EXPERIENCE WITH FIXED IN-CORE DETECTORS AT SEABROOK STATION

Joseph P. Gorski and Richard J. Cacciapouti
Yankee Atomic Electric Co.
580 Main Street
Bolton, MA 01740

Abstract

A uniform set of analyses were performed at nearly 40 exposure points over four cycles of operation with the two independent in-core detector systems. Full in-core analyses for each set of data collected with both movable fission chambers and fixed self-powered platinum detectors show comparable results for peaking values. Statistics of predicted to measured signal differences are good. Compared to Cycle 1, the axial or three dimensional component of uncertainty is unchanged after four cycles of operation. Over the same time, the radial uncertainty has decreased slightly. The uncertainty values used in Technical Specification surveillance has remained constant. The results show the use of self-powered platinum detectors to be a complete and independent system with accuracy and functionality expected of an in-core detector system.

Background

A Fixed In-core Detector System was designed and developed at Seabrook Station [1] to determine incur power distributions with self-powered platinum detectors. Seabrook Station is a four loop Westinghouse plant containing 193 assemblies and operating at 3411 MWt. Unlike most Westinghouse plants, Seabrook Station contains two complete and independent in-core detector systems. The first is a Movable In-core Detector System, which uses movable fission chambers typical of Westinghouse plants similar to Seabrook Station. The second detector system employs self-powered fixed platinum detectors. Both of these systems were installed during plant construction.

Description of Movable In-core Detector System

The Movable In-core Detector System uses 58 reactor core instrument thimbles. Each thimble is traversed by one or more of six movable fission chambers. The measurement of incur power requires the six movable fission chambers to be passed through the core at least 12 times. As the detector is passed through the core, the signals are collected and saved on the main plant computer as a neutron flux trace. Each detailed axial trace consists of 61 relative axial neutron flux measurements. These traces, which collectively make up a flux map, are then processed with analytical predictions of detector reaction rates by INCORE-3 [2] to infer the measured power distribution and corresponding peaking factors. The results are then compared to established limits to ensure that the core is operating within the limits specified in the Technical Specifications.

Description of Fixed In-core Detector System

The fixed detectors used at Seabrook Station are self-powered with platinum emitters and yield a signal proportional to the incident gamma and neutron flux. The Fixed In-core Detector System consists of 58 detector strings. Each string contains five self-powered platinum detectors for a total of 290 detectors in the core. These strings are an integral part of the instrument thimble. They are located in the same radial core locations as the Movable In-core Detector System. Each detector consists of a 13.5 inch long platinum emitter within the core and is connected to its associated lead wire. A compensation lead wire which is identical to the emitter lead, runs parallel to the emitter lead within the sheath of each detector to correct for gamma-induced background current. The emitter and leads are all packed in an Al_2O_3 dielectric insulator and bound in an Inconel sheath. The wires for a detector string form a helix around a central Inconel tube and are then bound by an Inconel sheath. The central Inconel tube is the path used by the movable fission chamber. The fixed incur detectors are spaced along the thimble so that they fall in the mid regions of the core between fuel assembly grids.

The data acquisition system, developed at Seabrook Station [1], consists of the Fixed In-core Detector Data Acquisition Software and two trains of front end multiplexing instrumentation. Each train reads 145 of the platinum detector channels. The signal developed within the platinum emitter is determined as the emitter and its lead signal less its compensation lead signal. Cross channel calibration is essentially avoided since only two analog to digital measurement devices, one per train, are used to develop all 290 signals.

Each channel loop is terminated with a 20KΩ precision resistor, which minimises detector leakage current and improves channel response time by maintaining a small resistance capacitance time constant.

The system hardware has been configured in such a manner that less than 0.08% of the detector signal is system noise. Signal common mode rejection is accomplished by maintaining a single common ground for each detector channel. The reactor ground is connected to each channel shield which envelopes the entire detector loop, including the multiplexer and analog to digital instruments. Digital filtering is accomplished in the monitoring instrumentation by averaging 32 samples from each channel every minute. This filtering removes any residual AC component and results in a signal to noise ration of 8×10^{-4} at full power conditions.

For the first three cycles of operation, Technical Specification surveillance was provided by the Movable In-core Detector System. Data was also collected with the Fixed In-core Detector System for comparison and to determine accuracy, reproducibility and signal degradation. To use the fixed detectors for Technical Specification surveillance, the system qualification was submitted to the US Nuclear Regulatory Commission [3] for approval.

