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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT BAW-10228P, "SCIENCE"

FRAMATOME COGEMA FUELS, INC.

1.0 BACKGROUND

BAW-10228P describes the SCIENCE code package submitted for review by Framatome Cogema Fuels, Inc., (FCF) for use in nuclear analysis of pressurized-water reactor (PWR) cores (Reference 1). SCIENCE is an integrated system of codes specifically designed for performing nuclear analysis of PWRs. The SCIENCE code package consists of core physics tools that are two-dimensional (2D) lattice calculations and three-dimensional (3D) core calculations and data manipulation codes. The SCIENCE code package consists of the codes APOLLO2-F, SMART, and COPILOTE.

The APOLLO2-F and SMART codes contain the physical description (models) of the SCIENCE code package, while COPILOTE serves as the interface between the user and the two physics codes, permitting sequencing and submittal of the calculations through interactive graphical interface.

2.0 TECHNICAL EVALUATION

2.1 Model Description

The underlying function of the SCIENCE code package is the linking of the major core physics codes, APOLLO2-F and SMART. APOLLO2-F calculates the parameters that are required by the SMART code. These parameters are the cross sections and the discontinuity factors, as well as the pin-to-pin reconstruction parameters (Reference 2).

For each type of composition, the parameters generated by the APOLLO2-F code are placed in data files referred to as "data libraries." The data libraries contain information regarding the dependence of these parameters on feedback system variables, such as burnup, xenon, soluble boron, moderator density, fuel temperature, and spectral effects (Reference 3). These libraries are generated in three steps:

- First, APOLLO2-F performs fuel depletion calculations and stores the data as depletion files. The stored data from the fuel depletion calculations account for the heterogeneity of the assembly under normal (reference) conditions and perturbed conditions. The perturbed condition is signified in this case by a change in the water density, thus indicating the spectral differences between actual conditions in the core and the normal reference core depletion.

- Second, APOLLO2-F takes the results of the depletion calculations and uses them to initialize the isotopic concentrations for new calculations in which one or more physical state variables of the assembly are modified with respect to their initial value(s). These calculations are typically referred to as restart calculations. Some of the variables are xenon level, moderator density, fuel temperature, and a variable that is representative of the control rod presence. All this generated data, representing numerous conditions that the assembly may encounter during the cycle depletion in the core, are placed in "restart" files for use by the SMART code.

- Third, APOLLO2-F creates two data files for each type of fuel. One file contains cross sections and discontinuity factors and the other file contains reconstruction data (pin-by-pin power distribution and burnup). These files form the libraries that contain parameters that are a function of the state variables, such as boron and xenon concentrations, burnup, moderator density, spectral history, fuel temperature profile, and control rod locations.

The fuel assembly is numerically fitted and geometrically represented by dividing the fuel assembly into cubic regions to account for all the possible variations that go into making up the assembly. These variations are represented by polynomial expansions, utilizing determined polynomial coefficients to reproduce the assembly parameters calculated by the APOLLO2-F restart calculations at the fitting point.

2.2 Description of Codes

APOLLO2-F is an assembly lattice code developed by the Commissariat a l'Energie Atomique and modified by FCF for its design needs. It solves the 99-group transport equation for an assembly geometry and furnishes the homogenized two-group cross sections for the SMART code. The transport equation is solved using the integral-differential equation form that is discretized based on the collision probability method. FCF pointed out that a coupling of the regrouped multicell calculation and the six-group homogeneous calculation permits a good compromise between accuracy and calculation cost.

This coupling is provided by heterogeneous/homogeneous equivalence functions contained in the code. The assembly calculations can be carried out on various geometries (one-eighth of an assembly, one-fourth of an assembly) with different boundary conditions and symmetry. A sophisticated self-shielding model is applied to the cross sections in order to correctly take resonances into account. The flux calculations can be performed with a search for critical buckling to obtain proper spectral weighting. APOLLO2-F contains a fuel depletion module. The reflector constants (radial or axial) are generated from one-dimensional (1D) APOLLO2-F calculations using the code's S_N option.

