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NEANSC INTERNATIONAL EVALUATION COOPERATION SG10 ACTIVITIES ON INELASTIC SCATTERING CROSS SECTIONS FOR WEAKLY ABSORBING FISSION-PRODUCT NUCLIDES

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ABSTRACT

An evaluation method of inelastic scattering cross sections of FP nuclides is investigated. The origins of the discrepancy found in the calculated and measured sample reactivity worths are also discussed emphasizing the effect of ambiguity in inelastic scattering cross sections and neutron spectra.

I. INTRODUCTION

In the integral tests[1,2] of the evaluated fission product nuclear data libraries such as JENDL-3.1 and JEF-1, the calculated sample reactivity worths are in good agreement with those measured at STEK[3] for strong absorbers (within about 20%), but there is anomalous behaviour for weak absorbers; calculation underestimates positive components (due to scattering) of the worth. It was pointed out that such behaviour came from incorrect inelastic scattering cross sections;[4] for most FP nuclide data in the current evaluated data libraries except JENDL-3, direct inelastic scattering cross sections are probably disregarded.[5] The subgroup 10 in NEANSC Evaluation Cooperation Working Party was organized in 1991 in order to review the inelastic scattering cross sections for the weakly absorbing FP nuclides, to recommend methods and model parameters for evaluation of the inelastic scattering cross sections of FP nuclides and to explain the discrepancy between the differential and integral data.

II. INELASTIC SCATTERING CROSS SECTIONS

The applicability of DWBA which was used in the evaluation for even-mass fission product nuclides of JENDL-3.1 was investigated by comparing JENDL-3.1 data with experimental data and with coupled-channel calculations for isotopes of Zr, Mo, Cd, Nd and Sm. **Figure 1** shows that the DWBA calculations of the excitation functions for vibrational levels of ^{92}Zr are in good agreement with the experimental data. It was confirmed that the cross sections for the vibrational levels calculated with the coupled-channel theory using slightly modified imaginary potential strength, W_s, gave a general agreement with the DWBA calculations in a wide energy range up to 20 MeV. The coupled-channel theory estimates well the cross sections for both vibrational and rotational levels of deformed isotopes of Nd and Sm. For example, the coupled channel-theory calculations for ^{150}Nd were made by considering the coupling of 0^+-2^+-4^+-6^+-8^+-10^+ (ground state rotational band) and 1^--3^--5^- (octapole vibrational band) with β_2=0.2848 and β_3=0.070. As for the 2^+ level at 1.77 MeV, the result of the coupled channel calculation with W_s=4.5 MeV agrees well with the DWBA calculation with W_s=9.13 MeV.

The measured inelastic scattering cross sections of Pd in the low energy region are rather larger than the evaluated data and it was suggested that this could be

reproduced by introducing the vibrational model with an enhanced p-wave neutron strength function.[6] At high energies, the DWBA calculation occasionally gives too high inelastic scattering cross sections in the mass range around A=100. At ECN, a coupled-channel analysis with a two-phonon vibrational model was made for ^{110}Pd. The analysis gave a large p-wave neutron strength function and reproduced well the cross sections measured at Geel for the one-phonon level at 373.8 keV.[7]

III. INTERCOMPARISON OF INTEGRAL TESTS

C/E-values of the sample reactivity worth and capture rate for FP nuclides are listed in **Table 1**. At JAERI, the STEK experiments and the capture rate measurements at CFRMF and EBR-II were analyzed using 70 group cross sections generated from JENDL-3. Average C/E values for the 5 STEK cores are given in the table. In Cadarache, analyses[8] of the Rossendorf experiments[9] measuring sample worths with typical SEG-lattice configurations and the STEK experiments are under way to test JEF-2. At ECN, JEF-1 was tested[3] with the STEK experiments. Since cross section data of JEF-1 and JEF-2 are the same for most nuclides except for the resonance parameters, the results of JEF-1 for hard spectra may be the same as those of JEF-2.

For the STEK experiments, the calculated worths are largely discrepant from the measured values for the weak absorbers, particularly oxide samples. Large discrepancy is also found for ^{100}Mo of the Rossendorf experiments. Its C/E-value of JEF-2 in SEG-7A having a hard neutron spectrum and energetically increasing adjoint spectrum can be interpreted with a too small calculated scattering effect (12% and 3% for inelastic and elastic contribution to the worth, respectively).[8] Perhaps, the major reason is too small inelastic scattering cross sections.

For the STEK experiments, the effect of direct inelastic scattering on the worth was examined for Zr and Mo isotopes and ^{150}Nd by comparing JENDL-3.1 and JENDL-3.2 in which the direct inelastic scattering cross sections are newly added for these nuclides.[10] For Zr and Mo, the direct inelastic scattering increases the worth (i.e., improves the C/E-values) as shown in **Fig. 2**, while improvement was insignificant for Nd isotopes because of their small direct inelastic scattering cross sections.

IV. NEUTRON SPECTRUM UNCERTAINTY

Neutron spectra of the STEK cores were calculated with the vectorized point-wise Monte Carlo code, MVP, using a three dimensional homogeneous model of the STEK reactor and corrected for a heterogeneous effect by the diffusion calculations. The results were compared with the original spectra reported from Petten. The present calculation gave almost the same spectra as the original ones which were obtained through the adjustment to reproduce the reactivity worths of standard samples. **Table 1** shows that the C/E-values in the second column calculated with the original spectrum are in good agreement with those in the third column obtained by the present spectrum within statistical errors of the Monte Carlo calculation. However, further calculations seem to be needed to obtain a definitive conclusion.

V. CONCLUSION

In the present work, it has been confirmed that the DWBA calculation is applicable for estimating the cross sections for one-phonon vibrational levels. The coupled channel theory is the best to estimate the excitation functions for both vibrational and rotational levels of deformed nuclei and for the mass range around 100.

