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METHODS FOR MONITORING
THE INITIAL LOAD TO CRITICAL
IN THE FAST TEST REACTOR

HANFORD ENGINEERING DEVELOPMENT LABORATORY
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D. L. Johnson

August 1975

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ABSTRACT

Conventional symmetric fuel loadings for the initial loading to critical of the Fast Test Reactor (FTR) are predicted to be more time consuming than asymmetric or trisector loadings. Potentially significant time savings can be realized by the latter, since adequate intermediate assessments of neutron multiplication can be made periodically without control rod reconnection in all trisectors. Experimental simulation of both loading schemes was carried out in the Reverse Approach to Critical (RAC) experiments in the Fast Test Reactor-Engineering Mockup Critical facility. Analyses of these experiments indicated that conventional source multiplication methods can be applied for monitoring either a symmetric or asymmetric fuel loading scheme equally well provided that detection efficiency corrections are employed. Methods for refining predictions of reactivity and count rates for the stages in a load to critical were also investigated.

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I. INTRODUCTION

One of the requirements of the Reactivity Surveillance Procedures (RSP) is that it provide reactivity monitoring during all subcritical operations. The standard way in which a reactor is monitored during the initial fuel loading is by plotting the inverse of the count rate of an in-core neutron detector as a function of the amount of fuel loaded. An extrapolation of the curve can provide an estimate of the number of additional fuel elements which can be loaded without producing a supercritical system. The basis for this method is the assumption that the reactivity of the subcritical system is inversely proportional to the steady state count rate, as shown below.

$$\rho_i = \frac{Q}{CR_i} \quad (1)$$

where ρ_i is the static reactivity, $\frac{K-1}{K}$, for configuration i,

CR_i is the steady state count rate of some detector,

and Q is assumed to be a constant.

This relation is derived from the point kinetics equation for steady state conditions from which it can be shown that Q is in reality not a constant but is given by

$$Q_i = \frac{\epsilon_i S_i}{\bar{\nu}_i}$$

where ϵ_i is the detection efficiency of the detector in units of counts per fission in the reactor for configuration i,

S_i is the effective external neutron source in the reactor for configuration i,

and $\bar{\nu}_i$ is the average number of neutrons per fission in the reactor.

The use of the inverse count rate relation therefore depends upon the degree to which Q remains nearly constant. In previous initial fuel loadings the inverse count rate method has worked reasonably well when near criticality and when fuel was loaded symmetrically about the core axis.

In the Fast Test Reactor (FTR) of the Fast Flux Test Facility there are two special features which could have a substantial effect upon the monitoring of the initial load to critical. First, the fuel itself provides a source of neutrons (e.g., from spontaneous fission and α, n reactions) and therefore the value of Q increases with the addition of each new fuel assembly regardless of where in the reactor it is loaded. Second, because of the longer time required to load fuel symmetrically, it may be more practical to make fuel additions asymmetrically (i.e., one trisector at a time). Asymmetric loading can be expected to cause Q to vary because the detection efficiency, ϵ_j , depends upon the orientation of the partially loaded core with respect to the location of the detector.

The special features of the FTR which were noted mean that there has been some doubt about whether or not the standard inverse count rate technique could provide a useful monitor of the initial load to critical. To study the problems of the initial FTR loading, a series of experiments was performed in the FTR-EMC in which the approach to critical was performed in reverse order [The Reverse Approach to Critical (RAC) experiments]¹.

The object of the work presented here is to demonstrate that the initial fuel loading in FTR can be safely monitored with either the inverse count rate technique or a suitable alternative. This will be done through use of the data from the RAC experiments coupled with calculations. In addition, an assessment of the relative merits of symmetric versus asymmetric fuel loading will be made.

II. BRIEF DESCRIPTION OF RAC EXPERIMENTS

The Reverse Approach to Critical experiments consisted of measurements in the FTR-EMC assembly with successively increasing numbers of fuel elements removed, both symmetrically and asymmetrically, from the fully loaded core. The data from these experiments consisted primarily of count rates from various neutron detectors (fission chambers) placed throughout the assembly including positions corresponding to the FTR low level flux monitors (LLFM). In addition, the reactivity of a few configurations was measured with the inverse kinetic rod drop technique (IKRD) and/or a

neutron noise technique in order to provide calibrations and data for any subsequent analyses.

