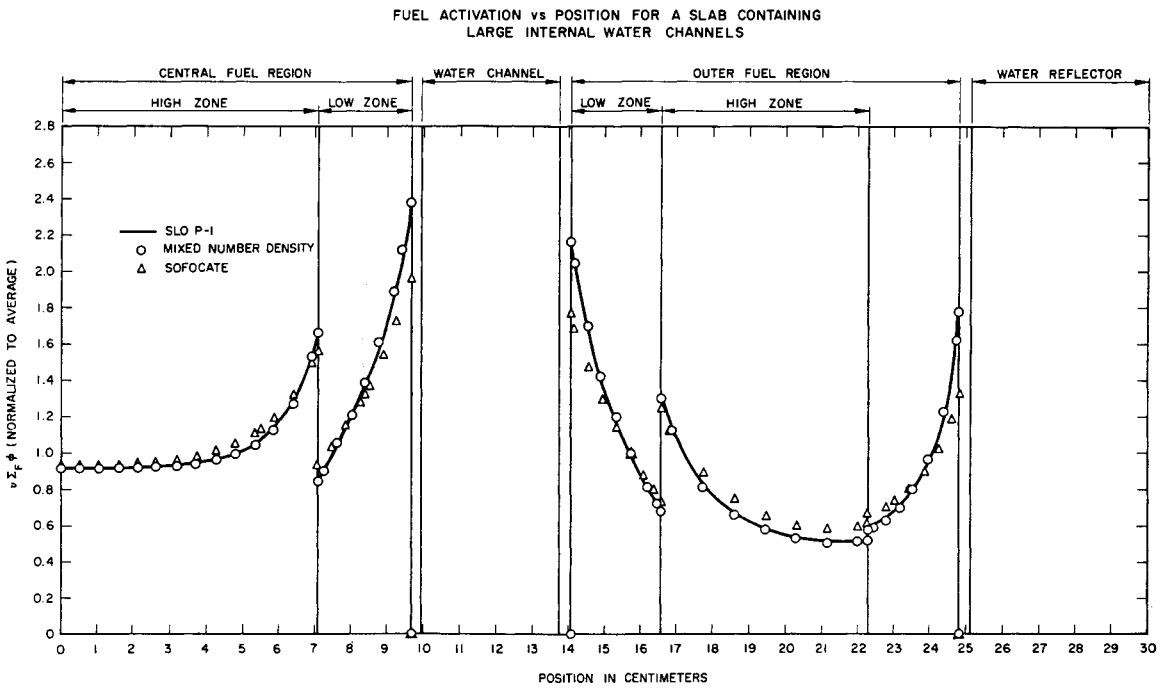

FIG. 3. Fuel activation versus position for a slab containing large internal water channels.

Wright and Feiner (*4*) from the analysis of water-gap peaking experiments. In effect, this representation combines the local SOFOCATE thermal utilization with a maxwellian activation shape.

An additional utility of this model lies in its ready application to existing few-group diffusion theory codes in one, two, or three dimensions. Comparisons of this model to both one and two-dimensional activation experiments are in progress and appear to verify its applicability when the Radkowsky prescription (*5*) is used for evaluating the scattering kernel.

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Let the Reactor Prevent Xenon Instability

The prediction of xenon spatial oscillations in large high-flux reactors has received considerable treatment in the literature by the reactor dynamics approach. It is difficult for most engineers or managers to satisfactorily judge the feasibility of a given reactor design with respect to the complex calculational results. I would like to suggest the use of two other familiar concepts in approaching this problem which are easily understood and which I feel support two practical conclusions:

(1) With proper design and operating flexibility it is practicable to expect good flux distribution control in spite of calculated indications of "instability thresholds" (this statement is in complete agreement, incidentally, with the box summary given in reference *1*, and with the conclusions given in references *2* and *3*).

(2) The timing and detection of the phenomenon are slow relative to human response time, precluding the issue of nuclear safety.

The suggested concepts, whose application is described below, are: (i) local buckling, or what might be called a "pseudo k_∞"; and (ii) very long priods or "trends," indicative in cases of constant total reactor power of increasing or decreasing local bucklings. Use of these concepts is aimed at obviating oscillations rather than describing them mathematically.

Suppose that in some subvolume of the pile, say region A, the net amount of xenon is increasing, whereas it is simultaneously decreasing in a symmetrical subvolume B. One could conclude, "xenon oscillations are starting, so start watching for the flux oscillations." But suppose that by means of astute control rod movements, the "pseudo k_∞" of subvolume A (the net multiplication within that

region including gains and losses from xenon, temperature effects and control rod movement in that subvolume) remained constant with time; and by similar control maneuvers assume that the "pseudo k_∞" of subregion B is also held constant with time. Then no flux distortion effects due to the xenon changes taking place within subregions A or B would occur, and the feared oscillation could not develop. Thus, use of the local buckling, or "pseudo k_∞" concept can make the "inherent instability" phenomenon academic if one is only astute enough to move the right amount of rod in the right place at the right time.

