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Mechanical Design for BWR Fuel Channels: Z4B Material

EMF-93-177
Revision 1
Supplement 2NP-A
Revision 1

Topical Report

June 2019

Framatome Inc.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 24, 2019

Mr. Gary Peters, Director
Licensing and Regulatory Affairs
Framatome Inc.
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: FINAL SAFETY EVALUATION FOR FRAMATOME INC. TOPICAL REPORT EMF-93-177, REVISION 1, SUPPLEMENT 2P, REVISION 1, "MECHANICAL DESIGN FOR BWR FUEL CHANNELS: Z4B MATERIAL" (EPID: L-2018-TOP-0029)

Dear Mr. Peters:

By letter dated July 25, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18211A307), Framatome, Inc. (Framatome) submitted Topical Report (TR) EMF-93-177, Revision 1, Supplement 2P, Revision 1, "Mechanical Design for BWR [boiling water reactor] Fuel Channels: Z4B Material," to the U.S. Nuclear Regulatory Commission (NRC) staff for review and approval. By letter dated April 23, 2019 (ADAMS Accession No. ML19101A419), an NRC draft safety evaluation (SE) regarding our approval of TR EMF-93-177, Revision 1, Supplement 2P, Revision 1, was provided for your review and comment. By letter dated May 20, 2019 (ADAMS Accession No. ML19142A094), Framatome provided comments on the draft SE. The NRC staff's disposition of the Framatome comments on the draft SE are discussed in the attachment (ADAMS Accession No. ML19149A488) to the final SE enclosed with this letter.

The NRC staff has found that TR EMF-93-177, Revision 1, Supplement 2P, Revision 1, is acceptable for referencing in licensing applications for nuclear power plants to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for our acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in licensing action requests, our review will ensure that the material presented applies to the specific plant involved. Requests for licensing actions that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that Framatome publish approved proprietary and non-proprietary versions of TR EMF-93-177, Revision 1, Supplement 2P, Revision 1, within 3 months of receipt of this letter. The approved versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The approved versions shall include an "-A" (designating approved) following the TR identification symbol.

As an alternative to including the RAIs and RAI responses behind the title page, if changes to the TR were provided to the NRC staff to support the resolution of RAI responses, and if the NRC staff reviewed and approved those changes as described in the RAI responses, there are two ways that the accepted version can capture the RAIs:

1. The RAIs and RAI responses can be included as an Appendix to the accepted version.
2. The RAIs and RAI responses can be captured in the form of a table (inserted after the final SE) which summarizes the changes as shown in the approved version of the TR. The table should reference the specific RAIs and RAI responses which resulted in any changes, as shown in the accepted version of the TR.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Framatome will be expected to revise the TR appropriately or justify its continued applicability for subsequent referencing. Licensees referencing this TR would be expected to justify its continued applicability or evaluate their plant using the revised TR.

Sincerely,

Dennis C. Morey, Chief
Licensing Processes Branch
Division of Licensing Projects
Office of Nuclear Reactor Regulation

Project No. 728
Docket No. 99902041

Enclosure:
Final Safety Evaluation

FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT EMF-93-177, REVISION 1, SUPPLEMENT 2P, REVISION 1

"MECHANICAL DESIGN FOR BWR FUEL CHANNELS: Z4B MATERIAL"

FRAMATOME INC.

PROJECT NO. 728/DOCKET NO. 99902041

1.0 INTRODUCTION

By letter dated July 25, 2018 (Ref. 1), Framatome Inc. (Framatome) requested review and approval of an advanced zirconium (Zr) alloy, Z4B, for batch application to existing boiling water reactor (BWR) fuel channel designs. Framatome developed Z4B to address excessive control blade friction due to abnormal fuel channel bow and bulge primarily caused by hydrogen-assisted accelerated irradiation-induced differential growth, galvanic style shadow corrosion from low exposure control blade insertion, and channel deformation/creep from differential pressure, that was experienced by the nuclear power industry when it transitioned to Zr-2 based fuel channel materials and thick-thin channel mechanical designs in the 2000s.

Z4B is a Zr-4 based material with increased alloying elements of iron (Fe) and chromium (Cr). It is manufactured with one of two heat options, either fully recrystallized annealed (RXA) or beta-quenched (BQ).

In 2017, the U.S. Nuclear Regulatory Commission (NRC) staff approved Framatome's expanded lead use channel (LUC) program for the Z4B zirconium alloy (Ref. 4). The purpose of the expanded LUC program was to allow greater numbers of channels to be exposed to varying in-reactor operating strategies, nuclear conditions, and water chemistry in order to gain experience and gather data for batch application. Reference 4 describes the LUC program and Reference 1 summarizes the results of the LUC program. Section 5.0 of this safety evaluation (SE) addresses the limitations and conditions (L&Cs) imposed on the use of Z4B channels by Reference 4 during the LUC program and any new L&Cs as a result of this review.

It is important to note that Framatome is not requesting any new performance models for the Z4B material, even though it has improved characteristics. Nor is Framatome requesting any changes to the methodology used in a licensee's safety analyses (SAs) evaluation models (EMs) for licensing Framatome's fuel products. Reference 1 justifies the existing Zr-4 based performance models (Refs. 2 and 3) and their application within a licensee's SA methods is applicable and conservative for use with Z4B.

EMF-93-177, Revision 1, Supplement 2P, Revision 1, "Mechanical Design for BWR Fuel Channels: Z4B Material," will be referred to as EMF-93-177 in the remainder of this SE.

Enclosure

2.0 REGULATORY EVALUATION

Regulatory guidance for the review of fuel system materials and designs and adherence to General Design Criteria (GDC)-10, GDC-27, and GDC-35 is provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 4.2, "Fuel System Design" (Ref. 5). In accordance with 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 coolability is always maintained.

The main focus of the limited SRP guidance with respect to BWR fuel bundle channels is control blade interference and insertability. SRP Section 4.2.II.1.A.v states:

> Control blade/rod, channel, and guide tube bow as a result of (1) differential irradiation growth (from fluence gradients), (2) shadow corrosion (hydrogen uptake results in swelling), and (3) stress relaxation, which can impact control blade/rod insertability from interference problems between these components. For BWRs, the effects of shadow corrosion should be considered for new control blade or channel designs, dimensions (e.g., the distance between control blade and channel is important), or materials. The effects of channel bulge should also be considered for interference problems for BWRs. Design changes can alter the pressure drop across the channel wall, thus necessitating an evaluation of such changes. Channel material changes can also impact the differential growth, stress relaxation, and the amount of bulge and therefore must be evaluated. If interference is determined to be possible, tests are needed to demonstrate control blade/rod insertability consistent with assumptions in safety analyses. Additional in-reactor surveillance (e.g., insertion times) may also be necessary for new designs, dimensions, and materials to demonstrate satisfactory performance.

With respect to ensuring control blade insertability under externally applied loads (i.e., safe shutdown earthquake and loss-of-coolant accident), SRP 4.2 Appendix A, Section IV states:

> For a BWR, several conditions must be met to demonstrate control blade insertability – (1) combined loads on the channel box must remain below the allowable value defined above for components other than grids (otherwise, additional analysis is needed to show that the deformation is not severe enough to prevent control blade insertion) and (2) vertical liftoff forces must not unseat the lower tieplate from the fuel support piece such that the resulting loss of lateral fuel bundle positioning could interfere with control blade insertion.

The NRC staff's review of EMF-93-177 is to ensure that the introduction of Z4B does not adversely impact the ability of existing BWR channel designs to satisfy these requirements.

3.0 TECHNICAL EVALUATION

The NRC staff's review of the EMF-93-177 is summarized below:

- Verify that the fuel channel design requirements are consistent with regulatory criteria identified in SRP 4.2 or are otherwise acceptable and justified.
- Verify that the Z4B channel design satisfies regulatory requirements.
- Verify that the Framatome experience database (in-reactor residence, post-irradiation examinations, and out-of-pile testing) supports the operating limits being requested and provides reasonable assurance that no anomalous behavior will occur during batch implementation.
- Verify that the impact of the Framatome channel designs on the reload design methodology, safety analyses, and setpoints has been properly addressed.
- Define the range of applicability and allowed manufacturing tolerances/variances (e.g., alloy composition, microstructure).
- Define future surveillance and reporting requirements as necessary. The NRC staff's review builds upon the Z4B enhanced LUC program (Ref. 4) and the operating experience and data collected from past and ongoing surveillance programs.

3.1 BWR Channel Design Requirements

The design requirements for Framatome's BWR channels are described in References 2 and 3 and are unchanged for Z4B materials and heat treatments. These design requirements have been previously approved and are consistent with the SRP and, therefore, remain acceptable.

3.2 Z4B Composition and Microstructure

The composition of Z4B is similar to that of Zry-4 as defined in ASTM B352/B352M, with the exceptions that Z4B has slightly higher Fe and Cr contents. The exact material contents are proprietary and will not be restated here. Zry-4 was developed based on Zry-2 with the intent to remove Ni from the alloy and avoid the high hydrogen pickup which is seen in Zry-2 which is thought to be a primary driver of irradiation growth in zirconium materials. Z4B and the Zircaloys are composed of about 98 weight percent zirconium and have a hexagonal crystal structure at room and service temperatures. Z4B also has improved corrosion resistance that may be necessary for some licensee's challenging reactor chemistry environments.

Framatome's Z4B is made in either the RXA or BQ final microstructure. The BQ process results in a quasi-isotropic texture that has demonstrated the ability to reduce the irradiation growth rate of Zircaloys.

3.3 Z4B Material Properties

The unirradiated Z4B properties (melting point, density, heat capacity, thermal conductivity, and thermal expansion) are nearly identical to those of Zr-4 which is fully expected. The slight increase of Fe and Cr in Z4B has an insignificant effect on parameters impacting elastic properties including Young's modulus, and Poisson's ratio. These parameters include bond length, coordination number, and charge of the metal ion. It is therefore acceptable to apply the existing Zr-4 based properties to Z4B.

