**ANALYSIS OF STORED FUEL, CONTROL ROD AND INHERENT SOURCE EFFECTS
ON THE CRBR EX-VESSEL SOURCE RANGE MONITORING SYSTEM***

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ABSTRACT

In order to determine the feasibility of an ex-vessel low-level flux monitor for use in the Clinch River Breeder Reactor, several possible problem areas needed to be analyzed. Among these were the effect of stored fuel on the detector, and the effect of control rod movements and source changes during refueling. This paper describes the techniques used and the results of such an analysis which was performed at ORNL in cooperation with the AEC and WARD.

1. INTRODUCTION

Refueling of the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor (CRBR) is to be accomplished under the reactor head by remote handling machines. During this operation, the sodium will remain in the core, the control rod drives are disconnected, and the head plugs are unsealed, thus an excursion during the refueling operation must be avoided. One mechanism for insuring that the core remains subcritical by a specified amount is to continuously and actively monitor the reactivity of the core during the refueling operation.

In the FFTF the monitoring is accomplished using three specially designed source level monitors (low level flux monitors, LLFM's) located in the radial shield approximately 113 cm from the core center. An earlier analysis was performed at ORNL (1) to explore the possibility of using the existing low-power monitors located outside the vessel in the reactor cavity. The results of this analysis indicated that the presence of unshielded stored fuel containing a large inherent neutron source masked the neutrons coming from the core unless a prohibitively large ²⁵²Cf source was placed in the core.

As a result of the FFTF analysis, the early CRBR designs (Fig. 1 and Table I) called for a stainless steel shield to be placed around the stored fuel with large ports left directly in front of the LLFMs in order to minimize the amount of shielding between the detectors and the core. Each detector set (10 fission chambers each containing 1.15 gm of ²³⁵U) were placed in a two-foot-cube of graphite to enhance the count rate at full shutdown. The graphite was surrounded on the outer five sides by borated carbide (B₄C) in order to minimize cavity and wall return. This configuration was analyzed at ORNL in order to determine the stored fuel background (2) given that design specifications required that no more than 10% of the count rate could be from the stored fuel at any time.

Calculations performed on the FFTF engineering mockup critical (EMC) assembly and the reverse approach to critical (RAC) (3, 4)

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assembly indicated considerable rod and source effects on the in-vessel detectors; thus, the evaluation of these effects on the CRBR ex-vessel detectors was included in the analysis.

2. STORED FUEL EFFECTS

Four DOT III (5) cases were set up in order to analyze the stored fuel effects. The geometry was based on the design shown in Fig. 1. The first two cases were for the reactor operating at full power (900 MW), one case with stored fuel and one case without stored fuel. The last two cases were for the reactor in a full shutdown condition (all control and safety rods inserted), again, one case with stored fuel and one case without stored fuel.

The DOT calculations used a 50-group cross section set previously used for FFTF analysis with S_6 quadrature and P_1 scattering. The problem was modeled in R- θ geometry with 60° symmetry. The $\theta=0^\circ$ position was along a line connecting the core center and the central detector in the graphite block shown in Figure 1.

The calculation was first performed in two steps. The first step consisted of a 60° segment which spanned the area from the core center to the outside of the radial shield (74-in. radius) as shown in Figure 2 (zone description in Table II). The second step covered the remaining regions as shown in Figure 3, (zone description in Table III), using the boundary angular flux from the first step as the source. In later problems it was found to be advantageous to change the step 1 θ intervals to correspond to the θ intervals in step 2 and combine the two steps into a single full geometry calculation.

Table IV indicates the magnitude and location of the various sources used in the analysis. The inherent sources are due to the (α ,n) and spontaneous fission in several plutonium isotopes. The fission sources consist of neutrons produced when the inherent source neutrons induce fission in the fuel (i.e., the multiplied source).

The reaction rates and count rates for the center-most detector in the graphite block are shown in Table V for both the full power and full shutdown configurations. As can be seen, at full power the stored fuel contributes about 10% of the count rate in the detector; however, at full shutdown the stored fuel contribution is 16.9 times that from the core, an unacceptable number according to the previously mentioned design specification.

In order to check if the detectors could be sufficiently shielded from the stored fuel without severe design modification, two other configurations were studied. These are shown in Figures 4 and 5. In Figure 4, the B_4C shield was extended inward to the core barrel. This represented the extreme in shielding the detector from the stored fuel and was never a plausible design configuration because of the expense of

B₄C, the presence of B₄C inside the reactor vessel, and because the extended shield violated the vessel integrity. The geometry shown in Figure 5 represented a more moderate design change in which the stored fuel shield thickness was increased and the reactor guard vessel was surrounded up to 45° by B₄C to eliminate the cavity and concrete return. The effects of the modifications are shown in Table V. Note, even the ultimate design did not meet the design specifications of 10% stored fuel background. This and other factors led to a design revision by Westinghouse Advanced Reactor Division (WARD) in which the stored fuel locations were reduced from 36 to 4.

