IEC-75

SG10: Activities on Inelastic Scattering Cross Sections for Weak Absorbing Fission Product Nuclides

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1. Objectives

(a) To write a status report on inelastic scattering cross sections for weak absorbing FP nuclides (e.g. even mass isotopes of Zr, Mo, Ru, Pd, Nd and Sm).

(b) To obtain a recommendation on methods and model parameters for evaluation of the inelastic scattering cross sections of FP nuclides.

(c) To examine the reliability of neutron spectra used for the analysis of the STEK sample worth. The spectra were adjusted to reproduce the worth of standard samples.

2. Background

The integral tests on the reactivity worths measured at STEK show good results for strong absorbers (within 20%) but a trend of underestimation for weak absorbers. Accordingly, Gruppelaar pointed out that such underestimation for the weak absorbers came from uncertain inelastic scattering cross sections: for most FP nuclides of the current evaluated data libraries, direct inelastic scattering cross sections are disregarded. Up to the specialists' meeting held at JAERI in May 1992, the data status for Zr, Mo, Pd and Nd isotopes assigned to the first priority nuclides were investigated by comparing the data in JENDL-3, JEF-2 and ENDF/B-VI with each other, and the DWBA method was turned out highly applicable for calculation of direct inelastic scattering cross sections. However, it was pointed out at the meeting that the DWBA method was not rigorous and might show an anomalous behavior of the inelastic scattering cross sections, and the coupled channel calculation was recommended as a benchmark for the DWBA calculation.

As for integral tests of cross sections, the results for JENDL-3 were reviewed: C/E values to the STEK experiments are generally in the range from 0.4 to 1.2 for the weak absorbers, while those for the strong absorbers are close to unity within 20%. The work on neutron spectrum calculation was also introduced aiming at evaluation of the uncertainties of the integral test itself.

This note describes the work made after the specialists' meeting.

3. Work on Inelastic Scattering Cross Sections

According to the recommendation at the specialists' meeting, the coupled channel theory was applied to the inelastic scattering calculations for vibrational levels of ^{90}Zr, ^{144}Nd and ^{150}Nd by using the ECIS code. Level schemes are shown in Fig. 1 for ^{144}Nd and ^{150}Nd. As is shown in Fig.2 for ^{144}Nd, the excitation functions for vibrational levels calculated with the coupled channel theory using slightly reduced imaginary potential strength, Ws, gave a general agreement with the DWBA results denoted with JENDL-3 in the wide energy range up to 20 MeV. Accordingly, we nearly reach the conclusion that the DWBA is applicable to the direct inelastic scattering cross sections for the vibrational levels. However, further study is desirable for Pd and/or Ru in the mass range around 100 to confirm the conclusion. The investigation for rotational level band is also in progress. The latest result for ^{150}Nd is shown in Fig. 3: coupled channel theory calculations were made by considering the 0^+–2^+–4^+–6^+–coupling and using β_2=0.2848. As for the 2^+ level at 1.77 MeV, the result of the coupled channel calculation with Ws = 4.5 MeV agrees well with the DWBA calculation (JENDL–3) with Ws=9.13MeV.

For the second priority nuclides such as Ru, Cd, Ba, Ce and Sm, the status review of the inelastic scattering cross sections has been started and it is now in progress. Graphical intercomparison of the evaluated data with experimental data was made for Cd and Sm. Figure 4 shows the results for Cd isotopes. The nuclear model and their parameters were surveyed for these nuclides and the direct inelastic scattering cross sections was estimated with DWBA.

4. Integral Test of Cross Sections

(a) Spectrum Calculations of STEK

Neutron spectra of the STEK cores were calculated with the vectorized pointwise Monte Carlo code, MVP, using a three dimensional homogeneous model of the STEK reactor and corrected for a heterogeneous effect according to the diffusion calculations. The results were compared with the original spectra reported from Petten and employed to the sample worth calculations. Figure 5 shows the comparison of neutron spectra in the test region of the STEK–4000 core calculated with the various models with the original spectrum (ECN–ADJUSTED). The Monte Carlo method gives appreciable improvement of sample reactivity worth of the weak absorbers, although some discrepancies are still remaining between the calculations and the measurements (See Fig. 6 and Table 1). In a lower energy range of which neutrons much contribute to worth of the strong absorbers in a large core, the Monte Carlo calculation corrected for a heterogeneous effect supports the original spectra which were obtained through the adjustment of a diffusion theory calculation spectrum to reproduce the reactivity worth of standard samples. Table 2 and 3 gives the results for standard samples and strongly absorbing nuclides, respectively. Further investigation about plate heterogeneity effects and the review of the C/E values of sample worth are in progress.

(b) Integral Test of JEF–2 and ENDF/B–VI Data

The integral tests for JEF–2 are being made at Cadarache. Details will be presented by Dr. Salvatores.

