

**FAST REACTOR BENCHMARK TESTS
ON THE JEF-1
EVALUATED NUCLEAR DATA FILE**

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ABSTRACT

In the framework of the JEF-1 benchmarking activity, four cross-section libraries for 31 isotopes with 71, 50, 26 and 25 energy group structures have been generated for the analysis of fast criticals. The evaluated nuclear processing system NJOY has been used for producing these libraries. The results of one-dimensional diffusion calculations for thirteen plutonium-fuel, seven uranium-fuel and two infinite homogeneous-media critical assemblies are compared against experimental values. These include effective multiplication factors and central reaction rate ratios. JEF-1 predicts several nuclear characteristics of fast reactors better than ENDF/B-IV and to a comparable precision with JENDL-2 and ENDF/B-V.

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1. INTRODUCTION

The first version of the Joint Evaluated File (JEF-1) is the result of a common effort of a number of laboratories in the NEA Data Bank Member countries (Ref. 1). It is a comprehensive library of evaluated nuclear data for fission reactor applications. Neutron interaction data are provided for some 300 nuclides which are coded in the ENDF-5 format. Format and physical consistency checks of these data were carried out by the CHECKER and FIZCON codes (Ref. 2). Point energy files were constructed from resonance parameter files using the RESEND (Ref. 3) and RECENT (Ref. 4) codes. In addition, extensive graphical displays have been produced for these point data files in order to check the validity of the neutron interaction data JEF-1 contains (Ref. 5). Moreover, relevant data at 2200m/sec, the thermal Maxwellian average at a temperature of 293 Kelvin, resonance integrals, the U-235 fission spectrum averages and 14 MeV values were intercompared with those of the following evaluated data files: JENDL-1, JENDL-2, ENDF/B-IV, ENDF/B-V, KEDAK-3, RCN-3 and UKNDL-81. (Ref. 6).

In the present report, applications of JEF-1 to fast reactor analysis are examined by calculating effective multiplication factors and central reaction rate ratios measured in various benchmark critical assemblies. For this purpose, four group cross-section libraries with different energy group structures have been generated by using the evaluated nuclear data processing system NJOY (Refs. 7,8). Three of the group structures (71, 50 and 25) are based on the energy boundaries of the JAERI fast set (Ref. 9), and the 26 group structure is of the ABBN type (Ref. 10). The 71 and 26 group cross sections were calculated with the NJOY system by assuming a Maxwellian weighting function for the thermal energy region, a $1/E$ -spectrum for the resonance energy range from 0.1 eV to 0.8208 MeV and a fission spectrum for the fast neutron energy range from 0.8208 to 15.0 MeV. The 50 and 25 group cross sections were produced by collapsing the 71 group cross sections with the CINX code (Ref. 11).

These libraries contain infinite-dilute cross sections for capture, elastic scattering, fission, total, elastic scattering removal and transport; average fission spectra for fissile nuclides, and Legendre moments of group to group scattering matrices for elastic, inelastic and $(n,2n)$ reactions. The resonance self-shielding factors are tabulated for a temperature of 300 Kelvin and several "effective background cross sections" following the Bondarenko scheme (Ref. 10). These data are provided in the standard formats of ISOTXS and BRK0XS (Ref. 12).

Benchmark calculations have been performed with one-dimensional diffusion theory for 21 critical assemblies (Ref. 13). These criticals consist of 18 benchmark assemblies selected by Hardie et al. (Ref. 14), the JOYO mock-up core (FCA-V-2) and the MOZART cores (MZA and MZB). These have a wide variety from 12 to 4000 litres of core sizes, from zero to eight concentration ratios of fertile to fissile materials in core, and of 14 plutonium and 7 uranium fuel cores. These benchmark results for JEF-1 are still not completely satisfactory although on the whole they are comparable with the ones for JENDL-2 and ENDF/B-V and better than the ones for ENDF/B-IV.

The following are the main differences between the previous (Ref. 13) and present calculations:

- 1) Accurate self-shielding factors are used for calculating effective elastic scattering removal cross sections, instead of elastic scattering self-shielding factors as in the previous calculations.
- 2) New experimental data are taken for the following critical assemblies: VERA-1B, VERA-11A (Ref. 15), and ZPR-6-7, ZPR-6-6A (Ref. 16).
- 3) Two infinite homogeneous media of uranium fuel, SCHERZO-550 and U02-740 (Ref. 17) were added in order to assess U-235 and U-238 cross sections.

The calculational method used for producing group cross section libraries with the NJOY system are described in Section 2. The benchmark calculation models are described in Section 3. The results of the benchmark tests for JEF-1 are discussed in Section 4.

2. CALCULATIONAL METHOD FOR GROUP CROSS SECTIONS

2.1 Processing Methods

Group-averaged cross sections have been calculated by using the evaluated nuclear data processing system NJOY (Ref. 7). Figure 2.1 shows the NJOY modules used and the data flow.

The JEF-1 evaluated data files are available in two forms:

- 1) A "parameter file" in which data in the resonance region are given in the form of resonance parameters both for the resolved and unresolved resonance energy ranges.
- 2) A "point file" in which the resolved resonance cross sections have been reconstructed from the resonance parameters at a temperature of 0 Kelvin.

The resonance reconstruction phase has been carried out with the following two codes: RECENT (Ref. 4) and RESEND (Ref. 3). Both have passed the adequacy test in a cross section processing code verification project (Ref. 27). The tolerance used for reconstructing the resonance cross sections was one per cent which is adequate for fast reactor applications.

In a first phase the module MODER was used in order to convert the files from display code (EBCDIC) to computer internal code (BINARY). The use of the binary files in the subsequent phases in fact speeds up the calculations considerably.

In the next phase the module RECONR was used. The purpose of this module is normally to reconstruct resonance cross sections from the parameters. In the case of the "point file" RECONR was used essentially to transform all energy interpolation laws to the linear-linear form. The linear interpolation form is necessary to obtain correct results in all the other modules. A tolerance of one per cent has been used for the linearizations. The energy grid was represented with seven significant decimal figures. RECONR then produced a point evaluated nuclear data file PENDF.

The PENDF file was then Doppler-broadened from a temperature of 0 to 300 Kelvin with BROADR which uses the method called "kernel broadening" (Ref. 29). The energy grid was then thinned to a tolerance of one per cent for the cross sections. BROADR then produced a new PENDF file which includes the broadened cross sections.

The module UNRESR was used to calculate the effective self-shielded and temperature-dependent cross sections in the unresolved resonance regions. These calculations are essentially based on the ETOX method (Ref. 30) and neglect both the in-sequence overlapping effects and the mutual interference effects between different resonant nuclides.

The GROUPR module generates the multi-group cross sections by using as input PENDF files produced either with BROADR or UNRESR. In addition to producing the group cross sections, group-to-group neutron scattering and fission matrices were calculated by using the energy and angular distributions taken from the "parameter file". Moreover, the total neutron yield per fission, the average cosine of the elastic scattering angle μ and the average elastic scattering lethargy increment γ were also calculated. A Legendre polynomial expansion of $\ell=3$ has been used.

For generating these cross sections a smooth component of the weighting function of the following form was used:

$$W(E) = \text{"Thermal} + 1/E + \text{Fission"}^{\text{"}}$$

where "Thermal" and "Fission" stand for Maxwellian spectrum with a temperature of 0.025 eV and for fission spectrum with a temperature of 1.40 MeV, respectively. The energy boundary between "Thermal" and "1/E" is 0.1 eV and the boundary between "1/E" and "Fission" is 0.8208 MeV.

Constant collision density for the neutron slowing-down energy region was assumed on the basis of the narrow resonance approximation. The resonance shielded cross sections for all isotopes were calculated for a temperature of 300 Kelvin and for several background cross section values which are the sum of the total cross sections of the other isotopes in the mixture per atom of the considered isotope. Total, capture, elastic, elastic removal, fission and transport cross sections were self-shielded and all the information is stored in a binary file called GENDF.

The module CCCR translates most of the information stored in GENDF into ISOTXS and BRKOKS format. It also computes the self-shielding factors from the resonance shielded cross sections of the GENDF. An ISOTXS and a BRKOKS file has been produced for each of the 31 isotopes. These files were merged into one ISOTXS and one BRKOKS file with the LINX code (Ref. 31) as shown in Fig. 2.2.

The group cross sections and the resonance self-shielding factors were generated with four different energy group structures as shown in Tables 2.1 and 2.2. Three of these use as the basic energy grid the one of the JAERI fast set, JFE3J2R (Ref. 9), which has a quarter lethargy per group. The 71-group structure is the JAERI fast set structure to which one additional fast group above 10 MeV has been added. The 50-group structure is the one of LIB-IV (Ref. 24) and is a subset of the one with 71-groups. The 25-group structure has essentially a half lethargy width per group in the important part of the neutron energy spectrum of a fast reactor. The 50- and 25-group cross sections were generated by collapsing the 71-group data with the CINX code (Ref. 11). The 26-group library is the ABBN group structure (Ref. 10), the energy boundaries of which differ from the half-lethargy structure of the 25-group library. These four libraries contain the group constants data for 31 isotopes which were selected in such a way as to cover the fast reactor benchmark testing. The list of the isotopes, their JEF-1 "material number" and their background cross section grid are shown in Table 2.3.

2.2 Group Constants Calculated with the GROUPR Module

GROUPR uses a generalized group integral concept:

$$\tilde{\sigma}_g = \frac{\int_g F(E) \tilde{\mu}(E) \phi(E) dE}{\int_g \phi(E) dE}$$

where the integrals are over the incident neutron energies in group g, ϕ is a weighting function depending on energy E and "background cross section" and F is called the "feed function" and is different for different data types. F is unit for neutron cross section, μ for ratio quantities like μ with respect to elastic scattering and ν with respect to fission yield.

The weighting function is given by:

$$\phi_i^{(E, T, \sigma_0)} = \frac{w(E)}{[\sigma_0 + \sigma_t^{(E, t)}]^{l+1}}$$

where l is the Legendre moment order ($l=0$ refers to flux- and $l=1$ to current weighting), T is the temperature of the material and i is an index indicating the nuclide.

Two-body scattering is computed with a centre-of-mass Gaussian quadrature which gives accurate results even for small Legendre components of the group-to-group matrix. In this case F takes the following form:

$$F_{lg'}(E) = \int_{g'} dE \int_{-1}^{+1} dw f(E \rightarrow E', w) P_l(\mu[w])$$

where $f(E \rightarrow E', w)$ is the probability of scattering from E to E' through the centre-of-mass cosine w and P_l is the Legendre polynomial for the laboratory cosine μ (Ref. 32).

The two slowing down parameters ξ (average elastic scattering lethargy increment) and γ (average square elastic scattering lethargy increment/2 ξ) are calculated by using a special definition (Ref. 33). ξ is closely related to the elastic removal cross section:

$$\xi_g = \frac{\Delta u_g \int_g du \int_{g'} du' \sigma_e(u' < -u) \phi(u)}{\int_g du \sigma_e(u) \phi(u)}$$

and γ is defined by:

$$\gamma_g = \frac{\int_g du \int_{g'} du' (u_g - u) \sigma_e(u' < -u) \phi(u)}{\int_g du \int_{g'} du' \sigma_e(u' < -u) \phi(u)}$$

where u_g is the lethargy at the bottom of group g .

The average fission spectrum is computed by using the following formula:

$$\chi_g = \frac{\sum_{g'} \sigma_{f,g \leftarrow g'} \phi_{g'}}{\sum_{g'} \nu_{g'} \sigma_{fg'} \phi_{g'}}$$

where $\sigma_{fg \leftarrow g}$, is the fission matrix element defined as follows:

$$\int_g dE \int_{g'} dE' \nu \sigma_f(E) \chi(E \rightarrow E') w(E) / \int_g w(E) dE$$

2.3 Group Cross Section Collapsing

Both the 71- and 26- group cross section library has been directly generated with the NJOY system as shown in Fig. 2.1. The 50- and 25- group cross section libraries have been produced by collapsing the 71-group library with the CINX code (Ref. 11) for economical reasons. The procedure is shown in Fig. 2.2. The 50-group library was produced in order to make a direct comparison with the similar LIB-IV library based on ENDF/B-IV possible.

In the collapsing algorithms CINX preserves the reaction rates. For vector cross sections (total, capture, elastic, fission, inelastic, $(n,2n)$ etc.) the following formula is used:

$$\sigma_{xG} = \frac{\sum_{g \in G} \sigma_{xg} \phi_g}{\sum_{g \in G} \phi_g}$$

where G indicates the coarse group that contains one or more fine groups g .

For other quantities ν (total neutron yield per fission), μ (average cosine of elastic scattering angle) and ξ (average elastic scattering lethargy increment), the appropriate reaction rates have to be used in order to obtain correct group collapsed data:

$$Q_{xG} = \frac{\sum_{g \in G} Q_{xg} \phi_g}{\sigma_{xG} \phi_g}$$

where Q_{xg} represents the quantity that requires reaction rate collapsing; and $Q_{xg} = \nu_g \sigma_{fg}$; for ν , $Q_{xg} = \mu_g \sigma_{eg}$ for μ and $Q_{xg} = \xi_g \sigma_{eg}$ for ξ are used respectively. This formula is exact for ν and μ but is an approximation for ξ .

The fission spectrum is collapsed by the following approximation:

$$\chi_G = \sum_{g \in G} \chi_g$$

The Legendre moments of the group-to-group scattering matrices are collapsed by preserving the transfer reaction rate:

$$\sigma_{x\ell; G \rightarrow G'} = \frac{\sum_{g \in G} \sum_{g' \in G'} \sigma_{x\ell; g \rightarrow g'} \phi_g}{\phi_G}$$

the elastic removal cross section is obtained by:

$$\bar{\sigma}_{rG} = \bar{\sigma}_{eG} - \bar{\sigma}_{e0; G \rightarrow G}$$

the transport cross section by:

$$\bar{\sigma}_{tr,G} = \bar{\sigma}_{tG} - \mu_G \bar{\sigma}_{eG}$$

The resonance self-shielding factors are collapsed by the following algorithms:

$$f_{xG}(T, \bar{\sigma}_o) = \frac{\bar{\sigma}_{xG}(T, \bar{\sigma}_o)}{\bar{\sigma}_{xG}} =$$

$$= \frac{1}{\bar{\sigma}_{xG}} - \frac{\sum_{g \in G} \frac{f_{xg}(T, \bar{\sigma}_o) \bar{\sigma}_{xg} \phi_g}{f_{tg}(T, \bar{\sigma}_o) \bar{\sigma}_{tg} + \bar{\sigma}_o}}{\sum_{g \in G} \frac{\phi_g}{f_{tg}(T, \bar{\sigma}_o) \bar{\sigma}_{tg} + \bar{\sigma}_o}}$$

where all $\bar{\sigma}$ without brackets refer to infinite dilute cross sections and x stands for capture, elastic and fission. The self-shielding factors for the total cross section is given by:

$$f_{tg}(T, \bar{\sigma}_o) = \frac{\sum_x f_{xg}(T, \bar{\sigma}_o) \bar{\sigma}_{xg}}{\sum_x \bar{\sigma}_{xg}}$$

The current weighting total self-shielding factor which is used to calculate the effective diffusion coefficient is defined by:

$$f_{tot,g}(T, \bar{\sigma}_o) = \frac{1}{\bar{\sigma}_{tg}} \frac{\sum_{g \in G} f_{tot,g}(T, \bar{\sigma}_o) \bar{\sigma}_{tg} j_g}{\sum_{g \in G} j_g}$$

where the current is approximated by:

$$j_g = \int_g dE \frac{\phi(E)}{[\bar{\sigma}_{t(E,T)} + \bar{\sigma}_o]^2}$$

Furthermore, the transport self-shielding factor is calculated by:

$$f_{tr\ g} = \frac{f_{totG} \sigma_{tG} - \mu_G f_{eG} \sigma_{eG}}{\sigma_{tG} - \mu_G \sigma_{eG}}$$

2.4 Comparative Graphs

In order to have a graphical comparison, the 50-group cross sections of JEF-1 and the corresponding data from LIB-IV were plotted together with their ratios. For this purpose a program that translates the ISOTXS and BRK0XS files to ENDF-5 histogram form was developed and called CCENDF. The resulting file is then fed into the comparative plotting program COMPLOT (Refs. 34, 35).

Some of the most significant plots for Fe, U-238 and Pu-239 are shown in Appendix A. The deviations observed in these figures are sometimes not only due to the different data base but also to the different processing system used. In fact LIB-IV was produced with the MINX code.

The different sets of collapsed and uncollapsed group constants are compared in Appendix B for U-238. From the graphs it appears that the collapsing algorithms are performing well, an exception, however, can be observed for ξ .

Table 2.1
71-, 50-, 25-Group Structure

Groups			Neutron Velocity (cm/sec)	Upper Energy (eV)	Lethargy Width
71	50	25			
1	1	1	4.64200E+09	1.50000E+07	0.4055
2	2		4.06340E+09	1.00000E+07	1/4
3			3.59795E+09	7.78802E+06	1/4
4	3		3.18392E+09	6.06531E+06	1/4
5			2.81584E+09	4.72371E+06	1/4
6	4	2	2.48913E+09	3.67881E+06	1/4
7			2.19951E+09	2.86500E+06	1/4
8	5	3	1.94308E+09	2.23130E+06	1/4
9			1.71617E+09	1.73770E+06	1/4
10	6	4	1.51548E+09	1.35340E+06	1/4
11			1.33805E+09	1.05400E+06	1/4
12	7	5	1.17825E+09	8.20852E+05	1/4
13			1.03981E+09	6.39281E+05	1/4
14	8	6	9.17623E+08	4.97871E+05	1/4
15	9		8.09795E+08	3.87741E+05	1/4
16	10	7	7.14646E+08	3.01971E+05	1/4
17	11		6.30676E+08	2.35180E+05	1/4
18	12	8	5.56567E+08	1.83160E+05	1/4
19	13		4.91166E+08	1.42640E+05	1/4
20	14	9	4.33454E+08	1.11090E+05	1/4
21	15		3.82522E+08	8.65171E+04	1/4
22	16	10	3.37574E+08	6.73791E+04	1/4
23	17		2.97909E+08	5.24751E+04	1/4
24	18	11	2.62905E+08	4.08681E+04	1/4
25	19		2.32014E+08	3.18281E+04	1/4
26	20	12	2.04752E+08	2.47880E+04	1/4
27	21		1.80691E+08	1.93050E+04	1/4
28	22	13	1.59459E+08	1.50340E+04	1/4
29	23		1.40723E+08	1.17090E+04	1/4
30	24	14	1.24187E+08	9.11882E+03	1/4
31	25		1.09594E+08	7.10171E+03	1/4
32	26	15	9.67166E+07	5.53081E+03	1/4
33	27		8.53521E+07	4.30741E+03	1/4
34	28	16	7.53232E+07	3.35461E+03	1/4
35	29		6.64726E+07	2.61261E+03	1/4
36	30	17	5.86616E+07	2.03470E+03	1/4
37	31		5.17686E+07	1.58460E+03	1/4
38	32	18	4.56857E+07	1.23410E+03	1/4
39	33		4.03176E+07	9.61122E+02	1/4
40	34	19	3.55801E+07	7.48521E+02	1/4
41	35		3.13993E+07	5.82951E+02	1/4
42	36	20	2.77099E+07	4.54001E+02	1/4
43	37		2.44538E+07	3.53580E+02	1/4
44	38	21	2.15803E+07	2.75360E+02	1/4
45			1.90447E+07	2.14451E+02	1/4
46	39		1.68069E+07	1.67020E+02	1/4
47			1.48319E+07	1.30070E+02	1/4
48	40	22	1.30892E+07	1.01300E+02	1/4
49			1.15512E+07	7.88932E+01	1/4

Groups			Neutron Velocity (cm/sec)	Upper Energy (eV)	Lethargy Width
71	50	25			
50	41		1.01939E+07	6.14421E+01	1/4
51			8.99612E+06	4.78511E+01	1/4
52	42		7.93903E+06	3.72671E+01	1/4
53			7.00610E+06	2.90230E+01	1/4
54	43	23	6.18284E+06	2.26030E+01	1/4
55			5.45640E+06	1.76030E+01	1/4
56	44		4.81528E+06	1.37100E+01	1/4
57			4.24943E+06	1.06770E+01	1/4
58	45		3.75013E+06	8.31532E+00	1/4
59			3.30947E+06	6.47602E+00	1/4
60	46		2.92060E+06	5.04351E+00	1/4
61			2.57742E+06	3.92791E+00	1/4
62	47	24	2.27457E+06	3.05901E+00	1/4
63			2.00730E+06	2.38241E+00	1/4
64	48		1.77143E+06	1.85540E+00	1/4
65			1.56330E+06	1.44500E+00	1/4
66	49		1.37961E+06	1.12540E+00	1/4
67			1.21749E+06	8.76422E-01	1/4
68	50		1.07443E+06	6.82562E-01	1/4
69			9.48181E+05	5.31581E-01	1/4
70		25	8.36769E+05	4.13991E-01	1/4
71			2.81095E+05	3.22421E-01	10.65
				1.00000E-05	

Table 2.2
26-Group Structure

Groups	Neutron Velocity (cm/sec)	Upper Energy (eV)	Lethargy Width
1	3.82746E+09	1.05000E+07	0.47836
2	3.06710E+09	6.50789E+06	0.47836
3	2.44493E+09	4.03358E+06	0.47836
4	1.89691E+09	2.50001E+06	0.56972
5	1.43788E+09	1.41421E+06	0.56972
6	1.03669E+09	8.00002E+05	0.69315
7	7.33060E+08	4.00001E+05	0.69315
8	5.18352E+08	2.00001E+05	0.69315
9	3.59371E+08	1.00000E+05	0.76753
10	2.44835E+08	4.64160E+04	0.76753
11	1.66804E+08	2.15444E+04	0.76753
12	1.13642E+08	1.000000E+04	0.76753
13	7.74317E+07	4.64160E+03	0.76753
14	5.28000E+07	2.15444E+03	0.76753
15	3.59604E+07	1.000000E+03	0.76753
16	2.44895E+07	4.64160E+02	0.76753
17	1.66822E+07	2.15444E+02	0.76753
18	1.13646E+07	1.000000E+02	0.76753
19	7.74241E+06	4.64160E+01	0.76753
20	5.27479E+06	2.15444E+01	0.76753
21	3.59374E+06	1.000000E+01	0.76753
22	2.44836E+06	4.64160E+00	0.76753
23	1.66805E+06	2.15444E+00	0.76753
24	1.13643E+06	1.000000E+00	0.76753
25	7.74235E+05	4.64160E-01	0.76753
26	2.64440E+05	2.15444E-01	9.97787
		1.00000E-05	

Table 2.3

Characteristics of the Group Cross Section Libraries

*** FILE ISOTXS -- VERSION 1 --- ***
 *** FILE BRKOXS -- VERSION 1 -- ***

USER IDENTIFICATION JEF-1 NJOY

FILE CONTROL PARAMETERS

NGROUP	NUMBER OF ENERGY GROUPS IN SET	71	50	26	25
NISO	NUMBER OF ISOTOPES IN SET	31			
MAXUP	MAXIMUM NUMBER OF UPSCATTER GROUPS	0			
MAXDN	MAXIMUM NUMBER OF DOWNSCATTER GROUPS	71	50	26	25
MAXORD	MAXIMUM SCATTERING ORDER	4			
ICHIST	SET FISSION SPECTRUM FLAG	0			
ICHIST=1	SET VECTOR =NGROUP, SET MATRIX				
NSCMAX	MAXIMUM NUMBER OF BLOCKS OF SCATTERING DATA	4			
NSBLOK	BLOCKING CONTROL FOR SCATTERING DATA SELF-SHIELDING DATA	71	50	26	25
NISOSH	NUMBER OF ISOTOPES WITH SELF- SHIELDING FACTORS	31			
NSIGPT	TOTAL NUMBER OF VALUES OF SIGPT WHICH ARE GIVEN.	206			
NTEMPT	TOTAL NUMBER OF VALUES OF TEMPERATURE WHICH ARE GIVEN.	31			

No.	Isotope	Name	MAT	T (Kelvin)	Resonance Self-shielding Grid						
					ISOTXS	BRKOXS	log10(sigma0)				
01)	H-1	4011	300	300	5,	4,	3,	2,	1,	0,	-4
02)	BE	4049	300	300	5,	4,	3,	2,	1,	0,	-4
03)	B-10	4050	300	300	5,	4,	3,	2,	1,	0,	-4
04)	B-11	4051	300	300	5,	4,	3,	2,	1,	0,	-4
05)	C	4060	300	300	4,	3,	2,	1,	0,	-4	
06)	N-14	4074	300	300	4,	3,	2,	1,	0,	-4	
07)	O-16	4086	300	300	5,	4,	3,	2,	1,	0	
08)	NA-23	4113	300	300	5,	4,	3,	2,	1,	0,	-4
09)	AL-27	4137	300	300	5,	4,	3,	2,	1,	0,	-4
10)	SI	4140	300	300	5,	4,	3,	2,	1,	0,	-4
11)	TI	4220	300	300	5,	4,	3,	2,	1,	0,	-4
12)	V	4230	300	300	5,	4,	3,	2,	1,	0,	-4
13)	CR	4240	300	300	5,	4,	3,	2,	1,	0,	-4
14)	MN-55	4255	300	300	5,	4,	3,	2,	1,	0,	-4
15)	FE	4260	300	300	5,	4,	3,	2,	1,	0,	-4
16)	NI	4280	300	300	5,	4,	3,	2,	1,	0,	-4
17)	CU	4290	300	300	5,	4,	3,	2,	1,	0,	-4
18)	GA	4310	300	300	5,	4,	3,	2,	1,	0	
19)	MO	4420	300	300	5,	4,	3,	2,	1,	0,	-4
20)	PB	4820	300	300	5,	4,	3,	2,	1,	0,	-4
21)	U-233	4923	300	300	5,	4,	3,	2,	1,	0	
22)	U-234	4924	300	300	5,	4,	3,	2,	1,	0	
23)	U-235	4925	300	300	5,	4,	3,	2,	1,	0,	-4
24)	U-236	4926	300	300	5,	4,	3,	2,	1,	0,	-4
25)	U-238	4928	300	300	5,	4,	3,	2,	1,	0	
26)	NP-237	4937	300	300	5,	4,	3,	2,	1,	0	
27)	PU-239	4949	300	300	5,	4,	3,	2,	1,	0,	-4
28)	PU-240	4940	300	300	5,	4,	3,	2,	1,	0	
29)	PU-241	4941	300	300	5,	4,	3,	2,	1,	0	
30)	PU-242	4942	300	300	5,	4,	3,	2,	1,	0	
31)	AM-241	4951	300	300	5,	4,	3,	2,	1,	0,	-4

Fig. 2.1 NJOY Modules Used for Generating 71 and 26 Group Cross Sections of JEF-1

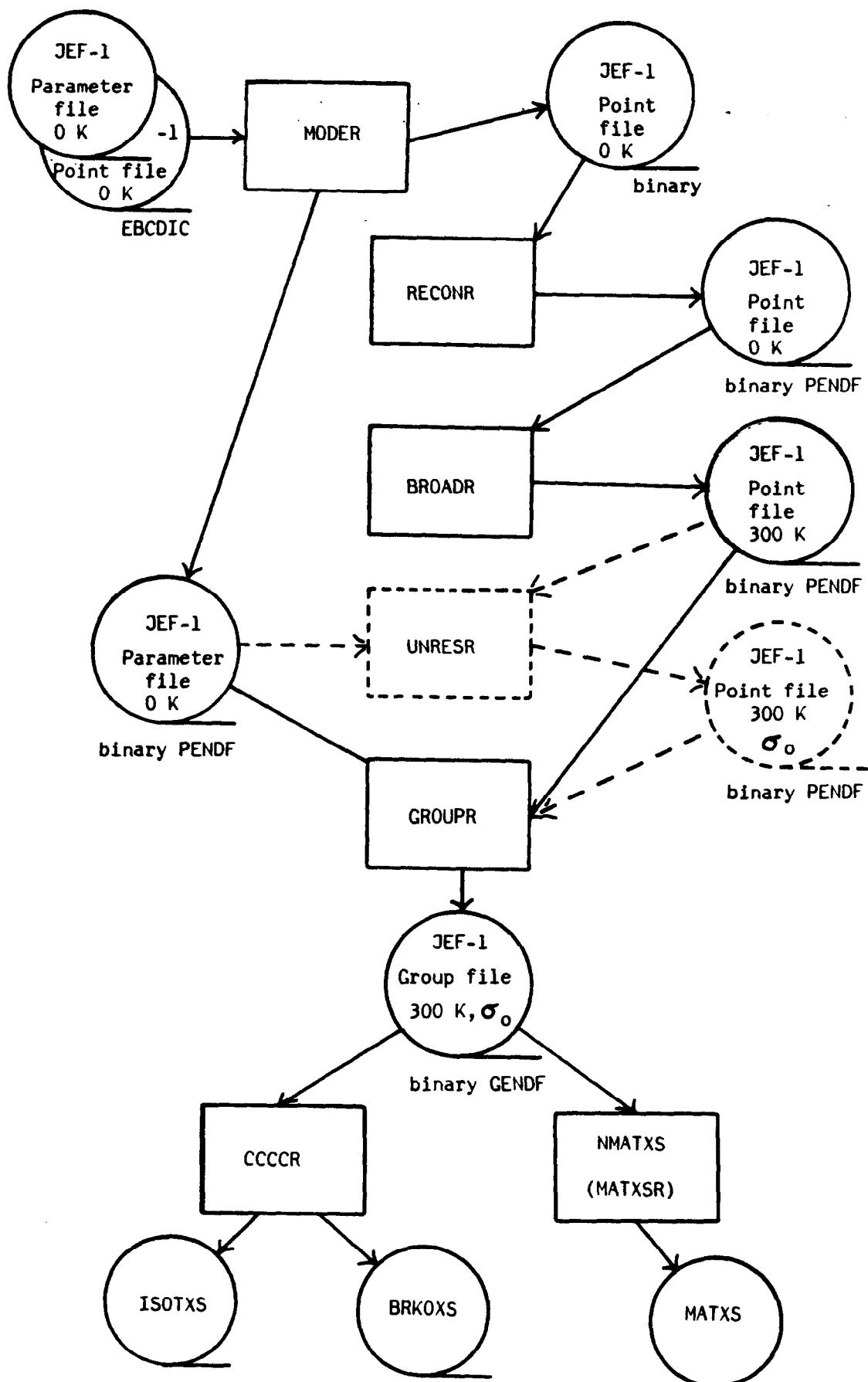
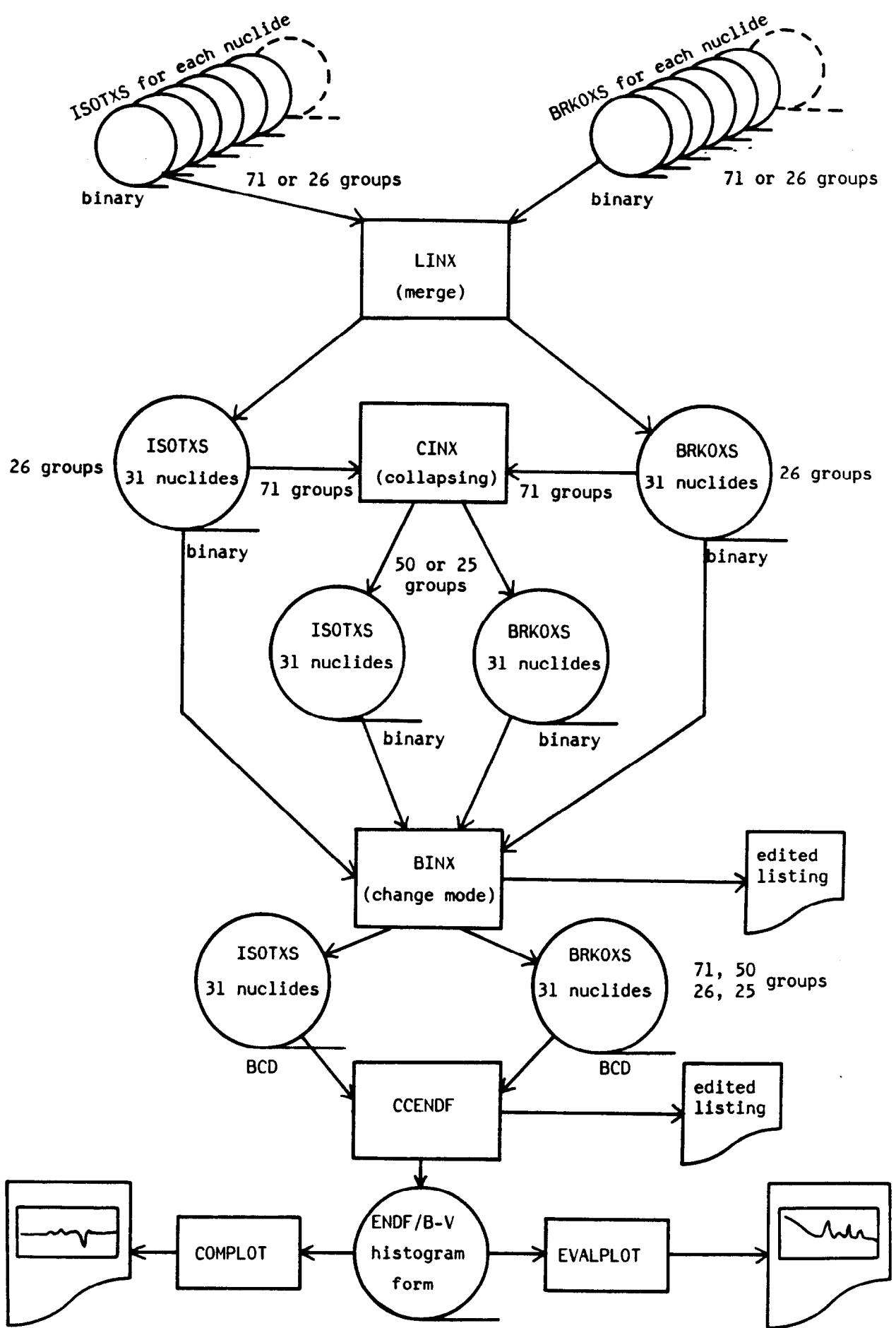


Fig. 2.2 Creation of Master Library



3. BENCHMARK CALCULATION MODELS

3.1 Characteristics of Critical Assemblies

For the benchmark test of JEF-1, 20 fast critical assemblies and two infinite homogeneous media were selected. The seventeen assemblies selected by Hardie et al. (Ref. 13) for benchmark testing of ENDF/B-IV, a mock-up experiment of JOYO (FCA-V-2) of JAERI and two of the MOZART program assemblies (MZA and MZB), a cooperation between the UK and Japan, were adopted. The geometrical models and atomic number densities used for the present calculations are shown in Appendix C. The main characteristics for these assemblies are as follows:

- 1) There are 14 plutonium and 8 uranium fuel cores (Table 3.1).
- 2) The core volumes vary from 12 to 4000 litres (Table 3.1).
- 3) The in-core concentration ratios of fertile to fissile materials (N_8/N_9 or N_8/N_5) range from zero to 17 (Table 3.1).
- 4) The hardness index for the core neutron spectrum (Ref. 18) varies from 0.369 to 5.14 (Table 3.1). It is given by $\nu \sum_f / \sum_s$, where

$$\frac{\nu}{\sum_s} = \frac{\sum_j \xi_j N_j \sigma_{Pj}}{\sum_j N_j \sigma_{Pj}}$$

$$\xi_j = \frac{2}{A_j + \frac{3}{2}}$$

and A_j , N_j , σ_{Pj} stand for the atomic mass, atomic number density and potential scattering cross sections for nuclide j in the core. \sum_f and \sum_s are one-group cross sections calculated with one-dimensional diffusion theory.

- 5) ZPR-3-48 and ZPR-3-49: ZPR-3-49 has the same composition as ZPR-3-48 and differs only in that all sodium is removed. Sodium void effect can, as a consequence, be estimated by examining the change in reactivity for the two assemblies.
- 6) ZPR-3-49 and ZPR-3-50: In ZPR-3-49, carbon is added to the composition of ZPR-3-50; its neutron spectrum is therefore softer than the one of ZPR-3-50.
- 7) ZPR-3-53 and 56B have depleted uranium and nickel reflectors, respectively.
- 8) VERA-11A and -1B, and ZPR-6-7 and ZPR-6-6A are called mirror reactors. VERA-11A and ZPR-6-7 are Pu-fuel cores but VERA-1B and ZPR-6-6A are U-fuel cores. Thus, the effects due to the difference in fissile materials used as fuels on nuclear characteristics are studied by analysing these assemblies.

- 9) SCHERZO-556 and UO2-740 are infinite homogeneous media of uranium metal with a U-235 enrichment of 5.56% and uranium di-oxide with a U-235 enrichment of 7.40%. The analysis for these assemblies is useful to assess the quality of U-235 and U-238 cross sections.
- 10) MZA, MZB, ZPPR-2 and ZPR-6-7 have compositions and environments similar to a large fast breeder reactor with plutonium fuel.

Therefore, analyses for these assemblies are very important to check the applicability of cross section sets to fast reactor calculations.

3.2 Benchmark Calculation Procedure

The benchmark assembly described by Hardie et al. (Ref. 14) were modelled with one-dimensional diffusion theory in spherical geometry with the exception of ZPPR-2 for which a 1-D cylindrical model was used. Also for FCA-V-2, MZA and MZB, spherical models in the one-dimensional diffusion theory were considered (Ref. 19). Factors that correct the simplified modelling used in the calculations were then applied to the effective multiplication factors obtained with the one-dimensional diffusion code EXPANDA-GS (Ref. 20). These take into account geometry effects (1-D to 2-D correction), effects of the approximated theory used (diffusion to transport correction) and heterogeneity effects. The correction factors were taken from Refs. 14 and 18 and are shown in Table 3.2.

The adopted procedure for benchmark calculations is shown in Fig. 3.1. In this scheme the C4TOJFS3 code (Ref. 21) translates the data files from the CCCC-ISOTXS and BRKDXS format to a JFS-3 type library. In the EXPANDA-GS code the resonance self-shielding factors are interpolated by using cubic spline functions (Ref. 22).

The BENKEF code corrects the effective multiplication factors calculated by EXPANDA-GS using the correction factors of Table 3.2, and compares them with the experimental values. The BENSPE code calculates the central reaction rate ratios using the neutron flux and the effective cross sections obtained by EXPANDA-GS. These quantities are compared with the experimental values in Table 3.3.

Table 3.1 Characteristics of the fast critical assemblies

PU-FUEL CORES				
ASSEMBLY	NB/N9	CORE VOLUME(1)	HARDNESS	INDEX
VERA-11A	0.06	12	1.60	
ZEBRA-3	8.6	50	5.14	
SNEAK-7A	3.0	110	0.679	
ZPR-3-53	1.6	220	0.369	
SNEAK-7B	7.0	310	0.801	
ZPR-3-50	4.6	340	0.416	
ZPR-3-48	4.6	410	0.645	
ZPR-3-49	4.6	450	0.753	
ZPR-3-56B	4.6	610	0.698	
ZPR-6-7	6.5	3100	0.499	
ZPPR-2	5.5	2400	0.50	
MZA	3.9	570	0.775	
MZB	5.8	1800	0.543	
FCA-5-2	2.3	200	1.06	

U-FUEL CORES				
ASSEMBLY	NB/N5	CORE VOLUME(1)	HARDNESS	INDEX
VERA-1B	0.07	30	1.01	
ZPR-3-5F	1.1	50	4.93	
ZPR-3-12	3.8	100	1.20	
ZPR-3-11	7.6	140	4.63	
ZEBRA-2	6.2	430	0.573	
ZPR-6-6A	6.0	4000	0.522	
SCHERZO	17.0		4.0	
UD2-740	12.6		0.51	

Table 3.2 Correction factors applied to the K_{eff} calculated by one-dimensional diffusion theory

No.	ASSEMBLY	FUEL	1D to 2D TRANSPORT	HETERO	TOTAL	EXPERIMENT
1	VERA-11A	PU	0.0035	0.0472	0.0	* 0.0607 1.00
2	VERA-1B	U	0.0038	0.0237	0.0	* 0.0275 1.00
3	ZPR-3-5F	U	-0.0028	0.0192	0.0	* 0.0164 1.00
4	ZEBRA-3	PU	-0.0006	0.0126	0.0	* 0.012 1.00
5	ZPR-3-12	U	-0.0009	0.0099	0.0	* 0.009 1.00
6	SNEAK-7A	PU	0.0061	0.0120	-0.0045	0.0136 1.00
7	ZPR-3-11	U	0.0001	0.0060	0.0	* 0.0061 1.00
8	ZPR-3-53	PU	-0.0160	0.0087	0.0230	0.0167 1.00
9	SNEAK-7B	PU	0.0042	0.0047	-0.0021**	0.0068 1.00
10	ZPR-3-50	PU	-0.0133	0.0056	0.0220	0.0143 1.00
11	ZPR-3-48	PU	-0.0009	0.0064	0.0183	0.0238 1.00
12	ZEBRA-2	U	-0.0007	0.0033	0.0	* 0.0026 1.00
13	ZPR-3-49	PU	-0.0139	0.0068	0.0158	0.0087 1.00
14	ZPR-3-56B	PU	-0.0166	0.0065	0.0102	0.0001 1.00
15	ZPR-6-7	PU	-0.0020	0.0016	0.0166	0.0162 1.00
16	ZPR-6-6A	U	-0.0013	0.0013	0.0073	0.0073 1.00
17	ZPPR-2	PU	0.0003	0.0024	0.0176	0.0202 1.00
18	MZA	PU	-0.0196	0.0075	0.0140	0.0019 1.0108
19	MZB	PU	-0.0186	0.0036	0.0123	-0.0027 1.0040
20	FCA-5-2	PU	-0.0150	0.0044	0.0151	0.0045 1.00
21	SCHERZO	U				1.00
22	UD2-740	U				1.00

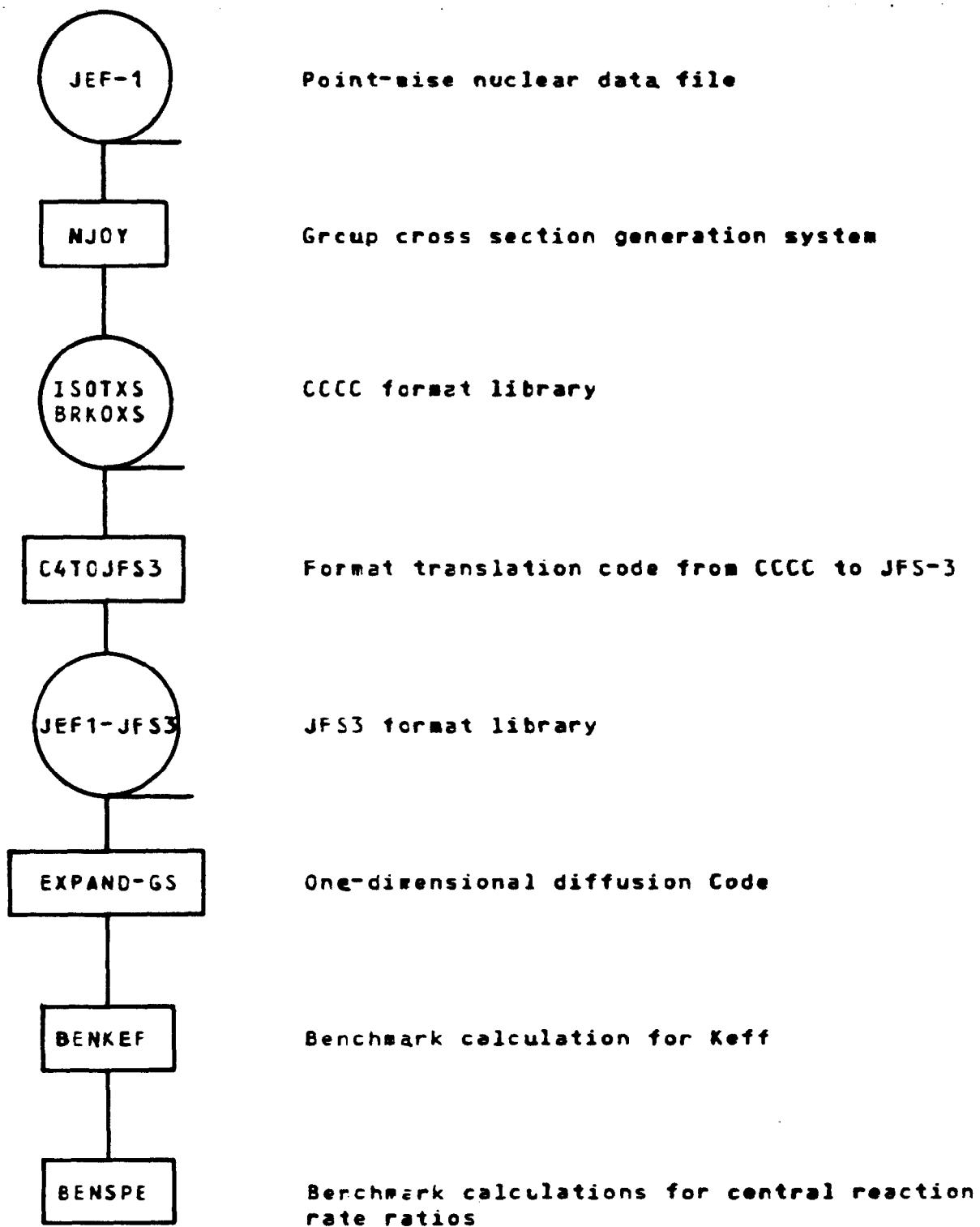
* The atom densities and sizes were adjusted to account for heterogeneities.
 ** Includes corrections for cylindrization, actual control rod position, and heterogeneities.

Table 3.3 Experimental data of reaction rate ratios

ASSEMBLY	F8/F6	F9/F6	F0/F6	C8/F6	C8/F9
VERA-11A	0.102	1.18	0.475	0.158	
VERA-1B	0.086	1.200	0.399	0.135	0.122
ZPR-3-6F	0.078	1.220	0.530	0.104	0.085
ZEBRA-3	0.0461	1.190	0.373		
ZPR-3-12	0.047	1.120		0.123	0.110
SNEAK-7A	0.0448	1.016		0.1376	0.135
ZPR-3-11	0.038	1.190	0.340	0.112	0.094
ZPR-3-53	0.0254	0.928	0.174		
SNEAK-7B	0.0330	1.012		0.131	0.129
ZPR-3-50	0.0251	0.903	0.159		
ZPR-3-48	0.0326	0.975	0.243	0.138	0.141
ZEBRA-2	0.0320	0.987	0.237	0.136	0.138
ZPR-3-49	0.0345	0.986			
ZPR-3-56B	0.0308	1.028	0.282		
ZPR-6-7	0.022	0.9425		0.132	0.140
ZPR-6-6A	0.0241			0.1378	
ZPPR-2	0.0201	0.937	0.170		
MZA	0.03366	1.0134	0.2699	0.1314	0.1297
MZB	0.02256	0.9488	0.1919	0.1351	0.1424
FCA-5-2	0.03960	1.1040		0.1400	0.1268
SCHERZO	0.0227			0.1154	
U02-740	0.0243	0.953		0.1386	

Note: The experimental data of VERA-11A and VERA-1B were taken from Ref.(15). The data of ZPR-6-7 and -6A were taken from Ref.(16).

Fig 3.1 Procedure of Benchmark Calculations



4. DISCUSSION OF BENCHMARK TESTING

The calculated results are shown and compared with the experimental data in Tables 4.1 - 4.24. The different libraries are identified by the following symbols:

- a) JEF1-71F: 71 group cross section library derived from JEF-1 with the NJOY system.
- b) JEF1-50F: 50 group cross section library obtained by collapsing the 71 group data with the CINX code (Ref. 11).
- c) JEF1-25F: 25 group cross section library obtained by collapsing the 71 group data with the CINX code.
- d) JEF1-26: 26 group cross section library derived from JEF-1 with the NJOY system. Elastic scattering self-shielding factors were used for calculating effective elastic scattering removal cross sections, because the self-shielding factors for elastic removal were not included in this library.
- e) JFS3J2R: 70 group cross section library derived from JENDL-2 with the TIMS-PGG system (Ref. 20).
- f) ENDFB4: 50 group cross section library derived from ENDF/B-IV called LIB-IV (Ref. 24) which was produced with the MINX code (Ref. 23).

4.1 Effective Multiplication Factors

The effective multiplication factors calculated with one-dimensional diffusion theory, the correction factors and the corrected K_{eff} are shown in Tables 4.1 - 4.6 for the six group constant libraries described above. The corrected values are compared in Table 4.7. In this table results obtained with JEF-71F are taken as a reference and the parentheses show the per cent deviations of the ratio between calculated and experimental values (C/E) of the other libraries. From this table, the following can be observed:

- 1) The results for JEF1-71F and JFS3J2R are in good agreement with each other for large plutonium fuel cores. Some large discrepancies are observed, however, for small plutonium and all uranium cores. The main discrepancies between the two cross section sets are as follows:
 - (a) The U-235 data of JEF-1 were taken from the ENDF/B-V standard file and they differ in particular from the JENDL-2 data in the fission spectrum and cross sections.
 - (b) The Pu-239 data of JEF-1 contain newly evaluated information; the γ -values, the resonance and $(n,2n)$ cross sections are different from the JENDL-2 data.
 - (c) The Cr, Fe and Ni structural material data of JEF-1 are taken from the KEDAK-3 file.
 - (d) The calculational method for obtaining resonance self-shielding factors and the weighting function differ in the NJOY and TIMS-PGG systems.

- (e) The top energy boundary is 15 MeV for JEF1-71F and 10.5 MeV for JFS3J2R. The effect of the different top group boundary on the effective multiplication factors are described in Section 4.6.
 - (f) The B-10 absorption cross section of JEF1-71F is smaller than the one of JFS3J2R in the high energy region ($(n,t + 2 \alpha)$ reaction was omitted in the calculation of NJOY).
- 2) The underprediction of Keff for large size cores (ZPR-6-7, ZPPR-2, MZA and ZPR-6-6A) that is obtained with ENDF/B-IV data for the plutonium cores is smaller for JEF1-71F and JFS3J2R:
- The Keff for JEF1-71F, JFS3J2R and ENDFB4 are compared as a function of core volume (V) in Fig. 4.1. Moreover, the results for JEF1-71F are shown as a function of the concentration ratio of fertile to fissile materials in Fig. 4.2 and of the spectral hardness in Fig. 4.3.
- 3) The discrepancies between the C/E-values calculated for the four different group structure sets JEF1-71F, JEF1-50F, JEF1-25F and JEF1-26 are displayed in Table 4.7 and Fig. 4.4. The results obtained with the collapsed JEF1-71F data to JEF1-50F and -25F are larger than the ones for JEF1-71F, and their deviations increase with increasing core volumes. On the other hand, considerable discrepancies between the results for JEF1-71F and JEF1-26 are observed, and the deviations are independent of core volume. In particular, the discrepancies between the JEF1-25F and JEF1-26 results are noticeable, although these libraries differ only in the elastic removal cross sections treatment and the group energy structures.

