KERNFORSCHUNGSZENTRUM

KARLSRUHE

November 1976 KFK 1785

Institut für Neutronenphysik und Reaktortechnik
Projekt Schneller Brüter

The inelastic scattering angle-energy correlation and its effect on the critical parameters of fast assemblies

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Abstract

The report contains a brief description of the inelastic scattering angle energy correlation effect and its influence on the critical parameters of some reactor systems. The accuracy of a possible approximate treatment is also investigated. It turns out that the effect results in a small, but remarkable correction of keff and the reaction rates.

Die Abhängigkeit der Energie der inelastisch gestreuten Neutronen vom Streuwinkel und ihre Auswirkung auf die kritischen Parameter schneller Anordnungen

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Zusammenfassung

Dieser Bericht enthält eine kurze Beschreibung des inelastischen Streuwinkel-Energiekorrelationseffektes. Der Einfluß auf kritische Parameter für einige Reaktorsysteme wird diskutiert. Die Genauigkeit einer möglichen Näherung wird ebenfalls untersucht. Es wird festgestellt, daß der Effekt einen kleinen aber bemerkenswerten Einfluß auf keff und die Reaktionsraten hat.

In most of theoretical approaches to nuclear reactor calculation, the neutron energy loss due to an inelastic scattering event is usually taken as $Q\times(A+1)/A$, where Q is the level excitation energy and A is the scatterer mass per neutron mass, i.e. the scattering kernel has the form of

$$\delta(E-E'+Q\times(A+1)/A) \qquad (1)$$

where E' is the initial neutron energy and E is the final one. Recently however, there are some theoretical works [1],[2], concerning the fact that the output spectrum of the inelastic scattered neutrons can be significantly changed by the scattering angle-energy correlation effect (ISAC). This effect resembles the elastic scattering angle-energy correlation which is responsible for the elastic slowing-down process, and is described by the following theory.

Notations:

A atomic mass per neutron mass
t laboratory scattering angle
μ center of mass scattering angle
Q level excitation energy
E' incident energy
E final energy

The relation between the laboratory angle and the energy loss is

$$t = \frac{A+1}{2}\sqrt{\frac{E}{E'}} - \frac{A-1}{2}\sqrt{\frac{E'}{E}} + \frac{Q\times A}{2\sqrt{E\times E'}} \qquad (2)$$

The relation between the laboratory and the center-of-mass scattering angles is

$$\mu(E',t) = \beta(E')(t^2-1+st\sqrt{t^2-t^{\times 2}(E')}) \qquad (3)$$

Zum Druck eingereicht am 11.10.1976

where

$$\beta(E') = \frac{1}{A}\sqrt{\frac{E'}{E'-Q\times(A+1)/A}} \tag{4}$$

$$t^{\times}(E) = \sqrt{1-1/\beta^2(E')} \tag{5}$$

$$s = \begin{cases} 1 & \text{if } E' > \frac{A}{A-1}\,Q \\ +1 & \text{if } \frac{A+1}{A}\,Q \le E' \le \frac{A}{A-1}\,Q \end{cases} \tag{6}$$

and the inverse relation

$$t = \frac{(\mu+\beta(E'))}{\sqrt{\beta^2(E')+2\beta(E')\mu+1}} \tag{7}$$

The relation between the incident and final energies as well as the laboratory scattering angle is

$$E = \frac{1}{(A+1)^2}\left(t\sqrt{E'} + s\sqrt{(t^2-1)E'+A^2(E'-Q(A+1)/A)}\right)^2 \tag{8}$$

If $\frac{A+1}{A}\,Q \le E' \le \frac{A}{A-1}\,Q$ then there are two final energy values for one laboratory angle. For the sake of simplicity, this double-valued region will be omitted as it has a negligible contribution to the transfer matrix elements [1]. Thus $\frac{A}{A-1}Q$ is taken as the labor threshold energy for inelastic scattering. It is easy to show that (8) is a monotonic function of t, thus the minimum and maximum final energies are at t = ±1, i.e.

