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**IN-CORE INSTRUMENTATION
TEST PROGRAM**

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MASTER

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UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

FEB 12 1973

Mr. James F. Mallay
Manager, Licensing
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Dear Mr. Mallay:

We have completed our review of your topical report, BAW-10001, dated August 1969, "Incore Instrumentation Test Program." In the context that the instrumentation is used only for physics calculation verification and fuel management, we consider the report adequate. However, if credit for power flattening beyond the capability of the excore instrumentation becomes necessary, the detection characteristics of this system would require further review.

Sincerely,

A handwritten signature in dark ink, appearing to read "R. C. DeYoung".

R. C. DeYoung, Assistant Director
for Pressurized Water Reactors
Directorate of Licensing

ABSTRACT

In-core flux monitors are used in Babcock & Wilcox-designed central station power reactors to provide power distribution information to confirm physics calculations and to execute a fuel management program. To qualify the all-solid self-powered detector as an in-core monitoring device, B&W initiated several programs to qualify this device for the operating environment of a PWR. These programs included the following features:

1. Determination of the detector's basic physics characteristics.
2. Lifetime tests in a radiation environment.
3. Mechanical integrity tests of the detector and its assembly.

Test results may be summarized as follows:

1. The electrical resistance of the detectors does not change as a result of prolonged exposure.
2. The rhodium neutron sensitivity decreases predictably as a function of neutron exposure, and the depletion of sensitive material can be accurately estimated without using external calibration devices. The detector is spectrum sensitive and can be computer compensated for variations in the flux spectrum. The background effects can be closely approximated for all axial positions by using a single background detector.
3. Reproducibility between detectors can be controlled by manufacturing quality control procedures.
4. The all-solid detector is highly reliable; there was no failure of any detector that met specifications upon installation.
5. The assembly developed for central station use permits manual insertion-withdrawal with only small forces, and without the use

of lubricants. The assembly seal proved to be highly reliable and was quickly installed.

6. Both computers and conventional picoammeters provide accurate readings of the detector output.

7. There is no indication of lifetime limitation other than sensitivity loss resulting from neutron interaction.

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1. INTRODUCTION

1.1. Background

During 1962 and 1963, B&W conducted studies of the in-core monitoring systems that were being used in power reactors. Early in 1964, the development of the self-powered detector showed promise of fulfilling the need for an in-core monitoring detector in PWRs. However, many unknowns had to be investigated before the device could be adopted for commercial PWR use.

This report summarizes the development and testing to qualify the self-powered detector for pressurized water reactor service. B&W's test program investigated the basic physics characteristics of the rhodium detector, the mechanical details of the in-core monitor assembly, and the effects of long exposure to reactor environmental conditions. The major uncertainties of self-powered detectors related to use in PWRs before the development program were as follows:

1. Availability of detectors possessing the quality, and in the quantity, needed.
2. As-received reliability of detectors.
3. Relative sensitivity between two detectors.
4. Magnitude of interaction between detectors.
5. Magnitude and distribution of background radiation.
6. Effect of temperature on detectors.
7. Rate of rhodium depletion in neutron flux.
8. Rate of change of the detector's electrical properties with time and exposure.
9. Effect of the PWR lattice on results.
10. Relationship between detector signal (neutron flux) and local power in a PWR.

Except for the lifetime testing, all development work was performed at B&W's Critical Experiment Laboratory (CEL) in Lynchburg,

Virginia. The longevity tests were performed at Consumers Power Company's Big Rock Point Reactor in Michigan, and at the Babcock & Wilcox Test Reactor (BAWTR) in Lynchburg, Virginia.

1.2. General Design Requirements

In evaluating an in-core monitoring system, the following design criteria were set:

1. The in-core system should monitor sufficient points to determine neutron flux and power conditions throughout the reactor core.
2. The device must measure local power within $\pm 10\%$, and should preferably measure it within $\pm 5\%$.
3. The device should measure local power with the required accuracy above 15% of rated power.
4. The in-core device should have a life expectancy of at least one year.
5. The in-core assembly must fit the small core lattice of a PWR.
6. The in-core assembly must not interfere with refueling operations.
7. The in-core design should minimize the time required to remove the assemblies to prevent prolongation of refueling periods.
8. The in-core assembly must not interfere with rod drives on the reactor head.
9. The device must be economical.

Each of the design criteria has been met. The system is capable of measuring local power within $\pm 5\%$, and the lifetime of the detector is several average full-power flux years. The assembly is small, easily retractable, and does not prolong refueling time. Sufficient assemblies are included to monitor power locally throughout the entire nuclear core.