5. Time Schedule

The work will be finished by March 1994.

Table-1 C/E values of reactivity worth for weakly absorbing FP nuclides.

Nuclides	Monte-Carlo+Hetero Effects Flux		Original(ECN Adjusted) Flux
	<C/E>	δ (C/E)	<C/E>
^{90}Zr *	0.705	0.123	0.674
^{92}Zr *	0.532	0.138	0.479
^{96}Zr *	0.622	0.156	0.571
^{92}Mo	0.877	0.338	0.947
^{94}Mo	1.006	0.468	1.099
^{98}Mo	0.975	0.103	1.027
^{100}Mo	1.041	0.190	1.089
^{104}Pd	1.078	0.217	1.101
^{106}Pd	1.120	0.106	1.147
^{108}Pd	0.998	0.149	1.065
^{110}Pd	0.649	0.456	0.722
^{128}Te *	0.407	0.279	0.386
^{130}Te *	0.549	0.269	0.457
^{140}Ce *	0.843	0.118	0.795
^{142}Ce *	0.675	0.183	0.642
^{142}Nd *	0.043	0.079	0.009
^{144}Nd *	0.645	0.336	0.628
^{146}Nd *	0.696	0.236	0.590
^{148}Nd *	0.728	0.100	0.767
^{150}Nd *	0.641	0.097	0.675