3.4 Z4B Operating Experience

Z4B material was first irradiated in test programs beginning in 1995. Z4B fuel channels have been used on a large number of fuel assemblies irradiated in different BWRs since 2009, in both RXA and BQ variants. These BWRs cover the range of all lattice types. In 2009, several Z4B BQ fuel channels on ATRIUM 10XP fuel assemblies were inserted in a German BWR that has demanding corrosion conditions. Some of these fuel channels reached their end of life in 2016 and the remaining fuel channels reached end of life in 2017 without any operational issues. These fuel channels have performed well and displayed very low growth. Bulge and bow of these fuel channels are also low.

Post-irradiation examination (PIE) measurements show the corrosion performance of these fuel channels is better than that of Zr-4 fuel channels. Also, in 2009, Z4B RXA fuel channels on ATRIUM 10A fuel assemblies were inserted in a U.S. BWR that has demanding corrosion conditions. PIE campaigns were held after each biennial cycle. The last of these fuel channels were discharged in 2015 without any operational issues. These fuel channels have performed well and have displayed low growth. Bulge and bow of these fuel channels are also low. Hot cell examinations of coupons harvested from some of these fuel channels showed lower hydrogen uptake and lower average oxide thickness for a Z4B RXA fuel channel relative to a co-resident Zry-4 fuel channel.

In 2012, Z4B RXA fuel channels on ATRIUM 11 lead fuel assemblies were inserted in a German BWR that has demanding corrosion conditions. These fuel channels are planned to complete six annual cycles of irradiation before being discharged. PIE campaigns were held after each of five annual cycles comparable to U.S. end of life burnups. These fuel channels have performed well and have displayed low growth. Bulge and bow of these fuel channels are also low.

In 2013, Z4B RXA fuel channels on ATRIUM 11 lead fuel assemblies were inserted in a Swiss BWR. PIE inspections of visual condition and fuel channel length were performed after each of four annual cycles. These fuel channels have performed well and have displayed low growth.

In 2014, Z4B BQ fuel channels were inserted on ATRIUM 10XM fuel assemblies in a U.S. BWR. Four of these Z4B BQ fuel channels were discharged in 2018 after their second biennial cycle. Fifteen of the remaining 16 fuel channels are planned to complete a third cycle in 2020. The remaining fuel channel is expected to be discharged in 2022 or 2024.

Also, in 2014, Z4B BQ fuel channels on ATRIUM 11 lead fuel assemblies were inserted in a Finnish BWR. PIE examinations of visual condition and fuel channel length were conducted after each of three annual cycles. These fuel channels have performed well and have displayed low growth. A PIE campaign after the fourth annual cycle is planned to include fuel channel dimensional measurements.

In 2015, Z4B BQ fuel channels on ATRIUM 11 lead fuel assemblies were inserted between two different U.S. BWRs. These lead fuel assemblies completed their first biennial cycle in late 2017. No operational issues were encountered for the fuel channels exposed for one biennial cycle. Visual inspections of two Z4B BQ fuel channels after one biennial cycle showed the fuel channels were in good condition. A PIE campaign after the second biennial cycle is planned to include fuel channel dimensional measurements.

Additionally, reload batches of Z4B RXA fuel channels have been delivered to a Finnish BWR in 2016 and 2017 with continuing deliveries planned, including ATRIUM 11 reloads of Z4B BQ fuel channels in 2018 and 2019. Z4B RXA fuel channels on ATRIUM 10XM fuel assemblies have completed one and one-half annual cycles and Z4B RXA fuel channels on ATRIUM 10XM fuel assemblies have completed one half of an annual cycle.

In 2018, Z4B BQ fuel channels on ATRIUM 10XM fuel assemblies started operation in a U.S. BWR.

Results from these lead programs have and will provide assurance of safe operation for reload quantities of Z4B fuel channels or, in the case of unsatisfactory performance trends, allow for remediating measures (e.g., modified core loading or rechanneling) to be taken before any safety issues arise.

3.5 Z4B Performance Evaluation

Framatome has requested use of Z4B material on existing approved Framatome channel designs.

Existing approved mechanical design requirements and calculational methods will be used to confirm the performance of Framatome channels manufactured with Z4B material. The NRC staff finds the continued use of these design requirements and methods, along with the material properties described in Section 3.3, acceptable for Z4B channels.

Operating experience has shown that channel distortion and associated control blade interference has been a major problem in the U.S. BWR commercial fleet. The goal of introducing Z4B channel material is to resolve this issue. Contributing factors for channel distortion include (1) creep bulge, (2) fluence gradient-induced bow, and (3) shadow corrosion-induced bow. Each will be addressed below.

Creep Bulge:

Creep bulge in channels occurs because of the differential pressure between the inside and outside of the bundle. At a given axial position, the pressure drop is effectively a constant stress on the channel face that induces an elastic bulge that over time results in permanent strain. Channel deformation due to creep bulge has not been a major concern in the industry and, by itself, has not led to control blade interference issues. The purpose of this review is to provide reasonable assurance that the use of Z4B does not exacerbate creep bulge and/or introduce a new problem. Based upon the measured creep data, the NRC staff finds Z4B channel performance with respect to creep bulge acceptable.

Fluence Gradient-Induced Bow:

Irradiation growth is mainly attributed to the anisotropic redistribution of irradiation-induced vacancies and interstitials into dislocation loops on preferred crystallographic planes. Channel bowing occurs when a flux gradient across the channel box induces differential growth on opposite faces of the channel box. In bundles located toward the core periphery, a higher neutron flux would be experienced on the channel face toward the core interior, relative to the face toward the core periphery. Channel deformation due to fluence gradient-induced bow has been a major concern in the industry and, coupled with shadow corrosion-induced bow, has resulted in control blade interference issues. The purpose of this review is to provide reasonable assurance that Z4B channels provide improved or equivalent performance or, at least, do not exacerbate fluence gradient-induced bow and/or introduce a new problem.

The database supporting the fluence gradient-induced bow performance and model is sufficient to provide a basis for determination. As described in Section 3.4, ongoing and future Z4B LUC programs are expected to provide an additional amount of new data to confirm performance and validate models although it is not a condition of this SE that Framatome must gather future data.

Based upon the irradiation growth database the NRC staff finds Zr-4 fluence gradient-induced bow performance and models acceptable to be applied to Z4B. Revisions to the bow model based upon future data collection are allowed under the provisions described in Section 5.

Shadow Corrosion-Induced Bow:

Shadow corrosion is an enhanced irradiation corrosion mechanism that occurs on zirconium alloys when a dissimilar material (such as a stainless steel control blade) is near the zirconium surface (such as a BWR channel) and the water chemistry is oxygenated. When a fuel bundle is controlled early in life, the increased corrosion on the blade side relative to the non-blade side results in a difference in hydrogen absorbed in channel material. Hydrogen is absorbed into the metal as part of the corrosion process and causes a volume change resulting in channel bow.

Because direct measurement of shadow corrosion-induced bow is only possible when the fluence gradient is zero, shadow bow is generally observed by accounting for the fluence gradient induced bow. After accounting for fluence bow in the data, the end of life channel bow correlates well with the Effective Full Insertion Days (EFID) for previous channel materials. Framatome's results for Z4B RXA and BQ show little to no correlation to EFID.

The NRC staff agrees that Z4B material is a very effective fix to shadow corrosion bow and application of the existing methods to Z4B is very conservative and, therefore, acceptable.

Z4B Corrosion:

As with any in-reactor material the first and foremost performance requirement is that the material withstands corrosion to the extent that it maintains structural integrity, and thus, maintains its ability to perform its design requirements. For channels, maintaining structural integrity is the only corrosion performance requirement, which in practice means that the component must maintain a minimum thickness of metal.

The chemical composition of Z4B targets a reduction in corrosion and hydrogen uptake with respect to Zry-4. The optional BQ heat treatment does not significantly affect corrosion or hydrogen uptake. Framatome's corrosion program consists of irradiated Z4B spacer grid hot

cell exams, irradiated Z4B fuel channel hot cell exams, and pool-side eddy-current generalized oxide thickness measurements. In all cases, the corrosion performance of Z4B was superior to that of Zr-4 material. Based upon the information presented in the topical report (TR), the NRC staff finds the corrosion performance of Z4B acceptable and application of the existing approved Zr-4 models to Z4B also acceptable.

Revisions to the corrosion models based upon future data collection are allowed under the provisions described in Section 5.

Calculating CPR with Z4B Channels:

There is no change to the SA methodology proposed in this TR. The existing methodology for calculating fuel bundle critical power ratio are fully applicable to Z4B material channels as currently approved.

Other Considerations:

Framatome has stated "Existing BWR fuel channel distortion/control blade friction counter measures and fuel channel management guidelines for cores containing Z4B BQ fuel channels will continue to be applied until a full core of Z4B BQ fuel channels has experienced no observations of control blade-to-channel interference (e.g., slow to settle, no settle, delayed scram) for 3 consecutive years within a C- or S-Lattice design." The NRC staff finds that this is a good practice but is not a requirement for the approval of this TR.

The NRC staff also concludes that licensee technical specification (TS) surveillance programs for scram time testing and reactor protection system (RPS) slow-to-settle detection are sufficient to provide future assurance that the health and safety of public will be fully maintained in the event of future fuel channel operational challenges.

3.6 Range of Applicability

The fully RXA and BQ Z4B alloy channel material is approved for batch application to BWR channel designs based on currently approved design methodologies (Refs. 7 and 8).

The fully RXA and BQ Z4B alloy channel material is approved for batch application to BWR Type 2 (BWR/2), Type 3 (BWR/3), Type 4 (BWR/4), Type 5 (BWR/5), and Type 6 (BWR/6) designs.

