JEF-2.2 ANALYSES OF SMALL SAMPLE REACTIVITY WORTH MEASUREMENTS MADE IN THE SEG ASSEMBLIES.

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1. INTRODUCTION.

Small sample reactivity worth measurements have been made in the fast spectrum assemblies SEG built in the ROSSENDORF fast - thermal coupled reactor RRR/SEG. The pile oscillator technique was used and samples having a range of different sizes were measured. From these, extrapolated zero sample size reactivity worth values were derived, using calculated sample size corrections to improve the accuracy of extrapolation. (These corrections were each calculated using several different data sets). Thus the experiments provide data on both the infinite dilution reactivity worths and resonance shielding (or sample size) effects.

Measurements were made in different spectra and a special feature of the cores was that compositions were chosen so as to give either a flat adjoint spectrum, as in SEG-4 and 5, (to minimise the scattering contribution to the overall effect) or a strongly varying monotonic adjoint spectrum to enhance the scattering contributions (SEG-6 EK10 and EK45). Thus information is obtained separately on the capture and scattering contributions.

The data are normalised to measurements for a standard material having well-known cross-sections. The choice of standard introduces a small uncertainty because of differences between the C/E values for potential standards. In particular there is a difference in C/E-values for B-10 and U-235 and also between C and H (although the uncertainties for the latter are comparable with the differences). B-10 has been chosen as the standard for the measurements in the capture cross-section sensitive cores and C in the scattering cross-section sensitive cores.

The calculations have been made using the JEF-2/ECCO/ERANOS system. The cell code ECCO is used to derive broad group cross-sections for the various regions of the reactor, treating the heterogeneity effects. The whole reactor is calculated in RZ geometry using modules of the ERANOS system. The reactivity worths are then obtained using the perturbation theory module of ERANOS and the flux and importance spectra calculated for the central position of the core together with cross-sections for the sample derived using ECCO calculations which model the sample material in the environment of the central region of the core. ECCO uses the fine group (plus within group probability table) library derived from JEF-2.2 for these calculations . A calculational study of sample size effects has been made for three materials, Nb, Mo and Zr, measured in SEG-5. One dimensional cylindrical models representing the sample and the core environment were used in ECCO, the calculations being made for infinite dilution, and two sample diameters corresponding to the mean chords of representative sizes of sample. (These calculations are expensive and so have been limited to this number).

In the following sections the SEG-5 results (already reported to the JEF Project) are summarised, the SEG-6 (scattering cross-section sensitive) results are presented and the studies of sample size effects described. Preliminary calculations have also been made for SEG-4 but the definitive calculations await the processing of improved cadmium data, cadmium having been used to modify the spectrum in this core.

2. ANALYSIS OF THE SEG-5 RESULTS.

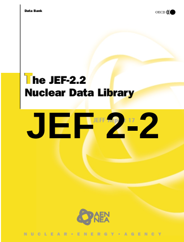
Measurements have been made for selected structural materials and fission product isotopes. These measurements are most sensitive to the capture cross-section. The C/E values for the extrapolated zero sample size values (CRW) are summarised in Table 1, the normalisation being to the measurement for the B-10 sample.

For Cd and Sm-149 calculation overestimates the effect by about 20% ± 9%. For Mo-95 and Rh-105 the discrepancies are marginally significant, an overestimation of 13% ± 10% for Mo-95 and an underestimation by 10% ± 7% for Rh-103.

3. ANALYSIS OF THE SEG-6 RESULTS.

These results are sensitive to the scattering cross-sections, the relative contributions to the total effect being given in Tables 2 and 3 together with the C/E values. The normalisation is to the measurement for carbon. Again suggestions can be given of the changes which would result in improved agreement between calculation and measurement, taking into account the results for SEG-5:

Significant discrepancies are observed for Mo, Fe, Cr, Ni, Zr, Ti, Cd, Be, Cu, Ta, Si and Co mostly at about the 10% level but for Be, Si and Co there is an overestimation by about 20 to 30%.



The following changes would improve the agreement:

(a). Average inelastic scattering cross-sections.
For Mo, Fe, Cr, Zr and Co the predominant effect is due to inelastic scattering. Taking into account the results found for the average capture effect in SEG-5 an increase of about 10% in the average inelastic scattering cross-sections of Zr, Fe, Cr, Mo and Ta is suggested.

Decreases in the average inelastic scattering cross-sections of Ni (by about 10%) and Co (by about 20%) are also suggested by the combined results from the two cores.