Power shape determination

The gamma and neutron interactions result in an axial signal which is not directly representative of power. The method used for determining power from this system begins with an assumption that the ability to predict the detector's measured signal from a neutronics calculation is equal to the ability of the same calculation to predict the incur power distribution. This implies that any differences between predicted and measured detector signals can be applied to local power predictions to infer the measured power [4].

The generation of a three-dimensional measured power distribution involves a combination of measured signals and analytical signal to power conversion factors. The fixed in-core detectors provide continuous signal data, which is collected and stored once per minute. The power distribution and predicted signals are generated with SIMULATE-3 [5]. The SIMULATE-3 model of Seabrook Station consists of four nodes per assembly radially and 24 nodes per assembly axially. When a measured power distribution is required, the SIMULATE-3 model is updated to the current plant conditions. Using these conditions, SIMULATE-3 calculates the power distribution and the detector constants. The detector constants include both the neutron and gamma responses [6] for the platinum detectors.

The Fixed Detector In-core Code (FINC) was developed by Yankee to infer the three-dimensional power distribution. FINC performs a cubic spline fit of the predicted and measured signals to axially expand the five original measured and predicted signals to twenty-four equal axial intervals (nodes). This is consistent with the axial resolution of the neutronics code model. The signals are assumed to be zero at an extrapolated distance above and below the bottom of core, reducing the differences between prediction and measurement in these areas.

From these mathematically created axial detector signals, measured to predicted signal ratios are determined for use in the inferred power distribution calculation. Thus, the ratio of the measured to predicted detector signal for all 24 axial nodes in all 58 instrumented locations are generated. These ratios represent the local differences between the predicted and measured power in the instrumented locations in the core. Once the detector measured to predicted signal ratios have been determined, the full core measured power distribution is generated.

Since not all fuel assemblies in the core contain detectors, a system of determining power in uninstrumented locations is required. The FINC code uses a proportional weighting method to couple instrumented and uninstrumented assemblies in radial power distribution calculations. These weights are applied as given in the following equation:

$$P_{jk}^{meas} = P_{jk}^{pred} * \frac{\sum_{i}^{I} w_i \left(S_i^{meas} / S_i^{pred}\right)}{\sum_{i}^{I} w_i}$$

where:

P^{meas}	is measured power at location jk
P^{pred}	is predicted power at location jk
w	is weighting factor between I and jk
S^{meas}	is measured detector signal at location I
S^{pred}	is predicted detector signal at location I

This method of using detector ratios to modify the local predicted power distribution is applied in each of the 24 axial planes defined in the SIMULATE-3 model. The predicted power of axial nodes near a detector will be modified by the detector ratio determined for that axial node and the radial weighing scheme. The predicted axial power distribution for each individual assembly is modified by the local detector ratio. This means that the axial power shape in uninstrumented assemblies is derived from the predicted axial power shape in the uninstrumented assembly modified by local measurements from local instrumented locations.

Core operational data consistent with current operational conditions are used to update the SIMULATE-3 predictive model. Model update calculations of detector constants are performed very quickly on high-powered workstation computers at Seabrook Station. Thus, detector responses and incur power distributions can be predicted for these conditions and used directly with the measurement data.

Fixed and movable detector results comparisons

During normal operation of the plant, an in-core detector analysis is performed to determine the in-core power distribution on a monthly basis. The purpose of this analysis is to demonstrate that the maximum peaking factors, as determined by the in-core power distribution, are less than the limits assumed in the safety analysis. Nearly forty in-core power distributions have been processed by both the Fixed In-core Detector System and the Movable In-core Detector System for the same conditions. Data collected from both of these systems are compared in this work to show that both systems are reporting similar results for the same core conditions.

The primary parameters of concern for Technical Specification surveillance are the axial peak power in any pin, F_q, and the integrated peak power in any pin, $F_{\Delta h}$. Each of these three values have been compared for each surveillance made with both the Fixed In-core Detector System and the Movable In-core Detector System. Results for Cycles 1-4 are presented in Tables1-4.

The results provided in Tables 1-4 display a deviation in F_q between the Movable and Fixed In-core Detector Systems. As cycle burnup increases, the Fixed In-core Detector System predicts a lower value of F_q than that determined from the Movable In-core Detector System. All other data is in good agreement and confirms the accuracy of the Fixed In-core Detector System at determining the required surveillance parameters.