The lifetime of Z4B channels is restricted to the same limitations as outlined for Framatome's existing channel designs as described in Reference 3. Any fuel channel projected to exceed any of these limitations during the upcoming reload cycle shall not be loaded into the reactor, except as allowed in accordance with Framatome's approved lead use program (Ref. 6) to obtain high burnup data.

4.0 CONCLUSION

By letter dated July 25, 2018 (Ref. 1), Framatome requested review and approval of an advanced zirconium alloy, Z4B, for application to existing BWR fuel channel designs. Recent operating experience has shown that channel distortion and associated control blade interference has been a major problem in the U.S. BWR commercial fleet. The goal of introducing Z4B channel material is to resolve this issue.

In 2017, the NRC staff approved Framatome's expanded LUC program for the Z4B zirconium alloy (Ref. 4). The purpose of the expanded LUC program was to allow greater numbers of Z4B channels to be exposed to varying in-reactor operating strategies, nuclear conditions, and water chemistry, in order to gain experience and gather data for batch application. The data being collected in the Z4B expanded LUC program provides confirmation of Z4B channel performance and data to validate performance models.

The NRC staff has completed its review of EMF-93-177 Revision 1, Supplement 2P, Revision 1 and finds it acceptable. Licensees referencing EMF-93-177 Revision 1, Supplement 2P, Revision 1, will need to comply with the conditions listed in Section 5.0 below.

With regard to the use of Z4B channels, the NRC staff has concluded, based on the considerations discussed above, that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the commission's regulations, and (3) issuance of this SE will not be inimical to the common defense and security or to the health and safety of the public.

5.0 LIMITATIONS AND CONDITIONS

Licensees referencing EMF-93-177 Revision 1, Supplement 2P, Revision 1 must ensure compliance with the following L&Cs:

1. The range of applicability of Z4B channels is limited to those items described in Section 3.6 of this SE.

EMF-93-177 provides sufficient information to support the use of BWR fuel assembly channels using Z4B material in batch quantities. The TR demonstrates that the previously approved fuel assembly channel models for Zr-4 are either applicable to, or conservative to, channels using Z4B material. The TR provides adequate information to demonstrate that Z4B channels are not expected to experience abnormal channel bow. Therefore, the L&Cs in the NRC approved TR ANP-10336P-A do not need to be complied with for fuel channels using Z4B material inserted in accordance with the Fuel Channel Irradiation Program.

A disposition for each L&C in the SE for ANP-10336P-A (Ref. 4) is provided below.

1. <u>Z4B lead use channels may be used in quantities up to 8 percent of the total number of channels in the core. This limit is exclusive of other lead assembly programs. The NRC has approved this expanded LUC program in order to acquire data which may demonstrate Z4B fuel channels have improved resistance to fuel channel distortion.</u> Since EMF-93-177 demonstrates that Z4B channels have improved resistance to fuel channel distortion and the use of Z4B channels in batch quantities is approved, the

restriction to 8 percent of the total number of channels in the core is no longer applicable.

2. The supplemental surveillance plan, described in Section 2.1 of the TR, must be fulfilled.

   Since EMF-93-177 demonstrates that Z4B channels have improved resistance to fuel channel distortion and the use of Z4B channels in batch quantities is approved the requirement to perform additional surveillance is no longer applicable to channels loaded under the LUC program.

3. Channel growth, bulge, and bow measurements from at least 10 percent of the Z4B channels irradiated under the expanded LUC program must be collected following the second cycle of operation. Upon discharge, this data must be collected from at least 50 percent of the Z4B LUCs. This requirement is void upon batch approval of Z4B channels.

   This requirement is eliminated for the Fuel Channel Irradiation Program with the approval of Z4B channels for batch quantities.

4. Upon availability, all data collected will be added to AREVA's database and compared with Zircaloy-4 predictive models.

   This requirement is eliminated for the Fuel Channel Irradiation Program with the approval of Z4B channels for batch quantities. This restriction is unnecessary since this is the common practice.

5. As further in-reactor experience and measurements are collected, AREVA will continue to demonstrate that Z4B LUCs satisfy design requirements for each reload cycle.

   This requirement is eliminated with the approval of Z4B channels for batch quantities. This restriction is unnecessary since this is a design requirement.

6. To assure continued in-reactor performance of the LUCs with regard to unanticipated channel distortion, AREVA must provide an annual report, documenting the ongoing experience with the enhanced LUC program, including any anomalous indications identified in the supplemental surveillance plan, and provide an updated database of post-irradiation measurements.

   Since EMF-93-177 demonstrates that Z4B channels have improved resistance to fuel channel distortion and the use of Z4B channels in batch quantities is approved, the requirement to provide an annual report for the Fuel Channel Irradiation Program is no longer applicable. The experience with Z4B channels will continue to be addressed in the annual fuel performance meetings between the NRC and Framatome.

7. Existing BWR channel distortion - control blade interference counter measures, including fuel management guidelines and augmented monitoring and inspection programs will continue to be applied for cores containing Z4B channels.

   This requirement is proposed to be superseded by the requirement in Section 7 of the TR which states:
   "Existing BWR fuel channel distortion / control blade friction counter measures and fuel

channel management guidelines for cores containing Z4B RXA fuel channels will continue to be applied until a full core of Z4B RXA fuel channels has experienced no observations of control blade-to-channel interference (e.g., slow to settle, no settle, delayed scram) for 3 consecutive years within a C- or S-Lattice design."

This requirement is in Section 7.1 for RXA and is repeated in Section 7.2 for BQ.

Although the NRC staff finds that this is a good practice, it is not a requirement for the approval of this TR and therefore not a L&C.

The NRC staff also concludes that licensees' TS surveillance programs for scram time testing and RPS slow-to-settle detection are sufficient to provide future assurance that the health and safety of the public will be fully maintained in the event of future fuel channel operational challenges.

TR Updates:

With respect to modification to Z4B composition, heat treatments, and changes to the mechanical designs of Framatomes BWR channels, those changes may be implemented **without** further NRC review and approval as long as the following criterion are met:

- Improved limits may be credited in the future as long as Framatome uses the methodology previously used to provide the basis for its existing channel irradiation limits. This is to say that incorporating additional PIE measurement data into the operating experience database may be credited for use in less restrictive limits as long as the same approved analytical methods are used to derive the new limits. Use of unapproved statistical methods would require NRC review and approval.

- New mechanical designs may be implemented under the LUC program and subsequent batch application as long as there are no approved analysis methodology deviations.

- New zirconium based channel materials may be implemented under the LUC program and subsequent batch application as long as there are no approved analysis methodology deviations.

6.0 REFERENCES

1. EMF-93-177 Revision 1 Supplement 2P Revision 1, "Mechanical Design for BWR Fuel Channels: Z4B Material," July 2018 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML18211A318).

2. EMF-93-177(P)(A), Revision 1, "Mechanical Design for BWR Fuel Channels," Framatome ANP, August 2005 (ADAMS Accession No. ML052370370).

3. EMF-93-177 (P)(A), Revision 1, Supplement 1 P-A, Revision 0, "Mechanical Design for BWR Fuel Channels Supplement 1: Advanced Methods for New Channel Designs," AREVA NP, September 2013 (ADAMS Accession No. ML18211A309 (Non-publicly available)).
4. ANP-10336P-A, Revision 0, "Z4B Fuel Channel Irradiation Program" July 2017 (ADAMS Accession No. ML17298A159).

5. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 4.2, "Fuel System Design," Revision 3, March 2007 (ADAMS Accession No. ML070740002).

6. ANP-10336P, Revision 0, "Z4B Fuel Channel Irradiation Program" June 2015 (ADAMS Package Accession No. ML15188A230).

7. BAW-10247PA, Revision 0, "Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors," AREVA NP, April 2008.

8. ANP-10307PA, Revision 0, "AREVA MCPR Safety Limit Methodology for Boiling Water Reactors," AREVA NP, June 2011.

Attachment: Resolution of Comments

Principal Contributor: J. Dean, NRR/DSS/SNPB

Date: June 24, 2019

RESOLUTION OF COMMENTS BY THE OFFICE OF NUCLEAR REACTOR REGULATION ON DRAFT SAFETY EVALUATION FOR TOPICAL REPORT EMF-93-177, REVISION 1, SUPPLEMENT 2P, REVISION 1, "MECHANICAL DESIGN FOR BWR FUEL CHANNELS: Z4B MATERIAL"

FRAMATOME, INC.

DOCKET NO. 99902041

This attachment provides the U.S. Nuclear Regulatory Commission (NRC) staff's review and disposition of the comments made by Framatome Inc. (Framatome) on the draft safety evaluation (SE) for Topical Report (TR) EMF-93-177, Revision 1, Supplement 2P, Revision 1, "Mechanical Design for BWR Fuel Channels: Z4B Material." Framatome provided the comments by letter dated May 20, 2019 (Agencywide Documents Access and Management System Accession No. ML19142A094).

Page	Line	Proposed Change/Comment	NRC Resolution of Proposed Change/Comment
1	31	Reference 3 should either be changed to Reference 1, or a new Reference added for the topical report under review: EMF-93-177 Revision 1, Supplement 2P, Revision 1	The final SE was modified to indicated Reference 1 as the correct source.
1	39	Reference 3 should either be changed to Reference 1, or a new Reference added for the topical report under review: EMF-93-177 Revision 1, Supplement 2P, Revision 1	The final SE was modified to indicated Reference 1 as the correct source.
3	22	Reference 3 should be Reference 4	The NRC staff agrees with this editorial suggestion. The final SE was modified accordingly.
3	33	Change "ASTM 8352/8352M" to "ASTM B352/B352M"	The NRC staff agrees with this editorial suggestion. The final SE was modified accordingly.
3	43-44	Move the sentence that starts with "The BQ process" to the end of the previous paragraph and change "The BQ process also result in" to "Z4B also has"	The NRC staff agrees with the proposed change. The final SE was modified accordingly.
7	43	Change "Framatomes's" to "Framatome's"	The NRC staff agrees with this editorial suggestion. The final SE was modified accordingly.