$$E_{min} = \frac{1}{(A+1)^2}\left(\sqrt{E'} - A\sqrt{E'-Q\,\frac{A+1}{A}}\right)^2 \tag{9a}$$

$$E_{max} = \frac{1}{(A+1)^2}\left(\sqrt{E'} + A\sqrt{E'-Q\,\frac{A+1}{A}}\right)^2 \tag{9b}$$

and the inverse relations

$$E' = \frac{1}{(A-1)^2}\left(\sqrt{E_{min}} + A\sqrt{E_{min} + Q\frac{A-1}{A}}\right)^2 \qquad (10a)$$

$$E' = \frac{1}{(A-1)^2}\left(\sqrt{E_{max}} - A\sqrt{E_{max} + Q\frac{A-1}{A}}\right)^2 \qquad (10b)$$

In the limit $A\to\infty$ the formulae (3) and (8) change into

$$\mu = t \qquad (3')$$

$$E = E' - Q \qquad (8')$$

However in this case the formula (2) becomes meaningless i.e. no correlation can be stated between the energy loss and the scattering angle. Thus one must take care in applying this limiting case in the program.

The limit $A\to\infty$ does not entirely correspond to the neglection of the scattering kinematics, i.e. to the application of kernel (1). For this purpose $Q\to\frac{A+1}{A}Q$ (i.e., the difference between the laboratory and center-of--mass energies) would have to be used besides formulae (3') and (8').

It can easily be shown [2] that the average output energy of an inelastic scattering process, taking ISAC into account, is exactly

$$\langle E\rangle = (1-\alpha/2)E' - Q\frac{A}{A+1} \qquad (11)$$

where

$$\alpha = \frac{4A}{(A+1)^2}$$

A recent computer program based on the formalism described above makes possible the exact treatment of ISAC /3/. There is, however, a possible approximate treatment of ISAC with a scattering kernel /4/

$$\delta(E-(1-\alpha/2)E'+Q\frac{A}{A+1}) \qquad (12)$$

This approximation my be of some importance because it can be used by most of the existing inelastic scattering codes (e.g. /5/) after some slight modification.

The effect of ISAC on the critical parameters of several reactor systems has been investigated by means of the computer program /3/. This computer program is able to calculate inelastic scattering matrices taking ISAC into account as well as neglecting it. After slight modification the approximate scattering matrices due to (12) can also be calculated.

For critical calculation a 26-group O-dimensional code has been used. The 26-group constants underlying the calculation were obtained from the KFKINR set /6/ after exchanging the inelastic transfer probabilities for those calculated in one of the above ways.

Table I. contains the composition of fast reactor mixtures to be calculated. ISAC has been taken into account for the following elements: C, O, Al, Cr, Na, Ni, Fe, U235, U238, Pu239.

Table II. contains the relative deviation of k_{eff} calculated with the n-th option from that calculated with the total neglection of ISAC (i.e. $\Delta k_n=1-k_{eff_n}/k_{eff}$).

Tables II-IV contain similar quantities corresponding to the reaction rates

$$\int dE\sigma_f(U238)\phi \;/\; \int dE\sigma_f(U235)\phi$$

and

$$\int dE\sigma_f(U235)\phi \;/\; \int dE\sigma_c(U238)\phi$$

respectively. ($\sigma_f(x)$ and $\sigma_c(x)$ are the fission and capture cross sections of the element x in the mixture).

The options are the following:

1. The inelastic scattering matrices of the above 10 elements were calculated with ISAC
2. As 1. but with the approximation (12)
3. Only the matrix of Al was calculated with ISAC
4. As 3. but with the approximation (12)
5. Only the matrix of Fe was calculated with ISAC
6. As 5. but with the approximation (12)
7. Only the matrix of U238 was calculated with ISAC
8. As 7. but with the approximation (12)

The calculation without ISAC is always the reference option.