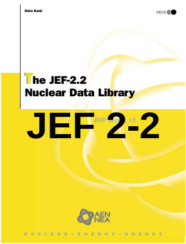
(b). Average elastic scattering cross-sections. For Be and Si the predominant component is elastic scattering for which a reduction of about 25% and 20%, respectively, is indicated.

4. ANALYSIS OF SAMPLE SIZE EFFECTS.

ECCO calculations have been made in cylindrical geometry for samples of Nb, Zr and Mo having diameters of 0.2 cm and 1.0 cm in a supercell representing the central region of the reactor. These have been followed by RZ geometry reactor calculations in which the samples have a height of 3.9 cm and the above diameters. Consequently the effective mean chords in the reactor calculations are 0.195 cm and 0.887 cm respectively. The results are shown graphically in Figs. 1, 2 and 3. It can be seen that the sample size effects are well predicted for Nb and Zr but that there is a discrepancy for the larger sized Mo sample for which there is an overestimation of the worth relative to the extrapolated zero sample size value. Using the JEF-2 calculated sample size effects to extrapolate the measured values to zero sample size results in values which are 2% higher for Nb and 3% lower for Zr but these changes are within the ranges of uncertainty. It is concluded that the resonance data for Mo, (or its processing) should be reviewed.

5. CONCLUSIONS.

The small sample reactivity worth measurements made in the SEG series of cores provide valuable information on the capture and scattering cross-sections of the major structural materials and also a verification of the resonance shielding treatment (of relevance also to Doppler effect predictions). Information is also given for absorber materials and selected fission product isotopes.



Some suggestions have been made concerning possible errors in the JEF-2.2 cross-section data but before clear conclusions can be drawn the results must be included in the overall data adjustment study.

CEA Cadarache, 30 November 1994.

Table 1 : C/E-values of standards, structural materials and fission product nuclides measured in SEG-5, related to the C/E-value of boron-10.

The error consists of the experimental error for the CRW of the material and of the accuracy of the C/E-value for boron-10.

MAT	CRW (mcent/g)	C/E (JEF-2)	Error (%)
B-10	- 1230 ± 20	1.000	2
Ta	- 31.5 ± 1.0	0.956	7
U-235	+ 31.2 ± 2.0	1.084	10
Mo	- 7.4 ± 0.5	0.964	10
Mn	- 12.0 ± 0.5	0.952	7
Cd	- 10.0 ± 0.5	1.215	9
Nb	- 10.0 ± 0.6	1.022	9
Cu	- 4.5 ± 0.5	1.119	14
Zr	- 1.05 ± 0.1	1.032	13
W	- 10.0 ± 0.5	1.085	8
Fe	- 0.7 ± 0.06	1.084	11
Cr	- 0.8 ± 0.06	1.032	10
Ni	- 1.3 ± 0.1	1.073	10
Co	- 20.0 ± 1.5	0.992	10
B-10	- 1174 ± 20	1.000	2
Mo-95	- 14.5 ± 1.0	1.133	10
Mo-97	- 14.0 ± 1.0	0.954	10
Mo-98	- 5.0 ± 0.6	1.061	15
Mo-100	- 4.1 ± 0.5	0.888	16
Rh-103	- 27.0 ± 1.0	0.901	7
Pd-105	- 30.2 ± 1.0	1.064	7
Ag-109	- 31.5 ± 1.5	0.929	8
Cs-133	- 19.5 ± 2.0	0.926	13
Nd-143	- 16.0 ± 1.0	0.896	9
Nd-145	- 18.0 ± 1.0	1.066	9
Sm-149	- 83 ± 5	1.191	9
Eu-153	- 75 ± 5	1.091	10

Results of SEG-6 EK10 using JEF2/ECCO/ERANOS:

$$C/E = \frac{C_i \; E_{ref} \; A_{ref} \; \rho_{ref}}{E_i \; C_{ref} \; A_i \; \rho_i}$$

