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CALCULATION OF THE
ISOTHERMAL DOPPLER
COEFFICIENT FOR THE
SOUTHWEST EXPERIMENTAL
FAST OXIDE REACTOR (SEFOR)

MAY 1971

HANFORD ENGINEERING DEVELOPMENT LABORATORY

UNITED STATES ATOMIC ENERGY COMMISSION

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L. D. O'Dell

May 1971

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ABSTRACT

A series of one-dimensional calculations are described for the Southwest Experimental Fast Oxide Reactor, SEFOR. These calculations were performed in order to determine the model requirements for calculating the SEFOR Doppler coefficient. Selected whole core sodium worths were also calculated.

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1.0 INTRODUCTION

The one-dimensional diffusion code, 1DX⁽¹⁾, was used in spherical geometry to study the model requirements necessary for calculating the Doppler coefficient of core I-E⁽²⁾ of the Southwest Experimental Fast Oxide Reactor, SEFOR. This SEFOR core (I-E) which contained 627 fuel rods, 108 tightner rods, 14 B₄C rods, and 7 guinea pig rods was chosen for this study because reactivity temperature effects were measured on this core between 450°K and 678°K. These reactivity measurements were obtained by heating the whole core from the initial temperature of 450°K to 678°K. The primary sodium temperature was stabilized for two or three hours at 505°K, 617°K, and 678°K during the heating to ensure that both thermal and nuclear equilibrium were attained at these points. The reactor power level was held constant at 600 watts throughout the heating of the core.

The spherical model and compositions which were used in all calculations were obtained from reference (2) and an internal letter from P. Greebler, L. D. Noble, G. R. Pflasterer, and D. Wintzer on the "Predicted SEFOR Minimum Critical Loading" sent to distribution. These compositions and dimensions are given in Appendix A. The basic cross section set used throughout the calculations is a Cross Section Evaluation Working Group modification of the most recent ENDF/B Version II set. The temperature range over which the Doppler calculations were performed was from 300°K to 2100°K. The results of these calculations are described in Section 2.0.

In Section 3.0, the results of whole core sodium worth calculations are given. These calculations were performed in spherical geometry using 1DX and the modified ENDF/B Version II cross section set. Conclusions are presented in Section 4.0.

2.0 SEFOR CORE I-E DOPPLER COEFFICIENT CALCULATIONS

2.1 Individual Contributions of U^{238} , Pu^{239} , and Pu^{240} to the Doppler Coefficient

The individual contributions of U^{238} , Pu^{239} , and Pu^{240} were assessed by varying the temperature at which the cross sections of each of these three isotopes were calculated. The temperatures used for these three isotopes were 300, 700, 1400, and 2100°K, while the cross sections of all other isotopes were always calculated at a temperature of 300°K. All calculations were performed in 29 energy groups with no B_4C in the core. The results are given in Tables 2.1, 2.2, and 2.3 for U^{238} , Pu^{239} , and Pu^{240} respectively.

Several observations can be made from these three tables. First, note that U^{238} is by far the major contributor to the Doppler coefficient. Second, note that the contribution to the Doppler coefficient from each isotope is nearly constant over the temperature range between 300°K and 2100°K.

TABLE 2.1Contribution of U^{238} to the SEFOR Core I-E Doppler Coefficient

<u>Temperature Range ($^{\circ}K$)</u>	<u>δk_{eff}</u>	<u>Doppler ($T dk/dT$)</u>
300 to 700	-0.00691	-0.00815
300 to 1400	-0.01253	-0.00813
300 to 2100	-0.01576	-0.00810

TABLE 2.2Contribution of Pu^{239} to the SEFOR Core I-E Doppler Coefficient

<u>Temperature Range ($^{\circ}K$)</u>	<u>δk_{eff}</u>	<u>Doppler ($T dk/dT$)</u>
300 to 700	0.00018	0.00021
300 to 1400	0.00041	0.00026
300 to 2100	0.00055	0.00028

TABLE 2.3Contribution of Pu²⁴⁰ to the SEFOR Core I-E Doppler Coefficient

<u>Temperature Range (°K)</u>	<u>δk_{eff}</u>	<u>Doppler ($T dk/dT$)</u>
300 - 700	-0.000094	-0.00011
300 - 1400	-0.000184	-0.00012
300 - 2100	-0.000241	-0.00012

2.2 Effect of Including the Bell Modification in Doppler Coefficient Calculations

The Bell self-shielding correction⁽³⁾ was incorporated into the calculation of the resonance shielded cross sections and the U^{238} Doppler coefficient calculated. The temperatures at which the U^{238} cross sections were calculated were 300°K and 1400°K with the cross sections of all other isotopes being calculated only at 300°K. The calculations were all made with 29 energy groups and with no B_4C included in the core.

The U^{238} Doppler coefficient obtained using the Bell modification is compared with the U^{238} Doppler coefficient calculated without the Bell modification in Table 2.4. Note that including the Bell modification has caused the U^{238} Doppler coefficient to increase by ~14%.

