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Title: Further Investigation of Spectral Temperature Feedbacks

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FURTHER INVESTIGATION OF SPECTRAL TEMPERATURE FEEDBACKS

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INTRODUCTION

A renewed interest in the phenomenon of possible positive temperature reactivity feedback coefficients in dilute fissile solutions has occurred over the past ten years.[1,2] Examination of the geologic disposal of fissile materials often includes the study of the possibility of autocatalytic reactions (those with positive feedback coefficients of reactivity) as the result of the different effective multiplications for fissile material in wet and dry ground. However, another postulated autocatalytic reaction occurs for dilute solutions of plutonium. Such solutions have been seen, through calculations, to have positive temperature reactivity feedback coefficents.[3,4] Including a non-$1/v$ neutron poison like gadolinium enhances the effect (although larger feedback coefficients are unimportant if criticality cannot be achieved).

This paper serves two purposes: (1) to introduce some new calculations of the temperature coefficients for uranium solutions, and (2) to examine some simplified calculations based on earlier work.[4] Uranium solutions, while never having positive temperature coefficients, show trends in the feedback coefficient as a function of solution concentration that are similar to those seen for plutonium solutions. For both the plutonium and uranium solutions, the feedback coefficient experiences a local minimum near the over/under moderation transition point. The earlier work on the simplified calculations is expanded to include better treatment of cross sections and to include strict numerical integration techniques.

BACKGROUND

The temperature coefficient of reactivity feedback has essentially two components, the feedback from density changes as a function of temperature and the feedback from changes in the thermal neutron spectrum that result from temperature changes. The latter effect is the result of the energy-dependent cross sections for neutron interactions; as the thermal neutron spectrum is altered by changes in the macroscopic temperature of the system, different nuclear interaction cross sections are encountered by the neutrons. This causes increases or decreases in the fission and parasitic absorption rates, which directly translates to a reactivity feedback mechanism.

The change in reactivity, R, as a function of temperature is given formally by

$$\frac{dR}{dT} = \frac{\partial R}{\partial \rho}\frac{d\rho}{dT} + \frac{\partial R}{\partial T_n}\frac{dT_n}{dT} \quad . \tag{1}$$

The first term in Eq. (1) describes the (geometry-dependent) reactivity feedback as a result of density changes as a function of temperature, and the second term in Eq. (1) describes the (material-dependent) reactivity feedback that results from neutron spectral shifts as a function of temperature. It is this second term that is of interest in this paper. If the system contains large amounts of hydrogen, then the neutron spectrum will be very thermalized. If the thermal flux can be approximated by a Maxwellian distribution, then the thermal neutron flux is given by

$$\phi_M(E,T_n) = C\frac{E}{T_n^{3/2}}e^{-E/kT_n} \quad , \tag{2}$$

where C is a constant and k is Boltzmann's constant. Using the standard four factor formula definitions for a thermal system ($\varepsilon \approx 1, p \approx 1$), the reactivity, which is defined as usual as $(k-1)/k$, is

$$R = 1 - \frac{1}{k} = 1 - \frac{\int_0^{E_T} dE\ \phi_M(E,T_n)\ \Sigma_a(E)}{\int_0^{E_T} dE\ \phi_M(E,T_n)\nu\Sigma_f(E)} \quad , \tag{3}$$

where E_T is the upper limit of the thermal region (assumed to be 0.4 eV) and the usual definitions of the macroscopic cross sections are used. Eq. (3) clearly exhibits the temperature dependence of the reactivity. Differentiating Eq. (3) with respect to the neutron temperature yields the spectral temperature feedback coefficient as

$$\alpha = \frac{\partial R}{\partial T_n}\frac{\partial T}{\partial T} = \frac{1}{[k(T_n)]^2}\frac{dk(T_n)}{dT_n} = \frac{1}{T_n}\frac{I(\Sigma_a)I'(\nu\Sigma_f) - I(\nu\Sigma_f)I'(\Sigma_a)}{I(\Sigma_a)^2} \tag{4}$$

with

$$I(\Sigma) = \int_0^{E_T} dE\ \Sigma(E)\, E\, e^{-E/kT_n} \quad , \tag{5a}$$

and

$$I'(\Sigma) = \int_0^{E_T} dE\ \Sigma(E)\, E\, e^{-E/kT_n}\left[\frac{E}{kT_n} - \frac{3}{2}\right] \quad . \tag{5b}$$

Eqs. (4) and (5) allow for a simplified analysis that can be performed to estimate the spectral reactivity feedback coefficient in dilute solutions of fissile material.

