January 14, 2004

Mr. James Mallay
Director, Regulatory Affairs
Framatome ANP
3815 Old Forest Road
Lynchburg, VA 24501

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT BAW-10231P, "COPERNIC FUEL ROD DESIGN CODE" CHAPTER 13, MOX APPLICATIONS (TAC NO. MB7547)

Dear Mr. Mallay:

On July 31, 2000, Framatome ANP (FANP) submitted Topical Report (TR) BAW-10231P, "COPERNIC Fuel Rod Design Code," Chapter 13, MOX Applications, to the staff. On November 21, 2003, an NRC draft safety evaluation (SE) regarding our approval of BAW-10231P was provided for your review and comments. By letter dated December 4, 2003, FANP commented on the draft SE. The staff's disposition of FANP's comments on the draft SE are discussed in the attachment to the final SE enclosed with this letter.

The staff has found that BAW-10231P, Chapter 13, is acceptable for referencing in licensing applications for pressurized water reactors to the extent specified and under the limitations delineated in the report and in the enclosed SE. The SE defines the basis for acceptance of the report.

Our acceptance applies only to material provided in the subject report. We do not intend to repeat our review of the material described in the report. When the report appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests 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 FANP 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, draft SE comments, and original report pages that were replaced. The accepted version shall include a "-A" (designating accepted) following the report identification symbol.

If the NRC's criteria or regulations change so that its conclusion in this letter, that the TR is acceptable, is invalidated, FANP and/or the licensees referencing the TR will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the topical report without revision of the respective documentation.

Sincerely,

/RA by Stephen Dembek for/

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

Project No. 728

Enclosure: Safety Evaluation

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BAW-10231P, "COPERNIC FUEL ROD DESIGN COMPUTER CODE"

CHAPTER 13 - MOX APPLICATIONS

FRAMATOME ANP

PROJECT NO. 728

1.0 INTRODUCTION

Framatome Cogema Fuels (FCF) (now known as Framatome ANP [FANP]) submitted to the NRC staff Chapter 13 (Reference 1) of Topical Report (TR) BAW-10231P, entitled "COPERNIC Fuel Rod Design Computer Code," for review and approval. Chapter 13 describes a design and analysis methodology for mixed oxide (MOX) fuel rod performance. MOX fuel pellets have a mixture of uranium dioxide (UO_2) and plutonium dioxide (PuO_2). This report deals with the use of weapons grade (WG) PuO_2 in MOX fuel designs.

The staff has previously approved the COPERNIC code for UO_2 licensing applications (References 2 and 3) with advanced cladding material, M5, to a peak rod average burnup of 62 GWd/MTU. Although Chapter 13 is an extended application of the COPERNIC code, detailed MOX fuel designs including irradiation experiences are described in other FANP TRs such as BAW-10238(P), Revision 1, entitled "MOX Fuel Design Report," that describes FANP's use of WG $PuO_{2.}$ FANP requested an approval of the COPERNIC code for MOX licensing applications to a Pu content of 6 weight percent (wt%) and a peak rod average burnup of 53 GWd/MThm. Although FANP obtained some data beyond 53 GWd/MThm, the staff review and audit verifications are only up to a peak rod average burnup of 50 GWd/MThm. The staff considers that since this fuel will be irradiated for a maximum of two fuel cycles, 50 GWd/MThm will be sufficient. This conservative limitation is appropriate after considering the applicable data and audit calculations.

As a result of the staff's review, assisted by its consultant, Pacific Northwest National Laboratory (PNNL), two requests for additional information (RAIs) were sent to FANP (References 4 and 5). FANP provided responses in References 6, 7, and 8.

This review addresses those major computer models of the MOX fuel design features in the COPERNIC code that are different from the UO_2 fuel design features, and the MOX fuel design licensing applications. The licensing applications include fuel melting analysis, fuel rod internal pressure, cladding strain, and stored energy for a loss-of-coolant accident (LOCA).

The staff used the NRC audit code, FRAPCON-3.2 with MOX properties (Reference 9), to evaluate the models and analytical results from the COPERNIC code. The FRAPCON-3.2

code is a modification of the UO_2 version of the FRAPCON-3 code (Reference 10). The FRAPCON-3.2 code has been verified against thermal data from irradiated MOX fuel rod segments to rod average burnup of 60 GWd/MThm. The verification process demonstrated that the FRAPCON-3.2 code provided best-estimate predictions of the thermal and fission gas release data for MOX fuel rods.

