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Additional Information for the Review of BAW-10247(P), "Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors"

Ref. 1: Letter, James F. Mallay (FANP) to Document Control Desk (NRC), "Request for Review and Approval of BAW-10247(P), 'Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors'," NRC:04:047, August 19, 2004.

Framatome ANP requested the NRC's review and approval of the topical report BAW-10247(P), 'Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors' in Reference 1. This letter provides additional information to support the review.

During preparation of the RODEX4 code for transmittal to the NRC, a number of errors were identified in the code. The majority of the errors had no significant impact. The correction of one of the errors resulted in a need to retune the model in order to preserve the accuracy of the benchmarks.

The initial error identified was related to the use of an uninitialized variable. In response to the identification of this error, a detailed review of all of the source code was performed using a static source code analysis tool. This additional investigation identified a number of additional minor code issues.

A description of the code errors and the impact of correcting the code errors and retuning the code are provided in Attachment A to this letter. A proprietary and a non-proprietary version of the attachment are provided.

Framatome ANP considers some of the information contained in the attachments to this letter to be proprietary. The affidavit provided with the original submittal of the reference report (Reference 1) satisfies the requirements of 10 CFR 2.390(b) to support the withholding of this information from public disclosure.

Sincerely,

Ronnie L. Gardner

Ronnie L. Gardner, Manager
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cc: D. G. Holland
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Attachment A

Revisions to RODEX4 and BAW-10247(P)

1.0 Introduction

The RODEX4 code has been modified to correct errors identified while preparing the code for transmittal to the NRC to support the RODEX4 review. The majority of the errors had no significant impact. The correction of one of the errors resulted in a need to retune the model in order to preserve the accuracy of the benchmarks.

The initial error identified was related to the use of an uninitialized variable. In response to the identification of this error a detailed review of all of the source code was performed using a static source code analysis tool. This additional investigation identified a number of additional code issues.

A number of changes to the code and the benchmark data base were also made which are unrelated to the recently identified code errors. These items have a negligible impact on the code results. Since changes to the code were being made to correct the recently discovered errors these items were also changed for convenience.

A description of the changes and the impact on the benchmark results is provided below.

2.0 Changes

2.1 Recently Identified Error Corrections

1. There was an array dimension inconsistency in an argument being passed to the Cesium release model subroutine. The correction of this problem increased significantly the calculated cesium release from the pellet. Since cesium release affects fuel solid swelling, this correction contributed to decrease solid swelling.

   The change in solid swelling due to the correction mentioned above required an adjustment of the fuel densification and cladding axial growth parameters of the Framatome ANP fuel in order to maintain the fission gas release and rod axial elongation predictions as given by the original code.

2. A non-initialized variable was being used in the calculation of the power depression factors for Gadolinia fuel.

3. A missing term in the fuel specific heat calculation was corrected.

2.2 Additional Code Changes

1. The default value of the Corrosion Enhancement Factor of CWSR Zircaloy-2 was changed from [ ]. Note that the benchmark test cases explicitly set this value and the use of the default option was not exercised.

2. The wrong units were being printed for the radial size of chips in the rod characterization routine. The printed value was correct but the units were being printed as mm instead of μm.

3. The subroutines which calculate the transient temperature distribution in the pellet assumed the pellet inner radius to be zero. The routines were modified to make them applicable to annular pellets.

4. The fuel enthalpy is calculated using a correlation and the coefficients applied for Gd_2O_3 were initially set identical to the UO_2 values to prevent the possibility of non-conservative enthalpies being obtained for gadolinia fuel at high temperature. The coefficients were reset to values appropriate for Gd_2O_3.

5. Updates were made to the subroutine which calculates the specific heat of the fuel to include the stoichiometric ratio which was included in the reference model for this subroutine. Two conversion constants (universal gas constant and the fuel density used to convert from J/(kg-K) to J/(m^3-K)) used in this routine were modified slightly to make them consistent with the values used in the remainder of the code.

6. The function which calculates the specific heat of Zircaloy used a correlation based on recent measurements but that was not consistent with the Zircaloy enthalpy and specific-heat models present in the remainder of the code. This model was updated to be consistent with the Zircaloy enthalpy and specific heat models.

7. The Zircaloy enthalpy routine was found to be using enthalpy values which were inaccurate at temperatures above 1213 K. The enthalpy table was updated to provide accurate values up to 2098 K.

2.3 Database Changes

Since August 2004 minor updates have been made of the RODEX4 validation database. One fuel rod was corrected to insure the gas fractions sum to 100 percent. The database was also updated because the new axial growth parameters mentioned above are stored in the database. The only other change was the use of the recent rod puncture results (instead of Kr-85 γ-scan results) for the determination of the fission gas release in H.B. Robinson high burnup rods. None of these changes had any significant impact.

3.0 Impact on Results

The impact of all the changes in total is deemed to be inconsequential. The calculational impact on the major fuel performance models is summarized in Table 4.1.

4.0 Submittal Document Updates

Because the impact of all the RODEX4 code errors is deemed to be inconsequential, the conclusions drawn in the previously provided NRC submittal document, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, BAW-10247(P), Rev 0, August 2004, remain valid. However, some of the scatter plots and some values in selected tables do show small differences. The plots which do show differences are attached.

The affected figures and tables in the topical report will be corrected when the approved version of the topical report is issued.

Table 4.1

Fuel Specific Heat	The fuel specific heat model has been made consistent with the fuel enthalpy model, which slightly reduces the fuel temperatures in the transient calculations.
Zircaloy Specific Heat	The zircaloy specific heat model has been made consistent with the zircaloy enthalpy model, which also has some small affects on the fuel temperatures in the transient calculations.
Fission Gas Release	The general agreement between the measurement results and the code predictions is unchanged (see Figures 1 and 2). The mean values of log(C/M) for the commercial database are: log(C/M) = 0.0075 with *original code* log(C/M) = 0.0020 with *corrected code* The change of the mean value of log(C/M) for the Commercial Database is less than 1%.
Fuel Centerline Temperature	Minor differences are observed but the general agreement between the measurement results and the code prediction is unchanged (see Figures 3 and 4). The mean C/M, the standard deviation and the mean quadratic deviation are respectively: Mean C/M 1.000 K/K *original* and 1.000 K/K *corrected* Standard Dev. 0.029 K/K *original* and 0.029 K/K *corrected* Quadratic Dev. 36.8 K *original* and 37.0 K *corrected*
Cladding Deformation	The agreement between the measured and calculated rod profilometry measurements is unchanged (see Figures 5 through 7). The cladding deformations during the ramp obtained with the two code versions are similar.

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Figure 1 Fission Gas Release – International Database

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Figure 2 Fission Gas Release – Commercial Database

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Figure 3 Halden Temperature Database – Fuel Centerline Temperature

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Figure 4 Halden Temperature Database - Temperature Deviation

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Figure 5 Mark-BEB Rod 65-2 – Rod Diameter at Mid-Pellet

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Figure 6 Mark-BEB Rod 65-2 - Rod Diameter at Pellet End

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Figure 7 Mark-BEB Rod 65-2 - Diameter Increase