8	10	Change "Ref. 3" to "Ref. 4"	The NRC staff agrees with this editorial suggestion. The final SE was modified accordingly.
10	46	Change "Supplemt" to "Supplement"	The NRC staff agrees with this editorial suggestion. The final SE was modified accordingly.

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Mechanical Design for BWR Fuel Channels: Z4B Material

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Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Complete rewrite.

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Nomenclature

Acronym	Definition
AOO	Anticipated Operational Occurrence
ASTM	American Society for Testing and Materials
BIB	Bundle-in-Basket
BQ	Beta-quench
BWR	Boiling Water Reactor
BOL	Beginning of Life
CBQ	Controlled Beta-Quench
MWd/kgU	MegaWatt days per kilogram Uranium
NRC	Nuclear Regulatory Commission
PIE	Post Irradiation Examination
RXA	Recrystallized
SLMCPR	Safety Limit Minimum Critical Power Ratio
Zry-2	Zircaloy-2
Zry-4	Zircaloy-4

ABSTRACT

The purpose of this topical report is to justify the use of BWR fuel channels made from Z4B material. The applicability of mechanical and safety analysis methods for evaluating Zircaloy-2 (Zry-2) and Zircaloy-4 (Zry-4) Boiling Water Reactor (BWR) fuel channels to Z4B fuel channels is demonstrated. The evaluations in this topical report show that reload licensing analyses using the methods previously-approved for Zry-2 and Zry-4 fuel channels can be used for reload licensing analyses of Z4B fuel channels.

Z4B is compositionally similar to Zry-4 but with slightly increased iron and chromium compared to the ASTM-specified range for Zry-4 to optimize performance relative to abnormal channel bow. Z4B has demonstrated excellent in-reactor performance in leads as well as material test programs.

This topical report contains a description of the composition and microstructure of Z4B, its properties, and in-reactor experience including an evaluation of how the performance data supports the applicability of existing fuel channel licensing methods.

1.0 INTRODUCTION AND SUMMARY

The primary objective of this topical report is to extend the applicability of mechanical methods for evaluating Zircaloy-2 (Zry-2) and Zircaloy-4 (Zry-4) Boiling Water Reactor (BWR) fuel channels as described in References 1 and 2 to fuel channels made from a proprietary zirconium alloy called Z4B. Additionally, the impact on fuel rod thermal-mechanical and safety methodologies is evaluated.

Excessive control blade friction due to abnormal fuel channel bow remains a significant technical challenge to the BWR industry. As part of the efforts to resolve this issue, Framatome Inc. (Framatome) has developed a new zirconium alloy, Z4B, which demonstrates improved bow performance relative to Zry-2 and Zry-4 fuel channels. Z4B is the result of Framatome's extensive research and experience with zirconium alloys. Z4B is compositionally very similar to Zry-4 but with slightly increased iron and chromium relative to the ASTM-specified range for Zry-4 to optimize performance. Z4B was first irradiated in test programs beginning in 1995. It has demonstrated excellent in-reactor performance as a material for water channels and fuel channels as well as in a material test program for spacer grid strips.

This topical report contains a description of the composition of Z4B, its properties, and in-reactor experience including an evaluation of how the performance data supports existing fuel channel licensing methods.

This information is intended to be supplemental to the topical report. The existing information in References 1 and 2 is not replaced by this document and may still be applied to current fuel channel designs.

2.0 BACKGROUND

Fuel channel bow refers to any deviation from straightness of the fuel channel which surrounds the BWR fuel assembly. The size of the water gaps between adjacent fuel channels and between fuel channels and adjacent fuel rods is altered by fuel channel bow. From a neutronic perspective, when the channel bow results in an enlargement of the local water gap, the neutron thermal flux is increased locally. The power in the neighboring fuel rods will therefore be higher than in the non-bowed condition. The reverse is true when the local water gaps are reduced (Reference 16). From a mechanical perspective, a reduced gap between adjacent fuel channels can result in slow-to-settle control blades (or inoperable control blades in extreme cases). Both the neutronic and mechanical effects of channel bow can lead to a potential safety issue.

There are two contributors to initial fuel channel bow prior to irradiation: as-fabricated bow and as-installed bow. Fuel channel manufacturing is highly controlled allowing less than 1.5 mm of lateral bow over a total length of about 4 meters (Reference 4). Installation of fuel channels on the fuel assembly as well as emplacement of the fuel assembly in the reactor core can also potentially contribute to initial bow. During irradiation, differential growth of opposite sides of the fuel channels due to differences in fluence (i.e., fluence gradients) can lead to "normal" fuel channel bow.

Abnormal fuel channel bow refers to any source of fuel channel bow not related to initial bow or normal differential irradiation growth of opposite sides of the fuel channel. Historically, abnormal bow has been more prevalent for Zry-2 fuel channels than Zry-4 fuel channels (Reference 4). While abnormal fuel channel bow is not fully understood and is a topic of active research in the nuclear industry, there are two primary proposed mechanisms of abnormal bow: shadow corrosion-induced bow and hydrogen-assisted accelerated irradiation-induced growth (Reference 4).

Shadow corrosion-induced bow results from early control blade exposure leading to increased oxide and hydrogen uptake on the control blade side of the fuel channels resulting in differential growth between channel sides and increased bow. Shadow

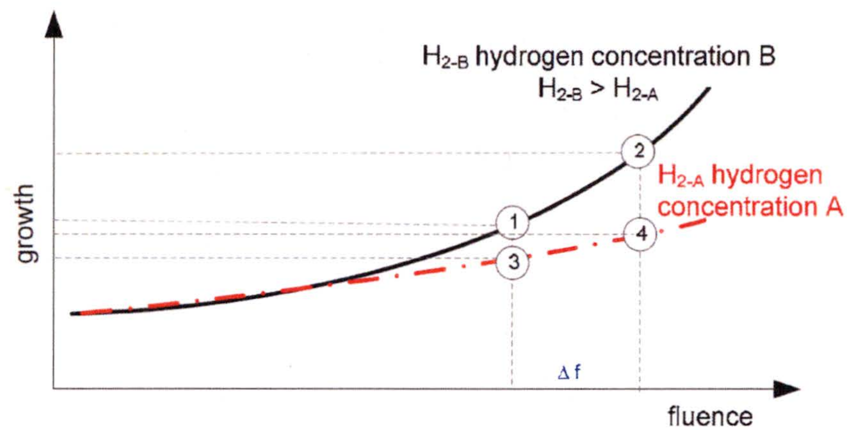
corrosion is also not fully understood but is thought to be an irradiation-enhanced form of galvanic corrosion occurring in areas where a zirconium alloy is in contact, or in close proximity to, a dissimilar metal component such as a stainless steel control blade. Shadow corrosion is aptly named as the shape of the component is often reproduced in an area of thicker oxide, suggestive of a shadow cast by the component on the zirconium alloy surface. The oxides formed on Zircaloys have a higher volume than the underlying metal and can thus impart tensile stresses on the Zircaloy substrate. The shadow oxide is typically thicker and denser than the uniform corrosion oxide. The increased thickness of the shadow oxide relative to the uniform corrosion oxide on the fuel channel opposite side may impart higher stress on the controlled side leading to differences in stress-assisted irradiation growth across channel sides (Reference 5). Similarly, hydrides have a larger molar volume than the Zircaloy substrate and differences in hydride concentration (i.e., hydride swelling) between opposing fuel channel sides can lead to differences in length between channel sides and channel bow (Reference 6). Although shadow corrosion is commonly formed early in life, abnormal bow is observed later in life after significant differentials in oxide thickness and hydrogen contents between channel sides develop (References 4 and 6). In contrast to Zry-2, Zry-4 fuel channels have shown very little sensitivity to shadow corrosion-induced bow displaying relatively small differences in oxide thicknesses and hydrogen contents between channel sides (References 4, 6 - 8).

The hydrogen-assisted accelerated irradiation-induced growth mechanism was proposed based on observations that Zry-2 channels with little or no control blade exposure have shown high bow values, as well as analyses showing that the increased hydride concentrations due to shadow corrosion were not sufficient to explain all abnormal bow events (Reference 4). This mechanism proposes that the early onset of accelerated growth at higher exposures results from a synergistic effect of hydrogen in solution with irradiation-induced dislocations leading to increased growth (Reference 9). Schematically (Figure 2-1) if a controlled fuel channel face has a higher hydrogen content (point 1) than the corresponding uncontrolled face (point 3), the controlled face will have higher growth than the uncontrolled face at a given fluence. Increased fluence

could lead to larger differences in growth between controlled and uncontrolled sides (points 2 and 4). Positive fluence gradients would result in even larger differences in growth between channel sides, offsetting points 1 and 2 to the right relative to points 3 and 4.