4.2 Central Reaction Rate Ratios

Tables 4.8 - 4.19 show the following central reaction rate ratios calculated with one-dimensional diffusion models:

$Pu-239(n,f)/U-235(n,f)$, $U-238(n,f)/U-235(n,f)$,
 $U-238(n,c)/U-235(n,f)$, $Pu-240(n,f)/U-235(n,f)$, $U-234(n,f)/U-235(n,f)$,
 $B-11(n,a)/U-235(n,f)$, $B-10(n,a)/U-235(n,f)$, $Fe(n,c)/U-235(n,f)$,
 $U-235(n,f)/Pu-239(n,f)$, $Pu-240(n,f)/Pu-239(n,f)$, $Pu-241(n,f)/Pu-239(n,f)$ and $U-238(n,c)/Pu-239(n,f)$, where the reactions (n,c) , (n,f) and (n,a) stand for the radiative capture, fission and absorption.

Furthermore, their evaluated values are compared against the experimental data in Tables 4.20 - 4.24.

- 1) $Pu-239(n,f)/U-235(n,f)$ (F9/F5): Tables 4.8 and 4.21, Figs. 4.5, 4.6 and 4.7

For the results obtained with JEF-1 the underprediction is smaller than the one observed for JFS3J2R. It is especially noticeable that the predictions of JEF-1 for ZPR-6-7, ZPPR-2, MZA and MZA are considerably improved.

It may be considered that the main reason for this is the difference between the U-235 data of JEF-1 and JENDL-2.

This appears clearly when comparing the results for U-238(n,c)/U-235(n,f) (C8/F5) and U-238(n,c)/Pu-239(n,f) (C8/F9) calculated by using JEF1-71F with those of JFS3J2R. The results obtained with JEF1-71F and JFS3J2R differ by about 2% for C8/F5 and by a very small amount for C8/F9.

- 2) U-238(n,f)/U-235(n,f) (F8/F5): Tables 4.9 and 4.20, Figs. 4.8 - 4.10.

The results obtained with JEF1-71F and ENDFB4 are overestimated generally for both the plutonium and uranium cores. When compared with the experimental values, the overestimation increases with decreasing number of groups in the libraries. Large discrepancies between JEF1-71F and JFS3J2R are due to the differences in the U-235 data.

The calculated results underestimate the experimental values for VERA-11A and VERA-1B. In the previous calculations (Ref. 13), however, they were overpredicted. The results of a new analysis of these experiments have become available in the meantime (Ref. 15); they differ from the previous analysis by about +30%.

- 3) Pu-240(n,f)/U-235(n,f) (F0/F5): Tables 4.11 and 4.22, Figs. 4.11 - 4.13.

Remarkable overpredictions are observed especially for the U-fuel cores.

The measured data for threshold fission reaction may be of low quality.

- 4) U-238(n,c)/U-235(n,f) (C8/F5): Tables 4.10 and 4.23, Figs. 4.14 - 4.16. Figures 4.14 - 4.16 show the C/E - values computed with JEF1-71F as a function of core volume, concentration ratios of fertile to fissile materials and spectral hardness, respectively. Figure 4.14 shows that there is a clear dependence of the C/E-value on the core volume. The calculated values underestimate the experimental results for smaller core volumes. This tendency is observed also for the results calculated by using other libraries. In Fig. 4.16, the results calculated by E. Fort et al. (Ref. 18) are identified with the symbol PUCAD and UCAD. These results show a dependence of the C/E - values on the spectral hardness, such a dependence does not show up clearly however in the present calculations.

- 5) U-238(n,c)/Pu-239(n,f) (C8/F9): Tables 4.19 and 4.24, Figs. 4.17 - 4.19.

The calculated results show a similar tendency as the one for U-238(n,c)/U-235(n,f) (C8/F5).

- 6) Pu-241(n,f)/Pu-239(n,f) (F1/F9): Table 4.18.

The discrepancies between the results obtained with JEF1-71F, JFS3J2R and ENDFB4 are very small; the same applies when comparing the results calculated with the four libraries of JEF-1.

- 7) Fe (n,c)/U-235(n,f): Table 4.15.

In several assemblies with a soft core spectrum such as ZPR-6-7, ZPR-6-6A and MZB, the values calculated with JEF1-71F are larger by 10% than the ones obtained with JFS3J2R; they are in very good agreement however with those of ENDFB4. These values decrease for large core assemblies with decreasing number of groups of the collapsed libraries.

8) $B-10(n,a)/U-235(n,f)$: Table 4.14.

The values for JEF1-71F are larger than the ones for JFS3J2R, with the exception of the results of the hard spectrum cores VERA-1B, ZPR-3-6F and ZEBRA-3. This last effect is caused by the fact that the reaction $(n,t+2\alpha)$ was omitted in the generation of JEF1-71F.

9) $B-11(n,a)/U-235(n,f)$: Table 4.13.

JEF1-71F gives larger values than JFS3J2R.

4.3 Analysis of SCHERZO-556 and U02-740

Simple benchmark calculations with JEF-1 data were performed for the two infinite homogeneous media SCHERZO-556 and U02-740 (Ref. 17), in order to assess the quality of U-235 and U-238 cross sections. SCHERZO-556 is a uranium metal assembly with a U-235 enrichment of 5.56% and U02-740 is a uranium dioxide assembly with a U-235 enrichment of 7.40 %. Reaction rate ratios of U-238 fission to U-235 fission (F_8/F_5), U-238 capture to U-235 fission (C_8/F_5) and Pu-239 fission to U-235 fission (F_9/F_5) were measured in these assemblies.

The benchmark calculations for these two assemblies were performed using the one-dimensional diffusion code EXPANDA-GS (Ref. 20). The infinite dimension was modelled using a slab geometry (size 24 m) and four cross section sets of different group structure based on the JEF-1 and the JFS3J2R set were used. These results are shown in Table 4.25. Furthermore, the results calculated in the UK (Ref. 1) are also shown in Table 4.25. The atomic number densities used for these calculations are shown in Table 4.26.

The results calculated by using the 71-group cross section set in the UK and the Data Bank are in very good agreement with each other. The results for the 50- and 25-group sets show larger values than the 71-group results for the effective multiplication factors and the central reaction rate ratios of U-238 to U-235 fissions. The ratio of U-238 capture to U-235 fission obtained with the 25-group set shows values which are 2% smaller than the ones for the 71- and 50- group sets in the U02-740 assembly. However, the 26-group result shows a smaller value for Keff and the difference between 25- and 26-group results is about 2% for SCHERZO-550. In order to investigate this discrepancy, the one-group cross sections were calculated and these are shown in Tables 4.27 - 4.29. Large discrepancies are observed for the $(n,2n)$ cross section of U-235 and U-238 and for the fission cross section of U-238. This may suggest a non-negligible contribution of the highest energy group from 10.5 to 15.0 MeV on the Keff. This contribution was consequently examined by neglecting all reaction cross sections for the first-group from 10.0 to 15.0 MeV in the 71- and 50-group libraries. However, this effect amounts only to about 0.2% (Table 4.25).

4.3.1 Comparison of Fission Spectrum

Figures 4.20 - 4.25 show the comparison of U-235 and Pu-239 fission spectra relative to the 25-, 26-, 50- and 71-group structures. The fission spectra for the 71- and 26- groups were calculated directly by using the NJOY system, and those for the 25- and 50- groups were obtained by collapsing the 71-group spectra with the CINX code (Ref. 11).

The fission spectra of Pu-239 and U-235 for 71-, 50- and 25- groups are compared in Figs. 4.20 and 4.22. It appears that the collapsing calculation of CINX is correct from these figures. Figures 4.21 and 4.23 compare the fission spectra of Pu-239 and U-235 for 25- and 26- groups, respectively. These show the consistency of the fission spectra for two different group structures calculated with the NJOY system.

Figures 4.24 and 4.25 show the comparison of fission spectra for Pu-239 and U-235. Small discrepancies are observed both in the lower and higher energy range and these are the cause for the small discrepancies between effective multiplication factors as shown in Table 4.31.

4.3.2 Comparison of Neutron Spectrum

Figures 4.26 - 4.31 show the comparison of neutron spectra for 25-, 26-, 50- and 71- energy groups calculated with the one-dimensional diffusion code EXPANDA-GS. The effect of collapsing energy group from 71 to 50 or 25 on the neutron spectrum at the core centre can be observed in Figs. 4.26 and 4.29.

The neutron spectra become slightly softer with energy groups collapsed to a smaller number. Figures 4.27, 4.28, 4.30 and 4.31 show the comparison of the core neutron spectra calculated by the two different energy structures of 25 and 26 groups. Large discrepancies between the 25 and 26 group neutron spectra are observed near 1 MeV for the U02-740 assembly in Fig. 4.28. The reason for these discrepancies may be found in the difference of the neutron elastic removal cross sections in the different energy group structures.

4.4 Comparison Between the Results Calculated for VERA-11A and ZPR-6-7

Considerable discrepancies between Keff calculated with one-dimensional diffusion codes in the UK and at the Data Bank were found for large cores such as the ZPR-6-7 and MZB assemblies. The discrepancy for the Keff corrected for transport and heterogeneity effects was about 1.0% for ZPR-6-7 as seen in Table 4.30. The results calculated by one-dimensional diffusion codes are directly compared for VERA-11A and ZPR-6-7 in Table 4.31.

For VERA-11A, the results from the UK and the Data Bank are in very good agreement with each other, but a discrepancy of 0.8% is observed for ZPR-6-7.

The core neutron spectrum in ZPR-6-7 is softer than the one in VERA-11A, and the effect of the resonance region on the Keff-calculation becomes very important.

The different method used for interpolating resonance self-shielding factors may be considered as one of the causes for this discrepancy. The self-shielded effective microscopic cross sections of U-238 and Pu-239 calculated for the core region of ZPR-6-7 assembly by the UK and the Data Bank are compared in Table 4.3. The comparisons cover 6-groups in the energy range from 4.3 to 11.7 KeV which is an important region in fast reactor calculations. Differences of the order of $1 \sim 2\%$ in the effective cross sections between the UK and the Data Bank can be observed for U-238 absorption and they are negligibly small for capture and fission of Pu-239.

In Table 4.33, the Keff calculated by using two different interpolation methods, cubic spline and rational functions (Ref. 22) are compared, and the difference in Keff is about 0.3% for ZPR-6-7. Furthermore, for calculating the SIGMA-0 parameter, the effects of iteration and non-iteration treatments (Ref. 25) on Keff are shown in Table 4.33, and the effect is about 0.1%.

In Figs. 4.32 - 4.34, the core neutron spectra in the ZPR-6-7 assembly are compared for different energy group structures, and the discrepancies are especially observed in the energy regions below 1 MeV.

4.5 The Effect of Exact Elastic Removal Self-Shielding Factors on Effective Multiplication Factors

In the previous benchmark calculations (Ref. 13), the elastic scattering self-shielding factors were used for calculating the effective elastic removal cross sections because the elastic removal self-shielding factors were not contained in the JEF1 group cross section library. Recently, these missing self-shielding factors were included into the 71-group cross section library. The removal self-shielding factors collapsed from 71- to 50- and 25-groups were calculated as follows:

Infinite dilute cross section for elastic removal:

$$\sigma_{er}^G = \sigma_{er,L} \phi_L^0 / \sum_{g \in G} \phi_g^0$$

Effective removal cross section:

$$\tilde{\sigma}_{er}^G = \tilde{\sigma}_{er,L} \phi_L^0 / \sum_{g \in G} \frac{\phi_g^0}{f_{t,g} \sigma_{t,g} + \sigma_0}$$

Elastic removal self-shielding factor:

$$f_{er}^G = \tilde{\sigma}_{er}^G / \sigma_{er}^G$$

where the subscript L indicates the lower fine energy group g contained in the broad group G, and ϕ_g^0 is the smooth component of the weighting function.

The benchmark tests were performed for 20 fast critical benchmarks, and the results obtained were compared with the previous results in Table 4.34. In this Table, the symbols JEF1-71F, JEF1-50F and JEF1-25F show the use of elastic removal self-shielding factors, and JEF1-71, JEF1-50 and JEF1-25 show the use of elastic scattering self-shielding factors for calculating the effective removal cross sections.

The results show that the underpredictions for the effective multiplication factors have become smaller when compared with the previous calculations.

4.6 The Effect on Effective Multiplication Factors and Reaction Rate Ratios of the Top Energy Group (10.0 - 15.0 MeV)

The top energy boundary differs in some of the cross section libraries:

For JEF1-71F, JEF1-50F and JEF1-25F it is of 15.0 MeV, for JEF1-26 of 10.5 MeV and for JFS3J2R of 10.0 MeV. In this section, the effect of neglecting the top energy group (10.0 - 15.0 MeV) for JEF1-71F on Keff and central reaction rate ratios is examined. All reaction cross sections for this energy group were neglected and the fission spectrum was renormalized. This modified library is called JEF1-70F. The results calculated by using JEF1-70F are compared with those of JEF1-71F in Table 4.35; the Keff-values are slightly smaller for JEF1-70F. It amounts to 0.25 per cent for ZEBRA-3 with the hardest core spectrum, and it becomes negligibly small for the assemblies with a softer core spectrum.

The central reaction rate ratios of U-238(n,f)/U-235(n,f) calculated by using the two libraries JEF1-71F and JEF1-70F are compared in Table 4.36. The effects of neglecting the highest energy group on this reaction rate ratio are less than 1.0 per cent. The effects for other reaction rate ratios were very small and their tables were suppressed.

Table 4.1 K-eff CALCULATED WITH LIBRARY SET --- JEF1-71F

NO.	ASSEMBLY	CALC.-K	CORRECTION	CORR.-K
1	VERA-11A	0.93430	0.05070	0.98500
2	VERA-1B	0.95918	0.02750	0.98668
3	ZPR-3-6F	0.98368	0.01640	1.00008
4	ZEBRA-3	0.97862	0.01200	0.99062
5	ZPR-3-12	0.98999	0.00900	0.99899
6	SNEAK-7A	0.98547	0.01360	0.99907
7	ZPR-3-11	0.99481	0.00610	1.00091
8	ZPR-3-53	0.98066	0.01670	0.99736
9	SNEAK-7B	0.98755	0.00680	0.99445
10	ZPR-3-50	0.98383	0.01430	0.99813
11	ZPR-3-48	0.97686	0.02380	1.00066
12	ZEBRA-2	0.98324	0.00260	0.98584
13	ZPR-3-49	0.99327	0.00870	1.00197
14	ZPR3-56B	0.99091	0.00010	0.99101
15	ZPR-6-7	0.97822	0.01620	0.99442
16	ZPR-6-6A	0.99008	0.00730	0.99738
17	ZPPR-2	0.98116	0.02020	1.00136
18	MZA	1.00256	0.00190	1.00446
19	MZB(1)	0.99768	-0.00270	0.99498
20	FCA-5-2	0.97934	0.00450	0.98384

Table 4.2 K-eff CALCULATED WITH LIBRARY SET --- JEF1-50F

NO.	ASSEMBLY	CALC.-K	CORRECTION	CORR.-K
1	VERA-11A	0.93524	0.05070	0.98594
2	VERA-1B	0.95886	0.02750	0.98636
3	ZPR-3-6F	0.98498	0.01640	1.00138
4	ZEBRA-3	0.98087	0.01200	0.99287
5	ZPR-3-12	0.99224	0.00900	1.00124
6	SNEAK-7A	0.98784	0.01360	1.00144
7	ZPR-3-11	0.99745	0.00610	1.00355
8	ZPR-3-53	0.98095	0.01670	0.99765
9	SNEAK-7B	0.99156	0.00680	0.99836
10	ZPR-3-50	0.98753	0.01430	1.00183
11	ZPR-3-48	0.97905	0.02380	1.00285
12	ZEBRA-2	0.98672	0.00260	0.98932
13	ZPR-3-49	0.99547	0.00870	1.00417
14	ZPR3-56B	0.99147	0.00010	0.99157
15	ZPR-6-7	0.98120	0.01620	0.99740
16	ZPR-6-6A	0.99039	0.00730	0.99769
17	ZPPR-2	0.98317	0.02020	1.00337
18	MZA	1.00434	0.00190	1.00624
19	MZB(1)	1.00066	-0.00270	0.99796
20	FCA-5-2	0.97957	0.00450	0.98407

Table 4.3 K-eff CALCULATED WITH LIBRARY SET --- JEF1-26F

NO.	ASSEMBLY	CALC.-K	CORRECTION	CORR.-K
1	VERA-11A	0.93733	0.06070	0.98803
2	VERA-1B	0.96291	0.02750	0.98041
3	ZPR-3-6F	0.98914	0.01640	1.00564
4	ZEBRA-3	0.98191	0.01200	0.99391
5	ZPR-3-12	0.99894	0.00900	1.00594
6	SNEAK-7A	0.99123	0.01360	1.00483
7	ZPR-3-11	1.00139	0.00610	1.00749
8	ZPR-3-53	0.98101	0.01670	0.99771
9	SNEAK-7B	0.99751	0.00680	1.00431
10	ZPR-3-50	0.99038	0.01430	1.00468
11	ZPR-3-48	0.98264	0.02380	1.00644
12	ZEBRA-2	0.99308	0.00260	0.98568
13	ZPR-3-49	0.99947	0.00870	1.00817
14	ZPR3-56B	0.99296	0.00010	0.99306
15	ZPR-6-7	0.99028	0.01620	1.00648
16	ZPR-6-6A	0.99397	0.00730	1.00127
17	ZPPR-2	0.99117	0.02020	1.01137
18	MZA	1.01131	0.00190	1.01321
19	MZB(1)	1.00964	-0.00270	1.00694
20	FCA-5-2	0.98410	0.00450	0.98860

Table 4.4 K-eff CALCULATED WITH LIBRARY SET --- JEF1-26

NO.	ASSEMBLY	CALC.-K	CORRECTION	CORR.-K
1	VERA-11A	0.93599	0.06070	0.98669
2	VERA-1B	0.96334	0.02750	0.98084
3	ZPR-3-6F	0.97531	0.01640	0.99171
4	ZEBRA-3	0.97841	0.01200	0.98041
5	ZPR-3-12	0.98196	0.00900	0.99096
6	SNEAK-7A	0.99133	0.01360	1.00493
7	ZPR-3-11	0.98141	0.00610	0.98751
8	ZPR-3-53	0.98720	0.01670	1.00390
9	SNEAK-7B	0.99114	0.00680	0.99794
10	ZPR-3-50	0.99359	0.01430	1.00789
11	ZPR-3-48	0.98082	0.02380	1.00462
12	ZEBRA-2	0.98048	0.00260	0.98308
13	ZPR-3-49	0.99829	0.00870	1.00599
14	ZPR3-56B	0.98989	0.00010	0.98999
15	ZPR-6-7	0.97833	0.01620	0.99453
16	ZPR-6-6A	0.98101	0.00730	0.98831
17	ZPPR-2	0.98065	0.02020	1.00085
18	MZA	1.00348	0.00190	1.00538
19	MZB(1)	0.99728	-0.00270	0.99468
20	FCA-5-2	0.97896	0.00450	0.98146

Table 4.5 K-eff CALCULATED WITH LIBRARY SET --- JFS3J2R

NO.	ASSEMBLY	CALC.-K	CORRECTION	CORR.-K
1	VERA-11A	0.94269	0.05070	0.99339
2	VERA-1B	0.97149	0.02750	0.99899
3	ZPR-3-6F	0.99642	0.01640	1.01282
4	ZEBRA-3	0.98836	0.01200	1.00035
5	ZPR-3-12	0.99716	0.00900	1.00616
6	SNEAK-7A	0.99028	0.01360	1.00388
7	ZPR-3-11	0.99873	0.00610	1.00483
8	ZPR-3-53	0.97418	0.01670	0.99088
9	SNEAK-7B	0.99648	0.00680	1.00328
10	ZPR-3-50	0.98242	0.01430	0.99672
11	ZPR-3-48	0.97841	0.02380	1.00221
12	ZEBRA-2	0.98982	0.00260	0.99242
13	ZPR-3-49	0.99921	0.00870	1.00791
14	ZPR3-56B	0.99066	0.00010	0.99076
15	ZPR-6-7	0.97669	0.01620	0.99289
16	ZPR-6-6A	0.99450	0.00730	1.00180
17	ZPPR-2	0.97981	0.02020	1.00001
18	MZA	1.00395	0.00190	1.00585
19	MZB(1)	0.99726	-0.00270	0.99456
20	FCA-6-2	0.98694	0.00460	0.99144

Table 4.6 K-eff CALCULATED WITH LIBRARY SET --- EBDFB4

NO.	ASSEMBLY	CALC.-K	CORRECTION	CORR.-K
1	VERA-11A	0.93628	0.05070	0.98598
2	VERA-1B	0.96818	0.02750	0.99568
3	ZPR-3-6F	0.99452	0.01640	1.01102
4	ZEBRA-3	0.98884	0.01200	1.00084
5	ZPR-3-12	0.99663	0.00900	1.00463
6	SNEAK-7A	0.98310	0.01360	0.99670
7	ZPR-3-11	1.00665	0.00610	1.01275
8	ZPR-3-53	0.96928	0.01670	0.98598
9	SNEAK-7B	0.99021	0.00680	0.99701
10	ZPR-3-50	0.97757	0.01430	0.99187
11	ZPR-3-48	0.97132	0.02380	0.99512
12	ZEBRA-2	0.98497	0.00260	0.98757
13	ZPR-3-49	0.98962	0.00870	0.99832
14	ZPR3-56B	0.96499	0.00010	0.96509
15	ZPR-6-7	0.97235	0.01620	0.98855
16	ZPR-6-6A	0.98038	0.00730	0.98768
17	ZPPR-2	0.96676	0.02020	0.98696
18	MZA	0.98782	0.00190	0.98972
19	MZB(1)	0.98879	-0.00270	0.98609
20	FCA-6-2	0.97318	0.00460	0.97768

TABLE 4.7 SUMMARY OF C/E-VALUES OF K-EFF
FOR PU-FUEL CORES

NO.	ASSEMBLY	EXPERIMENTAL	JEF1-71F	JEF1-60F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	1.00000	0.98500	0.98594	0.98803	0.98859	0.99339	0.98698
4	ZEBRA-3	1.00000	0.99062	(-0.028)	(-0.308)	(-0.172)	(-0.851)	(0.201)
6	SNEAK-7A	1.00000	0.99907	(-0.228)	(-0.333)	(-0.021)	1.00035	1.00084
8	ZPR-3-53	1.00000	0.99736	0.99765	0.99771	1.00493	1.00388	(-1.032)
9	SNEAK-7B	1.00000	0.99445	0.99836	1.00431	0.99794	1.00328	0.99701
10	ZPR-3-50	1.00000	0.99813	1.00183	1.00468	1.00789	0.99572	0.99187
11	ZPR-3-48	1.00000	1.00056	(-0.370)	(-0.656)	(-0.978)	(-0.142)	(-0.627)
13	ZPR-3-49	1.00000	1.00197	1.00417	1.00817	1.00899	1.00791	0.99832
14	ZPR3-56B	1.00000	0.99101	0.99157	0.99306	0.98999	0.99076	0.96509
15	ZPR-6-7	1.00000	0.99442	0.99740	1.00648	0.99453	0.99289	0.98855
17	ZPPR-2	1.00000	1.00136	1.00337	1.01137	1.00085	1.00001	0.98696
18	MZA	1.01080	0.99372	0.99549	1.00239	0.99644	0.99511	0.87918
19	MZB(1)	1.00400	0.99101	0.99399	1.00293	0.99061	0.99059	0.98216
20	FCA-6-2	1.00000	0.98384	(-0.300)	(-1.203)	(-0.040)	(-0.042)	(-0.893)
	* AVERAGE OF C/E		0.99447	0.99650	1.00092	0.99682	0.99710	0.98803
	* AVERAGE(C/E)-1.0		-0.00553	-0.00350	0.00092	-0.00318	-0.00290	-0.01191
	* AVERAGE OF ABS(1.0-C/E)		0.00610	0.00545	0.00645	0.00735	0.00542	0.01209
	* STND.DEV. OF C/E		0.00552	0.00607	0.00712	0.00800	0.00557	0.00943

Table 4.7 (continued)
FOR U-FUEL CORES

NO.	ASSEMBLY	EXPERIMENTAL	JEF1-71F	JEF1-60F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
2	VERA-1B	1.00000	0.98668	0.98636	0.99041	0.98084	0.99899	0.99568
3	ZPR-3-6F	1.00000	1.00008	(-0.032)	(-0.378)	(-0.531)	(-1.248)	(0.912)
5	ZPR-3-12	1.00000	0.99899	1.00138	1.00564	0.99171	1.01282	1.01102
7	ZPR-3-11	1.00000	1.00091	(-0.130)	(-0.646)	(-0.837)	(-1.274)	(1.094)
12	ZEBRA-2	1.00000	0.98584	(-0.225)	(-0.694)	(-0.909)	(-1.0616)	1.00463
16	ZPR-6-6A	1.00000	0.99738	(-0.263)	(-0.657)	(-0.875)	(-0.718)	(0.565)
	* AVERAGE OF C/E		0.99498	0.99659	1.00106	0.98707	1.00284	0.99989
	* AVERAGE(C/E)-1.0		-0.00502	-0.00341	0.00106	-0.01293	0.00284	-0.00011
	* AVERAGE OF ABS(1.0-C/E)		0.00535	0.00547	0.00589	0.01293	0.00570	0.00958
	* STND.DEV. OF C/E		0.00627	0.00648	0.00616	0.00394	0.00631	0.01025

SUMMARY OF ALL ASSEMBLIES

* AVERAGE OF C/E	0.99453	0.99653	1.00096	0.99389	0.99882	0.99159
* AVERAGE(C/E)-1.0	-0.00537	-0.00347	0.00096	-0.00611	-0.00118	-0.00841
* AVERAGE OF ABS(1.0-C/E)	0.00587	0.00546	0.00622	0.00902	0.00560	0.01134
* STND.DEV. OF C/E	0.00676	0.00619	0.00684	0.00833	0.00637	0.01110

Table 4.8 CALCULATED CENTRAL REACTION RATE RATIO ----- F9/F5

NO.	ASSEMBLY	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	1.17671	1.17738	1.16894	1.16283	1.16295	1.14753
2	VERA-1B	1.16539	1.16850	1.16523	1.16050	1.13961	1.13800
3	ZPR-3-6F	1.26770	1.26888	1.27067	1.26106	1.23766	1.24502
4	ZEBRA-3	1.19422	1.19395	1.19106	1.18759	1.17148	1.17797
5	ZPR-3-12	1.12745	1.12900	1.12625	1.12155	1.10459	1.11718
6	SNEAK-7A	0.98483	0.98847	0.99236	0.98838	0.97641	0.98434
7	ZPR-3-11	1.19032	1.19036	1.18898	1.18519	1.16464	1.17614
8	ZPR-3-53	0.89064	0.89314	0.88280	0.88335	0.86980	0.87191
9	SNEAK-7B	1.01378	1.01988	1.02468	1.00458	0.99542	1.00808
10	ZPR-3-50	0.91210	0.91657	0.91149	0.91659	0.88931	0.90151
11	ZPR-3-48	0.98244	0.98530	0.99021	0.98354	0.96090	0.97792
12	ZEBRA-2	1.00226	1.00561	1.00646	1.00452	0.98389	0.99532
13	ZPR-3-49	1.00850	1.01029	1.01109	1.00685	0.98992	1.00165
14	ZPR-3-56	0.98518	0.99009	0.99323	0.98113	0.96587	0.98820
15	ZPR-6-7	0.93065	0.93584	0.94611	0.93152	0.90880	0.93011
16	ZPR-6-6A	0.98853	0.97271	0.98489	0.96726	0.94740	0.96421
17	ZPPR-2	0.93112	0.92547	0.94903	0.93213	0.91036	0.93214
18	MZA	1.00555	1.00925	1.01973	1.00003	0.98698	1.00457
19	MZB	0.94377	0.94870	0.96107	0.94379	0.92346	0.94407
20	FCA-5-2	1.08427	1.08767	1.10179	1.07761	1.06385	1.07526

Table 4.9 CALCULATED CENTRAL REACTION RATE RATIO ----- F8/F5

NO.	ASSEMBLY	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.09038	0.09217	0.09159	0.09074	0.09176	0.08621
2	VERA-1B	0.08470	0.08797	0.08816	0.08664	0.07675	0.08166
3	ZPR-3-6F	0.08223	0.08340	0.08367	0.08172	0.07400	0.07973
4	ZEBRA-3	0.04533	0.04695	0.04706	0.04707	0.04665	0.04692
5	ZPR-3-12	0.06181	0.06292	0.06319	0.06185	0.04837	0.05142
6	SNEAK-7A	0.04381	0.04638	0.04549	0.04461	0.04368	0.04440
7	ZPR-3-11	0.04108	0.04172	0.04205	0.04127	0.03902	0.04092
8	ZPR-3-53	0.03078	0.03287	0.03275	0.03234	0.03106	0.03142
9	SNEAK-7B	0.02386	0.03600	0.03608	0.03422	0.03351	0.03484
10	ZPR-3-50	0.02998	0.03142	0.03141	0.03112	0.03007	0.03080
11	ZPR-3-48	0.03445	0.03654	0.03584	0.03656	0.03461	0.03578
12	ZEBRA-2	0.03500	0.03606	0.03622	0.03617	0.03301	0.03493
13	ZPR-3-49	0.03793	0.03908	0.03912	0.03887	0.03618	0.03879
14	ZPR-3-56	0.03034	0.03158	0.03199	0.03118	0.03078	0.03260
15	ZPR-6-7	0.02195	0.02289	0.02303	0.02274	0.02232	0.02331
16	ZPR-6-6A	0.02413	0.02513	0.02522	0.02457	0.02332	0.02478
17	ZPPR-2	0.02198	0.02294	0.02310	0.02278	0.02234	0.02354
18	MZA	0.03354	0.03480	0.03601	0.03438	0.03397	0.03639
19	MZB	0.02300	0.02396	0.02410	0.02380	0.02334	0.02442
20	FCA-5-2	0.04496	0.04643	0.04678	0.04646	0.04295	0.04560

Table 4.10 CALCULATED CENTRAL REACTION RATE RATIO --- C8/F5

NO.	ASSEMBLY	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.11921	0.11907	0.12233	0.12360	0.11507	0.12227
2	VERA-1B	0.12164	0.12067	0.12182	0.12402	0.12228	0.12429
3	ZPR-3-6F	0.09776	0.09724	0.09607	0.09877	0.09566	0.09778
4	ZEBRA-3	0.10884	0.10885	0.10909	0.10989	0.10631	0.10770
5	ZPR-3-12	0.11985	0.11966	0.11931	0.11971	0.11909	0.11902
6	SNEAK-7A	0.13407	0.13351	0.13223	0.13253	0.13119	0.13572
7	ZPR-3-11	0.10932	0.10938	0.10958	0.11068	0.10976	0.10787
8	ZPR-3-53	0.15018	0.14925	0.14861	0.14805	0.14863	0.15291
9	SNEAK-7B	0.13421	0.13360	0.13178	0.13291	0.13098	0.13456
10	ZPR-3-50	0.13501	0.13440	0.13201	0.13232	0.13353	0.13743
11	ZPR-3-48	0.13332	0.13288	0.13304	0.13358	0.13107	0.13457
12	ZEBRA-2	0.13167	0.13152	0.13033	0.13035	0.13029	0.13291
13	ZPR-3-49	0.13240	0.13199	0.13091	0.13102	0.12943	0.13345
14	ZPR-3-56	0.13745	0.13692	0.13685	0.13682	0.13440	0.13750
15	ZPR-6-7	0.14126	0.14080	0.14003	0.14209	0.13906	0.14298
16	ZPR-6-6A	0.14149	0.14096	0.13993	0.14227	0.13947	0.14242
17	ZPPR-2	0.14118	0.14073	0.13991	0.14199	0.13899	0.14275
18	MZA	0.13698	0.13653	0.13443	0.13732	0.13287	0.13597
19	MZB	0.14064	0.14022	0.13914	0.14167	0.13822	0.14186
20	FCA-5-2	0.12887	0.12851	0.12593	0.13004	0.12867	0.12853

Table 4.11 CALCULATED CENTRAL REACTION RATE RATIO ---- F0/F5

NO.	ASSEMBLY	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.51883	0.52392	0.51910	0.51476	0.51816	0.50289
2	VERA-1B	0.50200	0.51175	0.50970	0.50249	0.48606	0.49007
3	ZPR-3-6F	0.54214	0.54604	0.54449	0.53792	0.50821	0.54342
4	ZEBRA-3	0.37062	0.37371	0.37336	0.37613	0.36764	0.38630
5	ZPR-3-12	0.36170	0.36808	0.36782	0.36717	0.34558	0.37726
6	SNEAK-7A	0.28906	0.29618	0.29684	0.28698	0.28113	0.29809
7	ZPR-3-11	0.34949	0.35377	0.34852	0.35682	0.33973	0.36573
8	ZPR-3-53	0.21260	0.21112	0.21669	0.21641	0.21167	0.21557
9	SNEAK-7B	0.25308	0.26425	0.26520	0.24612	0.24998	0.26790
10	ZPR-3-50	0.21470	0.22157	0.22041	0.21892	0.21291	0.22337
11	ZPR-3-48	0.25476	0.26217	0.26390	0.26087	0.25241	0.26998
12	ZEBRA-2	0.25531	0.26311	0.26268	0.26142	0.24701	0.26935
13	ZPR-3-49	0.27865	0.28445	0.28426	0.28215	0.27687	0.29141
14	ZPR-3-56	0.23604	0.24678	0.25180	0.23393	0.23531	0.25733
15	ZPR-6-7	0.18556	0.19520	0.19845	0.18602	0.18516	0.20075
16	ZPR-6-6A	0.20378	0.21416	0.21679	0.20211	0.19842	0.21760
17	ZPPR-2	0.18568	0.19546	0.19889	0.18536	0.18527	0.20226
18	MZA	0.25748	0.26731	0.27077	0.25696	0.25614	0.27639
19	MZB	0.19430	0.20402	0.20731	0.19401	0.19358	0.21062
20	FCA-5-2	0.32777	0.33813	0.34191	0.32313	0.31589	0.34145

Table 4.12 CALCULATED CENTRAL REACTION RATE RATIO ---- F4/F5

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.46844	0.47188	0.46757	0.46275	0.44978	0.43225
2	VERA-1B	0.46131	0.46899	0.45724	0.44954	0.40157	0.41935
3	ZPR-3-6F	0.60234	0.60529	0.50413	0.49501	0.44973	0.48003
4	ZEBRA-3	0.36026	0.36250	0.35266	0.35469	0.32821	0.34586
5	ZPR-3-12	0.32977	0.33478	0.33495	0.33354	0.30049	0.32743
6	SNEAK-7A	0.35426	0.36073	0.29256	0.24861	0.24008	0.24995
7	ZPR-3-11	0.31154	0.33608	0.33665	0.33798	0.30332	0.34902
8	ZPR-3-53	0.17055	0.18671	0.18006	0.18294	0.16940	0.17284
9	SNEAK-7B	0.22487	0.23664	0.24033	0.21303	0.21072	0.22734
10	ZPR-3-50	0.18235	0.18816	0.18759	0.18633	0.17131	0.18097
11	ZPR-3-48	0.22367	0.23013	0.23194	0.22858	0.21001	0.22649
12	ZEBRA-2	0.22621	0.23085	0.23094	0.22961	0.20572	0.22602
13	ZPR-3-49	0.24650	0.25102	0.25154	0.24901	0.23205	0.24572
14	ZPR-3-56	0.20716	0.21801	0.22414	0.20231	0.19524	0.21702
15	ZPR-6-7	0.15802	0.16796	0.17234	0.15550	0.14805	0.16495
16	ZPR-6-6A	0.17575	0.18650	0.19049	0.17183	0.16065	0.16106
17	ZPPR-2	0.16812	0.16820	0.17277	0.15564	0.14816	0.16635
18	MZA	0.22782	0.23738	0.24216	0.22365	0.21462	0.23429
19	MZB	0.16674	0.17666	0.18120	0.16444	0.15615	0.17429
20	FCA-5-2	0.29598	0.30589	0.31123	0.28748	0.27072	0.29455

Table 4.13 CALCULATED CENTRAL REACTION RATE RATIO -- B11(n,a)/U235(n,f)

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.00138	0.00138	0.00130	0.00149	0.00122	0.00158
2	VERA-1B	0.00135	0.00136	0.00146	0.00136	0.00127	0.00162
3	ZPR-3-6F	0.00080	0.00083	0.00091	0.00074	0.00075	0.00093
4	ZEBRA-3	0.00085	0.00086	0.00086	0.00089	0.00077	0.00092
5	ZPR-3-12	0.00108	0.00108	0.00117	0.00115	0.00102	0.00118
6	SNEAK-7A	0.00198	0.00197	0.00196	0.00200	0.00181	0.00220
7	ZPR-3-11	0.00077	0.00078	0.00082	0.00076	0.00072	0.00084
8	ZPR-3-53	0.00229	0.00228	0.00223	0.00223	0.00218	0.00273
9	SNEAK-7B	0.00162	0.00160	0.00163	0.00171	0.00146	0.00170
10	ZPR-3-50	0.00231	0.00231	0.00225	0.00226	0.00219	0.00271
11	ZPR-3-48	0.00116	0.00110	0.00136	0.00131	0.00108	0.00123
12	ZEBRA-2	0.00178	0.00178	0.00162	0.00183	0.00158	0.00198
13	ZPR-3-49	0.00190	0.00190	0.00186	0.00188	0.00174	0.00212
14	ZPR-3-56	0.00100	0.00096	0.00115	0.00115	0.00093	0.00105
15	ZPR-6-7	0.00102	0.00097	0.00118	0.00119	0.00096	0.00109
16	ZPR-6-6A	0.00096	0.00092	0.00113	0.00110	0.00091	0.00101
17	ZPPR-2	0.00102	0.00097	0.00116	0.00118	0.00086	0.00108
18	MZA	0.00099	0.00095	0.00113	0.00114	0.00092	0.00104
19	MZB	0.00101	0.00096	0.00117	0.00117	0.00095	0.00107
20	FCA-5-2	0.00087	0.00085	0.00099	0.00097	0.00080	0.00092

Table 4.14 CALCULATED CENTRAL REACTION RATE RATIO -- B10(n,a)/U235(n,f)

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.93775	0.93678	0.95345	0.95583	0.93161	0.94205
2	VERA-1B	0.97117	0.96542	0.97670	0.99429	1.00669	0.97133
3	ZPR-3-6F	0.74282	0.74077	0.73613	0.76913	0.78924	0.73253
4	ZEBRA-3	0.89243	0.89371	0.90016	0.90718	0.91555	0.86961
5	ZPR-3-12	1.03802	1.03510	1.04247	1.05669	1.06539	1.00101
6	SNEAK-7A	1.33709	1.33125	1.33619	1.35648	1.30968	1.29992
7	ZPR-3-11	0.89886	0.89937	0.90225	0.91203	0.92963	0.87377
8	ZPR-3-53	1.63883	1.63993	1.69107	1.65075	1.69359	1.61274
9	SNEAK-7B	1.26537	1.27499	1.26992	1.30872	1.26384	1.23808
10	ZPR-3-50	1.56096	1.56789	1.58448	1.56327	1.52270	1.51885
11	ZPR-3-48	1.36938	1.36542	1.36250	1.37286	1.35982	1.31655
12	ZEBRA-2	1.38057	1.32612	1.34531	1.34327	1.32454	1.28374
13	ZPR-3-49	1.30560	1.30308	1.30712	1.31414	1.26180	1.26082
14	ZPR-3-56	1.35799	1.34947	1.32561	1.36987	1.32088	1.28819
15	ZPR-6-7	1.49618	1.48868	1.48829	1.49893	1.44922	1.42977
16	ZPR-6-6A	1.42376	1.41606	1.39645	1.43483	1.39281	1.36055
17	ZPPR-2	1.49451	1.48563	1.46563	1.49699	1.44752	1.42460
18	MZA	1.31260	1.30553	1.28935	1.32738	1.27996	1.25226
19	MZB	1.45212	1.45501	1.43435	1.46649	1.41728	1.39479
20	FCA-5-2	1.13402	1.12771	1.09956	1.14948	1.12788	1.09239

Table 4.15 CALCULATED CENTRAL REACTION RATE RATIO -- Fe(n,c)/U235(n,f)

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.01378	0.01383	0.01524	0.01782	0.01279	0.01341
2	VERA-1B	0.01433	0.01423	0.01564	0.01844	0.01440	0.01400
3	ZPR-3-6F	0.00733	0.00731	0.00716	0.00751	0.00768	0.00700
4	ZEBRA-3	0.00905	0.00912	0.00928	0.00959	0.00910	0.00855
5	ZPR-3-12	0.01254	0.01258	0.01321	0.01505	0.01244	0.01172
6	SNEAK-7A	0.03259	0.03246	0.03380	0.03678	0.02997	0.03292
7	ZPR-3-11	0.00895	0.00901	0.00910	0.00937	0.00913	0.00838
8	ZPR-3-53	0.08268	0.08183	0.08278	0.08092	0.08238	0.08029
9	SNEAK-7B	0.02174	0.02170	0.02304	0.02686	0.01990	0.02031
10	ZPR-3-50	0.06090	0.06063	0.06075	0.06100	0.06888	0.06145
11	ZPR-3-48	0.03899	0.03898	0.03697	0.03980	0.03674	0.03828
12	ZEBRA-2	0.02731	0.02740	0.02965	0.03302	0.02617	0.02676
13	ZPR-3-49	0.02830	0.02834	0.02942	0.03207	0.02596	0.02783
14	ZPR-3-56	0.03224	0.03200	0.02920	0.03343	0.02860	0.03153
15	ZPR-6-7	0.04443	0.04414	0.03950	0.04318	0.03983	0.04564
16	ZPR-6-6A	0.03540	0.03519	0.03202	0.03616	0.03200	0.03554
17	ZPPR-2	0.04413	0.04382	0.03923	0.04301	0.03951	0.04498
18	MZA	0.02041	0.02041	0.02716	0.03072	0.02626	0.02573
19	MZB	0.03992	0.03988	0.03585	0.03938	0.03668	0.04136
20	FCA-5-2	0.01831	0.01826	0.01723	0.02084	0.01690	0.01665

TABLE 4.16 CALCULATED CENTRAL REACTION RATE RATIO ---- F5/F9

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.84983	0.84934	0.85548	0.85997	0.85988	0.87143
2	VERA-1B	0.85008	0.85580	0.85520	0.85170	0.87749	0.87874
3	ZPR-3-6F	0.78883	0.78810	0.78598	0.79298	0.80797	0.80320
4	ZEBRA-3	0.83737	0.83765	0.83959	0.84204	0.85362	0.84892
5	ZPR-3-12	0.88696	0.88574	0.88790	0.89153	0.90531	0.89511
6	SNEAK-7A	1.00620	1.00154	1.00065	1.01175	1.02416	1.01591
7	ZPR-3-11	0.84011	0.84009	0.84105	0.84375	0.85863	0.85096
8	ZPR-3-53	1.12279	1.11965	1.13276	1.11939	1.14969	1.14681
9	SNEAK-7B	0.98641	0.98051	0.97592	0.99544	1.00460	0.99199
10	ZPR-3-50	1.09538	1.09210	1.09711	1.09100	1.12447	1.10925
11	ZPR-3-48	1.01787	1.01492	1.00988	1.01573	1.04069	1.02258
12	ZEBRA-2	0.99775	0.99442	0.99467	0.99560	1.01637	1.00470
13	ZPR-3-49	0.99157	0.98982	0.98904	0.99319	1.01018	0.99835
14	ZPR-3-56	1.01604	1.01001	0.99678	1.01923	1.03426	1.01194
15	ZPR-6-7	1.07452	1.06856	1.05473	1.07251	1.09914	1.07514
16	ZPR-6-6A	1.03463	1.02805	1.01555	1.03385	1.06552	1.03712
17	ZPPR-2	1.07397	1.06784	1.05370	1.07282	1.09845	1.07280
18	MZA	0.99448	0.99054	0.98055	0.99987	1.01318	0.99545
19	MZB	1.05958	1.05408	1.04050	1.05955	1.06289	1.05924
20	FCA-5-2	0.92228	0.91940	0.90761	0.92798	0.93998	0.93000

TABLE 4.17 CALCULATED CENTRAL REACTION RATE RATIO ---- F0/F9

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.44091	0.44499	0.44408	0.44267	0.44556	0.43824
2	VERA-1B	0.43076	0.43786	0.43743	0.43300	0.40896	0.43055
3	ZPR-3-6F	0.42766	0.43033	0.42851	0.42557	0.41062	0.43647
4	ZEBRA-3	0.31034	0.31400	0.31347	0.31672	0.31382	0.32794
5	ZPR-3-12	0.32081	0.32602	0.32659	0.32738	0.31376	0.32769
6	SNEAK-7A	0.29056	0.29564	0.29704	0.28934	0.29304	0.30283
7	ZPR-3-11	0.29351	0.29720	0.29818	0.30107	0.29170	0.31122
8	ZPR-3-53	0.23871	0.24758	0.24772	0.24224	0.24359	0.24724
9	SNEAK-7B	0.24964	0.25910	0.25979	0.24401	0.25113	0.26575
10	ZPR-3-50	0.23539	0.24208	0.24181	0.23884	0.23941	0.24778
11	ZPR-3-48	0.25931	0.26609	0.26651	0.26524	0.26258	0.27608
12	ZEBRA-2	0.25573	0.25164	0.26125	0.26024	0.26106	0.27061
13	ZPR-3-49	0.27630	0.28155	0.28114	0.28023	0.27668	0.29093
14	ZPR-3-56	0.23959	0.24926	0.25079	0.25643	0.24338	0.25040
15	ZPR-6-7	0.19939	0.20858	0.20931	0.19862	0.20351	0.21683
16	ZPR-6-6A	0.21084	0.22017	0.22016	0.20895	0.20944	0.22668
17	ZPPR-2	0.19941	0.20872	0.20957	0.19886	0.20351	0.21698
18	MZA	0.25506	0.26486	0.26553	0.25695	0.25952	0.27513
19	MZB	0.20588	0.21506	0.21571	0.20567	0.20962	0.22310
20	FCA-5-2	0.30230	0.31088	0.31032	0.29986	0.29702	0.31755

TABLE 4.18 CALCULATED CENTRAL REACTION RATE RATIO - Pu241(n,f)/Pu239(n,f)

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	1.13253	1.13167	1.13916	1.14364	1.12487	1.14282
2	VERA-1B	1.14214	1.13869	1.14186	1.14666	1.15336	1.15132
3	ZPR-3-6F	1.06520	1.06424	1.06486	1.06294	1.06892	1.06680
4	ZEBRA-3	1.12642	1.12707	1.12926	1.13157	1.13031	1.1606
5	ZPR-3-12	1.18770	1.18607	1.18833	1.19226	1.19302	1.17052
6	SNEAK-7A	1.33410	1.32947	1.33042	1.33886	1.32338	1.32827
7	ZPR-3-11	1.31310	1.31339	1.32125	1.33806	1.33951	1.1907
8	ZPR-3-53	1.47845	1.48304	1.53209	1.47869	1.46847	1.52063
9	SNEAK-7B	1.31743	1.30922	1.30345	1.32684	1.30971	1.29289
10	ZPR-3-50	1.44523	1.44337	1.46523	1.43438	1.43819	1.45475
11	ZPR-3-48	1.34959	1.34626	1.34378	1.34484	1.34510	1.33289
12	ZEBRA-2	1.32821	1.32402	1.32688	1.32253	1.32498	1.30897
13	ZPR-3-49	1.31846	1.31629	1.31727	1.31736	1.30890	1.30264
14	ZPR-3-56	1.34029	1.34266	1.32856	1.36220	1.34177	1.31751
15	ZPR-6-7	1.42156	1.41441	1.40333	1.41744	1.41635	1.39778
16	ZPR-6-6A	1.37502	1.36659	1.35506	1.37220	1.37314	1.34879
17	ZPPR-2	1.42096	1.41358	1.40194	1.41664	1.41564	1.39469
18	MZA	1.82268	1.81774	1.80670	1.82710	1.81659	1.29777
19	MZB	1.40364	1.39668	1.38445	1.40085	1.39772	1.37723
20	FCA-5-2	1.23249	1.22840	1.21496	1.24020	1.23335	1.21317

TABLE 4.19 CALCULATED CENTRAL REACTION RATE RATIO ---- C8/F9

NO.	ASSEMBLY	JEF1-71F	JEF1-50	JEF1-25	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.10130	0.10113	0.10465	0.10629	0.09894	0.10655
2	VERA-1B	0.10429	0.10327	0.10465	0.10587	0.10730	0.10921
3	ZPR-3-6F	0.07711	0.07664	0.07680	0.07832	0.08044	0.07864
4	ZEBRA-3	0.09114	0.09117	0.09159	0.09253	0.09246	0.09143
5	ZPR-3-12	0.10631	0.10590	0.10593	0.10673	0.10781	0.10553
6	SNEAK-7A	0.13477	0.13372	0.13232	0.13408	0.13436	0.13788
7	ZPR-3-11	0.09184	0.09189	0.09216	0.09331	0.09424	0.09179
8	ZPR-3-53	0.16862	0.16710	0.16834	0.16573	0.17087	0.17537
9	SNEAK-7B	0.13238	0.13100	0.12860	0.13231	0.13159	0.13348
10	ZPR-3-50	0.14803	0.14677	0.14569	0.14436	0.15015	0.15245
11	ZPR-3-48	0.13670	0.13485	0.13435	0.13681	0.13640	0.13761
12	ZEBRA-2	0.13197	0.13079	0.12952	0.12876	0.13242	0.13354
13	ZPR-3-49	0.13128	0.13064	0.12947	0.13012	0.13074	0.13323
14	ZPR-3-56	0.13951	0.13829	0.13542	0.14090	0.13900	0.13914
15	ZPR-6-7	0.15178	0.15046	0.14769	0.15253	0.15285	0.16372
16	ZPR-6-6A	0.14639	0.14492	0.14211	0.14708	0.14721	0.14771
17	ZPPR-2	0.15162	0.15027	0.14742	0.15232	0.15257	0.16314
18	MZA	0.13523	0.13429	0.13183	0.13732	0.13462	0.13535
19	MZB	0.14902	0.14780	0.14477	0.15010	0.14958	0.15027
20	FCA-5-2	0.11886	0.11815	0.11430	0.12067	0.11907	0.11954