To illustrate the configurations studied in the RAC experiment, Figure 1 shows schematic diagrams of the RAC configurations drawn as if the core were a right circular cylinder. The configurations are labeled B through G with B representing the fully loaded core and the others having some fraction of the fuel in rows 5 and 6 removed. Fuel removal is indicated by shading in the outer two rings. In configuration B the primary and secondary control rods are indicated by black dots and the positions of four near-midplane fission chambers (indicated by F5, F6, F7 and F10) are shown. The detectors at large distances from the core center (F5, F6 and F7) correspond to FTR low level flux monitors in the radial shield.

The figure is drawn to indicate two separate loading schemes which could have occurred starting from the bottom at G, the configuration having no fuel in rows 5 and 6, and moving upward. For each of the configurations there were one or more measurements made after withdrawing some or all of the control rods. A specific configuration of fuel and control rod pattern was indicated by a letter and number (e.g., G.1 was configuration G with all control rods withdrawn). Note that of the eight different fuel configurations, only three are loaded symmetrically (B, H and G) and the bulk of the data comes from asymmetrically loaded configurations.

III. ANALYSIS OF THE DATA FROM RAC EXPERIMENTS

This report is not intended to represent the complete analysis of the RAC experiments which will be presented at a later date. Rather it is an evaluation of that part of the available information which pertains to the question of, "What is required to adequately monitor the initial approach to critical in FTR?"

The first thing to examine is the question of how useful an inverse count rate plot would be in an initial load to critical. There was sufficient count rate data to make such plots for only two types of configurations: those with all control rods fully inserted and those with all rods fully withdrawn. Figure 2 shows plots of inverse count rates of

FIGURE 1. Simplified schematic diagrams of the configurations for which measurements were taken during the RAC experiments. Shaded regions indicate fuel removal. Reactivity increases from bottom to top.

various detectors (normalized to those occurring for configuration G) as a function of the number of fuel assemblies loaded in the outer core zone for configurations with all rods inserted. The two sets of data indicate the two separate loading schemes derivable from the RAC experiments as illustrated from bottom to top of Figure 1.

Notice that, as anticipated, the plots differ substantially depending upon which detector one uses. If one were to try to load the reactor, based upon such plots, it is quite likely that the most conservative approach would be taken. For example, in the bottom plot for detector F6, extrapolating beyond configuration F1 one would predict a critical system at about 18 fuel assemblies which would limit the next fuel loading to only two additional assemblies. The use of such plots, as are shown, would tend to unnecessarily slow down the loading procedure because of excessive conservatism.

It should be noted that the plots for the in-core detector (F10) differ from those of the other three LLFM detectors. The other three are very sensitive to the location of the fuel in the outer zone (see, for example, the wide variation in the data for configuration F1). Here the count rate for detector F6 is abnormally high because, for configuration F1, the fuel which has been loaded is all in the same trisector as the detector. The count rates for detectors F5 and F7 for configuration F1 are much lower because these detectors are farther away from the center of the fuel.

It should also be noted that even when the fuel is in a symmetric configuration there is a difference between the plots for the in-core detector and the LLFMs. See, for example, the data in the upper plots for configuration H1. Here, all the row 5 fuel has been loaded symmetrically, as shown in Figure 1. We see that all three of the LLFM detectors behave nearly identically because they are each the same distance from a symmetrical core but they differ from the in-core detector. This is because there is a difference in detection efficiency, ϵ , between the in-core position and the LLFM positions.

FIGURE 2. Plots of inverse count rates versus fuel elements loaded.

The conclusion to be drawn from this information is that the standard inverse count rate technique is unsatisfying for monitoring the initial approach to critical in FTR because the data are not proportional to reactivity and the conservatism necessary when using such plots would tend to lead to excessively slow fuel loading. It is clear from the above that a better monitoring scheme is highly desirable for the initial FTR loading.

An improved monitoring method is obtained by correcting the data, shown in Figure 2 for the changes in detection efficiency, ϵ , and source, S , which occur for the various configurations. Notice that the ratio of count rates which is plotted in Figure 2 can be expressed in terms of Equation (1), as follows:

$$\frac{CR_o}{CR_i} = \frac{\rho_i}{\rho_o} \left(\frac{Q_o}{Q_i} \right) \quad (2)$$

where the 'o' represents the reference configuration (in this case, configuration G which has no fuel in the outer core). Note that if Q did not vary between configurations then the count rate ratio would be equal to the reactivity ratio. It is because the Q s vary differently for each detector that the count rate ratios give the different plots shown in Figure 2. If one were to multiply the count rate ratio by the ratio of Q s appropriate for specific detectors one would then have the desired reactivity ratio. Thus,

$$\frac{CR_o}{CR_i} \left(\frac{Q_i}{Q_o} \right) = \frac{\rho_i}{\rho_o} \quad (3)$$