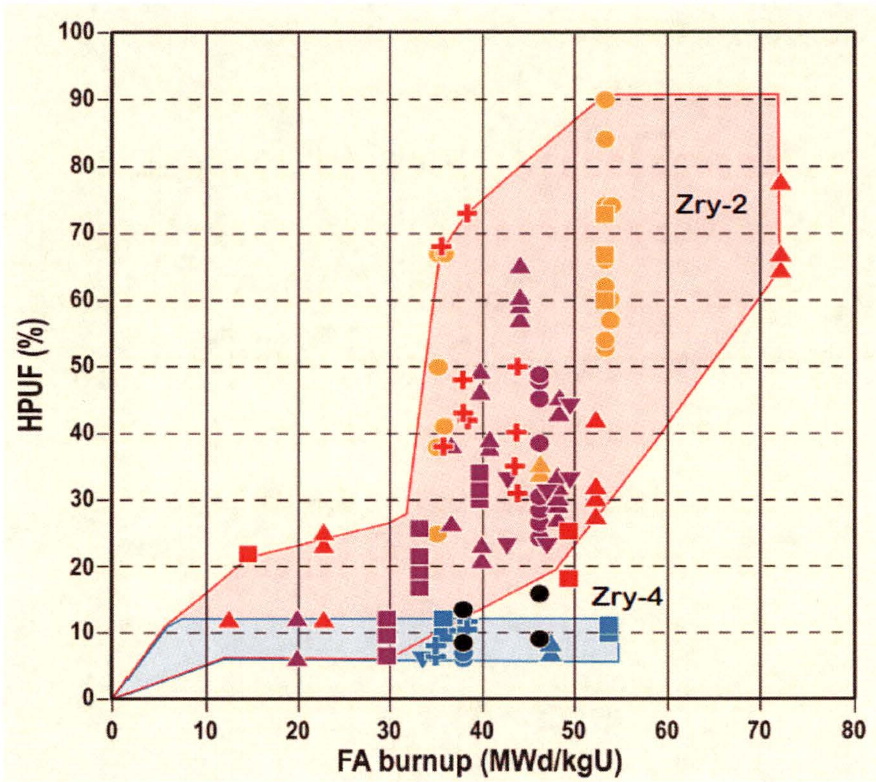
The hydrogen-assisted accelerated irradiation-induced growth mechanism is consistent with the observation that Zry-4 fuel channels have shown very little sensitivity to shadow corrosion-induced bow relative to Zry-2 in that the hydrogen pickup fraction (HPUF) of Zry-2 accelerates after a burnup of about 32 MWd/kgU and shows significant scatter (Figure 2-2). No such acceleration in Zry-4 HPUF is observed and there is little scatter in HPUF values for Zry-4. Differences in HPUF between opposing faces of Zry-2 fuel channels would lead to differences in hydrogen content and differential growth leading to abnormal bow.

Framatome has pursued development of an alloy (Z4B) based on Zry-4 targeting improvements in corrosion resistance and hydrogen pickup in order to minimize the potential for abnormal bow. The reason for the increase in HPUF for Zry-2 at higher exposures is a result of the irradiation induced dissolution of the nickel-bearing second phase particles (SPPs) which do not exist in the Ni-free Zry-4 (Reference 11) or Z4B. It should be noted that both proposed mechanisms for abnormal bow have in common a dependence on hydrogen pickup from the corrosion process.



Source: Reference 9

Figure 2-1 Schematic of hydrogen-assisted accelerated irradiation-induced growth mechanism



Source: Reference 11

Figure 2-2 Hydrogen pickup fraction (HPUF) of Zry-2 and Zry-4 BWR structural components

3.0 REGULATORY REQUIREMENTS SUMMARY

The fuel system consists of arrays of fuel rods, spacer grids, end plates, and fuel channel boxes. In accordance with NUREG-0800, "Standard Review Plan," Section 4.2, "Fuel System Design" (Reference 3), the objectives of this topical report are to provide assurance that with the use of Z4B as a fuel channel material (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.

Reference 3, Section 4.2.II.1.A.v states (specifically for fuel channels)

> Control blade/rod, channel, and guide tube bow as a result of (1) differential irradiation growth (from fluence gradients), (2) shadow corrosion (hydrogen uptake results in swelling), and (3) stress relaxation, which can impact control blade/rod insertability from interference problems between these components. For BWRs, the effects of shadow corrosion should be considered for new control blade or channel designs, dimensions (e.g., the distance between control blade and channel is important), or materials. The effects of channel bulge should also be considered for interference problems for BWRs. Design changes can alter the pressure drop across the channel wall, thus necessitating an evaluation of such changes. Channel material changes can also impact the differential growth, stress relaxation, and the amount of bulge and therefore must be evaluated. If interference is determined to be possible, tests are needed to demonstrate control blade/rod insertability consistent with assumptions in safety analyses. Additional in-reactor surveillance (e.g., insertion times) may also be necessary for new designs, dimensions, and materials to demonstrate satisfactory performance.

The base topical report (References 1 and 2) and this supplement to the topical report address the items in the above paragraph.

4.0 Z4B MATERIAL DEFINITION

4.1 *Composition*

The composition of Z4B is similar to that of Zry-4 as defined in ASTM B352/B352M (Reference 10), with the exceptions that Z4B has slightly higher iron (Fe) and chromium (Cr) contents (Table 4-1). [

] Zry-4 was developed based on Zry-2 with the intent to remove Ni from the alloy and avoid the high hydrogen pickup which is seen in Zry-2 (Figure 2-2). Z4B and the Zircaloys are composed of about 98 wt% zirconium and have a hexagonal crystal structure at room and service temperatures.

The motivation for the slightly higher amounts of Fe and Cr in Z4B is to improve the corrosion resistance and hydrogen uptake relative to Zry-4. Industry experience indicates that slight increases of Fe and Cr act to reduce the corrosion rate of Nb-free alloys such as Zry-4 and Z4B (Reference 11). Reference 11 (Table 4-2) indicates that the "best alloy content" for Fe is ≥ 0.3% and for Cr is ≥ 0.15% leading to improvements in corrosion resistance and hydrogen uptake. These values compare well with the ranges for Z4B and, as discussed in Section 6.1, the improvements in corrosion resistance and hydrogen uptake have been confirmed for Z4B fuel channels. As indicated in Table 4-2, the solubility of Fe and Cr in the zirconium matrix are very low meaning that these elements exist primarily in second phase particles (SPPs). Given the similarity in composition of Z4B and Zry-4, the solubility of Fe and Cr in the alloy matrix are equivalent for these alloys and the additional concentrations of these elements in Z4B could result in a larger number of SPPs, a larger average SPP size, or both depending on the details of material processing. Framatome's processing of Z4B targets formation of slightly larger, and hence more irradiation-resistant, SPPs than in Zry-4.

4.2 *Microstructure and Manufacturing*

Framatome's Z4B is made in either the recrystallized (Z4B RXA) or beta-quenched (Z4B-BQ) final microstructure (Figure 4-1). The BQ process results in a quasi-isotropic

texture that has demonstrated the ability to reduce the irradiation growth rate of Zircaloys (e.g., Figure 7-1). The majority of fuel channels used in the nuclear industry have been in the recrystallized form. For both recrystallized and final BQ fuel channel strips, processing begins with [

] The final microstructure of Z4B-BQ fuel channel sheets (Figure 4-1b) consists of α-laths with homogenously dispersed precipitates [

] resulting in optimum resistance to corrosion processes. [

]

It should be noted that the first Z4B-BQ lead fuel channels, which were inserted in Plant C04 (see first row in Table 6-1), were fabricated before the current BQ fuel channel sheet process discussed above was industrialized. For this lead fuel channel program, Z4B RXA sheet material was formed into square boxes and then controlled beta-

quenched (CBQ) in final form. A summary of the CBQ process can be found in Reference 15. Although the final microstructure of these fuel channels was the same as shown in Figure 4-1b, the CBQ process was retired in favor of the BQ sheet process which is better suited to industrialization.

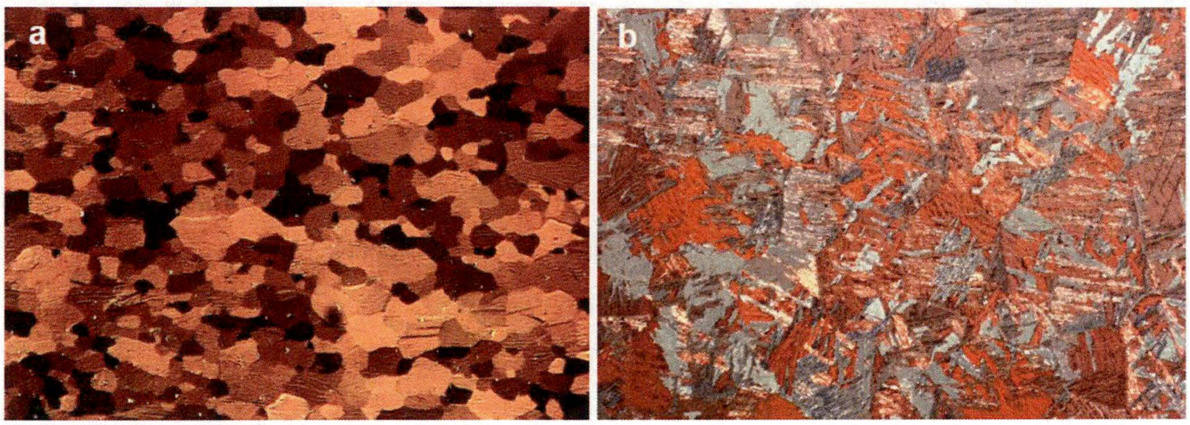
Table 4-1 Alloying elements in fuel channel materials

Element		Composition range, wt%		
		ASTM Zry-2	ASTM Zry-4	Z4B
Tin	(Sn)	1.20 – 1.70	1.20 – 1.70	[ ]
Iron	(Fe)	0.07 – 0.20	0.18 – 0.24	[ ]
Chromium	(Cr)	0.05 – 0.15	0.07 – 0.13	[ ]
Nickel	(Ni)	0.03 – 0.08	-	-

Table 4-2 Effect of alloying elements on corrosion of zirconium alloys

Element	Solubil. (%)	Best alloy content (%)	Out-pile corrosion	In-PWR corr.	LiOH corr.	In-BWR corr.	HPUF
Sn	2	0/>1	—	═	+ +	+	0
Nb	0.5	0.5/>2	+ +	+ +	0	—/+	+/0
Fe	<0.01	≥0.3	+ +	+ +	+ +	+	0/+
Cr	<0.01	≥0.15	+/—	+	+ +	+	+ (>0.15)
Ni	<0.01	0.05	+ +	+		+	═/0
V	<0.01	≥0.15	+/—	+	+ +	+	+
Cu	<0.1	≥0. 5	+				0
0: no effect, — increase, ═ strong increase, + reduction, ++ strong reduction, 0/+ effect differs in different environments.							