Table 4.20 COMPARISON OF C/E-VALUES FOR CENTRAL REACTION RATE RATIO, F8/F6
FOR PU-FUEL CORES

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-80F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.10200	0.88608	0.90361	0.89798	0.88964	0.89965	0.84522
4	ZEBRA-3	0.04610	1.00494	1.01836	1.02089	1.02106	1.01203	1.01786
5	SNEAK-7A	0.04480	0.97780	1.01305	1.01536	0.99349	0.97489	0.99110
8	ZPR-3-53	0.02640	1.21166	1.29394	1.28950	1.27332	1.22271	1.23705
9	SNEAK-7B	0.03300	1.02607	1.06060	1.06312	1.03711	1.01859	1.05578
10	ZPR-3-50	0.02510	1.19452	1.26178	1.26142	1.23986	1.19818	1.22727
11	ZPR-3-48	0.03260	1.05676	1.09334	1.09933	1.09089	1.06177	1.09751
13	ZPR-3-49	0.03450	1.09948	1.13280	1.13394	1.12656	1.10665	1.12425
14	ZPR-3-56	0.03080	0.98516	1.02535	1.03866	1.01242	0.99939	1.05860
15	ZPR-6-7	0.02200	0.99790	1.04066	1.04673	1.03367	1.01438	1.05953
17	ZPPR-2	0.02010	1.09345	1.14127	1.14932	1.13357	1.11139	1.17120
18	MZA	0.03366	0.99638	1.03372	1.04019	1.02135	1.00918	1.05126
19	MZB	0.02256	1.01870	1.06214	1.06822	1.05518	1.03439	1.08229
20	FCA-5-2	0.03960	1.13540	1.17247	1.18122	1.14786	1.08458	1.15143
■ AVERAGE OF C/E		1.04895	1.08879	1.09266	1.07686	1.05341	1.08360	
■ AVERAGE(C/E)-1.0		0.04895	0.08879	0.09266	0.07686	0.05341	0.08360	
■ AVERAGE OF ABS(1.0-C/E)		0.07133	0.10266	0.10714	0.09355	0.07142	0.10698	
■ STND.DEV. OF C/E		0.08622	0.09865	0.09821	0.09723	0.08296	0.09675	

Table 4.20 (CONTINUED)
FOR U-FUEL CORES

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-80F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
2	VERA-1B	0.08600	0.98492	1.02294	1.02508	0.99581	0.89250	0.94958
3	ZPR-3-8F	0.07800	1.05428	1.06929	1.07276	1.04773	0.94876	1.02218
5	ZPR-3-12	0.04700	1.10232	1.12595	1.13178	1.10536	1.02917	1.09401
7	ZPR-3-11	0.03800	1.08106	1.09779	1.10660	1.08616	1.02691	1.07689
12	ZEBRA-2	0.03200	1.09362	1.12681	1.13172	1.09920	1.03153	1.09163
16	ZPR-6-8A	0.02410	1.00136	1.04266	1.04640	1.01945	0.96745	1.02808
■ AVERAGE OF C/E		1.05293	1.08089	1.08572	1.06895	0.98272	1.04373	
■ AVERAGE(C/E)-1.0		0.05293	0.08089	0.08572	0.06895	-0.01728	0.04373	
■ AVERAGE OF ABS(1.0-C/E)		0.05795	0.08089	0.08572	0.06036	0.04648	0.06053	
■ STND.DEV. OF C/E		0.04504	0.03955	0.04096	0.04121	0.05167	0.05082	

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■ AVERAGE OF C/E	1.05014	(-)	1.08642	(3.455)	1.09051	(3.844)	1.07148	(2.032)	1.03220	(-1.708)	1.07164	(2.047)
■ AVERAGE(C/E)-1.0	0.05014		0.08642		0.09051		0.07148		0.03220		0.07164	
■ AVERAGE OF ABS(1.0-C/E)	0.05732		0.09606		0.10071		0.08359		0.06394		0.09305	
■ STND.DEV. OF C/E	0.07826		0.08541		0.08523		0.08482		0.08166		0.08752	

Table 4.21 COMPARISON OF C/E-VALUES OF CENTRAL REACTION RATE RATIO, F9/F6
FOR PU-FUEL CORES

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	1.18000	0.99721	0.99778	0.99062	0.98645	0.98555	0.97249
4	ZEBRA-3	1.19000	1.00354	1.00332	1.00089	0.99798	0.98444	0.98989
6	SNEAK-7A	1.01600	0.97916	0.98274	0.98361	0.97282	0.96103	0.96884
8	ZPR-3-63	0.92800	0.96574	0.96243	0.96130	0.96266	0.93729	0.93956
9	SNEAK-7B	1.01200	1.00176	1.00779	1.01253	0.99267	0.98361	0.99612
10	ZPR-3-50	0.90300	1.01007	1.01403	1.00940	1.01505	0.98483	0.99835
11	ZPR-3-48	0.97600	1.00660	1.00952	1.01456	1.00773	0.98453	1.00197
13	ZPR-3-49	0.98600	1.02282	1.02463	1.02644	1.02115	1.00398	1.01588
14	ZPR-3-56	1.02800	0.95835	0.96313	0.97591	0.95440	0.94054	0.96128
15	ZPR-6-7	0.94260	0.98743	0.99294	1.00596	0.98835	0.96531	0.98685
17	ZPPR-2	0.93700	0.99373	0.99944	1.01284	0.99480	0.97157	0.99482
18	MZA	1.01338	0.99227	0.99592	1.00626	0.98683	0.97395	0.99131
19	MZB	0.94877	0.99473	0.99992	1.01297	0.99475	0.97332	0.99505
20	FCA-5-2	1.10400	0.98212	0.98521	0.99800	0.97609	0.96363	0.97397
■ AVERAGE OF C/E		0.99211 (-)	0.99563 (0.355)	1.00002 (0.797)	0.98934 (-0.279)	0.97240 (-1.987)	0.98474 (-0.743)	
■ AVERAGE(C/E)-1.0		-0.00789	-0.00437	0.00002	-0.01066	-0.02760	-0.01526	
■ AVERAGE OF ABS(1.0-C/E)		0.01429	0.01284	0.01439	0.01694	0.02817	0.01781	
■ STND.DEV. OF C/E		0.01735	0.01703	0.01857	0.01805	0.01743	0.01885	

Table 4.21 (CONTINUED)

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
2	VERA-1B	1.20000	0.97116	0.97375	0.97103	0.96708	0.94968	0.94833
3	ZPR-3-6F	1.22000	1.03909	1.04007	1.04154	1.03365	1.01448	1.02051
5	ZPR-3-12	1.12000	1.00665	1.00803	1.00558	1.00138	0.98624	0.99749
7	ZPR-3-11	1.19000	1.00027	1.00029	0.99914	0.99696	0.97859	0.98752
12	ZEBRA-2	0.98700	1.01546	1.01886	1.01870	1.01775	0.99685	1.00843
16	ZPR-6-6A	---	---	---	---	---	---	---
■ AVERAGE OF C/E		1.00653 (-)	1.00820 (0.166)	1.00720 (0.067)	1.00316 (-0.334)	0.98519 (-2.120)	0.99245 (-1.398)	
■ AVERAGE(C/E)-1.0		0.00653	0.00820	0.00720	0.00316	-0.01481	-0.00755	
■ AVERAGE OF ABS(1.0-C/E)		0.01806	0.01870	0.01913	0.01795	0.02060	0.01912	
■ STND.DEV. OF C/E		0.02205	0.02181	0.02318	0.02236	0.02144	0.02465	

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■ AVERAGE OF C/E	0.99590 (-)	0.99894 (0.306)	1.00191 (0.603)	0.99298 (-0.294)	0.97676 (-2.022)	0.98677 (-0.817)
■ AVERAGE(C/E)-1.0	-0.00410	-0.00106	0.00191	-0.00702	-0.02424	-0.01323
■ AVERAGE OF ABS(1.0-C/E)	0.01528	0.01438	0.01563	0.01720	0.02618	0.01816
■ STND.DEV. OF C/E	0.01975	0.01922	0.02014	0.02021	0.01940	0.02081

Table 4.22 COMPARISON OF C/E-VALUES OF CENTRAL REACTION RATE RATIO, F0/F5

FOR PU-FUEL CORES								
NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-80F	JEF1-26F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.47600	1.09227	1.10299	1.09285	1.08369	1.09086	1.05872
4	ZEBRA-3	0.37300	0.99361	1.00189	1.00097	1.00840	0.98582	1.03566
6	SNEAK-7A	---	---	---	---	---	---	---
8	ZPR-3-53	0.17400	1.22185	1.27081	1.25682	1.24371	1.21766	1.23889
9	SNEAK-7B	---	---	---	---	---	---	---
10	ZPR-3-50	0.15900	1.35029	1.39417	1.38621	1.37685	1.33905	1.40486
11	ZPR-3-48	0.24300	1.04838	1.07890	1.08603	1.07354	1.03874	1.11103
13	ZPR-3-49	---	---	---	---	---	---	---
14	ZPR-3-56	0.28200	0.83704	0.87512	0.89219	0.82954	0.83445	0.91250
15	ZPR-6-7	---	---	---	---	---	---	---
17	ZPPR-2	0.17000	1.08223	1.14977	1.16996	1.09034	1.08984	1.18975
18	MZA	0.25993	0.99068	1.02839	1.04170	0.98471	0.98542	1.06331
19	MZB	0.19194	1.01233	1.06287	1.08010	1.01082	1.00856	1.09735
20	FCA-6-2	---	---	---	---	---	---	---
■ AVERAGE OF C/E			1.07095 (-)	1.10722 (- 3.887)	1.11187 (- 3.821)	1.07795 (- 0.654)	1.06558 (- 0.602)	1.12356 (- 4.913)
■ AVERAGE(C/E)-1.0			0.07095	0.10722	0.11187	0.07795	0.06558	0.12356
■ AVERAGE OF ABS(1.0-C/E)			0.11068	0.13498	0.13583	0.11923	0.10880	0.14301
■ STND.DEV. OF C/E			0.13857	0.14332	0.13629	0.14786	0.13718	0.13240

Table 4.22 (CONTINUED)

FOR U-FUEL CORES								
NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-80F	JEF1-26F	JEF1-26	JFS3J2R	ENDFB4
2	VERA-1B	0.39900	1.25815	1.28258	1.27745	1.25937	1.16806	1.22825
3	ZPR-3-8F	0.53000	1.02291	1.03026	1.02734	1.01496	0.95889	1.02531
5	ZPR-3-12	---	---	---	---	---	---	---
7	ZPR-3-11	0.34000	1.02790	1.04050	1.04272	1.04947	0.99920	1.07568
12	ZEBRA-2	0.23700	1.08148	1.11017	1.10835	1.10304	1.04226	1.13648
16	ZPR-6-6A	---	---	---	---	---	---	---
■ AVERAGE OF C/E			1.09761 (-)	1.11588 (- 1.864)	1.11397 (- 1.490)	1.10671 (- 0.828)	1.04210 (- 5.057)	1.11643 (- 1.715)
■ AVERAGE(C/E)-1.0			0.09761	0.11588	0.11397	0.10671	0.04210	0.11643
■ AVERAGE OF ABS(1.0-C/E)			0.09761	0.11588	0.11397	0.10671	0.06306	0.11643
■ STND.DEV. OF C/E			0.09549	0.10104	0.09917	0.09366	0.07847	0.07661

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■ AVERAGE OF C/E	1.07915 (-)	1.10989 (- 2.848)	1.11251 (- 3.091)	1.08680 (- 0.709)	1.06835 (- 1.928)	1.12137 (- 3.912)
■ AVERAGE(C/E)-1.0	0.07915	0.10989	0.11251	0.08680	0.06835	0.12137
■ AVERAGE OF ABS(1.0-C/E)	0.10666	0.12910	0.12910	0.11538	0.09472	0.13483
■ STND.DEV. OF C/E	0.12748	0.13183	0.12604	0.13418	0.12263	0.11792

Table 4.23 COMPARISON OF C/E-VALUES OF CENTRAL REACTION RATE RATIO, C8/F5
FOR PU-FUEL CORES

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	0.15800	0.75446	0.75359	0.77427	0.78226	0.72827	0.77384
4	ZEBRA-3	---	---	---	---	---	---	---
6	SNEAK-7A	0.13760	0.97437	0.97028	0.96101	0.96313	0.96339	0.98631
8	ZPR-3-53	---	---	---	---	---	---	---
9	SNEAK-7B	0.13100	1.02449	1.01987	1.00594	1.01459	0.99987	1.02714
10	ZPR-3-50	---	---	---	---	---	---	---
11	ZPR-3-48	0.13800	0.96606	0.96291	0.96406	0.96794	0.94976	0.97516
13	ZPR-3-49	---	---	---	---	---	---	---
14	ZPR-3-56	---	---	---	---	---	---	---
15	ZPR-6-7	0.13200	1.07008	1.06670	1.06081	1.07640	1.05352	1.08318
17	ZPPR-2	---	---	---	---	---	---	---
18	MZA	0.13144	1.03458	1.03119	1.02282	1.04480	1.01092	1.03451
19	MZB	0.13610	1.04095	1.03783	1.02985	1.04857	1.02308	1.05003
20	FCA-5-2	0.14000	0.92051	0.91790	0.89950	0.92885	0.90477	0.91809
▪ AVERAGE OF C/E		0.97319 (-)	0.97003 (-0.324)	0.96478 (-0.864)	0.97832 (-0.527)	0.95295 (-2.080)	0.98103 (0.806)	
▪ AVERAGE(C/E)-1.0		-0.02681	-0.02997	-0.03522	-0.02168	-0.04705	-0.01897	
▪ AVERAGE OF ABS(1.0-C/E)		0.06934	0.06886	0.06507	0.06778	0.06893	0.06768	
▪ STND.DEV. OF C/E		0.09424	0.09340	0.08594	0.08769	0.09579	0.09161	

Table 4.23 (CONTINUED)

FOR U-FUEL CORES

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
2	VERA-18	0.13500	0.90032	0.89387	0.90238	0.91854	0.90680	0.92063
3	ZPR-3-6F	0.10400	0.93991	0.93504	0.92371	0.94967	0.95733	0.94023
5	ZPR-3-12	0.12300	0.97443	0.97206	0.96998	0.97321	0.96819	0.96763
7	ZPR-3-11	0.11200	0.97603	0.97662	0.97838	0.98737	0.97994	0.96314
12	ZEBRA-2	0.13600	0.96963	0.96707	0.96827	0.95107	0.95799	0.97731
16	ZPR-6-5A	0.13780	1.02678	1.02297	1.01549	1.03242	1.01210	1.03363
▪ AVERAGE OF C/E		0.96452 (-)	0.96127 (-0.336)	0.96803 (-0.572)	0.96673 (-0.437)	0.96356 (-0.099)	0.96708 (0.266)	
▪ AVERAGE(C/E)-1.0		-0.03548	-0.03873	-0.04197	-0.03127	-0.03644	-0.03292	
▪ AVERAGE OF ABS(1.0-C/E)		0.04441	0.04638	0.04713	0.04208	0.04047	0.04410	
▪ STND.DEV. OF C/E		0.03843	0.03963	0.03682	0.03561	0.03176	0.03515	

FOR ALL ASSEMBLIES

▪ AVERAGE OF C/E	0.96947 (-)	0.96628 (-0.329)	0.96189 (-0.782)	0.97421 (0.489)	0.96750 (-1.235)	0.97505 (0.576)
▪ AVERAGE(C/E)-1.0	-0.03053	-0.03372	-0.03811	-0.02579	-0.04260	-0.02495
▪ AVERAGE OF ABS(1.0-C/E)	0.06885	0.06923	0.06738	0.06676	0.06674	0.06757
▪ STND.DEV. OF C/E	0.07567	0.07634	0.06937	0.07043	0.07562	0.07330

Table 4.24 COMPARISON OF C/E-VALUES OF CENTRAL REACTION RATE RATIO, CB/F9
FOR PU-FUEL CORES

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
1	VERA-11A	---	---	---	---	---	---	---
4	ZEBRA-3	---	---	---	---	---	---	---
6	SNEAK-7A	0.13500	0.99830	0.99050	0.98015	0.99322	0.99523	1.02130
8	ZPR-3-53	---	---	---	---	---	---	---
9	SNEAK-7B	0.12900	1.02623	1.01549	0.98693	1.02562	1.02004	1.03471
10	ZPR-3-50	---	---	---	---	---	---	---
11	ZPR-3-48	0.14100	0.96241	0.95648	0.95287	0.96320	0.96738	0.97597
13	ZPR-3-49	---	---	---	---	---	---	---
14	ZPR-3-56	---	---	---	---	---	---	---
15	ZPR-6-7	0.14000	1.08412	1.07470	1.05493	1.08950	1.09179	1.09803
17	ZPPR-2	---	---	---	---	---	---	---
18	MZA	0.12970	1.04264	1.03541	1.01645	1.05874	1.03795	1.04358
19	MZB	0.14240	1.04646	1.03791	1.01866	1.05409	1.06112	1.05525
20	FCA-5-2	0.12680	0.93735	0.93177	0.90139	0.95169	0.93900	0.94271
▪ AVERAGE OF C/E		(1.01393)	(1.00604)	(0.98848)	(1.01944)	(1.01465)	(1.02451)	(1.043)
▪ AVERAGE(C/E)-1.0		0.01393	0.00604	-0.01152	0.01944	0.01465	0.02451	
▪ AVERAGE OF ABS(1.0-C/E)		0.04306	0.04068	0.03667	0.04569	0.04276	0.04774	
▪ STND.DEV. OF C/E		0.04740	0.04613	0.04627	0.04801	0.04809	0.04762	

Table 4.24 (CONTINUED)

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-50F	JEF1-25F	JEF1-26	JFS3J2R	ENDFB4
2	VERA-1B	0.12200	0.86487	0.84649	0.86694	0.87695	0.87952	0.89520
3	ZPR-3-6F	0.08500	0.80716	0.90162	0.88944	0.92141	0.94640	0.92400
5	ZPR-3-12	0.11000	0.96642	0.96275	0.96303	0.97029	0.98011	0.96849
7	ZPR-3-11	0.09400	0.97699	0.97756	0.98045	0.99262	1.00253	0.97653
12	ZEBRA-2	0.13800	0.95342	0.94773	0.93926	0.93307	0.95957	0.96768
16	ZPR-6-6A	---	---	---	---	---	---	---
▪ AVERAGE OF C/E		(0.93177)	(0.92723)	(0.92682)	(0.93867)	(0.95363)	(0.94638)	(1.1566)
▪ AVERAGE(C/E)-1.0		-0.06823	-0.07277	-0.07418	-0.06133	-0.04637	-0.05362	
▪ AVERAGE OF ABS(1.0-C/E)		0.06823	0.07277	0.07418	0.06133	0.04739	0.05362	
▪ STND.DEV. OF C/E		0.04524	0.04773	0.04608	0.04043	0.04165	0.03153	
FOR ALL ASSEMBLIES								
▪ AVERAGE OF C/E		(0.97970)	(0.97320)	(0.96238)	(0.98578)	(0.98922)	(0.99195)	
▪ AVERAGE(C/E)-1.0		-0.02030	-0.02680	-0.03762	-0.01422	-0.01078	-0.00805	
▪ AVERAGE OF ABS(1.0-C/E)		0.06364	0.06405	0.06230	0.06221	0.04469	0.05019	
▪ STND.DEV. OF C/E		0.06167	0.06083	0.06557	0.06009	0.05456	0.05675	

Table 4.26 SIMPLE FAST SPECTRUM BENCHMARK RESULTS

ASSEMBLY	EXPERIMENT	CALCULATION/EXPERIMENT					
		UK 71G	DATA BANK 71G	B6G	25G	26G	JFS3
SCHERZO -566	Keff 1.00	0.9893	0.9887 (0.9889)(0.9885)	0.9913 0.9891 ^a	0.9954 0.9917 ^a	0.9749 0.9961 ^a	0.991
	F8/F6 0.0227±0.0002	1.08	1.08	1.10	1.14	1.09	1.04
	CB/F6 0.1154±0.0017	1.02	1.03	1.03	1.03	1.03	1.02
U02-740	Keff 1.00	0.9903	0.9891 (0.9879)(0.9937)	0.9950 0.9891 ^a	1.0066 0.9975 ^a	0.9904 1.008 ^a	0.996
	F8/F6 0.0243±0.0002	1.02	1.03	1.05	1.05	1.02	0.970
	CB/F6 0.1385±0.0018	0.995	0.996	0.994	0.975	0.968	0.98
	FB/F6 0.953±0.012	0.999	1.000	1.003	1.009	0.996	0.982

Note: The UK-results were taken from the paper presented at the Santa Fe conference (Ref. 1)

The parentheses show the results calculated by neglecting the top energy group cross sections from 15 to 10 MeV.

^a show the results calculated by using self-shielding factors of elastic removal in place of elastic scattering for calculating the effective removal cross sections.

Table 4.26 ATOMIC NUMBER DENSITY USED FOR THE BENCHMARK CALCULATIONS

ASSEMBLY	ENRICHMENT (%)	COMPOSITIONS (x10 ⁻²⁴ at/cc)		
		U-235	U-238	O-16 PU-239
SCHERZO	5.56	2.6302E-3	4.4676E-2	
U02-740	7.40	1.6495E-3	2.0641E-2	4.46E-2 1.0E-20

Table 4.27 ONE GROUP MICROSCOPIC CROSS SECTIONS

NUCLIDE	TOTAL(DIF)	FISSION	CAPTURE	ABSORPTION	MU-FISSION	ELASTIC	INELASTIC	(N,2N)	TOTAL REMOVAL	
SCHERZO										
U-235	7.80441E+00	1.45725E+00	3.40320E-01	1.79767E+00	3.64309E+00	7.63204E+00	7.20606E-01	5.95100E-04	1.79697E+00	
236	U-238	7.52657E+00	3.61745E-02	1.73916E-01	2.10090E-01	9.88718E-02	8.89150E+00	1.10988E+00	9.11637E-04	2.09180E+01
U-235	7.82184E+00	1.45267E+00	3.38365E-01	1.79104E+00	3.67288E+00	7.88419E+00	7.10734E-01	1.36680E-03	1.78957E+00	
236	U-238	7.66714E+00	3.67238E-02	1.73192E-01	2.09916E-01	1.01428E-01	8.94377E+00	1.09627E+00	2.20813E-03	2.07699E-01
U0-2										
U-235	9.52454E+00	1.94443E+00	5.88816E-01	2.53124E+00	4.71305E+00	8.62312E+00	5.49595E-01	6.86809E-04	2.53058E+00	
U-238	8.41846E+00	4.81234E-02	2.60545E-01	3.08668E-01	1.31181E-01	9.82528E+00	8.43143E-01	1.01212E-03	3.07656E-01	
236	PU-239	9.51941E+00	1.84504E+00	5.66721E-01	2.40176E+00	5.37983E+00	8.85274E+00	5.07085E-01	8.63030E-04	2.40090E+00
D-16	3.14723E+00	0.00000E+00	1.14710E-03	1.14710E-03	0.00000E+00	3.55315E+00	1.96238E-04	0.00000E+00	1.14703E-03	
U-235	9.27152E+00	1.88422E+00	5.59195E-01	2.44341E+00	4.61839E+00	8.50698E+00	5.89747E-01	1.57703E-03	2.44183E+00	
U-238	8.25370E+00	4.79968E-02	2.54487E-01	3.02484E-01	1.32286E-01	9.70723E+00	8.70314E-01	2.64777E-03	2.99928E-01	
236	PU-239	9.24403E+00	1.81155E+00	5.15029E-01	2.32658E+00	5.29049E+00	8.71727E+00	5.17381E-01	1.46456E-03	2.32612E+00
D-16	3.11437E+00	0.00000E+00	1.21019E-03	1.21019E-03	0.00000E+00	3.81677E+00	5.22661E-04	0.00000E+00	1.20974E-03	

Table 4.28 REACTION RATE FOR EACH NUCLIDE

	SUMPHI	NUCLIDE	PHI*FISSION(MICRO.)	PHI*ABSORPTION(MICRO.)	ALPHA
SCHERZO	7.10193E+01				
26G		U-235	1.03493E+02	1.27662E+02	1.23354E+00
		U-238	2.86909E+00	1.49205E+01	5.80770E+00
26G	7.14525E+01	U-235	1.03797E+02	1.27974E+02	1.23293E+00
		U-238	2.82401E+00	1.49990E+01	5.71605E+00
UD2-740	9.44868E+01	U-235	1.83723E+02	2.39169E+02	1.30179E+00
		U-238	4.54703E+00	2.91651E+01	5.41410E+00
26G		PU-239	1.74332E+02	2.26936E+02	1.30174E+00
		O-16	0.00000E+00	1.08385E+01	0.00000E+00
26G	9.72728E+01	U-235	1.83283E+02	2.37678E+02	1.29678E+00
		U-238	4.66879E+00	2.94234E+01	5.30216E+00
26G		PU-239	1.76215E+02	2.26313E+02	1.28430E+00
		O-16	0.00000E+00	1.17718E+01	0.00000E+00

Table 4.29 ONE GROUP MACROSCOPIC CROSS SECTIONS

LIB.	DIFFUSION	FISSION	CAPTURE	ABSORPTION	MU-FISSION	ELASTIC	TOTAL	REMOVAL	ALPHA
SCHERZO	26G	9.34272E-01	5.44898E-03	8.66498E-03	1.41140E-02	1.37273E-02	4.17310E-01	1.40717E-02	2.59020E+00
	26G	9.29430E-01	5.46150E-03	8.62749E-03	1.40890E-02	1.38314E-02	4.19730E-01	1.39863E-02	2.57969E+00
UD2-740	26G	1.01068E+00	4.20066E-03	6.39702E-03	1.06977E-02	1.04819E-02	3.76498E-01	1.05767E-02	2.52287E+00
	26G	1.02703E+00	4.09872E-03	6.22923E-03	1.03279E-02	1.03486E-02	3.76707E-01	1.02726E-02	2.61980E+00

Table 4.30 COMPARISON OF Keff AND CENTRAL REACTION RATE RATIOS

ZPR-6-7

EXP.	CALCULATION/EXPERIMENT						
	JEF1-71	JEF1-26	JENDL-2	ENDF/B-V	ENDF/B-IV	ANL	JAERI
D.B	UK	D.B	D.B	ANL	LANL	D.B	ANL
Keff	1.00	0.9915	1.000	1.004	0.9929	0.9946	0.9878
						0.9886	0.9844
						0.9855	
F8/F5	0.022	1.002		1.04	1.01	0.987	0.993
	(0.023)	(0.985)		(1.00)	(0.97)		(1.01)
F9/F5	0.8425	0.988	0.877	1.01	0.965	0.985	0.981
	(0.953)	(0.977)	(0.967)	(0.995)	(0.955)		(0.976)
C8/F5	0.132	1.07	1.03	1.07	1.05	1.06	1.08
	(0.135)	(1.04)	(0.996)	(1.04)	(1.02)		(1.06)
C8/F9	0.140	1.08	1.05	1.06	1.09	1.07	1.10
	(0.143)	(1.06)	(1.03)	(1.04)	(1.07)		(1.07)

ZPR-6-6A

Keff	1.00	0.9943	0.9999	1.002	0.9862	0.9899	0.9877	0.9850	0.9895
F8/F5	0.0241	1.005	1.046	0.957	0.982	0.986	1.03		
	(0.0246)	(0.989)	(1.03)	(0.952)		(1.01)			

C8/F5	0.1378	1.03	1.02	1.01	1.04	1.04	1.03		
	(0.139)	(1.02)	(1.01)	(1.00)		(1.02)			

*) show the results for the experimental data used in previous calculations.

UK : SN-CALCULATION,CORRECTION FACTOR--HETERO + 1D/2D

LANL: NJOY SYSTEM,1-D DIFFUSION,CORRECTION FACTOR--SN + HETERO + 1D/2D

ANL : MC-2 CODE,1-D DIFFUSION,CORRECTION FACTOR--SN + HETERO + 1D/2D

JAERI : TIMS-PGG SYSTEM,1-D DIFFUSION,CORRECTION FACTOR-- SN + HETERO + 1D/2D

Table 4.31 COMPARISON OF Keff CALCULATED WITH DIFFERENT FISSION SPECTRA

ASSEMBLY	GROUP	X(PU-239)		X(U-235)	AVE. X
		D.B.	UK		
VERA-11A	71	0.9349	0.9351	0.9330	0.9339
	25	0.9379	-	0.9372	0.9369
	26	0.9368	-	0.9321	0.9360
ZPR-6-7	71	0.9757	0.9837	0.9745	0.9753
	26	0.9883	-	0.9881	0.9879
	26	0.9785	-	0.9745	0.9783

(No correction factors were applied)

Table 4.32 Comparison of Effective Microscopic Cross Sections Calculated for Core Region of ZPR-6-7 Assembly

Group	U-238		Pu-239	capture
	absorption	fission		
28	UK	0.5453	1.804	0.9374
	DB	0.5490	1.806	0.9382
29	UK	0.5810	1.801	1.060
	DB	0.5870	1.804	1.061
30	UK	0.6497	2.163	1.800
	DB	0.6549	2.166	1.301
31	UK	0.6904	2.129	1.645
	DB	0.7010	2.133	1.648
32	UK	0.7611	2.333	1.951
	DB	0.7650	2.336	1.965

Table 4.33 COMPARISON OF Keff CALCULATED BY USING DIFFERENT INTERPOLATIONS FOR SELF-SHIELDING FACTORS --- 71 GROUP SET

	SPLINE FUNCTION	RATIONAL FUNCTION	DIFFERENCE
VERA-11A	0.9339 (0.9338)	0.9335 (0.9335)	0.0004 (0.0003)
ZPR-6-7	0.9753 (0.9751)	0.9782 (0.9789)	-0.0029 (-0.0028)

In the parentheses the results obtained by iterating over
SOGMA-0 are shown.
(No correction factors were applied)

Table 4.34 COMPARISON OF C/E-VALUES OF K-EFF CALCULATED USING ELASTIC SCATTERING AND REMOVAL SELF-SHIELDING FACTORS FOR CALCULATING EFFECTIVE REMOVAL CROSS SECTION FOR PU-FUEL CORES

NO.	ASSEMBLY	EXPERIMENTAL	JEF1-71F	JEF1-71	JEF1-50F	JEF1-50	JEF1-25F	JEF1-25
1	VERA-11A	1.00000	0.98500 (-)	0.98455 (-0.045)	0.98594 (0.095)	0.98578 (0.079)	0.98503 (0.308)	0.98755 (0.259)
4	ZEBRA-3	1.00000	0.99062 (-)	0.99037 (-0.026)	0.99270 (0.228)	0.99391 (0.211)	0.99354 (0.333)	0.99354 (0.295)
6	SNEAK-7A	1.00000	0.99907 (-)	0.99841 (-0.066)	1.00144 (0.238)	1.00122 (0.215)	1.00483 (0.576)	1.00452 (0.546)
8	ZPR-3-53	1.00000	0.99736 (-)	0.99634 (-0.103)	0.99765 (0.029)	0.99682 (0.054)	0.99771 (0.035)	0.99695 (-0.041)
9	SNEAK-7B	1.00000	0.99445 (-)	0.99413 (-0.032)	0.99836 (0.293)	0.99768 (0.325)	1.00431 (0.891)	1.00441 (1.001)
10	ZPR-3-50	1.00000	0.99813 (-)	0.99726 (-0.088)	1.00183 (0.370)	1.00022 (0.209)	1.00468 (0.656)	1.00277 (0.464)
11	ZPR-3-48	1.00000	1.00066 (-)	0.99913 (-0.153)	1.00285 (0.218)	1.00221 (0.165)	1.00644 (0.578)	1.00540 (0.474)
13	ZPR-3-49	1.00000	1.000197 (-)	1.00079 (-0.118)	1.00417 (0.219)	1.00376 (0.179)	1.00817 (0.619)	1.00726 (0.527)
14	ZPR3-56B	1.00000	0.99101 (-)	0.98755 (-0.349)	0.99157 (0.057)	0.99029 (-0.072)	0.99306 (0.208)	0.99250 (0.151)
15	ZPR-6-7	1.00000	0.99442 (-)	0.99150 (-0.293)	0.99740 (0.300)	0.99587 (0.146)	1.00648 (1.213)	1.00409 (0.973)
17	ZPPR-2	1.00000	1.00136 (-)	0.99849 (-0.286)	1.00337 (0.201)	1.00237 (0.101)	1.01137 (1.000)	1.00961 (0.824)
18	MZA	1.01080	0.99372 (-)	0.99153 (-0.220)	0.99549 (0.178)	0.99617 (0.146)	1.00239 (0.872)	1.00136 (0.769)
19	MZB(1)	1.00400	0.99101 (-)	0.98838 (-0.266)	0.99399 (0.300)	0.99289 (0.190)	1.00293 (1.203)	1.00064 (0.972)
20	FCA-5-2	1.00000	0.98384 (-)	0.98246 (-0.141)	0.98407 (0.023)	0.98425 (0.042)	0.98860 (0.485)	0.98837 (0.461)
■ AVERAGE OF C/E		0.99447 (-)	0.99292 (-0.156)	0.99550 (0.204)	0.99580 (0.134)	1.00092 (0.649)	0.99993 (0.548)	
■ AVERAGE(C/E)-1.0		-0.00553	-0.00708	-0.00350	-0.00420	0.00092	-0.00007	
■ AVERAGE OF ABS(1.0-C/E)		0.00610	0.00719	0.00645	0.00659	0.00645	0.00580	
■ STND.DEV. OF C/E		0.00652	0.00556	0.00607	0.00688	0.00712	0.00675	

Table 4.34 (CONTINUED)

FOR U-FUEL CORES

NO.	ASSEMBLY	EXPERIMENTAL	JEF1-71F	JEF1-71	JEF1-70F	JEF1-70	JEF1-25F	JEF1-25
2	VERA-1B	1.00000	0.98668	0.98619 (-0.049)	0.98636 (-0.032)	0.98689 (-0.022)	0.99041 (-0.378)	0.99103 (-0.441)
3	ZPR-3-6F	1.00000	1.00008	(-)	0.99969 (-0.039)	1.00138 (0.130)	1.00146 (0.138)	1.00581 (0.573)
5	ZPR-3-12	1.00000	0.99899	(-)	0.99860 (-0.039)	1.00124 (0.225)	1.00111 (0.213)	1.00570 (0.572)
7	ZPR-3-11	1.00000	1.00091	(-)	1.00072 (-0.020)	1.00255 (0.263)	1.00348 (0.256)	1.00735 (0.657)
12	ZEBRA-2	1.00000	0.98584	(-)	0.98541 (-0.044)	0.98532 (0.352)	0.98588 (0.308)	0.99488 (0.998)
16	ZPR-6-6A	1.00000	0.99738	(-)	0.99433 (-0.306)	0.99769 (0.030)	0.99875 (-0.064)	0.99989 (0.252)
* AVERAGE OF C/E		0.99498 (-)	0.99416 (-0.083)	0.99659 (0.162)	0.99643 (0.146)	1.00106 (0.610)	1.00078 (0.582)	
* AVERAGE(C/E)-1.0		-0.00502	-0.00584	-0.00341	-0.00357	0.00106	0.00078	
* AVERAGE OF ABS(1.0-C/E)		0.00535	0.00608	0.00547	0.00559	0.00569	0.00551	
* STND.DEV. OF C/E		0.00627	0.00624	0.00648	0.00639	0.00616	0.00610	
FOR ALL ASSEMBLIES								
* AVERAGE OF C/E		0.99463 (-)	0.99329 (-0.134)	0.99653 (0.191)	0.99599 (0.137)	1.00096 (0.837)	1.00018 (0.559)	
* AVERAGE(C/E)-1.0		-0.00537	-0.00671	-0.00347	-0.00401	0.00096	0.00018	
* AVERAGE OF ABS(1.0-C/E)		0.00587	0.00686	0.00546	0.00559	0.00622	0.00571	
* STND.DEV. OF C/E		0.00576	0.00580	0.00619	0.00604	0.00684	0.00657	

Table 4.35 The Effect of the Highest Energy Group (10.0 - 15.0 MeV) on Keff

for Pu-fuel Cores

NO.	ASSEMBLY	EXPERIMENTAL	JEF1-71F	JEF1-70F
1	VERA-11A	1.00000	0.98500 (-)	0.98388 (-0.114)
4	ZEBRA-3	1.00000	0.99062 (-)	0.98814 (-0.250)
6	SNEAK-7A	1.00000	0.99907 (-)	0.99783 (-0.124)
8	ZPR-3-53	1.00000	0.99736 (-)	0.99870 (-0.066)
9	SNEAK-7B	1.00000	0.99445 (-)	0.99285 (-0.160)
10	ZPR-3-5D	1.00000	0.99813 (-)	0.99692 (-0.122)
11	ZPR-3-48	1.00000	1.00066 (-)	0.99933 (-0.133)
13	ZPR-3-49	1.00000	1.00197 (-)	1.00048 (-0.149)
14	ZPR3-56B	1.00000	0.99101 (-)	0.99020 (-0.082)
15	ZPR-6-7	1.00000	0.99442 (-)	0.99341 (-0.102)
17	ZPPR-2	1.00000	1.00136 (-)	1.00043 (-0.092)
18	MZA	1.01080	0.99372 (-)	0.99285 (-0.088)
19	MZB(1)	1.00400	0.99101 (-)	0.99007 (-0.095)
20	FCA-6-2	1.00000	0.98384 (-)	0.98298 (-0.087)
* AVERAGE OF C/E		0.99447 (-)	0.99329 (-0.119)	
* AVERAGE(C/E)-1.0		-0.00553	-0.00671	
* AVERAGE OF ABS(1.0-C/E)		0.00610	0.00684	
* STND.DEV. OF C/E		0.00652	0.00652	

Table 4.35 (continued)
for U-fuel cores

NO.	ASSEMBLY	EXPERIMENTAL	JEF1-71F	JEF1-70F
2	VERA-1B	1.00000	0.98668	0.98595
3	ZPR-3-6F	1.00000	(-0.00008)	0.99907
5	ZPR-3-12	1.00000	(-0.00008)	0.99782
7	ZPR-3-11	1.00000	(-0.00081)	0.99839
12	ZEBRA-2	1.00000	0.98584	0.98473
16	ZPR-6-6A	1.00000	(-0.00738)	0.99684
			(-)	(-0.055)
▪ AVERAGE OF C/E		0.99498	0.99397	(-0.102)
▪ AVERAGE(C/E)-1.0		-0.00502	-0.00603	
▪ AVERAGE OF ABS(1.0-C/E)		0.00535	0.00603	
▪ STND.DEV. OF C/E		0.00627	0.00616	
FOR ALL ASSEMBLIES				
▪ AVERAGE OF C/E		0.99463	0.99349	(-0.114)
▪ AVERAGE(C/E)-1.0		-0.00537	-0.00651	
▪ AVERAGE OF ABS(1.0-C/E)		0.00687	0.00660	
▪ STND.DEV. OF C/E		0.00576	0.00573	

Table 4.36 The Effect of the Highest Energy Group (10.0 ~ 15.0 MeV)
on Central Reaction Rate Ratios, F8/F6

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-70F
1	VERA-11A	0.10200	0.88608	0.88279
4	ZEBRA-3	0.04610	1.00494	1.00032
6	SNEAK-7A	0.04480	0.97780	0.97324
8	ZPR-3-53	0.02540	1.21165	1.20538
9	SNEAK-7B	0.03300	1.02607	1.02140
10	ZPR-3-50	0.02510	1.19452	1.18837
11	ZPR-3-48	0.03260	1.05676	1.05167
13	ZPR-3-49	0.03450	1.09948	1.09423
14	ZPR-3-56	0.03080	0.98516	0.98017
15	ZPR-6-7	0.02200	0.99790	0.99300
17	ZPPR-2	0.02010	1.09345	1.08797
18	MZA	0.03365	0.99638	0.99149
19	MZB	0.02256	1.01970	1.01457
20	FCA-6-2	0.03960	1.13640	1.13173
▪ AVERAGE OF C/E		1.04895	1.04403	(-0.469)
▪ AVERAGE(C/E)-1.0		0.04895	0.04403	
▪ AVERAGE OF ABS(1.0-C/E)		0.07133	0.06965	
▪ STND.DEV. OF C/E		0.08622	0.08569	

Table 4.36 (continued)

for U-fule Cores

NO.	ASSEMBLY	EXPERIMENT	JEF1-71F	JEF1-70F
2	VERA-1B	0.08600	0.98492	0.98280
3	ZPR-3-6F	0.07800	1.05428	1.05205
5	ZPR-3-12	0.04700	1.10232	1.09959
7	ZPR-3-11	0.08800	1.08106	1.07831
12	ZEBRA-2	0.03200	1.09362	1.09070
16	ZPR-6-6A	0.02410	1.00136	0.99873
* AVERAGE OF C/E		1.05293	1.05036	(-0.243)
* AVERAGE(C/E)-1.0		0.05293	0.05036	
* AVERAGE OF ABS(1.0-C/E)		0.05795	0.05652	
* STND.DEV. OF C/E		0.04504	0.04484	

FOR ALL ASSEMBLIES

* AVERAGE OF C/E	1.05014	1.04593
* AVERAGE(C/E)-1.0	0.05014	0.04593
* AVERAGE OF ABS(1.0-C/E)	0.05732	0.05571
* STND.DEV. OF C/E	0.07626	0.07584

Fig. 4.1 Comparison of K_{eff} (C/E -values) calculated with JEF1-71F, JFS3J2R and ENDFB4

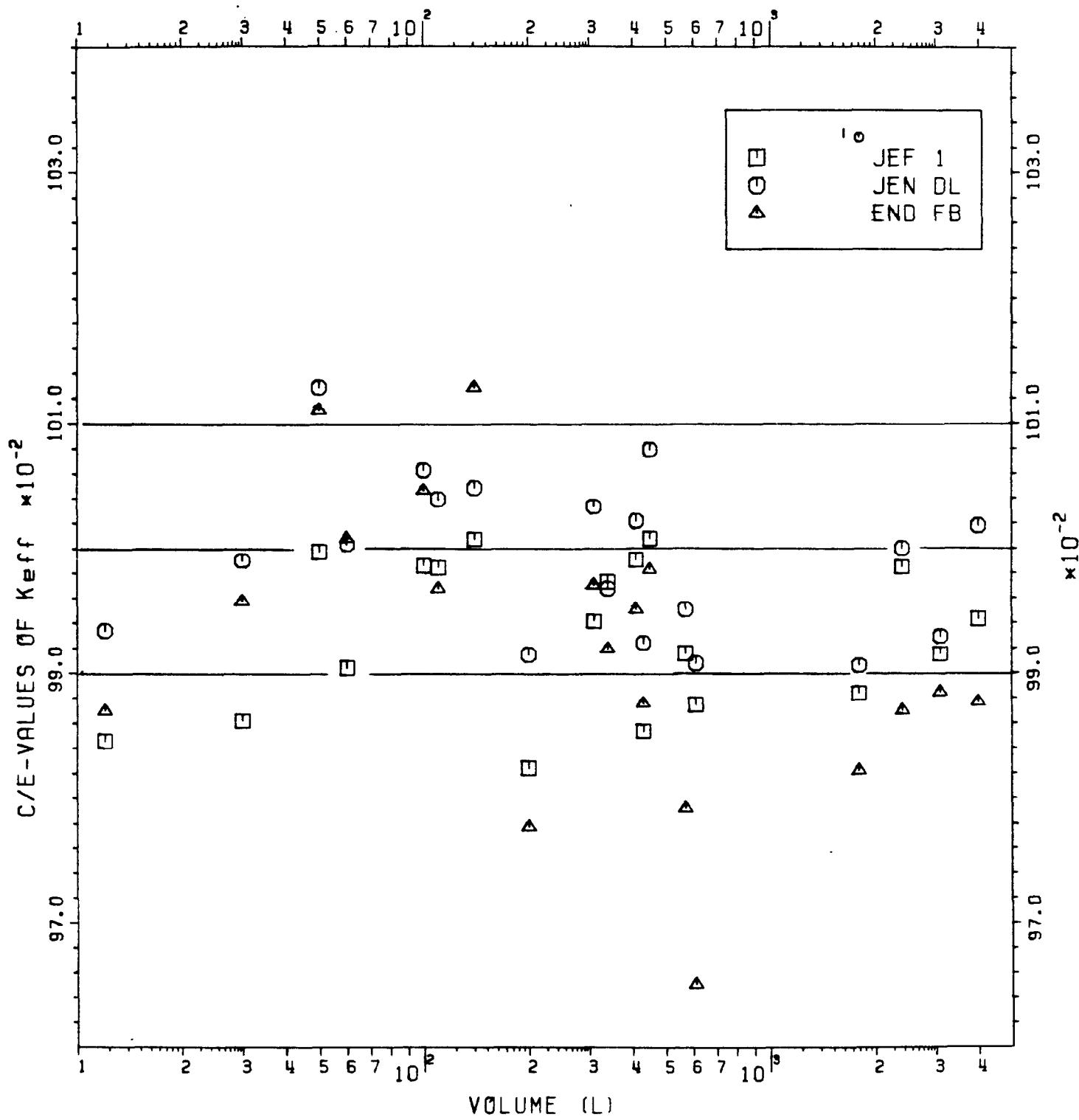


Fig. 4.2 C/E-values of K_{eff} for JEFI-71F as the function of the concentration ratios of fertile to fissile materials

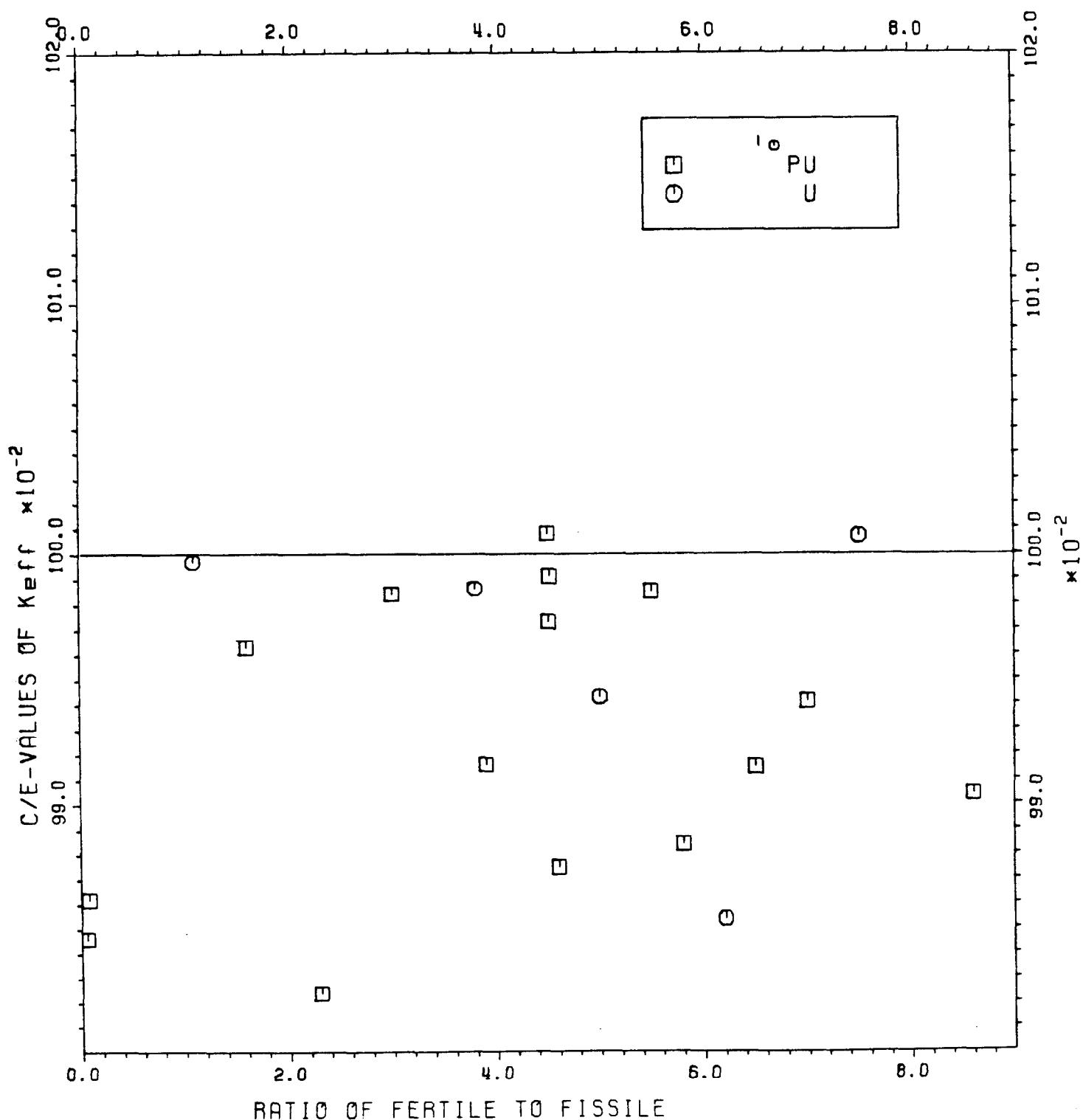


Fig. 4.3 C/E-values of K_{eff} for JEF1-71F as the function of the spectral hardness