keff = 1.0001
dcrit= 8.54 cm

MAT	Ai	Ei (mcent/g)	C/E rel.to C	error(%)	CAPT(%)	EL(%)	INEL(%)
C	12	-7.05 +- 0.06	1.000	4	0.4	98.5	1.1
B-10	10	-85.1 +- 5.0	0.973	9	90.5(n,a)	9.3	0.1
H	1	-1059 +- 10.0	1.067	8	0.	100	0.
Mo	95.95	-1.53 +- 0.03	0.965	5	23.4	13.4	63.2
Fe	55.85	-1.20 +- 0.02	0.890	5	6.1	26.5	67.4
Ni	58.71	-1.52 +- 0.05	1.121	7	35.3	41.2	23.5
Al	26.98	-2.09 +- 0.04	0.942	6	3.8	68.1	28.1
Zr	91.22	-0.99 +- 0.03	0.836	6	7.5	29.5	63.0
Ti	47.90	-1.62 +- 0.04	1.062	6	6.2	52.6	41.1
Cd	112.4	-1.71 +- 0.02	1.155	5	33.4	7.7	58.9
Pb	207.21	-0.27 +- 0.02	1.028	10	3.9	20.5	75.6
Bi	209.0	-0.29 +- 0.02	0.998	10	4.6	20.5	74.9
Mg	24.32	-3.03 +- 0.24	1.040	11	2.3	77.1	20.6
Be	9.013	-13.5 +- 0.2	1.312	5	6.1	82.2	11.7
W	183.86	-1.26 +- 0.04	0.949	7	27.1	5.3	67.6
Cu	63.54	-1.40 +- 0.04	1.075	6	18.5	26.9	54.6
Rh	102.91	-2.87 +- 0.13	1.049	8	55.7	6.7	37.6

Table 2 - Experimental CRW, C/E-values and total errors of sample materials in SEG-6 EK 10, and partial contributions to the reactivity effect

Results of SEG-6 EK45 using JEF2/ECCO/ERANOS

$$C/E = \frac{Ci \quad Eref \quad Aref \quad rhoref}{Ei \quad Cref \quad Ai \quad rhoi}$$

keff = 1.0001
dcrit= 8.55 cm

MAT	dens.	Ai	Ei (mcent/g)	C/E rel.to C	error%	CAPT%	EL%	INEL%
C	0.01948	12.01	-7.35 +- 0.06	1.000	3	0.4	98.6	1.0
B-10	0.01598	10	-95.9 +- 6	0.896	10	90.4	9.4	0.2
H	E-10	1	-1099 +- 10	1.071	8	0.	100	0.
Mo	E-10	95.95	-1.70 +- 0.04	0.913	5	23.2	12.8	64.0
Fe	E-10	55.85	-1.22 +- 0.04	0.916	5	6.1	25.9	68.0
Cr	E-10	52.01	-1.21 +- 0.04	0.915	5	5.7	33.2	61.1
Ni	E-10	58.71	-1.55 +- 0.05	1.133	7	35.9	39.6	24.5
Al	E-10	26.98	-2.00 +- 0.06	1.032	6	3.8	68.0	28.2
Zr	E-10	91.22	-1.01 +- 0.03	0.860	6	7.6	28.5	63.9
Ti	E-10	47.90	-1.93 +- 0.05	0.921	6	6.3	51.4	42.3
Cd	E-10	112.41	-1.89 +- 0.05	1.105	5	32.8	7.6	59.6
Pb	E-10	207.21	-0.32 +- 0.02	0.913	10	3.8	20.2	76.0
Bi	E-10	209.0	-0.30 +- 0.02	1.016	10	4.6	20.1	75.3
Mg	E-10	24.32	-3.01 +- 0.08	1.094	11	2.3	76.7	21.0
Be	E-10	9.013	-14.04+- 0.10	1.323	5	6.1	82.1	11.8
W	E-10	183.86	-1.34 +- 0.03	0.942	7	26.7	5.2	68.1
Cu	E-10	63.54	-1.45 +- 0.02	1.095	6	18.2	26.6	55.2
Au	E-10	197.0	-1.63 +- 0.07	0.963	9	43.3	3.7	53.0
Mn	E-10	54.94	-1.53 +- 0.03	1.076	6	8.9	30.5	60.6
Ta	E-10	180.95	-2.15 +- 0.02	0.895	5	49.7	2.8	47.5
V	E-10	50.95	-1.91 +- 0.05	1.016	7	3.4	43.5	53.1
Si	E-10	28.09	-1.82 +- 0.09	1.207	9	6.0	74.0	20.0
Nb	E-10	92.91	-1.96 +- 0.04	0.955	6	28.4	57.7	13.9
Co	E-10	58.94	-1.25 +- 0.02	1.241	6	8.1	31.5	60.4
U-235	E-10	235	+10.9 +- 0.07	0.978	5	6.5	0.3	6.1
						f:112.9		
U-238	E-10	238	-0.703+- 0.04	0.923	10	62.8	5.0	113.8
						f: 81.6		
Th	E-10	232	-1.35 +- 0.04	0.865	7	48.5	2.7	56.6
						f: 7.8		

