a certain date (less than two years) to support a licensing activity or renewal date (note it in Comments)	3	3
Review Progress (Points are cumulative as applicable)	Accepted for review	0.3	
	RAI issued	0.5	
	RAI responded	1.2	
	SE Drafted	2.0	
Management (LT/ET) discretion adjustment		-3 to +3	
Total Points (Add the total points from each factor and total here):			8
Comments: Request Approval by December 2017 for LAR Reference.			