Source: Reference 11



Source: Reference 14

Figure 4-1 General appearance of fuel channel microstructure in the a) recrystallized and b) beta-quenched conditions

5.0 Z4B PROPERTIES

Given the similarity in chemical composition and underlying hexagonal crystal structure of Z4B to the Zry-4, it is reasonable to expect no significant differences in basic properties between these alloys.

5.1 *Melting Point*

Framatome has calculated the melting temperatures of Zry-4 and Z4B for their nominal composition, and for two limiting conditions. [

] These calculations were performed using the [

]

The calculated Zry-4 melting points are [

] The small differences in melting temperatures between Zry-4 and Z4B are not significant.

5.2 *Density*

Framatome has calculated the room temperature density of Zry-4 and Z4B (also considering the second phase particles) for their nominal composition and for the two limiting conditions discussed in Section 5.1. The calculated Zry-4 densities are

[ ]

[ ] The small differences in density between Zry-4 and Z4B are not significant.

5.3 *Heat Capacity*

Framatome has calculated the heat capacity of Zry-4 and Z4B for their nominal composition and for the two limiting conditions discussed in Section 5.1. The calculated Zry-4 and Z4B heat capacities as a function of temperature are shown in Figure 5-1. The small differences in heat capacity between Zry-4 and Z4B are not significant.

5.4 *Thermal Conductivity*

As discussed in Reference 12, which documents the material property correlations for cladding materials used in the FRAPCON-3.5, FRAPTRAN 1.5, and MATPRO codes: "The thermal conductivity of the cladding is primarily a function of temperature. Other characteristics such as residual stress levels, crystal orientation, and minor composition differences, may have secondary effects on thermal conductivity." In Reference 12, the thermal conductivity correlation is applied to Zry-2, Zry-4, ZIRLO, Optimized ZIRLO, and M5™ cladding materials which vary in composition and microstructure. Given their compositional similarity, there are no significant differences in thermal conductivity between Zry-4 and Z4B.

5.5 *Thermal Expansion*

Reference 12, which documents the material property correlations for cladding materials used in the FRAPCON-3.5, FRAPTRAN 1.5, and MATPRO codes, calculates axial and diametral components of thermal expansion as a function of temperature. Calculations are performed for single crystals and then applied to polycrystalline materials through the use of volume-weighted averaging of crystal orientation. In Reference 12, the thermal expansion correlations are applied to Zry-2, Zry-4, ZIRLO, Optimized ZIRLO, and M5™ cladding materials which vary in composition and microstructure. Z4B-BQ has a quasi-isotropic texture meaning properties such as the thermal expansion would

be quasi-isotropic as well. Given their compositional similarity, there are no significant differences in thermal expansion between Zry-4 and Z4B.

5.6 *Mechanical Properties*

Z4B and Zry-4 are composed of about 98 wt% zirconium and have a hexagonal crystal structure. The slight increase of Fe and Cr in Z4B (Table 4-1) will have an insignificant effect on parameters impacting elastic properties including Young's modulus, and Poisson's ratio. These parameters include bond length, coordination number, and charge of the metal ion.

The Safety Evaluation for Reference 1 restricts Framatome to using Zry-2 or Zry-4 channel material with strength greater than or equal to the values approved in Reference 1. The small chemistry differences between Z4B and Zry-4 do not significantly affect the mechanical properties, and the specified mechanical properties of Z4B RXA and Z4B-BQ meet or exceed the values approved in Table 2.1 of Reference 1 as shown in Table 5-1. The requirement for the quasi-isotropic Z4B-BQ material is the higher of the transverse and longitudinal Zry-4 RXA strength ensuring Z4B-BQ mechanical performance meets or exceeds that of Zry-4 RXA. The minimum mechanical properties defined in Reference 1 for Zry-2 and Zry-4 fuel channels shall be used for mechanical analyses of Z4B fuel channels, consistent with the Safety Evaluation for Reference 1, meaning that Framatome will take no credit for the increased strength requirements of BQ material in the safety analyses. Therefore, the previously-approved fuel channel strength is appropriate for use with Z4B fuel channels.

Although the irradiated mechanical properties of Z4B have not been explicitly determined, it is conservative to perform mechanical analyses assuming the unirradiated condition (see Reference 1, Sections 3.2 and 3.3) due to the irradiation hardening behavior of zirconium alloys which results in significant increases in both ultimate and yield strengths.

Table 5-1 Required strength of fuel channel materials

[ ]

[ ]

Figure 5-1 Mass heat capacity of Zry-4 and Z4B

6.0 Z4B IRRADIATION EXPERIENCE

Z4B material was first irradiated in test programs beginning in 1995. It has demonstrated excellent in-reactor performance as a material for water channels and fuel channels as well as in a material test program for spacer grid strips. Z4B fuel channels have been used on [

] These BWRs cover the range of all lattice types. A summary of Z4B fuel channel irradiation experience is shown in Table 6-1.

[

]

[

]

[

]

Framatome's Z4B irradiation experience has already provided bow data from Z4B RXA fuel channels with burnups up to [

] Figure 6-1 shows a schematic time line with the approximate dates that fuel channel bow and bulge measurements will be (or have been) obtained. Also indicated are the numbers of fuel channels measured or projected to be measured.

Table 6-2 shows estimates for the total number of channel bow data points (including those measured in previous years) which are projected to be available at the end of each year for Z4B RXA and Z4B-BQ fuel channels. The "Higher Exposure" columns

indicate bow measurements which will be from Z4B fuel channels that have been operated [ ] For the U.S., this definition of higher exposure is conservative in that some U.S. fuel channels are designed to be discharged after two biennial cycles having achieved EOL burnups. By the end of 2020, five sets of lead fuel channels listed in Figure 6-1 will have reached EOL and the remaining five sets of lead fuel channels will be nearing EOL or have been irradiated for at least four years. Table 6-2 shows the existing Framatome Z4B lead fuel channel programs are projected to supply a total of [

]

As can be seen in Figure 6-1, exposure of the Z4B-BQ fuel channels irradiated in Plant C04 (manufactured using the CBQ process) was completed in 2017 and final bow measurements were taken. All additional Z4B-BQ bow measurements listed in Table 6-2 will be from Z4B-BQ fuel channels manufactured using Z4B-BQ sheets. Therefore, by the end of 2021 Framatome Z4B-BQ sheet lead fuel channel programs are projected to supply a total of [

] Results from these leads programs will provide assurance of safe operation for reload quantities of Z4B fuel channels or, in the case of unsatisfactory performance trends, allow for remediating measures (e.g., modified core loading or re-channeling) to be taken before any safety issues arise.

6.1 *Corrosion and Hydrogen Uptake*

[

]

The chemical composition of Z4B targets a reduction in corrosion and hydrogen uptake with respect to Zry-4. This improved performance has been demonstrated through a

[ ] (see Figures 6-2 and 6-3), recent hot cell measurements on Z4B fuel channels, and poolside measurements collected on Z4B fuel channels in a European lead fuel channel program (Figures 6-4 through 6-7). The optional BQ heat treatment does not significantly affect corrosion or hydrogen uptake.

6.1.1 Spacer Grid Strips

[

]

The purpose of measuring oxide and hydrogen in spacers made of Z4B is to be able to infer the behavior for channels. It is not planned to use Z4B material for spacers.

6.1.2 Fuel Channel Hot Cell

Z4B fuel channels were irradiated for up to three biennial cycles in Plant A33 which has demanding corrosion conditions. After one biennial exposure cycle, [

]

[

]

A comparison of average oxide thicknesses for these fuel channel coupons is shown in Figure 6-4. Figure 6-4 shows that the [ ] Side A of both two-biennial cycle fuel channels experienced control blade exposure during their first year of exposure [ ], while Side C faces away from the control blade. Only [ ] Side A of the one-biennial cycle Z4B fuel channel had the control blade fully inserted for about [ ]. The EFID value for the single biennial cycle fuel channel was [ ]

A comparison between hydrogen uptake and pickup fraction for these fuel channel coupons is shown in Figure 6-5. Figure 6-5 shows that the [ ] This is a result of the lower average corrosion rate of Z4B relative to Zry-4. One of the mechanisms leading to abnormal bow is thought to be related to differences in hydride content between the controlled and uncontrolled sides of the fuel channel. As expected, with minimal differences in corrosion, the hydrogen uptake difference is also small.

6.1.3 Fuel Channel General Corrosion

Figure 6-6 shows the uniform corrosion thickness versus exposure measured on Zry-4 and Z4B fuel channels. The bulk of these data are from pool-side eddy-current

measurements while those labeled "(HC)" are from the hot cell measurements on the fuel channel coupons discussed in the previous section. Figure 6-6 shows that the corrosion data for Z4B is similar to that of Zry-4, but are lower on average. This is likely a result of the optimized chemistry (i.e., increase in Fe and Cr) of Z4B relative to Zry-4.

Neither the material change to Zry-4 to create the Z4B material nor the addition of an optional BQ heat treatment will increase fuel channel corrosion relative to Zry-4. The Zry-4 fuel channel corrosion analyses performed for reload fuel channels are appropriate for use on Z4B fuel channels.

