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ATOMIC ENERGY COMMISSION

CRITICALITY STUDIES OF FAST ASSEMBLIES WITH THE NEW 27-GROUP CROSS-SECTION SET

by

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Experimental Reactor Physics Section

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ABSTRACT

A test of 27-group cross-section set[1] (Garg-set) recently derived from ENDF/B library has been carried out in the criticality studies of the Pu^{239}, U^{235} and U^{233} based metal, oxide and carbide fuelled fast critical assemblies. A total of twenty fast critical assemblies of different sizes and varying neutron spectra have been selected for analysis. The selected assemblies are JEZEBEL, ZEBRA-3, SNEAK-7A, SNEAK-7B, ZPR-3-48, ZPR-3-49, ZPR-3-50, ZPR-3-53, ZPR-6-7, POPSY, VERA-1B, ZPR-3-11, ZPR-3-12, JEMIMA-1, JEMIMA-2, GODIVA, TOPSY, ZEBRA-2, ZPR-6-6A and U^{233} SPHERE. Some of these assemblies were recommended by the Cross-Section Evaluation Working Group[2] for testing the new cross-section data.

A comparison of K_{eff}-values has been made with those given by Hardie et al[4], Mills[5], Benzi et al[7] and Best et al[12]. The K_{eff} - values obtained with the modified ABBN-set (MABBN-set)[3,13] have also been given. Based on these analyses it has been observed that the Garg-set predicts well the criticality of uranium and plutonium based hard-spectra assemblies. In the soft-spectra systems it underpredicts criticality because of the following reasons:

(a) It makes use of the higher capture cross-sections of structural and coolant elements given in ENDF/B - Version IV library.

(b) It does not account for the resonance self-shielding effects of cross-sections.

It has also been observed that the Garg-set gives better results than the MABEN-set for dense and dilute plutonium-based and the hard uranium-based assemblies. This superior trend of the Garg-set is slightly lost in the uranium-based dilute systems because of large differences in the capture cross-sections of structural elements of these two sets.

CRITICALITY STUDIES OF FAST ASSEMBLIES WITH THE NEW 27-GROUP CROSS-SECTION SET

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1. INTRODUCTION

A 27-group cross-section set[1] (Garg-set) for 28 elements was recently derived from the ENDF/B library. The energy structure of 26 groups was identical to that of the ABBN-set[3] and the 27th group was added between 10.5 Mev and 15.0 Mev mainly to account for (n,2n), (n,p) and (n, α) reactions which assume significance in hard-spectra fast reactors or fusion-fission systems. The accuracy of this set in the prediction of reactor parameters is to be established before it can be used as a design tool in the conceptual studies of reactors. To meet this end, a selection of twenty plutonium and uranium based fast critical assemblies was made for criticality studies. The selected assemblies are JEZEBEL, ZEBRA-3, SNEAK-7A, SNEAK-7B, ZPR-3-48, ZPR-3-49, ZPR-3-50, ZPR-3-53, ZPR-6-7, POPSY, VERA-1B, ZPR-3-11, ZPR-3-12, JEMIMA-1, JEMIMA-2, GODIVA, TOPSY, ZEBRA-2, ZPR-6-6A and U^{233} sphere. Some of these assemblies were recommended by the Cross-Section Evaluation Working Group[2] and the others were taken from the papers of Hardie et al[4] and Mills[5]. These assemblies represent very soft to very hard neutron spectra and therefore would prove to be good testing beds of group cross-sections in the Kev to Mev energy range. Resonance self-shielding effects of cross-sections start showing up in the criticality calculations of the soft-spectra assemblies whereas they are not so important in the hard-spectra systems. In these studies unshielded cross-sections are used throughout. This would help bringout the importance of self-shielded cross-sections in certain specific assemblies. The calculated K_{eff} - values are compared with those given by Hardie et al, Benzi et al[7], Best et al[12] and Mills.

2. CALCULATIONAL MODEL

The criticality calculations have been carried out with the neutron transport theory code DTF-IV[6] in S_4 or S_{16} angular quadratures. The equivalent spherical models of all the assemblies reported here are given by Mills and Hardie et al and they have been adopted in these analyses. The 27-group Garg-set and the 26-group modified ABBN-set[3,13] have been used. In the Garg-set the cross-sections for U^{233}, U^{235}, U^{238}, Pu^{239}, Pu^{240} and Pu^{241} have been evaluated from ENDF/B Version III library whereas these for C, O, Na, Cr, Fe and Ni have been obtained from ENDF/B Version IV library. In the modified ABBN-set the capture and fission cross-sections of Pu^{239} and capture cross-sections of U^{238} have been re-evaluated in the light of new measured data.