2.0 REGULATORY EVALUATION

The objectives of the fuel system safety review are to provide assurance that (1) the fuel system is not damaged as a result of normal operation and anticipated operational occurrences, (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. The staff acceptance criteria are based on Chapter 4.2, "Fuel System Design," of the Standard Review Plan (SRP). These criteria include three parts: (1) design bases that describe specified acceptable fuel design limits as depicted in General Design Criterion 10 to 10 CFR Part 50, Appendix A, (2) design evaluation that demonstrates that the design bases are met, and (3) testing, inspection, and surveillance plans that show that there is adequate monitoring and surveillance of irradiated fuel. The design bases include (1) fuel system damage, (2) fuel rod failure, and (3) fuel coolability.

3.0 TECHNICAL EVALUATION

3.1 Fuel Thermal Conductivity

The COPERNIC MOX fuel thermal conductivity model is similar to that used for UO_2 (including the burnup dependence) with the addition of two terms, which are functions of PuO_2 content and oxygen-to-metal (O/M) ratio. The staff compared the COPERNIC MOX thermal conductivity model to the MOX thermal conductivity model (Reference 11) used in the FRAPCON-3.2 code. The MOX thermal conductivity model in FRAPCON-3.2 is based on the Duriez model (Reference 12) for unirradiated MOX fuel pellets (with O/M dependence) along with the burnup dependence proposed by the staff's consultant, PNNL (References 13 and 14). The comparison showed that the two models were close for the low burnup regime, and FRAPCON-3.2 had slightly higher fuel temperature predictions than COPERNIC for the high burnup regime.

The comparison of the COPERNIC MOX thermal conductivity model to in-reactor Halden fuel temperature data also showed a similar trend of good agreement between the two except at the high burnup regime. The COPERNIC model could slightly underpredict fuel temperatures at the high burnup regime. Overall, the COPERNIC model showed consistent results with the FRAPCON-3.2 code and Halden data.

Based on the overall good agreement of the temperature predictions, the staff concludes that the MOX thermal conductivity model is acceptable for the COPERNIC MOX code to a peak rod average burnup of 50 GWd/MThm.

3.2 Fission Gas Release

Fission gas release is important because it degrades the fuel-to-clad gap conductance and simultaneously increases fuel rod pressures. There are two fission gas release (FGR) models in the COPERNIC code: a steady-state model and a transient model. FANP has FGR data from the Halden reactor as well as its own irradiation program.

The audit code FRAPCON-3.2 uses a release model that is taken from the American Nuclear Society (ANS) Standard 5.4 (Reference 15) and a thermally-activated diffusion model proposed by Forsberg and Massih (Reference 16) with modifications to the diffusion coefficient. The FRAPCON-3.2 model also assumes that the fission gas is stored on the grain boundary until saturation, and the gas saturation level is the same for MOX and UO_2 fuel. The COPERNIC code adopts a similar approach.

The COPERNIC code was compared to MOX FGR from steady-state power operations. The COPERNIC comparisons to the data showed that the code provided a best-estimate calculation of FGR for steady-state operations. The COPERNIC code assumes that the transient release model for MOX is identical to that for UO_2 fuel. The transient release results were compared to power ramp data. The COPERNIC code conservatively overpredicted the measured FGR on most of the power ramp data. Based on the overprediction of the majority of the data, the staff considers that the FGR models have adequate conservatism and the predictions are acceptable.

FGR has significant impact on the end-of-life (EOL) rod pressure analysis for the peak operating rods within a core. The rod pressure analysis generally limits the peak linear heat generation rates (LHGRs) at high burnup levels. The staff performed an audit calculation of an EOL rod pressure provided by FANP using best-estimate input values. This audit calculation demonstrated that the audit code predicted slightly higher rod pressures than the COPERNIC code at EOL, but the differences were very small when compared to the uncertainties in the analysis.

Based on the good agreement between the two codes, the staff concludes that the FGR predictions are acceptable for the COPERNIC MOX code to peak rod average burnup of 50 GWd/MThm.

3.3 Fuel Densification and Swelling

The fuel densification and swelling models in COPERNIC are important for cladding strain, fuel melting, and LOCA analyses. FANP determined the fuel densification according to the recommendation of Regulatory Guide 1.126, “An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification” (Reference 17). FANP provided data to demonstrate that the MOX fuel was similar to UO_2 fuel in fuel densification and swelling performance. The COPERNIC predictions also compared reasonably well with those measured from MOX fuel. A comparison of the densification and swelling models in COPERNIC and FRAPCON-3.2 showed that the two models were very similar in densification kinetics.