6.1.4 Fuel Channel Shadow Corrosion

Figure 6-7 shows the shadow oxide thickness versus exposure for Zry-4 and Z4B fuel channels. It can be seen that the shadow corrosion performance of Zry-4 is subject to significant variability. One source of such variability may be related to plant-to-plant variability in water chemistry and operational history. Shadow corrosion measurements from Z4B tend to be lower than those measured on Zry-4. This may be a result of the optimized chemistry (i.e., increase in Fe and Cr) of Z4B.

Neither the material change of fuel channel material from Zry-4 to create Z4B nor the optional addition of a BQ heat treatment will increase fuel channel shadow corrosion relative to Zry-4.

6.2 *Fuel Channel Deformation*

6.2.1 Fuel Channel Bulge

Fuel channel deformation is primarily a combination of bulge and bow. In general, fuel channel bulge is well understood, predictable, and can be accurately modeled. Fuel channel bulge is a creep process caused by differential pressure between the inside and outside of the fuel channel, which is enhanced during irradiation. Fuel channel bulge is evaluated using the methods in References 1 and 2. The slightly increased iron and chromium content in Z4B and the optional BQ process do not increase fuel channel bulge. As can be seen in Figure 6-8, bulge data collected from

[ ] thick Z4B RXA fuel channels are similar to or below bulge data collected from their Zry-4 RXA "sister channels" (i.e., fuel channels located in a symmetric location and sharing the same irradiation cycles).

Shown in Figure 6-9, is Z4B RXA fuel channel bulge data from ATRIUM 11 lead fuel assemblies in Plant C05. These fuel channels have a total wall thickness of [ ] No sister channel fuel channel bulge data are available for these fuel channels; however, it is clear that the bulge of these fuel channels was also low. This provides assurance that the previously-approved fuel channel licensing methods bound the performance of Z4B RXA fuel channels.

Figure 6-10 shows the bulge data collected from [ ] This provides assurance that the previously-approved fuel channel licensing methods bound the performance of Z4B-BQ fuel channels.

As there is also no change in design for Z4B fuel channels, the fuel channel bulge calculated with current methods per References 1 and 2 is conservatively applicable to Z4B fuel channels.

6.2.2 Fuel Channel Growth and Bow

The impacts of fuel channel irradiation growth on several fuel assembly interfaces are considered in design (e.g., engagement of the fuel channel with the seal spring). However, 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 (Reference 18). Current fuel designs will be licensed using the fuel rod and water channel growth correlations included in Reference 18.

As discussed in Section 7.0, Framatome has received NRC approval for a fuel channel bow evaluation methodology in Reference 16 to evaluate the impact of fuel channel bow on fuel rod performance. For these analyses, fuel channel growth is calculated using a mechanistic model based on fluence. As shown in Figure 7-1, [

] The primary objective of the BQ process is to minimize irradiation growth through creation of a quasi-isotropic texture in the BQ material. Reference 13 indicates that the irradiation growth strain in any given direction of a polycrystalline zirconium alloy is related to crystallographic texture and is roughly proportional to a growth anisotropy factor G_d given by

$$G_d = 1 - 3f_d^c$$

Where f_d^c is the resolved fraction of basal poles in the direction *d*. The authors also note that other factors such as grain boundary orientation and intergranular stresses can contribute to the magnitude and direction of irradiation growth. The quasi-isotropic texture (and grain boundary orientation) resulting from the BQ process leads to $f_d^c \cong 1/3$ (G_d is close to zero) and low values of irradiation growth are expected and observed (Figure 7-1). Low irradiation growth results in lower differential growth between fuel channel sides and low channel bow.

One of the mechanisms leading to abnormal bow is thought to be related to differences in hydride content between the controlled and uncontrolled sides of the fuel channel (Section 2.0). Z4B has been shown to [

]

[

] The Z4B-BQ bow measurements generally remain within the range of the NRC-approved fuel channel bow correlation as shown in Figure 6-11.

Framatome quantifies early control blade exposure through characterization of the Effective Full Insertion Days (EFID) as shown below (Reference 4):

$$EFID = \sum (F \times C_i \times \Delta D_i)$$

where,

$EFID$	= Effective Full Insertion Days, days
F	= 1.0 for first year of exposure
	= 0.66 for second year of exposure
	= 0.33 for third year of exposure
	= 0 after the third year of exposure
C_i	= control rod insertion fraction, 0 to 1
ΔD_i	= time of control blade insertion, days

EFID can be considered to represent the effect of control blade exposure (shadow corrosion) on fuel channel bow. Figure 6-12 shows Z4B RXA and Z4B-BQ fuel channel bow versus EFID. Also included are the bow values from their Zry-4 RXA sister fuel channels (some of which were rotated relative to their fuel assemblies beginning with the start of the fifth (two fuel channels with exposures of about [ ]) or eighth (one fuel channel with exposure of about [ ]) annual cycles. From this plot, it can be seen that there is [

]

[

]

Neither the use of Z4B nor the optional BQ heat treatment will increase fuel channel distortion relative to Zry-4 RXA fuel channels. As there is also no change in design for Z4B fuel channels, the fuel channel bow calculated with current methods per Reference 1 is applicable to Z4B fuel channels. This provides assurance that the previously-approved fuel channel licensing methods bound the performance of Z4B fuel channels.

6.3 *Planned Irradiations*

Table 6-3 shows a summary of Z4B fuel channel irradiations planned to start before 2021. As mentioned previously, [

] The forecast for U.S. reactors could increase pending the approval of this topical report.

In summary, a sufficient amount of data has been collected on the in-reactor performance of Z4B material to support reload supplies of Z4B fuel channels. Increasing quantities of Z4B fuel channels continue to be delivered, irradiated, and measured. The existing Z4B fuel channel lead programs and reloads will provide performance data well in advance of any US reloads approved under this topical report providing assurance of safe operation, or, in the case of adverse trends, allowing for

remediating measures to be taken such as changes in core design or rechanneling before any safety issues arise.

Table 6-1 Z4B fuel channel irradiation experience

Table 6-2 Projected number of bow data points for Z4B fuel channels

[ ]

Table 6-3 Planned Z4B fuel channel irradiations

[ ]

Figure 6-1 Timeline for Z4B PIE showing completed and projected number of fuel channels to be measured

Figure 6-2 Oxide thickness on spacer grid strips

Figure 6-3 Hydrogen uptake in spacer grid strips

Figure 6-4 Average oxide thicknesses on fuel channels

[ ]

Figure 6-5 Hydrogen uptake in fuel channels

[ ]

Figure 6-6 Uniform oxide thickness on fuel channels

[ ]

Figure 6-7 Shadow oxide thickness on fuel channels

[ ]

Figure 6-8 [ ] fuel channel bulge compared to their Zry-4 RXA sister channels

[

]

Figure 6-9 Advanced ATRIUM 11 Z4B fuel channel bulge

[ ]

Figure 6-10 [ ] fuel channel bulge compared to their Zry-4 RXA sister channels

[ ]

Figure 6-11 Z4B fuel channel bow

Figure 6-12 Comparison of Z4B fuel channel bow versus Effective Full Insertion Days (EFID)

7.0 EFFECT ON FUEL ROD AND SAFETY METHODS

The analyses and discussions in the previous sections have shown that the mechanical methods approved for Zry-4 fuel channels can be appropriately used for the analysis of Z4B fuel channels. Framatome has received NRC approval for a fuel channel bow evaluation methodology in Reference 16 to evaluate the impact of fuel channel bow on fuel rod performance. This methodology is also used in Reference 17 for Safety Limit Minimum Critical Power Ratio evaluations. As discussed in Appendix B of Reference 16, the method involves [

]

Shown in Figure 7-1 is a plot of the approved growth model, the RXA channel data that was used to produce that growth model, as well as the Z4B RXA fuel channel growth data. Also shown are the Z4B-BQ fuel channel growth data from Plant C04 and, for illustration, a parabolic trend line for that data.

7.1 *Z4B RXA Fuel Channel Bow*

Given the similarity in chemical composition and microstructure of Z4B RXA to Zry-4 RXA, it is reasonable to expect no significant differences in the predicted bow behavior between fuel channels fabricated from these materials. As shown in Figure 7-1, the [

] The approved fuel channel growth model coefficients from Appendix B of Reference 16 are used to [

]

Figure 7-2 shows [

]

Table 7-1 shows that the [

] Both data sets have small (near zero) biases and similar standard deviations. As discussed in Reference 16 Appendix B, [

] A plot similar to Figure B.3 in Reference 16 Appendix B is shown in Figure 7-3. An F-test was conducted to evaluate whether the Z4B RXA data was part of the larger population of RXA bow data used to develop the approved bow model. The results of this F-test (Table 7-2) comparing the two samples

(RODEX4 and Z4B RXA bow residuals) shows the null hypothesis that the variance of the residuals is equal cannot be rejected (F < F Critical). Thus, as expected, it can be concluded that the Z4B RXA bow data is part of the larger population of RXA bow data and is adequately represented by the approved bow model used in the RODEX4 statistical methodology.

Existing BWR fuel channel distortion / control blade friction counter measures and fuel channel management guidelines for cores containing Z4B RXA fuel channels will continue to be applied until a full core of Z4B RXA fuel channels has experienced no observations of control blade-to-channel interference (e.g., slow to settle, no settle, delayed scram) for 3 consecutive years within a C- or S-Lattice design.

7.2 *Z4B-BQ Fuel Channel Bow*

It is clear from Figure 7-1 that [

] . For this reason, the same type of analyses presented in Section 7.1 cannot be undertaken for Z4B-BQ fuel channel bow. From Figure 7-1, for a given fluence gradient centered on a given fluence, a lower bow would be predicted for a Z4B-BQ fuel channel than for an RXA fuel channel. As discussed in Section 2.0, the size of the water gaps between adjacent fuel channels and between the fuel channel and adjacent fuel rods are altered by fuel channel bow. From a neutronic perspective, when the channel bows away from adjacent fuel rods, the local water gap between the fuel channel and adjacent rods is increased. The result is an increase in thermal neutron flux and a concomitant increase in local pin power. The reverse is true for the opposite side of the fuel assembly when the fuel channel bows toward adjacent fuel rods, resulting in a local reduction in water gap, thermal neutron flux and pin power. Overall, fuel channel bow has a negative influence on BWR fuel performance margins and straighter fuel channels are better in this respect.