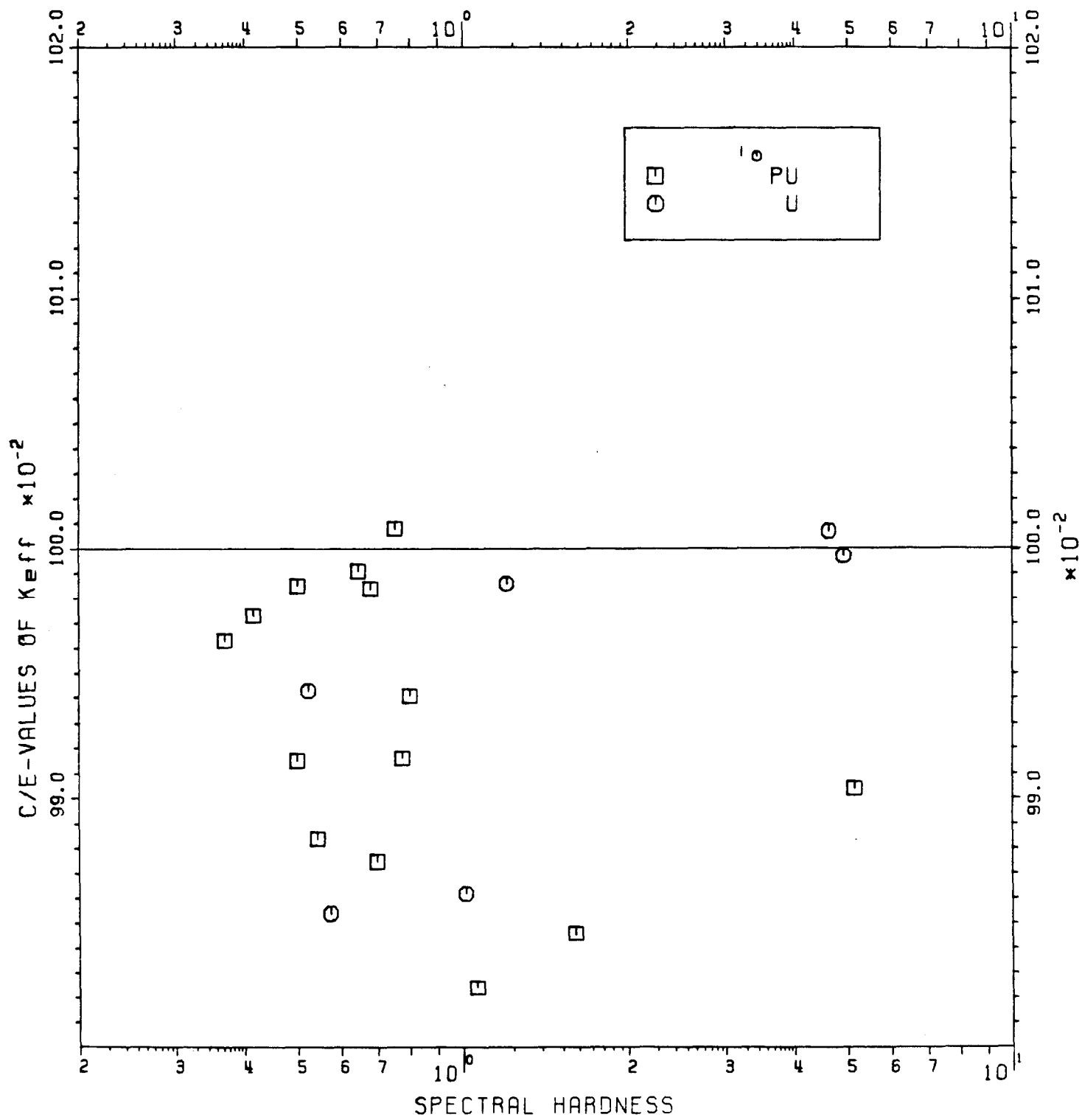


Fig. 4.4 Deviations of K_{eff} for JEF1-50F, JEF1-25F and JEF1-26 from the ones for JEF1-71F

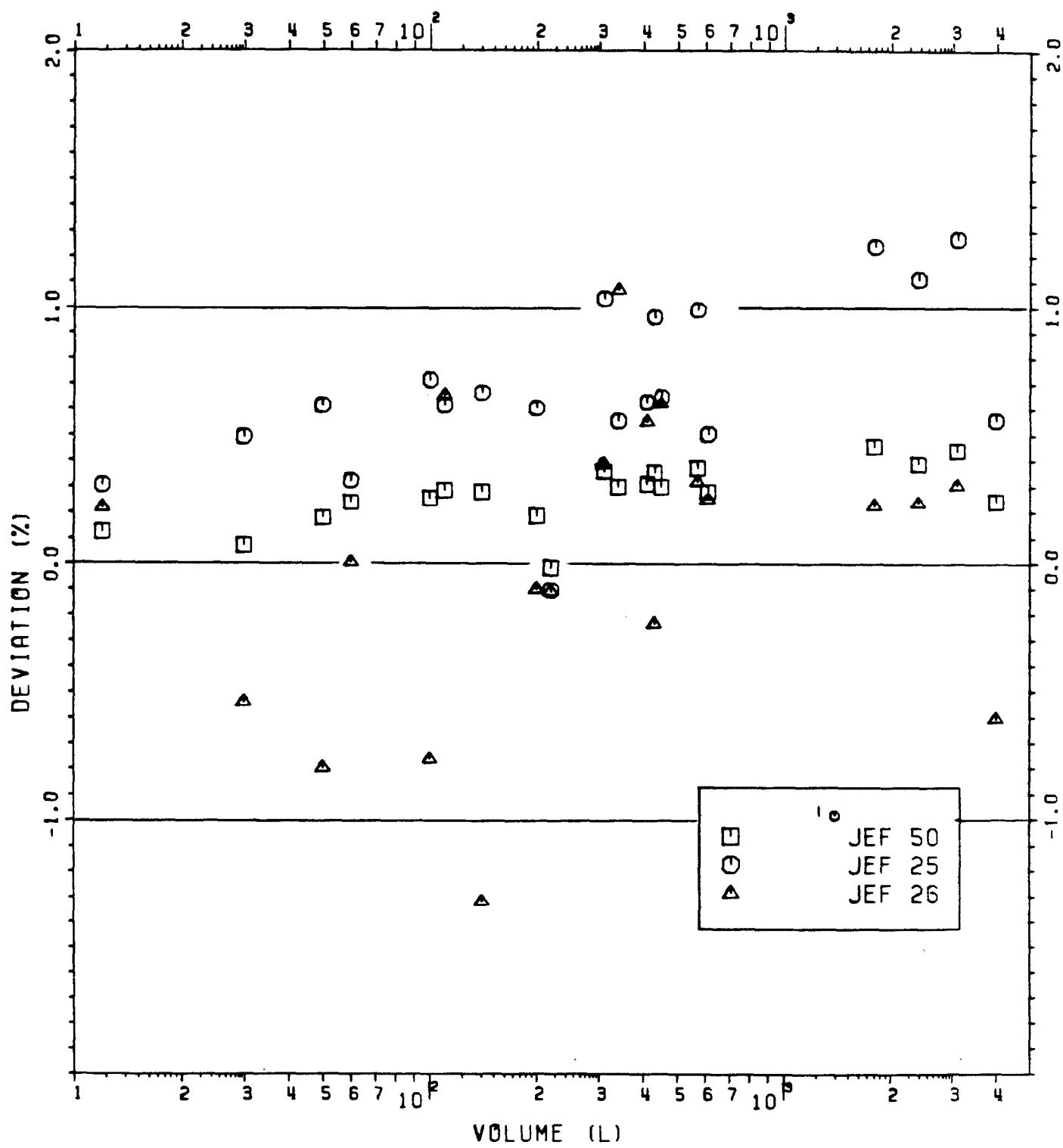


Fig. 4.5 C/E-values of F9/F5 as the function of core volumes (1)

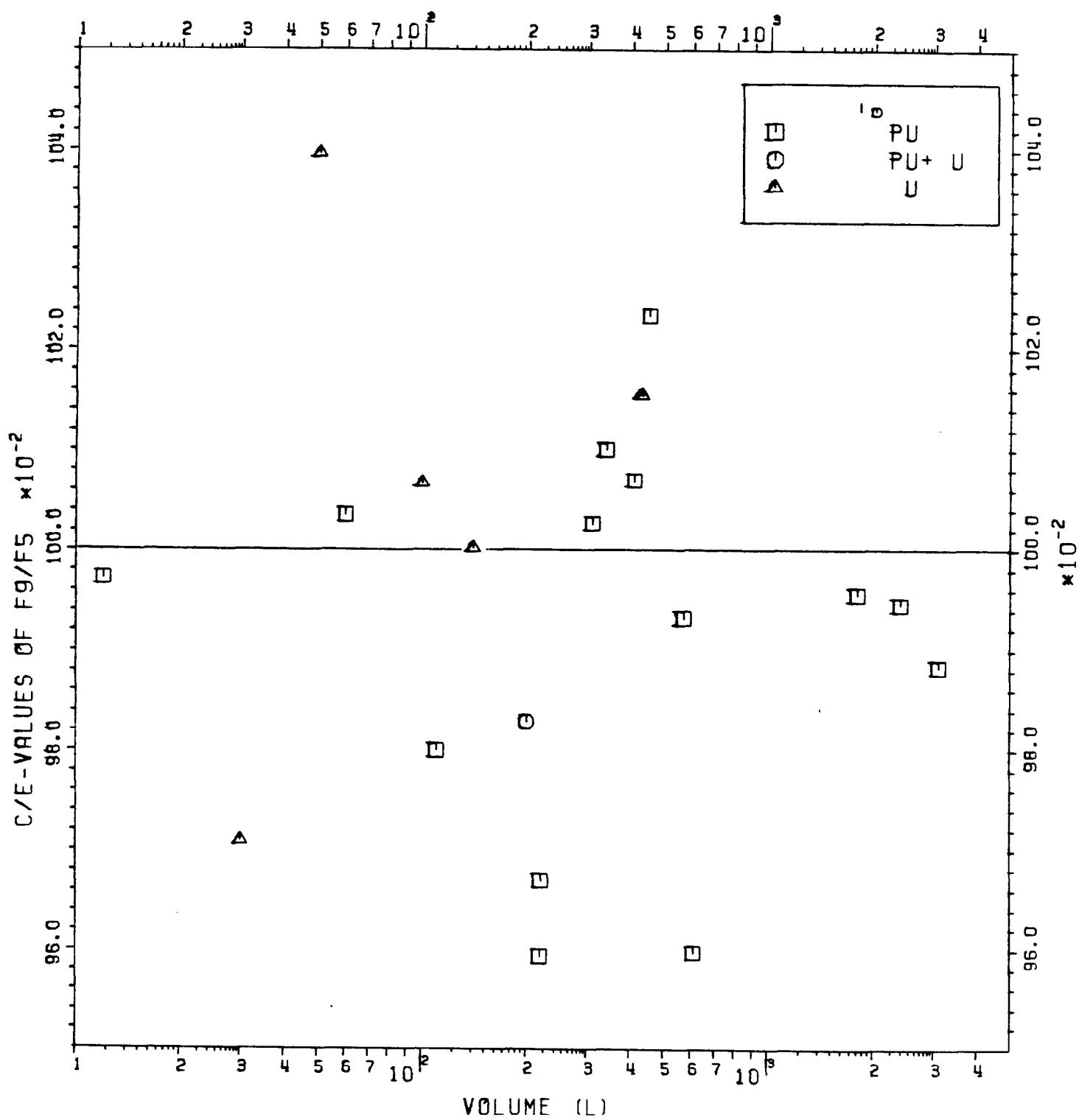


Fig. 4.6 C/E-values of F9/F5 as the function of the ratios of fertile to fissile

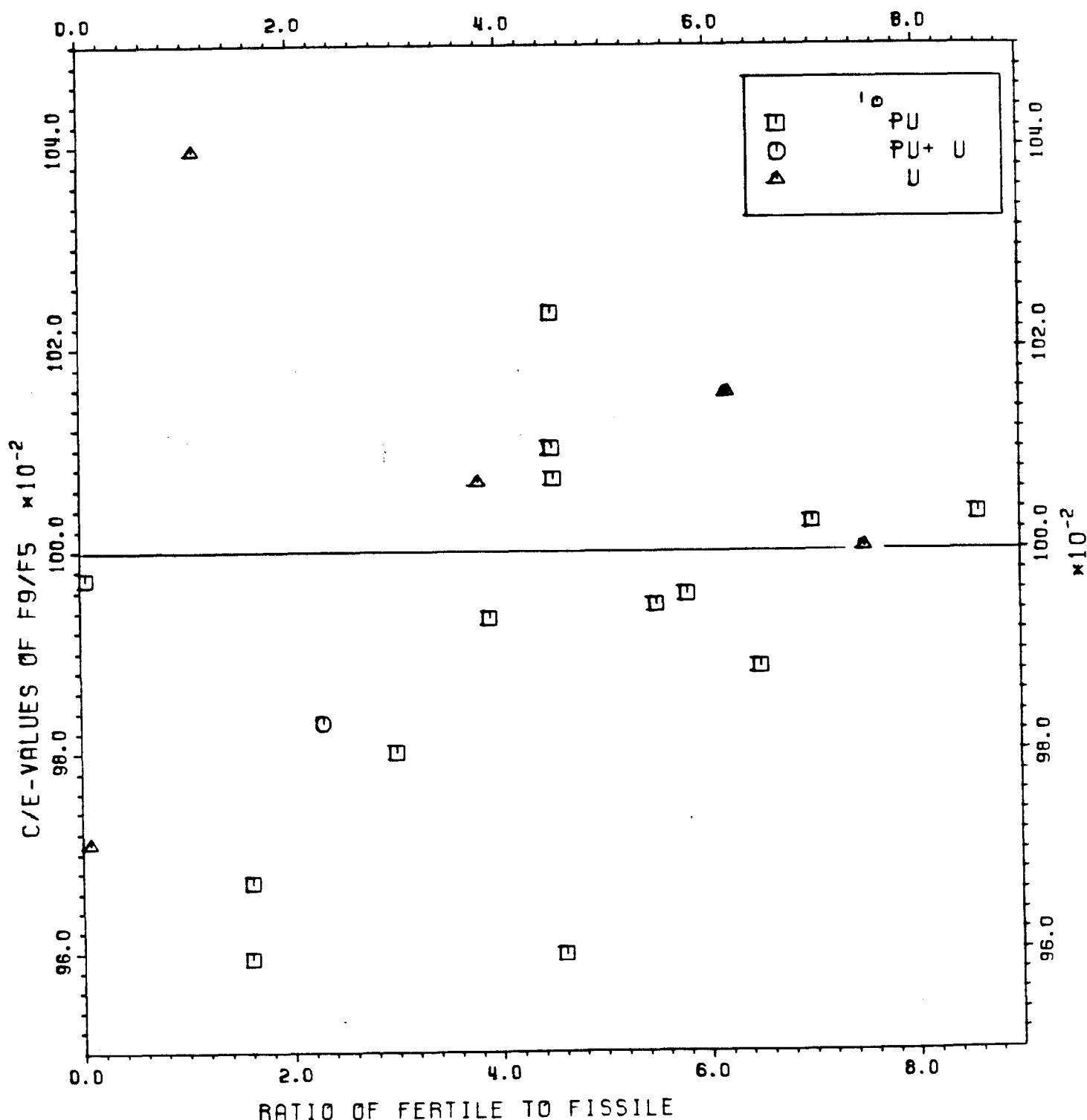


Fig. 4.7 C/E-values of F9/F5 as the function of spectral hardness

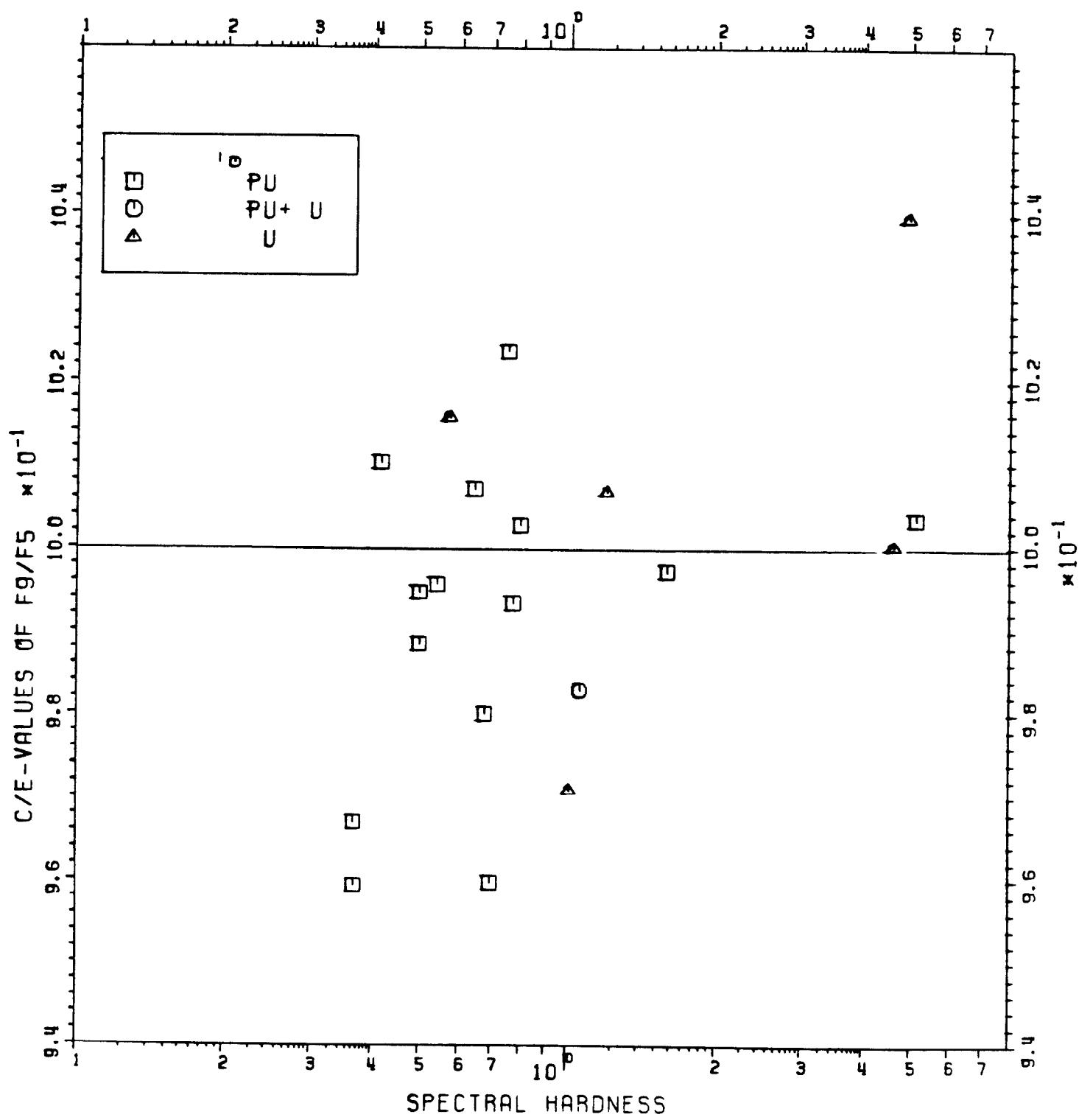


Fig. 4.8 C/E-values of F8/F5 as the function of core volumes (1)

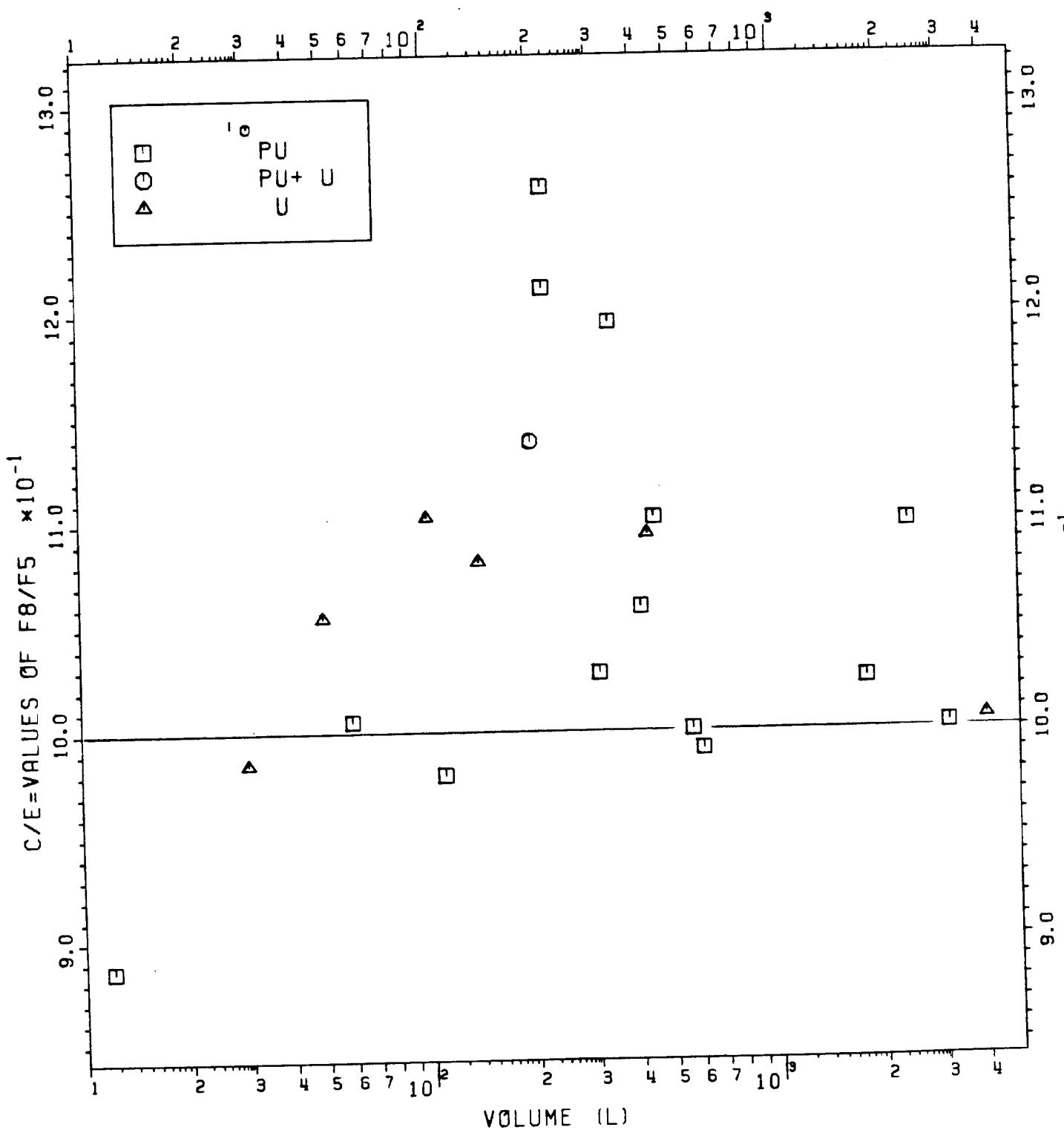


Fig. 4.9 C/E-values of F8/F5 as the function of the ratios of fertile to fissile

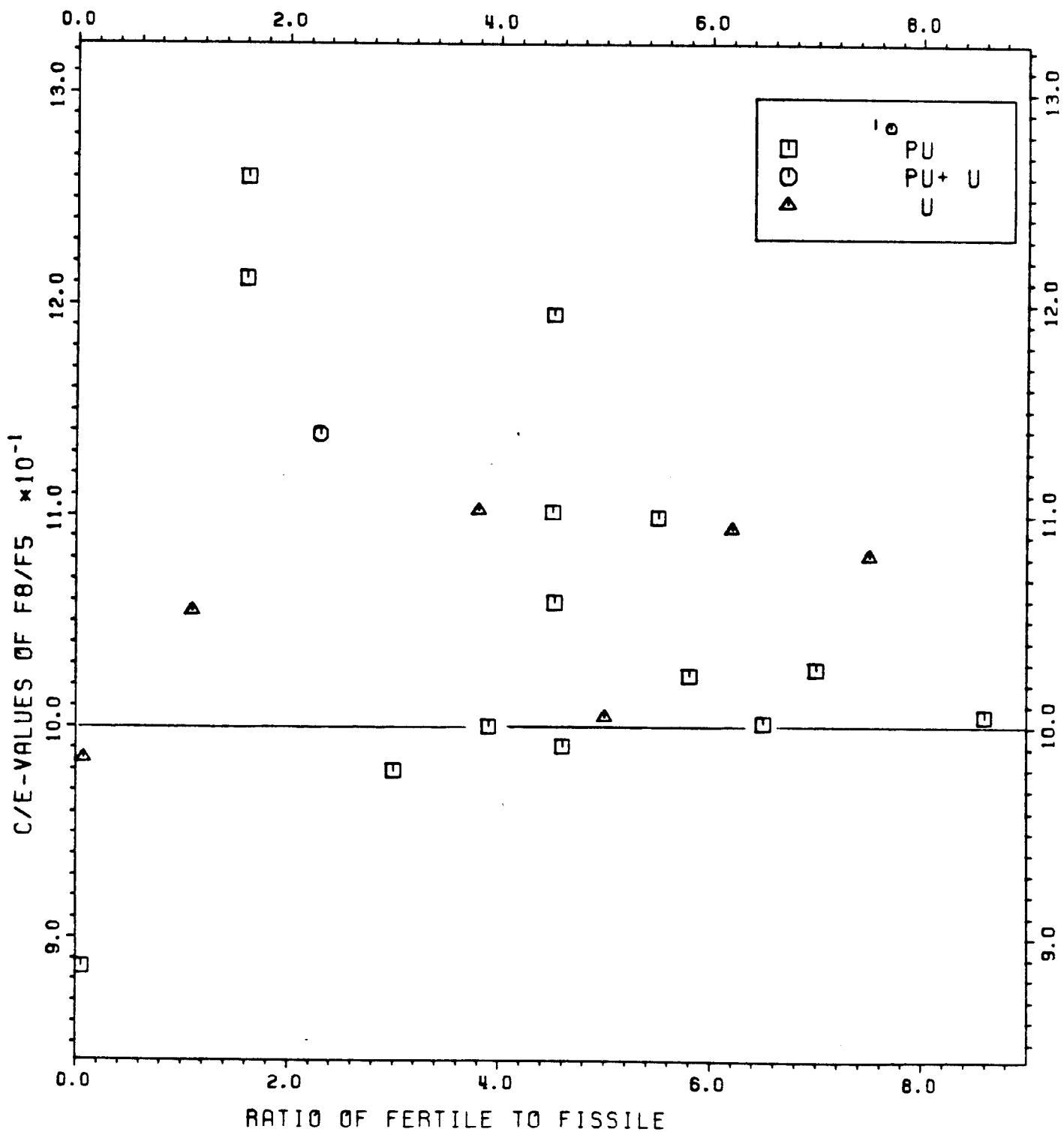


Fig. 4.10 C/E-values of F8/F5 as the function of spectral hardness

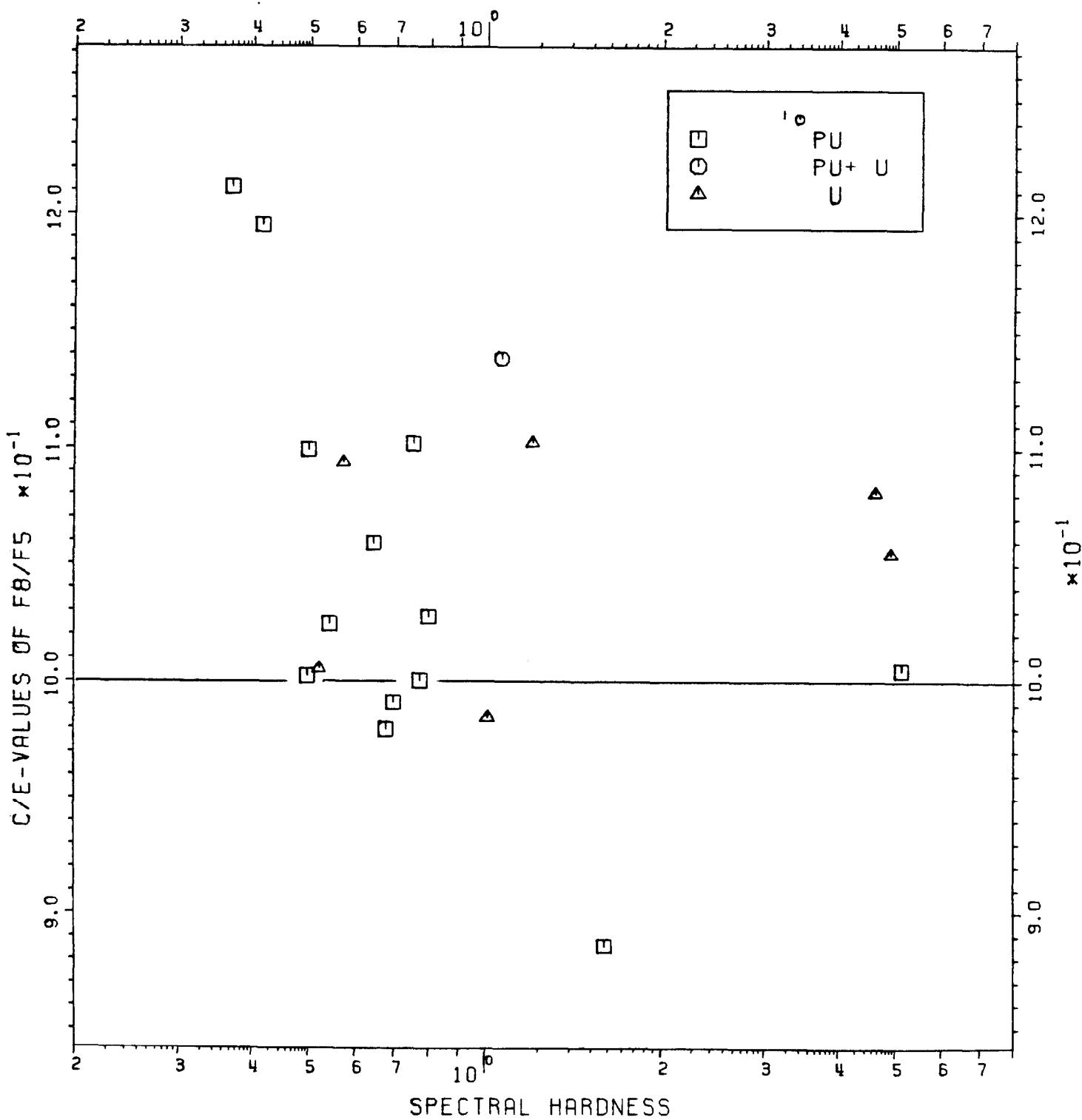


Fig. 4.11 C/E-values of F0/F5 as the function of core volumes (1)

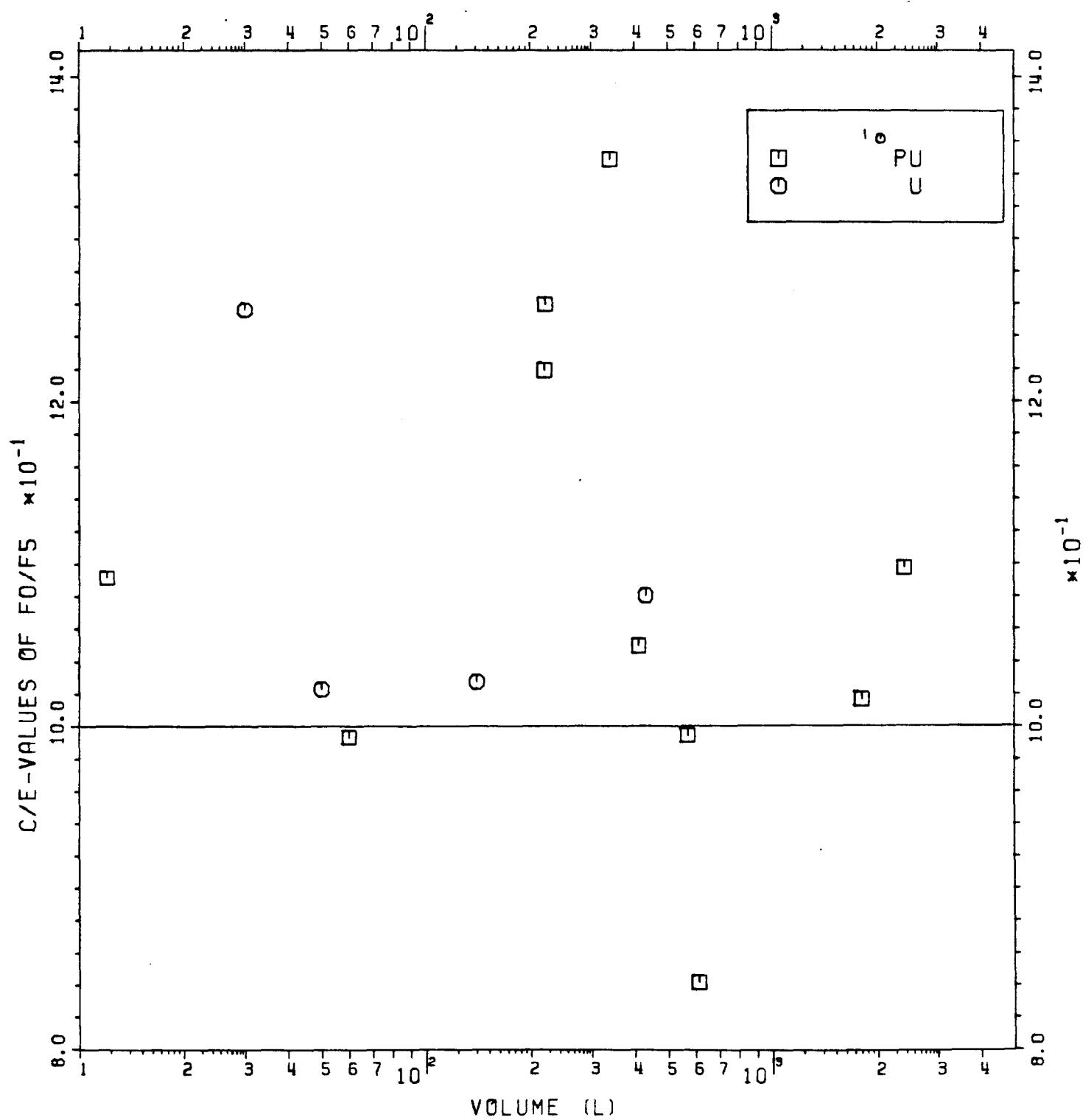


Fig. 4.12 C/E-values of F0/F5 as the function of the ratios of fertile to fissile

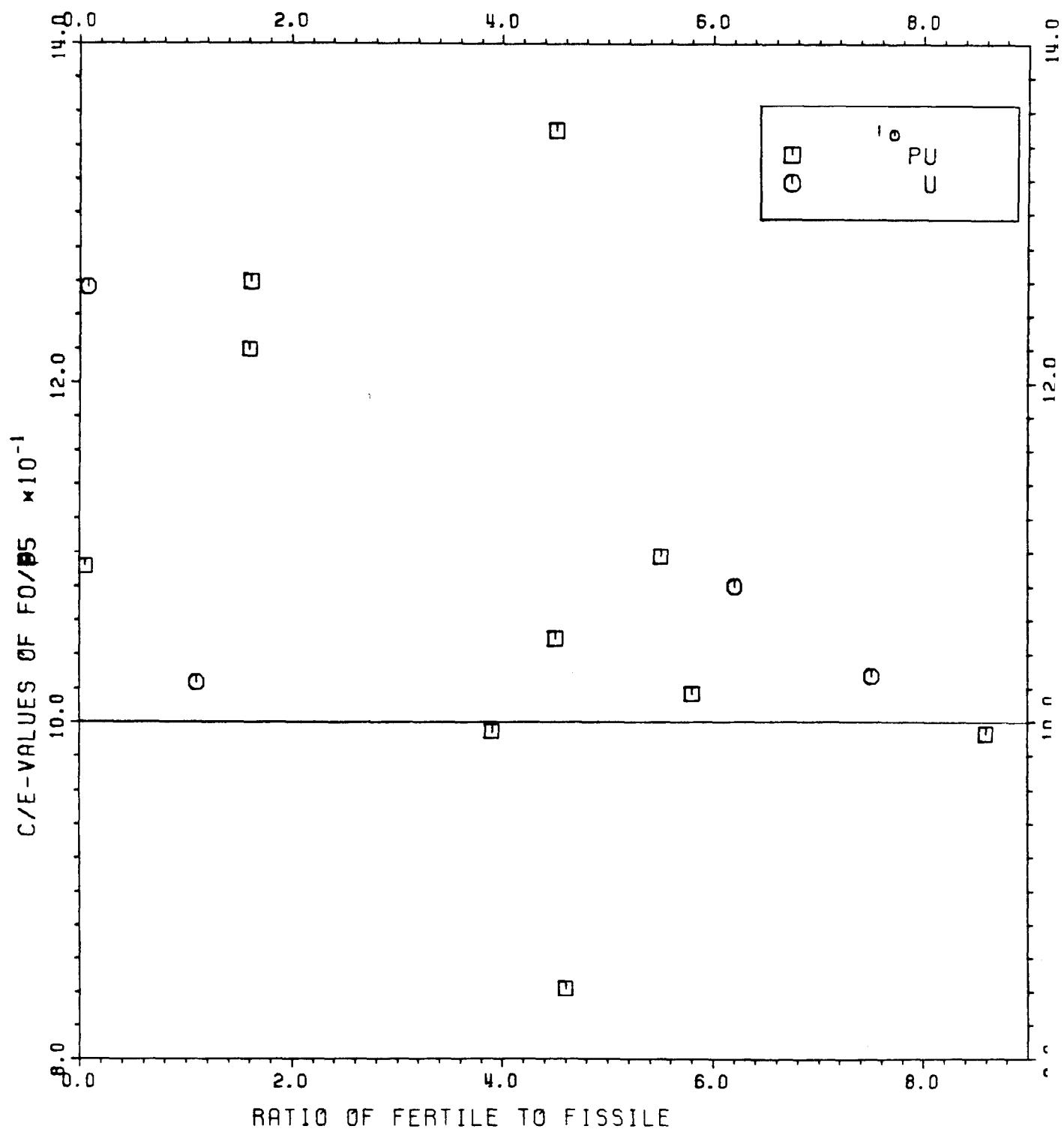


Fig. 4.13 C/E-values of F0/F5 as the function of spectral hardness

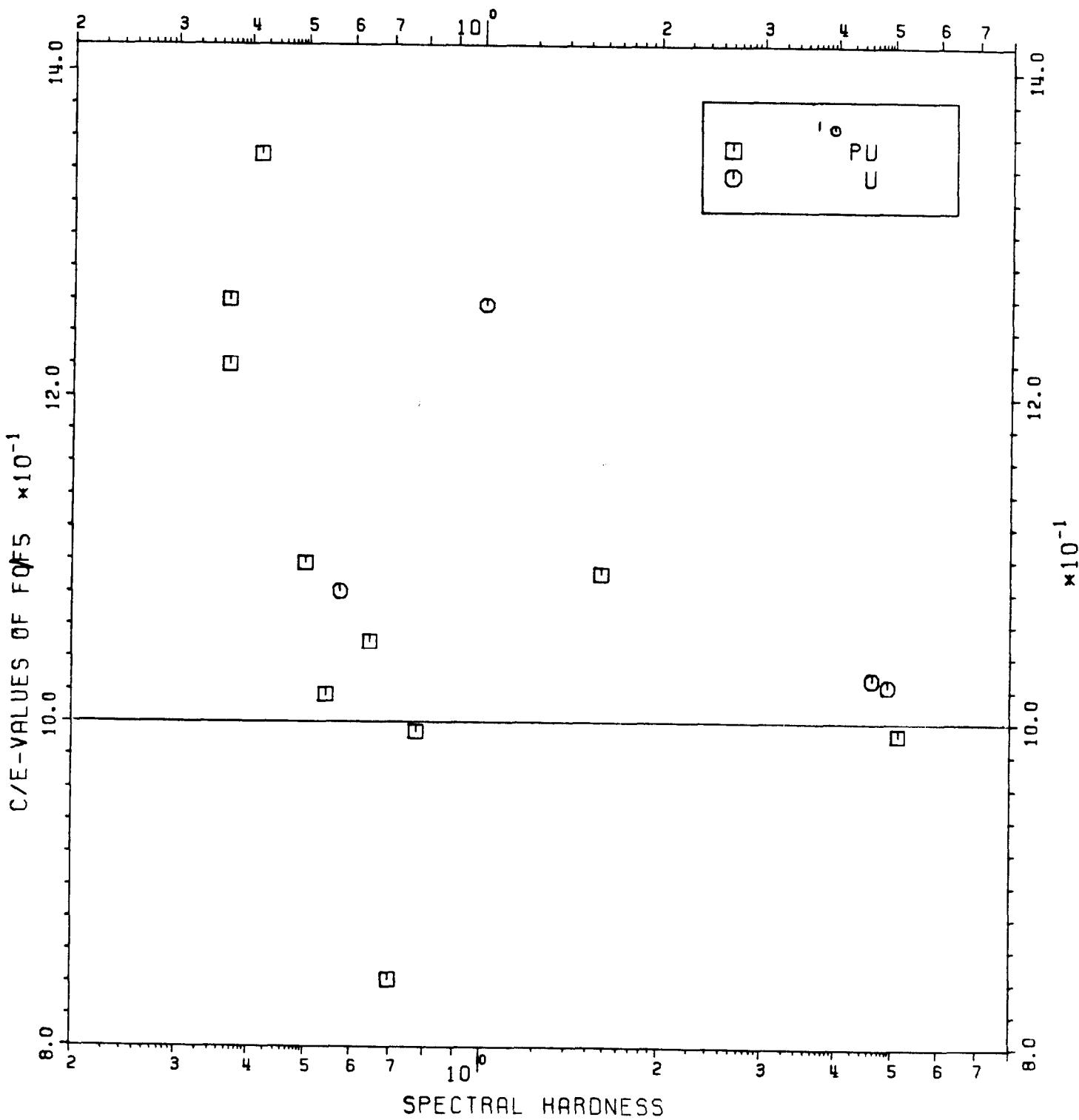


Fig. 4.14 C/E-values of C8/F5 as the function of core volumes (1)

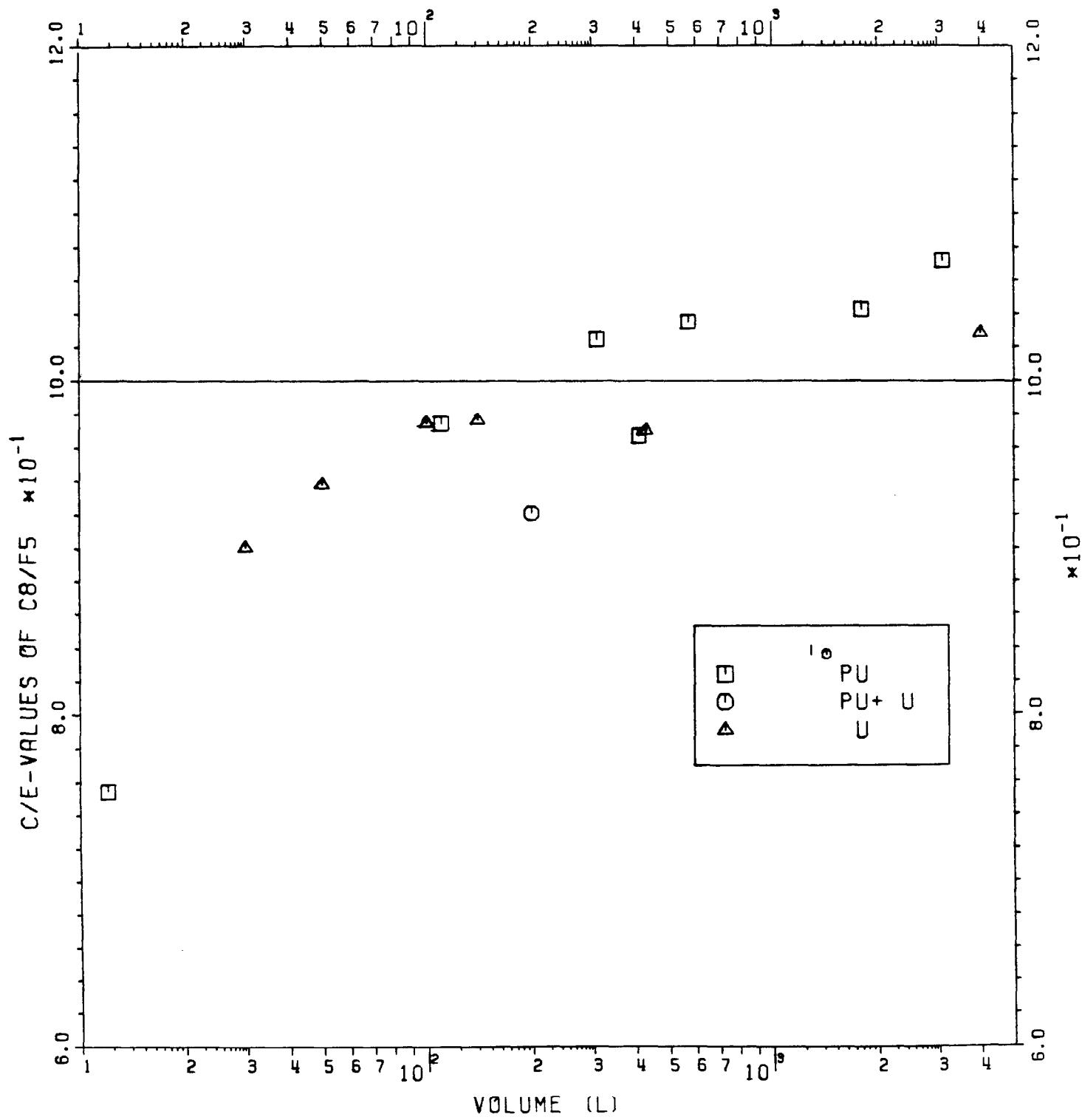


Fig. 4.15 C/E-values of C8/F5 as the function of the ratios of fertile to fissile

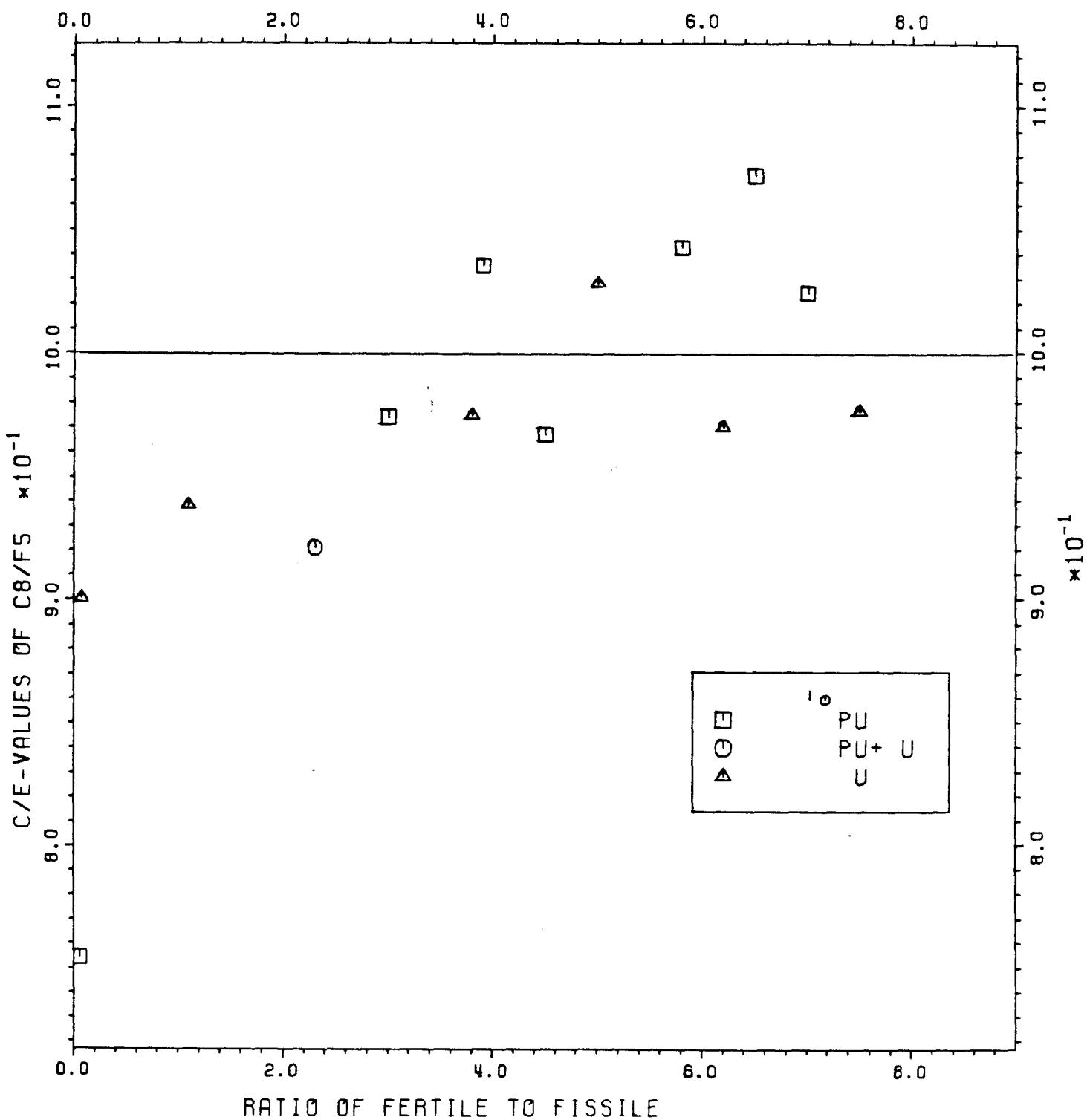


Fig. 4.16 C/E-values of C8/F5 as the function of spectral hardness

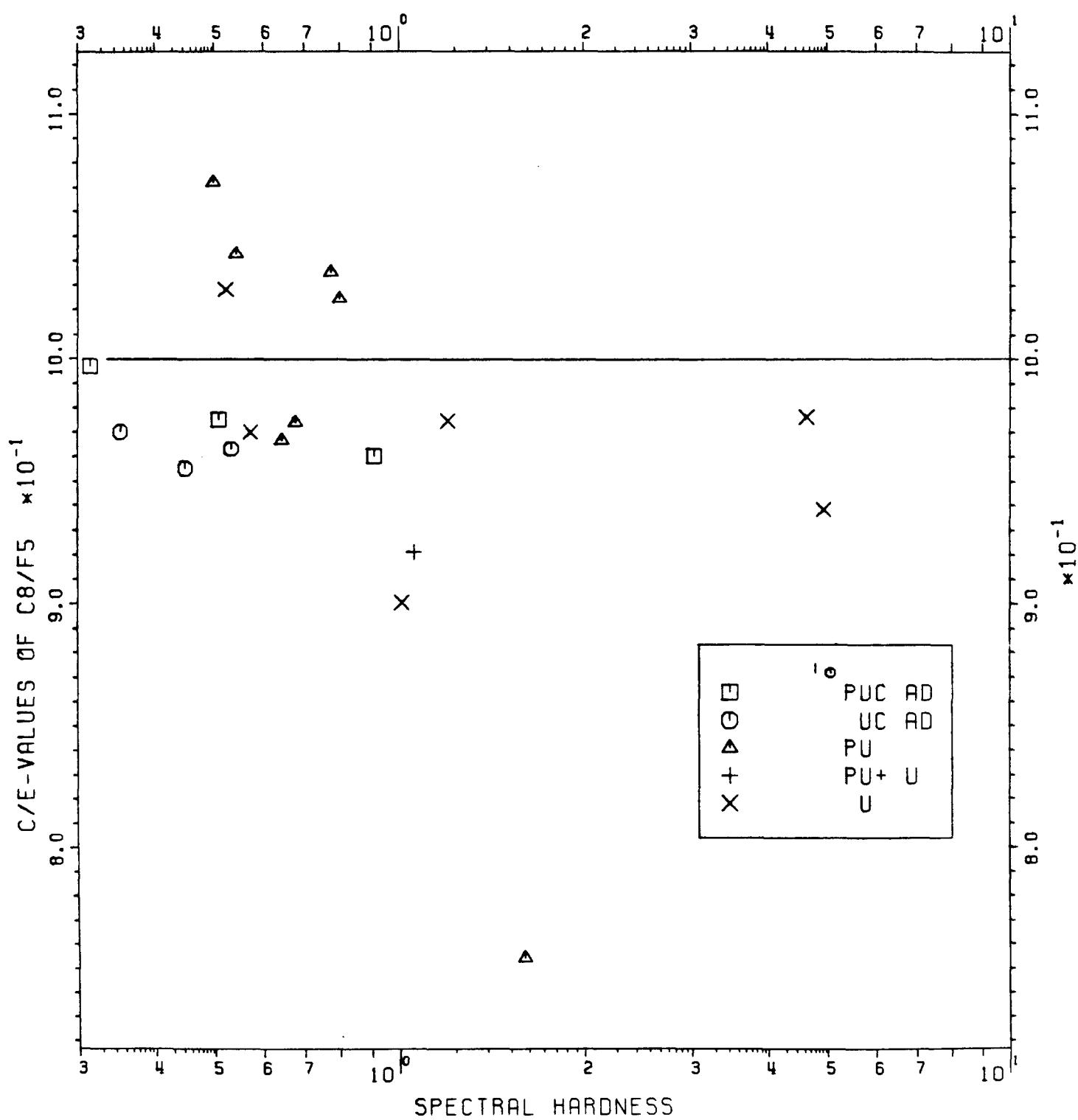


Fig. 4.17 C/E-values of C8/F9 as the function of core volumes (1)

