CONF-840901--3

DE84 010506

CONF-840901--3

FIXED-SOURCE PERTURBATION WORTH CALCULATIONS

K.S. Smith and R.W. Schaefer

Argonne National Laboratory-West
Applied Physics Division

INTRODUCTION

Material worth measurements are routinely performed in fast reactor critical programs. Until recently, such measurements were usually made by inserting cylindrical samples via stainless steel tubes.[1] Such measurements pose difficult problems for the analyst since the geometry is very complicated. An alternative measurement utilizes a drawer oscillator[1] to remove or insert a fuel plate. In such a measurement, samples are large enough to cause significant distortions of the local flux. Consequently, it is important to account for local flux distortions when calculations of such experiments are performed. Traditional analysis techniques have not addressed many of the complicated phenomemon associated with the measurements, and large (10-20%) discrepancies exist between calculated and experimental sample worths.[2] The intent of this paper is to describe new analysis techniques which have been developed to compute accurately sample worths for complicated geometries and large perturbing samples.

In traditional analysis of plate removal experiments, exact perturbation calculations are usually performed. The term exact refers to the fact that the reactor flux distribution has been computed for the perturbed and unperturbed configurations. The difficulty with exact perturbation calculations in plate-type critical assemblies is that the reactor calculations are performed with cross sections that have been spatially homogenized over each drawer. As a result, the accuracy of the exact perturbation calculation is limited by the accuracy of the flux distributions that were used to perform the homogenization. Traditionally the flux distributions are obtained from one-dimensional repetitive lattice calculations. In the experiments, a single drawer is perturbed, and the assumption of an infinite lattice is suspect. In addition, multidimensional effects are not treated.

A FIXED SOURCE PERTURBATION METHOD

In order to avoid these difficulties, a new method for performing sample reactivities has been developed. By starting from the static neutron balance equation for the real and adjoint angular fluxes, one can derive a rigorous expression for reactivity of the following form:

$$\frac{\Delta k}{k} = \frac{k_o \int_S \psi_o^{*+} (\psi^+ - \psi_o^+)\Omega \cdot n}{\langle \psi_o^* B_o \psi \rangle_r} , \qquad \text{Eq.1}$$

where S is the surface between the perturbed region of the reactor and the unperturbed region of the reactor, r,

ψ and ψ_o are the outgoing angular fluxes for the perturbed and unperturbed configurations,

and B_o is the fission production operator.

The physics of the terms in Eq. 1 is easily understood. The numerator is simply the change in the rate at which importance is introduced into the unperturbed region of the reactor from the perturbed region of the reactor. The denominator is simply the rate at which neutron importance is produced in the unperturbed region of the reactor.

Equation 1 is evaluated by using a combination of full assembly calculations and local fixed-source calculations. Full assembly XYZ diffusion calculations are performed to obtain the denominator of Eq. 1. The double P_0 approximation[3] is used to approximate the incoming angular flux (c_0^-) and outgoing adjoint flux (ψ_o^{*+}) on the surface of the perturbed region of the reactor. The numerator in Eq. 1 is approximated by performing two fixed-source response calculations to obtain ψ^+ and ψ_o^+, that is

$$\psi^+ = R\,\psi^-, \qquad \psi_o^+ = R\psi_o^-, \qquad \text{Eq. 2}$$

where R_o and R represent the unperturbed and perturbed neutron transport operators. The implicit assumption in Eq. 2 is that the angular flux entering into the perturbed region of the reactor is unaffected by the perturbation. The denominator of Eq. 1 is approximated by assuming that fission production in the unperturbed region of the reactor is unaffected by the perturbation.

APPLICATIONS

The fixed-source problems have been solved by both discrete ordinates and Monte Carlo methods. One-dimensional S_n calculations have been most useful in validating the method with model problems. When complex three-dimensional geometries or sample resonance effects are important, continuous energy Monte Carlo calculations are used. The VIM[4] code was modified to perform these Monte Carlo calculations.