TABLE 2.4

EFFECT OF INCLUDING THE BELL SELF-SHIELDING CORRECTION
ON THE SEFOR CORE I-E DOPPLER COEFFICIENT

<u>Temperature Range (°K)</u>	<u>Bell Modification</u>	<u>δk_{eff}</u>	<u>Doppler ($T dk/dT$)</u>
300 to 1400	NO	-0.01253	-0.00813
300 to 1400	YES	-0.01425	-0.00925

2.3 Variation of the Calculated Doppler Coefficient with the Cross Section Set Employed

The U^{238} Doppler coefficient was calculated over the temperature range from 300°K to 1400°K using four cross section sets. These four sets are the 26-group ABN⁽⁴⁾ (original Russian) set, the 26-group FTR-III⁽⁵⁾ design set, the 29-group ENDF/B Version II set, and the 29-group modified ENDF/B Version II set. The calculations for all four cross section sets were performed with the 1DX code in spherical geometry with no B_4C included in the core region. All cross sections with the exception of the U^{238} cross sections were calculated only at 300°K. The Bell modification was not included.

Two types of group cross section interpolation schemes were also studied. The first scheme was the standard 1DX semilog linear interpolation scheme which is used to account for the variation in resonance self-shielding factors (f-factors) with both temperature and σ_0 ⁽¹⁾. The second scheme utilizes a Lagrange interpolation formula⁽⁶⁾ for three points to account for temperature variations and fits a four point arctanh curve to the σ_0 values. These two schemes were both used with the 26-group ABN and FTR-III cross section sets.

The results of the comparison between cross section sets is given in Table 2.5 and the results for the two interpolation schemes in Table 2.6. Observe in Table 2.5 the strong variation in the Doppler coefficient with cross section set, the FTR-III Doppler being ~20%

higher than the modified ENDF/B Version II Doppler. The results shown in Table 2.6 indicate that the two interpolation schemes affect the calculated Doppler by only ~1% for these two cross section sets.

TABLE 2.5
EFFECT OF CROSS SECTION SET ON THE
CALCULATED DOPPLER COEFFICIENT FOR SEFOR CORE I-E

<u>Temperature Range (°K)</u>	<u>Cross Section Set</u>	<u>δk_{eff}</u>	<u>Doppler (T dk/dT)</u>
300 to 1400	ABN	-0.01381	-0.00896
300 to 1400	FTR-III	-0.01536	-0.00997
300 to 1400	ENDF/B-II	-0.01288	-0.00836
300 to 1400	Mod. ENDF/B-II	-0.01253	-0.00813

TABLE 2.6
EFFECT OF CROSS SECTION INTERPOLATION SCHEME ON THE
SEFOR CORE I-E CALCULATED DOPPLER COEFFICIENT

<u>Temperature Range (°K)</u>	<u>Cross Section Set</u>	<u>Interpolation Scheme</u>	<u>δk_{eff}</u>	<u>Doppler (T dk/dT)</u>
300 to 1400	ABN	linear semilog	-0.01361	-0.00884
300 to 1400	ABN	Lagrange & Arctanh	-0.01381	-0.00896
300 to 1400	FTR-III	linear semilog	-0.01518	-0.00985
300 to 1400	FTR-III	Lagrange & Arctanh	-0.01536	-0.00997

2.4 Dependence of the Doppler Coefficient on the Number of Energy Groups

Using the modified ENDF/B Version II cross section set in 29 and 14 energy groups, the U^{238} Doppler coefficient was calculated for the temperature range between 300°K and 1400°K. The cross sections for all isotopes except U^{238} were generated only at 300°K and the Bell modification was not included in any of the calculations. Furthermore, the B_4C in the core region was not taken into account.

The results of these calculations are shown in Table 2.7. Observe that the 14-group set underpredicts the U^{238} Doppler coefficient by less than 1%.

TABLE 2.7

EFFECT OF THE NUMBER OF ENERGY GROUPS ON THE
CALCULATED DOPPLER COEFFICIENT FOR SEFOR

<u>Temperature</u> <u>Range (°K)</u>	<u>Number of</u> <u>Energy Groups</u>	<u>δk</u>	<u>Doppler</u> <u>($T \, dk/dT$)</u>
300 to 1400	29	-0.01253	-0.00813
300 to 1400	14	-0.01246	-0.00809

2.5 Change in the Doppler Coefficient Due to the Inclusion of B_4C in the Core Region

Three U^{238} Doppler coefficient calculations were performed over the temperature range between 300°K and 1400°K. The first had no B_4C in the core region and the second had B_4C homogeneously smeared throughout the core. The third calculation had a B_4C shell which contained the same B^{10} mass as the smeared case but had the same surface area and volume as the 14 B_4C rods in core I-E. These calculations were all made at a base temperature of 300°K in spherical geometry with the 29-group modified ENDF/B Version II cross section set.

The results for the three methods of handling B_4C are given in Table 2.8. Note that including the B_4C in the core decreases the calculated U^{238} Doppler coefficient by ~12%.