Here the concept of "trend" control makes the astute control maneuver simple. A monitor point within subvolume A sensitive to neutron flux level informs the operator whether that region is increasing or decreasing in flux level. With the total reactor power held constant, such a local change in flux corresponds to a very long reactor period measurement thus indicating a local change in reactivity. Therefore, a control tip within subvolume A is inserted or withdrawn to keep the local flux indicator, and thus the local "pseudo k_∞," at a near constant level. Similarly, the trend is noted in region B, and compensating rod moves are made in region B.

Probably the main reasons these concepts work in practice (which they have for many years) are that: (i) they are based on sound reactor physics concepts; and (ii) reaction times of the instruments and operators are very short compared to the 9.2 and 6.7 hr half-lives of Xe^{135} and its precursor I^{135}, respectively.

One other point—the possibility that these slow (order of hours) xenon oscillations could threaten reactor safety (*4*) would imply that the reactor under study was not adequately instrumented and operated to control those flux distortions which frequently arise due to other operating factors. In other words, xenon spatial oscillations should be regarded as an operating efficiency factor, not as a nuclear safety hazard.

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Thermal Neutron Flux in a Cell with Temperature Discontinuities

In solving the reactor equations, it is customary to treat the thermal neutrons as a monoenergetic group, with the slowing down density as a source term. By taking appropriately averaged cross sections for this equivalent thermal group, reasonably accurate calculations can be made for a homogeneous reactor. Many design problems in practice, however, involve adjacent regions with markedly different temperatures. The lattice cell of a reactor may contain high-temperature fuel elements, while the coolant may be below the boiling point of water. The interpretation of lattice measurements, in which the part of the lattice being studied is held at an elevated temperature, is complicated by uncertainties as to the width of the transition region caused by the temperature discontinuity.

Although a straightforward multigroup approach will solve the problem to any required degree of accuracy, many groups are needed to represent the energy distribution adequately, and the thermal calculation may require more effort than the rest of the analysis. As an alternative for design calculations, the following method employs the formalism of few-group theory while retaining the qualitative features of the neutron distribution in space and energy. The basic procedure is to approximate the actual neutron distribution by a superposition of overlapping thermal groups, one in equilibrium with each region of uniform temperature in the system. Neutrons in the non-equilibrium groups will then make transitions into the local equilibrium group at a rate which can be easily calculated for a heavy gas moderator.

Consider a system made up of N regions of different but uniform temperature and composition. Within the nth region, let $\chi_n(E)$ denote the equilibrium thermal neutron distribution (that is, the steady-state distribution that would exist in an infinite medium) normalized to unity with some convenient cutoff energy. The total flux, as a function of position and energy, will be approximated by

$$\phi(r, E) \cong \phi_1(r)\chi_1(E) + \cdots + \phi_N(r)\chi_N(E) \qquad (1)$$

where $\phi_n(r)$ is the total flux of neutrons at r in the group in equilibrium with region n. The individual group fluxes are defined throughout the system, and in general will have considerable overlap in energy.

Within region 1, the group fluxes will satisfy balance equations of the form:

$$\begin{aligned} &-D_1\nabla^2\phi_1 + \Sigma_{a1}\phi_1 = \Sigma_{12}\phi_2 + \cdots + \Sigma_{1N}\phi_N + q \\ &-D_n\nabla^2\phi_n + (\Sigma_{an} + \Sigma_{1n})\phi_n = 0, \qquad n = 2, \cdots, N \end{aligned} \qquad (2)$$

where D_n and Σ_{an} are the diffusion constant and absorption cross section for neutrons of the nth group, $\Sigma_{1n}\phi_n$ is the rate at which neutrons are transferred from group n to the equilibrium group 1, and q is the slowing down density of fast neutrons, all evaluated in region 1. Corresponding equations hold for each of the other regions. Although diffusion theory has been assumed, transport approximations such as spherical harmonics or S_N theory could also be used.

The transfer cross sections, Σ_{1n}, can be evaluated immediately under the assumption of a heavy gas moderator. To first order in $\mu = 1/A$, the ratio of neutron to moderator mass, the differential scattering cross section can be written (*1*)

$$\begin{aligned} &\Sigma_s(E \to E') \cong \Sigma_0\delta(E - E') \\ &+ \mu\Sigma_0 \cdot (E' + E)\sqrt{(E'/E)}[\delta'(E' - E) + kT\delta''(E' - E)] \end{aligned} \qquad (3)$$

where Σ_0 is the bound atom cross section, T is the Kelvin temperature of the moderator, and k is the Boltzmann