June 18, 2003

Mr. James F. Mallay
Director, Regulatory Affairs
Framatome ANP
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: SAFETY EVALUATION OF FRAMATOME ANP TOPICAL REPORT BAW-10186P-A, REVISION 1, SUPPLEMENT 1, "EXTENDED BURNUP EVALUATION" (TAC NOS. MB3650 AND MB7548)

Dear Mr. Mallay:

By letter dated November 19, 2001, Framatome ANP submitted Supplement 1 to BAW-10186P-A, Revision 1, "Extended Burnup Evaluation," for review by the NRC staff. Framatome ANP has two fuel designs, Mark-B and Mark-BW, for Babcock & Wilcox-designed and Westinghouse-designed pressurized water reactors (PWRs), respectively. The staff previously approved both Mark-B and Mark-BW fuel designs to peak rod average burnup limits of 62,000 and 60,000 MWd/MTU, respectively, as described in the approved Topical Report (TR) BAW-10186P-A, Revision 1, "Extended Burnup Evaluation." At that time, Framatome ANP requested a burnup limit of 60,000 MWd/MTU for Mark-BW fuel rods due to the limited irradiation data available. Supplement 1 requests an extension of Framatome ANP's Mark-BW fuel design with an advanced cladding material M5 to the burnup limit of 62,000 MWd/MTU. The justification for this extension of the Mark-BW fuel burnup limit to 62,000 Mwd/MTU is based on the similarity to the Mark-B product and the additional data now available regarding the Mark-BW fuel. In addition, Framatome ANP has committed to performing additional post irradiation examinations of high burnup fuel. Data will be acquired on lead test assemblies and full batches of fuel. The results of these examinations will be presented to the NRC during the fuel vendor fuel performance review meetings.

The staff has completed its review of the subject TR and finds it is acceptable for referencing in licensing applications to the extent specified and under the limitations delineated in the report and in the associated safety evaluation (SE). The enclosed SE defines the basis for acceptance of the report.

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

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

In accordance with the guidance provided on the NRC website, we request that Framatome publish an accepted version of this TR within three months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed SE between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in appendices historical review information, such as questions and accepted responses, and original report pages that were replaced. The accepted version shall include a "-A" (designated accepted) following the report identification symbol.

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

Sincerely,

/RA/

Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 693

Enclosure: Safety Evaluation

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Sincerely,
/RA/
Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 693

Enclosure: Safety Evaluation

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT BAW-10186P-A, REVISION 1, SUPPLEMENT 1,

"EXTENDED BURNUP EVALUATION"

FRAMATOME ANP

PROJECT NO. 693

1.0 INTRODUCTION

On November 19, 2001, Framatome ANP submitted Supplement 1 to Topical Report (TR) BAW-10186P-A, Revision 1, "Extended Burnup Evaluation," for NRC staff review and approval. Supplement 1 provides justification for extension of the burnup limit for the Mark-BW fuel design with an advanced cladding material M5 to 62,000 MWd/MTU. Previously, Framatome ANP requested an approved burnup limit of 60,000 MWd/MTU for Mark-BW fuel rods due to the limited irradiation data available. As part of this submittal, Framatome ANP provided more irradiation data and updated models.

Framatome ANP has two fuel designs, Mark-B and Mark-BW, for Babcock & Wilcox-designed and Westinghouse-designed pressurized water reactors (PWRs), respectively. These fuel designs are mainly for reload licensing applications of PWRs. TR BAW-10229-A, "Mark-B11 Fuel Assembly Design Topical Report," describes the recently approved Mark-B fuel design. The staff previously approved the Mark-BW fuel design in TR BAW-10172P-A, "Mark-BW Mechanical Design Report." The staff approved both Mark-B and Mark-BW fuel designs to peak rod average burnup limits of 62,000 and 60,000 MWd/MTU, respectively, as described in the TR BAW-10186P-A, Revision 1, "Extended Burnup Evaluation."

The staff approved the advanced cladding material M5 for fuel designs in TR BAW-10227P-A, "Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel." Unlike Zircaloy, M5 is a zirconium-based material with nominally 1 percent niobium added. The staff also approved using M5 as cladding and other structural components for both Mark-B and Mark-BW fuel designs. The staff approved the same burnup limits of 62,000 and 60,000 MWd/MTU, as described previously, for Mark-B and Mark-BW fuel designs, respectively, with the M5 cladding material.