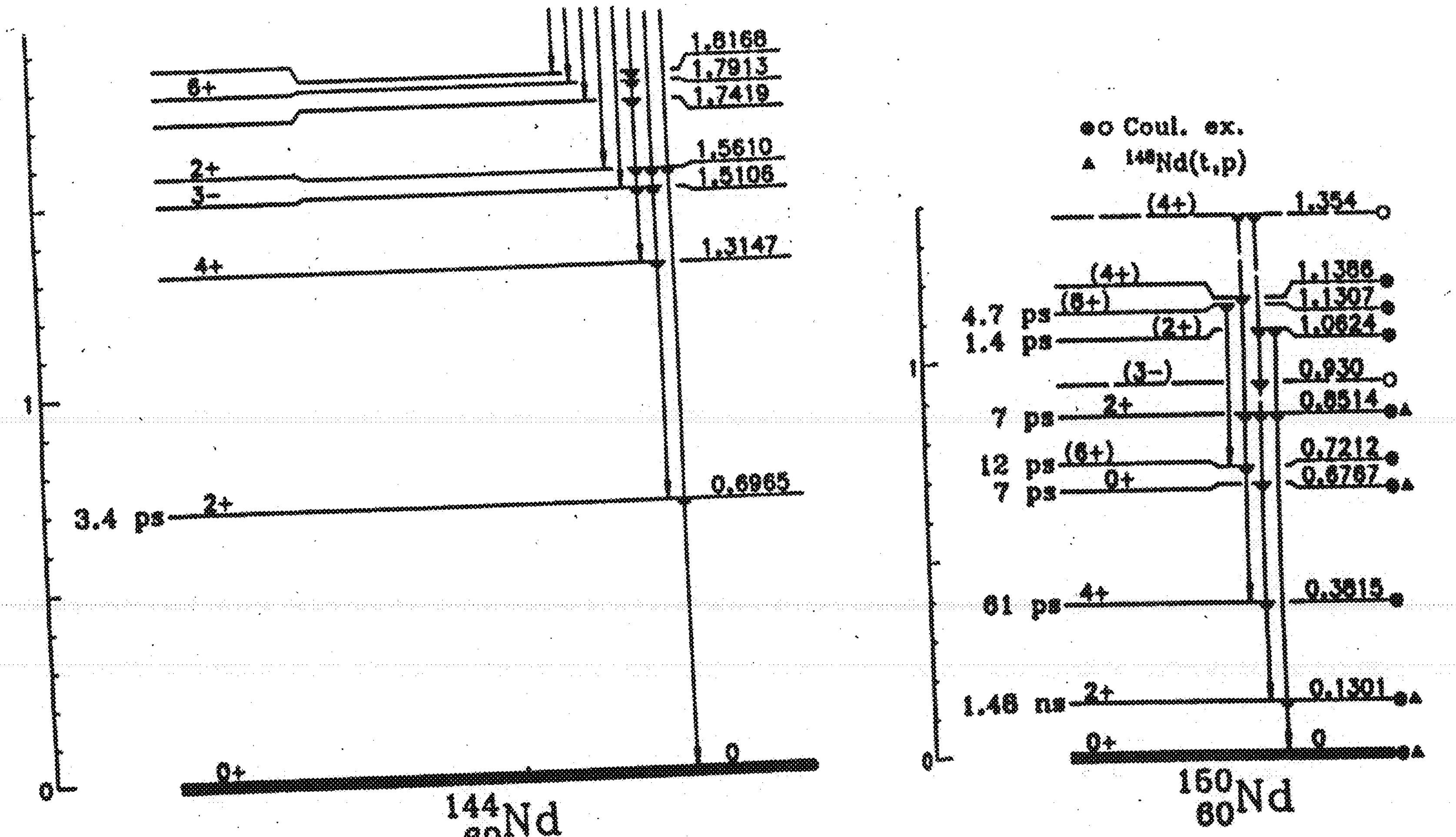
* : Oxiedes

Table-2 C/E values of reactivity worth for standard samples

Nuclides	Monte-Carlo+Hetero Effect Flux		Original(ECN Adjusted) Flux
	<C/E>	δ(C/E)	<C/E>
^{10}B	0.963	0.018	0.981
C	0.823	0.020	0.829
N	0.847	0.085	0.850
O	0.753	0.030	0.729
Al	0.871	0.037	0.817
Pb	0.823	0.025	0.662
^{235}U	0.962	0.021	0.946

Table-3 C/E values of reactivity worth for strongly absorbiing FP nuclides