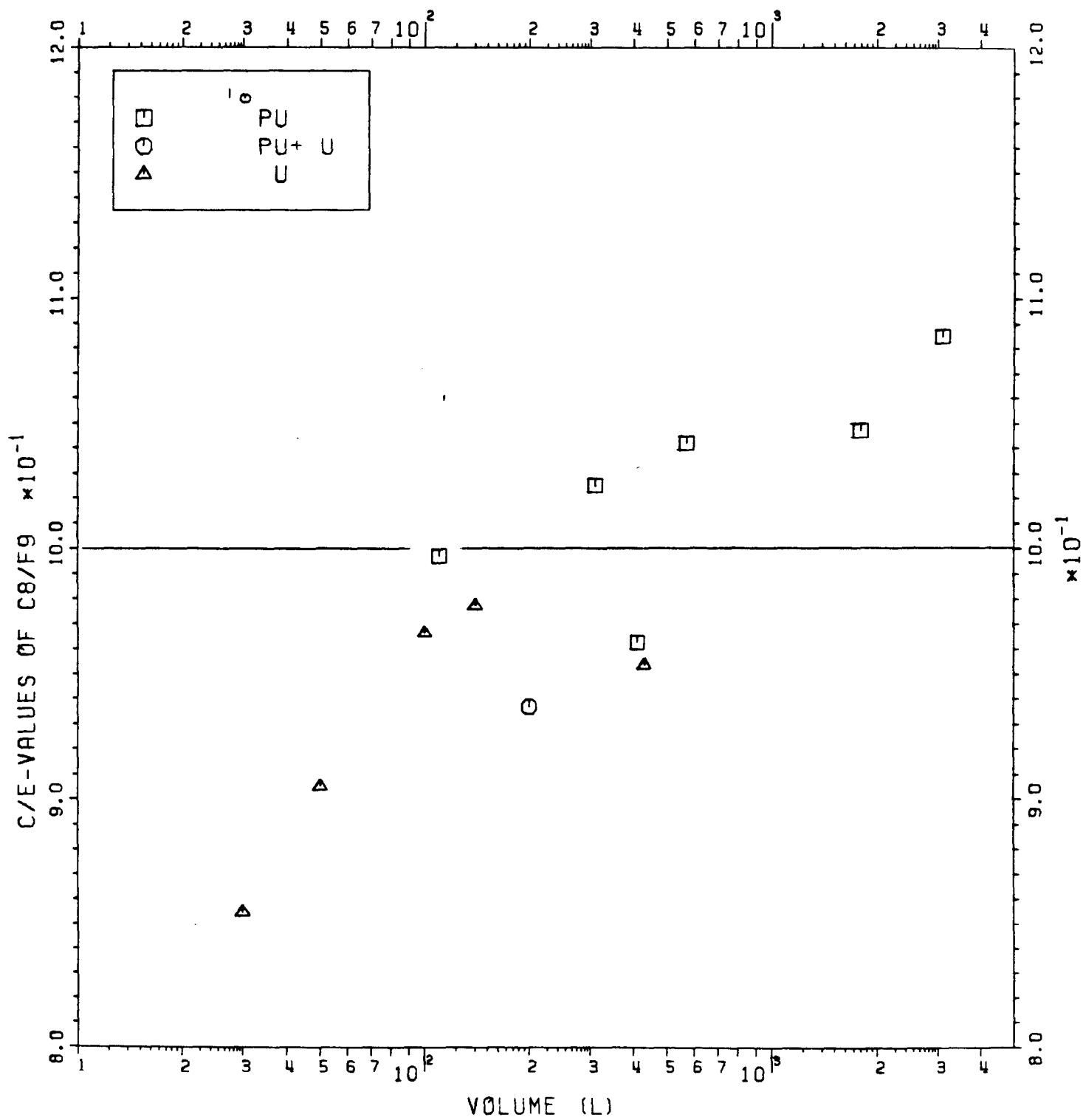


Fig. 4.18 C/E-values of C8/F9 as the function of the ratios of fertile to fissile

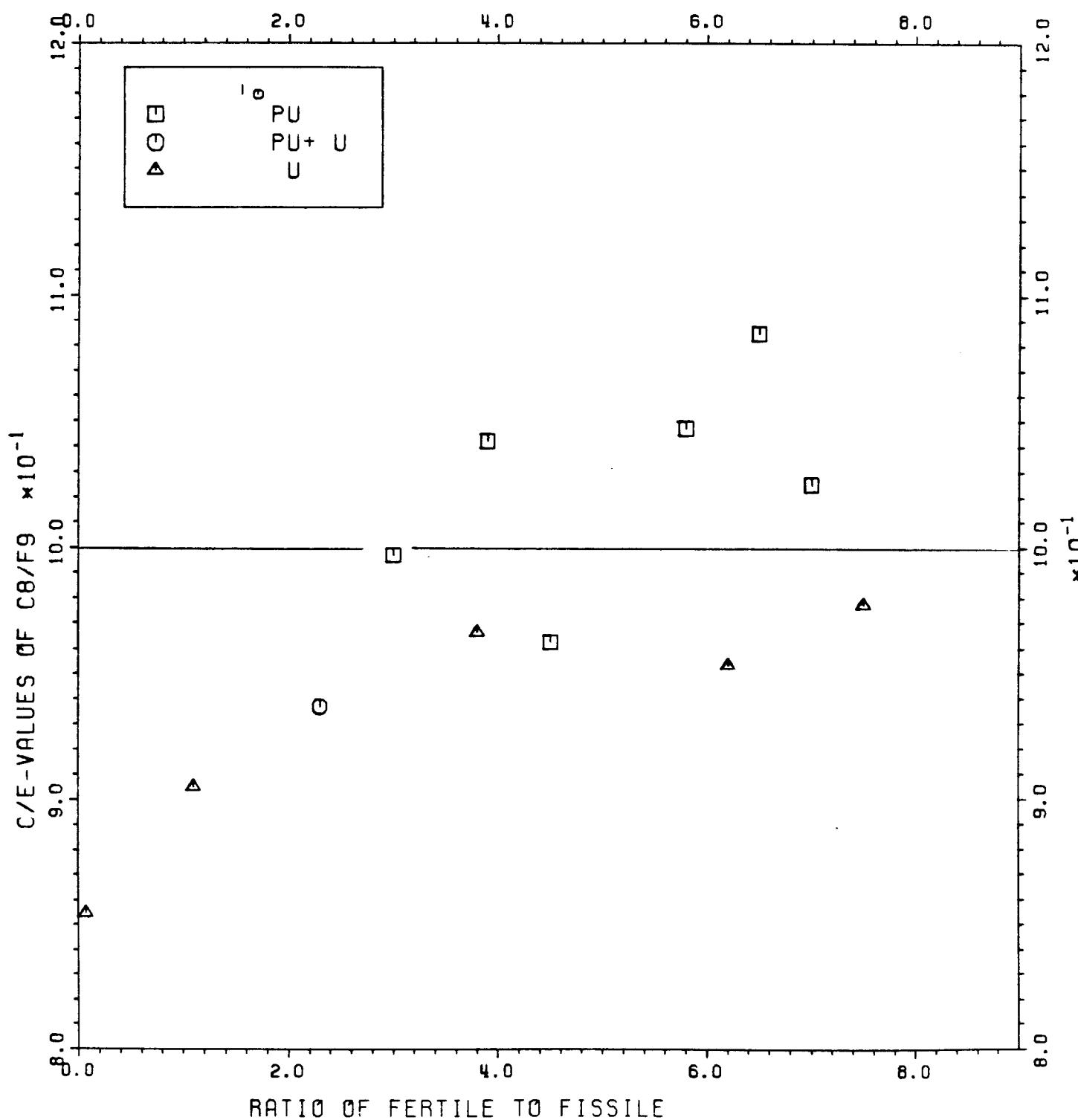


Fig. 4.19 C/E-values of C8/F9 as the function of spectral hardness

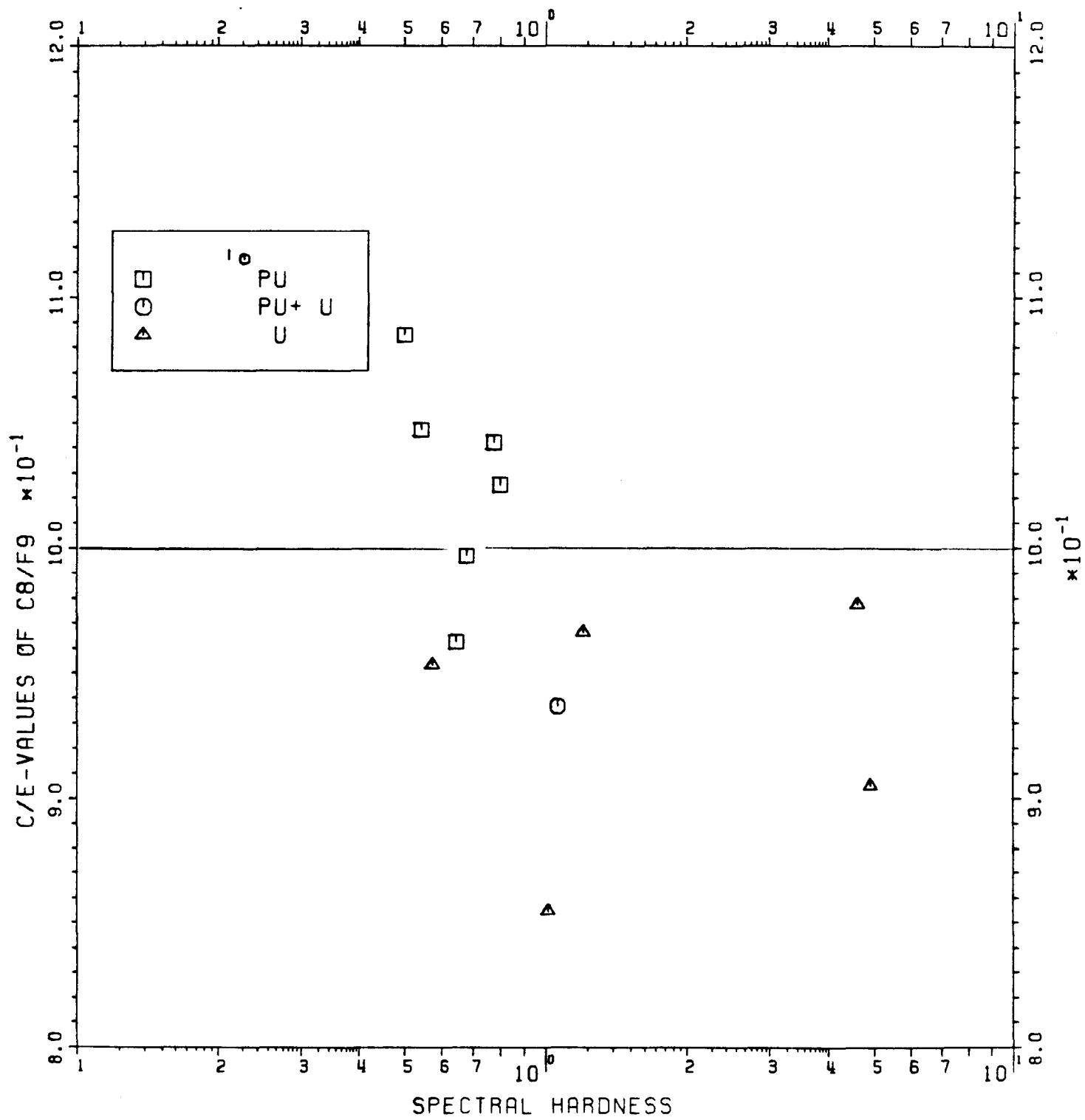


Fig. 4.20 Comparison of Pu-239 fission spectrum for 25, 50 and 71 energy groups

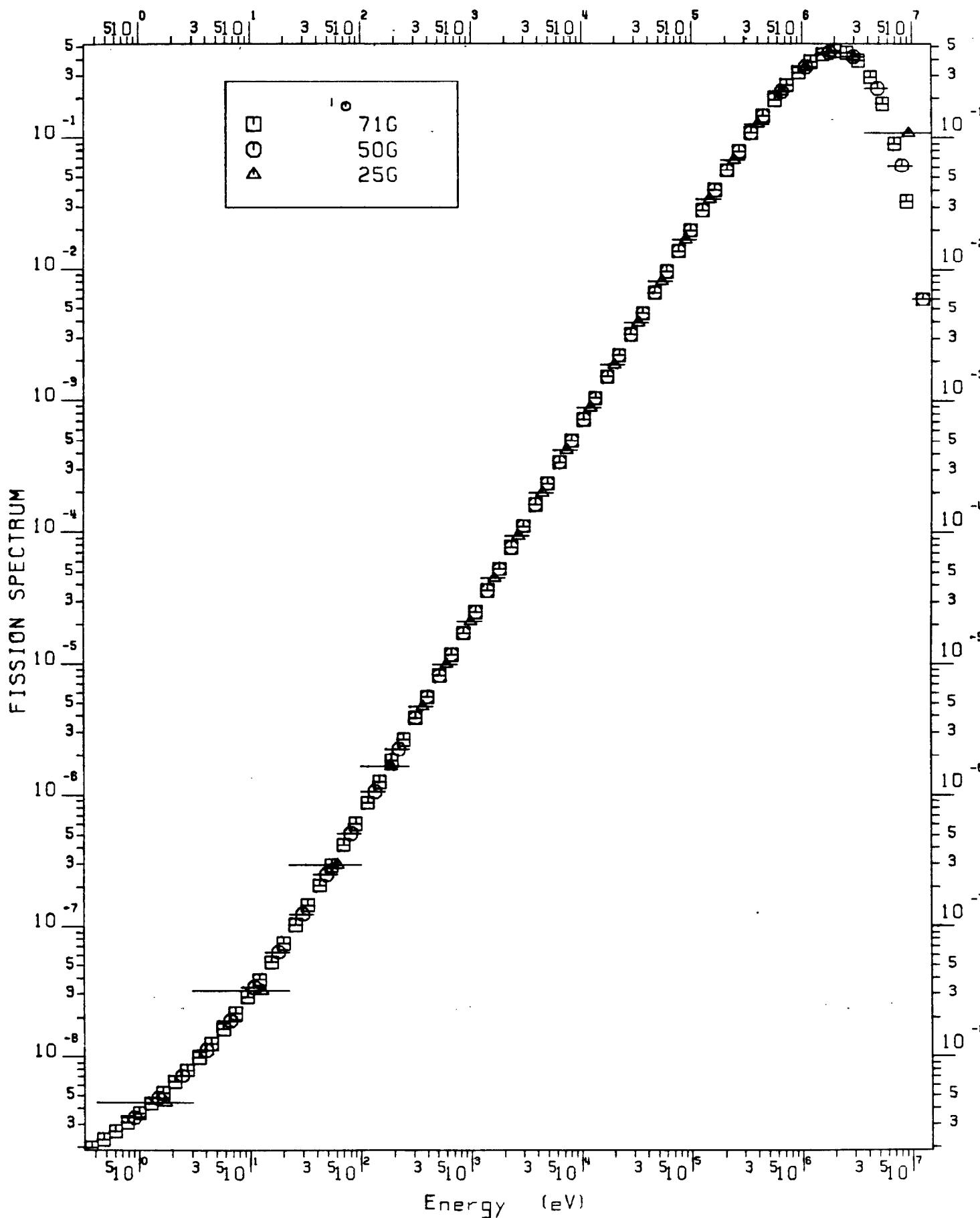


Fig. 4.21 Comparison of Pu-239 fission spectrum for 25 and 26 energy groups

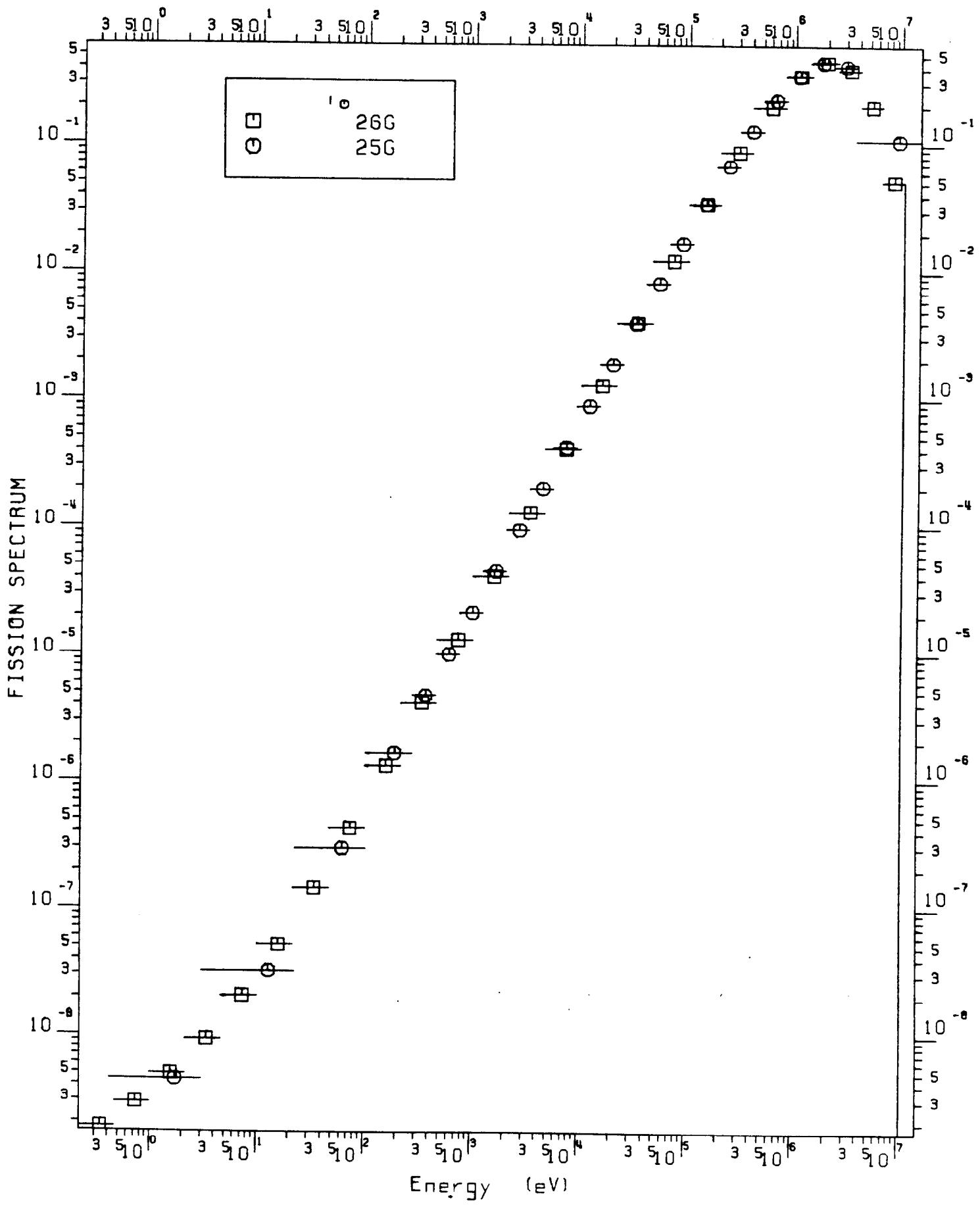


Fig. 4.22 Comparison of U-235 fission spectrum for 25, 50 and 71 energy groups

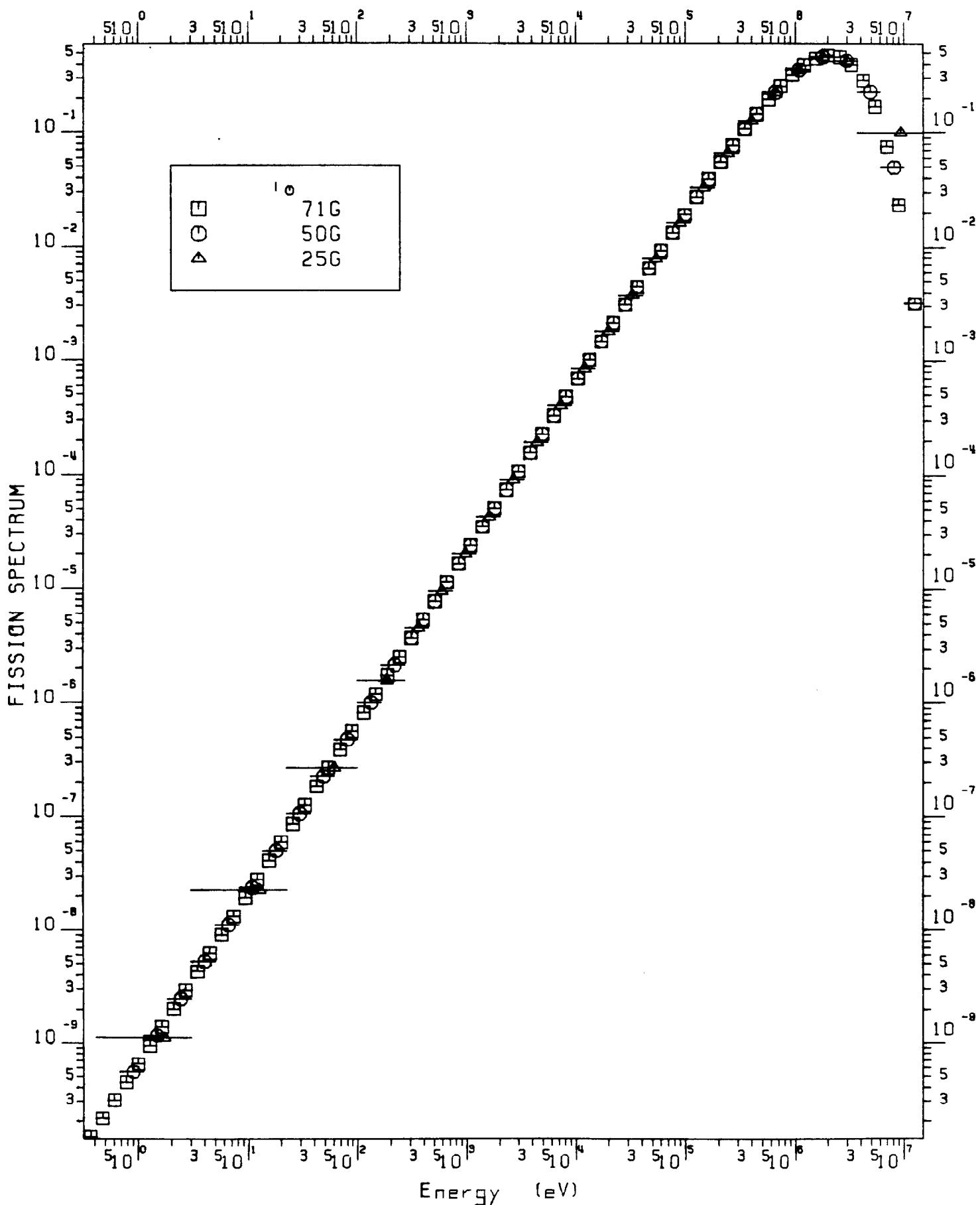


Fig. 4.23 Comparison of U-235 fission spectrum for 25 and 26 energy groups

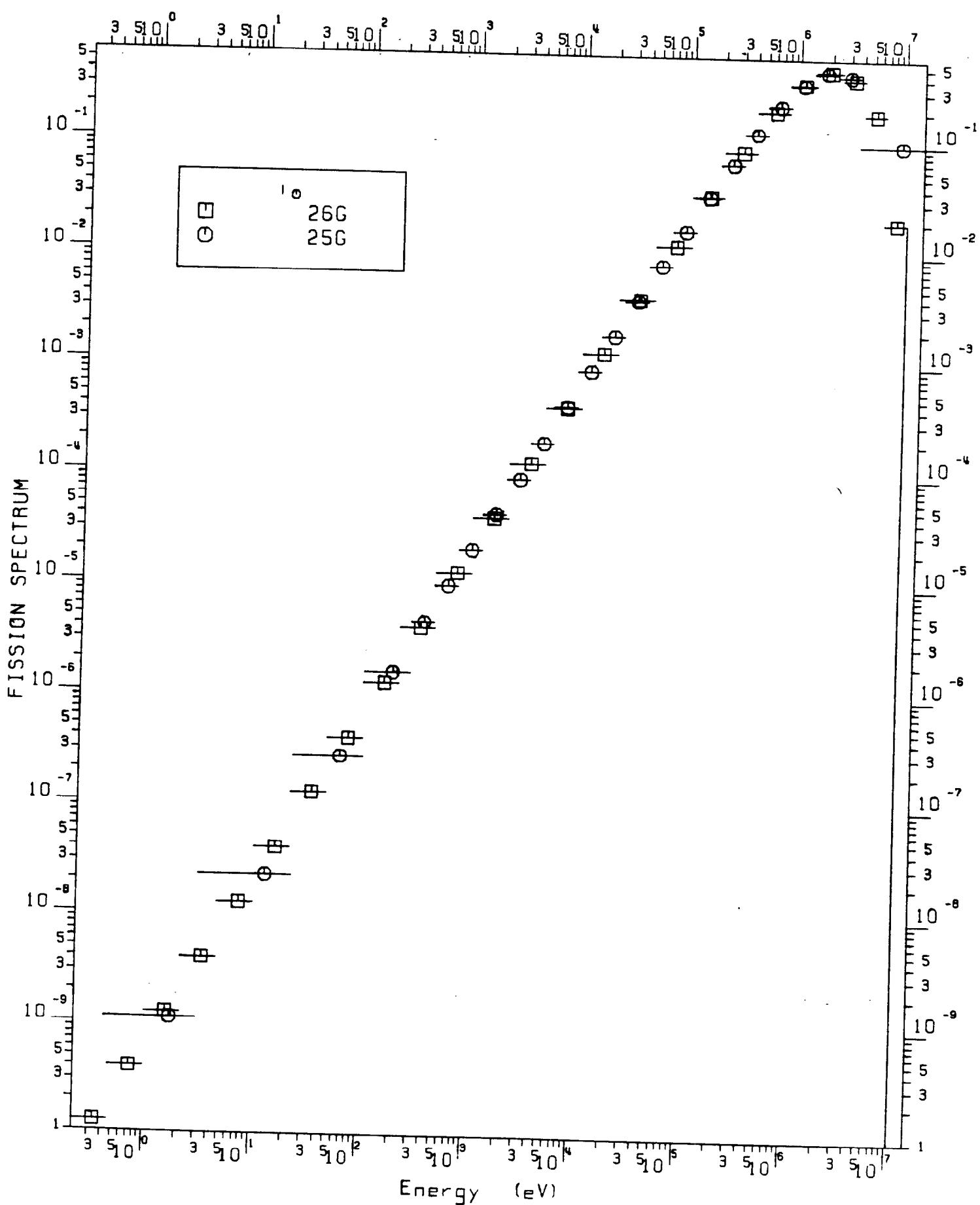


Fig. 4.24 Comparison of U-235 and Pu-239 fission spectrum for 25 energy groups

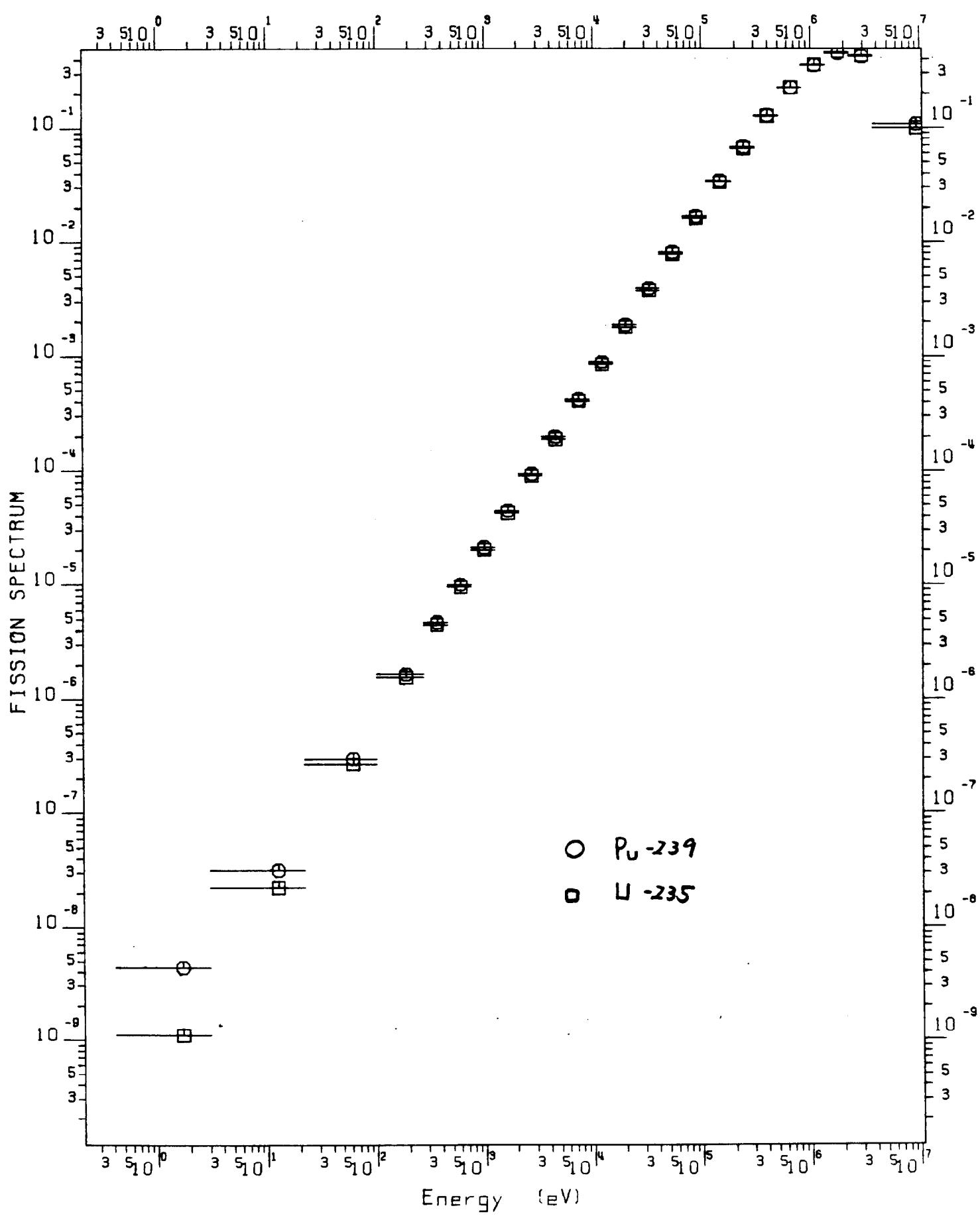


Fig. 4.25 Comparison of U-235 and Pu-239 fission spectrum for 26 energy groups

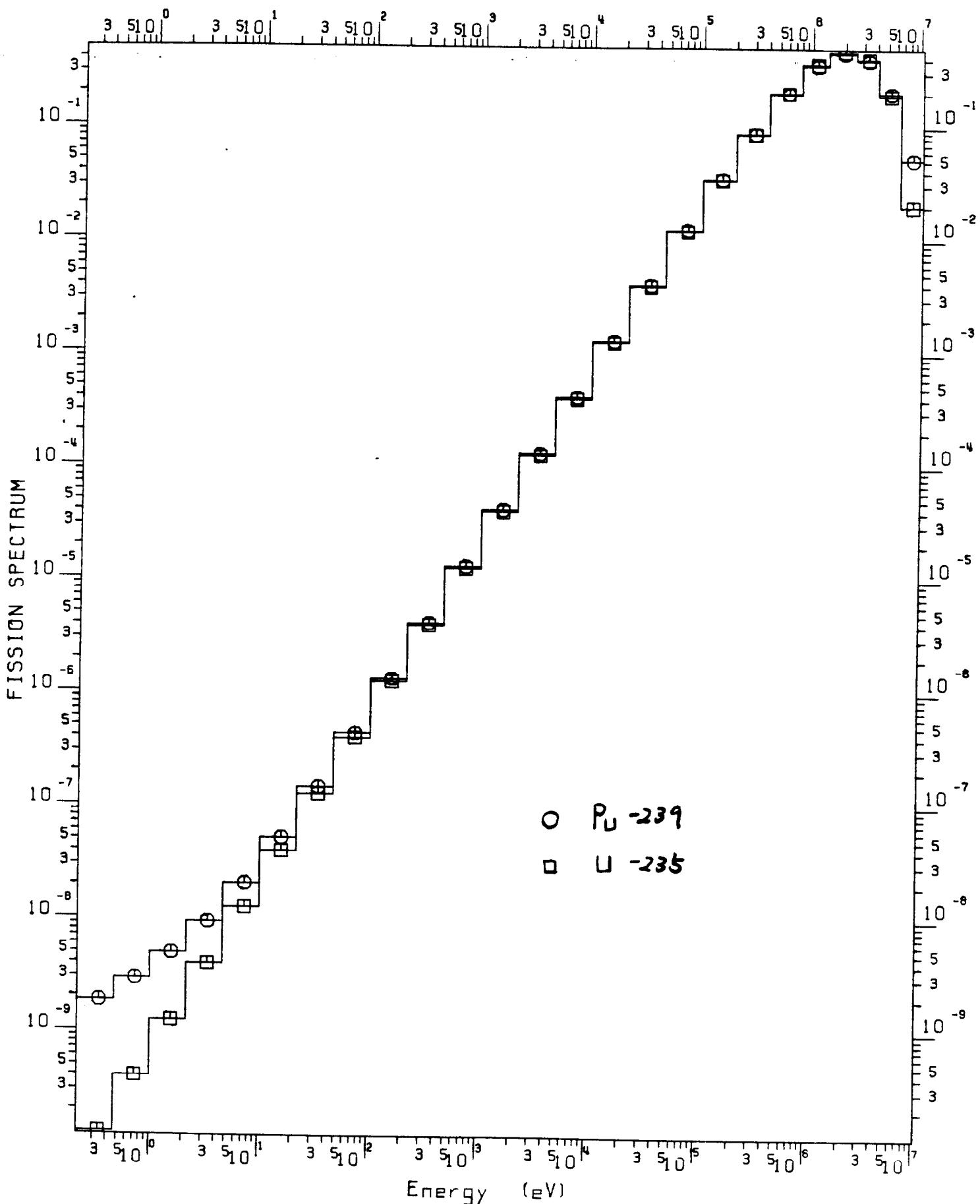


Fig. 4.26 Comparison of neutron spectrum for 25, 50 and 71 groups at the core center of UO₂-740

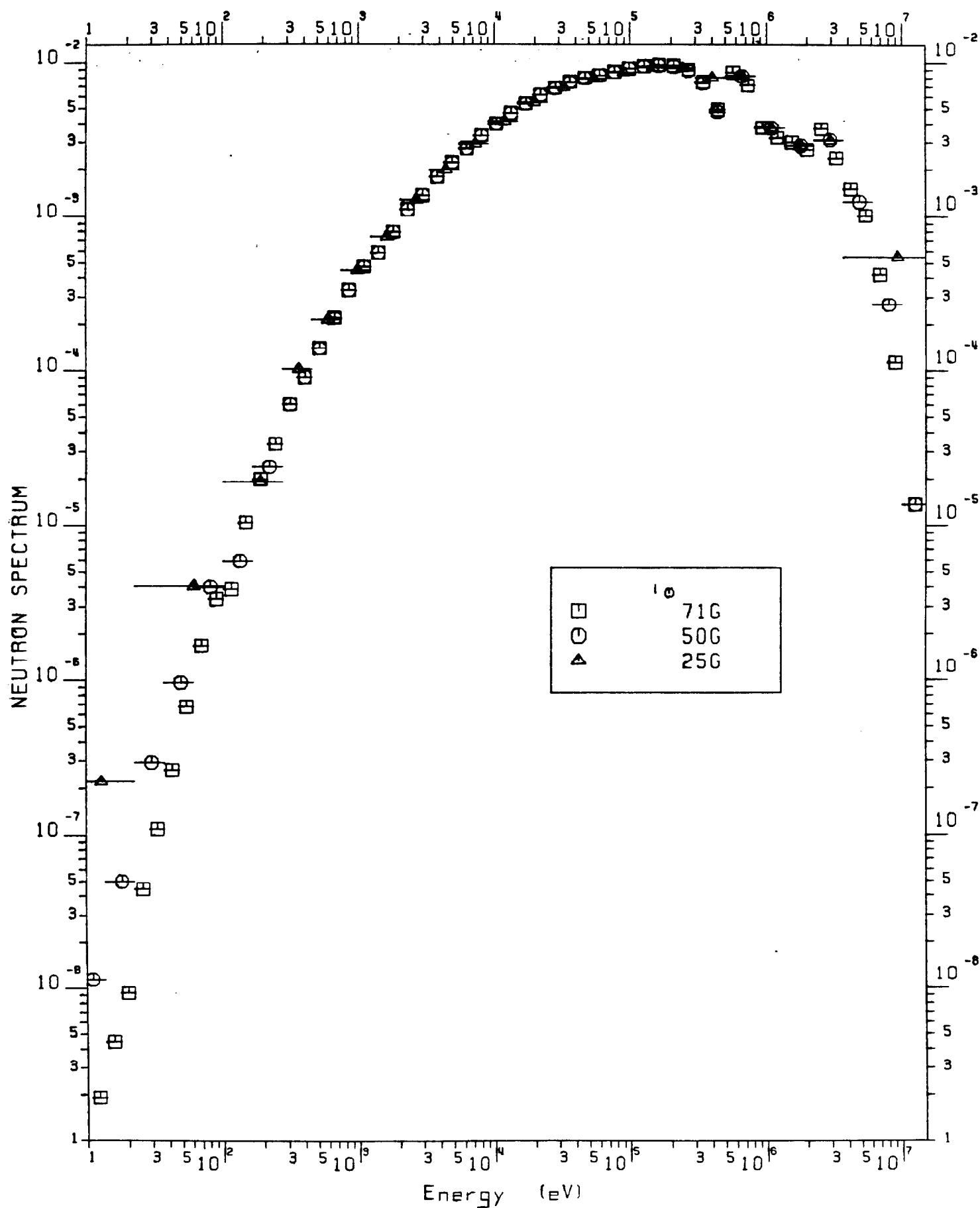


Fig. 4.27 Comparison of neutron spectrum for 25 and 26 groups in the energy range from 0.2 eV to 15 MeV at the core center of UO₂-40

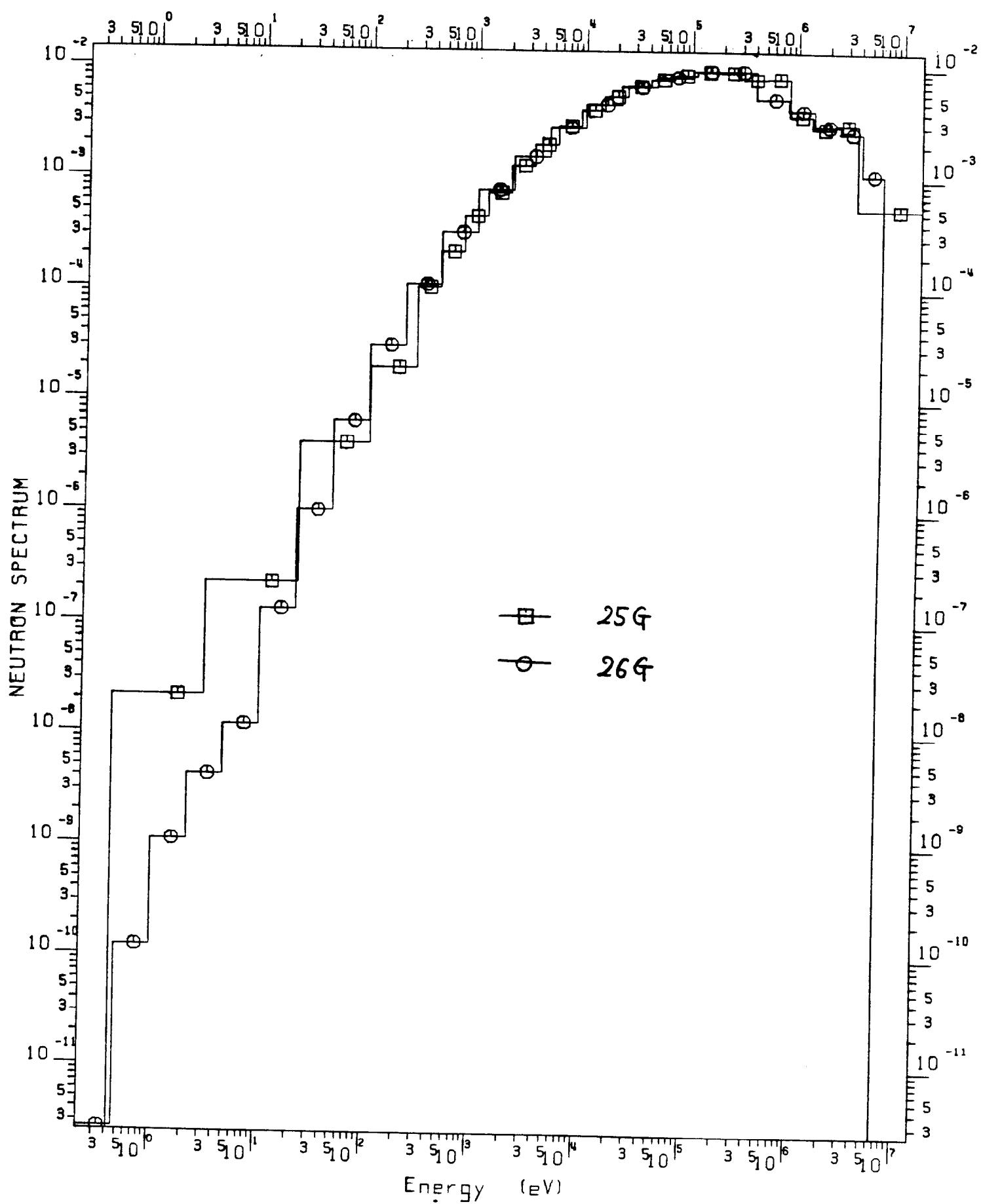


Fig. 4.28 Comparison of neutron spectrum for 25 and 26 groups in the energy range from 100 eV to 15 MeV at the core center of UO₂-740

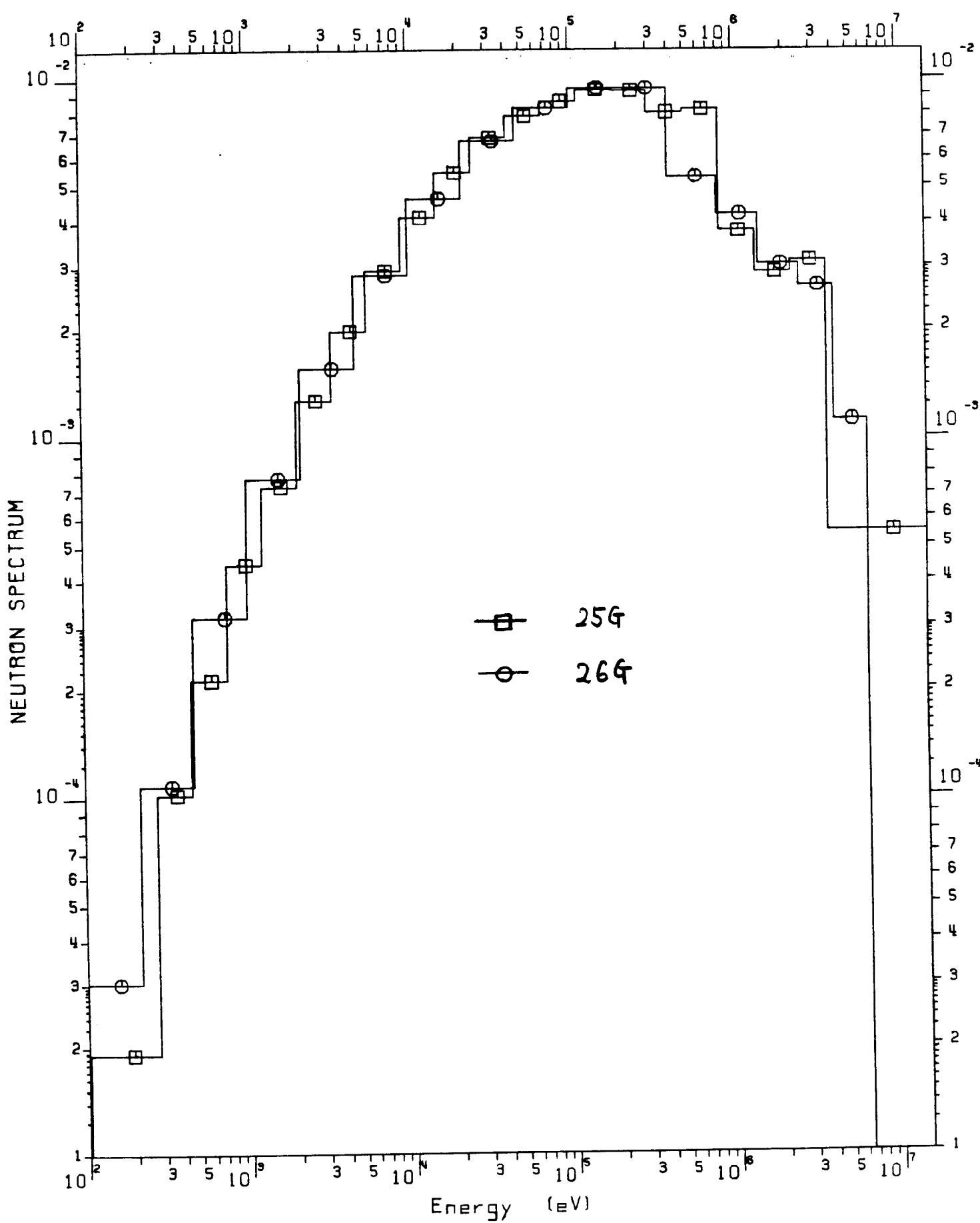


Fig. 4.29 Comparison of neutron spectrum for 25, 50 and 71 groups at the core center of SCHERZC-556

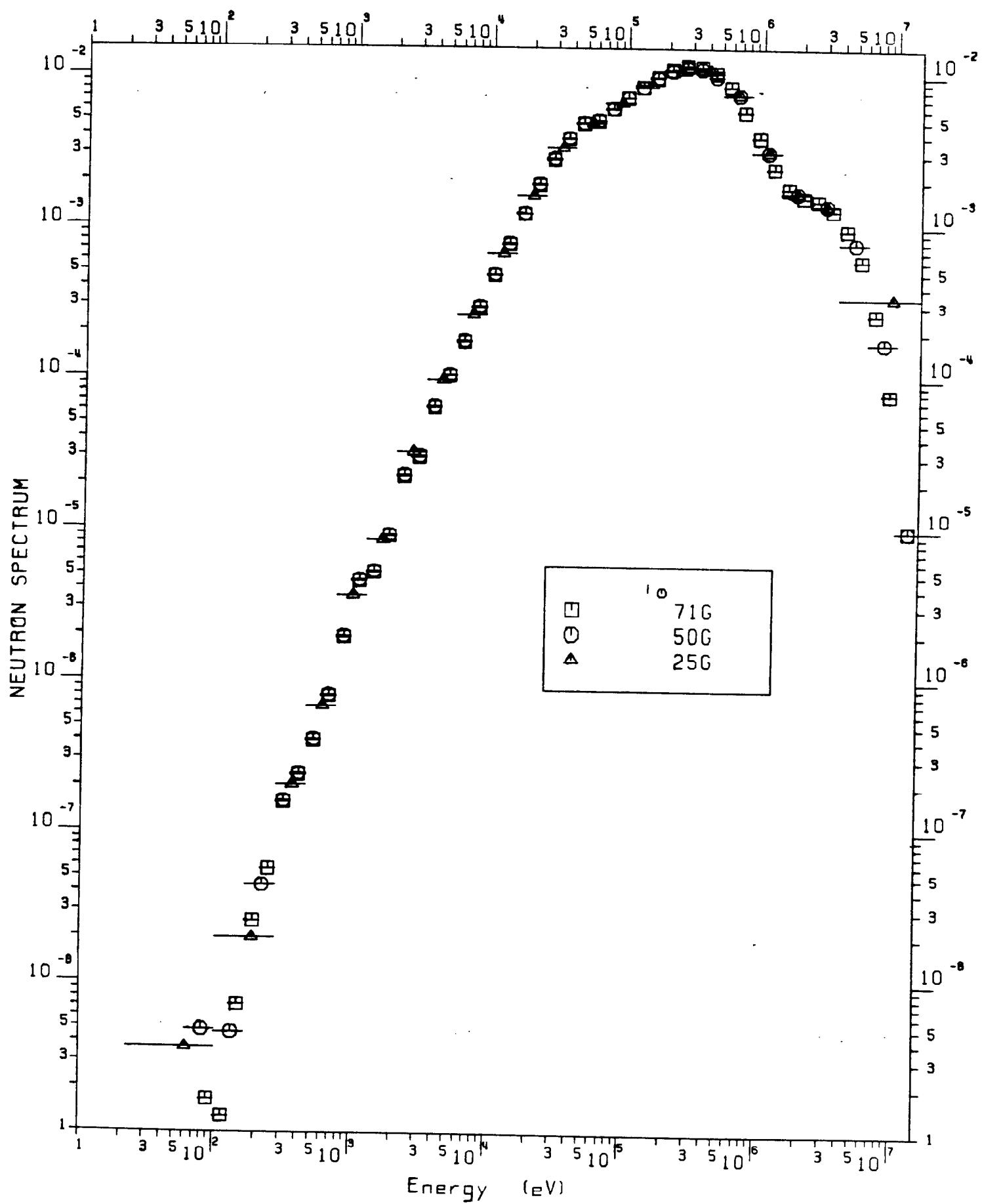


Fig. 4.30 Comparison of neutron spectrum for 25 and 26 groups at the core center of SCHERZO-556