The SMART code solves the two-energy group diffusion equation for the core geometry under static or kinetic conditions. It solves a neutron balance equation using the average flux and provides the core power distributions for assemblies and also for each pin (on a pin-by-pin basis) in every assembly. The nodal expansion method is used to solve the neutron balance equation. It is based on a coupling between a coarse mesh finite difference calculation and a calculation of the neutron current at each interface.

The calculation of the nodal currents is performed by solving a 1D diffusion equation at each calculation node interface. The solution for the adjustment of the nodal currents is obtained by making assumptions of the fast and thermal neutron flux shapes on both sides of the interface and building a system of equations that can be solved directly. This solution is referred to as the "two-node" problem. The accuracy of the process is improved by using discontinuity factors, quadratic transverse leakage, and burnup gradients within the node. The burnup and spectral effects are modeled using a microscopic fuel depletion model.

The main depletion chains for the heavy nuclei and the main fission products are explicitly treated by SMART. The two energy group microscopic cross sections required to calculate isotopic depletion are obtained from data generated by the APOLLO2-F code. The microscopic cross sections and the isotopic densities resulting from the depletion calculations provide the macroscopic cross sections for the flux solution. The microscopic cross sections are stored in "multi-parameterized" data libraries from which the core calculation interpolates, depending on the local node conditions. A set of seven parameters is selected for cross section dependency: burnup, boron concentration, xenon, moderator density, fuel temperature, a spectral history parameter, and a control rod presence parameter. The SMART code calculates fuel pin information for power and burnup and reaction rates in the instrument tube by means of a pin reconstruction algorithm. The SMART code also solves the time-dependent two-energy group diffusion equation for 3D core geometry.

COPILOTE is an operating environment rather than a conventional calculational computer code. It is the graphical user interface by which the user processes input and output, controls the flow of data from one code to another, and displays the status of the calculations.

2.3 Measurement Comparisons

In Section 4 of the submittal, FCF provided numerous examples comparing the results of APOLLO2-F and the SMART code with measurement data. The data were collected from six reactors (Three Mile Island Unit 1, Oconee Units 1 and 2, McGuire Unit 1, Gravelines Unit 5, and Sequoyah Unit 1). These cores were selected on the basis of obtaining a wide variety of conditions, such as the type of burnable poison, fuel enrichment, loading patterns, and control rod patterns. Reactivity predictions versus core burnup, control rod worth, reactivity coefficients, and power distributions were provided (on a local and global basis) and compared to measured data from operating PWRs.

The agreement between measured data and SCIENCE prediction is generally very good. The SCIENCE results were just as good or better than prior FCF licensed codes predictions. The uncertainties for single bank worths and total bank worths that are supported by the data presented are 15 percent and 10 percent, respectively. Previous FCF methodology (Reference 1) contained a bias difference between the 15x15 and the 17x17 bank worth results. This bias difference was again observed in the SCIENCE methodology. The cause of the bias is due to the different sources of the measured results. The 15x15 data were obtained exclusively from B&W plants. Nearly all of the 17x17 data were obtained from other vendors using various measurement techniques (Reference 4).

Good agreement was achieved for ejected rod worths, critical boron concentrations, temperature coefficients, and power Doppler coefficients. In addition, review of the data shows that SCIENCE accurately predicts the core total peak and radial power peak. The nuclear reliability factors (NRFs) that SCIENCE uses to adjust the predicted local and global power distribution, were found to be less than those previously established NRFs provided in Reference 1. The staff agrees with the presented results.

2.4 Qualification Methods for Future Modifications to the Science Code Package

FCF intends to periodically update the SCIENCE code package to incorporate the latest analytics and computation techniques. Consequently, any code development or improvement of the SCIENCE code package would necessitate benchmarking and validating the SCIENCE code package to ensure that any new feature(s) implemented will produce results in keeping with a standard set of qualification criteria as stated in the submitted Topical Report BAW-10228P.