Nuclides	Monte-Carlo+Hetero Effet Flux		Original(ECN Adjusted) Flux
	<C/E>	δ(C/E)	<C/E>
^{95}Mo	0.969	0.045	0.998
^{99}Tc	0.859	0.026	0.872
^{105}Pd	0.883	0.027	0.894
^{107}Pd	0.888	0.019	0.899
^{149}Sm	0.841	0.018	0.851
^{153}Eu	0.888	0.020	0.899
^{159}Tb	1.009	0.024	1.017



（振動核の例）

β_2、β_3：ＪＥＮＤＬ－３

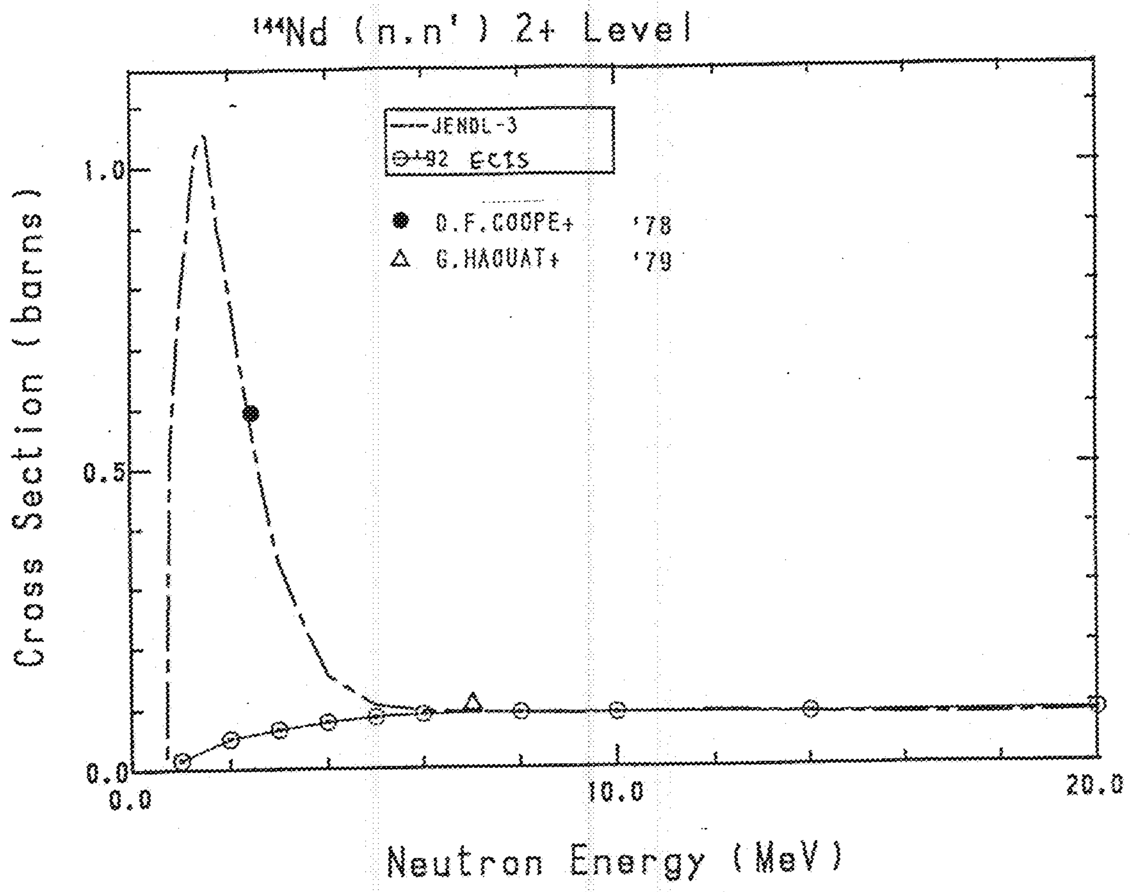
Ｗｓ＝９．１→７．０

（変形核の例）

$0^+-2^+-4^+-6^+$ couple

ＷＳ＝９．１６→４．５

Fig. 1 Level schemes for ^{144}Nd (vibrational) and ^{150}Nd (rotational).



