REACTIVITY OF SUBSTITUTION ELEMENTS

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Dr. R.L. Murray
North Carolina State College
Raleigh, North Carolina

Consultant

Alco Products, Inc.
Post Office Box 414
Schenectady, N. Y.

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Reactivity of Substitution Elements

Raymond L. Murray

Introduction.

A method is sought for predicting the reactivity differences between fuel elements attached to control absorbers and fixed fuel elements. (It is assumed that a simple method, readily understood and applied is of immediate interest.) The approach described in this report is based on a logic that is admittedly approximate, and which should be subjected to experimental check.

Physical Situations and Analysis.

There are several cases of interest, corresponding to various orientations of the control fuel element involved, and of the remaining control elements.

Case A. All control rods but one are fully inserted in the core; one control element is pulled out, thus introducing what will be designated as a follower fuel element.

A sketch of the arrangement is shown in Figure 1. Experimental measurements can be and have been made for this case. It is found that substitution experiments yield a good fit to the J_0^2 weighting. Calculations for the center line rod by two group, three region (core, element and reflector) are available,* and agree reasonably well with experiment. This success leads one to presume that in the region of the reactor containing other control absorbers that the flux is effectively a chopped Bessel function. This assumption will be assumed to include the special case of a bank region.

* APAE-27, page 89 ff.

Figure 1.

Case B. A control rod is pulled completely out of a core that contains a bank of other rods, partially withdrawn, as shown in Figure 2.

Since the bank has been raised from its original full in position, the net reactivity of the system increases. If K_{eff} were equal to 1 originally, it is now equal to a value greater than 1. Thus, any substitution of fuel of the follower for that in the fixed fuel element has a lesser effect on the reactor than in Case A, by the factor $1/K_{eff}$.

An additional effect is associated with the flux pattern. The neutron flux has become distorted to a shape involving a peaking in the lower region. Figure 3 shows typical plots of the flux distribution along the axis, in which the chopped cosine of Case A is compared with the distorted flux in Case B. The ratio of substitution reactivities for Cases B and A associated with flux distortions is given by perturbation theory as

$$\frac{\rho_B}{\rho_A} = \frac{\int_0^H \phi_B^2(z) dz}{\int_0^H \phi_A^2(z) dz}$$

Figure 3.

Axial Flux Distribution

where $\phi_A(z)$ is the cosine and ϕ_B is the new flux, the integrals of which can be taken as equal for essentially constant power normalization, i.e.,

$$\int_0^H \phi_A(z) dz = \int_0^H \phi_B(z) dz$$

The latter flux can be deduced from measurements or from window shade calculations.

Combining the reactor reactivity scale factor, the axial flux effect, and a possible off-center J_0^2 weighting, the reactivity difference (follower vs fixed fuel) is

$$\rho_B(r) = \frac{\rho_A(0) J_0^2 \left(j_0 \frac{r}{R}\right) \int_0^H \phi_B^2(z) dz}{K_{eff} \int_0^H \phi_A^2(z) dz}$$

where the functional dependency of ρ on r and 0 refers to elements at r and at 0 respectively.

Case C. The bank of rods is pulled out to a uniform distance, as shown in Figure 4.

Figure 4.

It is desired to estimate the reactivity difference due to followers, assuming the original interpolations or calculations (e.g. windowshade) were made assuming all fixed fuel elements. Here, the perturbation effect is relevant only in the lower portion of the reactor. The value of substitution reactivity difference of the portion of the follower that is within the core (a distance z) bears a ratio to the reactivity difference value if the follower were fully in the core:

$$\frac{\rho_C(z)}{\rho_A(H)} = \frac{\int_0^z \phi_C^2(z) dz}{\int_0^H \phi_A^2(z) dz}$$

where $\phi_A(z)$ is again the cosine distribution and $\phi_C(z)$ is the actual distorted distribution which is approximately as in Case B. Again, $1/K_{eff}$ scaling and J_0^2 weighting are to be applied.

Comments.

There are several weaknesses in the above procedure. For example, the distorted flux in the follower region of Case B is not necessarily equal to the windowshade plot, but is somewhat more peaked. One should use experimental flux traverses along this axis, if available. Also, use of a perturbation theory implies an essentially critical reactor, whereas the reactor with bank out definitely has a K_{eff} greater than unity.

The method is felt however, to contain most of the physical factors, exclusive of fine structure effects.