2. IN-CORE MONITORING SYSTEM DESIGN

2.1. Theory of Operation

Traditionally, neutron flux profiles are measured in nuclear reactors of all types by activating wires inpile and subsequently counting them outpile. This practice is extended with the all-solid neutron detector, which allows continuous reading of a segment of high-purity* wire in place in the reactor. This is accomplished by isolating the sensitive wire (emitter) from the electrical ground and attaching a lead-wire to it to allow measurement of the current (flow of electrons) into the wire to replace escaping beta particles (see sketch below). The emitter material is rhodium. Because the rhodium in the emitter is depleted slowly by the neutron bombardment, the rate of depletion may be predicted with good accuracy.

Since the neutron flux is measured only in the region occupied by the emitter (4 inches long), for PWR applications a number of detectors are bound together in an assembly (with emitters at different locations) to provide discrete data points that give axial power distribution.

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* Quite often, flux wire activation analysis is uncertain because of impurities in the wire sample. Since rhodium is a 99.5% pure metal, these errors are minimized.

Some background effects occur in both the leadwire section of the detectors as well as the rhodium section. Therefore, each assembly of detectors contains an emitterless (background) detector extending up through the core to the uppermost neutron detector. The signal from this detector is used to deduce the background correction factor for all neutron detector signals.

2.2. System Description

2.2.1. General

The basic in-core monitoring systems for B&W PWRs comprise assemblies of self-powered neutron detectors located at pre-selected positions within the core. An in-core monitoring arrangement is shown in Figure 1 as an example. An in-core detector assembly containing seven local flux detectors and one background detector, is installed in the instrumentation tube of each fuel assembly as shown in Figure 2. The local detectors are placed at different axial elevations to provide the axial flux gradient. The outputs of the local flux detectors are referenced to the background detector output, so that the differential signal is a true measure of neutron flux. Readout for the in-core detectors is by the plant computer, but multipoint recorder readouts of selected detectors are provided independently.

When the reactor is depressurized, the in-core detector assemblies can be inserted or withdrawn through guide tubes which originate at a shielded area in the reactor building (Figure 2). These guide tubes enter the bottom head of the reactor vessel where internal guides extend up to the instrumentation tubes of the selected fuel assemblies. The instrumentation tube serves as a guide for the in-core detector assembly. During refueling operations, the in-core detector assemblies are withdrawn to allow free transfer of the fuel assemblies. After the fuel assemblies are placed in their new locations, the in-core detector assemblies are returned to their fully inserted positions.

2.2.2. Calibration Techniques

Since the nature of the detectors permits the manufacture of nearly identical detectors, the relative accuracy between individual detectors can be controlled to a high degree.

Initial calibration of the detectors is not required. The in-core self-powered detectors are controlled to precise levels of initial sensitivity by quality control during manufacture. The sensitivity of a detector changes over its lifetime because of detector burnup, control rod positions, fuel burnup, and the like. The detector signals are computer compensated continuously for burnup of the neutron-sensitive material. The results of experimental programs to determine the magnitude of these factors have been incorporated into calculations and will be used to correct the output of the in-core detectors. Operation of detectors in both power and test reactors has demonstrated that the compensation program, coupled with the initial sensitivity, provides detector readouts that are accurate enough to eliminate the need for a calibration system.

2.2.3. Detection and Control of Xenon Oscillations

Under power operating conditions, the in-core detectors supply information to the operator in the control room. Each individual detector measures the neutron flux at its locality and is used to determine the local power density. Individual power densities are then averaged and a peak-to-average power ratio is calculated. Upon initial installation, the self-powered detector is capable of measuring the relative flux within 5% when used in conjunction with an adjacent background detector. The sensitivity of the detector will decrease with exposure to neutron flux owing to transmutation of the emitter in the detector. However, the use of integrated current inventories should limit additional inaccuracies to 1% per year for the average flux conditions.

2.3. Operational Design Basis

2.3.1. Rhodium and Background Signal Strength

The operation of an in-core monitoring string in an assumed cosine-shaped flux at the beginning of life (BOL) of the assembly and in a possible condition near the end of life (EOL) is predicted in this section.