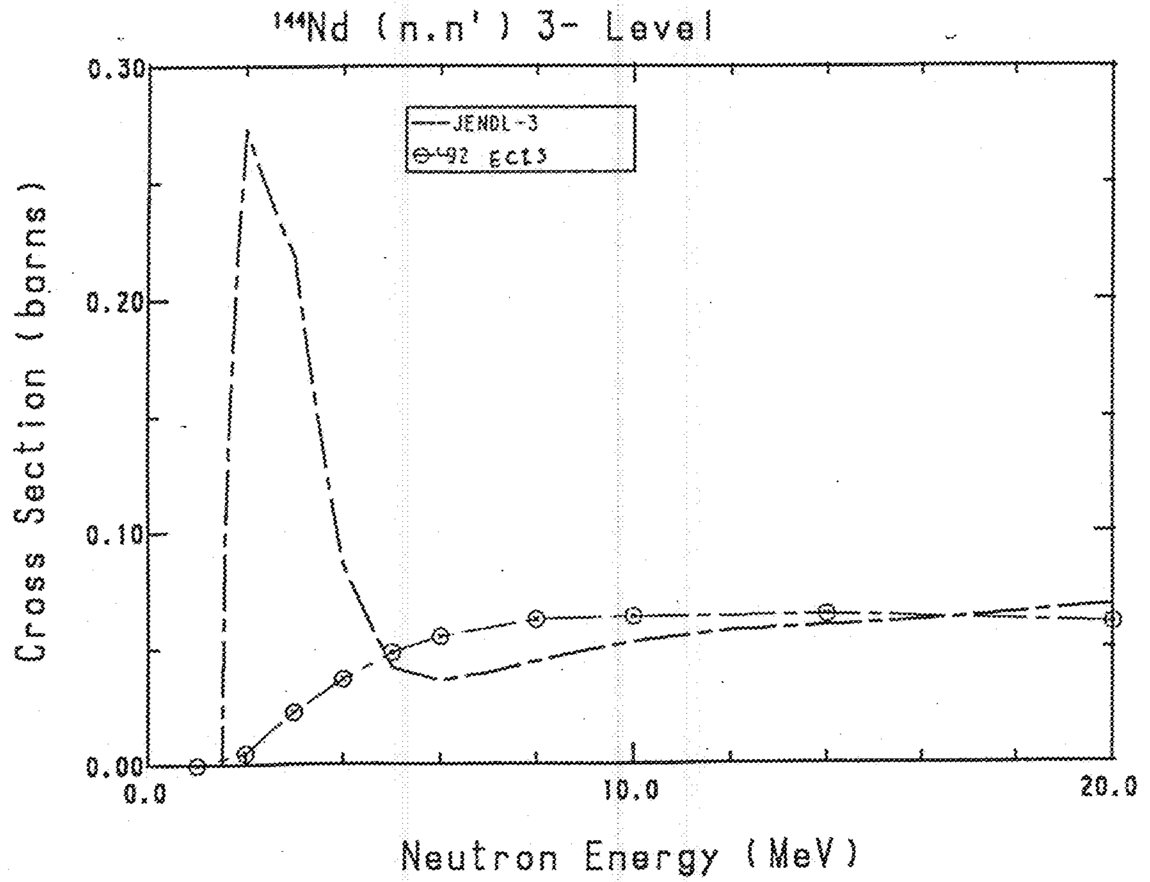


Fig. 2 Comparison of calculated and measured level excitation functions for ^{144}Nd. JENDL-3 (DWBA calculation) with Ws=9.1MeV, ECIS (coupled channel calculation) with Ws=7.0MeV.