3. URANIUM BASED ASSEMBLIES

The ten uranium based assemblies VERA-1B, ZPR-3-11, ZPR-3-12, JEMIMA-1, JEMIMA-2, GODIVA, TOPSY, U^{233}-SPHERE, ZEBRA-2 and ZPR-6-6A are summarised in Table-I. Their compositions are given in Table-II. It is observed from these two Tables that these assemblies represent very soft to very hard fast systems and therefore they should be suitable to test the resonance self-shielding effects of cross-sections and the cross-sections of U^{235} and U^{238} in the high energy region. The calculated K_{eff} - values are tabulated in Table-III. In respect of VERA-1B, ZPR-3-11, ZPR-3-12, ZEBRA-2 and ZPR-6-6A the K_{eff} - values obtained by Hardie et al are given in column 2 of this Table. In the case of JEMIMA-1, JEMIMA-2, GODIVA, TOPSY and U^{233}-SPHERE the K_{eff} - values of Mills are shown in this column. Mills underpredicts criticality in the first four of these assemblies by 1.5%, 1.1%, 0.9% and 0.9% respectively whereas the Garg-set overpredicts these assemblies by 1.5%, 1.0%, 2.0% and 3.2% respectively. The corresponding MABBN K_{eff} - values are higher by 1.8%, 2.2%, 2.6% and 3.8%. Thus the MABBN-set is more discrepant towards the higher side. Hemment and Pendlebury(10) calculated GODIVA by 3.0% overcritical and TOPSY by 3.9% overcritical. These values are higher than those of the MABBN-set. In the case of U^{233}-SPHERE Mills overpredicted reactivity by 1.2% whereas the Garg-set underpredicts it by 1.5%.

It is observed from Table-III that the Garg-set gives comparable K_{eff}-values of VERA-1B, ZPR-3-11 and ZPR-3-12 to those of Hardie et al whereas the MABBN-set overpredicts them by 2% to 3%. Baker has analysed these assemblies with a number of cross-section sets. VERA-1B was found be overcritical by 0.9% to 1.4%, ZPR-3-11 was calculated 1.7% under-critical to 1.1% overcritical and ZPR-3-12, 0.2% undercritical to 1.6% over-critical. In respect of ZEBRA-2 and ZPR-6-6A the agreement is not so good and this reflects the total effects of resonance self-shielding and higher capture cross-sections of structural and coolant elements. In these two cases the MABBN-set gives higher K_{eff}-values by 4.9% and 9.1% compared to those of the Garg-set. It may, however, be noted that ZEBRA-2 appears to be well represented by the unshielded MABBN-set. This picture is likely to change when the resonance self-shielding corrections and the revised higher capture cross-sections of structural elements are taken into account. Similar considerations apply to ZPR-6-6A assembly. Baker has calculated ZEBRA-2 by 0.8% to 1.5% overcritical. Ceechini and Gandini[11] have calculated this assembly by 0.5% to 1.9% overcritical whereas Hardie et al have calculated it by 1% undercritical. This indicates the broad spectrum of calculated K_{eff}-values with different cross-section sets and calls for the adjustment of cross-sections in similar assemblies. It is seen from Table-III that on the average the criticality predictions with the Garg-set match exactly those of Mills and Hardie et al whereas the predictions of the MABBN-set are higher by 2.7%.

4. PLUTONIUM BASED ASSEMBLIES

A brief account of the plutonium based assemblies is contained in Table-IV. The assemblies are JEZEBEL, ZEBRA-3, SNEAK-7A, SNEAK-7B, ZPR-3-48, ZPR-3-49, ZPR-3-50, ZPR-3-53, ZPR-6-7 and POPSY. Their core sizes vary from 0.4 litre to 3100 litres and they represent very dense to very dilute fast systems. Table-V gives their core and reflector compositions. Table-VI gives their calculated K_{eff}-values. Column 2 of this Table gives the K_{eff}-values obtained by Mills, Hardie et al, Benzi et al[7] or Best et al[12] with the shielded cross-sections. In the case of Hardie et al the K_{eff}-values shown in this column are those obtained with a 42 group cross-section set which was derived from ENDF/B- Version III library. The values calculated by us are recorded in columns 3 and 4 of this Table.

