IMFBR REACTIVITY SURVEILLANCE USING EX-CORE DETECTORS

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In this paper some aspects of general reactivity surveillance of LMFBRs are considered. For both FFTF and CRBR, surveillance during shutdown or refueling is to be accomplished with detectors placed outside the pressure vessel. The modified source multiplication (MSM) technique will be used to convert the detector signal to a reactivity. Validation of this low-level flux monitoring approach has come through critical experiments for both FFTF and CRBR. Because of their importance to plant safety, the FFTF experiments have been analyzed in some detail. While these analyses have been concentrated on specific experiments, the generic implications of reactivity predictions using ex-core detectors have not received much attention. It is to this latter area that the present study is addressed.

In using MSM, reactivity change is inferred from the inverse count rate of a particular detector, a known reference reactivity and count rate, and a series of multiplicative factors that are generally based on calculations. By far the two most important of these corrections are detector efficiency and effective neutron source changes.

The effective source term involves the ratio of the average importance of source neutrons compared to the average importance of fission neutrons. This ratio is then computed at a reference and perturbed condition to form an effective source factor. It is a term generally dominated by the neutron flux and adjoint flux in the core, with little influence noted from beyond the core regions. Because of this fact few-group diffusion theory appears to be adequate. Actually the effective source correction can be determined experimentally by using: (a) \textsuperscript{252}Cf importance data which measure the importance of fission neutrons, (b) fission chamber or foil irradiation data which measure the total fission rate, and (c) the known distribution of source neutrons from \textsuperscript{240}Pu spontaneous fission. Experience has shown that few-group diffusion calculations of these parameters compare quite favorably with measured values. The effective source factor has been observed to lie generally within \pm 10\% of unity, over a wide range of core perturbations done on ZPPR.

The detector efficiency is defined as the rate of events in the detector relative to the fission rate in the entire reactor. A detector efficiency factor is obtained by comparing this ratio in a perturbed state to that at the reference condition. This ratio is a sensitive function of detector location, and of the type of perturbation considered. For this reason past computations of ex-core detector efficiency changes have often involved very detailed methods. In Fig. 1 a detector efficiency ratio map is shown from ZPPR-7B, where the perturbation consists of inserting B\textsubscript{4}C mockup rods in the six positions in the outer control ring.

One characteristic of detector efficiency factors appears in the figure. As one goes outward from the core center along a ray, the factor is almost constant starting at about the radial reflector. The reason for this is that the source in the reactor begins to look like a point source. It is evident that there is a great deal of azimuthal variation, implying that the point
reactor source is dependent on an angular variable. An important point to note is that since the efficiency factor takes on an asymptotic value at about the radial reflector, few-group diffusion theory (which predicts the in-core and near-core flux quite well) is all that is required to predict efficiency changes for detectors located well outside the core.

Comparisons of diffusion and transport calculations have also revealed that even though the former method may fail in an absolute sense at distances far from the core, detector efficiency ratios computed with the two methods closely agree. Thus the inaccuracies inherent in diffusion calculations are present to approximately the same degree in both the reference and perturbed states.

Finally, from calculations and ZPRR experiments it appears that the particular type of ex-core detector (e.g., $^{235}$U(n,f), $^{10}$B(n,α)), and the local environment in which the detector is placed, have little or no impact on the efficiency change. This is because at radii beyond the radial reflector the spectral change induced by core perturbations is filtered through the blanket and reflector and is not significantly propagated beyond the reflector. Adjoint flux calculations$^{6,7}$ are useful in understanding this point, and reveal the birthplace and energy of neutrons which ultimately reach the ex-core detectors.$^{8}$

The conclusion of this work is that calculations necessary to use MSM techniques with ex-core detectors for reactivity surveillance can be simple few-group diffusion calculations. No matter how far the detectors are placed from the core, deep-penetration methods are unnecessary if the reactivity perturbations are confined to regions in the core.
Fig. 1. Detector Efficiency Ratios for Insertion of Outer Ring Rods in ZPPR-7B.
REFERENCES