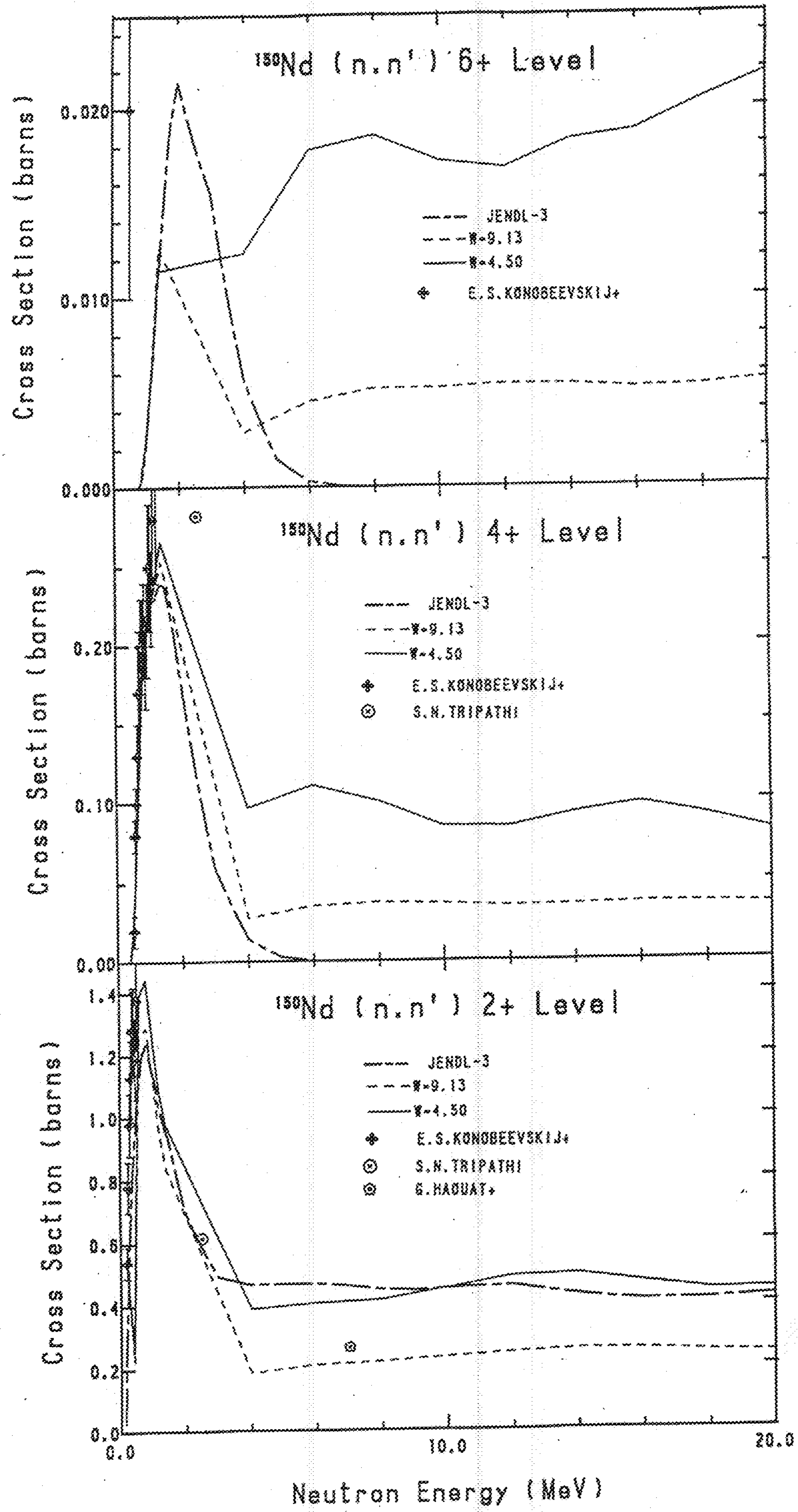


Fig. 3 Comparison of calculated and measured level excitation functions for ^{150}Nd. JENDL-3 (DWBA calculation) with Ws=9.13MeV, ECIS (coupled channel calculation) with Ws=9.13MeV and 4.5MeV.