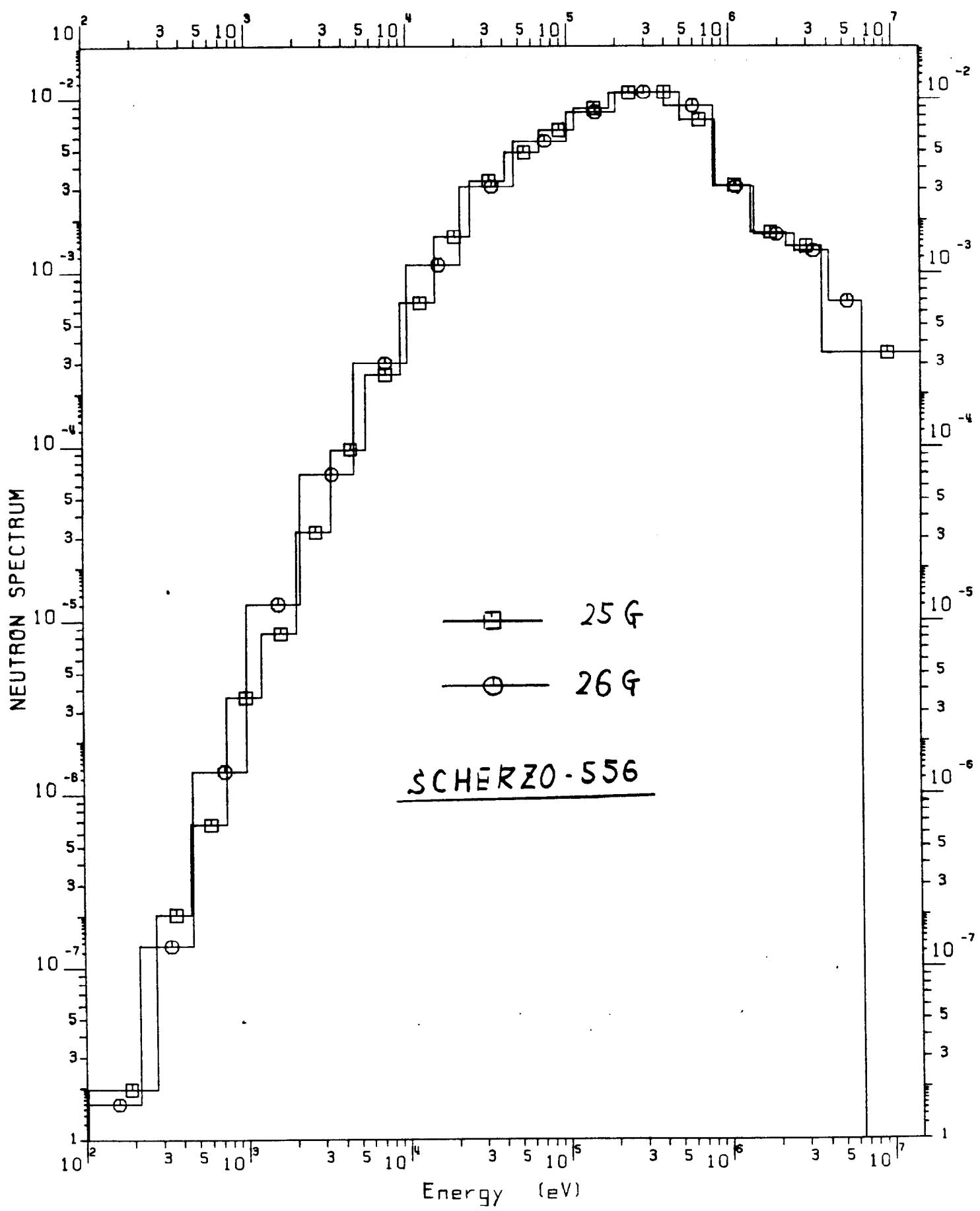


Fig. 4.31 Comparison of neutron spectrum for 25 and 26 groups at the core center of SCHERZO-556

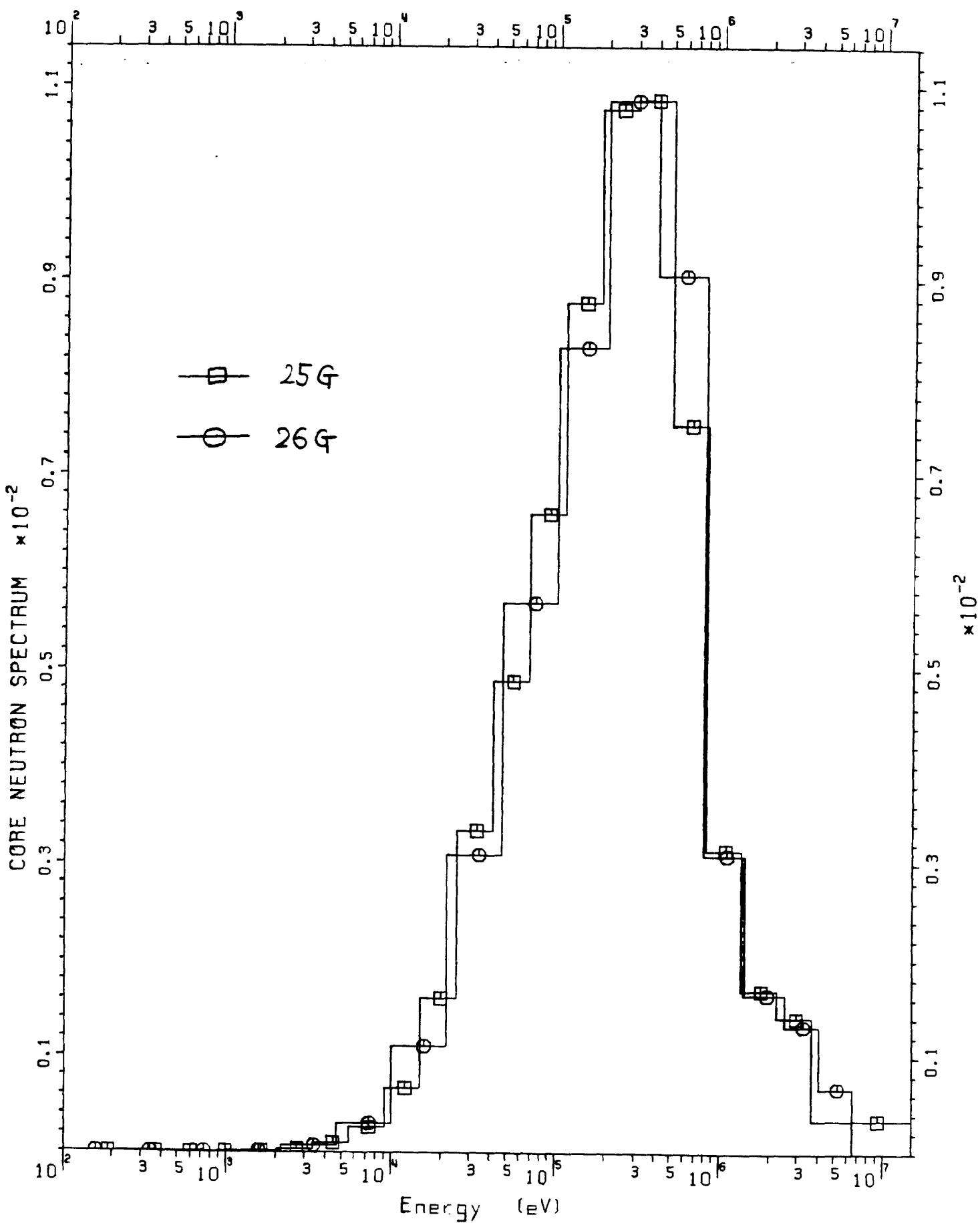


Fig. 4.32 Comparison of neutron spectrum for 25, 50 and 71 groups at the core center of ZPR-6-7

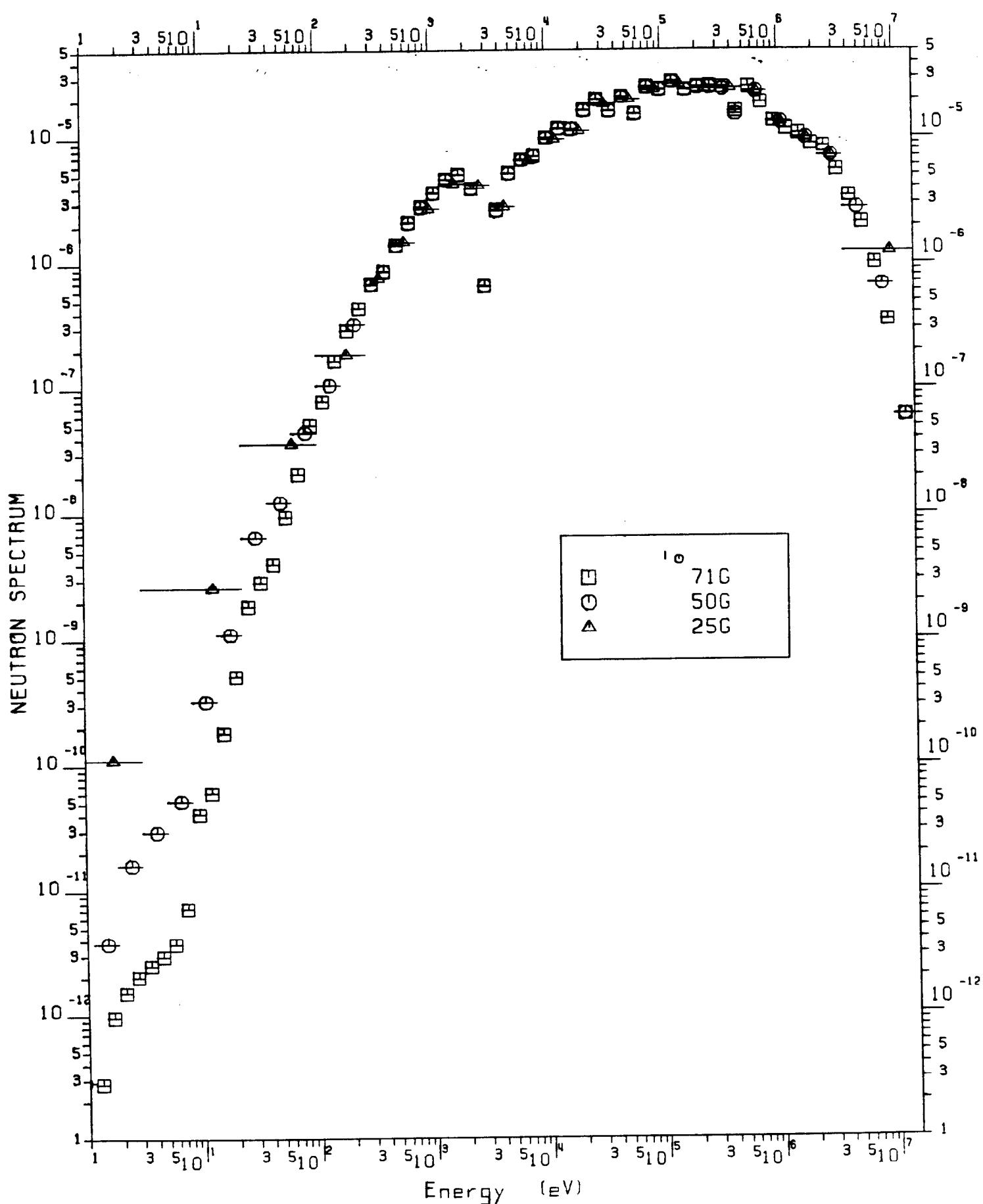


Fig. 4.33 Comparison of neutron spectrum for 25, 50 and 71 groups at the core center of ZPR-6-7

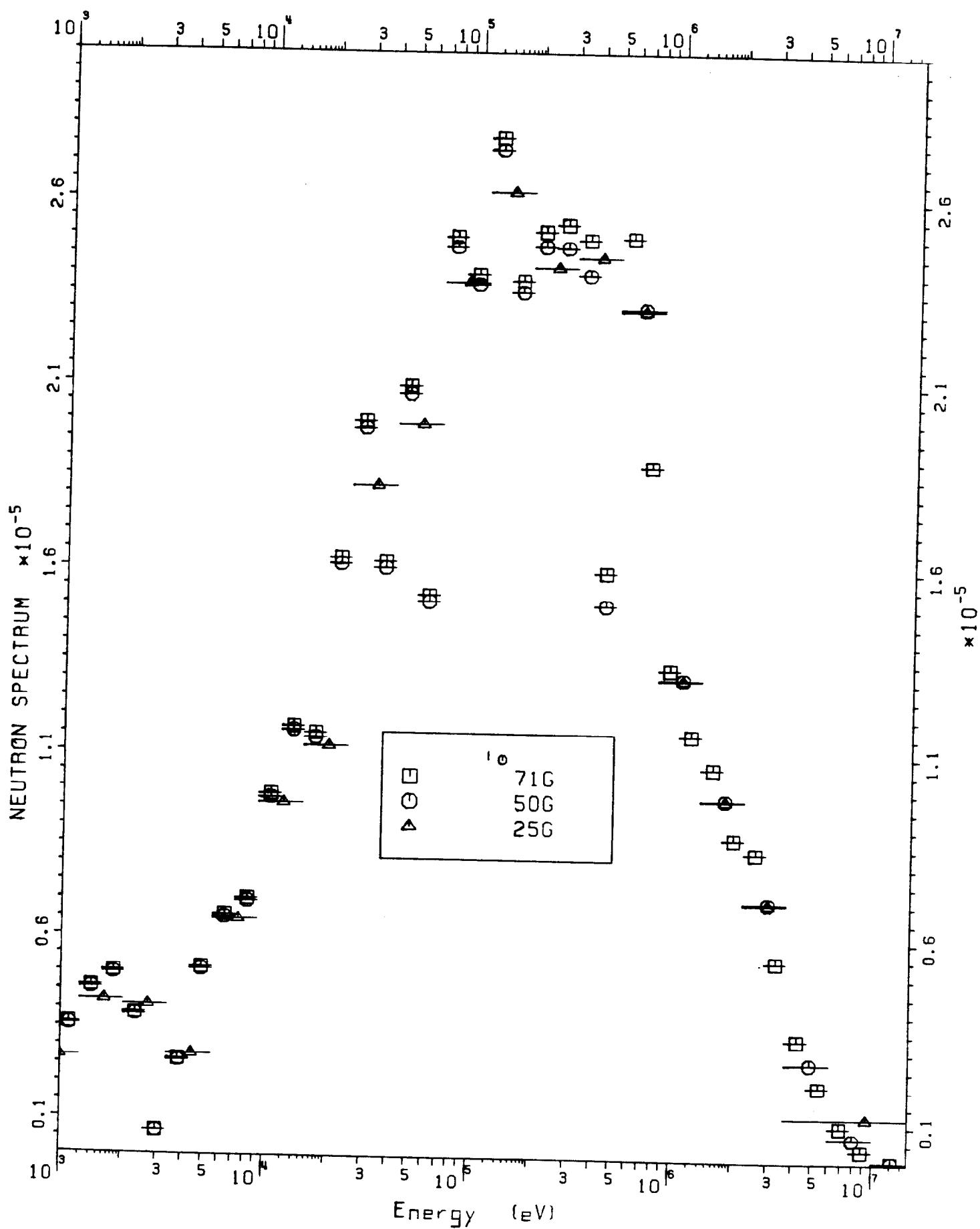
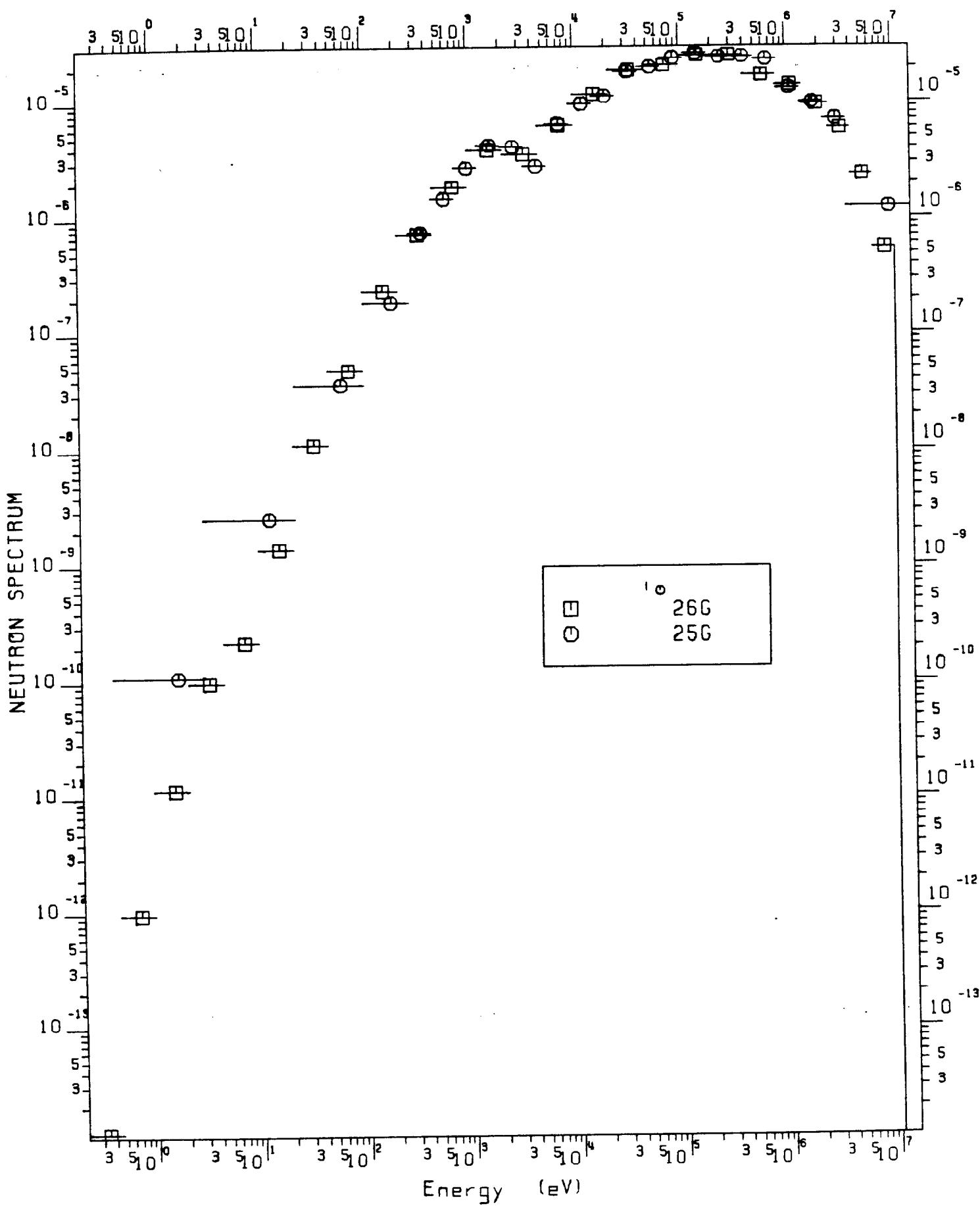


Fig. 4.34 Comparison of neutron spectrum for 25 and 26 groups at the core center of ZPR-6-7



5. CONCLUDING REMARKS

JEF-1 predicts satisfactorily several primary nuclear characteristics of fast reactors, and on the whole the results are comparable with the ones of JENDL-2 and ENDF/B-V. However, several problems which were observed for JENDL-2 and ENDF/B-V exist also for JEF-1:

- 1) The effective multiplication factors calculated by using JEF-1 underpredict the experimental values for both the Pu- and U-fuel cores.
- 2) The central reaction rate ratios of U-238(n,f) to U-235(n,f) and Pu-240(n,f) to U-235(n,f) are overpredicted.
- 3) The reaction rate ratios of U-238(n,c) to U-235(n,f) or Pu-239(n,f) are overestimated for the Pu fuel cores and underestimated for the U fuel cores.

The results for the effective multiplication factors are rather sensitive to the choice of the group structure. For data structures with a small number of energy groups it is doubtful whether the choice of the smooth component of the weighting function used here is adequate. A more realistic energy weighting of cross sections in these cases would most probably diminish the significantly large discrepancies. The treatment for elastic removal cross section is considered as a primary reason for the discrepancies. The removal cross section could be improved by using, for example, the "REMO-correction" method (Refs. 9 and 26).

The discrepancy observed between K_{eff} calculated in the UK and at the Data Bank is not clear. The different methods used for the resonance region, such as the interpolation of self-shielding factors and SIGMA-0 background potential cross section, may be a cause for it.

The cross section libraries JEF1-71F, JEF1-50F, JEF1-25F, JEF1-26, JFS3J2R and ENDFB4 described in this report are available upon request to users from the NEA Data Bank member countries.

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- 33) R.E. MacFarlane: "TRANSX-CTR: A Code for Interfacing MATXS Cross Section Libraries to Nuclear Transport Codes for Fusion System Analysis", LA-9863-MS, (1984).
- 34) D.E. Cullen: "Program EVAPLOT (Version 79-1): Plot Data in the Evaluated Nuclear Data File/Version B (ENDF/B) Format", UCRL-50400, Vol. 17, Part E, 1979.
- 35) D.E. Cullen: Summary of ENDF/B Pre-Processing Codes. IAEA-NDS-39, Rev. 1 (6/83), 1983.

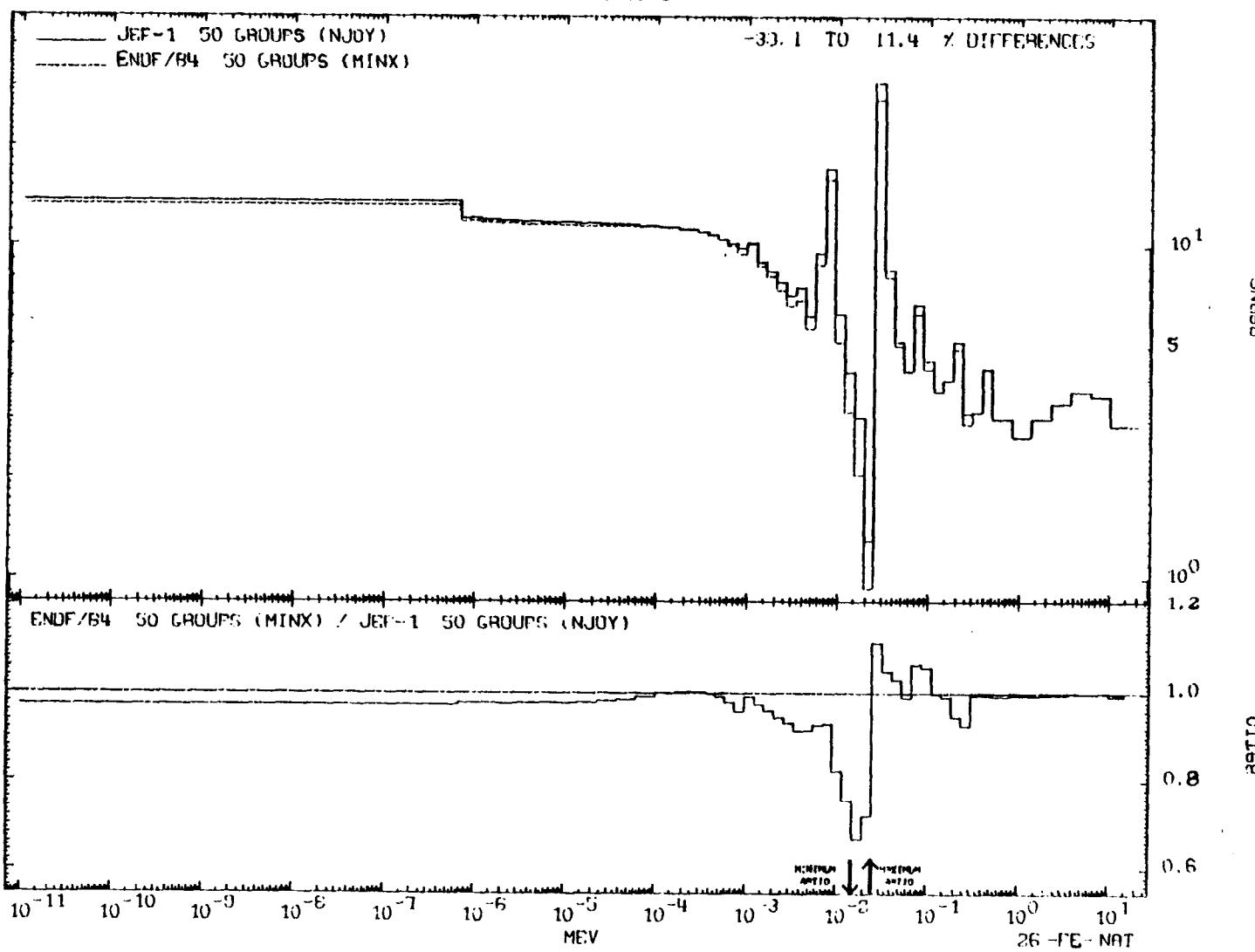
Appendix A

Comparison of Group Cross Sections for JEF1-50F and ENDFB4

MAT 4260

TOTAL
CROSS SECTIONS

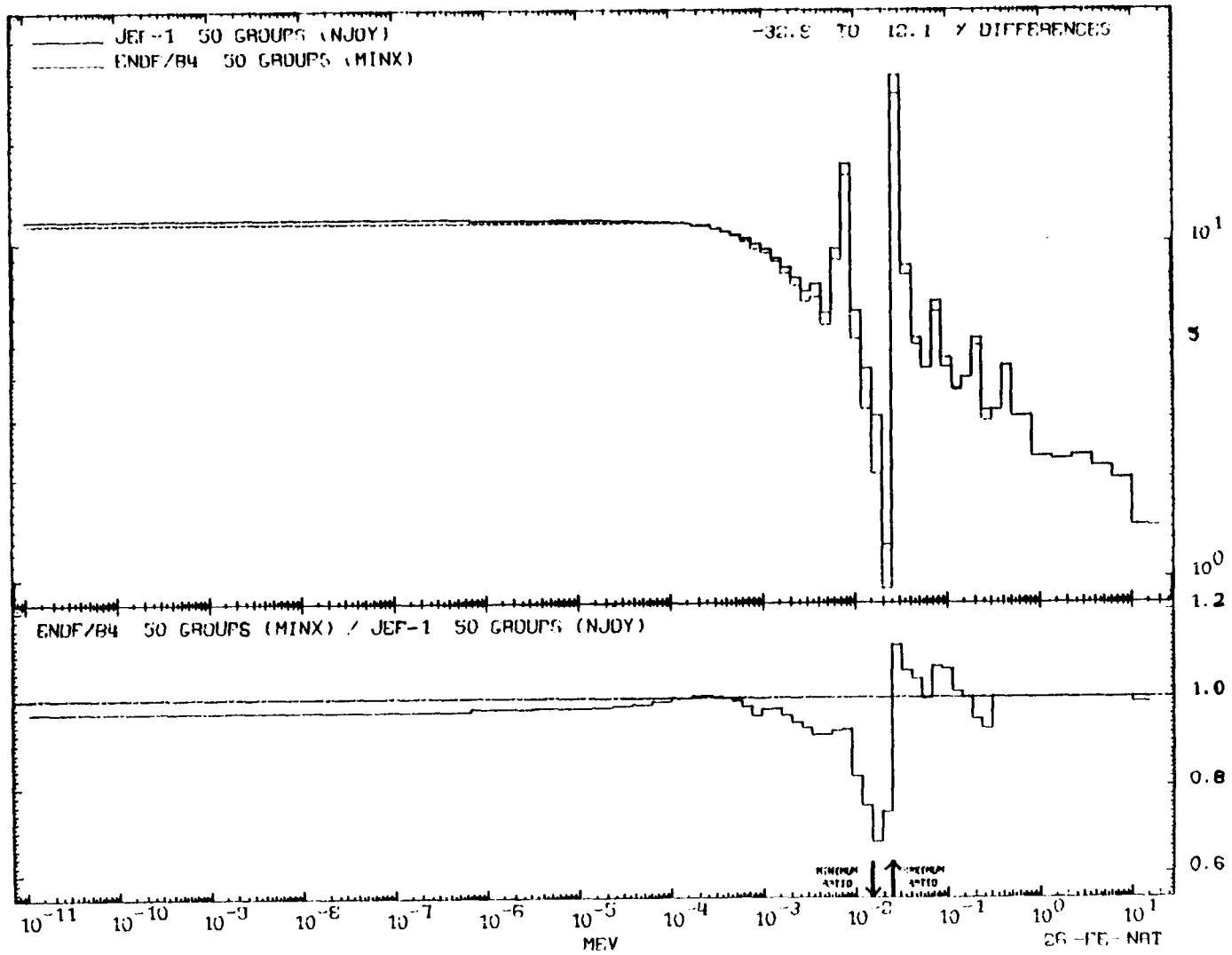
26 -Fe -NAT



MAT 4260

ELASTIC
CROSS SECTIONS

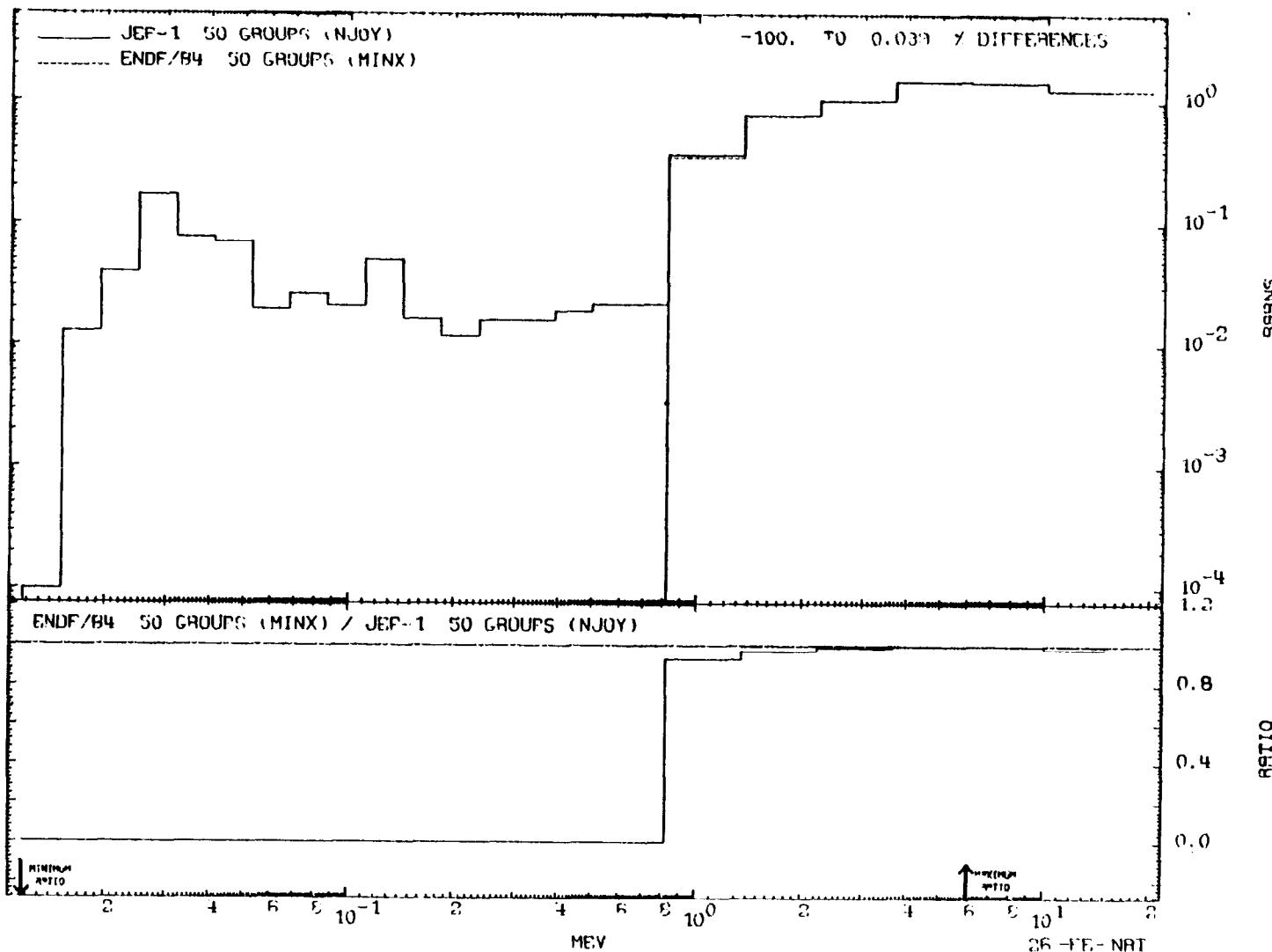
26 -FE - NAT



MAT 4260

INELASTIC
CROSS SECTIONS

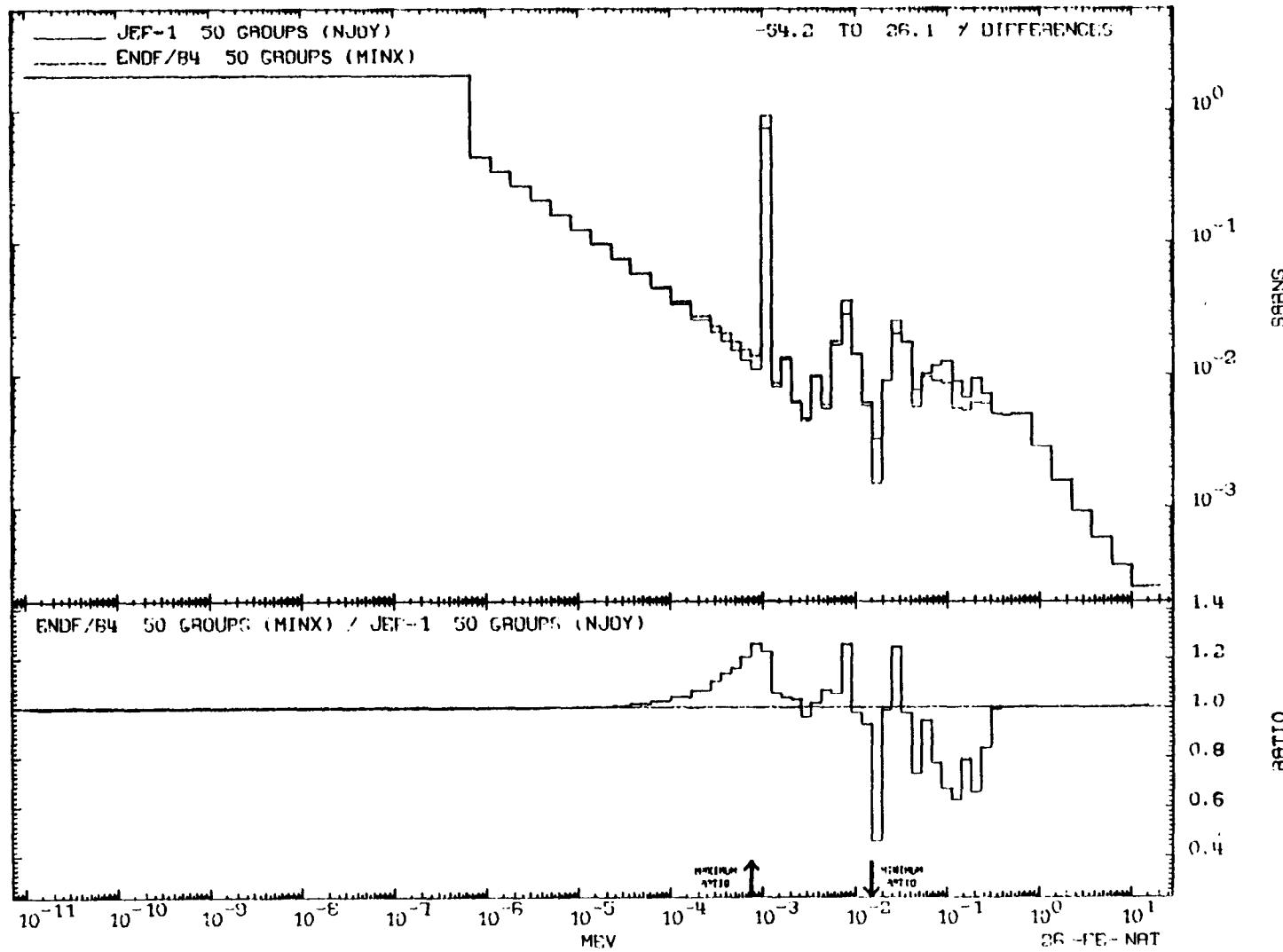
26 -FE- NAT



MAT 4260

(N,GAMMA)
CROSS SECTIONS

26 -FE- NAT



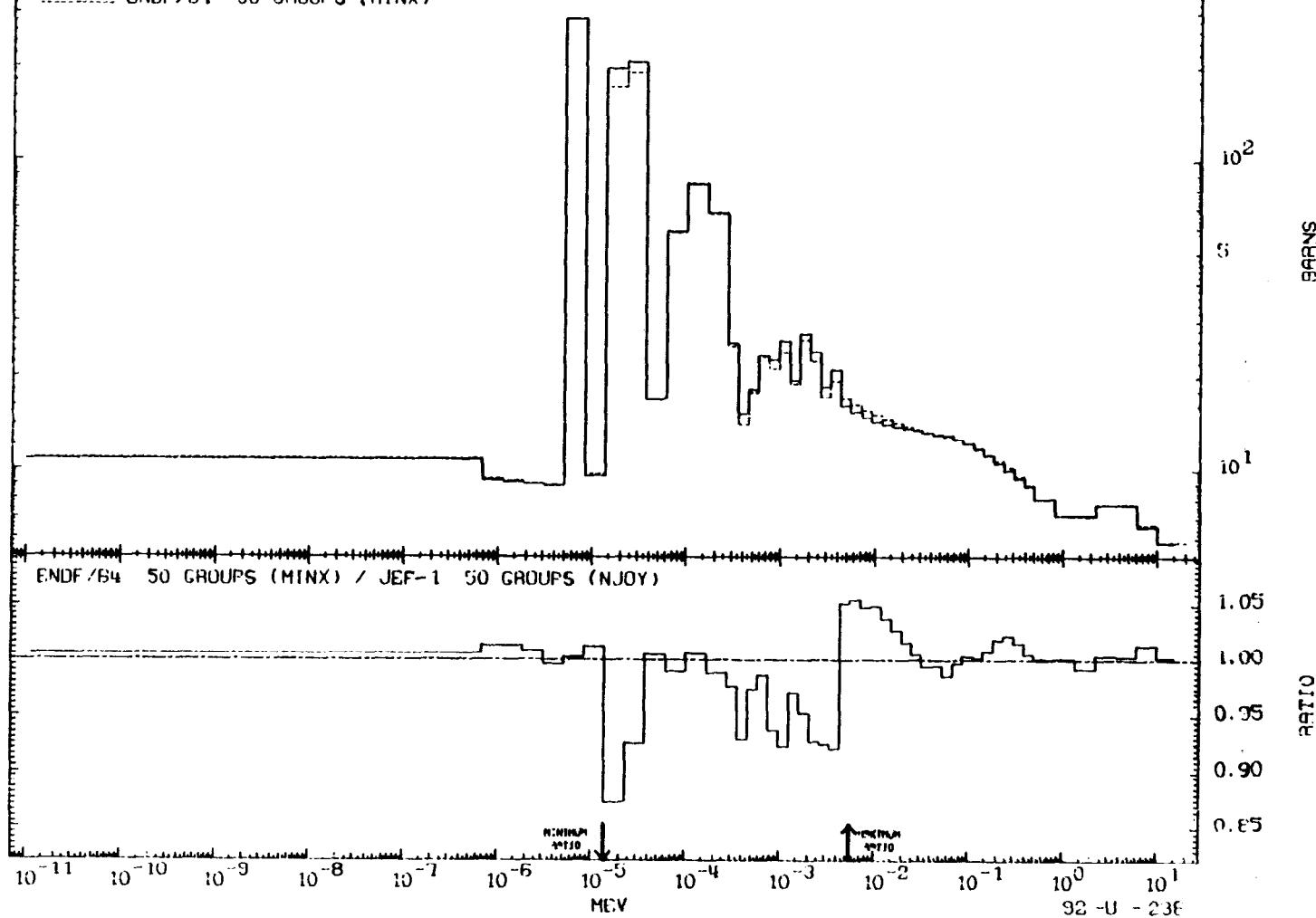
MAT 4929

TOTAL
CROSS SECTIONS

92-U-238

— JEF-1 50 GROUPS (NJOY)
---- ENDF/B4 50 GROUPS (MINX)