The rhodium signal will vary with both axial and radial positions in the core. Figure 3 is a plot of the axial neutron flux (2200 m/s) shape that has been normalized to a 12-foot-high core and a peak

Table 1. Central Station Signal Predictions

<u>Detector No.</u>	<u>Distance above fuel bottom, in.</u>	<u>Flux, 10^{13} nv</u>	<u>BOL corrected rhodium signal, nA</u>	<u>Background signal (-), nA</u>	<u>EOL rhodium signal, nA</u>	<u>EOL rho- dium signal to back- ground ratio</u>
1	133.7	2.4	312	35	170	4.85
2	113.1	4.8	624	30	325	10.8
3	92.6	6.6	858	25	318	12.7
4	72	7.2	938	18	310	17.2
5	57.4	6.6	858	6	342	57
6	30.9	4.8	624	4	354	88
7	10.3	2.4	312	1	204	204

neutron flux value of 7.2×10^{13} nv. Table 1 lists flux values and calculated BOL and EOL output currents for each detector.

The curve in Figure 3 has been used to predict background currents for each detector listed in Table 1. Since the lead wires extend from the bottom of the vessel, the top detectors have the highest background. For this prediction it has been assumed that the background is proportional to the area under the neutron flux curve. The highest background signal for the total core length has been calculated to be about -35 nA.

2.3.2. Detector Electrical Properties

To operate with a readout impedance of 10^6 ohms, the detector's insulation resistance must be significantly larger than 10^5 ohms. A typical detector with an insulation resistance of 10^9 ohms, at environmental conditions of flux and temperature, would constitute an acceptable leakage resistance, and any leakage current from the detector would be negligible. Analysis of the test data indicates that there will be no degradation of the detector's insulation resistance for exposures up to five average flux years.

2.3.3. Rhodium Depletion Rate

The detector's lifetime is primarily a function of the rhodium depletion rate. The depletion rate is directly proportional to the expended current, and calibration during the detector lifetime is dependent on the current inventory.

The error for the best estimate of the total charge available is currently 2 to 3%. When this uncertainty is applied to the depletion formula,

$$S(t) = S(0) \left[1 - \frac{Q(t)}{Q(\infty)} \right]$$

where

$S(t)$ = sensitivity at time, t
 $S(0)$ = initial sensitivity
 $Q(t)$ = charge consumed up to time, t
 $Q(\infty)$ = initial charge available

the resultant uncertainty in $S(t)$ is 2 to 3% when $\frac{Q(t)}{Q(\infty)}$ is 0.5. Thus, if no refinements were made in the present model, the uncertainty due to rhodium depletion would be 3 to 5% at 60% depletion, i. e., $\left(\frac{Q(t)}{Q(\infty)} = 0.4\right)$. The average detector will reach this depletion after about 60 months.

The peak flux (7.2×10^{13} nv) shown on Figure 3 represents an extreme, since the peak flux would not remain at the same location throughout the detector's lifetime. The average flux (4.2×10^{13} nv) represents a better picture of detector lifetime. It appears that assemblies could serve for five years on the average. Assemblies in the higher flux regions of the core will be replaced more frequently and near the edge of the core considerably less frequently.

3. DEVELOPMENT TESTS

3.1. Parametric and PWR Environment Tests

During the "proof of principle" tests it became evident that additional information on the activation and properties of the rhodium detector would be required before self-powered neutron detectors could be utilized. Therefore, B&W initiated, and is continuing, a development program to investigate the self-powered detector for PWR use.

3.1.1. Test Core

To simulate PWR applications, the properties of rhodium were measured in a water-moderated critical assembly with configurations that provided a realistic neutron environment. The parameters of the cores in which measurements were made are typical of those used in water-moderated power reactors. The unperturbed basic lattice contained 0.475-inch-OD fuel rods with 2.46% enriched UO_2 , and the lattice pitch was 0.644 inch.

3.1.2. Effects of Shielding on Background Signal

The atomic particles originating outside the detector can contribute to the background signal. Measurements of the background detector response versus the total absorber thickness between the oxide fuel and the detector were therefore undertaken to determine the magnitude of the background signal produced by beta particles originating from fission product decay within the oxide fuel and to determine the minimum shielding required to eliminate it.

Except for one measurement, the shielding data were taken with the arrangement shown in Figure 4. The 3/4-inch-diameter aluminum tube shown in the figure was located along the core axis and traversed the entire core. The total absorber thickness surrounding the background detector was varied by interchanging various sizes of type-321 stainless steel and Zircaloy-4 tubing. In some cases, the intervening

space was filled with the borated moderator. The single measurement with a different shielding geometry was designed to bring the detector and a fuel rod as close together as was physically possible. For the measurement, the detector was taped to a fuel rod that replaced the 3/4-inch-diameter aluminum tube in the center of the lattice.