The results presented in the tables II-IV allow us to draw the following conclusions:

1. ISAC changes the k_{eff} by $\leq \pm 0.2\%$ and the reaction rates by a maximum of 1-2% depending on the actual system. In an unfavourable case the change may even be larger as is shown by a recalculation of the systems given in /2/. In these cases the results for k_{eff} are Carbide 11/1 3.76E-3 (6.7E-3), Carbide 9/1 3.53E-3 (5.3E-3), Carbide 5/12 2.93E-3 (3.7E-3), Oxide 11/1 3.23E-3 (5.5E-3), Oxide 5/1 2.51E-3 (3.2E-3). The Δk_{eff} given in /2/ are in

paranthesis. The significant deviation of the two calculation is proably due to the different group-constant systems, because the k_∞ -s also show significant deviations.

2. The ISAC is relatively important for U238, because the inelastic scattering of U238 plays an important role in the given fast reactor systems. It is true that the average lethargy change due to an elastic scattering on U238 is small, but the energy loss due to ISAC is proportional to the incident energy and it may not be so small compared with the final energy of the inelastic scattering process.

3. The approximate calculation with the kernel (12) gives satisfying results. In the comparison of the values one should take into account that a relatively large rounding error can be assigned to numbers on the order of 10^{-5} or less. It should be noted that the matrix elements calculated exactly and approximately were compared directly. It is proved that the transfer probabilities to the groups of higher energy are in good agreement with each other. There have been significant deviations in the transfer probabilities to the groups of few eVs, but these probabilities are in any case very small.

4. As a 208-group system was available /7/, several systems were calculated also with 208 groups.
These calculations show nearly to the same effect, i.e. it seems that the accuracy of a 26-groups calculation is satisfactory for investigation of the effect of ISAC on integral reactor quantities.

5. The systems 12-15 (SNEAK-3A series) display how this effect changes with then appearance of light elements, i.e. with the rising role of elastic scattering and with reactor spectrum softening. The more H and C are present in the system, the smaller is the $\Delta \cdot keff$.

6. The

$$\int dE\sigma_f(U238)\phi \; / \; \int dE\sigma_f(U235)\phi$$

and

$$\int dE\sigma_f(U235)\phi \; / \; \int dE\sigma_c(U238)\phi$$

can be taken as a measure of the hardness of the spectrum. In most of the cases this quantity is decreased by ISAC, however the few exceptions illustrate the complexity of the spectral problems of the fast systems.

References

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DESCRIPTION OF THE CALCULATED REACTOR SYSTEMS TABLE I.

SYSTEM	NO	COMPOSITION								BUCKLING
SUAK-U1B	1	AL	NI	U 235	U 238					1.793E-02
		4.277E-03	7.160E-04	8.243E-03	3.288E-02					
SUAKUh1B	2	AL	C	H	NI	U 235	U 238			1.845E-02
		4.277E-03	7.442E-03	1.488E-02	5.690E-04	6.546E-03	2.611E-02			
ZPRIII10	3	CR	FE	NI	PU239	U 235	U 238			8.137E-03
		2.960E-03	1.171E-02	1.780E-03	1.000E-10	5.688E-03	2.779E-02			
ZPRIII25	4	CR	FE	NI	PU239	U 235	U 238			3.172E-03
		1.400E-03	5.550E-03	8.400E-04	1.000E-10	3.442E-03	3.560E-02			
ZPRIII48	5	AL	C	CR	FE	MO	NA	NI	PU239	2.701E-03
		1.090E-04	2.077E-02	2.681E-03	9.985E-03	2.060E-04	6.231E-03	1.330E-03	1.645E-03	
		PU240	PU241	PU242	U 235	U 238				
		1.060E-04	1.100E-05	4.000E-07	1.600E-05	7.427E-03				
ZEBRA-6A	6	AL	B 10	C	CR	CU	FE	NA	NI	3.460E-03
		2.504E-03	1.000E-10	2.959E-02	1.270E-03	8.290E-04	4.255E-03	4.474E-03	4.430E-04	
		PU239	PU240	PU241	U 235	U 238				
		1.879E-03	1.440E-04	1.600E-05	4.600E-05	6.353E-03				
ZPRIII55	7	AL	C	CR	FE	NI	PU239	PU240	PU241	0.0
		1.110E-04	3.727E-02	1.895E-03	6.177E-03	8.390E-04	1.068E-03	5.100E-05	5.000E-06	
		U 235	U 238							
		3.300E-05	1.528E-02							
VERA-11A	8	C	CR	CU	FE	NI	PU239	PU240		1.746E-02
		4.606E-02	1.580E-03	7.960E-03	6.070E-03	6.650E-04	7.240E-03	3.700E-04		