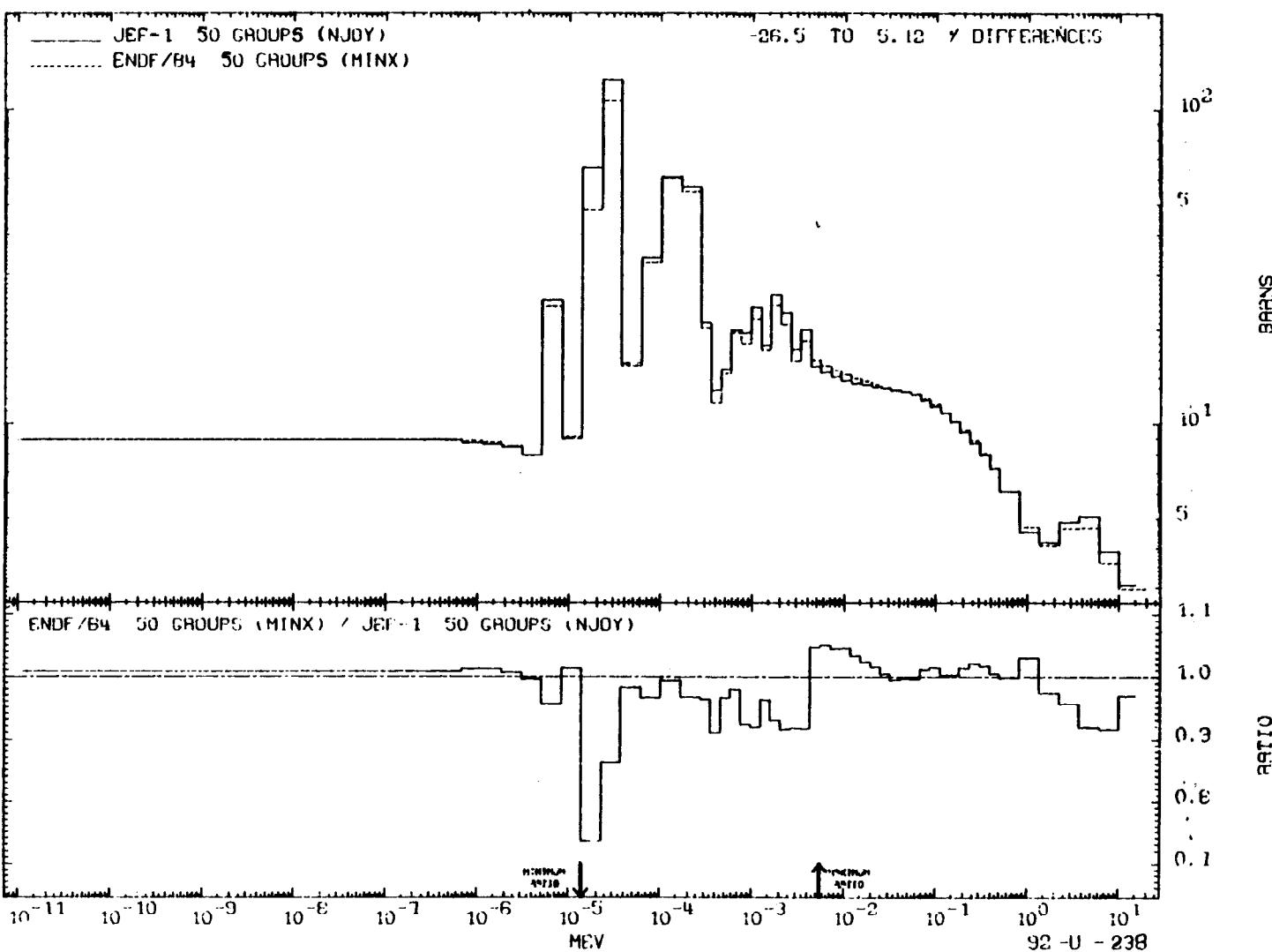
-12.7 TO 5.42 MEV DIFFERENCES



MAT 4928

ELASTIC
CROSS SECTIONS

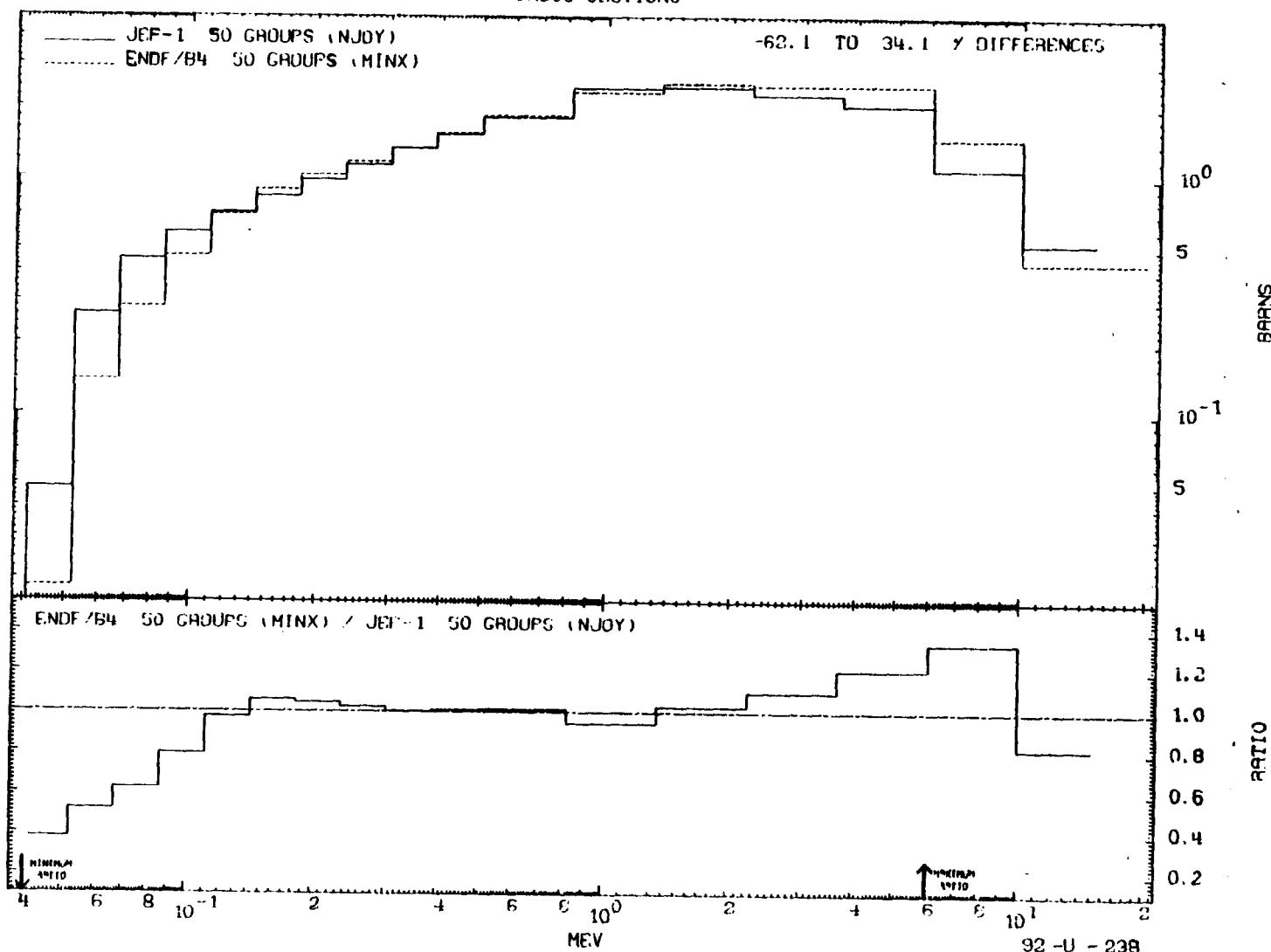
92-U-238



MAT 4928

INELASTIC CROSS SECTIONS

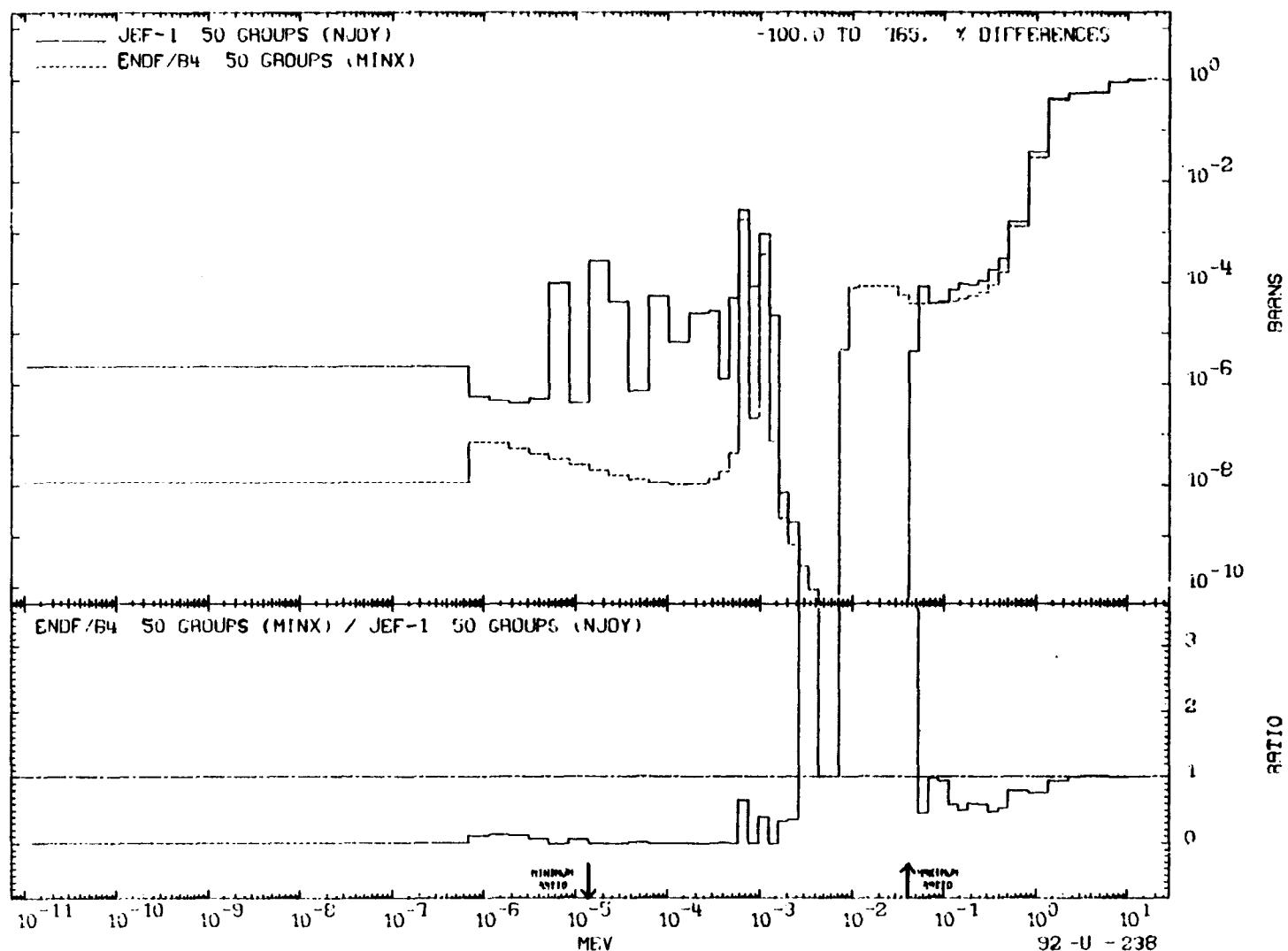
92 -U - 238



MAT 4929

Fission
Cross Sections

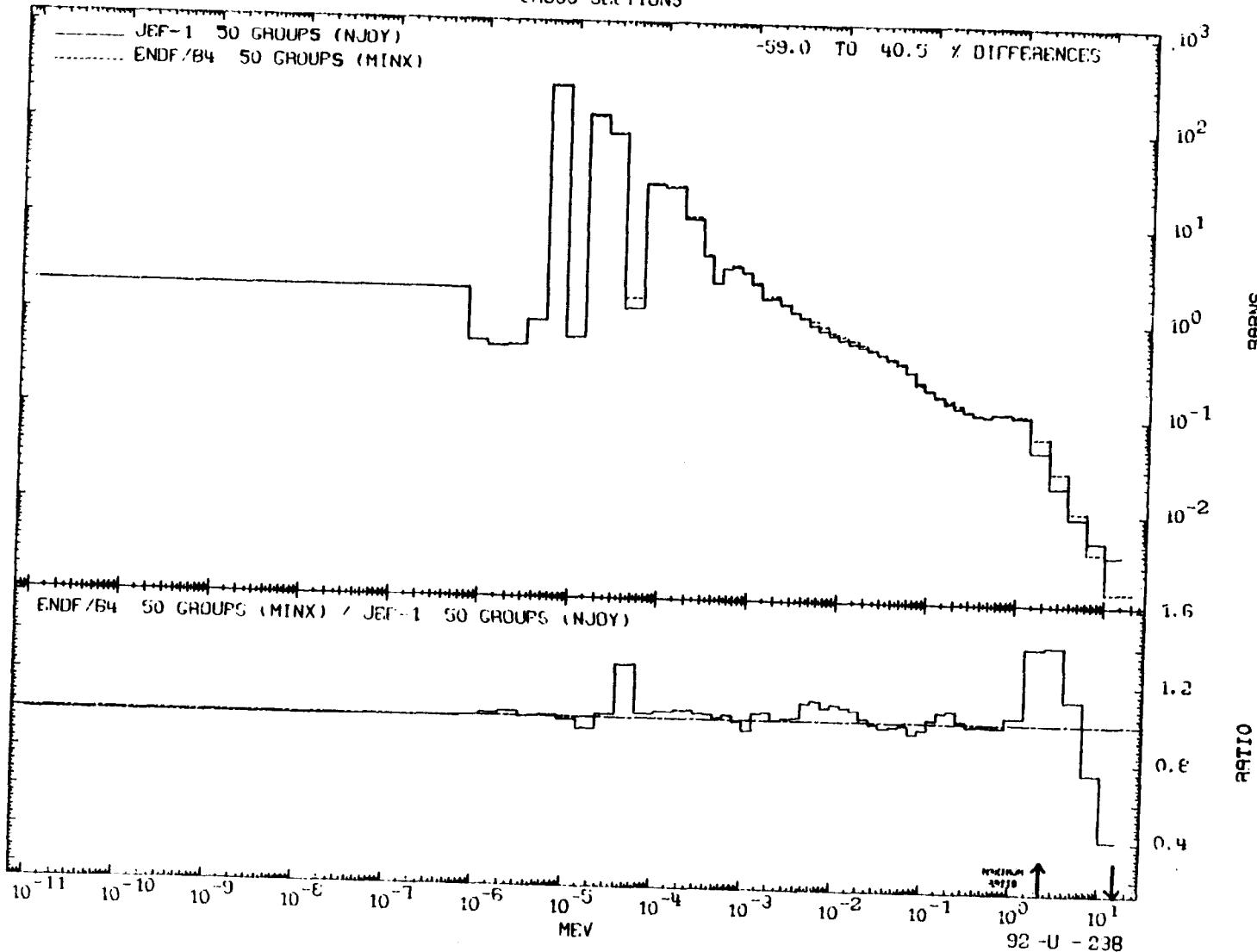
92-U-238



MAT 4929

(N,GAMMA)
CROSS SECTIONS

92-U-238

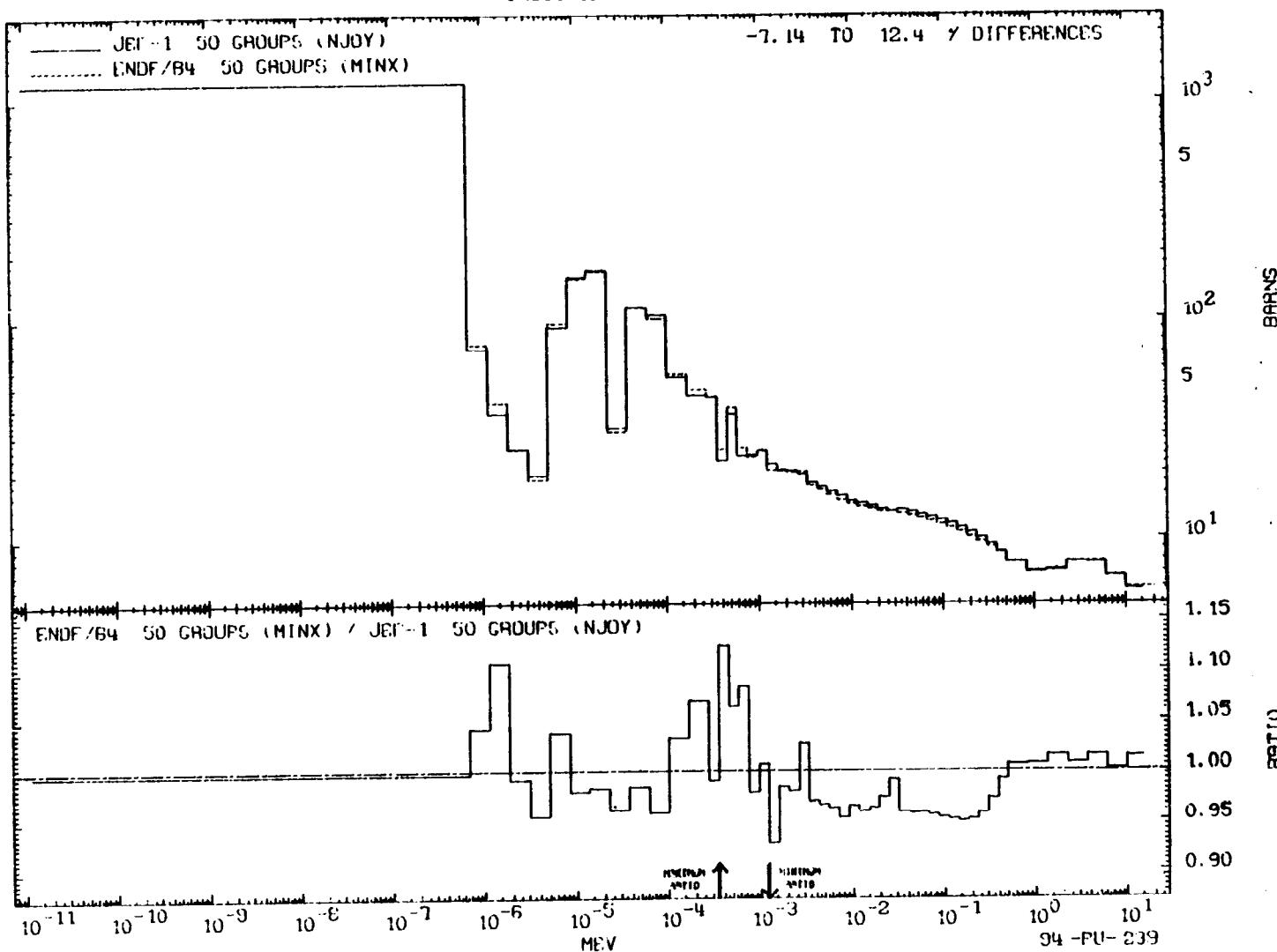


106

MAT 4949

TOTAL
CROSS SECTIONS

94 -PU- 239

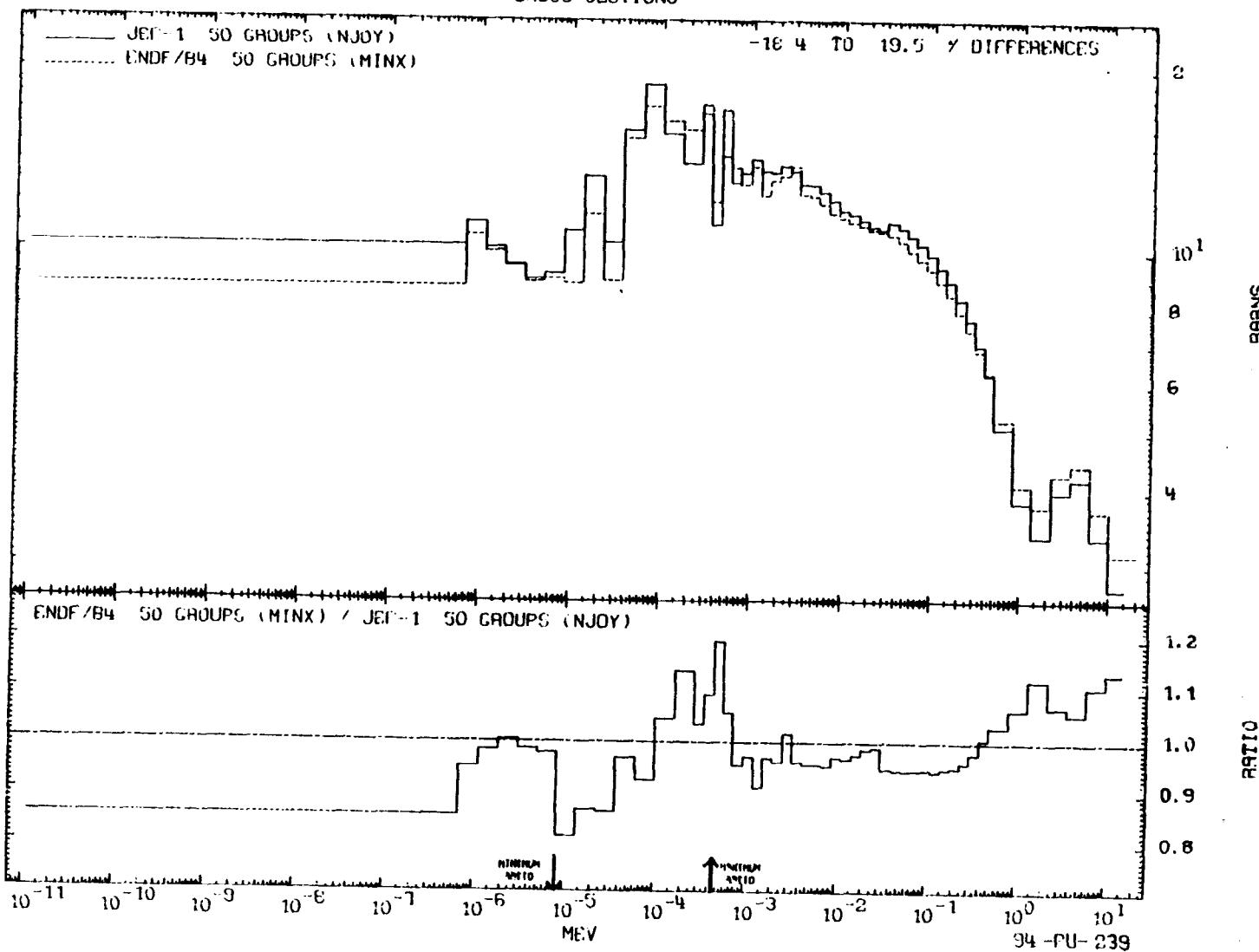


107

MAT 4949

ELASTIC
CROSS SECTIONS

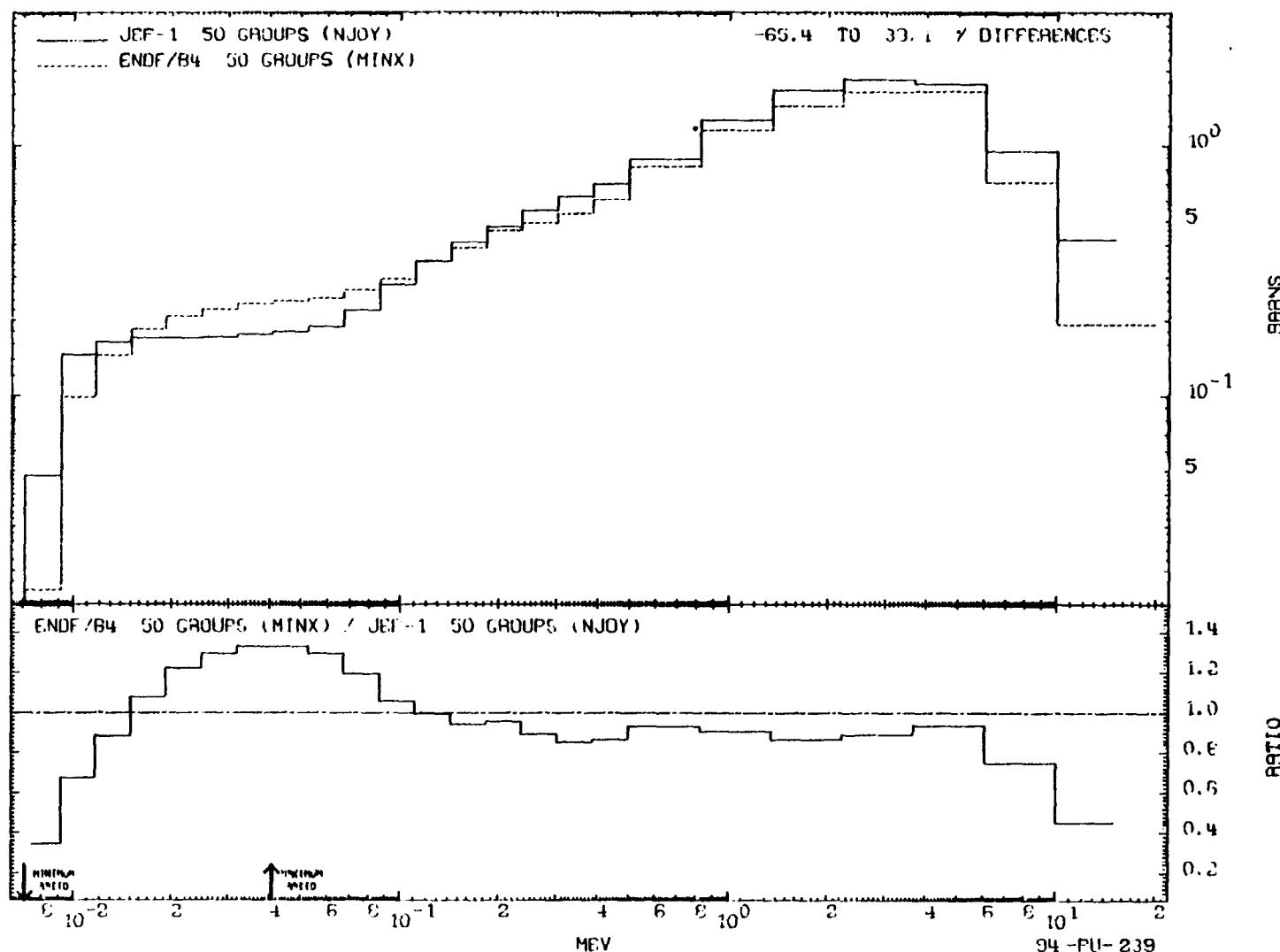
94 -PU- 239



MAT 4949

INELASTIC
CROSS SECTIONS

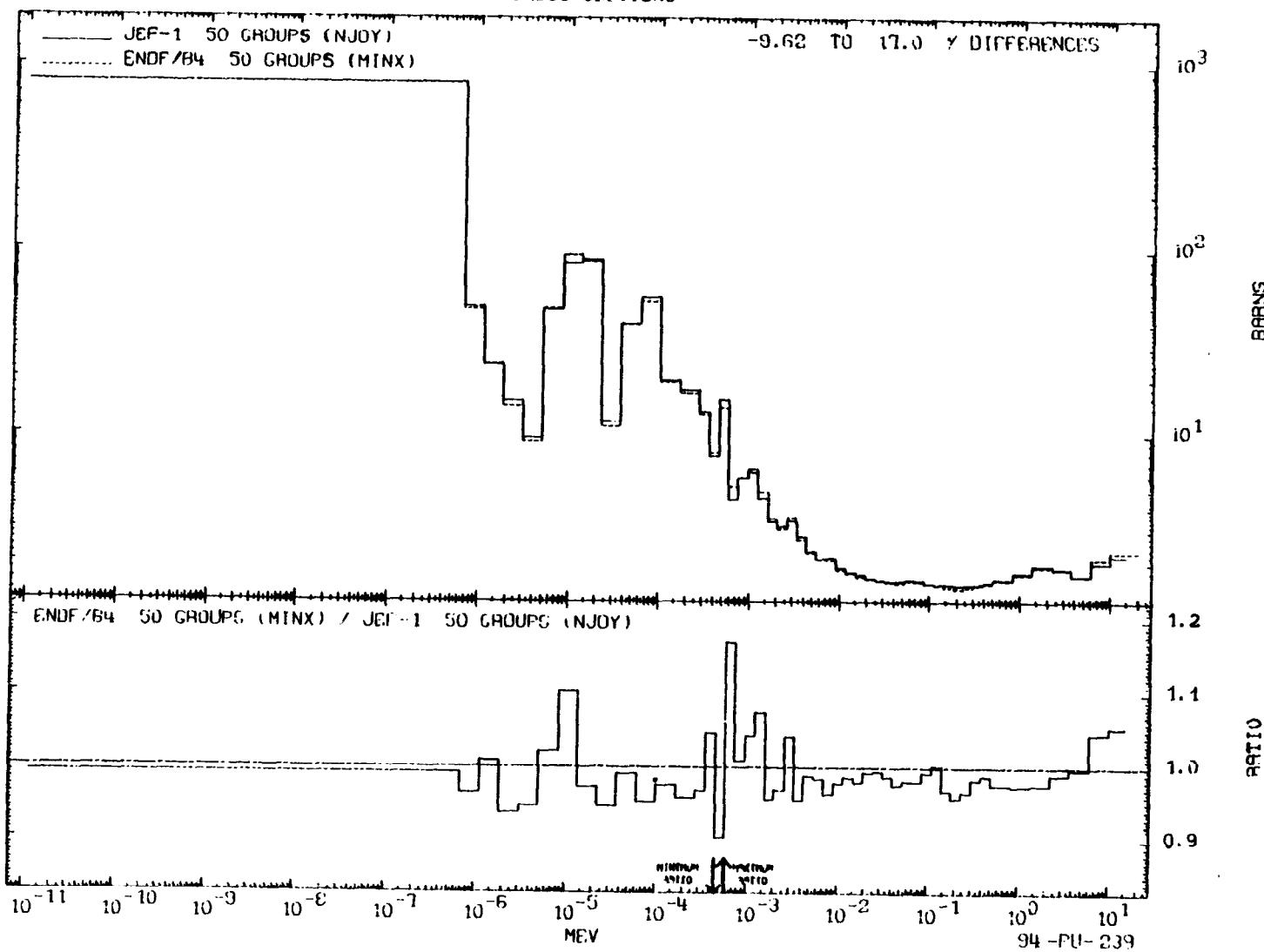
94 -PU- 239



MAT 4949

MISSION
CROSS SECTIONS

94 -PLU- 239

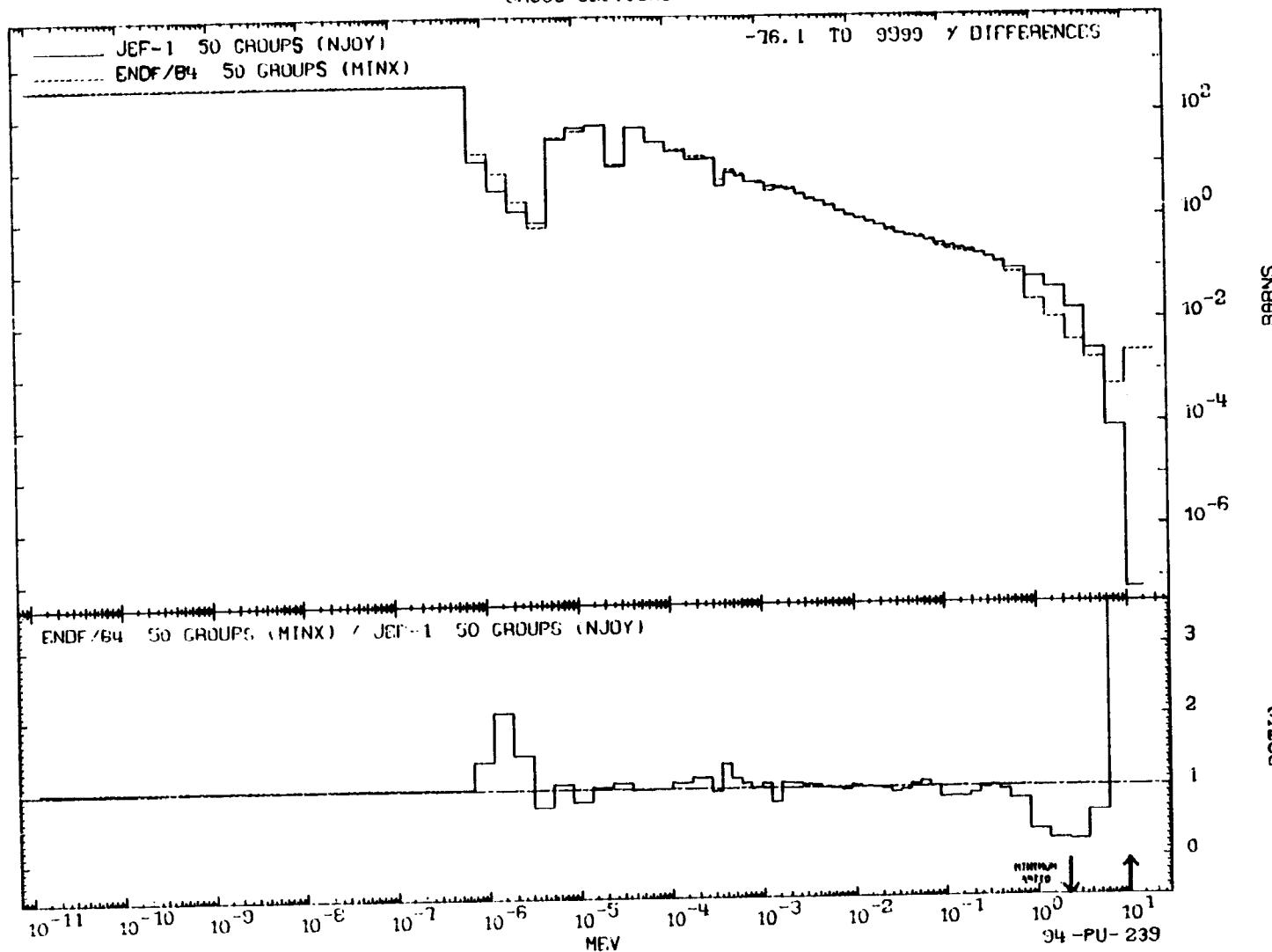


OTT

MAT 4949

(N,GAMMA)
CROSS SECTIONS

94 -PU- 239



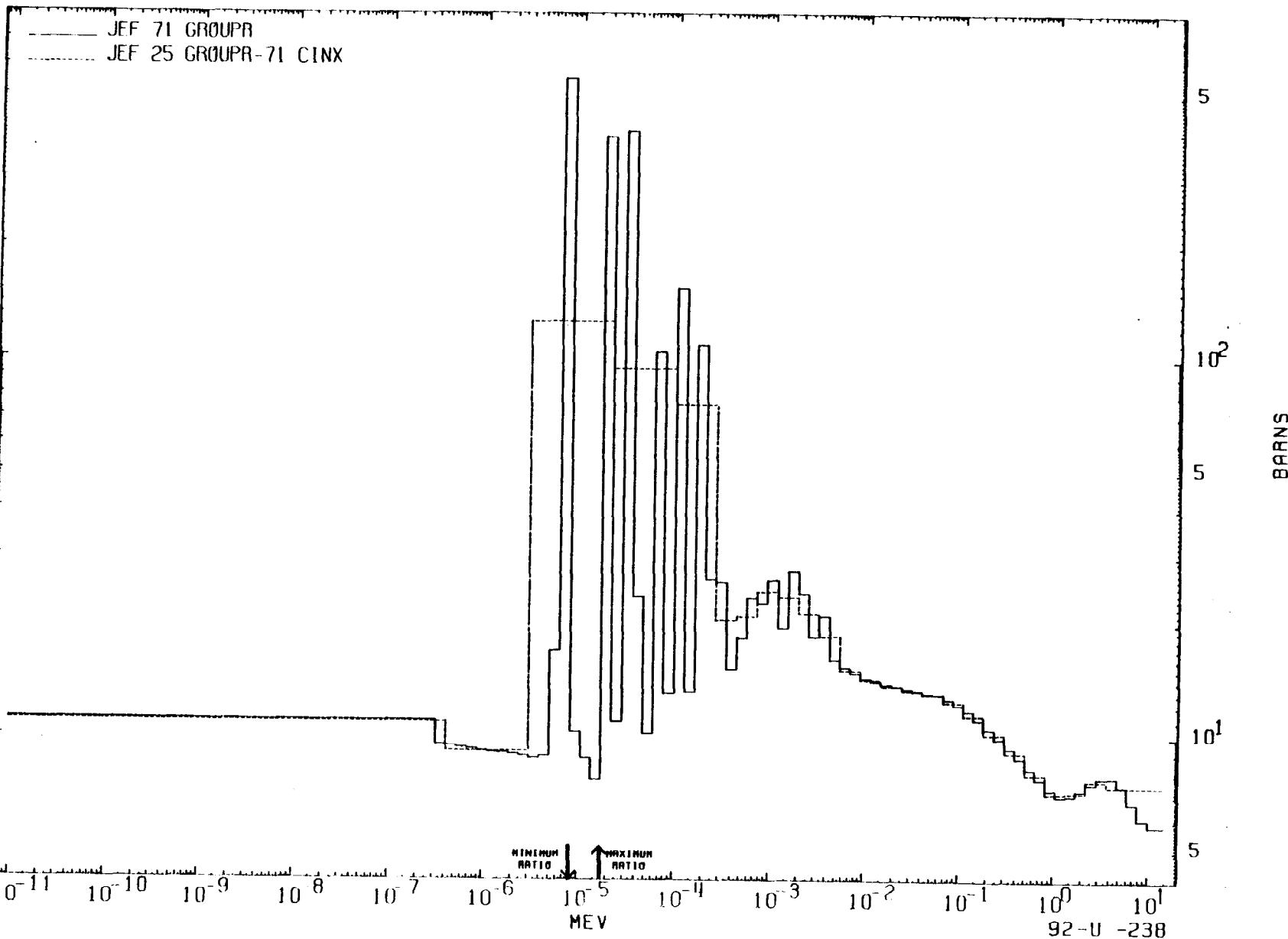
Appendix B

Comparison of Group Constants of U-238
for JEF-71F, JEF-25F and JEF1-26

MAT 4928

TOTAL
CROSS SECTIONS

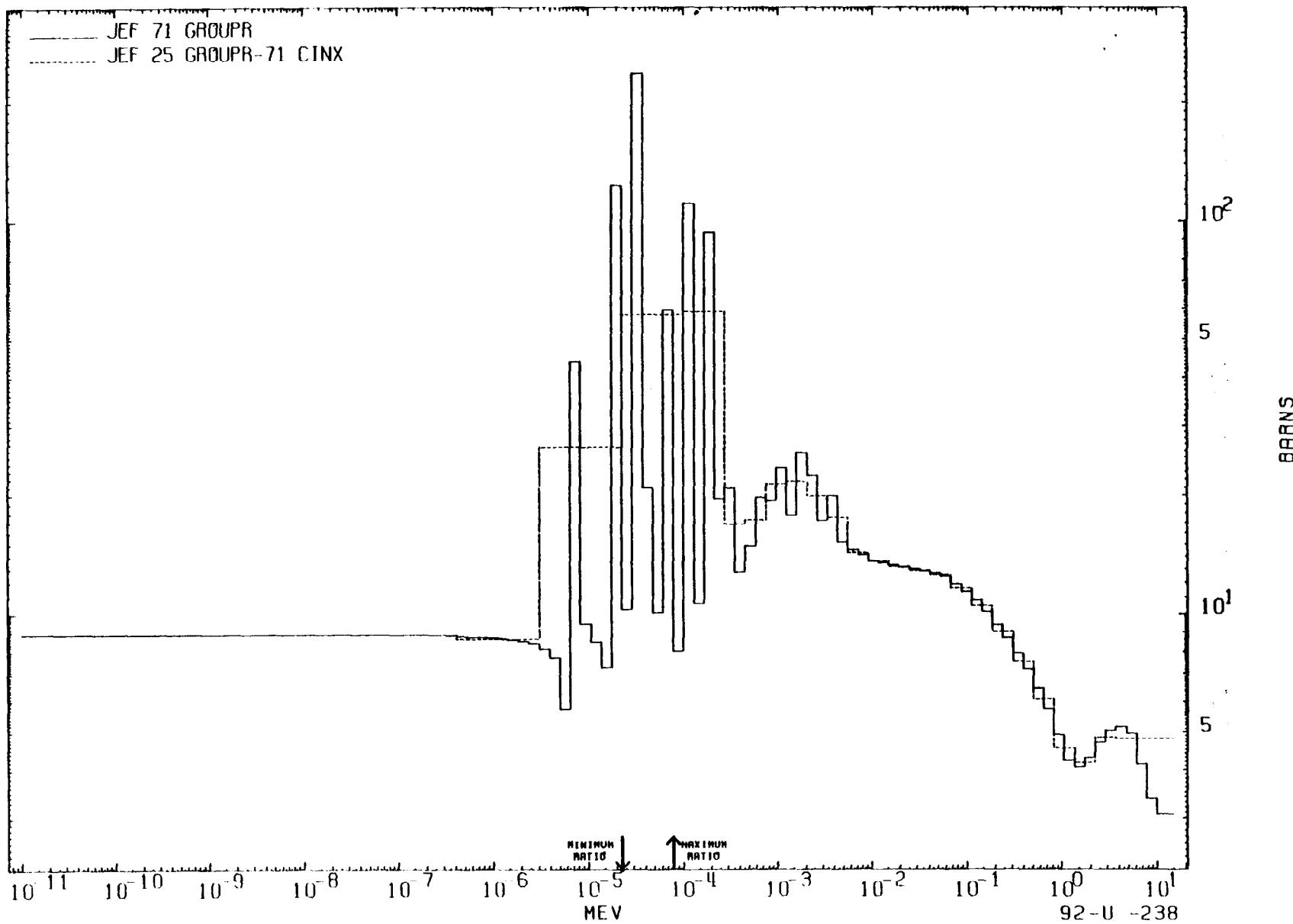
92-U -238



MAT 4928

ELASTIC
CROSS SECTIONS

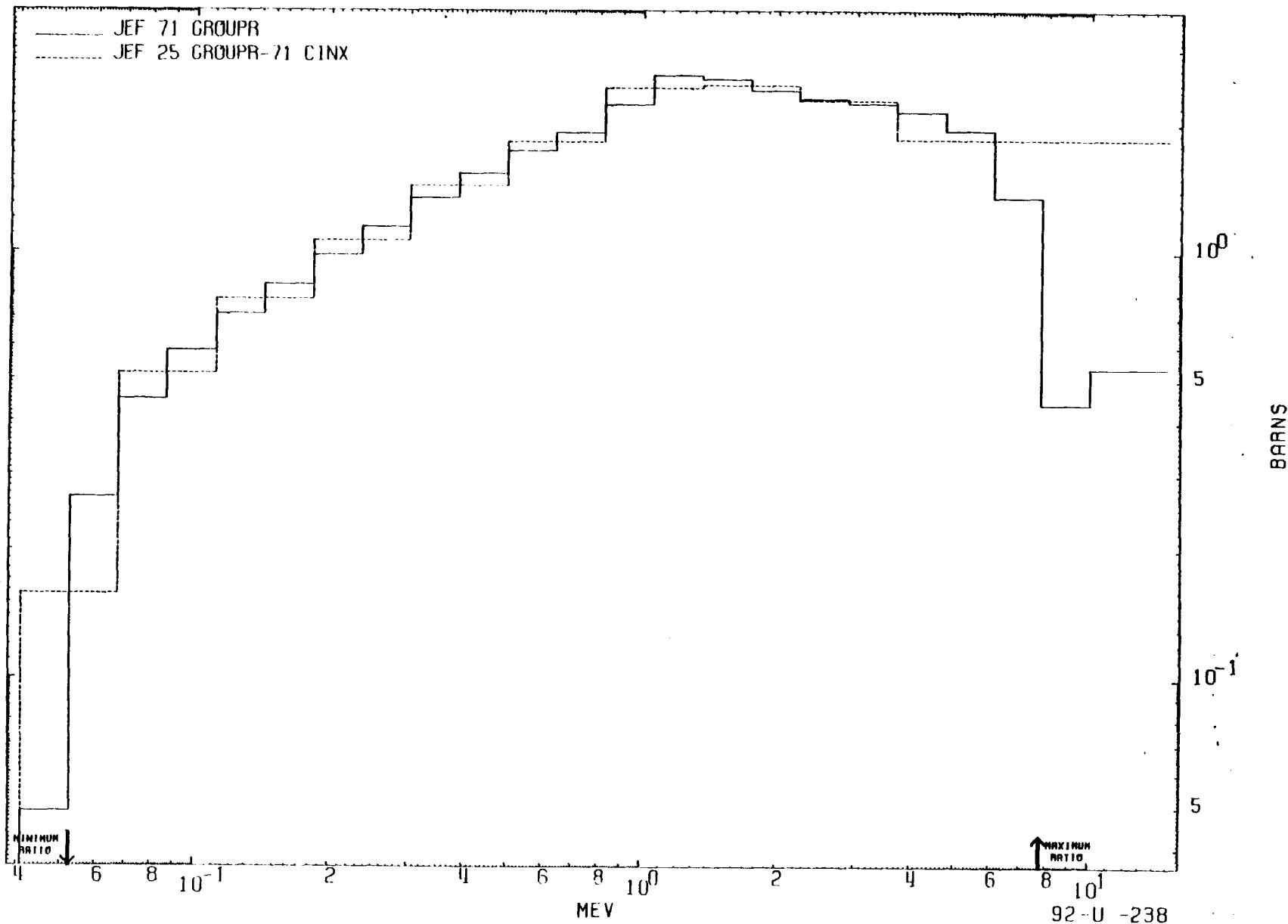
92-U -238



MAT 4928

INELASTIC
CROSS SECTIONS

92-U -238

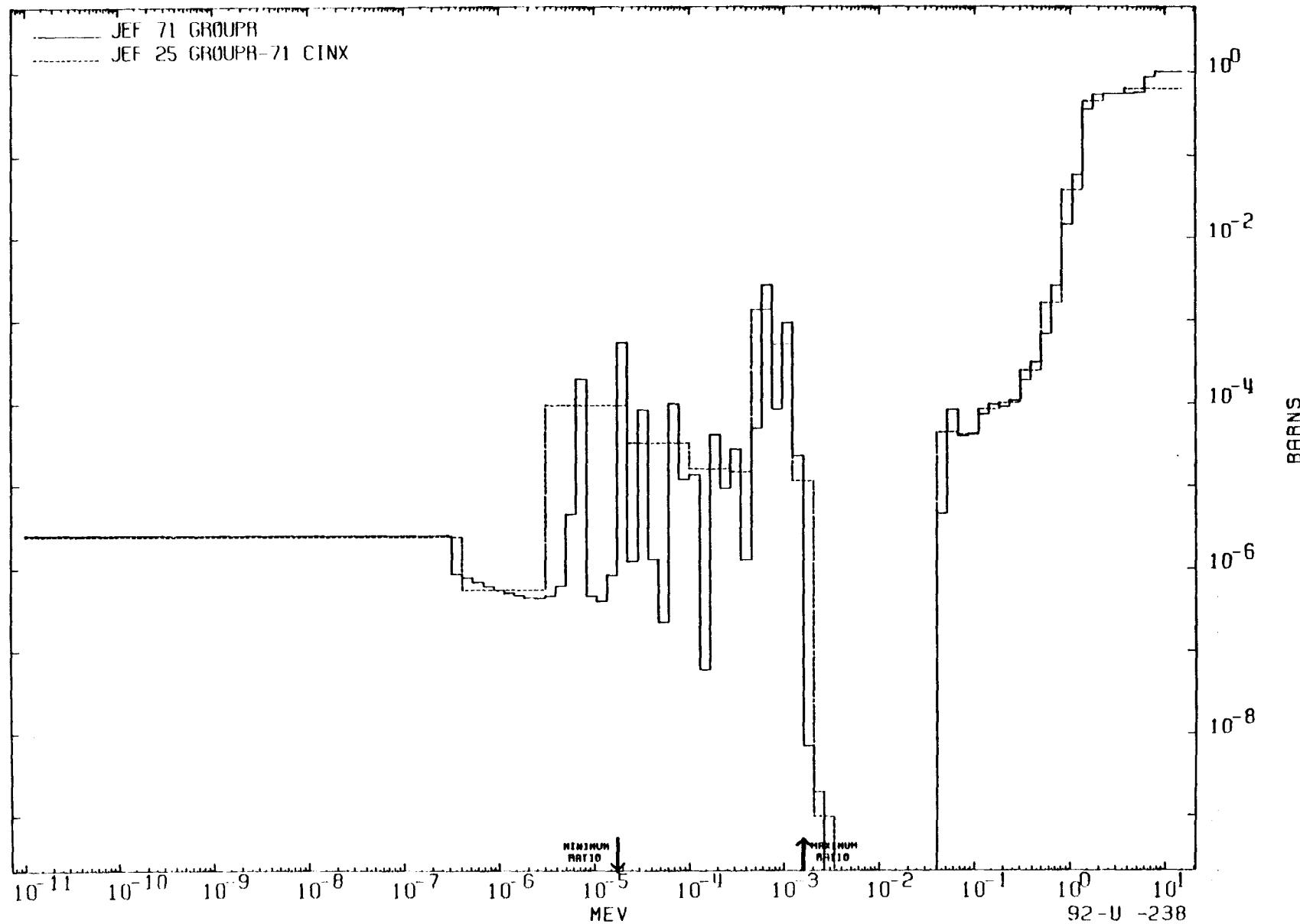


MAT 4928

FISSION
CROSS SECTIONS

92-U -238

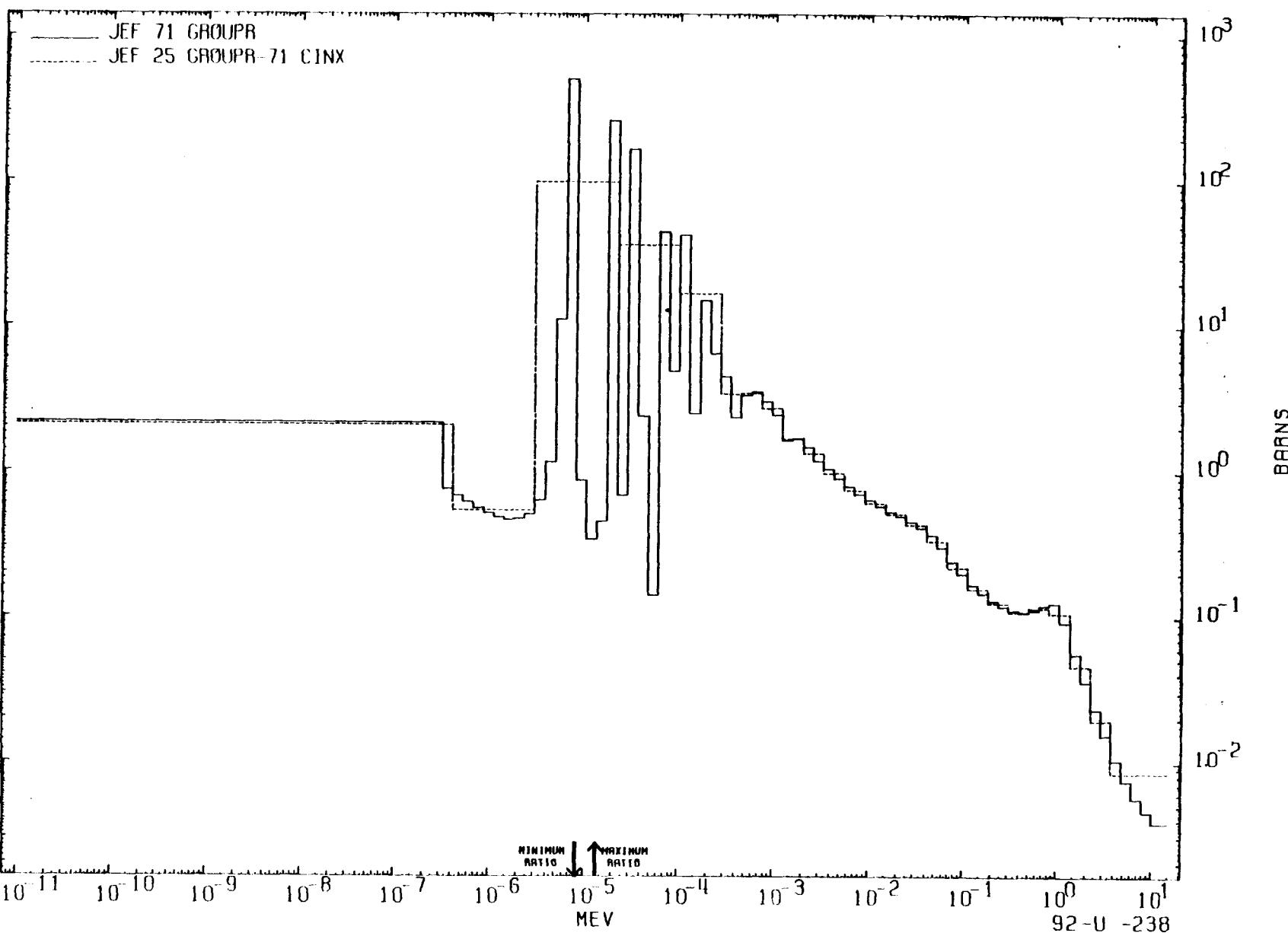
116



MAT 4928

(N, GAMMA)
CROSS SECTIONS

92-U -238

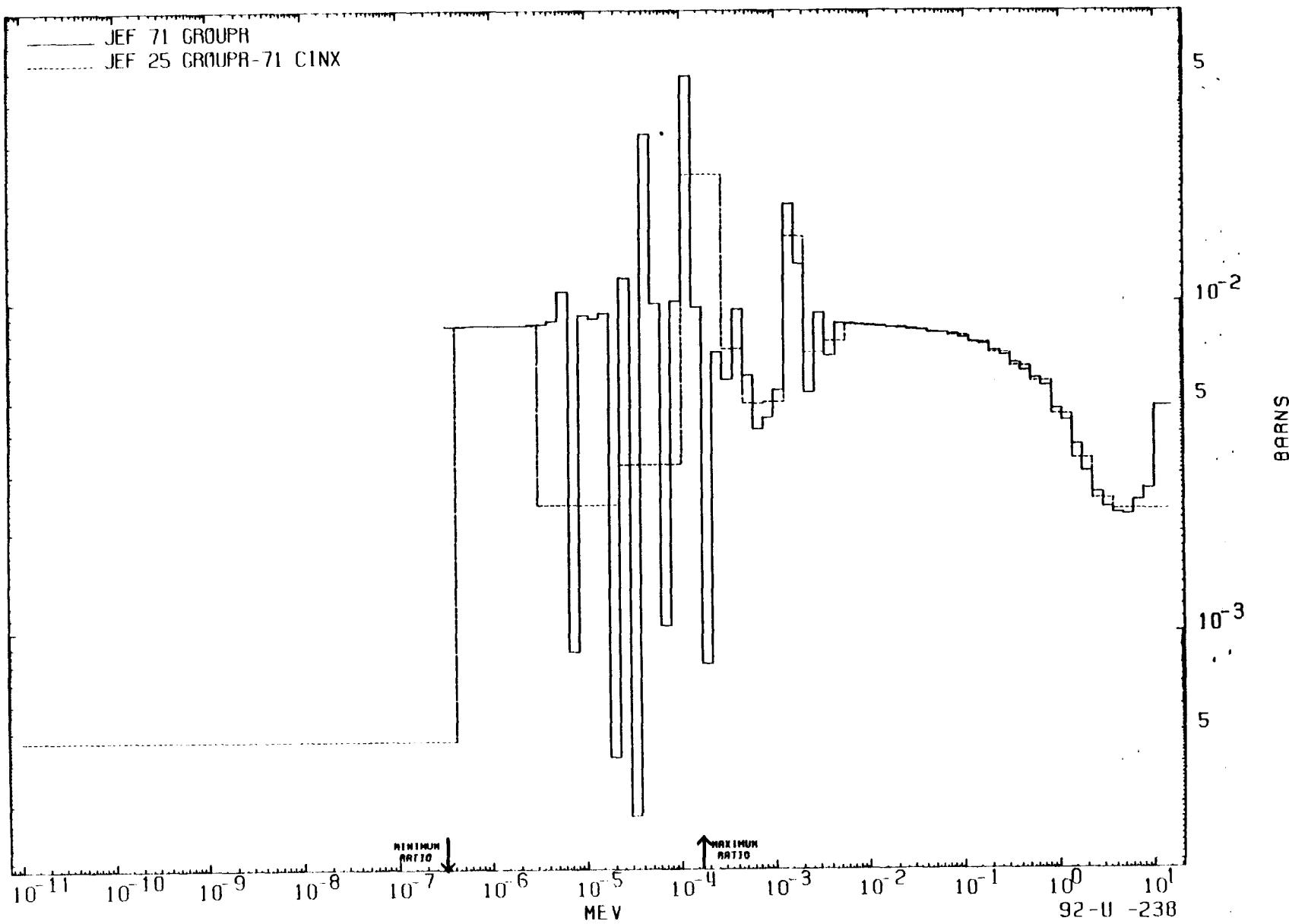


MAT 4928

XI

92-U -238

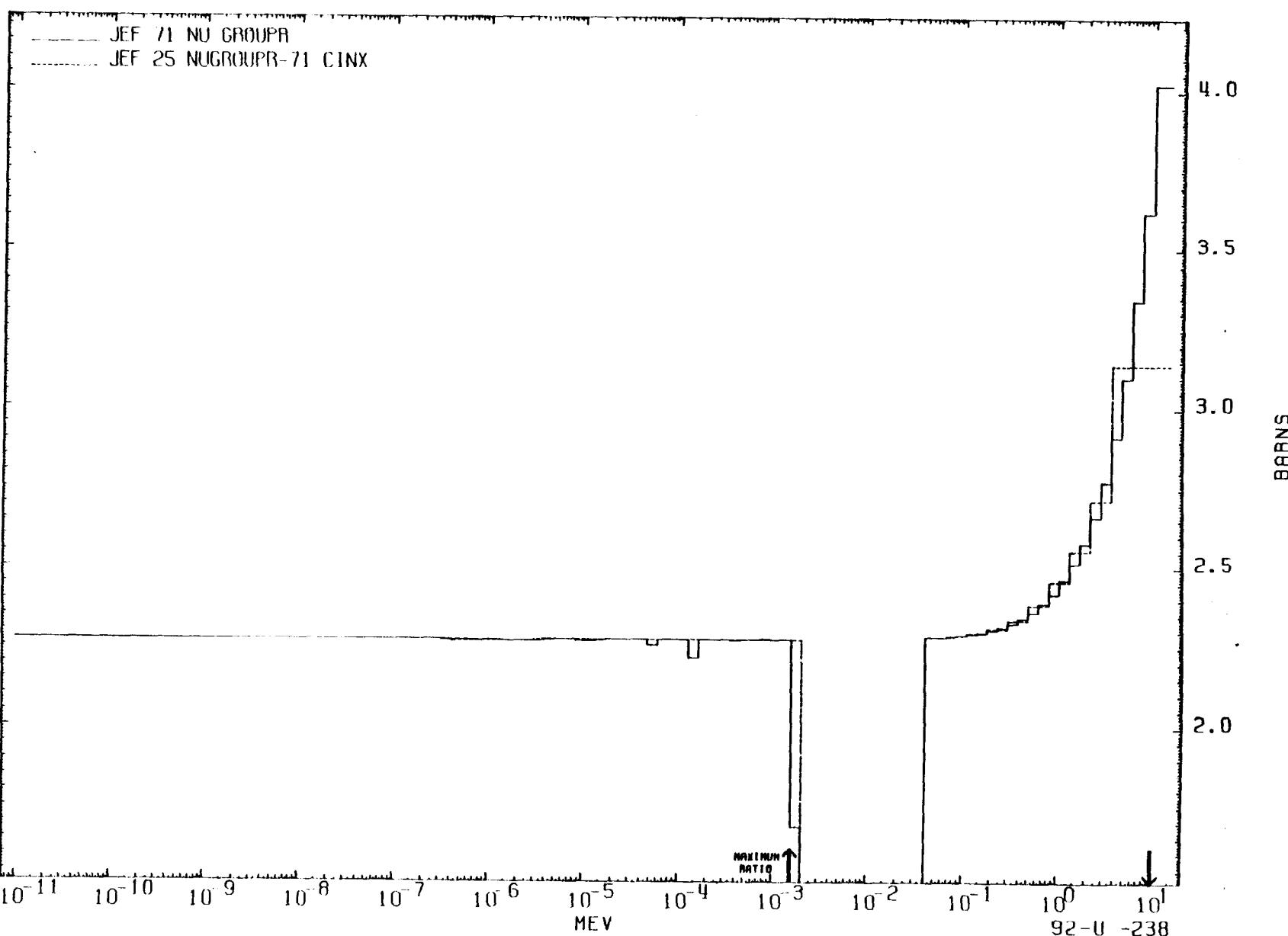
118



MAT 4928

NU

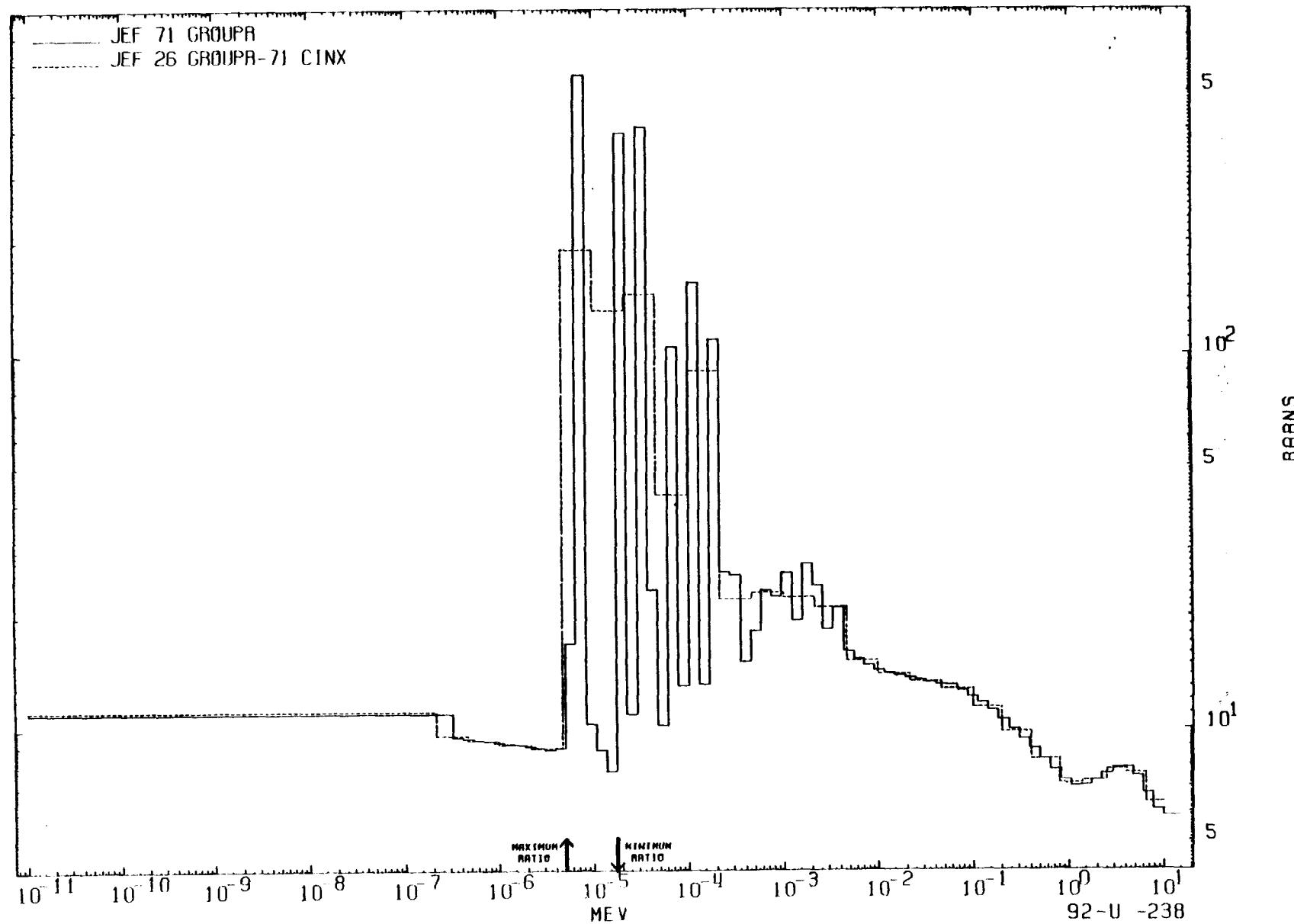
92-U -238



MAT 4928

TOTAL
CROSS SECTIONS

92-U -238

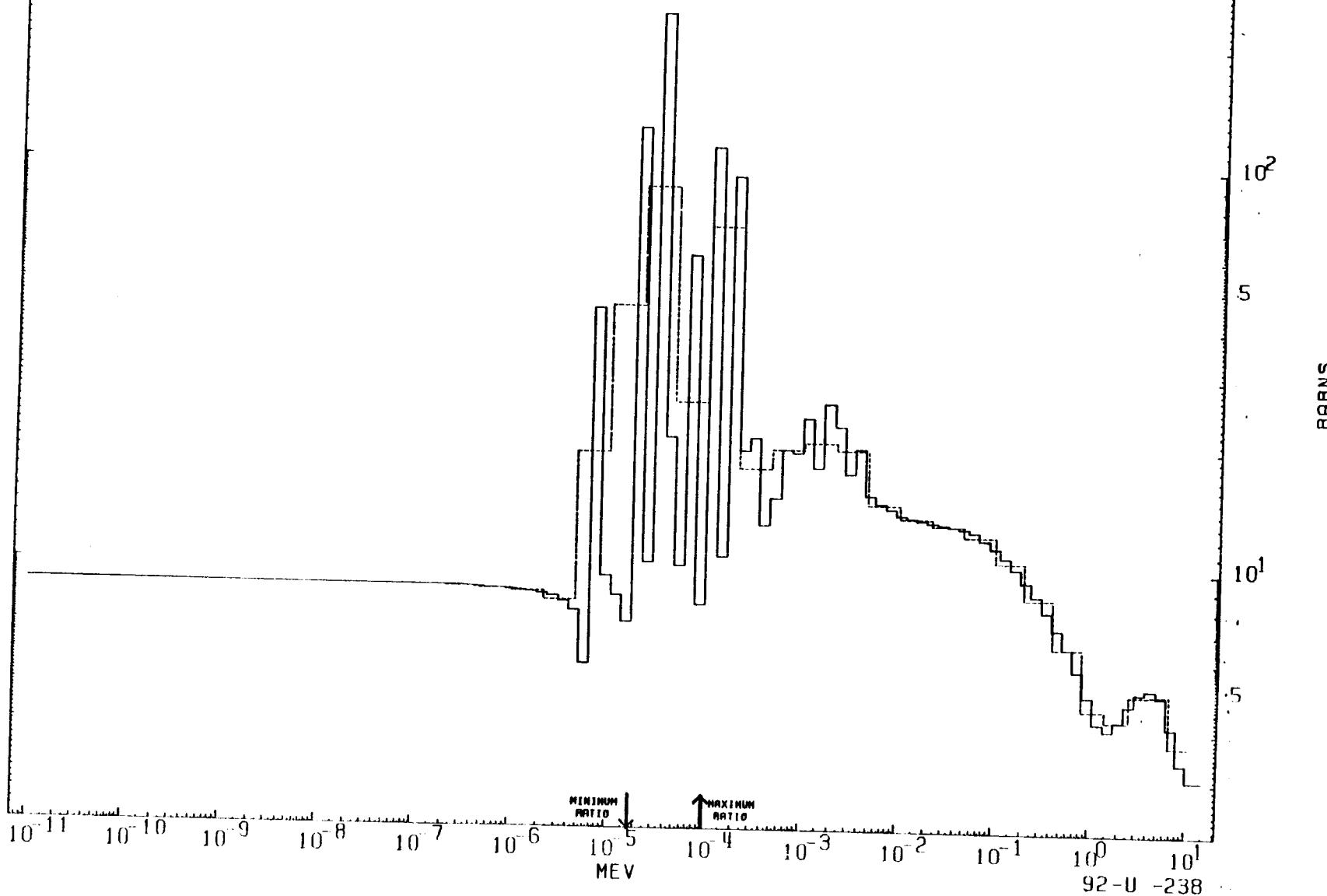


MAT 4928

ELASTIC
CROSS SECTIONS

92-U -238

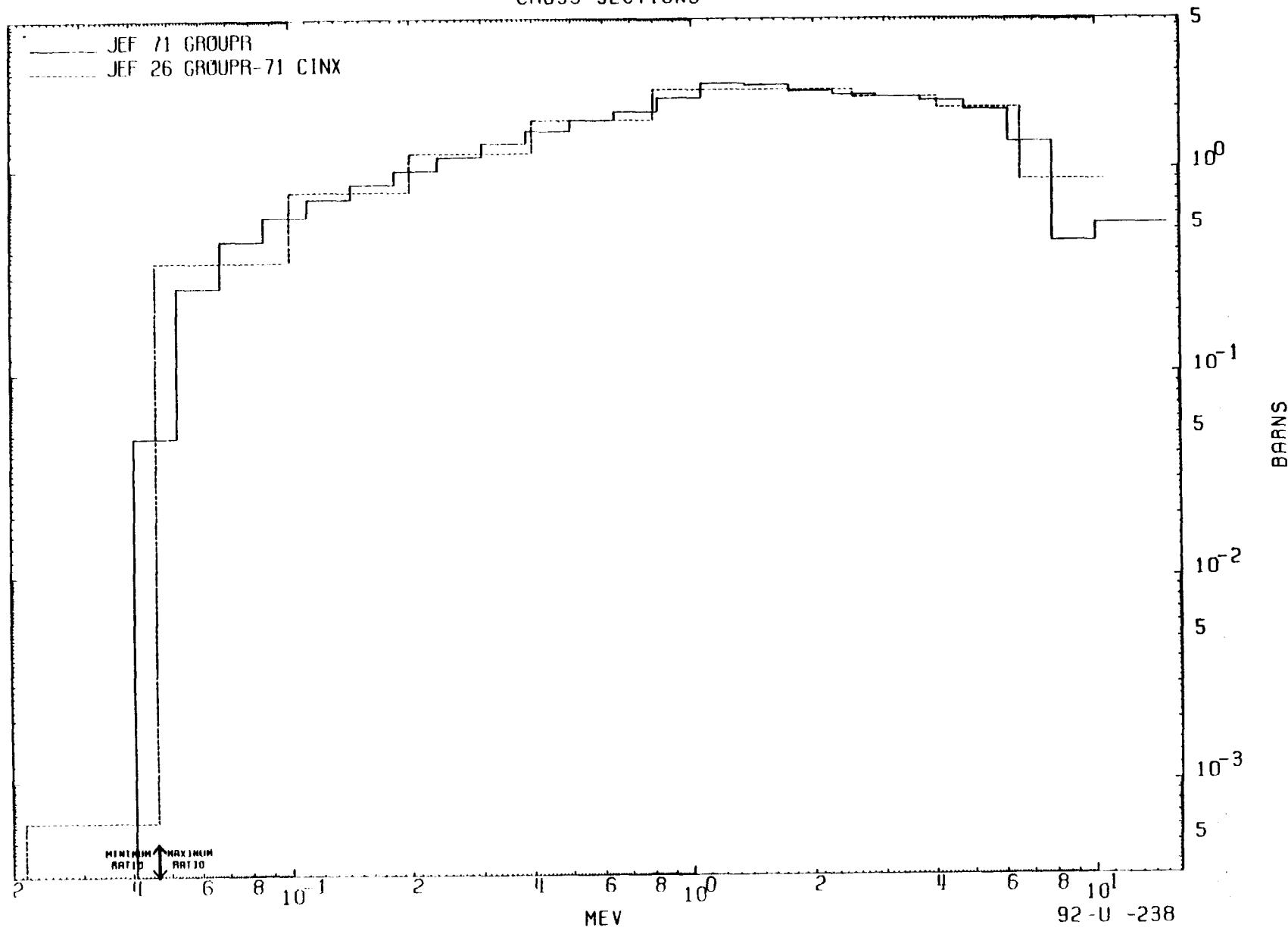
JEF 71 GROUPR
JEF 26 GROUPR-71 CINX



MAT 4928

INELASTIC
CROSS SECTIONS

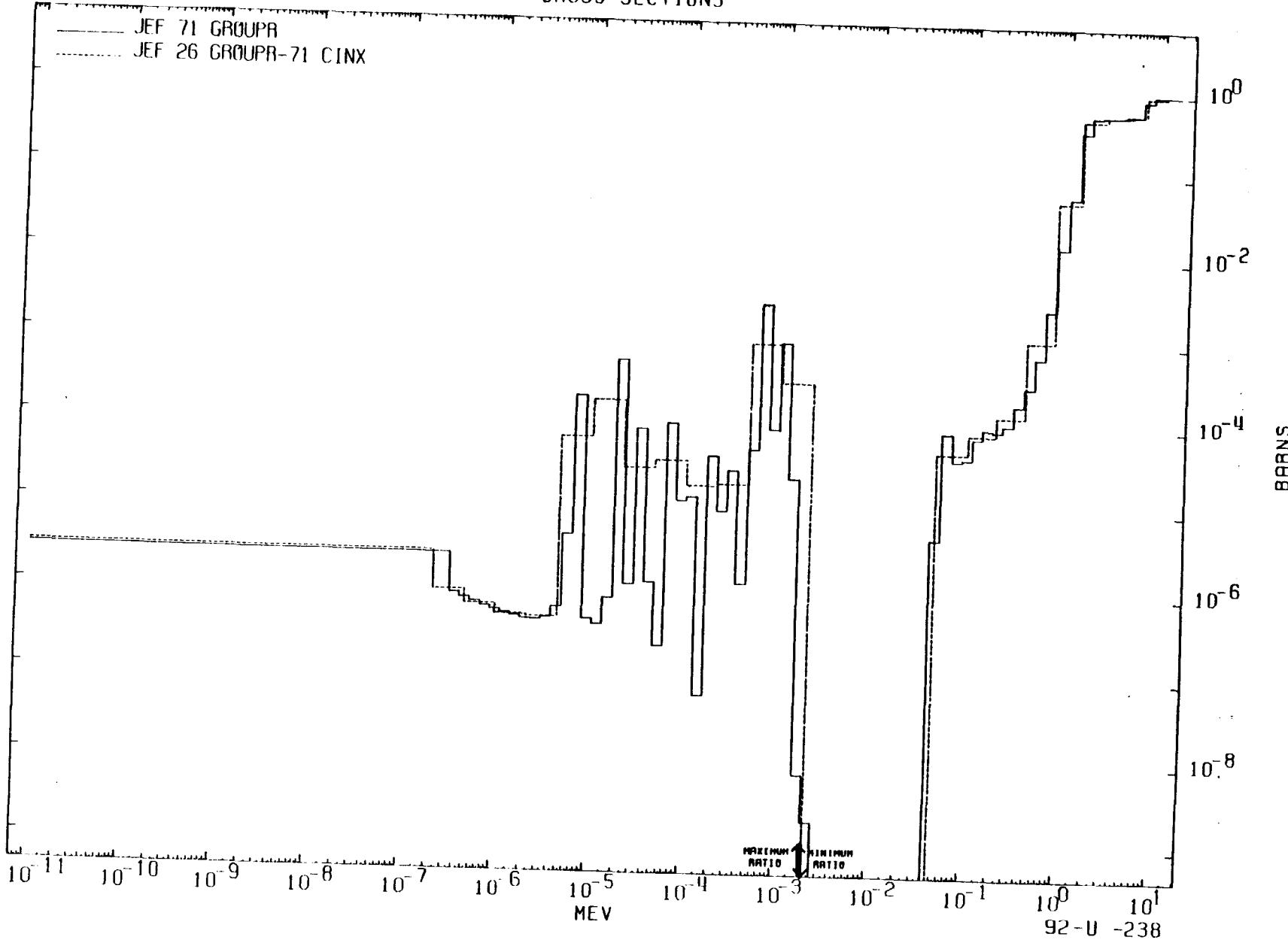
92-U -238



MA1 4928

FISSION
CROSS SECTIONS

92-U -238

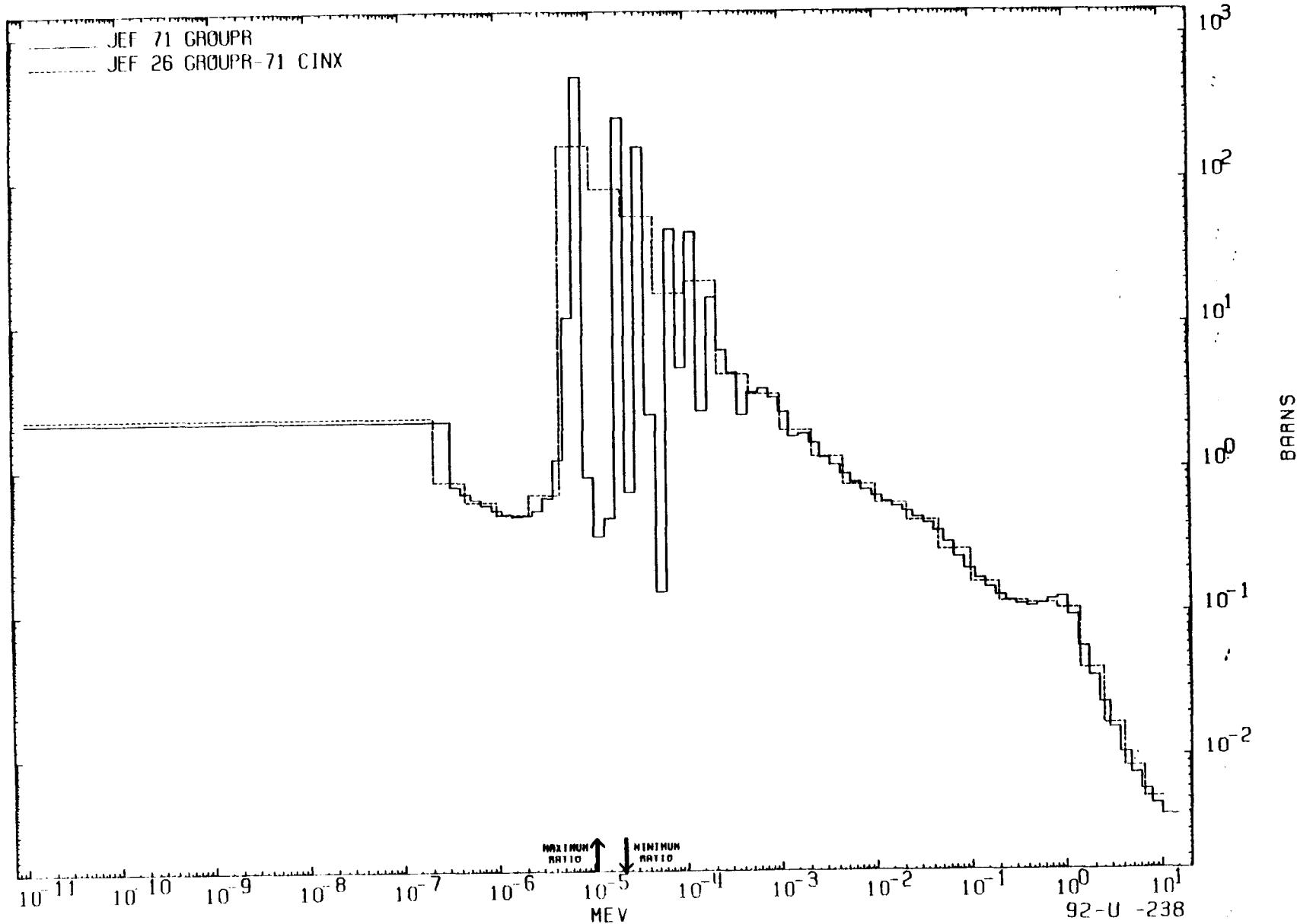


MAT 4928

(N, GAMMA)
CROSS SECTIONS

92-U -238

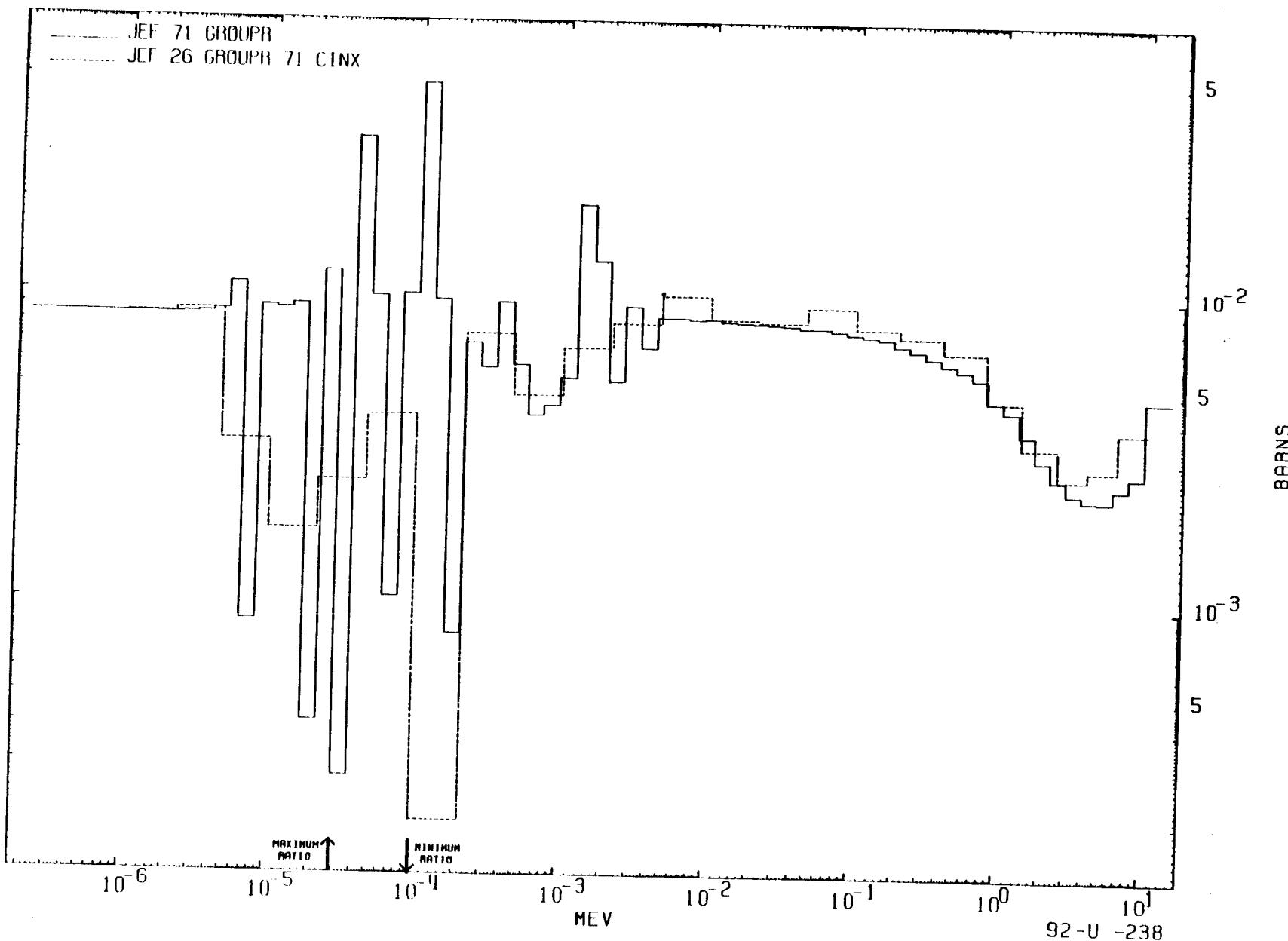
JEF 71 GROUPR
JEF 26 GROUPR-71 CINX



MAT 4928

XI

92-U -238

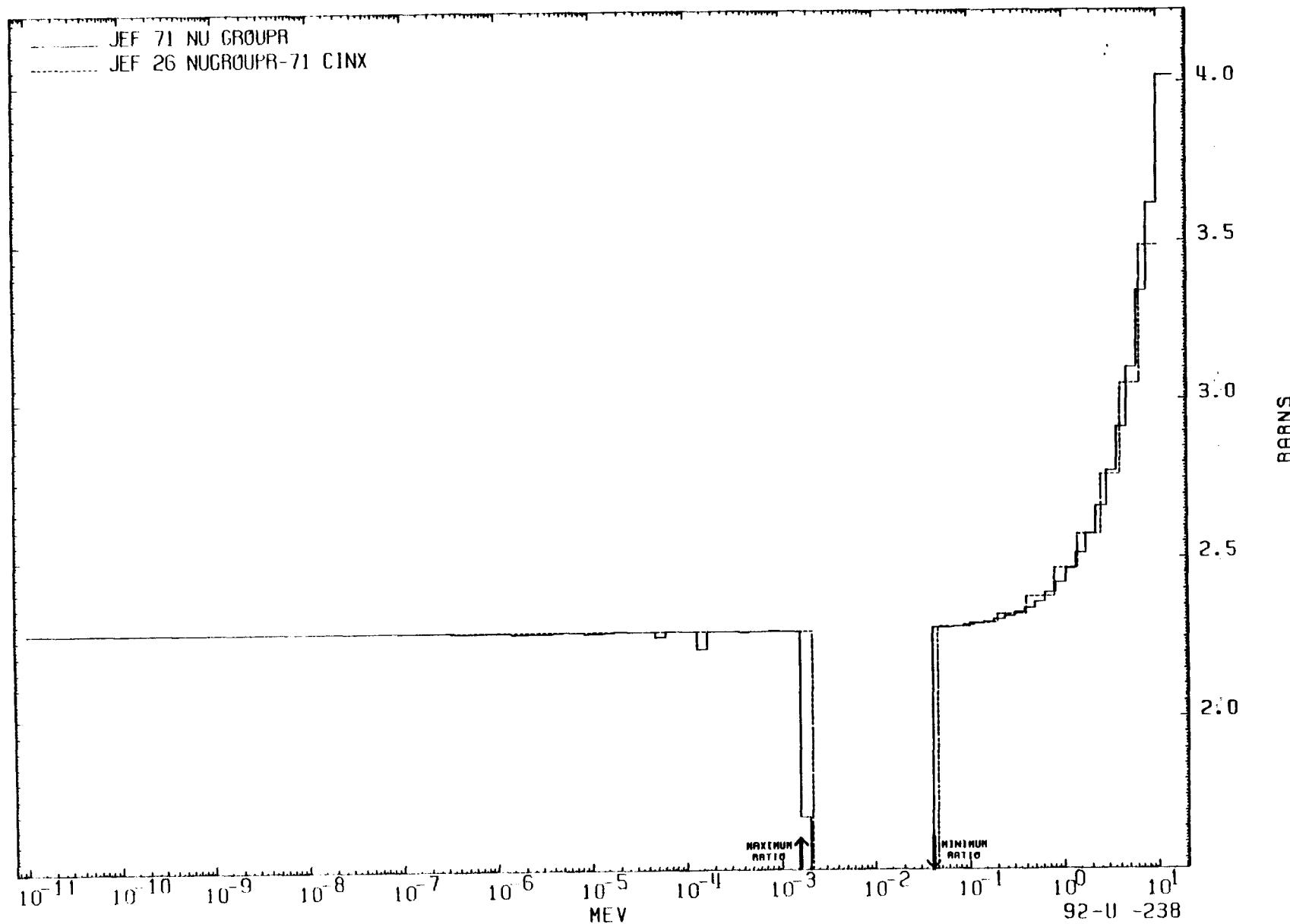


MAT 4928

NU

92-U -238

126



**Appendix C Atomic Number Densities and Geometrical Models
for Benchmark Criticals**

IN THE FOLLOWING TABLES, THE CODE NUMBERS CORRESPONDING TO THE NUCLIDES AS FOLLOWS;

949 -- PU-239, 940 -- PU-240, 941 -- PU-241, 928 -- U-238, 925 -- U-235,
924 -- U-234, 926 -- U-236, 105 -- B-10, 115 -- B-11, 42 -- Mo,
29 -- Cu, 28 -- Mn, 26 -- Fe, 25 -- Mn, 24 -- Cr,
13 -- Al, 11 -- Na, 8 -- O-16, 6 -- C

**** VERA-11A 2-REGION SPHERE MODEL**

8	8	5	---	NO. OF ELEMENTS IN EACH REGION	
10	48	88	---	NO. OF MESHES IN EACH REGION	
0.06992 0.3496			1.075	---	MESH WIDTH (CM) IN EACH REGION

----- ATOMIC NUMBER DENSITIES -----

949 7.213	-3940 3.70	-4941 2.80	-6 6 4.6204	-2 24 1.579	-3
26 6.533	-4928 6.65	-4 29 2.402	-6 6 4.6204	-2 24 1.579	-3
949 7.213	-3940 3.70	-4941 2.80	-6 6 4.6204	-2 24 1.579	-3
26 6.533	-4928 6.65	-4 29 2.402	-6 6 4.6204	-2 24 1.579	-3
925 2.50	-4928 3.44	-2 24 1.70	-3 26 6.50	-3 28 7.10	-4

**** VERA-1B 2-REGION SPHERE MODEL**

7	7	5	---		
10	44	84	---		
0.2871 0.4785 0.9863			---		
924 9.20	-5925 7.363	-3928 4.55	-4 6 5.7540	-2 24 6.890	-4
26 6.3410	-3 28 1.635	-3 28 1.635	-3 13 1.9019	-2 24 1.918	-3
924 9.20	-5925 7.363	-3928 4.55	-4 6 5.7540	-2 24 6.890	-4
26 6.3410	-3 28 1.635	-3 28 1.635	-3 13 1.9019	-2 24 1.918	-3
925 2.50	-4928 3.44	-2 24 7.08	-4 26 6.464	-3 28 1.682	-3

**** ZPR-3-6F 2-REGION SPHERE MODEL**

8	8	7	---		
10	48	78	---		
0.11498 0.5749 1.0167			---		
924 6.90	-5925 6.756	-3928 7.547	-3 13 1.9019	-2 24 1.918	-3
26 7.712	-3 28 8.39	-4 25 8.0	-3 13 1.9019	-2 24 1.918	-3
924 6.90	-5925 6.756	-3928 7.547	-3 13 1.9019	-2 24 1.918	-3
26 7.712	-3 28 8.39	-4 25 8.0	-3 13 1.9019	-2 24 1.918	-3
925 8.9	-5925 4.0026	-2 24 1.359	-3 24 1.129	-3 26 4.539	-3
28 4.94	-4 26 4.7	-5			

TABLE (CONTINUED)

**** ZEBRA-3 2-REGION SPHERE MODEL**

14	14	11	---		
10	48	78	---		
0.11836 0.5918 1.017			---		
925 2.264	-4928 3.1775	-2949 3.466	-3940 1.834	-4941 1.27	-5
6 4.2	-6 13 1.9	-6 24 8.64	-4 26 4.599	-3 28 4.83	-4
42 8.0	-6 25 6.4	-6 29 4.3702	-3 11 5.4	-3 28 4.83	-4
925 2.264	-4928 3.1775	-2949 3.466	-3940 1.834	-4941 1.27	-5
6 4.2	-6 13 1.9	-6 24 8.64	-4 26 4.599	-3 28 4.83	-4
42 8.0	-6 25 6.4	-6 29 4.3702	-3 11 5.4	-3 28 4.83	-4
925 2.268	-4928 4.1269	-2 24 8.2	-6 13 1.9	-6 24 8.64	-4
26 3.344	-3 28 4.83	-4 42 8.0	-6 25 6.4	-6 29 4.0	-6
11 5.4	-6				

**** ZPR-3-12 2-REGION SPHERE MODEL**

9	9	7	---		
10	48	78	---		
0.1438 0.7190 1.0167			---		
924 4.6	-5925 4.516	-3928 1.6948	-2 6 2.6762	-2 24 1.419	-3
26 5.704	-3 28 6.21	-4 25 5.9	-6 11 6.9	-6 26 6.762	-3
924 4.6	-5925 4.516	-3928 1.6948	-2 6 2.6762	-2 24 1.419	-3
26 5.704	-3 28 6.21	-4 25 5.9	-6 11 6.9	-6 26 6.762	-3
925 8.9	-5925 4.0026	-2 24 1.237	-3 25 4.971	-3 28 6.41	-4
25 5.2	-6 11 6.0	-6			

**** SNEAK-7-A 2-REGION SPHERE MODEL**

14	14	9	---		
10	48	68	---		
0.1425 0.7125 1.50			---		
925 5.86	-5928 7.9604	-3949 2.6374	-3940 2.380	-4941 2.15	-5
6 2.18462	-2 6 2.60987	-2 13 8.0	-6 24 2.2423	-3 26 7.9802	-3
28 1.1664	-3 42 1.65	-6 25 1.109	-4 11 9.33	-5	
925 5.86	-5928 7.9604	-3949 2.6374	-3940 2.380	-4941 2.15	-5
6 2.18462	-2 6 2.60987	-2 13 8.0	-6 24 2.2423	-3 26 7.9802	-3
28 1.1664	-3 42 1.65	-6 25 1.109	-4 11 9.33	-5	
925 1.624	-4928 3.99401	-2 6 1.35	-6 24 1.1080	-3 26 3.9634	-3
28 9.845	-4 42 1.00	-6 25 8.75	-6 11 4.53	-6	

**** ZPR-3-11 2-REGION SPHERE MODEL**

7	7	6	---		
10	38	58	---		
0.21074 1.0537 1.50			---		
924 4.6	-5925 4.586	-3928 3.4373	-2 24 1.486	-3 26 5.681	-3
28 7.18	-4 25 2.08	-4			
924 4.6	-5925 4.586	-3928 3.4373	-2 24 1.486	-3 26 5.681	-3
28 7.18	-4 25 2.08	-4			
925 8.9	-5928 4.0026	-2 24 1.196	-3 26 4.925	-3 28 5.36	-4
25 1.11	-4				

TABLE (CONTINUED)

** ZPR-3-53 2-REGION SPHERE MODEL							
11	11	6					
10	48	78					
0	18773	0.93865	1.2443				
925	6.0	-5928	2.615	-3949	1.669	-3940	1.07
6.5	5898	-2	13 1.11	-4	24 2.081	-3	26 7.134
42	2.08	-4				-3	28 9.70
925	6.0	-5928	2.615	-3949	1.669	-3940	1.07
6.5	5898	-2	13 1.11	-4	24 2.081	-3	26 7.134
42	2.08	-4				-3	28 9.70
925	8.3	-5928	3.9770	-2	6 2.4	-5	24 1.311
28	6.11	-4				-3	26 4.496
** SNEAK-7B 2-REGION SPHERE MODEL							
14	14	9					
10	58	78					
0	16256	0.8128	1.50				
925	2.663	-5928	1.45794	-2949	1.8312	-3940	1.652
8.3	3.1936	-2	6 6.31	-5	13 1.2112	-3	24 2.7560
28	4.4594	-3	42 1.84	-5	25 6.46	-5	11 1.174
925	2.663	-4928	1.45794	-2949	1.8312	-3940	1.652
8.3	3.1936	-2	6 6.31	-5	13 1.2112	-3	24 2.7560
28	1.4594	-3	42 1.84	-5	25 6.46	-5	11 1.174
925	1.624	-4928	3.99401	-2	6 1.35	-5	24 1.1080
28	9.845	-4	42 1.00	-5	25 8.76	-5	11 4.53
** ZPR-3-50 2-REGION SPHERE MODEL							
12	12	6					
10	58	88					
0	17372	0.8686	1.3447				
925	1.6	-5928	7.404	-3949	1.645	-3940	1.064
6.4	594	-2	13 1.1	-4	24 1.816	-3	26 7.3
42	2.05	-4	25 7.6	-5		-3	28 7.96
925	1.6	-5928	7.404	-3949	1.645	-3940	1.064
6.4	594	-2	13 1.1	-4	24 1.816	-3	26 7.3
42	2.05	-4	25 7.6	-5		-3	28 7.96
925	8.3	-5928	3.9613	-2	24 1.161	-3	26 4.671
25	4.8	-5				-3	28 5.08

TABLE (CONTINUED)

** ZPR-3-48 2-REGION SPHERE MODEL							
13	13	7					
10	58	78					
0	18098	0.9049	1.50				
925	1.6	-5928	7.405	-3949	1.645	-3940	1.064
6.2	0.0770	-2	11 6.355	-3	13 1.09	-4	24 2.531
28	1.119	-3	42 2.06	-4	25 1.06	-4	
925	1.6	-5928	7.405	-3949	1.645	-3940	1.064
6.2	0.0770	-2	11 6.355	-3	13 1.09	-4	24 2.531
28	1.119	-3	42 2.06	-4	25 1.06	-4	
925	8.3	-5928	3.9690	-2	24 1.225	-3	26 4.925
25	5.1	-5	11 6.0	-5		-3	28 5.36
** ZEBRA-2 2-REGION SPHERE MODEL							
12	12	11					
10	58	88					
0	1818	0.9090	1.0667				
925	2.526	-3928	1.5667	-2	8 1.544	-4	6 3.7992
24	8.54	-4	26 3.9783	-3	28 4.83	-4	42 8.0
29	4.0	-6	11 5.4	-5		-6	25 6.4
925	2.526	-3928	1.5667	-2	8 1.544	-4	6 3.7992