Framatome ANP will redesign the Mark-BW fuel with the advanced cladding material M5, rather than the conventional Zircaloy-4, for reload licensing applications. The fuel assembly structural materials like guide tubes, spacer grids, etc., may be either Zircaloy-4 or M5. Previously, the staff approved the Mark-BW fuel design to a burnup limit of 60,000 MWd/MTU rather than

62,000 MWd/MTU because Framatome ANP did not provide sufficient data to support the higher limit. Framatome ANP has obtained additional high burnup data. Based on the additional data and the similarity to the Mark-B fuel design, Framatome ANP requests to extend the burnup limit for Mark-BW fuel design with the M5 cladding material to 62,000 MWd/MTU.

2.0 REGULATORY EVALUATION

The acceptance criteria are based on Section 4.2, "Fuel Design System," of the Standard Review Plan (SRP). These criteria include three parts: (1) design bases – describes specified acceptable fuel design limits (SAFDLs) as depicted in General Design Criterion (GDC) 10 to 10 CFR Part 50, Appendix A, (2) design evaluation – demonstrates that the design bases are met, and (3) testing, inspection, and surveillance plans – shows that there are adequate monitoring and surveillance of irradiated fuel. For this review, the staff focused mainly on those areas where it determined that the data were insufficient in the previous review and could have impacts in the fuel performance of Mark-BW fuel design. These areas included, but were not limited to: fuel rod and assembly growth, oxidation, control rod drop time, and post-irradiation examination (PIE).

3.0 TECHNICAL EVALUATION

3.1 High Burnup Data

Framatome ANP recently expanded the Mark-BW fuel performance data base. Framatome ANP has a comprehensive PIE program that collects lead test assembly (LTA) irradiation data in high burnup regimes from various plants including Catawba, McGuire, North Anna, and Oconee. Framatome ANP provided a list of plants with completed PIEs. The PIE involves poolside and hotcell examinations of Mark-B and Mark-BW fuel rods with either Zircaloy-4 or M5 cladding. Framatome ANP has also committed to continue collecting data as described below. Based on the additional PIE data and the Framatome ANP commitment, the staff concludes that Framatome ANP has provided adequate high burnup data to support the peak rod average burnup limit of 62,000 MWd/MTU.

3.2 Fuel Rod and Assembly Axial Growth

Fuel rods tend to grow and close the lower clearance with the bottom nozzle earlier than the upper clearance with the top nozzle. The loss of these clearances will cause fuel bowing. All bowing phenomena will lead to thermal and hydraulic penalties during reactor operations. The Framatome ANP design basis for rod axial growth is that adequate clearance be maintained between fuel rod ends and top and bottom nozzles to accommodate the difference in the growth of fuel rods and fuel assembly. The clearance between the fuel rod top ends and the top nozzle is called the shoulder gap. A shoulder gap closure model estimates the time of the clearance disappearance, thereby commencing fuel rod bowing. Similarly, for assembly growth, Framatome ANP requires that sufficient axial clearance between core plates and bottom and top nozzles be maintained for fuel assembly irradiation growth during the assembly lifetime. Assembly growth is a result of guide thimble growth. Similarly, excessive assembly growth to close axial clearances between core plates and top and bottom nozzles will cause the assembly to bow.

Framatome ANP updated the shoulder gap closure model including Zircaloy-4 growth data to support the extension of the burnup limit to 62,000 MWd/MTU. The new model is conservative because it is based on the maximum shoulder gap closure for those assemblies measured during PIEs. The result showed that the Framatome ANP fuel designs of existing Zircaloy-4 cladding have adequate clearances to support the new burnup limit of 62,000 MWd/MTU. According to the information in TR BAW-10227P-A, the M5 fuel rods have shown consistently lower growth rates than the Zircaloy-4 fuel rods. Therefore, Framatome ANP concluded that the new shoulder gap closure model is also conservative for the M5 clad fuel rods for the extension of the burnup limit to 62,000 MWd/MTU. Based on the irradiation performance and the staff's review of the use of M5 in TR BAW-10227P-A, the staff agrees with the Framatome ANP assessment.