The results are presented in Figure 5. The data fall into several groups depending on the type of shield material adjacent to the detector. Although there is some signal attenuation with increased absorber thickness, the dominant signal variation clearly results from changes in the detector environment. This suggests that signal variations result mainly from charged particles originating in the shield material. Both gamma and neutron-induced reactions result in the production of energetic charged particles, principally by the processes of photoelectric emission, Compton scattering, pair production, and beta emission following neutron activation. Since these measurements were made for irradiation times much shorter than the half-lives of most potential activation products, it is unlikely that the latter process is responsible, although it might be significant for long-term reactor operation.

A more probable explanation is that the observed signal variation results from photoelectric and Compton electron effects (pair production effects presumed to cancel). The photoelectric and Compton scattering cross sections of the shielding materials used appear to be of sufficient magnitude to produce the observed signal variation, and the correction would be in the direction to reduce the observed signal variation.

3.1.3. Detector Response Versus Boron Concentration

The net (background corrected) equilibrium detector signal was measured in five clean critical lattices. Boron concentrations in the moderator-coolant ranged from 0 to 1500 ppm. All measurements were made at midcore height in a center water hole created by removing a fuel rod and allowing the resulting space to fill with moderator. To facilitate positioning of the detector, an open-ended, 0.439-inch-diameter by 0.036-inch-wall aluminum tube was mounted along the core axis in the center water hole. The detector was centered inside the aluminum tube with Teflon spacers.

In a power reactor installation, the detector signal can be measured with a standard nanoammeter or picoammeter. However, the very small currents produced in the low-power critical assembly required the use of a more sensitive instrument. An electrometer was employed, and the total charge produced by a given critical assembly operation was measured. The equilibrium current was calculated from the charge.

The 2200-meter-per-second neutron flux (ϕ_0) was measured with bare and cadmium-covered dysprosium-aluminum wires. The wires were loaded into a sample holder, illustrated in Figure 6, and positioned at precisely the same location as that of the rhodium element of the detector. Small corrections ($\approx 1\%$) were made to account for a slight deviation of the dysprosium absorption cross section from $1/V$ behavior in the thermal region.

The final ratios have an estimated random uncertainty of 1.5% and a systematic error of 4.2%. Within statistics, the net detector signal (S), in amps, produced by a unit thermal flux (ϕ_0), in $n/s\text{-cm}^2$, does not vary over the range of neutron spectra involved. The relationship between ϕ_0 and the net signal (S) from a detector located in the asymptotic neutron spectrum region of any of the five lattices studied may be expressed by the equation

$$S = K\phi_0 R/R - 1 \quad (1)$$

where K is detector sensitivity and R the cadmium ratio of the rhodium element.

3.1.4. Measurements With Activated Rhodium Samples

Since the principal signal from the neutron flux monitor under study results from the beta decay of activated rhodium wire, many of the basic parameters associated with the detector can be determined by analyzing the decay of rhodium samples that have been activated in a known neutron flux. Parameters obtained by this approach include:

1. K (in equation 1) for a 4.75-inch-long element.
2. The effective 2200 m/s capture cross section (Σ_{th}) of rhodium wire versus diameter.

3. The probability (P) versus diameter that a beta particle born in a rhodium wire will escape from the wire.
4. The half-life of $^{104}\text{Rh}^m$.
5. The half-life of ^{104}Rh .

The beta emission rate (B) from an activated rhodium sample can be expressed as the sum of two exponentials following irradiation:

$$B = I_1 e^{-\lambda_1 t_w} + I_2 e^{-\lambda_2 t_w} \quad (2)$$

When the beta decay of an irradiated sample was fit by least squares to equation 2, half-life values of $^{104}\text{Rh}^m$ and ^{104}Rh were obtained from the fitting constants λ_1 and λ_2 . The detector sensitivity K was obtained from the fitting constants I_1 and I_2 and a measurement of the 2200 m/s thermal neutron flux (ϕ_0). The beta escape probability was determined by beta and gamma counting the ^{104}Rh isotope in identical activated rhodium samples. Thus the beta-to-gamma count rate ratio was directly proportional to the beta escape probability (P). The proportionality constant was evaluated by beta and gamma counting a 0.0001-inch-thick activated rhodium foil for which P was unity.

Measurements of the type described were made with bare and cadmium-covered rhodium wire 10, 20, and 30 mils in diameter. K (equilibrium beta emission) was measured for the different rhodium wire diameters (Figure 7). Comparison of K above with the more accurately measured rhodium type monitor sensitivity showed agreement within experimental error limitations.