The method to be used to qualify SCIENCE for future changes is similar to the method presented in this submittal and previous topical report submittals. This method will require that neutron code qualification be based on the ability of the modified SCIENCE code package to predict several key neutronic parameters. Some of these parameters are critical boron or k-effective at hot zero power, critical boron or critical k-effective at hot full power, individual bank rod worths, total rod worths, ejected rod worths, isothermal temperature coefficients, power Doppler coefficients, hot pin power, and hot pellet power (see Table 5.1 of References 1 and 3). These parameters will be recalculated with the modified SCIENCE code package and compared to measured results and new statistics generated along with their associated uncertainties. Subjecting the modified code package to the listed criteria will emphasize the contributions of the implemented features to the code package rather than highlight the differences between the two code packages. Consequently, any modifications to the SCIENCE code package that meet the listed criteria in Tables 5-1 and 5-2 of this submittal will validate the modifications made to the SCIENCE code package. If the changes to the SCIENCE code package meet the criteria, FCF will internally document the changes to the code package and the associated results without notifying the NRC since there were no changes to the uncertainties or their application. However, if changes to the uncertainties occur, FCF will submit supporting documentation to the NRC whenever the method changes affect the uncertainties to be applied in licensing applications.

The methodology and the data provided in this submittal, Topical Report BAW-10228P, form the basis for the current SCIENCE code package. Future application of the current SCIENCE code package to data not provided in this topical report (such as new fuel designs) will require revalidation of the SCIENCE code package.

2.5 Range of Applicability of Benchmarking

The chosen benchmarks in this topical report include the types of fuel and poison that are typically licensed. The data presented in this topical report are sufficient to qualify the SCIENCE code package for the typical fuel types listed in this submittal. If a new fuel design is used that contains materials (poison, mixed oxide fuel and/or hafnium control rods, etc.) outside this collection of benchmarks, additional benchmarks will have to be established. In

accordance with its agreement, (Reference 4), FCF will submit to the NRC staff a description of the new design feature, the new benchmarks, and any impact on the current uncertainty factors.

3.0 CONCLUSION

The staff has reviewed the analyses in Topical Report BAW-10228P, "SCIENCE," and finds it acceptable for licensing applications, subject to the following conditions in accordance with FCF's agreement (Reference 4) :

1. The SCIENCE code package shall be applied in such a manner that predicted results are within the ranges of the validation criteria presented in Table 5-1 and the measurement uncertainties presented in Table 5-2.

2. Fuel designs to which the SCIENCE code package will be applied shall be within the validation bases of BAW-10228P. The bases of BAW-10228P are considered valid for the following conditions:

   - 15x15 or 17x17 UO2 fuel designs.
   - U235 enrichments less than or equal to a maximum of 5.0 w/o.
   - Gadolinia loadings less than or equal to 8.3 w/o (nominal 8.0 w/o).

3. The following uncertainties shall be applied to the SCIENCE code package results:

   - Maximum pin peaking uncertainty of 3.8 percent.
   - Maximum pellet peaking uncertainty of 4.8 percent.
   - Total rod worth uncertainty of 100 percent.
   - Bank rod worth uncertainty of 15 percent.

4. The SCIENCE code package shall only be used for PWR licensing analyses by FCF unless approved by the NRC for use by other organization.

4.0 REFERENCES

1. Letter from T. A. Coleman, Vice President of Government Relations, Framatome Cogema Fuels, Inc., to the NRC, regarding the submittal of the SCIENCE code package, dated October 12, 1998.

2. R. Sanchez, J. Mondot, Z. Stankowski, A. Cossic, and I. Zmijarevic, "APOLLO2-F: A User-oriented, Portable Modular Code for Multi-group Transport Assembly Calculations." International Topical Meeting on Advances in Reactor Physics, Mathematics and Computation, Paris, France, April 27-30, 1987.

3. R. Sanchez and M. Vergain, "An Acceleration Procedure for the Iterative Solution of the Flux Current Equations in the APOLLO2-F Code." International Topical Meeting on the Physics of Reactors: Operation and Design Computation, Marseilles, France, PHYSOR 90, April 23-27, 1990.

4. Letter from T. A. Coleman, Vice President of Government Relations, Framatome Cogema Fuels, Inc., to the NRC, regarding the submittal of Topical Report BAW-10228P, "SCIENCE", dated September 23, 1999.

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