Evaluation of Babcock and Wilcox Topical Report

BAW-10123

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Reviewed by: Core Performance Branch/W. Brooks

The Power Generation Group of Babcock and Wilcox has submitted licensing Topical Report BAW-10123 entitled "Nuclear Applications Software Package" for our review. This report provided a brief description of the incore detector system hardware and a detailed description of the software employed to obtain neutronic and thermal-hydraulic parameters for the current generation Babcock and Wilcox designed cores having 205 fuel assemblies. It is one of a series of topical reports which have been submitted by Babcock and Wilcox in order to provide the staff with generic information on the nuclear design of B&W reactors and to facilitate the review of such designs. Our evaluation of this report follows.

1. Summary of Report

The report consists of three main sections (1) a brief description of the incore system hardware, (2) an extended description of the nuclear software, and (3) a description of the thermal-hydraulic software. In addition an appendix describes the curve fitting techniques employed in the software.

The current generation cores contain 62 incore detector assemblies each of which consists of seven detectors distributed uniformly over the axial dimension of the fuel assembly. Each detector is approximately 4.75 inches in active length and is a self-powered neutron detector. Thus 434 discrete values of neutron flux - distributed over the core - are measured. In addition to the self powered neutron detectors each assembly contains a background detector and a thermocouple located just above the fueled portion of the assembly.

Each self-powered neutron detector consists of a high purity rhodium emitter (4.75 inches long) which is attached to a zirconium leadwire and enclosed in an inconel sheath which is filled with a ceramic insulator. The leadwire and sheath form a coaxial cable which extends through the bottom of the pressure vessel to a pressure connectors through which leads pass to the signal processing equipment. The signal is produced by neutron activation of the rhodium -103 to rhodium -104 which decays by beta (electron) emission. Some fraction of the electrons have sufficient energy to traverse the insulator and be absorbed in the sheath. The rhodium is thus left with a positive potential. Connecting the lead wire and sheath through an external resistor produces a voltage which is proportional to the flux at the detector site.

The function of the software package is to convert the detector current readings to power in the assembly segments which are instrumented and to construct a core power distribution. After this various characteristics of the power distribution (e.g., axial offset and quadrant power tilt) are obtained. This function is accomplished in several steps, as follows.

1. The detector signals are corrected for leakage, background (due to gamma irradiation), and rhodium depletion to obtain instrument independent signals (i.e., the signal that would be produced by an ideal, undepleted detector).

2. The detector signals are converted to instrumented assembly segment powers. This is done in two steps - detector signal to power in the eight surrounding rods, and finally to power in the assembly segment.

3. The segment powers are expanded to obtain powers in uninstrumented assemblies. Thus a core power distribution is obtained.

4. The core power is normalized to the core heat balance.

5. Data are provided to the thermal-hydraulic software for calculation of thermal parameters (e.g., channel flow and DNBR).

6. Core parameters for use in comparing to limiting conditions of operation and for core follow are calculated.

7. Certain quantities such as core reactivity balances and xenon worths are calculated on demand by the operator.

Each of these steps is discussed in detail. Calculational algorithms are presented and discussed. The various options present in the calculational stream are given and the criteria for choice of options presented. For example, the manner of substituting readings for defective detectors depends on the number of good detectors in the string. Likewise, the choice of the manner in which the power in non-instrumented assemblies is inferred depends on whether a significant quadrant tilt exists in the core.

2. Summary of Evaluation

We have reviewed the description of the nuclear and thermal-hydraulic software package presented in topical report BAW-10123. The following comments summarize our evaluation.

The self powered nuclear detectors have been thoroughly tested and have been used in operating reactors by Babcock and Wilcox and others for several years. This use has demonstrated their acceptability for relative power measurements in reactors. The correction applied to the output current to account for detector depletion has been experimentally determined to be accurate. Corrections for leakage are determined in place. The presence of a background detector in the incore instrument string permits accurate corrections for background gamma effects to be properly accounted for.

The technique of performing the conversion from detector signal to segment power in two steps is industry-wide practice and is acceptable. The ratio of power in the eight immediately surrounding rods to detector signal is computed for a base case enrichment for each fuel design.

Transport theory is used to perform the conversion. Correction factors are then applied to account for the variations from the base case of fuel enrichment, xenon concentrations, soluble boron concentration, precent burnup of the detectors, moderator temperature, power history, and presence of lumped burnable poison or control rods. Each of these factors is determined as a function of core burnup. The use of transport theory for this calculation is state-of-the-art and is acceptable. The correction factor technique is widely used in the industry and is acceptable.

Conversion from the eight-rod power to full assembly segment power is carried out in a similar manner except that the various factors are calculated with diffusion theory rather than transport theory. This is consistent with design practice and is acceptable. The powers in uninstrumented assemblies are obtained one level at a time. For each level the quadrant tilt is determined. If it is below some low preset value the power in uninstrumented assemblies is simply set equal to that in symmetric instrumented assemblies. If the tilt is greater than the preset value a surface spline fitting routine is used to obtain the uninstrumented values. The spline is a two-dimensional interpolating polynomial based on the small deflection equation for an infinite plate. The symmetric portion of the power distribution is taken out by averaging the detector signals for each symmetric ring of detectors. The fit is then made to the departure from average of the signals. In this manner the effect of uncertainties in the fit are minimized. This fitting procedure is state-ofthe-art and is acceptable.

After the core power distribution is obtained at the seven detector levels final adjustments are made to account for the presence of any misaligned control rods and for any asymmetries present in the fuel or lumped burnable poison loadings. These adjustments are in the form of multiplication factors which are precalculated by design methods and stored in the computer. Such correction factors are small and design method calculations are suitable and acceptable. The segment powers in each assembly are determined by axially spline fitting a curve through the detector level segment powers and the spline fit is integrated over each segment length to obtain 205-by-7 segment powers The sum of these segment powers is then normalized to the power from the system heat balance. The spline fitting technique is a commonly used one and is acceptable. After the power normalization has been performed the axial offset and quadrant tilt are calculated in a straightforward manner using the spline fitted axial distributions and the integrated assembly powers respectively. The algorithms used in the calculation derive directly from the defintion of the two quantities and are acceptable.

The calculations of the various core and segment parameters needed for the major calculations - core and segment burnups, energy conversion factors, average flux, fission cross-section, and xenon and iodine calculations are straightforward application of standard techniques and are acceptable. The algorithms used to calculate the thermal hydraulic quantities - linear heat generation rate and departure from nucleate boiling ratio (DNBR) are straightforward and acceptable. Appropriate uncertainties are applied to the best estimates calculated values to arrive at values to be compared to limits. The BAW-2 critical heat flux correlation, which has been accepted by the staff, is used in the DNBR calculation.

3. Evaluation Procedure

The review of topical report BAW-10123 has been conducted within the guidelines provided by the Standard Review Plan, Section 4.3. Sufficient information has been provided to permit the conclusion that the measurement and analysis techniques employed by the Nuclear Applications Software Package are state-of-the-art and are acceptable.

4. Regulatory Position

Based on our review of licensing topical report BAW-10123 we conclude that it is acceptable for reference in licensing actions with respect to the description of the incore detector sysem for 205 fuel assembly plants and for the description of the algorithms and techniques employed in the various calculations employing this system.