DESCRIPTION OF THE CALCULATED REACTOR SYSTEMS/CONT. TABLE I.

SYSTEM	NO	COMPOSITION								BUCKLING
U235	9	U 235 1.000E 00								0.0
U238	10	U 238 1.000E 00								0.0
PU239	11	PU239 1.000E 00								0.0
SNEAK3A0	12	AL 1.292E-02	C 3.600E-05	CR 3.638E-03	FE 1.217E-02	MG 6.400E-05	MO 3.900E-05	NI 1.842E-03	O 1.455E-02	2.479E-03
		SI 1.870E-04	TI 3.940E-05	U 235 2.027E-03	U 238 8.114E-03					
SNEAK3A1	13	AL 1.292E-02	C 4.063E-04	CR 3.638E-03	FE 1.217E-02	H 7.412E-04	MG 6.400E-05	MO 3.900E-05	NI 1.842E-03	2.519E-03
		O 1.455E-02	SI 1.870E-04	TI 3.940E-05	U 235 2.027E-03	U 238 8.114E-03				
SNAEK3A2	14	AL 1.292E-02	C 9.217E-04	CR 3.638E-03	FE 1.217E-02	H 1.772E-03	MG 6.400E-05	MO 3.900E-05	NI 1.842E-03	2.555E-03
		O 1.455E-02	SI 1.870E-04	TI 3.940E-05	U 235 2.027E-03	U 238 8.114E-03				
SNEAK3A3	15	AL 1.292E-02	C 1.828E-03	CR 3.647E-03	FE 1.220E-02	H 3.584E-03	MG 6.400E-05	MO 3.900E-05	NI 1.842E-03	2.621E-03
		O 1.453E-02	SI 1.880E-04	TI 4.000E-05	U 235 2.031E-03	U 238 8.104E-03				
SNEAK3A1	16	AL 1.292E-02	C 4.063E-04	CR 3.638E-03	FE 1.217E-02	H 7.412E-04	MG 6.400E-05	MO 3.900E-05	NI 1.842E-03	2.201E-03
		O 1.455E-02	SI 1.870E-04	TI 3.940E-05	U 235 2.027E-03	U 238 8.114E-03				

DESCRIPTION OF THE CALCULATED REACTOR SYSTEMS/CONT. TABLE I.

SYSTEM	NO	COMPOSITION								BUCKLING
SNEAK3A2	17	AL	C	CR	FE	H	MG	MO	NI	2.555E-03
		1.292E-02	9.217E-04	3.638E-03	1.217E-02	1.772E-03	6.400E-05	3.900E-05	1.842E-03	
		O	SI	TI	U 235	U 238				
		1.455E-02	1.870E-04	3.940E-05	2.027E-03	8.114E-03				
GODIVA	18	U 234	U 235	U 238						6.726E-02
		4.920E-04	4.500E-02	2.498E-03						
ZPRIX-2S	19	AL	CR	FE	NI	U 235	U 238			0.0
		1.649E-03	1.952E-03	6.839E-03	8.643E-04	2.140E-03	3.323E-02			
JEZEBEL	20	CU	PU239	PU240	PU241					9.221E-02
		1.375E-03	3.705E-02	1.751E-03	1.170E-04					
SNEAK-7A	21	AL	C	CR	FE	MO	NB	NI	O	6.035E-03
		8.043E-06	2.610E-02	2.353E-03	7.971E-03	1.655E-05	8.884E-06	1.166E-03	2.185E-02	
		PU239	PU240	PU241	PU242	SI	U 235	U 238		
		2.637E-03	2.369E-04	2.153E-05	1.082E-06	9.337E-05	5.861E-05	7.960E-03		
SNEAK-7B	22	AL	C	CR	FE	H	MG	MO	NB	3.132E-03
		1.204E-05	6.596E-05	2.860E-03	9.958E-03	7.595E-06	5.340E-06	1.979E-05	9.029E-06	
		NI	O	PU239	PU240	PU241	PU242	SI	U 235	
		1.460E-03	3.384E-02	1.974E-03	1.773E-04	1.612E-05	8.100E-07	1.197E-04	1.063E-04	
		U 238								
		1.457E-02								
SNEAK-8	23	C	CR	FE	MO	NB	NI	SI	U 235	0.0
		1.356E-05	1.196E-03	3.955E-03	9.970E-06	8.544E-06	1.293E-03	4.532E-05	2.375E-03	
		U 238								
		3.809E-02								