Based on the comparison of the two codes with the densification and swelling data, the staff concludes that the fuel densification and swelling models are acceptable for the COPERNIC MOX code to a peak rod average burnup of 50 GWd/MThm.

3.4 Power-to-Melt Analysis

The difference between COPERNIC and FRAPCON-3.2 fuel thermal conductivity models at the high temperature regime leads to a difference in power-to-melt calculations. The staff performed an audit calculation using the FRAPCON-3.2 code. The results showed that the two codes predicted very closely at the beginning of life, but the COPERNIC code predicted a slightly higher result than the FRAPCON-3.2 code for higher burnups. The staff considers that the minor difference in the power-to-melt analysis has little impact in the overall safety analyses.

Based on the conservative thermal models and the comparisons with the audit code, the staff concludes that the power-to-melt analysis is acceptable for the COPERNIC MOX code to a peak rod average burnup of 50 GWd/MThm.

3.5 Fuel Rod Internal Pressure

FANP uses the COPERNIC code to verify the maximum EOL rod pressure for a MOX fuel design. FANP provided an EOL fuel rod internal pressure analysis of a Mark-BW fuel design. The staff performed an audit calculation with FRAPCON-3.2 using the same input, and FRAPCON-3.2 predicted similar results as COPERNIC.

Based on the similar results, the staff concludes that the fuel rod internal pressure analysis is acceptable for the COPERNIC MOX code to a peak rod average burnup of 50 GWd/MThm.

3.6 Clad Strain

Chapter 4.2 of the SRP establishes that the 1 percent strain limit should be used for normal operation and anticipated operational occurrences. FANP provided a clad strain analysis of a Mark-BW fuel design. The staff performed an audit calculation with FRAPCON-3.2 using the same input. The results showed that FRAPCON-3.2 predicted a slightly lower threshold than COPERNIC in reaching the 1 percent strain limit. The staff considers that the difference has little impact in the safety analyses because of the code conservatism and very limited irradiated strain data.

Based on the conservative mechanical models and compatible results, the staff concludes that the cladding strain analysis is acceptable for the COPERNIC MOX code to a peak rod average burnup of 50 GWd/MThm.

3.7 Stored Energy

FANP uses the COPERNIC MOX code to calculate initial fuel stored energy for LOCA analyses to verify that the MOX fuel design meets the requirements of Appendix K to 10 CFR Part 50. The fuel stored energy is approximately proportional to the fuel volume-average temperature.

The staff uses prediction-to-measurement comparisons at LHGR levels for LOCA stored energy calculations to estimate uncertainty including standard deviation in fuel performance codes. The uncertainty is then applied to code predictions to obtain a conservative stored energy prediction at a 95/95 tolerance level (bounding 95 percent of the measured data with a 95 percent confidence) for LOCA analyses. The staff used the FRAPCON-3.2 code to compare the results from the COPERNIC code for stored energy calculations to a peak rod average burnup of 50 GWd/MThm.

All fuel performance codes with UO_2 fuel examined by the staff, including the FRAPCON code, have a standard deviation equivalent to 6 to 8 percent. The 6 to 8 percent standard deviation is consistent with the standard deviation of the measured UO_2 fuel rod powers. FANP demonstrated that the COPERNIC code predicted best-estimate, i.e., small standard deviation, fuel centerline temperatures for the Halden MOX irradiated data. The COPERNIC code has a smaller standard deviation for the MOX data than for the UO_2 data. The COPERNIC code predicted small standard deviation on the MOX data may be attributed to two different reasons: (1) the LHGRs of the majority of the MOX data are low resulting in low measured temperatures, and (2) the number of irradiated MOX fuel rods is much smaller than the number of irradiated UO_2 fuel rods.

A comparison between predicted and measured fuel temperatures at a 95/95 tolerance level from these irradiated MOX data showed that the COPERNIC code slightly underpredicted fuel temperatures. The COPERNIC fuel temperature uncertainty performance is consistent with the audit code FRAPCON-3.2 behavior in that both codes slightly underpredict the data at a 95/95 tolerance level. The staff recognizes that the MOX fuel has a smaller data base than the UO_2 data base. In order to compensate for the smaller data base and the underprediction, FANP opted for a conservative approach using a large fuel uncertainty from the UO_2 data base for the MOX fuel stored energy calculations (Reference 18). Based on the small data base and conservative treatment of uncertainty, the staff accepted this conservative approach to address the under prediction.