Only a few of the Q s were experimentally measured in the RAC experiment and, of course, they will not be experimentally known during the initial loading of FTR. They can be calculated, however, and the ratio (Q_i/Q_o) can be evaluated rather accurately. This was done for the configurations of interest in the RAC experiment using 4-group two-dimensional diffusion theory calculations in the source mode as described in Reference 2. The

calculations involved evaluating the reactivity, ρ_i , and the count rate, CR_i , for each of the configurations, 'i', and for each detector. Then, the ratio is given by

$$\frac{Q_i}{Q_0} = \left(\frac{\rho_i}{\rho_0} \frac{CR_i}{CR_0} \right)' \quad (4)$$

where the prime indicates that all quantities are calculated.

It should be noted that this ratio is evaluated in the same fashion as the configuration factors, F_i , which are used in the Modified Source Multiplication (MSM) technique of subcritical reactivity monitoring². The difference is that here the reference configuration is the farthest subcritical state; whereas, for MSM, the reference configuration is near critical and the reactivity, ρ_0 , is measured accurately for calibration purposes. If the reactivity, ρ_0 , of the far subcritical reference configuration of interest could be measured for calibration purposes, then the modified inverse count rate technique described here would be essentially identical to the MSM technique. This can be seen from Equation (3) which shows that the reactivity, ρ_i , could be inferred for any other configuration.

The results of applying the calculated correction factor (Q_i/Q_0) to the data of Figure 2 are shown in Figure 3. It should be noted that the plots are not expected to be linear since the relation between reactivity and the number of elements loaded is not generally a linear one. Nevertheless, we see that for the most part the large differences between the various detectors have been removed. For example, in the upper plots, lines for detectors F10 (in-core) and F7 (LLFM) nearly coincide. If the corrections were perfect, all lines should coincide since the data points are supposed to represent the ratio, ρ_i/ρ_0 , a global quantity independent of detector location.

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FIGURE 3. Modified plots of inverse count rate versus fuel elements loaded. Corrected for changes in detection efficiency and the effective neutron source.

The degree to which they do not coincide indicates the limitations in modeling the reactor in the calculations. In fact, there was an error in modeling the material near to detectors F5 and F6 which explains why their corrected plots do not coincide with the plots for detectors F7 and F10. (The wrong kind of steel was modeled in the regions surrounding F5 and F6.) The plots for detector F10 should represent the most accurate information since the modeling of an in-core detector is expected to be more accurate than that of a detector far outside the core in the radial shield region. It is gratifying to see that the LLFM detector which was modeled accurately (F7) follows the plots from the in-core detector (F10) very closely. This means that asymmetric fuel loading patterns (which affect each of the LLFMs differently) can now be handled just as well as symmetric fuel loading patterns.

One now has some confidence that the modified inverse count rate plots, such as shown in Figure 3, can be reliably used to estimate the amount of fuel that can be loaded at each stage of the initial approach to critical. There is conservatism already built into such plots since the curvature tends to flatten when more fuel is loaded. (The reactivity worth per assembly decreases.) For example, in the upper plot using configurations G3 and H1 and detector F10, one would predict a critical system when about 28 fuel assemblies were loaded, whereas in fact, the system with all rods inserted could not be made critical at all.

In practice, one is usually most interested in reaching criticality when some of the control rods have been withdrawn. In the initial load to critical, the first configuration that could, in principle, achieve criticality would be one having all control rods withdrawn. There may be some advantage in finding this configuration since it will have the least excess reactivity and the largest shutdown margin of any critical loading when the rods are inserted. The geometry of this first configuration which can achieve criticality will depend upon the loading pattern (which as yet has not been chosen).

When the loading pattern has been chosen (i.e., either symmetric or asymmetric) one can perform an approach to critical with the count rate data provided by the three LLFMs and an in-core detector (if available). Each different pattern of control rod insertions will constitute a separate approach to critical plot. For example, Figure 4 illustrates the modified inverse count rate plots taken from the RAC experimental measurements for configurations having all rods fully inserted and also all rods withdrawn. The two lines represent the extremes within which the data for an approach to critical with a different rod pattern must lie. Note that the minimum number of outer fuel assemblies required for criticality is predicted to be about thirty. Another rod pattern which may be of interest would be that in which one control rod in each trisector is fully inserted and all others are withdrawn. Such a configuration is expected to be near criticality when the core is fully loaded. The modified inverse count rate plot taken with such a control rod pattern would lie somewhere in between the two extremes shown in Figure 4.