TABLE IIA
RELATIVE CHANGE IN KEFF (26-GROUP)

OPT./SYS.	1	2	3	4	5	6
1	-8.99E-04	-4.90E-04	-3.96E-04	4.85E-04	9.15E-04	4.36E-04
2	-8.91E-04	-4.80E-04	-3.91E-04	4.85E-04	9.08E-04	4.47E-04
3	2.53E-05	-4.32E-06	0.0	0.0	2.09E-06	3.28E-05
4	2.88E-05	-2.16E-06	0.0	0.0	2.09E-06	3.28E-05
5	0.0	0.0	1.99E-04	1.39E-04	3.12E-04	1.01E-04
6	0.0	0.0	1.99E-04	1.38E-04	3.07E-04	9.95E-05
7	-8.10E-04	-4.28E-04	-5.66E-04	2.97E-04	7.83E-05	3.54E-06
8	-8.05E-04	-4.26E-04	-5.62E-04	2.98E-04	7.83E-05	3.54E-06

TABLE IIA
RELATIVE CHANGE IN KEFF (26-GROUP)

OPT./SYS.	7	8	9	10	11	12
1	1.31E-03	-1.58E-04	3.61E-04	1.36E-03	6.77E-05	2.48E-04
2	1.35E-03	-1.57E-04	3.60E-04	1.37E-03	6.77E-05	2.57E-04
3	4.73E-06	0.0	0.0	0.0	0.0	1.19E-04
4	4.73E-06	0.0	0.0	0.0	0.0	1.27E-04
5	3.08E-04	-6.80E-05	0.0	0.0	0.0	2.42E-04
6	3.05E-04	-6.70E-05	0.0	0.0	0.0	2.40E-04
7	7.02E-04	0.0	0.0	1.36E-03	0.0	-1.40E-04
8	7.01E-04	0.0	0.0	1.37E-03	0.0	-1.39E-04

TABLE IIA
RELATIVE CHANGE IN KEFF (26-GROUP)

OPT./SYS.	13	14	15	16	17	18
1	1.46E-04	7.74E-05	3.31E-05	2.19E-04	7.74E-05	-3.39E-04
2	1.55E-04	8.75E-05	4.41E-05	2.26E-04	8.75E-05	-3.37E-04
3	8.86E-05	6.13E-05	3.86E-05	1.03E-04	6.13E-05	0.0
4	9.69E-05	7.03E-05	4.60E-05	1.10E-04	7.03E-05	0.0
5	1.98E-04	1.57E-04	1.15E-04	2.10E-04	1.57E-04	0.0
6	1.97E-04	1.56E-04	1.14E-04	2.09E-04	1.56E-04	0.0
7	-1.55E-04	-1.49E-04	-1.21E-04	-1.18E-04	-1.49E-04	-2.93E-05
8	-1.54E-04	-1.49E-04	-1.20E-04	-1.17E-04	-1.49E-04	-2.93E-05

TABLE IIA
RELATIVE CHANGE IN KEFF (26-GROUP)