Framatome ANP also updated the fuel assembly growth model. Framatome ANP plotted the Zircaloy-4 and M5 thimble growth curves separately due to the material dependence. The result showed that the clearances between core plates and the top and bottom nozzles are adequately maintained for Zircaloy-4 to support a burnup limit of 62,000 MWd/MTU. The updated growth model showed that the M5 thimble growth is consistently below the Zircaloy-4 thimble growth. Thus, the M5 thimble tubes have enough clearances with regard to the assembly growth to a burnup limit of 62,000 MWd/MTU. Based on the irradiation performance and the staff review of the use of M5 in TR BAW-10227P-A, the staff agrees with the Framatome ANP conclusion.

Therefore, based on the acceptable data and previous irradiation performance, the staff concludes that the performance of fuel rod growth and assembly growth is acceptable for Mark-BW fuel design to the peak rod average burnup limit of 62,000 MWd/MTU.

3.3 Oxidation and Crud

SRP Section 4.2 identifies cladding oxidation and crud buildup as potential fuel damage mechanisms in the design bases. Cladding oxidation (corrosion) usually results in crud buildup. The SRP does not establish specific limits on cladding oxidation and crud, but specifies that their effects be accounted for in the thermal and mechanical analyses. Recent PIE data demonstrated that extensive corrosion could occur and result in premature fuel failures. In order to maintain adequate fuel cladding ductility at high burnups, the total amount of oxidation or corrosion should be limited during normal operations, including anticipated operational occurrences. The staff has strongly recommended that fuel vendors and licensees establish a corrosion limit to prevent further degradation of fuel rods. Framatome ANP adopted a corrosion thickness limit of 100 microns in TR BAW-10186P-A, Revision 1. The staff also concluded in TR BAW-10227P-A that the same corrosion limit was applicable for the M5 cladding.

Framatome ANP has generated more corrosion data of M5 cladding for the burnup regime greater than 60,000 MWd/MTU. The result demonstrated that the M5 corrosion trend starts leveling off and does not increase significantly as Zircaloy-4 does in the high burnup regime. This behavior confirms that M5 cladding has a quality of lower sensitivity to oxidation kinetics for various irradiation conditions. Thus, the M5 cladding has a greater margin to the 100 microns limit than the Zircaloy-4 cladding. Because crud formation is partially due to clad oxidation, the M5 cladding will have less crud buildup with other crud buildup factors remaining

the same. Therefore, overall, the M5 cladding will perform better than the Zircaloy-4 cladding with respect to corrosion and crud.

Based on the new corrosion data, the staff concludes that the Mark-BW fuel rods with M5 cladding have acceptable performance of corrosion and crud buildup for the peak rod average burnup limit of 62,000 MWd/MTU.

3.4 Control Rod Drop Time

SRP Section 4.2 states that control rod reactivity must be maintained as a design basis. In the mid-1990s, several control rods failed to insert fully into the dashpot section during reactor scrams at some PWRs. The affected control rods were positioned in high burnup fuel assemblies. Upon inspection of the fuel assemblies, the control rods were found to be in good condition, but the guide thimbles were deformed. The deformed guide thimbles could cause longer control rod drop time and delay the reactor trip. The guide thimbles are made of Zircaloy tubes.

The staff issued Bulletin 96-01, "Control Rod Insertion Problems," requesting special actions to ensure compliance with the current licensing basis of shutdown margin and control rod drop times. The industry took action to redesign the affected fuel assemblies and improve core management to eliminate the problem. Although the staff resolved those issues in the Bulletin, the staff will continue monitoring the control rod performance, and require new fuel designs or burnup extensions to address this problem.

Framatome ANP's Mark-BW fuel design has a dashpot integral to the guide thimbles. Framatome ANP stated that no Mark-BW fuel assemblies had experienced any incomplete rod insertion problem. Framatome ANP presented control rod drop tests of Mark-BW fuel with M5 thimble tubes from four reactors. The results showed that there were no appreciable drop time changes from low to high burnup regimes. Based on the Framatome ANP control rod performance, the staff agrees with the observation.

Based on these drop tests and the fact that the M5 guide thimbles are less likely than Zircaloy guide thimbles to involve this problem, the staff concludes that the Mark-BW fuel control rod performance is acceptable for the peak rod average burnup limit of 62,000 MWd/MTU.