The fixed-source perturbation method has been applied to sample worth experiments in two critical assemblies. In the small but LMFBR-like assembly, ZPPR-12,[5] the worth of removing a 25.4 mm-long segment of fuel and the worths of substituting different fissile materials in this slot were calculated. In the hard spectrum, uranium-fueled assembly, U9,[6] a planar enriched uranium (EU) foil in a cavity transverse to the core plate loading was calculated. Diffusion theory assembly calculations and Monte Carlo fixed-source calculations were

used. The fixed-source calculations modeled, in plate-by-plate detail, the sample and a ~50 mm-thick region of the core surrounding the sample. Approximately 80 CPU minutes on an IBM 3033 computer were required for the Monte Carlo calculations of each sample, and results are shown in Table I. The ZPPR-12 fuel removal/substitution worths were as large as 10 cents, allowing statistical precision approaching 1%. The U9 sample was designed to be as nonperturbing as possible, such that it could be computed by standard deterministic methods. Despite the very small worth of the sample in U9, less than 1 cent, the Monte Carlo statistical precision was 6%.

CONCLUSIONS

The fixed-source perturbation method avoids the problems of generating effective homogenized cross sections for the perturbed region by allowing explicit calculation of the sample and its local environment. The assumptions made in its derivation are well satisfied by conditions of the small sample experiment. By using continuous energy Monte Carlo to solve the fixed-source problems, the geometric (and cross section) complexity found in experiments can be modeled. Monte Carlo-based perturbation calculations have been attempted in the past,[7] but the current effort marks the first time that actual small sample experiments have been analyzed with reasonable statistical precision. With only modest efficiency improvements it should be possible to calculate typical small sample worths to 1% statistical precision and to address local sample environment effects, the last remaining issue in the longstanding (fissile) central worth discrepancy.[8]

1. W.G. Davey and W.C. Redman, Techniques in Fast Reactor Critical Experiments, Chapter 2, Gordon and Breach Science Publishers, NY (1970).

2. L.G. LeSage and R.D. McKnight, "Discussion of Integral Experiment C/E Discrepancies," Proc. Inter. Conf. on Nuclear Cross Sections for Technology, Knoxville, TN, NBS Special Pub. 594 (1979).

3. A.F. Henry, Nuclear Reactor Analysis, MIT Press, Cambridge, MA (1975).

4. R.N. Blomquist, R.M. Lell, and E.M. Gelbard, "VIM - A Continuous Energy Monte Carlo Code at ANL," (Argonne National Laboratory) Proceedings of a Seminar-Workshop, Oak Ridge, TN, April 21-23, 1980.

5. K.S. Smith and R.W. Schaefer, "Recent Developments in the Central Worth Discrepancy," Nucl. Sci. Eng., (to be published).

6. R.W. Schaefer and R.G. Bucher, "Calculated and Measured Reactivities in the U9 Critical Assemblies," Proc. Topical Mtg. on Advances in Reactor Physics and Core Thermal Hydraulics, Kiamesha Lake, NY, Sept. 22-24, 1982, Nucl. Reg. Com., NUREG/CP-0034, 1, p. 93 (1982).

7. U. Feldman et. al., "Monte Carlo Small-Sample Perturbation Calculations," Proc. of Topical Meeting on Advances in Reactor Computations, Vol. II, p. 124, Salt Lake City, UT, March 28-31, 1983.

8. W.W. Little, Jr. and R.W. Hardie, "Discrepancy Between Measured and Calculated Reactivity Coefficients in dilute Plutonium Fueled Fast Critical," Nucl. Sci. Eng., 36 p. 115 (1969).

Table I. Sample Worth Results

Assembly	Sample	Measured Worth, ¢	C/E
ZPPR-12	CLAD Pu-U-Mo	7.1 ± 0.2%	1.08 ± 2.5%
ZPPR-12	CLAD Pu-Aℓ	10.8 ± 0.2%	1.08 ± 1.4%
ZPPR-12	EU	7.8 ± 0.2%	1.14 ± 1.8%
U9	EU	0.8 ± 0.5%	1.00 ± 5.7%

DISCLAIMER