Based on the best-estimate performance and a conservative approach to the 95/95 tolerance, the staff concludes that the stored energy analysis for LOCA initial conditions is acceptable for the COPERNIC MOX code to a peak rod average burnup of 50 GWd/MThm.

4.0 CONCLUSION

The staff has reviewed the FANP MOX fuel rod performance in Chapter 13 of the COPERNIC code of BAW-10231P. Based on the staff's review, as supplemented by its contractor's, PNNL, review and evaluation, the staff concludes that the COPERNIC code is acceptable for MOX fuel licensing applications up to a WG Pu content of 6 wt% and a peak rod average burnup of 50 GWd/MThm. Future staff reviews involving MOX fuel design, for example, BAW-10238(P) Revision 1, entitled "MOX Fuel Design Report," may result in additional restrictions on the licensing applications of the COPERNIC code.

5.0 REFERENCES

1. Framatome Cogema Fuels. July 31, 2000. *COPERNIC Fuel Rod Design Computer Code, Chapter 13 MOX Application.* BAW-10231P, Framatome Cogema Fuels, Lynchburg, Virginia, transmitted by letter, T. A. Coleman (Framatome Cogema Fuels) to U.S. NRC Document Control Desk, "Topical Report BAW-10231P, COPERNIC Fuel

Rod Design Computer Code, Chapter 13 MOX Applications," dated September 16, 1999, GR00-088.doc.

2. Framatome Cogema Fuels. September 1997. *COPERNIC Fuel Rod Design Computer Code*. BAW-10231P, Framatome Cogema Fuels, Lynchburg, Virginia, transmitted by letter, T. A. Coleman (Framatome Cogema Fuels) to U.S. NRC Document Control Desk, "Topical Report BAW-10231P, COPERNIC Fuel Rod Design Computer Code," dated September 16, 1999, GR99-191.doc.

3. Framatome Cogema Fuels. *COPERNIC Fuel Rod Design Computer Code, Chapter 12 Application Methodology (United States)*. BAW-10231P, Framatome Cogema Fuels, Lynchburg, Virginia, transmitted by letter, Stewart Bailey, NRC, to T. A. Coleman, Framatome Cogema Fuels, *- COPERNIC Fuel Rod Design Computer Code, Chapter 12 Application Methodology (United States)* Topical Report BAW-10231P, December 2, 1999, GR99-234.doc.

4. Letter, Stewart Bailey (NRC) to T. A. Coleman (Framatome ANP), "Request for Additional Information - Chapter 13 of Framatome Topical Report BAW-10231P (TAC No. MA9783)," May 14, 2001.

5. Letter, Drew Holland (NRC) to James Mallay (Framatome ANP), "Request for Additional Information - BAW-10231P, Chapter 13, COPERNIC MOX Applications, Fuel Rod Design Computer Code," dated April 25, 2002.

6. Letter, James Mallay (Framatome ANP) to NRC Document Control Desk, "Partial Response to RAI," NRC:01:033, July 27, 2001.

7. Letter, James Mallay (Framatome ANP) to NRC Document Control Desk, "Partial Response to RAI on Chapter 13 of BAW-10231P," NRC:02:021, April 26, 2002.

8. Letter, James Mallay (Framatome ANP) to NRC Document Control Desk, "Partial Response to RAI on Chapter 13 of BAW-10231P," NRC:02:038, July 17, 2002.

9. Berna, G.A., C.E. Beyer, K.L. Davis and D.D. Lanning. 1997. *FRAPCON-3: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup*. NUREG/CR-6534 (PNNL-11513) Vol. 2. U.S. Nuclear Regulatory Commission, Washington, D.C.

10. Lanning, D.D., C.E. Beyer and C.L. Painter. 1997. *FRAPCON-3: Modifications to Fuel Rod Material Properties and Performance Models for High-Burnup Applications*. NUREG/CR-6534 (PNNL-11513) Vol. 1. U.S. Nuclear Regulatory Commission, Washington, D.C. 20555-0001.

11. Lanning, D. D. and C. E. Beyer. 2002. "Proposed FRAPCON-3 MOX Fuel Thermal Conductivity Model Compare to Halden Fuel Temperature Data," *Presented at Enlarged Halden Program Meeting, September 8-13, 2002*.