Table 3 - Same, for SEG-6 EK 45

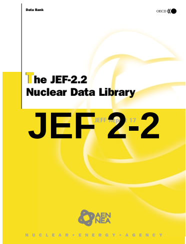
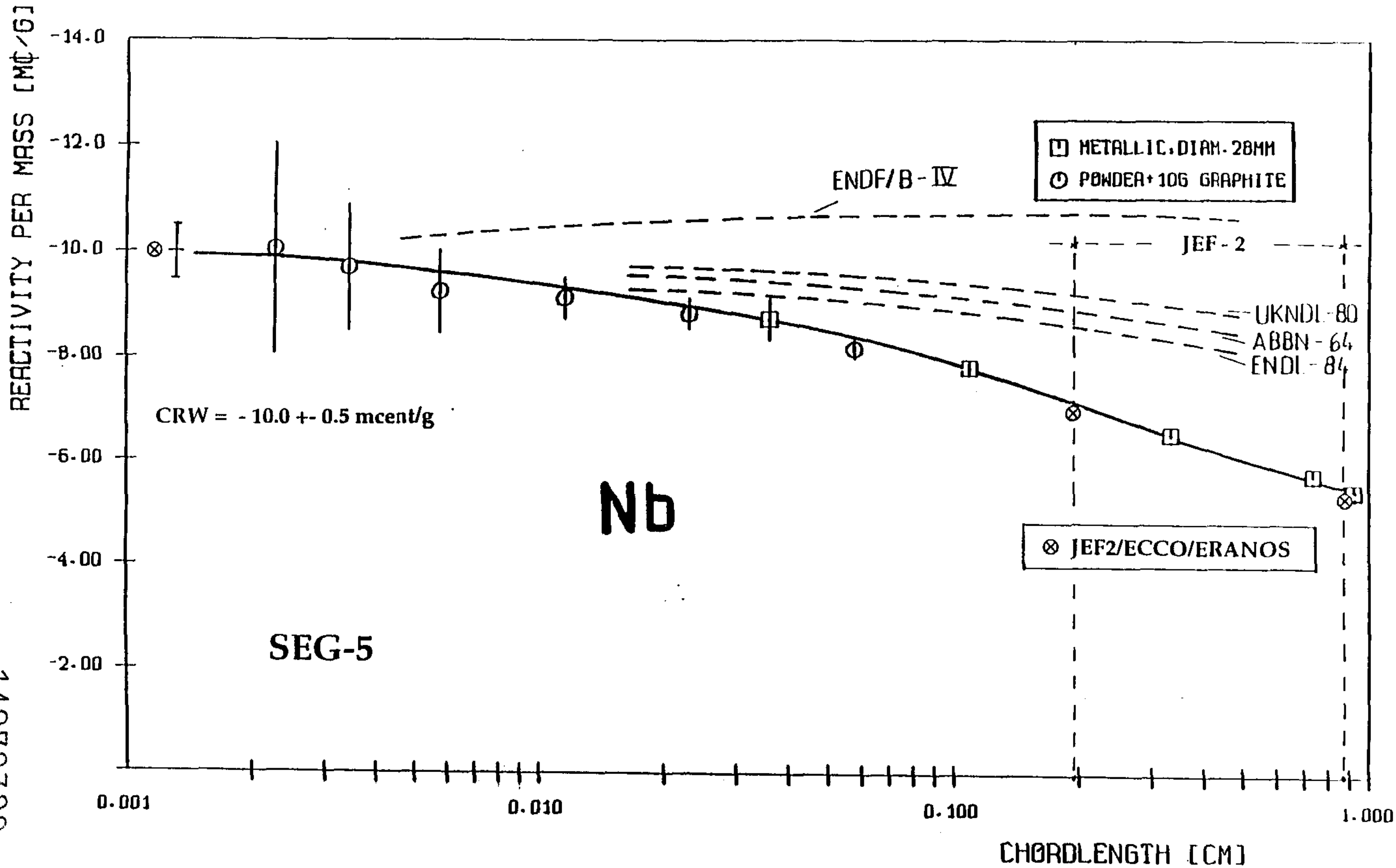


Figure 1 Variation of reactivity worth with sample size. Results for Nb.
Also shown are the variations following the application of corrections calculated using different cross-section libraries.