3.1.5. Detector Signal Versus Power Density

Measurements relating net detector signal and power density in an adjacent fuel rod were made in a critical assembly mockup of a fuel subassembly. The subassembly, 15 lattice pitches square, was located in the center of the critical assembly and was separated from the remainder of the core by artificial boundaries. Within the subassembly, a cluster of 17 water holes, created by removing fuel rods and allowing the resultant space to fill with moderator, mocked up an instrument hold and a cluster of 16 withdrawn control rods. In other similar

measurements, 0.400-inch-OD Ag-In-Cd poison pins (79.7 wt % Ag, 15.1 wt % In, and 5.1 wt % Cd) were inserted into the water holes to mock up a partially inserted or fully inserted control rod cluster.

Axial traverses of the net detector signal were determined for a variety of control rod cluster insertion depths. Detector positioning was as previously described. The relative power distribution along the length of an adjacent fuel rod was measured by counting collimated fission product decay gammas from the activated fuel rod. These measurements were then normalized to absolute values of fission density based on the ^{99}Mo content of irradiated fuel samples.

Correlation between the net detector signal and the fission density profile of the adjacent fuel rod is presented in Figures 8 through 11. The net detector signal (in units of amperes) has been scaled up by a factor of 1.75×10^{18} . To facilitate comparison, fission density determinations by fuel rod scanning have also been averaged over the 4-inch spans corresponding to the axial position of the sensitive portion of the detector.

3.2. Pressure Seal and Mechanical Insertion-Withdrawal Mockup Tests

3.2.1. In-Core Instrumentation Pressure Seal Tests

Seal tests were conducted at pressures exceeding the reactor vessel hydrostatic test pressure (3125 psig) and at temperatures from 70 to 180 F. The final pressure seal assembly design employing two silver-coated O-rings was tested at pressures exceeding 3650 psig and temperature cycles up to 180 F with no visible leakage.

3.2.2. Mechanical Insertion and Withdrawal Tests of Assemblies

In-core instrumentation assemblies are inserted and withdrawn within the in-core monitoring system piping during reactor refueling operations. The in-core monitoring system piping, which is between 100 and 130 feet long, has two 90 degree turns. Mechanical insertion and withdrawal tests were conducted on different types of in-core instrumentation assemblies to ensure that insertion-withdrawal forces do not exceed practical manual handling capabilities. The assemblies were inserted in a mockup of the in-core monitoring system

pipng (see Figure 12), and insertion and withdrawal forces were measured. Table 2 lists typical forces required for the insertion-withdrawal cycles.

**Table 2. Mechanical Insertion-Withdrawal Tests
Sample Data, In-Core Instrumentation
Assemblies**

(Average Force in Pounds)

<u>Distance, feet^(a)</u>	<u>Insertion</u>	<u>Withdrawal</u>
70 - 75	7-1/2	7
75 - 80	7	7
80 - 85	8	7
85 - 90	9	9
90 - 95	17	13
95 - 100	24	14-1/2
100 - 102	27	13-1/2

(a) The force required to insert and withdraw in-core instrumentation assembly from 0 to 70 feet was only the weight of the assembly.

3.3. Lifetime Irradiation Tests

One of the original objectives of the test program was to provide a self-powered detector that would have a minimum lifetime of three years. Arrangements were made with Consumers Power Company to test an assembly of these detectors in the Big Rock Point Reactor in Michigan. To provide an independent check, a second assembly was tested in the BAWTR in Lynchburg. Both assemblies are still operating and working well at the time of publication of this report. Detectors in the Big Rock Point Reactor have exceeded a five-year average-flux lifetime, and those in the BAWTR have exceeded a three-year average-flux lifetime. These longevity tests indicate that there has been no degradation

in the basic detector and that the rhodium depletion rate, through neutron interactions, is the only limiting factor in the detector's lifetime.

3.3.1. Babcock & Wilcox Test Reactor (BAWTR)

The all-solid (self-powered) detectors being tested at the BAWTR include six rhodium detectors and four background detectors. The test environment is a thermal flux of 8×10^{13} nv. Provisions are available to alter the temperature between 300 and 800 F. The basic readout device for the BAWTR test program is the Bailey Meter Company 750 data logging system. This system and the associated instrumentation systems monitor, record, and store all essential test data for information processing.