OPT./SYS.	19	20	21	22	23	
1	1.86E-03	-3.78E-05	2.46E-04	8.35E-04	1.77E-03	
2	1.86E-03	-3.78E-05	2.51E-04	8.29E-04	1.77E-03	
3	3.67E-05	0.0	0.0	0.0	0.0	
4	3.56E-05	0.0	0.0	0.0	0.0	
5	2.31E-04	0.0	1.25E-04	3.07E-04	1.21E-04	
6	2.26E-04	0.0	1.21E-04	3.03E-04	1.19E-04	
7	1.49E-03	0.0	4.69E-05	4.19E-04	1.55E-03	
8	1.49E-03	0.0	4.69E-05	4.18E-04	1.55E-03	

TABLE IIB
RELATIVE CHANGE IN KEFF (208-GROUP)

OPT./SYS.	1	2	3	4	5	7
1	-1.07E-03	-5.46E-04	-5.05E-04	5.63E-04	9.91E-04	1.33E-03
3	4.19E-05	6.07E-06	5.55E-07	0.0	2.06E-06	4.31E-06
4	4.66E-05	9.33E-06	0.0	0.0	2.62E-06	5.34E-06
5	0.0	0.0	2.35E-04	1.62E-04	3.37E-04	3.46E-04
7	-9.58E-04	-4.80E-04	-6.90E-04	3.47E-04	7.95E-05	7.67E-04
8	-9.62E-04	-4.82E-04	-6.91E-04	3.49E-04	8.06E-05	7.68E-04

TABLE IIB
RELATIVE CHANGE IN KEFF (208-GROUP)

OPT./SYS.	9	10	11	19	
1	3.66E-04	1.04E-03	4.76E-05	2.21E-03	
3	0.0	0.0	0.0	4.12E-05	
4	0.0	0.0	0.0	4.07E-05	
5	0.0	0.0	0.0	2.59E-04	
7	0.0	1.04E-03	0.0	1.78E-03	
8	0.0	1.04E-03	0.0	1.79E-03	

TABLE IIIA
RELATIVE CHANGE IN U238 FISSION PER U235 FISSION (26-GROUP)

OPT./SYS.	1	2	3	4	5	6
1	2.84E-03	1.79E-03	4.33E-03	2.30E-03	1.16E-02	8.69E-03
2	2.83E-03	1.83E-03	4.30E-03	2.30E-03	1.15E-02	8.84E-03
3	3.45E-04	3.51E-04	0.0	0.0	2.53E-05	6.22E-04
4	3.40E-04	3.47E-04	0.0	0.0	2.46E-05	6.20E-04
5	0.0	0.0	1.80E-03	7.88E-04	3.87E-03	1.74E-03
6	0.0	0.0	1.77E-03	7.75E-04	3.81E-03	1.71E-03
7	2.09E-03	1.08E-03	1.89E-03	1.26E-03	1.11E-03	9.56E-04
8	2.09E-03	1.08E-03	1.89E-03	1.26E-03	1.11E-03	9.58E-04

TABLE IIIA
RELATIVE CHANGE IN U238 FISSION PER U235 FISSION (26-GROUP)

OPT./SYS.	7	8	9	10	11	12
1	4.10E-03	0.0	0.0	0.0	0.0	8.69E-03
2	4.41E-03	0.0	0.0	0.0	0.0	8.63E-03
3	1.79E-05	0.0	0.0	0.0	0.0	2.67E-03
4	1.74E-05	0.0	0.0	0.0	0.0	2.67E-03
5	1.72E-03	0.0	0.0	0.0	0.0	4.23E-03
6	1.70E-03	0.0	0.0	0.0	0.0	4.16E-03
7	7.12E-04	0.0	0.0	0.0	0.0	7.34E-04
8	7.19E-04	0.0	0.0	0.0	0.0	7.38E-04

TABLE IIIA
RELATIVE CHANGE IN U238 FISSION PER U235 FISSION (26-GROUP)