The discrepancies of the measured and calculated sample worths in the STEK experiments are partially attributed to the unreasonable inelastic scattering cross sections. Modification of the inelastic scattering cross sections reduces the discrepancies in some degree. However, there are discrepancies for some strong absorbers and the standard samples such as carbon and oxygen whose cross sections are rather accurate. This suggests that there remain yet other factors such as errors in the adjoint spectra and resonance self-shielding effects.

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Table 1 Average C/E-values of JENDL-3.1, JEF-1 and JEF-2 for FP nuclides.

Nuclides	JENDL-3.1			JEF-2		JEF-1	
	STEK[2,b]	STEK[c]	CFRMF&EBR[2]	SEG-5[8]	SEG-7A[8]	STEK-1000[3]	S
Standard samples:							
B-10	0.98	0.96	–	1.00	1.00		
C-12	0.83	0.82	–	–	1.09	–	
Weak absorbers:							
Zr-92[a]	0.49	0.53	–	–	–	–	
Zr-96[a]	0.52	0.62	–	–	–	–	
Mo-94	1.11	1.01	–	–	–	–	
Mo-98	0.98	0.98	–	–	–	3.85	3.5
Mo-100	0.98	1.04	1.16	1.06	1.14	2.13	1.1
Pd-110	0.73	0.65	0.99	0.89	0.47	1.85	1.4
Ce-142[a]	0.67	0.68	–	–	–	1.28	1.2
Nd-146[a]	0.13	0.70	0.84	–	–	0.69	1.14
Strong absorbers:			1.24	–	–	–	1.16
Mo-95	1.01	0.97	–	–	–	1.39	1.27
Mo-97	1.00	0.96	–	1.13	0.96		1.02
Rh-103	1.04	1.01	–	0.95	0.96	1.12	
Pd-105	0.92	0.88	–	0.90	1.12	1.14	1.10
Ag-109	0.63	0.59	–	1.06	–	0.99	1.08
Cs-133	0.80	0.75	0.72	0.93	0.89	0.98	0.95
Nd-143	0.90	0.86	0.91	0.93	–	1.02	0.99
Nd-145	0.85	0.82	0.85	0.90	–	0.95	1.01
Sm-149	0.88	0.84	0.81	1.07	–	1.01	0.93
Eu-153[a]	0.92	0.89	0.83	1.19	1.50	0.97	1.01
			0.86	1.09	–	0.96	0.96
						–	1.06

N.B. a) Oxide sample. b) Using the ECN adjusted spectrum. c) Using the spectrum calculated by Monte Carlo m

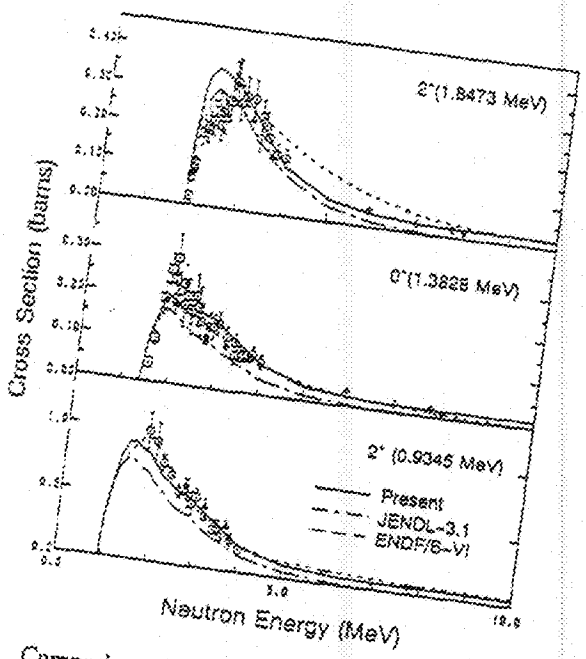

Fig. 1 Comparison of calculated and measured level excitation functions for ^{92}Zr.

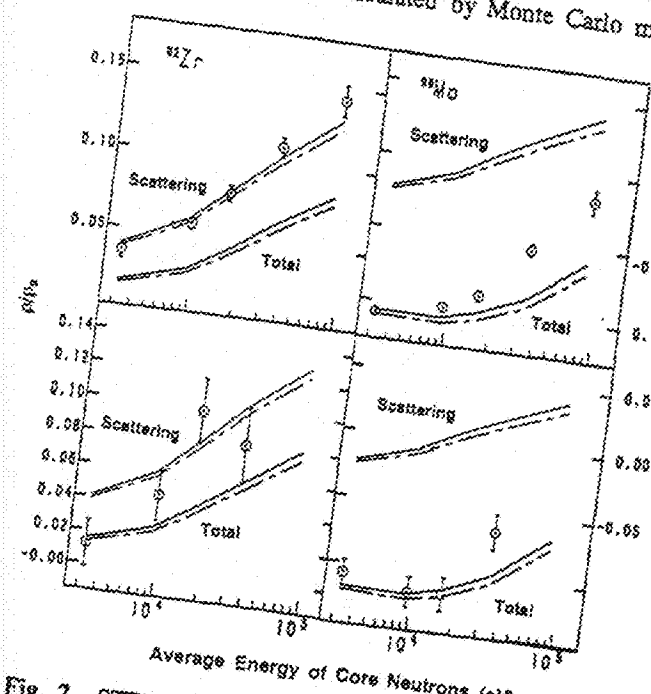

Fig. 2 STEK sample reactivity worth and its C/E value for $^{92}ZrO_2$ and ^{98}Mo samples. Solid line denotes JENDL-3.2, dash-doted line JENDL-3.1.