3.5 Reactivity Initiated Accident

The reactivity initiated accidents (RIAs) include a control rod ejection accident in PWRs. SRP Section 4.2 specifies that a fuel enthalpy limit of 280 cal/g should be observed during an RIA as a design basis.

Recent experimental data showed failure of high burnup fuel at lower enthalpy values than the 280 cal/g safety limit. However, there was a broad agreement among the staff and the industry, including the international community, that the effect of burnup degradation in the enthalpy safety limit for high burnup fuel is likely to be compensated by applying detailed three-dimensional analytical methods for RIAs. In addition, generic analyses performed by the industry assuming low enthalpy fuel failure, showed that the radiological consequences of rod ejection accidents met the acceptance criteria in the SRP.

The staff realizes that the fuel enthalpy safety limit in the SRP is not conservative and may decrease in the future. Further testing and evaluation are needed to better establish new limits. Recently, industry submitted a generic TR entitled, "Topical Report on Reactivity Initiated Accident: Bases for RIA Fuel and Core Coolability Criteria," for staff review. This TR intends to establish new safety limits of fuel failure and fuel coolability. Pending completion of the review, the staff considers that the current enthalpy safety limit continues to be acceptable until it is revised, and the use of M5 material in the Mark-BW fuel design is not expected to significantly impact the safety analyses. In addition, the staff considers that the probability of these accidents is low and the generic safety analyses provide reasonable assurance that radiological consequences will not violate the acceptance criteria in the SRP.

Since there are many similar features between Mark-B and Mark-BW fuel designs, the staff expects that Mark-BW fuel performs similarly as the Mark-B fuel under RIAs. Framatome ANP confirmed that the Mark-BW fuel design continues to meet the current fuel enthalpy limit to the peak rod average burnup limit of 62,000 MWd/MTU as the Mark-B fuel already did. Based on the similarity between the Mark-B and Mark-BW fuel designs, the staff concludes that the Mark-BW fuel design will have no impact in the RIA results for burnup limit extension from 60,000 to 62,000 MWd/MTU.

3.6 Post-Irradiation Examination

In the past few years, operating experiences have identified a series of fuel issues that raise important licensing questions. Among these issues are accelerated growth of rods and assemblies, higher cladding oxidation, incomplete control rod insertion events, etc. All of these issues are associated with high burnups. The NRC plan for addressing high burnup fuel issues is described in the document entitled, "Agency Program Plan for High Burnup Fuel," dated July 6, 1998 (ADAMS Accession Nos. ML011380085 and ML011380091). The staff has established a few basic burnup extension guidelines. In particular, the staff stresses the need for LTAs in the guidelines.

During the approval of TR BAW-10186P-A, Revision 1 and TR BAW-10227P-A, Framatome ANP made a commitment to acquire additional PIE data. The PIE program usually involves LTA irradiation in multiple plants to collect high burnup results. These high burnup results exceeding the current burnup limits will be able to support future licensing applications. Framatome ANP provided a list of completed and ongoing LTA inspections. The inspection includes various performance data such as cladding oxide, rod and assembly growth, shoulder gap, rod bow, control rod drop time, and cladding wear.

Based on Framatome ANP’s LTA commitment, which is consistent with the staff guidelines, the staff concludes that the PIE program is acceptable for Mark-BW fuel design up to the peak rod average burnup limit of 62,000 MWd/MTU.

4.0 CONCLUSION

The staff has reviewed Supplement 1 to TR BAW-10186P-A, Revision 1 that describes the Mark-BW fuel design with the advanced cladding material M5. Based on the staff's review of the applicable data and many similar features with the Mark-B design, the staff concludes that

the Mark-BW fuel design with the M5 cladding is acceptable for burnup extension to the peak rod average burnup limit of 62,000 MWd/MTU.

Therefore, the staff concludes that Supplement 1 to TR BAW-10186P-A, Revision1 provides adequate justification for the use of the Mark-BW fuel design with M5 cladding to the peak rod average burnup limit of 62,000 MWd/MTU. The approval of this Supplement supercedes the safety evaluation restrictions on burnup in TRs BAW-10186P-A, Revision 1 and BAW-10227P-A for the Mark-BW fuel design. In addition, Framatome ANP may incorporate this safety evaluation in the approved versions of TRs BAW-10186P-A, Revision 1 and BAW-10227P-A.

Principal Contributor: S. L. Wu

Date: June 18, 2003