RESULTS

A simple algorithm has been constructed to perform the calculations implied by Eqs. (4) and (5). The microscopic cross sections are fit to appropriately defined curves based on experimental data up to 0.4 eV (E_T). Integrals were evaluated using Romberg integration[5] or iterative Gauss-Legendre quadrature, where successively larger quadrature orders are used until two or more calculated values of the integral are within a prescribed tolerance.

The spectral temperature coefficient is essentially a property of the material; however, the critical assemblies are of finite size. The effects of density changes in a finite geometry can be included in a total temperature coefficient calculation for a critical system by first estimating the radius of the critical system using standard one-group theory.[6] This would yield a total temperature coefficient of reactivity.

Several calculations have been performed to determine the accuracy of the aforementioned treatment. First, the infinite-medium effective multiplication is easily determined using Eq. (3). A comparison of the simplified treatment discussed here to a detailed 69-group calculation using DANTSYS[7] is shown in Figure 1. At small concentrations, the agreement is close, but as the concentration increases, results from the two methods diverge. The inability of the simplified model to treat the effects of over and undermoderation is the most likely explanation, and is readily visible when the infinite multiplication factors for the two models are compared. Also, the spectral temperature coefficient is not independent of the geometry, as the critical and infinite-medium 69-group calculations indicate.

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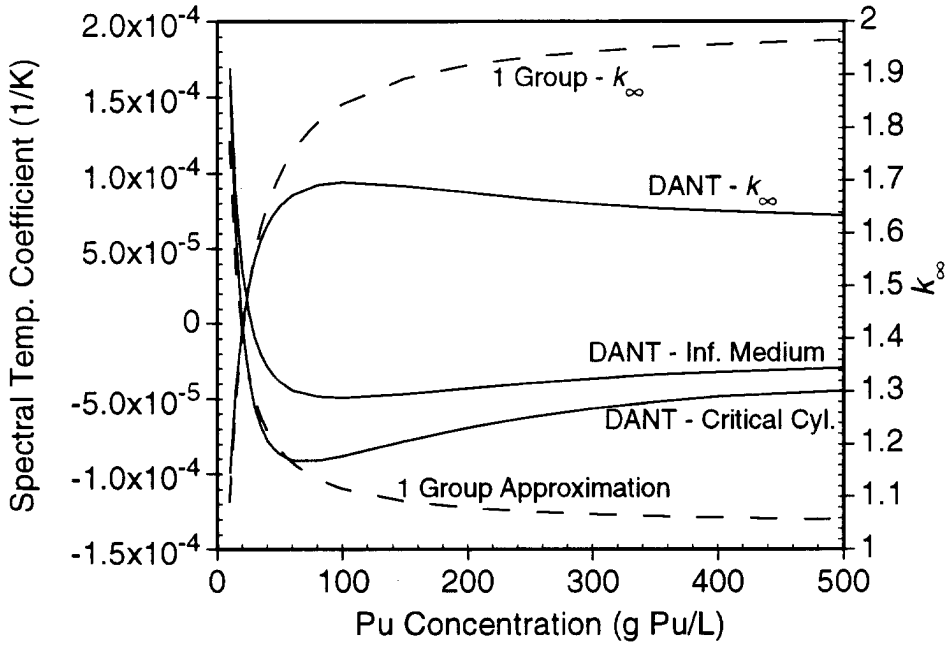

Fig. 1. The spectral temperature coefficient and multiplication factors for 69-group and 1-group models.

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