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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Harold Denton, Director
Office of Nuclear Regulatory Research

FROM: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER 118 VARIATION OF THE RESONANCE COMPONENT OF THE DOPPLER COEFFICIENT WITH DEPLETION

(L Shotkin DAE)

I. INTRODUCTION

As part of its commitment to provide the Office of Nuclear Reactor Regulation (NRR) with a better understanding of the physical basis for safety-related phenomena (Refs. 1 and 2), the Office of Nuclear Regulatory Research occasionally funds small university contracts for which there are no specific user requests, but which do complement other projects as well as increase physical understanding. This Research Information Letter reports the results of ~~one such project,~~ an analytical investigation of the effect of fission products on the resonance component of the local Doppler coefficient (Ref. 3). The Doppler effect, or broadening of nuclear resonant cross sections with temperature increase, is one of the major reactivity feedback mechanisms which terminates short-term power increases in nuclear reactors.

The work reported here complements an NRR-funded project at Brookhaven National Laboratory (BNL) which investigated the effect of depletion on the Doppler coefficient in boiling water reactors (Ref. 4). The present study (Ref. 3) includes the effect of fission products which was neglected in the BNL study, but which could significantly affect the magnitude of the Doppler coefficient at high burnup, or depletion. Although fission product effects are not explicitly referenced in some previous vendor studies (Ref. 5), NRC has been informed privately that their effect was included. Nevertheless, these vendor results differ from the results presented here.

II. TECHNIQUES FOR CALCULATING LOCAL DOPPLER COEFFICIENT WITH DEPLETION

Conventional calculation techniques, as typified by those used in the Brookhaven study (Ref. 4), do not account for the effect of fission product cross sections when calculating the Doppler coefficient with exposure. The buildup of actinides is included, especially Pu-240, which contributes toward making the Doppler coefficient about 20 percent more negative at an exposure of 30,000 MWD/T than at beginning-of-life (BOL) for a BWR. That is, the magnitude of the Doppler coefficient has previously been calculated to increase with exposure.

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In the present study of a BWR, the effect of fission product resonances on the resonance component of the local Doppler coefficient was calculated using the RABBLE code (Refs. 6 and 7). The extremely narrow group structure in this code permits one to take into account interferences and overlapping effects between resonances. For the calculations reported here, 17 broad energy subgroups were divided into ∿17,000 fine groups. RABBLE allows up to 16 resonant absorbers in a given calculation; 13 were used in this study. A graphical technique was used to choose those absorbers with the highest number densities and resonance absorption cross sections. The thermal and epithermal absorption of all other elements produced by the fuel depletion was also taken into account by introducing a pseudoelement with the appropriate number density and cross section.

The CINDER code (Ref. 8) was used to calculate the time-dependent number densities of the nuclides created by the fission process. CINDER is a general, one-point program which calculates the time-dependent concentration of nuclides following irradiation in a specified time-dependent flux. The cell characteristics calculated by the WIMS code (Ref. 9) were used as input data for the CINDER calculations. WIMS performs a spectrum calculation in the 69 energy-group structure for the unit cell and uses the resulting space-energy dependent flux to collapse the cross sections into a four-group structure. The calculations were carried out taking into account the spectrum changes during lifetime. The depletion out to 35,000 MWD/T was calculated in 100-hour time steps with readjustment of group ratios every 7,000 hours.

The above technique was checked out against a code sponsored by the Electric Power Research Institute (EPRI) which couples OZMA consistently with the well-known HAMMER code (Ref. 10). This latter code is limited in the number of resonant isotopes that can be handled explicitly with resonance profiles and was thus run with only 8 resonant absorbers, compared with 13 in the main study.

III. RESULTS

The results are expressed in terms of the fractional change in resonance absorption cross section from 800°K to 1200°K, $\frac{\Delta\Sigma a}{\Sigma a} = \frac{\Sigma a(1200°K) - \Sigma a(800°K)}{\Sigma a}$. Σa is averaged over the flux distribution in the epithermal energy group, as calculated by RABBLE, and averaged spacewise over the fuel cell. $\Delta\Sigma a/\Sigma a$ is the important resonance component of the Doppler coefficient (DC). The DC may be defined as:

$$\text{Doppler coefficient} = \frac{k\ (T_1) - k(T_2)}{k\ (T_1)\ k\ (T_2)} / (T_1 - T_2)$$

where the change in reactivity, $\Delta k/k$ is proportional to $\Delta\Sigma a/\Sigma a$.