The measured value of F_q can be separated into its radial and axial components $F_{\Delta h}$ and F_z. As shown in Tables 1-4, the $F_{\Delta h}$ data from the two measurement systems is comparable for all four cycles. Therefore, the F_z values do not agree between the systems. The deviation is due to the methodological differences used to analyse the data. Axial power distributions using the Movable In-core Detector System are biased by the ^{235}U fission spectrum using a single plane model in INCORE-3 to analyse the data. The methodology used in the analysis of Fixed In-core Detector System data considers fissions from all sources as explained below.

The Movable In-core Detector System uses a ^{235}U fission chamber detector to measure the neutron flux axially through the core in each of the instrumented locations. The ^{235}U fission chamber produces a current proportional to the fissions generated from the incident neutron flux on a ^{235}U element. Thus, the Movable In-core Detector System measures the fission rate of ^{235}U in the core as a function of axial core position. At the beginning of the cycle, the fresh fuel dominates the core axial power shape and the ^{235}U fission rate shape is nearly the same as the axial power shape. However, as the cycle burnup increases, the contribution from other nuclides becomes more dominant. The axial power shape within the core also changes from the classic cosine shape to a double humped shape. The double humped shape results from the depletion of the fuel in the central regions of the core and less depletion in regions above and below the centre of the core. The bottom of the core has a higher moderator density producing a softer spectrum, due to lower moderator temperature. The ^{235}U fission chamber is more sensitive to the softer spectrum at the bottom of the core than the harder spectrum near the top of the core. Thus, the axial power shape generated by the ^{235}U fission chamber will be more bottom peaked than the actual power shape.

From the data presented in Tables 1-4, Cycles 2 and 4 exhibit the deviation in F_q with burnup; while Cycles 1 and 3 do not appear to exhibit this deviation. Cycle 1 was a fresh core and most all fissions were from ^{235}U. Even by the end of the cycle the ^{235}U fissions dominated the axial power shape. In Cycle 2, essentially two-thirds of the core contained burned fuel from Cycle 1 and burnup dependence on F_q was observed near the end of the cycle. In Cycle 3, the peak F_q values do not appear to exhibit this trend near the end of the cycle. However, in Cycle 3, the peak F_q location is not the same as the peak $F_{\Delta h}$ location. The $F_{\Delta h}$ in the peak F_q location was measured higher with the Fixed In-core Detector System than that measured by the Movable In-core Detector System. Thus, the decrease in F_z was compensated by an increase in $F_{\Delta h}$. Cycle 4 showed the deviation and as expected the peak $F_{\Delta h}$ value was in the same location as the peak F_q for most of the cycle. Although the peak F_q locations determined by each system were not the same, they are very near one another and have essentially the same axial power shape.

The results demonstrate that, as the core depletes, the peak F_q from the Movable In-core Detector System using a single plane model in INCORE-3 code is usually greater than that given by the Fixed In-core Detector System using the FINC code. The peak F_q from the Movable In-core Detector System is consistent with the ^{235}U axial fission rate shape. The peak F_q from the Fixed In-core Detector System is consistent with the axial power shape derived from all isotopes.

The single plane model for INCORE-3 used by Seabrook Station for this analysis is not the latest in use at other Westinghouse plants with Movable In-core Detector Systems. A multi-plane model used by other Westinghouse plants compensates for ^{235}U reaction rate shape.

Use for technical specification surveillance

In the fourth cycle of operation, and after NRC approval, incur power distribution surveillance was performed with the Fixed In-core Detector System. To aid the plant Reactor Engineer Staff, a reactor analysis workstation was developed by Yankee to process the data as needed. The workstation contains all software required to generate incur constants and to develop power distributions from the platinum detector signals. A graphical user interface was developed based on specifications provided by the Reactor Engineering Staff.

Conclusion

Over four cycles of operation, the Fixed In-core Detector System has continued to demonstrate the same accuracy as in the first cycle. No detector failures or signal strength degradation has been seen. The raw millivolt signals given by the fixed detectors are about the same at the end of Cycle 4 as during Cycle 1 measurements. The results show the Fixed In-core Detector System using self-powered platinum detectors to be a complete and independent system with accuracy and functionality expected for an incur detector system.

REFERENCES

[1] Joseph P. Gorski and Alan G. Merrill, “In-core Power Monitoring Using Platinum In-core Detectors at Seabrook Station,” Advances in Mathematics, Computations, and Reactor Physics, International Topical Meeting, 28 April - 2 May, 1991, Pittsburgh, PA, USA.