OPT./SYS.	13	14	15	16	17	18
1	8.51E-03	8.23E-03	7.74E-03	8.51E-03	8.23E-03	9.49E-04
2	8.46E-03	8.18E-03	7.71E-03	8.45E-03	8.18E-03	9.50E-04
3	2.62E-03	2.54E-03	2.40E-03	2.62E-03	2.54E-03	0.0
4	2.62E-03	2.54E-03	2.40E-03	2.63E-03	2.54E-03	0.0
5	4.13E-03	3.99E-03	3.76E-03	4.15E-03	3.99E-03	0.0
6	4.06E-03	3.92E-03	3.71E-03	4.09E-03	3.92E-03	0.0
7	7.16E-04	6.65E-04	5.79E-04	6.78E-04	6.65E-04	7.05E-05
8	7.19E-04	6.68E-04	5.81E-04	6.82E-04	6.68E-04	7.05E-05

TABLE IIIA
RELATIVE CHANGE IN U238 FISSION PER U235 FISSION (26-GROUP)

OPT./SYS.	19	20	21	22	23	
1	1.27E-03	0.0	4.85E-03	4.33E-03	5.26E-04	
2	1.27E-03	0.0	5.04E-03	4.29E-03	5.38E-04	
3	1.58E-04	0.0	1.74E-06	1.83E-06	0.0	
4	1.58E-04	0.0	1.74E-06	2.09E-06	0.0	
5	1.06E-03	0.0	2.48E-03	2.57E-03	5.46E-04	
6	1.05E-03	0.0	2.45E-03	2.54E-03	5.39E-04	
7	-1.80E-04	0.0	7.98E-04	9.88E-04	-2.04E-04	
8	-1.65E-04	0.0	8.00E-04	9.92E-04	-1.89E-04	

TABLE IIIB
RELATIVE CHANGE IN U238 FISSION PER U235 FISSION (208-GROUP)

OPT./SYS.	1	2	3	4	5	7
1	2.87E-03	1.69E-03	4.33E-03	1.93E-03	1.17E-02	3.33E-03
3	3.85E-04	4.00E-04	0.0	0.0	2.70E-05	2.23E-05
4	3.84E-04	3.99E-04	0.0	0.0	2.64E-05	2.18E-05
5	0.0	0.0	1.89E-03	8.56E-04	3.92E-03	1.83E-03
7	2.06E-03	9.80E-04	1.81E-03	8.39E-04	1.09E-03	4.12E-04
8	2.06E-03	9.76E-04	1.80E-03	8.42E-04	1.08E-03	4.09E-04

TABLE IIIB
RELATIVE CHANGE IN U238 FISSION PER U235 FISSION (208-GROUP)

OPT./SYS.	9	10	11	19
1	0.0	0.0	0.0	5.25E-04
3	0.0	0.0	0.0	1.86E-04
4	0.0	0.0	0.0	1.88E-04
5	0.0	0.0	0.0	1.15E-03
7	0.0	0.0	0.0	-1.01E-03
8	0.0	0.0	0.0	-1.00E-03

TABLE IVA
RELATIVE CHANGE IN U235 FISSION PER U238 CAPTURE (26-GROUP)

CPT./SYS.	1	2	3	4	5	6
1	1.51E-03	1.79E-04	1.96E-03	2.25E-03	1.27E-03	1.04E-03
2	1.49E-03	1.81E-04	1.93E-03	2.23E-03	1.24E-03	1.02E-03
3	5.84E-05	2.69E-05	0.0	0.0	1.89E-06	6.60E-05
4	5.40E-05	2.73E-05	0.0	0.0	2.36E-06	6.36E-05
5	0.0	0.0	2.32E-04	6.94E-05	2.91E-04	1.48E-04
6	0.0	0.0	2.17E-04	6.69E-05	2.83E-04	1.45E-04
7	1.25E-03	1.18E-04	1.50E-03	2.04E-03	4.18E-04	3.32E-04
8	1.25E-03	1.18E-04	1.49E-03	2.03E-03	4.17E-04	3.31E-04