IV. COUNT RATE PREDICTIONS

The modified inverse count rate plots, described in the previous section, can be successfully used alone to estimate the number of fuel elements which can be safely loaded at each stage in the initial approach to critical. As a supplement to this technique it is possible to predict the reactivity and count rate for a specific configuration prior to changing the reactor to that configuration (i.e., by loading additional fuel or withdrawing control rods). After the change has been made, a comparison of the measured and predicted count rates will indicate whether or not the reactivity that could be inferred (it cannot be directly measured) from the measured count rate is within the uncertainty range of the predicted value. This technique could supply some additional confidence that the configuration after a change is made will still be subcritical.

The question that will be addressed in this section is what is required to provide accurate predictions of detector count rates and reactivities in the FTR initial approach to critical. Again, the data from

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FIGURE 4. The two extreme modified inverse count rate plots.

the RAC experiments were analyzed to provide this information.

The first thing done was to check how well the detector count rates could be calculated as compared to the count rates measured for each configuration. The calculations were the same as those described earlier which provided a prediction of the reactivity and count rates for each configuration. The measured and calculated count rates for each detector were compared by evaluating the ratio. An example of the dependence of this ratio upon the calculated reactivity is shown in Figure 5 for the in-core detector (F10).

If each reactor configuration were accurately modeled, one would expect the ratio to be the same for all configurations and independent of reactivity. The ratio can be less than unity, however, since it is proportional to the detector efficiency which was not known and not included in the calculations. Notice that the ratios in Figure 5 are not independent of reactivity but decrease as a function of subcritical reactivity. This is expected, since the calculations have not accounted for small biases and corrections to the model.

Let us say, for example, that the unbiased reactivity, calculated for a specific configuration, ρ_i^{CALC} , has a certain reactivity bias value, B_i , associated with it. Additional small corrections can occur because the core temperature during the count rate measurement may be different from that in the model, and also because the reactivity of the system may differ from the calculated value because of the decay of ^{241}Pu .

If one knew the bias value and other correction terms one could then evaluate an improved value of the reactivity of the system which should correspond closely to the actual reactivity. For example, the corrected reactivity can be expressed as

$$\rho_i^{\text{CORR}} = \rho_i^{\text{CALC}} + B_i + (T_i^{\text{MEAS}} - T_i^{\text{CALC}}) C_1 + (D_i^{\text{MEAS}} - D_i^{\text{CALC}}) C_2 \quad (5)$$

FIGURE 5. The ratio of measured to calculated detector count rates as a function of calculated reactivity. The solid line indicates only the general trend of the data. Reactivity bias corrections have not been applied.

where T_i^{MEAS} is the temperature of the reactor core at the time of the count rate measurement (approximately isothermal).

T_i^{CALC} is the core temperature used in the calculations.

C_1 is the partial derivative of the reactivity with respect to temperature (here assumed to be a constant).

D_i^{MEAS} is the day on which the count rate was measured.

D_i^{CALC} is the day corresponding to the fuel composition used for the calculations (normally, $D_i^{CALC}=0$).

C_2 is the partial derivative of the reactivity with respect to time (in days) due to decay of ^{241}Pu (here assumed to be a constant).

The temperature and decay corrections are generally much smaller than the bias; however, when the reactivity is small, they can have a significant effect.

The calculated count rate can be corrected for bias and other known corrections in the following manner. One can assume that for such small changes the product of the reactivity and count rate of a given detector is a constant (see Equation 1, for example). Therefore, using Equation (5), the corrected count rate is

$$CR_i^{CORR} = \frac{\rho_i^{CALC}}{\rho_i^{CORR}} CR_i^{CALC} . \quad (6)$$

Now when one takes the ratio of the measured count rate to the count rate which has been corrected for bias, etc., one should get a value nearly independent of the configuration and proportional to the detector efficiency. Here, this constant is defined as

$$\alpha \approx \frac{CR_i^{MEAS}}{CR_i^{CORR}} = \frac{CR_i^{MEAS}}{CR_i^{CALC}} \frac{\rho_i^{CORR}}{\rho_i^{CALC}} . \quad (7)$$

Using Equation (7), one can see that the ratios plotted in Figure 5 should vary with the calculated reactivity with a dependence given by

$$\frac{CR_i^{MEAS}}{CR_i^{CALC}} = \frac{\alpha \rho_i^{CALC}}{\rho_i^{CORR}} \quad (8)$$

where ρ_i^{CORR} is as in Equation (5).