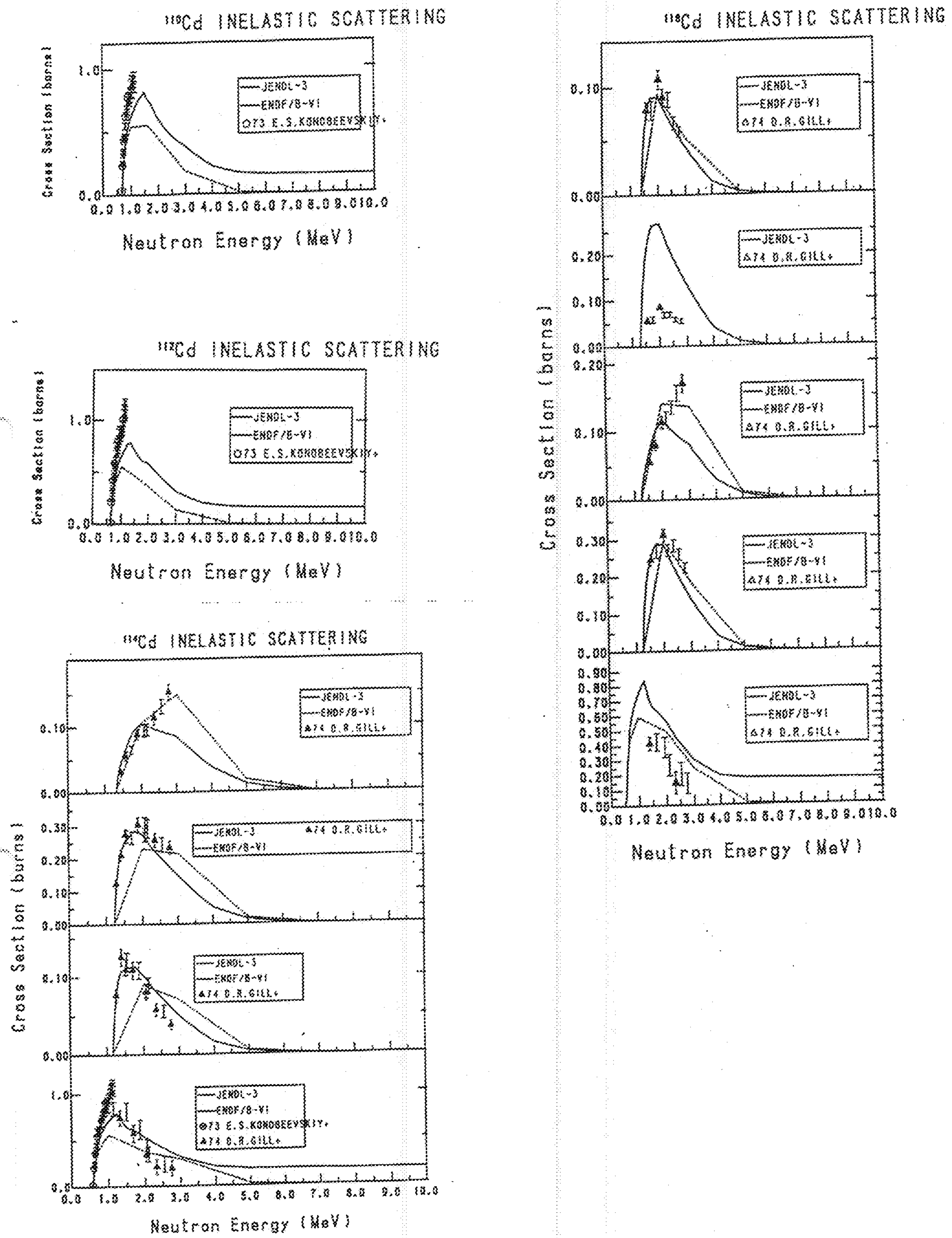
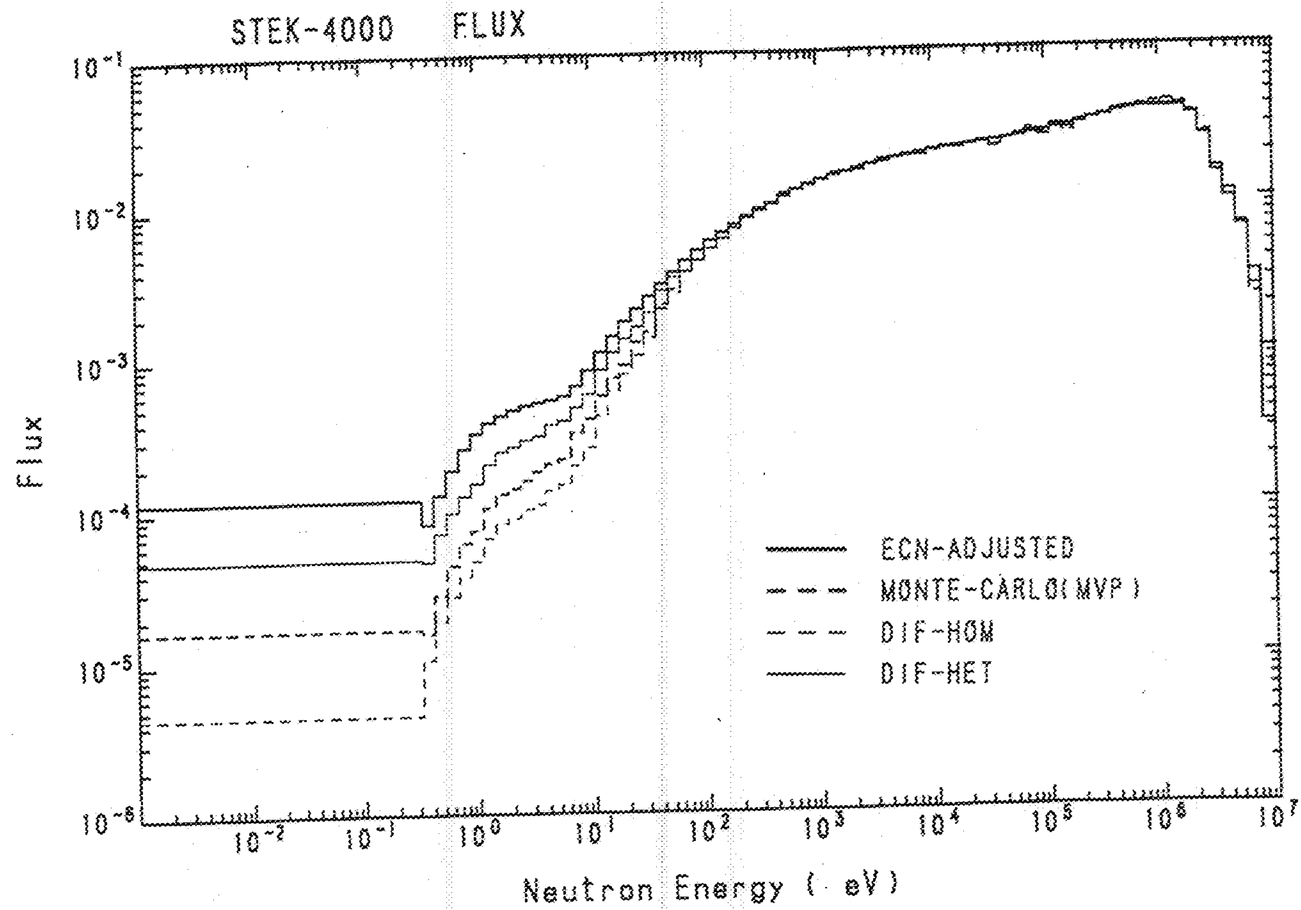