It is observed from Table-VI that the K_{eff}-values obtained with the Garg-set differ from those of Hardie et al by - 0.4% to + 4.7%. This difference is more pronounced in the soft-spectra assemblies.

On the average it is seen that the Garg-set underpredicts reactivity by 1.8% compared to that of Hardie et al. The reasons for this underprediction are:

i) The basic cross-sections of Na, Cr, Fe and Ni in the Garg-set are taken from the Version-IV of ENDF/B library. The capture cross-sections of these elements in Version-IV are higher than those in Version-III of ENDF/B library.

ii) The Garg-set does not account for the resonance self-shielding effects of cross-sections.

iii) The number of groups used in the Garg-set is 27 whereas Hardie et al have used 42 groups which give a better description of the Kev resonance energy region.

The K_{eff}-values obtained with the MABBN-set are consistently lower than those calculated with the Garg-set. It is inferred from columns 3 and 4 of Table-VI that the difference between the calculated results with these two sets varies from 0.3% to 1.8%. It is also noticed from this Table that on the average the MABBN-set gives lower reactivity by 1% compared to that of the Garg-set. It is, however, noted that in the Garg-set the capture cross-sections of Cr, Fe and Ni in the energy range 215 eV to 21.5 Kev are 2 to 40 times higher than those of the MABBN-set. If the capture cross-sections of these elements are not altered in the specified energy range the Garg-set would give K_{eff}-values still nearer unity.

ZEBRA-3 has been calculated by Baker[8] with a number of cross-section sets. His predictions varied from 3.1% undercritical to 2.6% overcritical. Mills and Filmore et al[9] have reported K_{eff}-values of ZPR-3-48 which are 2.3% undercritical and 1.6% overcritical respectively. The Garg-set in respect of these two assemblies appears to be quite adequate and can be improved by taking self-shielding effects into account. The hard-spectra assemblies e.g. JEZEBEL, ZEBRA-3 and ZPR-3-49 where self-shielding effects are not so important are represented adequately by this set.

5. CONCLUSIONS

This study has revealed that the hard spectra fast systems where the self-shielding cross-sections do not assume importance can be predicted well by the Garg-set. The MABBN results are more discrepant-towards the lower side in the case of plutonium critical assemblies and towards the higher side in the case of uranium-based systems. The fission cross-sections of U^{235} appear to be higher and those of U^{233} appear to be lower in the Mev energy region. The capture and scattering cross-sections of U^{238} are not yet accurately known in this energy region. However, the capture cross-sections of structural and coolant elements are the main culprits and these should be used with caution. In the soft-spectra systems they affect the criticality by about 2%.

In the dilute fast systems the resonance self-shielding effects of cross-sections may be quite significant and these should be evaluated for correct estimates of criticality. In these studies the effects of anisotropic scattering should also be taken into account. Studies on both these aspects have now been undertaken and their effect on K_{eff}-values of some of these assemblies would be reported in due course.

In this report criticality has been examined for metal, oxide and carbide fuelled fast critical assemblies of varying sizes and spectra. Based on these analyses it can be concluded that the Garg-set gives better results than the MABEN-set for dense and dilute plutonium-based and the hard uranium-based systems. Even in the dilute uranium-based assemblies the Garg-set is expected to give better results if the uncertainties in the capture cross-sections of structural and coolant elements are taken into account.

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Table - I

U-BASED CRITICAL ASSEMBLIES

Sr. No.	Assembly	Core Volume (litres)	Fissile-to-Fertile Ratio	Reflector Material	Reflector Thickness (cm)	Mode of Investigation	Remarks
1	VERA-1B	30	12.5	U^{238}	39.452	S_{16}	An assembly with a content of graphite which produces slightly soft spectrum. It is good for testing the high energy cross-sections of U^{235} and U^{238}.
2	ZPR-3-11	140	0.13	U^{238}	30.0	S_{16}	An assembly with a spectrum similar to that of VERA-1B. The objective is the same as in VERA-1B.
3	ZPR-3-12	100	0.26	U^{238}	30.5	S_{16}	An assembly similar to ZPR-3-11. The higher content of fissile material is compensated by graphite which is added to soften the spectrum. The objective is to test the cross-sections of U^{235} and U^{238} in the high energy region.
4	JEMIMA-1	13	0.61	--	--	S_{16}	A bare core assembly with a harder neutron spectrum. It is good for testing the cross-sections of U^{235} and U^{238} in the Mev energy range.
5	JEMIMA-2	35	0.195	U^{238}	7.62	S_{16}	An assembly with a softer spectrum than JEMIMA-1. The objective is the same as in JEMIMA-1.
6	GODIVA	2.8	15.38	--	--	S_{16}	A bare core assembly with a very hard neutron spectrum. It is suitable for testing the cross sections of U^{235} and U^{238} in the high energy range.