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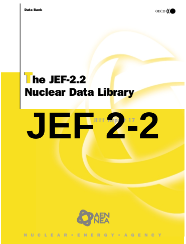

Figure 2 Variation of reactivity worth with sample size. Results for Zr. Also shown are the variations following the application of corrections calculated using different cross-section libraries.

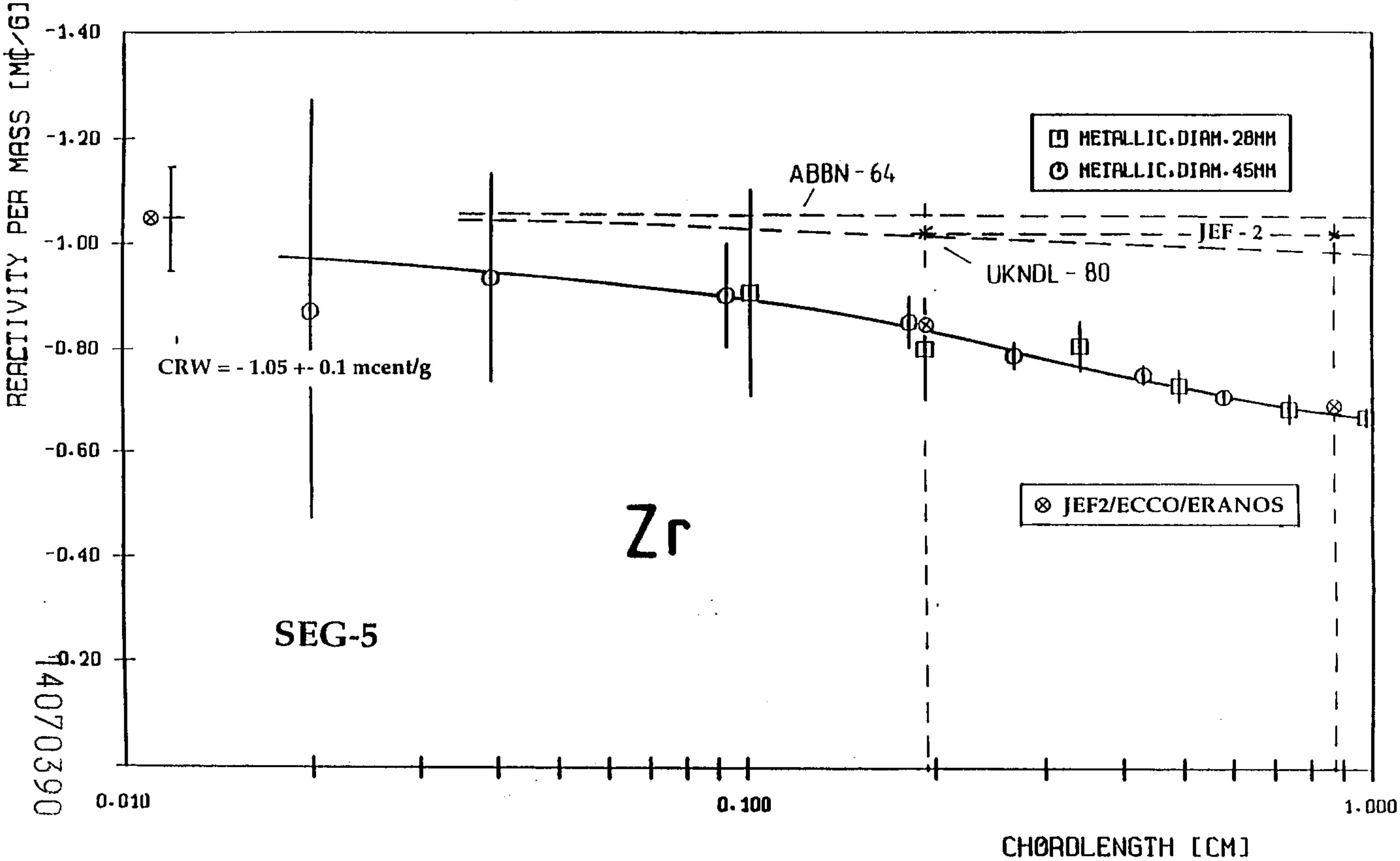

Figure 3 Variation of reactivity worth with sample size. Results for Mo.
Also shown are the variations following the application of corrections calculated using different cross-section libraries.