Fig. 4 Comparison of evaluated level excitation functions with experimental data for cadmium isotopes with even mass number.



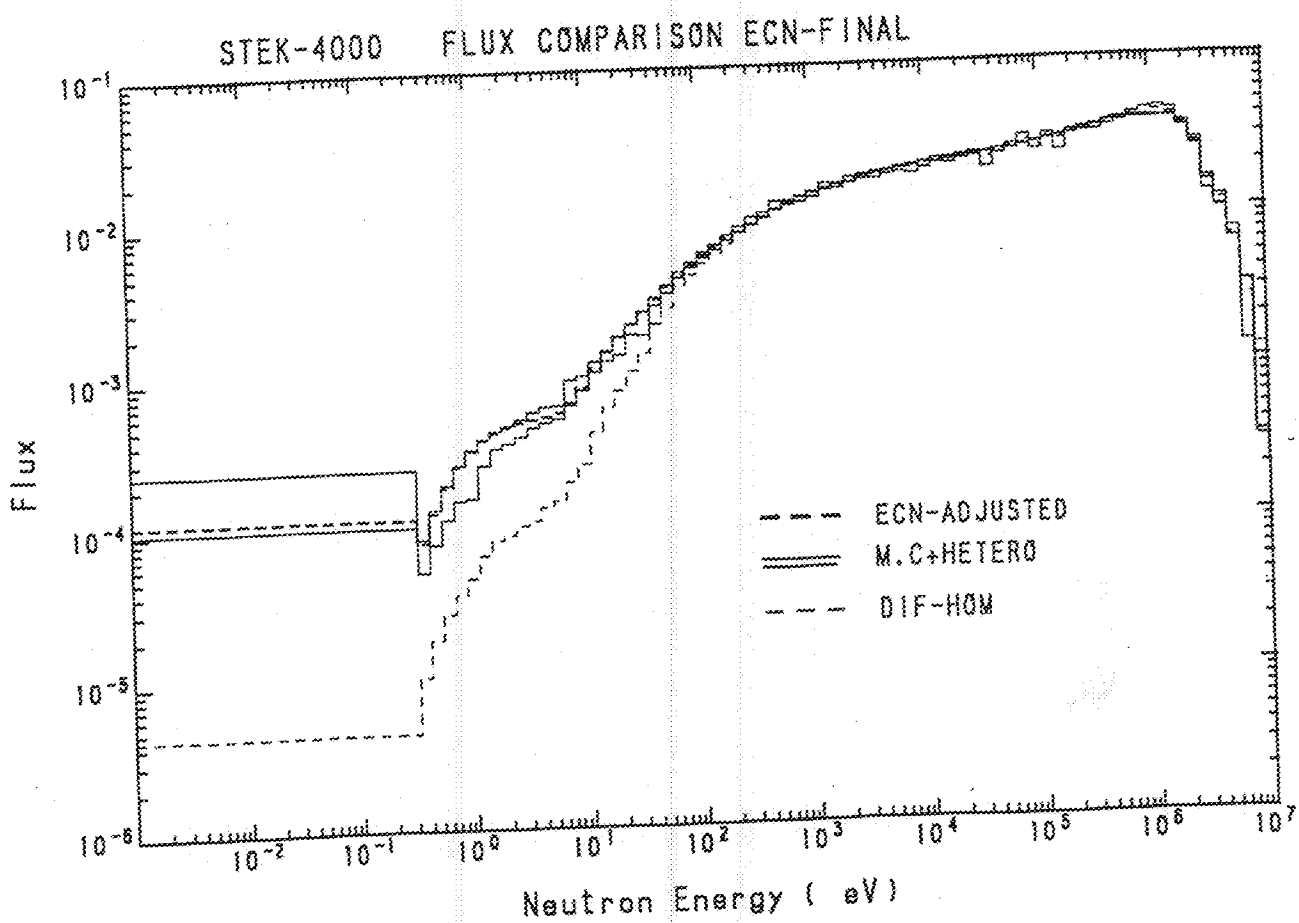


Fig. 5 Comparison of neutron spectra calculated with various models in case of STEK-4000 core.

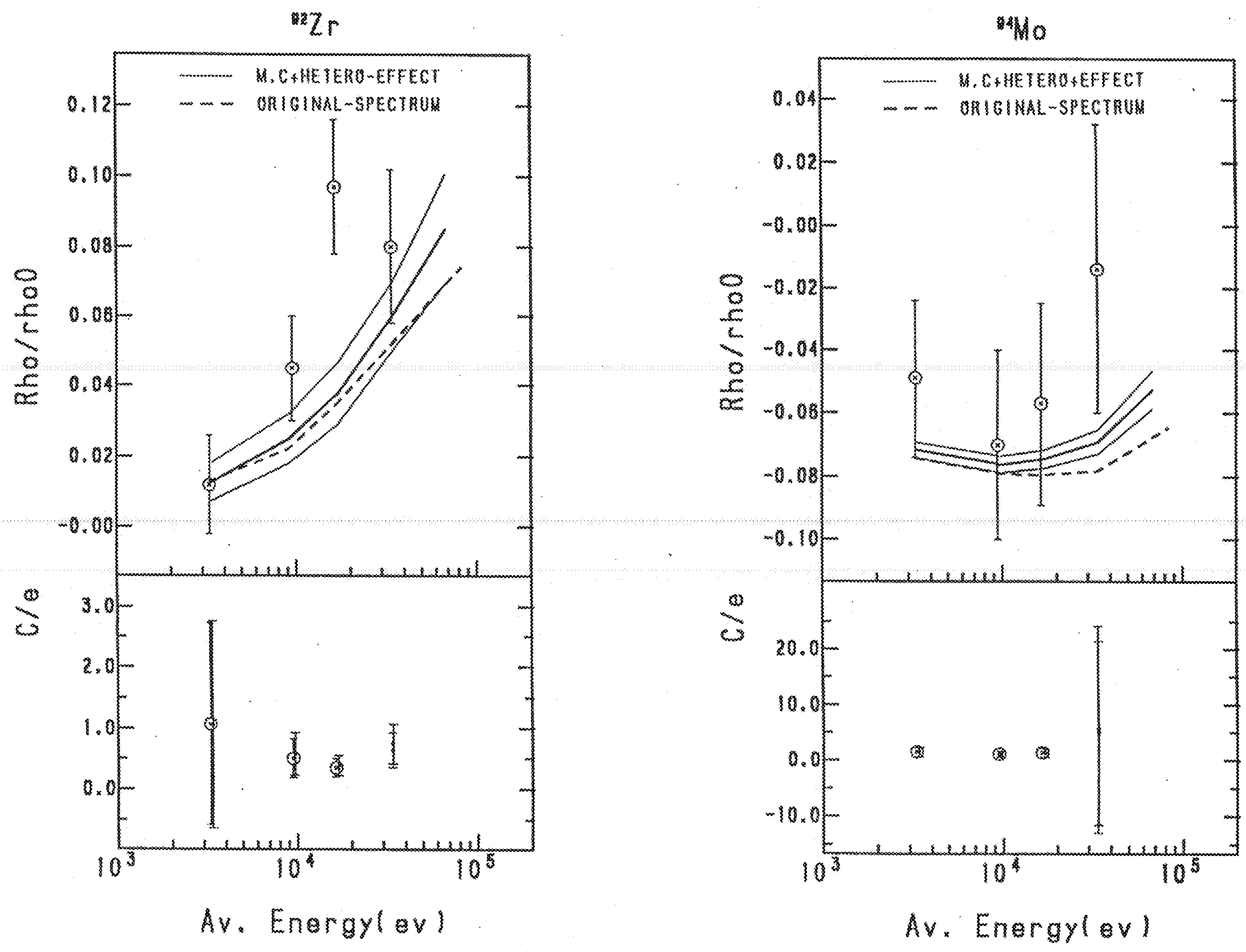


Fig. 6 Sample reactivity worth and its C/E value for $^{92}ZrO_2$ and ^{94}Mo samples.