Table-I (Cont.)

Sr. No.	Assembly	Core Volume (Litre)	Fissile-to-Fertile Ratio	Reflector Material	Reflector Thickness (cm)	Mode of Investigation	Remarks
7	TOPSY	0.93	15.56	U^{238}	22.86	S_{16}	An assembly with a spectrum softer than that of GODIVA. It tests the cross-sections of U^{235} and U^{238} in the high energy region.
8	U^{233} SPHERE	0.9	53.16	- -	- -	S_{16}	A bare core assembly with a very hard neutron spectrum - harder than that of GODIVA. It tests the cross-sections of U^{233} in the Mev energy range.
9	ZEBRA-2	430	0.16	U^{238} + Structural elements	31.70	S_4	The core contains graphite and produces spectrum similar to that of a large carbide power reactor. Self-shielding effects of cross-sections are to be tested.
10	ZPR-6-6A	4000	0.20	U^{238} + Structural elements	33.81	S_4	It represents a current large oxide system cooled by sodium. It is suitable for testing the resonance self-shielding effects of the cross-sections.

Table -II

ATOMIC DENSITIES (ATOMS/BARN-cm) IN U-BASED ASSEMBLIES

Isotope	VERA-1B		ZPR-3-11		ZPR-3-12		JEMIMA-1		JEMIMA-2	
	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector
U^{235}	0.007349	0.000250	0.004567	0.000089	0.004516	0.000298	0.01814	-	0.00777	0.00034
U^{238}	0.000561	0.034400	0.034438	0.040025	0.016994	0.041269	0.02952	-	0.03977	0.04721
O^{16}	-	-	-	-	-	-	-	-	-	-
C^{12}	0.057540	-	-	-	0.026762	0.000042	-	-	-	-
Na^{23}	-	-	-	-	—	-	-	-	-	-
Cr^{52}	0.000689	0.000708	0.001486	0.001196	0.001419	0.000864	-	-	-	-
Fe^{56}	0.006283	0.006464	0.005681	0.004925	0.005704	0.003323	-	-	-	-
Ni^{58}	0.001635	0.001682	0.000718	0.000536	0.000621	0.000483	-	-	-	-
U^{233}	-	-	-	-	-	-	-	-	-	-

Table-II (Cont.)

Isotope	GODIVA		TOPSY		ZEBRA-2		ZPR-6-6A		U^{233} SPHERE	
	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector
U^{235}	0.04508	-	0.04511	0.000346	0.002526	0.000298	0.001153	0.0000856	-	-
U^{238}	0.00293	-	0.00290	0.047694	0.015667	0.041269	0.0058176	0.0395508	0.00088	-
O^{16}	-	-	-	-	0.0001544	-	0.01390	0.0000230	-	-
C^{12}	-	-	-	-	0.037992	0.000042	-	-	-	-
Na^{23}	-	-	-	-	-	-	0.0092904	-	-	-
Cr^{52}	-	-	-	-	0.000864	0.000864	0.002842	0.001247	-	-
Fe^{56}	-	-	-	-	0.0036485	0.003323	0.013431	0.0044669	-	-
Ni^{58}	-	-	-	-	0.000483	0.000483	0.001291	0.0005407	-	-
U^{233}	-	-	-	-	-	-	-	-	0.04678	-

Table-III

K_{eff}-VALUES OF U-BASED CRITICAL ASSEMBLIES (K_{eff}^{exp} = 1.0000)