TABLE 2.8

METHODS OF HANDLING B_4C RODS IN SEFOR CORE
I-E DOPPLER COEFFICIENT CALCULATIONS

<u>Temperature Range ($^{\circ}K$)</u>	<u>Treatment of B_4C Rods</u>	<u>δk</u>	<u>Doppler ($T \, dk/dT$)</u>
300 to 1400	No B_4C	-0.01253	-0.00813
300 to 1400	Homo. B_4C	-0.01117	-0.00725
300 to 1400	B_4C Shell	-0.01093	-0.00710

2.6 Most Complete SEFOR Core I-E Doppler Coefficient Calculation

This final SEFOR Doppler coefficient calculation incorporates the model features which were found to be required in the previous sections. The 1DX code was used in spherical geometry with the 29-group modified ENDF/B Version II cross section set. The cross sections of all isotopes were generated at 300°K which was taken as the base temperature and the U^{238} cross sections were also generated at 1400°K. The Bell self-shielding correction was employed in all cross section calculations and the B_4C in the core was treated using the shell model previously described.

The change in k_{eff} caused by increasing the temperature of U^{238} from 300°K to 1400°K was calculated to be -0.01235 which yields a calculated Doppler coefficient of -0.00802 over this temperature range. This compares to a Doppler coefficient of -0.00827⁽²⁾ which was derived from the total measured reactivity change between 450°K and 678°K for the SEFOR core I-E.

3.0 WHOLE CORE SODIUM WORTHS FOR SEFOR CORE I-E

For use in future studies involving Na feedback coefficients, the SEFOR whole core sodium worths were calculated in spherical geometry with the 1DX diffusion code. All cross sections were generated at 300°K using the modified ENDF/B Version II set and no B_4C was included in the core region. These sodium worth calculations were performed in both 29 and 14 energy groups to discover how the results are affected by the number of energy groups used in the calculation. The results for both 29 and 14 energy groups are given in Table 3.1. Note that the use of 14 instead of 29 energy groups resulted in an ~2% increase in the calculated sodium worth.

TABLE 3.1WHOLE CORE SODIUM WORTHS FOR SEFOR CORE I-E

<u>Sodium in Core (kg)</u>	<u>Sodium Removed (kg)</u>	<u>Number of Energy Groups</u>	<u>$\delta k/k$</u>
143.6	0.0	29	0.0 (Base Case)
129.2	14.4	29	-0.00084
100.5	43.1	29	-0.00259
71.8	71.8	29	-0.00447
100.5	43.1	14	-0.00266

4.0 CONCLUSIONS

The first series of calculations in this study was performed to determine the model detail required in Doppler coefficient calculations. The results of the study show that Doppler coefficients can be calculated within about 3% using the one-dimensional spherical model described below:

- a) Only the U^{238} contribution to the Doppler coefficient need be considered.
- b) The Bell self-shielding correction should be included in the generation of cross sections.
- c) The core poison rods can be treated by using a poison shell which has the same volume, surface area, and poison mass as the core rods.
- d) The use of a 14-group cross section set is adequate but some care must be taken in the choice of the particular set to be used.

In the second series of calculations, the whole core sodium worths for the SEFOR core I-E were calculated. It was found in this series of calculations that the whole core sodium worths could be adequately calculated using a 14 energy group cross section set as compared to a 29-group set.

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3. G. I. Bell. "A Simple Treatment for Effective Resonance Absorption Cross Sections in Dense Lattices," Nucl. Sci. and Eng., Vol. 5, p. 138, 1959.
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APPENDIX ACALCULATIONAL MODEL DETAILS

1. One-Dimensional Spherical Core Model

- a) Central zone corresponding to SEFOR central channel.

 $\text{radius} = 7.64 \text{ cm}$

- b) A single core zone representing a volume average between the SEFOR core and lower core.

 $\text{radius} = 50.955 \text{ cm}$

- c) The reflector was taken as a volume average between the upper, lower, and radial reflector and the downcomer and outer and inner vessel.

 $\text{radius} = 80.098 \text{ cm}$

- d)
- B_4C
- shell

Inner radius = 18.266 cm

Outer radius = 19.377 cm

2. Compositions (Atoms per barn-cm)

<u>Material</u>	<u>Central Zone</u>	<u>Core Zone</u>	<u>Reflector Zone</u>	<u>B₄C Shell</u>
U ²³⁵		0.00001472	1.49x10 ⁻⁷	
U ²³⁸		0.0069527	0.00006798	
Pu ²³⁹		0.0016014		
Pu ²⁴⁰		0.00014374		
O		0.020943	0.00016026	
C		0.00008621		0.0096177
Na	0.016615	0.0068099	0.0050927	
Al			0.0028555	
Cr	0.0038900	0.0038959	0.0026286	0.0062782
Fe	0.013343	0.013691	0.0087859	0.023922
Ni	0.0019946	0.0023261	0.037862	0.0024599
Mo		0.00011999	9.98x10 ⁻⁶	
B ¹⁰		0.00006862		0.0076528
B ¹¹		0.0002762		0.030812
Be		0.0036011	0.00002331	