As discussed in Section 6.2.2, the expected irradiation growth for BQ fuel channels is near zero due to their quasi-isotropic microstructure. Although some irradiation growth

at higher exposures may be caused by corrosion/hydrogen uptake, such evolutions would result in bow only if the oxide thickness/hydrogen uptake were different between two sides of the fuel channel. As discussed in Section 2.0 and shown in Section 6.1.2, oxide thickness and hydrogen uptake are similar on both fuel channel sides for both Z4B and Zry-4, even if one side is exposed to a control blade early in life. Effectively, the measured bow values for BQ fuel channels are equivalent to the negative of the (predicted (zero) – measured) residuals.

Figure 7-4 shows the measured Z4B-BQ fuel channel bow data from Plant C04 versus fluence gradient. The data are plotted such that the evolution of measured bow versus accumulated fluence gradient can be followed for each fuel channel and fuel channel side pair. One Z4B-BQ fuel channel [

] was rotated relative to its fuel assembly before its seventh and last annual cycle of operation. Fuel channel rotation is not a practice done in US plants with Framatome fuel. The abrupt change in bow values for this fuel channel is believed to be a result of the reinstallation process. No fluence data are available for the other rotated Z4B-BQ fuel channel.

Unlike the RXA data shown in Figure 7-2 which shows a relatively strong dependence on fluence gradient, the Z4B-BQ data has numerous examples of exhibiting little change in bow throughout their lifetime even when subjected to significant fluence gradients, as expected for a quasi-isotropic material. [

]

Figure 7-5 shows the same Z4B-BQ fuel channel bow data along with bow data collected from their Zry-4 RXA sister fuel channels. Three of the Zry-4 RXA sister fuel channels were rotated with respect to their fuel assemblies as a result of the customer's fuel channel bow management program. [

] It can be concluded from Figure 7-5 and the lower amount of fuel channel management applied, that the performance of Z4B-BQ fuel channels is superior to that of Zry-4 RXA fuel channels under the same exposure conditions.

As discussed in Reference 21, sources of uncertainty in fuel channel bow are primarily from as-fabricated and as-installed bow. It is reasonable to expect the uncertainty in as-fabricated and as-installed bow to be similar for BQ and RXA fuel channels because:

- RXA and BQ sheet materials have similar mechanical properties (Table 5-1) and are given similar stress-relief heat treatments (Section 4.2),
- [ ]
- As-installed bow should be similar as there is no difference in BQ and RXA fuel channel installation procedures.

It is difficult to estimate the combined as-fabricated and as-installed bow uncertainty as there are no measurements available of as-installed fuel channel bow available. In the case of the approved bow model, this combined uncertainty is represented by the [ ] The Z4B-BQ fuel channels in plant C04 present a unique opportunity in that their bow was measured after only one annual cycle. Given their low exposures and BQ microstructure, it is reasonable to conclude that the variation in measured bow of these first-cycle fuel channels is primarily due to as-fabricated and as-installed bow. The first row in Table 7-3 shows the statistics of these measurements. [ ]

[

] As discussed above, the bow uncertainty for Z4B-BQ fuel channels is expected to be equivalent to that of Zry-4 RXA and Z4B RXA fuel channels. This will be confirmed when sufficient bow data has been collected from fuel channels fabricated using the industrialized BQ sheet process. As discussed in Section 6.0, by the end of 2021, Framatome Z4B-BQ sheet lead fuel channel programs are projected to supply [ ] higher exposure data points. This amount of bow data is sufficient to provide assurance of safe operation for reload quantities of Z4B fuel channels or, in the case of unsatisfactory performance trends, allow for remediating measures (e.g., modified core loading or re-channeling) to be taken before any safety issues arise.

Existing BWR fuel channel distortion / control blade friction counter measures and fuel channel management guidelines for cores containing Z4B-BQ fuel channels will continue to be applied until a full core of Z4B-BQ fuel channels has experienced no observations of control blade-to-channel interference (e.g., slow to settle, no settle, delayed scram) for 3 consecutive years within a C- or S-Lattice design.

Table 7-1 RXA channel bow residuals bias and standard deviation

[ ]

Table 7-2 F-test of RODEX4 and Z4B RXA bow residuals

[ ]

Table 7-3 Z4B-BQ channel bow residuals bias and standard deviation

[ ]

[ ]

Figure 7-1 Z4B fuel channel growth versus fluence

Figure 7-2 Z4B RXA fuel channel bow versus fluence gradient

[ ]

Figure 7-3 Z4B RXA fuel channel bow with enhanced uncertainty bands

[ ]

Figure 7-4 Z4B BQ fuel channel bow versus fluence gradient

Figure 7-5 Z4B-BQ fuel channel bow compared to Zry-4 RXA sister fuel channel bow versus fluence gradient

8.0 REFERENCES

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CORRESPONDENCE

framatome

July 25, 2018
NRC:18:029

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852z

Request for Review and Approval of EMF-93-177 Revision 1 Supplement 2P Revision 1, "Mechanical Design for BWR Fuel Channels: Z4B Material"

Framatome Inc. (Framatome) requests the NRC's review and approval of the topical report EMF-93-177 Revision 1 Supplement 2P Revision 1, "Mechanical Design for BWR Fuel Channels: Z4B Material" for referencing in licensing actions.

Excessive control blade friction due to abnormal fuel channel bow remains a significant technical challenge to the BWR industry. As part of the efforts to resolve this issue, Framatome has developed a new zirconium alloy, Z4B, which demonstrates improved bow performance relative to Zry-2 and Zry-4 fuel channels. The topical report EMF-93-177 Revision 1 Supplement 2P Revision 1 is a follow-on to the topical report ANP-10336P-A Revision 0, "Z4B™ Fuel Channel Irradiation Program" to support the use of the Z4B channel material in batch quantities.

Framatome would appreciate NRC approval of this topical report by July 2019.

Framatome considers some of the material contained in Enclosure 1 to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support withholding information from public disclosure.

There are no regulatory commitments within this letter or its enclosures.

If you have any questions related to this submittal, please contact Ms. Gayle F. Elliott, Deputy Director, Licensing and Regulatory Affairs, by telephone at 434-832-3347 or by e-mail at Gayle.Elliott@framatome.com.

Sincerely,

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: J. G. Rowley
Project 728

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Enclosures:

1. EMF-93-177 Revision 1 Supplement 2P Revision 1, "Mechanical Design for BWR Fuel Channels: Z4B Material" (PROPRIETARY)
2. EMF-93-177 Revision 1 Supplement 2NP Revision 1, "Mechanical Design for BWR Fuel Channels: Z4B Material" (NON-PROPRIETARY)
3. Notarized Affidavit

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Alan B. Meginnis. I am Manager, Product Licensing, for Framatome Inc. and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the report EMF-93-177, Revision 1, Supplement 2P, Revision 1 "Mechanical Design for BWR Fuel Channels: Z4B Material," dated July 2018 and referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

(a) The information reveals details of Framatome's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.

(e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(a), 6(b), 6(c), 6(d) and 6(e) above.

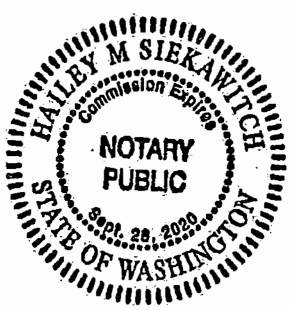
7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document have been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 25th day of July, 2018.

Hailey M Siekawitch
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 9/28/2020



UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 7, 2018

Mr. Gary Peters, Director
Licensing and Regulatory Affairs
Framatome Inc.
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: ACCEPTANCE FOR REVIEW OF FRAMATOME INC. TOPICAL REPORT EMF-93-177, REVISION 1, SUPPLEMENT 2P, REVISION 1, "MECHANICAL DESIGN FOR BWR FUEL CHANNELS: Z4B MATERIAL" (EPID: L-2018-TOP-0029)

Dear Mr. Peters

By letter dated July 25, 2018 (Agencywide Documents Access and Management System Accession No. ML18211A307), Framatome Inc. (Framatome) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report (TR) EMF-93-177, Revision 1, Supplement 2P, Revision 1, "Mechanical Design for BWR [Boiling Water Reactor] Fuel Channels: Z4B Material." The NRC staff has performed an acceptance review of TR EMF-93-177, Revision 1, Supplement 2P, Revision 1. We have found that the material presented is sufficient to begin our review. The NRC staff expects to issue its requests for additional information by March 1, 2019, and issue its draft safety evaluation (SE) by May 31, 2019. This schedule information takes in consideration the NRC's current review priorities and available technical resources and may be subject to change. If modifications to these dates are deemed necessary, we will provide appropriate updates to this information. The NRC staff estimates that the review will require approximately 480 staff hours including project management and contractor time. The review schedule milestones and estimated review costs were discussed and agreed upon in an email exchange between Framatome Licensing Engineer, Jerald Holm, and the NRC staff on October 10, 2018.

Section 170.21 of Title 10 of the *Code of Federal Regulations* requires that TRs are subject to fees based on the full cost of the review. You did not request a fee waiver; therefore, NRC staff hours will be billed accordingly.

If you have questions regarding this matter, please contact Jonathan G. Rowley at (301) 415-4053.

Sincerely,

Jonathan Rowley for

Dennis C. Morey, Chief
Licensing Processes Branch
Division of Licensing Projects
Office of Nuclear Reactor Regulation

Docket No. 99902041