TABLE IVA
RELATIVE CHANGE IN U235 FISSION PER U238 CAPTURE (26-GROUP)

OPT./SYS.	7	8	9	10	11	12
1	3.15E-04	0.0	0.0	0.0	0.0	1.45E-03
2	3.20E-04	0.0	0.0	0.0	0.0	1.41E-03
3	1.80E-06	0.0	0.0	0.0	0.0	2.94E-04
4	1.80E-06	0.0	0.0	0.0	0.0	2.73E-04
5	5.73E-05	0.0	0.0	0.0	0.0	3.64E-04
6	5.80E-05	0.0	0.0	0.0	0.0	3.51E-04
7	2.09E-04	0.0	0.0	0.0	0.0	6.14E-04
8	2.09E-04	0.0	0.0	0.0	0.0	6.12E-04

TABLE IVA
RELATIVE CHANGE IN U235 FISSION PER U238 CAPTURE (26-GROUP)

OPT./SYS.	13	14	15	16	17	18
1	1.06E-03	7.64E-04	5.25E-04	1.04E-03	7.64E-04	3.62E-04
2	1.03E-03	7.48E-04	5.14E-04	1.01E-03	7.48E-04	3.64E-04
3	2.40E-04	1.90E-04	1.42E-04	2.32E-04	1.90E-04	0.0
4	2.26E-04	1.81E-04	1.37E-04	2.19E-04	1.81E-04	0.0
5	3.04E-04	2.48E-04	1.94E-04	2.96E-04	2.48E-04	0.0
6	2.96E-04	2.43E-04	1.91E-04	2.87E-04	2.43E-04	0.0
7	3.85E-04	2.28E-04	1.17E-04	3.78E-04	2.28E-04	3.27E-05
8	3.84E-04	2.28E-04	1.17E-04	3.77E-04	2.28E-04	3.32E-05

TABLE IVA
RELATIVE CHANGE IN U235 FISSION PER U238 CAPTURE (26-GROUP)

OPT./SYS.	19	20	21	22	23	
1	2.34E-03	0.0	6.93E-04	8.60E-04	2.38E-03	
2	2.32E-03	0.0	6.92E-04	8.50E-04	2.36E-03	
3	1.37E-05	0.0	0.0	2.10E-07	0.0	
4	1.25E-05	0.0	0.0	2.10E-07	0.0	
5	7.38E-05	0.0	2.21E-04	1.73E-04	3.99E-05	
6	7.11E-05	0.0	2.17E-04	1.69E-04	3.77E-05	
7	2.15E-03	0.0	3.20E-04	6.09E-04	2.24E-03	
8	2.14E-03	0.0	3.19E-04	6.08E-04	2.23E-03	

TABLE IVB
RELATIVE CHANGE IN U235 FISSION PER U238 CAPTURE (208-GROUP)

OPT./SYS.	1	2	3	4	5	7
1	1.58E-03	1.87E-04	2.20E-03	2.79E-03	1.41E-03	3.51E-04
3	6.03E-05	3.40E-05	0.0	0.0	3.21E-06	-4.77E-07
4	4.98E-05	3.23E-05	0.0	0.0	2.47E-06	7.16E-07
5	6.70E-06	-4.36E-07	2.58E-04	7.58E-05	2.96E-04	6.15E-05
7	1.32E-03	1.23E-04	1.70E-03	2.55E-03	5.09E-04	2.60E-04
8	1.31E-03	1.23E-04	1.69E-03	2.54E-03	5.08E-04	2.60E-04

TABLE IVB
RELATIVE CHANGE IN U235 FISSION PER U238 CAPTURE (208-GROUP)

OPT./SYS.	9	10	11	19	
1	0.0	0.0	0.0	3.02E-03	
3	0.0	0.0	0.0	1.18E-05	
4	0.0	0.0	0.0	1.04E-05	
5	0.0	0.0	0.0	8.27E-05	
7	0.0	0.0	0.0	2.79E-03	
8	0.0	0.0	0.0	2.78E-03	