24	8.64	-4	26 3.9783	-3	28 4.83	-4	42 8.0
29	4.0	-6	11 5.4	-5		-6	25 6.4
925	2.98	-4928	4.1269	-2	6 4.2	-5	13 1.9
26	3.344	-3	28 4.83	-4	42 8.0	-6	25 6.4
11	5.4	-5				-6	29 4.0
** ZPR-3-49 2-REGION SPHERE MODEL							
12	12	6					
10	58	88					
0	19012	0.9506	1.2143				
925	1.6	-5928	7.406	-3949	1.644	-3940	1.064
6.2	0.0766	-2	13 1.09	-4	24 2.508	-3	26 1.0083
42	2.06	-4	25 1.06	-4		-2	28 1.121
925	1.6	-5928	7.406	-3949	1.644	-3940	1.064
6.2	0.0766	-2	13 1.09	-4	24 2.508	-3	26 1.0083
42	2.06	-4	25 1.06	-4		-2	28 1.121
925	8.3	-5928	3.9556	-2	24 1.242	-3	26 4.626
** ZPR-3-56B 2-REGION SPHERE MODEL							
12	12	5					
10	58	88					
0	21088	1.0544	1.1447				
925	1.4	-5928	6.195	-3949	1.358	-3940	1.81
6.1	0.03	-3	11 8.669	-3	24 2.5	-3	26 1.37
42	3.43	-4	25 2.2	-4		-2	28 1.09
925	1.4	-5928	6.195	-3949	1.358	-3940	1.81
6.1	0.03	-3	11 8.669	-3	24 2.5	-3	26 1.37
42	3.43	-4	25 2.2	-4		-2	28 1.09
11	7.879	-3	24 1.941	-3	26 7.824	-3	28 4.2261
12	12	5				-2	25 3.0

TABLE (CONTINUED)

** ZPR-6-7 2-REGION SPHERE MODEL													
12	12	8											
10	88	100											
0.2204	1.1020	2.8175											
925	1.26	-5928 5.78036	-3949 8.8672	-4940 1.1944	-4941 1.33	-5							
88	1.390	-2 11 9.2904	-3 24 2.842	-3 26 1.3431	-2 28 1.291	-3							
42	2.357	-4 25 2.21	-4										
925	1.25	-5928 5.78036	-3949 8.8672	-4940 1.1944	-4941 1.33	-5							
88	1.390	-2 11 9.2904	-3 24 2.842	-3 26 1.3431	-2 28 1.291	-3							
42	2.357	-4 25 2.21	-4										
925	8.56	-5928 3.96179	-2 8 2.4	-5 24 1.295	-3 26 4.637	-3							
28	6.636	-4 42 3.8	-6 25 9.98	-6									
** ZPR-6-8A 2-REGION SPHERE MODEL													
8	8	7											
10	88	100											
0.23918	1.1959	2.8175											
925	1.153	-5928 5.8176	-3 8 1.390	-2 11 9.2904	-3 24 2.842	-3							
26	1.3431	-2 28 1.291	-3 25 2.21	-4									
925	1.153	-3928 5.8176	-3 8 1.390	-2 11 9.2904	-3 24 2.842	-3							
26	1.3431	-2 28 1.291	-3 25 2.21	-4									
925	8.56	-5928 3.96508	-2 8 2.30	-5 24 1.247	-3 26 4.4669	-3							
28	6.407	-4 25 9.60	-5										
** ZPPR-2 5-REGION CYLINDRICAL MODEL													
15	15	15	12	12	8								
10	64	78	86	94	98								
0.2300	1.1600	1.9050	2.3425	2.3828	2.9275								
BUCKLING													
5.92	-4 5.92	-4 5.92	-4 5.92	-4 5.92	-4 5.92	-4							
925	1.23	-5928 5.5549	-3949 8.433	-4940 1.141	-4941 1.53	-5							
88	1.3116	-2 6 3.0	-5 11 8.933	-3 13 3.0	-6 24 2.702	-3							
26	1.2576	-2 28 1.221	-3 42 2.31	-4 25 2.09	-4 29 1.9	-3							
925	1.23	-5928 5.5549	-3949 8.433	-4940 1.141	-4941 1.53	-5							
88	1.3116	-2 6 3.0	-5 11 8.933	-3 13 3.0	-6 24 2.702	-3							
26	1.2576	-2 28 1.221	-3 42 2.31	-4 25 2.09	-4 29 1.9	-3							
925	1.15	-5928 5.1980	-3949 1.2741	-3940 1.724	-4941 2.31	-5							
88	1.1761	-2 6 2.3	-5 11 8.682	-3 13 4.0	-6 24 2.523	-3							
26	1.3852	-2 28 1.160	-3 42 3.41	-4 26 2.02	-4 29 2.0	-3							
925	2.4	-5928 1.1085	-3 42 3.41	-2 6 1.013	-3 11 6.492	-3							
26	2.0	-5 24 1.991	-3 26 6.931	-3 28 8.98	-4 42 1.4	-5							
925	1.57	-4 29 1.7											
13	2.4	-5928 1.1085	-2 8 2.0133	-2 6 1.013	-3 11 6.066	-3							
13	3.0	-6 24 2.172	-3 26 7.649	-3 28 9.87	-4 42 1.5	-5							
26	1.74	-4 29 1.6	-5										
6	5.58	-4 24 1.205	-3 26 7.5151	-2 28 5.13	-4 42 1.2	-5							
26	5.98	-4 29 1.3	-5 11 9.1	-5									

TABLE (CONTINUED)

** MZB 7-REGION SPHERE MODEL													
15	15	15	15	15	15	15	14	14	9				
10	40	46	48	52	58	62	68	78	90				
0.2500	1.4015	1.4524	1.4651	1.8861	1.9023	1.9119	2.1941						
9498	916317E-04	949401	832231E-04	949412	711883E-05	95254	293537E-05	959285	926857E-03				
61	1.10577E-04	81	255138E-02	261	253244E-02	281	810516E-03	119	242322E-03				
132	730518E-05	243	447433E-03	252	592416E-04	292	324749E-04	421	124641E-05				
9498	915317E-04	949401	832231E-04	949412	711883E-05	95254	293537E-05	959285	926857E-03				
61	1.10577E-04	81	255138E-02	261	253244E-02	281	810516E-03	119	242322E-03				
132	730518E-05	243	447433E-03	252	592416E-04	292	324749E-04	421	124641E-05				
9498	940394E-04	949401	825531E-04	949412	698123E-06	9292	293326E-06	959285	926484E-03				
61	1.14477E-04	81	255052E-02	261	253244E-02	281	619472E-03	119	243704E-03				
132	727679E-05	243	455182E-03	262	591512E-04	292	357492E-04	421	124624E-05				
9498	940394E-04	949401	825531E-04	949412	698123E-06	9292	293326E-06	959285	926484E-03				
61	0.062586E-04	81	255052E-02	261	253244E-02	281	6882107E-03	119	257019E-03				
132	727679E-05	243	4552276E-03	262	2534788E-04	292	357492E-04	421	124624E-05				
9498	916581E-04	949401	838067E-04	949412	742998E-05	95254	293484E-05	959285	926585E-03				
61	0.048065E-04	81	255094E-02	261	2534917E-02	281	880967E-03	119	257283E-03				
132	721186E-05	243	549894E-03	252	532701E-04	292	357578E-04	421	124636E-05				
9491	345700E-04	934903	317932E-04	949415	192833E-05	95253	881736E-05	959285	381122E-03				
63	1.19267E-03	81	078882E-02	261	251808E-02	281	693349E-03	118	684108E-03				
132	577202E-05	243	403311E-03	252	678221E-04	298	412130E-04	421	144693E-05				
9255	537491E-04	959287	644106E-03	1051	753696E-04	71154	630810E-09	61	128709E-02				
85	1.21978E-04	261	289106E-02	281	678413E-02	8119	099398E-03	136	831933E-02				
243	356167E-03	252	858001E-04	291	043136E-05	421	635068E-06	00	0				
64	616631E-04	254	957446E-02	282	300861E-04	111	685362E-04	131	372378E-02				
244	117345E-04	263	575375E-04	291	888036E-06	423	741112E-06	00	0				
** FCA-5-2 2-REGION SPHERE MODEL													
18	18	15											
10	48	78											
0.18116	0.9058	1.0											
949	0.0010458	940	0.00009325	941	0.00001069	925	0.0014700	928	0.0058359				
8	0.013101	11	0.0081341	13	0.0088295	24	0.0032734	26	0.011950				
28	0.0015345	105	0.	115	0.	6	0.	26	0.				
28	0.0010458	940	0.00009325	941	0.00001069	925	0.0014700	928	0.0058359				
8	0.013101	11	0.0081341	13	0.0088295	24	0.0032734	26	0.011950				
28	0.0015345	105	0.	115	0.	6	0.	26	0.				
29	0.0002891	928	0.039890	24	0.001827	26	0.006625	28	0.0007964				

TABLE (CONTINUED)

** MZA 6-REGION SPHERE MODEL

17	17	15	15	15	14	9
14	34	42	50	58	82	92
0.1558	1.4183	0.9746	1.0469	0.5709	1.5587	2.3294
925	3.886181E-5949	1.361012E-3928	6.367208E-3940	3.232607E-4	6.3.123281E-3	
8	1.079941E-211	8.579973E-326	1.251963E-2115	4.009848E-8	24.3.463726E-3	
29	4.963544E-4941	4.644822E-642	1.145005E-626	2.502263E-4	28.1.738612E-3	
105	1.143000E-813	2.600244E-6				
925	3.886181E-5949	1.361012E-3928	6.367208E-3940	3.232607E-4	6.3.123281E-3	
8	1.079941E-211	8.579973E-326	1.251963E-2115	4.009848E-8	24.3.463726E-3	
29	4.963544E-4941	4.644822E-642	1.145005E-626	2.502263E-4	28.1.738612E-3	
105	1.143000E-813	2.600244E-6				
925	3.883492E-5949	1.343325E-3928	6.363500E-3940	3.500438E-4	6.3.126006E-3	
8	1.079278E-211	8.514944E-326	1.261317E-224	3.448112E-3	29.9.960135E-4	
941	5.477312E-542	1.144755E-525	2.714402E-428	1.714983E-3	13.2.579548E-5	
925	3.885767E-5949	1.347098E-3928	6.356683E-3940	3.320482E-4	6.3.126891E-3	
8	1.080012E-211	8.519853E-326	1.260898E-224	3.448391E-3	29.4.963019E-4	
941	5.312421E-542	1.144967E-525	2.714488E-428	1.715343E-3	13.2.579969E-5	
925	3.885767E-5949	1.347873E-3928	6.3566837E-3940	3.304518E-4	6.3.116683E-3	
8	1.079740E-211	8.619840E-326	1.259815E-224	3.448059E-3	29.4.963019E-4	
941	5.344748E-542	1.144967E-526	2.714184E-428	1.714732E-3	13.2.499184E-5	
925	7.013167E-5928	9.717569E-3	6.1.443702E-228	3.317917E-3	11.6.066874E-3	
26	3.95105E-2118	1.340673E-824	2.030370E-229	6.8556061E-642	1.081886E-6	
25	4.20715E-428	1.025837E-3105	1.135431E-613	4.245644E-3		
6	4.848179E-426	5.310974E-424	3.451174E-429	1.582560E-642	3.135814E-6	
25	4.008082E-428	1.928590E-413	1.150333E-211	1.854708E-4		

** SCHERZO-566 INFINITE HOMOGENEOUS SLAB MODEL

120						
10.0						
0.0	-- BUCKLING					
925	2.6302 E-03928	4.46760E-02				

** U02 INFINITE HOMOGENEOUS SLAB MODEL

2						
120						
10.0						
0.0	-- BUCKLING					
925	1.6495 E-03928	2.0641 E-02949	1.00000E-20	8.4.46000E-02		