Table I gives the results for beginning-of-life (BOL) and end-of-life (EOL) compositions for a BWR cell initially containing UO_2 fuel and surrounded by water with 40 percent voids. This table shows two main results.

TABLE I CALCULATED VALUES OF $\frac{\Delta\Sigma a}{\Sigma a}$

CODES	BOL	EOL	Isotope Composition Considered FISSILE/FERTILE	FISSION PRODUCTS
			U-235 Pu-239	Nd-145
				Rh-103
RABBLE/WIMS	0.0300	0.0296	U-238 Pu-240	Pm-147
				Xe-131
			Pu-241	Cm-244
			U-236 Pu-242	Tc-99
				Others lumped into a pseudoelement
RABBLE/WIMS	0.0300	0.0323	U-235 Pu-239	Nd-145
			U-238 Pu-240	Pm-147
			Pu-241	
			Pu-242	
HAMMER/OZMA	0.0296	0.0318		No lumped absorbers

First, compare the RABBLE/WIMS values for $\Delta\Sigma/\Sigma a$ for the two isotope compositions considered. When more fission products are considered at EOL, the resonance component of the DC changes much less with depletion. Second, compare the RABBLE/WIMS with the HAMMER/OZMA values for $\Delta\Sigma a/\Sigma a$ for the same isotope composition, the one with fewer fission products. The results are in reasonable agreement, especially if one considers the completely different cross section representation in the two calculations. In the WIMS calculations, resonance cross sections were calculated by the one-level Breit-Wigner formalism with the full set of ENDF/B-IV resonance parameters. In the HAMMER calculations, tabulated resonance profiles were utilized.

Thus, the results in Table I show that:

1. The RABBLE/WIMS system has been checked out with an independent calculation, and

2. When sufficient fission products are included, the Doppler coefficient may decrease in magnitude with depletion; it does not appear that it will increase with depletion as much as a calculation which ignores fission products (Ref. 4) or which does not treat them as rigorously (Ref. 5) as the present study.

Similar results were obtained (Ref. 3) for a thorium composition fuel cell. The $\Delta\Sigma a/\Sigma a$ for thorium fuel actually showed a more dramatic magnitude decrease in Doppler resonant effect with depletion than did the UO_2 fuel.

IV. EVALUATION

For UO_2, the decrease in $\Delta\Sigma a/\Sigma a$ with depletion, shown in Table I, is attributed partly to the direct competition of unsaturated fission product resonances with U-238 resonances and partly to the overlap of such fission product resonances with the wings of the U-238 resonances. There is an offsetting effect due to the buildup of Pu-240, the resonances of which quickly saturate, particularly at 1.06 ev. However, overall there is a calculated decrease in the magnitude of $\Delta\Sigma a/\Sigma a$, when both background and resonance absorption of fission products are included.

These results have not been translated into changes in the Doppler coefficient in the present study. An earlier version of these results did try to calculate the Doppler coefficient and was criticized in a careful review by BNL personnel (Ref. 10). It turns out that it is not necessary to calculate the DC directly in order to demonstrate the main physical effects of fission product cross sections. Other BNL criticisms (Ref. 10) have been answered by the comparison with the HAMMER/OZMA results, by investigating the effect of time-step size and by including the effect of smooth corrections (Ref. 3).

V. RECOMMENDATION

At the present time, this does not appear to be a safety issue, as there are many engineering factors at high burnup (fuel geometry, spatial variation of depletion in the core, spatial variation of moderator density, etc.) which may mitigate the physics effects on the Doppler coefficient. Nevertheless, this study is important in that it adds to our understanding of the calculation of the Doppler coefficient and can aid NRR in reviewing vendor calculations of accidents in which Doppler feedback is important.

Summarized in this RIL.

The physics-dominated calculations reported in this Research Information Letter are complicated and were not attempted before for light water reactor conditions. They represent a first attempt to scope out if the problem warrants further investigation.

An independent calculation of depletion effect on the Doppler coefficient has recently been completed under EPRI sponsorship (Ref. 12). This EPRI study confirms the results of the present study that, including fission products (both background and resonance absorption), tends to keep the Doppler coefficient constant with depletion, rather than allowing it to become more negative. These results imply that the conservative value of the Doppler coefficient for safety calculations of increasing-power transients is the beginning-of-life value, and no credit should be given for more negative values at end-of-life unless fission products are correctly included in the calculation.

DFRoss/for

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