For the initial load to critical in FTR the quantities which are desired are predictions of the reactivity and the corresponding count rates to be compared to measured values. The predicted count rate for a given detector is called,

$$CR_i^{PRED} = \alpha CR_i^{CORR} = \frac{\alpha \rho_i^{CALC}}{\rho_i^{CORR}} CR_i^{CALC} . \quad (9)$$

In order to make such a prediction one needs two things in addition to the calculated reactivity and count rate: the value of α , and the bias value, B_i (one assumes the other corrections are well known). If one knows the bias for one configuration however, one can determine a value for α by taking the ratio, as in Equation (7). One can then assume this value applies to other configurations which are desired. Thus we find that accurate reactivity bias values are the quantities required for those configurations for which a predicted count rate is needed.

These biases were not known prior to analysis of the RAC experiments and therefore their values will provide one of the major results of the analysis. From this set of values one must then determine a simple correlation which will allow the prediction of biases for configurations in FTR which had no corresponding measurement in the FTR-EMC-RAC experiments.

The bias value for each configuration, B_i , was determined for each detector by requiring that Equation (7) (using Equation 5) be satisfied for each configuration. The value of α for each detector was determined ex-

perimentally for a few configurations by using the measured reactivity, ρ_i^{MEAS} , in place of ρ_i^{CORR} , in Equation (7). The reactivity measurements were made with the Inverse Kinetics Rod Drop technique (IKRD). The best value of α for a detector was taken to be the average of four separate measurements. (For example, the value for detector F10 was $\alpha = .5565$.) For the in-core detector (F10) and one of the LLFMs (F7) the individual α values were within $\pm 2\%$ of the average value, hence it is believed that realistic values were obtained.

The bias values were determined for each configuration separately from detectors F10 (in-core) and F7 (LLFM). The other two detectors (F5 and F6) were not used in this part of the analysis because it is believed that they were modeled incorrectly, as described earlier. A plot of the bias values for the configurations that were evaluated using the best value of α is shown in Figure 6 for detector F10 (in-core).

Several things can be noted. It appears that the biases for configuration G do not follow the trend established for the other less subcritical configurations. The reason for this is not understood but it may be that the few group approximation, the self-shielding corrections, or perhaps the axial buckling is not sufficiently accurate for these configurations. It appears that the biases shown in Figure 6 may be interpreted using only the assumption that the worth for fuel removal and poison removal each has constant but different bias correction factors. This will be discussed in the following paragraphs.

The configurations having all rods in are represented by the square symbols. The bias appears to be linearly related to the subcritical reactivity for each of these states if we ignore configurations F1 and G3.

Such a linear relationship is what one would expect if there were a constant fuel worth bias correction factor which applied to the reactivity worth of fuel inserted or removed from the reactor. To illustrate this, let us say that the worth calculated for removal of some fuel between configurations 'i' and 'j', each of which has all the control rods fully inserted, is given by

FIGURE 6. Reactivity bias values as a function of the calculated reactivity. The lines represent a fit to the data with the function shown.

$$W_{ij} = \rho_j^{\text{CALC}} - \rho_i^{\text{CALC}} . \quad (10)$$

Then, if biases are ignored, the new reactivity is related to the old reactivity, as shown below:

$$\rho_j^{\text{CALC}} = \rho_i^{\text{CALC}} + W_{ij} . \quad (11)$$

When biases are included one sees that now

$$\rho_j^{\text{CALC}} + B_j = \rho_i^{\text{CALC}} + B_i + W_{ij} + \Delta B_{ij} \quad (12)$$

where ΔB_{ij} is the bias correction associated with the fuel worth. If we now define a bias correction factor, F_{FUEL} , such that

$$F_{\text{FUEL}} \times W_{ij} = W_{ij} + \Delta B_{ij} \quad (13)$$

then

$$\Delta B_{ij} = (F_{\text{FUEL}} - 1) W_{ij} . \quad (14)$$

Note that the C/E ratio for fuel worth is $1/F_{\text{FUEL}}$. It can easily be shown that this is equivalent to a linear relationship between the bias of a configuration and the calculated reactivity.

$$B_i = B + (F_{\text{FUEL}} - 1) \rho_i^{\text{CALC}} \quad (15)$$

where B is a constant bias. This expression provides a good fit to the configurations having all rods in, as shown in Figure 6.