Assembly	K_{eff}	K_{eff}-GARG**	K_{eff}-MABEN**	$\frac{K_{eff}\text{-GARG}}{K_{eff}}$	$\frac{K_{eff}\text{-GARG}}{K_{eff}\text{-MABEN}}$
VERA-1B	1.0026+	0.9976	1.0185	0.9950	0.9795
ZPR-3-11	0.9924+	0.9996	1.0244	1.0073	0.9758
ZPR-3-12	1.0017+	1.0015	1.0314	0.9999	0.9711
JEMIMA-1	0.9855*	1.0151	1.0185	1.0300	0.9967
JEMIMA-2	0.9893*	1.0104	1.0215	1.0213	0.9892
GODIVA	0.9912*	1.0204	1.0257	1.0295	0.9949
TOPSY	0.9907*	1.0323	1.0379	1.0420	0.9946
U^{233} - SPHERE	1.0155*	0.9848	- -	0.9736	- -
ZEBRA-2++	0.9902+	0.9502	0.9965	0.9597	0.9536
ZPR-6-6A++	0.9988+	0.9411	1.0270	0.9422	0.9164
AV. Keff	0.9954	0.9953	1.0224	0.9999	0.9735

* K_{eff}-values obtained by Mills.

** K_{eff}-values obtained with unshielded cross-section sets.

\+ K_{eff}-values obtained with 42-group shielded cross-section set derived from ENDF/B - Version III by Hardie et al.

++ Assemblies with soft spectra in which the resonance self-shielding effects and the capture cross-sections of structural and coolant elements may be important in the prediction of criticality.

Table-IV

Pu-BASED CRITICAL ASSEMBLIES

Sr. No.	Assembly	Core Volume (Litres)	Fissile To-Fertile Ratio	Reflector Material	Reflector Thickness (cm)	Mode of Investigation	Remarks
1	JEZEBEL	1.1	21.23	-	-	S_{16}	A bare core assembly with a very hard neutron spectrum. It is good for testing the cross-sections of Pu^{239} in the Mev energy range.
2	ZEBRA-3	60	0.116	U^{238}+ Structural elements	30.50	S_4	A hard spectrum system. It tests the cross-sections of Pu^{239}, Pu^{240} and U^{238} in the Mev energy range.
3	SNEAK-7A	110	0.333	U^{238}+ Structural elements	30.0	S_4	A mixed oxide fuel system with graphite content.
4	SNEAK-7B	310	0.143	U^{238}+ Structural elements	30.0	S_4	A mixed oxide fuel system with higher content of U^{238}. It has softer spectrum compared to that of SNEAK-7A. Together with SNEAK-7A it is suitable to test the high energy cross-sections of Pu^{239} and U^{238}.
5	ZPR-3-48	410	0.222	U^{238}+ Structural elements	30.0	S_4	A mixed carbide system with additional content of graphite to obtain soft spectrum characteristic of a large power reactor cooled by sodium. Resonance self-shielding effects of cross-sections are to be tested.

Table -IV (Cont.)

Sr. No.	Assembly	Core Volume (Litre)	Fissile-To-Fertile Ratio	Reflector Material	Reflector Thickness (cm)	Mode of Investigation	Remarks
6	ZPR-3-49	450	0.222	U^{238} + Structural elements	36.43	S_4	Similar to ZPR-3-48 but with a harder neutron spectrum obtained by total removal of sodium. It is good for testing the sodium reactivity worth.
7	ZPR-3-50	350	0.222	U^{238} + Structural elements	40.34	S_4	Similar to ZPR-3-49 with additional graphite content to obtain softer spectrum characteristic of a large power reactor. Self-shielding effects of cross-sections are to be tested.
8	ZPR-3-53	220	0.625	U^{238} + Structural elements	37.33	S_4	An assembly with a larger content of graphite to yield soft spectrum. It is suitable for testing the resonance self-shielding effects of cross-sections.
9	ZPR-6-7	3100	0.154	U^{238} + Structural elements	33.81	[illegible]	A mixed oxide system to yield spectrum of current large fast reactors cooled by sodium. Self-shielding effects of cross-sections are to be tested.
10	POPSY	0.37	67.26	Natural Uranium	24.1	S_{16}	A hard spectrum system. It is suitable for testing the Mev energy range cross-sections of Pu^{239} and U^{238}.

