ADVANCED CORE MONITORING TECHNOLOGY FOR VVER REACTORS

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INTRODUCTION

Traditional VVER reactors use Rhodium fixed incore detectors as the mean to provide detailed core power distribution for surveillance purposes. Typically, the power-to-reaction-rate constants are generated by standard physics method and include pre-determined constants based on fixed core conditions. With the advancements of numerically efficient neutronic solver and workstation technology, a total *online core monitoring* and plant operation support package can be developed to provide both surveillance and streamlined plant operation.

1. BASIC BEACON CORE MONITORING METHODOLOGY

The BEACON online core monitoring system has been developed to provide continuous core monitoring and operational support for pressurized water reactor using movable detectors (fission chamber) and core thermocouples. The system is in operation at nine reactors in the United States and in Korea. The basic methodology for inferring continuous power distribution is based on the following principles:

a. The neutronic model employed by BEACON (namely, SPNOVA (1)) is calibrated against the movable detector flux trace measurements. Once the calibrated power distribution is obtained, the excore detectors and thermocouples are cross-calibrated to match this calibrated power distribution. The calibration factors are used until the next movable detectors flux map is taken.

b. The BEACON online nuclear model is updated by following the actual reactor operation as closely as possible. Typically, once every fifteen minutes, the model is updated by integrating the actual core operating history (i.e., power, pressure, temperature, control rod position) using the calibrated power distribution in step (a).

c. On a continuous basis, the core power distribution is provided to the user by applying the information obtained from the excore detectors and thermocouples measurement. The thermocouples information is not used on an absolute basis. Rather, the deviation of the continuous thermocouple measurements from the cross-calibrated values is what used in this process. During normal operation, the deviation will be very small, as expected. It is only in abnormal situation, such as a dropped rod, that the deviation would be large. It is precisely this deviation that is of important to the operators of a power plant.

Using a very efficient numerical technique, the BEACON system provides not only complete, three-dimensional power distribution, but the system is also designed to provide complete plant operation support and strategy (2). For VVER reactors, the issue of axial xenon oscillation control is of particular interest (3). In the reference, it was reported that frequent xenon oscillations were experienced with the VVER-1000 reactor. Xenon oscillation as a minimum causes operational problems requiring frequent operator intervention to control the oscillation and this action increases the duty of the control mechanism of the reactor. In more severe cases, the oscillation can cause power reductions or plant trips due to high core peaking factors. To address the reported xenon oscillation issues, Westinghouse recommends an advanced core control strategy, namely XeMode, in conjunction with a well-established core power distribution control philosophy, Constant Axial Offset Control (CAOC), to resolve the situation. It was demonstrated that with these two recommendations, the xenon oscillation can be effectively controlled with minimal changes to the control system hardware/software (4).

2. ADAPTATION OF THE BEACON SYSTEM FOR FIXED INCORE DETECTORS

An effective continuous core monitoring system must be designed to address two key requirements: 1) routine surveillance and 2) anomaly detection. Due to the different demand/response requirements, the optimal solution for VVER reactors with existing fixed incore detector is an adapted version of the BEACON advanced core monitoring and support system.

Fixed incore detectors, such as Rhodium, is a good complementary measurement device for the BEACON system. With the relatively slow response of the Rhodium material (Rh-103 beta decay with a half-life of fifty six minutes), the Rh. detector system is a good system for routine surveillance of core peaking factors and power distribution. For fast anomalous event detection, quicker responding measurement system and methodology need to be in place to provide logical, fast and accurate information to the reactor operator. The Westinghouse BEACON system, being adapted to use both the Rh. detectors and the existing core exit thermocouples, ideally addresses both requirements. The present, fast-response, thermocouple-based BEACON power distribution methodology can be adapted easily using the Rh. detectors as a continuous calibration source to fulfill this need. Furthermore, with an accurate incore-based calibration system, the overall uncertainty can be kept to a minimum level. The overall system is being modified as follows:

a. Rh. Detector Cross Sections

Standard reactor physics package is used to develop the Rh. detector microscopic cross section and dependencies. A table look-up relating the dependencies of the Rh. detector microscopic cross sections as a function of detector fraction remaining, fuel assembly enrichment, boron, water density etc. would be used by the SPNOVA computer program to reconstruction the reaction rate online.

b. Depletion of the Rh. Detector Material

The SPNOVA computer program has been licensed with the same uncertainty as the core design code, ANC, for all core design related applications. The SPNOVA constructs the instrumentation thimble (IT) flux by combining the homogeneous intra-assembly flux shape with an heterogeneous flux factor derived from the heterogeneous two-dimensional transport lattice code. The segment-wise reaction rate is calculated based on the following expression:

$$RR(x,y,Z,E) = \phi\ (x,y,Z,E) * N * \sigma\ (x,y,Z,E)$$

where $\sigma(x,y,Z,E)$ = F(No, Enr., Boron, water density etc)
N = Detector Number Density

and the depletion of the detector material is expressed as:

$$N(x,y,Z,t) = N(x,y,Z,to) * e^{-\{\phi\ (x,y,Z,E)\ \sigma(x,y,Z,E)\ \Delta T\}}$$

Note that since the BEACON system can construct the entire reaction rate on a three-dimensional basis, there is no need to pre-generate the power-to-reaction-rate ratio based on some fixed core conditions.

3. Calibration Methodology

The fixed incore detector information can be used to compliment both the excore detectors and the thermocouples information on a frequent calibration basis. Radially, the fixed incore detector signal can be used in its entirety to replace the existing movable detector as the surveillance and calibration source. Instead of having the calibration performed on a one per month basis with the movable detectors, the BEACON system with fixed incore can be calibrated on a once a week basis. More frequent calibration can also be performed if the core has experienced significant perturbation. Axially, the fixed incore detector signal can also be used to completely substitute the movable detector for excore detector calibration.

4. Continuous Core Monitoring Technology With Fixed Incore Detectors

The three-dimensional predicted reaction rate is adjusted to the measured fixed incore detector reaction rate via a simple adaptive technique. The adaptive technique ensures matching the predicted data to the segmented and integrated reaction rates from the fixed incore detectors. From this measured reaction rates, the power distribution is constructed using standard procedure. Information required for calculating the XeMode parameters can easily be extracted from the inferred power distribution and represent highly accurate and detailed incore-based data for power distribution control purpose. On a continuous basis, the thermocouple and excore detectors' information will continue to be used for fast detection of anomaly or changes in core behavior. In addition, with the available fixed incore detector information, confirmation of the thermocouple behavior to determine its validity can be accomplished with simple signal validation technology. This will further reduce the online core monitoring uncertainty and reliance on the availability of the thermocouples for online power distribution monitoring.

SUMMARY

With the advent of advanced numerical method and workstation technology, continuous core monitoring and total plant operation support are a reality with the BEACON system. Using established physics technology in conjunction with the existing features of the BEACON system, adaptation of the system for fixed incore detectors is a relatively straight forward task. The resultant system will provide more flexibility and accuracy than traditional fixed incore detector technology.

REFERENCES

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