If one or more control rods are withdrawn from a configuration having some fuel removed but initially with all control rods fully inserted, then the resulting change in bias is similar to that for fuel removal, and is given by

$$\Delta B_{ij} = (F_{\text{POIS}} - 1) W_{ij} \quad (16)$$

where F_{POIS} is the bias correction factor for poison removal and $W_{ij} = \rho_j - \rho_i$ is the worth for removal of poison from configuration 'i' which had all rods inserted. The C/E ratio for poison worths is $1/F_{POIS}$. Finally, we assume that the bias value for any configuration having a combination of fuel removed and poison withdrawn from the reactor can be expressed as

$$B_j = B + (F_{FUEL} - 1) \rho_i^{CALC} + (F_{POIS} - 1)(\rho_j^{CALC} - \rho_i^{CALC}) \quad (17)$$

where 'i' is a configuration having all rods inserted, and 'j' is a configuration having some poison withdrawn from configuration 'i'.

This expression was fit to the bias values determined for detector F10 (in-core) and F7 (LLFM) in order to determine the constants, B, F_{FUEL} , and F_{POIS} . This type of analysis was only partially successful. For detector F10, it was possible to establish values of B and F_{FUEL} which fit most of the configurations having all control rods in. It was difficult to establish a value for F_{POIS} which fit all the biases with poison removed; the factor appeared to vary with the subcriticality of the configuration from which the rods were removed. The nearly horizontal lines shown in Figure 6 illustrate the dependence expected when one uses a value for F_{POIS} which is appropriate for the less subcritical configurations. Note that there are some bias values which do not lie close to one of these horizontal lines. It is not clear at this time whether or not the trouble lies with the assumption that F_{POIS} is a constant or with some remaining inaccuracies in the modeling. The values of F_{FUEL} and F_{POIS} that were used appear to be consistent with previous EMC analyses.

To see how well the count rates can be predicted when Equation (17) is used to predict the bias values, we show in Figure 7 the ratio of the measured count rates to the predicted count rates (from Equation 9) as a function of the calculated reactivity. The value of α was taken to be that determined earlier from experimental IKRD measurements. Notice that even with the inaccuracies in predicting the bias values, most of the predicted count rates are within $\pm 10\%$ of the measured count rates. The predictions which are very far from the measured value (e.g., the I1 configuration) are

FIGURE 7. The ratio of measured to predicted detector count rates as a function of calculated reactivity. Here reactivity bias corrections have been applied.

disturbing since the cause is not yet known and more accuracy in the technique will be required for use in the FTR approach to critical.

The analysis just described for detector F10 (in-core) was also applied to detector F7 (LLFM). Unfortunately, the results were not as satisfactory. It was possible to determine a value for B , F_{FUEL} , and F_{POIS} using the biases determined from detector F7 but they were considerably different from those of detector F10 and the fit was not particularly good because of scatter in the bias values which were fit. When the count rates were predicted using the predicted bias values, larger deviations from the measured count rates were observed than for detector F10. It is believed that the problem lies in the modeling of the reactor near the LLFM positions. It appears that more care will be required to provide adequate predictions of the count rates in LLFM positions which are far from the core.

V. SUMMARY

It has been shown that a modified inverse count rate technique could have been used to satisfactorily monitor a simulated approach to critical in the RAC experiment. The modification involves a straightforward correction for the changes in effective neutron source strength and detection efficiency which occurred in the various configurations of the RAC experiment. The technique seems to be applicable to either a symmetric or an asymmetric loading pattern, hence either of these options can be expected to be monitored safely in the initial FTR approach to critical.

In addition to monitoring the approach to critical, some work has been done to refine the techniques for predicting the reactivities and count rates of the very far subcritical states which will occur during the initial approach to critical in FTR. Partial success has been achieved by assuming that reactivity bias values, which are required for accurate predictions of each configuration, can be described in terms of bias correction factors applicable to both fuel and poison reactivity worths. If reliable predictions are to be made before fuel or poison is moved during the FTR approach to critical, then improvements in the modeling will be required. For

example, additional zones for evaluating self-shielded cross sections, additional energy groups, and variation of the axial buckling can be examined.

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