3.3.2. Big Rock Point (BRP) Reactor

The Big Rock Point detectors include six rhodium and three background detectors. The maximum test environmental conditions are a thermal flux of approximately 1×10^{14} nv, and, an environmental temperature of 575 F. Besides conventional test instrumentation, a computer system processes BRP lifetime test data. Figure 13 shows a typical rhodium detector depletion curve compiled by the test instrumentation.

3.3.3. Lifetime Tests Evaluation

The tests at BRP and the BAWTR have indicated the lifetime characteristics of the detectors. They have also established that signal noise from industrial plant operating machinery is not induced in the cabling. The reproducibility of measurements made at the BAWTR is superior, as shown by the low scatter in data obtained during the lifetime tests (Figure 14), since flux values were verified by laboratory equipment. The verification had to be made by wire activation analysis, which has a wide tolerance in accuracy because of wire impurities and other factors. The BAWTR tests established that the available initial charge of the installed detectors varied within $\pm 4\%$.

Figures 15 through 18 present typical data obtained during various stages of the BRP test program. These figures compare data with the wire map data taken early in the program. As shown, the in-core detector data retains the shape of the wire scan even though slightly

depressed because of depletion of the rhodium-sensitive material. Figure 18 presents typical data taken early in 1969. At this stage there was considerable depletion of the rhodium, but the depletion-available charge curve (Figure 13) could still be used to reestablish the actual flux.

4. SUMMARY AND CONCLUSION

4.1. Detector Lifetime

The self-powered detectors have been exposed to reactor environments exceeding a five-year average full power (850 MWt) flux lifetime. The electrical leakage resistance has shown no signs of degradation with time. The lowest resistance has remained about 10^9 ohms. The rhodium is more than 60% depleted in the detector with the greatest fluence. The rhodium depletion rate curve is mathematically well defined and can be used to predict the detectors' remaining sensitivity.

4.2. Detector Sensitivity

Average sensitivity of the detector is 1.3×10^{-20} A/nv. Some sensitivity variations do occur based on the changing energy spectrum within the core due to changes in moderator chemistry, fuel burnout, control rod positions, and reactor environment. These effects are known and can be computer-compensated to determine the power distribution. Relative power distribution within the core can be determined by the in-core detector to an estimated accuracy of $\pm 5\%$ above 15% rated reactor power.

4.3. Reproducibility of Detector Capability

The reproducibility between detectors is maintained within $\pm 1\%$ by careful quality control during manufacture. The all-solid detector is simply constructed of high-purity concentric components, permitting precise tolerances to be imposed during manufacture to yield a highly reliable device. No detector that has passed the quality control requirements has failed during a prolonged irradiation test in a reactor environment.

4.4. Assembly Design

An in-core monitoring assembly including seven self-powered detectors and a background detector has been developed. The assembly is easily inserted or withdrawn during refueling operations without the use of lubricants and without prolonging the refueling operation. The mechanical pressure seal is highly reliable and quickly installed.

4.5. Conclusion

The all-solid self-powered detector is a reliable in-core monitoring device which can be used in PWR service to yield accurate core power distribution data.

Figure 1. Typical In-Core Detector Locations

Figure 2. Typical In-Core Monitoring Channel

Figure 3. Central Power Station — Predicted Flux Map With Rhodium Detector Results

Figure 4. Shielding Arrangement

Figure 5. Shielding Data Normalized

Figure 6. Bare and Cadmium-Covered Sample Holders

Figure 7. Equilibrium Beta Emission Rate From 4.75-Inch-Long Rhodium Wire Subjected to Unit 2200 m/s Thermal Neutron Flux

Figure 8. Relative Fission Power Vs Distance From Core Bottom With Ag-In-Cd Pins Withdrawn 0 cm

Figure 9. Relative Fission Power Vs Distance From Core Bottom With Ag-In-Cd Pins Withdrawn 58 cm

Figure 10. Relative Fission Power Vs Distance From Core Bottom With Ag-In-Cd Pins Withdrawn 87 cm

Figure 11. Relative Fission Power Vs Distance From Core Bottom With Ag-In-Cd Pins Fully Withdrawn

Figure 12. Reactor Mockup

Figure 13. Big Rock Point Detector 5 Lifetime Test

Figure 14. BAWTR Detector 7750 Lifetime Test

Figure 15. Big Rock Point Detector Data With Wire Scan Curve (3-20-67)

Figure 16. Big Rock Point Detector Data With Wire Scan Curve (11-2-67)

Figure 17. Big Rock Point Detector Data With Wire Scan Curve (6-10-68)

Figure 18. Big Rock Point Detector Data With Wire Scan
Curve (1-29-69)