12. Duriez, C., J.P. Allesandri, T. Gervais, and Y. Philipponneau. 2000. "Thermal Conductivity of Hypostoichiometric Low Pu Content (U,Pu)O_{2-x} Mixed Oxide." *Journal of Nuclear Materials* 277:143-158.

13. Lanning, D.D., C.E. Beyer, and M.E. Cunningham. 2000. "FRAPCON-3 Fuel Rod Temperature Predictions with Fuel Conductivity Degradation Caused by Fission Products and Gadolinia Additions," in *Proceedings of the ANS International Topical Meeting on Light Water Reactor Fuel Performance, Park City, Utah, April 2000,* pages 261 to 274.

14. Lanning, D. D. and C. E. Beyer. 2001. "Assessment of Recent Data and Correlations for Fuel Pellet Thermal Conductivity," *Presented at Enlarged Halden Program Meeting March 11-16, 2001*, HPR-356.

15. American Nuclear Society (ANS). 1982. *Method for Calculating the Fractional Release of Volatile Fission Products from Oxide Fuel,* ANSI/ANS-5.4-9182. ANS 5.4 of the Standards Committee of the American Nuclear Society.

16. Forsberg, K. and A. R. Massih. 1985. "Diffusion Theory of Fission Gas Migration in Irradiated Nuclear Fuel UO_2," *J. of Nucl. Mater.*, Vol. 135, pp. 140-148.

17. Regulatory Guide 1.126, Revision 1, "An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification," 1978.

18. Letter, James Mallay (Framatome ANP) to NRC Document Control Desk, "Final Responses to RAIs on Chapter 13 of BAW-10231P," NRC:03:027, April 18, 2003.

Attachment: Resolution of Comments

Principal Contributor: S. Wu

Date: January 14, 2004

RESOLUTION OF COMMENTS

ON DRAFT SAFETY EVALUATION EVALUATION FOR BAW-10231, "COPERNIC

FUEL ROD DESIGN CODE" CHAPTER 13, MOX APPLICATIONS

By letter dated December 4, 2003, Framatome ANP (FANP) provided comments on the draft safety evaluation (SE) for BAW-10231, "COPERNIC Fuel Rod Design Code," Chapter 13, MOX Applications. The following is the staff's resolution of those comments.

1. FANP Comment: Section 1.0, first paragraph, fourth sentence states, "Currently, there are two types of PuO_2 in MOX fuel designs used in commercial nuclear reactors: reactor-grade PuO2 fuel and WG PuO_2 fuel."

   FANP Proposed Resolution: Weapons-grade fuel is not currently used in commercial nuclear reactors. Framatome ANP suggests rewording this sentence to: "Currently, there are two types of PuO_2 in MOX fuel designs."

   NRC Action: The staff considers it necessary to point out that WG PuO_2 is the fuel material discussed in the report. To avoid confusion, reactor grade PuO_2 is not mentioned in the safety evaluation.

2. FANP Comment: The units for burnup for MOX fuel used throughout the SE are indicated as GWd/MTU.

   FANP Proposed Resolution: The units for burnup for MOX fuel should be indicated as GWd/MThm (gigawatt days per metric tonne of initial heavy metal).

   NRC Action: This comment was fully adopted in the final SE

3. FANP Comment: Section 1.0, second paragraph, last sentence states, "However, the staff notes that the MOX irradiated data provided by FANP and audit verifications are only up to a peak rod average burnup of 50 GWd/MTU."

   FANP Proposed Resolution: Data provided by FANP exceeded peak rod average burnup of 50 GWd/MThm in numerous instances. The original submittal, BAW-10231, Rev. 0, pages 5-48 and 5-49 (and pages 9-34 and 9-35), identifies six MOX data points in excess of 50 GWd/MThm.

   FANP suggested that this sentence state: "To support this request, FANP provided MOX irradiated data, including audit verifications, to peak rod average burnups extending to 63 GWd/MThm."

   NRC Action: This comment was addressed in the final SE, but not exactly as requested. The following wording was used: "Although FANP obtained some data beyond 53 GWd/MThm, the staff review and audit verifications are only up to a peak rod average burnup of 50 GWd/MThm. The staff considers that since this fuel will be irradiated for a maximum of two fuel cycles, 50 GWd/MThm will be sufficient. This conservative limitation is appropriate after considering the applicable data and audit calculations."