With only a few stored fuel locations, the preferred designs tended to be azimuthally asymmetric, and it was necessary to optimize the location of the stored fuel storage assemblies and transfer tubes relative to the LLFM locations. First, a S₆-P₁, 180°, R-θ, adjoint DOT calculation was run with the 0° angle bisecting the graphite block. There was no stored fuel or stored fuel shield present. The detector fission cross section smeared over the graphite block was used as a source for the adjoint calculation. The adjoint angular fluxes were folded with the leakage from an ANISN (6) calculation of four stored fuel assemblies shielded with either 6 in. or 12 in. of stainless steel (SS-304). Three guard vessel shielding configurations were analyzed. The first configuration had no shielding around the guard vessel. A contour plot of the adjoint flux folded with the leakage for this configuration is shown in Figure 6. Figure 7 is a similar contour plot except the B₄C shield has been extended to an angle 45° on the outer guard vessel wall. Figure 8 is a contour plot for the case with B₄C surrounding the guard vessel.

A value of 0.17 fissions/gm/sec was determined from earlier calculations to be the maximum allowed fission rate in the detector for a 10% background. Table VI contains the results of the study for the cases with no shielding around the guard vessel and the case with 45° of shielding. With no shielding around the stored fuel and 45° of shielding around the guard vessel, the minimum angle is 100° from the detector. A factor of 10 was used as the attenuation due to the 12 in. of shield present in the ANISN calculation.

An estimation of the effect of the spatial distribution of the stored fuel assemblies was made using the results from the case shown in Figure 7. For four stored fuel assemblies spaced approximately 9-in. apart with the array centered at an angle of 120° from the detector, the fractional contribution to the detector count rate by each assembly was 0.07, 0.12, 0.23, and 0.58. This wide range indicates the dramatic effect of position on the LLFM background count rate. The current design with the two primary detectors located at 120° from the stored fuel and a backup detector located directly behind the stored fuel is shown in Figure 9. A forward, 180°, R-θ DOT calculation was performed on this design with the exception that, instead of the single BF₃ chamber shown in Figure 9, ten ²³⁵U fission chambers were used in order to be consistent with earlier calculations.

At full shutdown and with stored fuel present, the maximum stored fuel background count rate in either of the two primary detectors was 3%

of the core count rate, well within the design specifications of 10%. The positioning of three LLFM modules at 120° angles results in no requirements for stored fuel shielding since the detector is beyond the minimum unshielded angle of 100° . Also, when no stored fuel is present one has three symmetric LLFM modules, and with stored fuel in place, the nearest detector responds only to the stored fuel, thereby allowing source measurements which can be useful for checking for anomalous source conditions.

3. CONTROL ROD EFFECTS

As mentioned in the Introduction, the EMC experiments indicated considerable spatial and spectral flux shifts at the FFTF LLFM location due to control rod movements. The analysis of rod effects on the CRBR ex-vessel detectors is a formidable problem and a novel two-step procedure was used. First, a 50-group, S_6-P_1 , 180° , R- θ , adjoint DOT problem was formulated similar to that used in the analysis of the stored fuel effects. The exception being that the geometry now extended from the blanket/reflector interface to 1 ft inside the concrete cavity wall. A forward 50-group S_2-P_1 , 360° , R- θ , DOT problem was formulated which extended from the core center to the reflector/radial shield interface.

Two cases were analyzed. In case 1, all of the control and safety rods were inserted except the row 4₃₅ safety rod A (located at $+30^\circ$ from the 0° line, see Figure 10). The ^{235}U reaction rate contours from the forward case are shown in Figure 11 (Table VII contains the information for interpretation of the symbols used in Figures 11 and 12). The outside ring in Figure 11 represents a contour near the reflector/shield interface. The angular fluxes from the 360° forward case were coupled to the boundary angular fluxes from the adjoint problem at the blanket/reflector interface using the FACT coupling code. The resulting response was the ^{235}U reaction rate of a detector located at 0° . The forward angular fluxes were rotated -120° and again coupled with the adjoint. The resulting response represented the ^{235}U reaction rate of a detector located at 120° . The outer contours in Figure 11 indicated little control rod influence. This was confirmed using the results indicated by case 1, Table VIII.

The second case was used as a confirmation of case 1. In this case rod A was inserted and safety rod B (located at 150° , see Figure 10) was withdrawn. ^{235}U reaction rate contours for this case are shown in Figure 12. The forward and adjoint angular fluxes were coupled and the forward rotated -120° and coupled again. This procedure gave the response of a detector located at 0° and 120° respectively. Case 2 should have a response ratio equal to the reciprocal of case 1 which is confirmed by the results of case 2 shown in Table VIII.

4. INHERENT SOURCE EFFECTS

The source changes during refueling as simulated by removal of fuel during the Reverse Approach to Critical (RAC) experiment on the ZPR-IX at Argonne were significant with respect to their effect on the FFTF LLFM. The effect of source asymmetry on the CRBR LLFM was analyzed using the same technique as was used for the rod effects. In this case all

the rods were inserted and the magnitude of the inherent source in the segment of the core from 0° to 60° was reduced by 50% representing a portion of a refueling sequence. Again, the forward angular fluxes were coupled with the adjacent boundary angular fluxes, rotated -120° and coupled again. The ^{235}U reaction rate contours from the forward case are shown in Figure 13. They indicate a significant effect which was confirmed by the reaction rate ratio shown in case 3, Table VIII.

5. CONCLUSIONS

The results of the analyses indicated that a workable ex-vessel LLEM can be engineered for the CRBR with four or less in-vessel stored fuel assemblies. Procedural controls must be provided to assure that the inherent source is not locally depleted in only one region of the core during refueling (7). Confirmatory experiments on ZPPR are currently being planned by ORNL, GE-BRO, and WARD.

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