[2] A.J. Harris and H.A. Jones, “The INCORE-3 Program,” WCAP-8402, March 1975.

[3] J.P. Gorski, “Seabrook Station Unit 1 Fixed In-core Detector System Analysis,” YAEC-1855-P-A, October 1992 (Yankee Atomic Electric Company Proprietary).

[4] Joseph P. Gorski, “Highly Detailed Axial Power Shape Generation from Fixed In-core Detector Systems,” Proceedings of the 1994 Topical Meeting on Advances in Reactor Physics, 11-15 April, 1994, Knoxville, Tennessee.

[5] K.S. Smith, K.R. Rempe and D.M. Ver Planck, “SIMULATE-3: Advanced Three-dimensional Two-group Reactor Analysis Code, Methodology,” STUDSVIK/NFA-89-04, November 1989.

[6] Dominic G. Napolitano and Donald R. Harris, “Sensitivity of Seabrook Station’s In-core Platinum Detectors,” Advances in Mathematics, Computations, and Reactor Physics, International Topical Meeting, 28 April - 2 May, 1991, Pittsburgh, PA, USA.

Table 1. Cycle 1 results

Date	Exposure MWd/MTU	Fixed Detector System		Movable Detector System	
		Maximum $F_{\Delta h}$	Maximum F_q	Maximum $F_{\Delta h}$	Maximum F_q
08/29/90	1945	1.376	1.995	1.361	1.949
09/26/90	2950	1.355	1.879	1.325	1.853
10/10/90	3468	1.336	1.801	1.316	1.788
11/08/90	4369	1.312	1.731	1.316	1.741
12/05/90	4850	1.313	1.704	1.309	1.712
01/04/91	5997	1.299	1.667	1.291	1.662
02/05/91	7214	1.297	1.640	1.283	1.632
03/18/91	8473	1.297	1.630	1.289	1.627
04/16/91	9266	1.289	1.611	1.278	1.621
05/20/91	10560	1.279	1.575	1.266	1.577
06/18/91	11570	1.272	1.564	1.261	1.582

Table 2. Cycle 2 results

Date	Exposure MWd/MTU	Fixed Detector System		Movable Detector System	
		Maximum $F_{\Delta h}$	Maximum F_q	Maximum $F_{\Delta h}$	Maximum F_q
11/01/91	415	1.473	1.842	1.442	1.832
11/08/91	682	1.468	1.901	1.433	1.892
12/04/91	1680	1.468	1.848	1.436	1.838
01/08/92	2966	1.464	1.768	1.429	1.767
02/04/92	3996	1.454	1.749	1.424	1.744
03/04/92	5101	1.444	1.767	1.420	1.786
04/01/92	6169	1.436	1.774	1.423	1.792
05/05/92	7466	1.428	1.758	1.413	1.781
06/02/92	8536	1.419	1.734	1.406	1.769
07/06/92	9840	1.407	1.705	1.409	1.767
08/07/92	11060	1.395	1.674	1.399	1.739

Table 3. Cycle 3 results

Date	Exposure MWd/MTU	Fixed Detector System		Movable Detector System	
		Maximum $F_{\Delta h}$	Maximum F_q	Maximum $F_{\Delta h}$	Maximum F_q
11/25/92	277	1.432	1.870	1.443	1.865
12/22/92	1099	1.420	1.921	1.426	1.890
1/28/93	2206	1.435	1.954	1.444	1.943
2/23/93	3189	1.437	1.948	1.453	1.925
3/23/93	4259	1.439	1.894	1.447	1.910
4/22/93	5402	1.448	1.849	1.443	1.874
5/26/93	6577	1.454	1.809	1.440	1.822
6/23/93	7649	1.454	1.787	1.440	1.802
7/26/93	8909	1.451	1.777	1.448	1.787
8/24/93	9881	1.449	1.751	1.437	1.755
10/14/93	11211	1.442	1.748	1.455	1.749
12/10/93	13200	1.432	1.757	1.426	1.767

Table 4. Cycle 4 Results

Date	Exposure MWd/MTU	Fixed Detector System		Movable Detector System	
		Maximum $F_{\Delta h}$	Maximum F_q	Maximum $F_{\Delta h}$	Maximum F_q
11/2/94	3499	1.443	1.855	1.441	1.868
12/8/94	4869	1.443	1.808	1.428	1.855
5/3/95	10439	1.397	1.676	1.404	1.721
8/31/95	14403	1.363	1.646	1.375	1.683