Table -V

ATOMIC DENSITIES (ATOMS/BARN-cm) IN Pu-BASED ASSEMBLIES

Isotope	JEZEBEL		ZEBRA-3		SNEAK-7A		SNEAK-7B		ZPR-3-48	
	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector
U^{235}	-	-	0.0002264	0.000298	0.0000586	0.0001624	0.0002663	0.0001624	0.000016	0.000083
U^{238}	-	-	0.031775	0.041269	0.0079604	0.0399401	0.0145794	0.0399401	0.007405	0.039690
Pu^{239}	0.03705	-	0.003466	-	0.0026374	-	0.0018312	-	0.001645	-
Pu^{240}	0.001751	-	0.0001834	-	0.0002380	-	0.0001652	-	0.000106	-
Pu^{241}	0.000117	-	0.0000127	-	0.0000215	-	0.0000149	-	0.000011	-
O^{16}	-	-	-	-	0.0218462	-	0.0331936	-	-	-
C^{12}	-	-	0.000042	0.000042	0.0260987	0.0000135	0.0000631	0.0000135	0.020770	-
Na^{23}	-	-	-	-	-	-	-	-	0.006231	-
Cr^{52}	-	-	0.000864	0.000864	0.0022423	0.0011080	0.0027560	0.0011080	0.002531	0.001225
Fe^{56}	-	-	0.004578	0.003323	0.0079713	0.0039549	0.0098021	0.0039549	0.01080	0.004925
Ni^{58}	-		0.000483	0.000483	0.0011664	0.0009845	0.0014594	0.0009845	0.001119	0.000536

Table -V (Contd.)

Isotope	ZPR-3-49		ZPR-3-50		ZPR-3-53		ZPR-6-7		POPSY	
	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector	Core	Reflector
U^{235}	0.000016	0.000083	0.000016	0.000083	0.000006	0.000083	0.0000126	0.0000856	-	0.000333
U^{238}	0.007406	0.039556	0.007404	0.039613	0.002615	0.039770	0.0057804	0.0396179	-	0.047242
Pu^{239}	0.001644	-	0.001645	-	0.001669	-	0.0008867	-	0.038809	-
Pu^{240}	0.0001064	-	0.0001064	-	0.000107	-	0.0001194	-	0.000577	-
Pu^{241}	0.000011	-	0.000011	-	0.000008	-	0.0000133	-	-	-
O^{16}	-	-	-	-	-	-	0.01390	0.000024	-	-
C^{12}	0.020766	-	0.04594	-	0.055898	0.000024	-	-	-	-
Na^{23}	-	-	-	-	-	-	0.0092904	-	-	-
Cr^{52}	0.002508	0.001242	0.001816	0.001161	0.002081	-	0.002842	0.001295	-	-
Fe^{56}	0.010083	0.004626	0.0073	0.004671	0.007134	-	0.013431	0.004637	-	-
Ni^{58}	0.001121	0.000611	0.000796	0.000508	0.000208	-	0.001291	0.0005635	-	-

Table -VI

K_{eff}-VALUES OF Pu-BASED CRITICAL ASSEMBLIES (K_{eff}^{exp} = 1.0000)

Assembly	K_{eff}	K_{eff}-GARG**	K_{eff}-MABEN**	$\frac{K_{eff}\text{-GARG}}{K_{eff}}$	$\frac{K_{eff}\text{-GARG}}{K_{eff}\text{-MABEN}}$
JEZEBEL	0.9891*	0.9972	0.9902	1.0082	1.0071
POPSY	1.0080***	1.0155	1.0007	1.0074	1.0148
ZPR-3-49	0.9985+	0.9928	0.9855	0.9943	1.0074
ZEBRA-3	0.9816+	0.9852	0.9764	1.0037	1.0090
SNEAK-7B	0.9893+	0.9655	0.9520	0.9759	1.0142
SNEAK-7A	1.0006+	0.9753	0.9613	0.9747	1.0146
ZPR-3-48++	0.9997+	0.9740	0.9706	0.9743	1.0035
ZPR-3-50++	0.9940+	0.9582	0.9413	0.9640	1.0180
ZPR-3-53++	1.0008+	0.9654	0.9547	0.9646	1.0112
ZPR-6-7++	0.9926+	0.9484	0.9453	0.9555	1.0033
AV. K_{eff}	0.9954	0.9778	0.9678	0.9823	1.0103

* K_{eff}-value obtained by Benai et al by Monte-Carlo method.
** K_{eff}-values obtained with unshielded cross-section sets.
*** K_{eff}-value obtained with ENDF/B - Version II by Best et al.
\+ K_{eff}-values obtained with 42-group shielded cross-section set derived from ENDF/B - Version III by Hardi et al.
\++ Assemblies with soft spectra in which the resonance self-shielding effects and the capture cross-sections of structural and coolant elements may be important in the prediction of criticality.