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INTERNATIONAL ATOMIC ENERGY AGENCY
CONFERENCE ON NUCLEAR DATA-
MICROSCOPIC CROSS SECTIONS AND OTHER
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CAPTURE CROSS SECTION MEASUREMENTS FOR SOME MEDIUM AND HEAVY WEIGHT NUCLEI USING A LARGE LIQUID SCINTILLATOR [1)]

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1. Introduction

In the past few years many neutron capture cross sections in the kev region have been measured, since they are of interest for nuclear reaction theory and for the design of fast reactors. But there are still many materials not yet investigated, and there are large discrepancies among existing results; thus further experiments are required.

We have measured neutron capture cross sections of 12 elements in the energy range from 10 to 150 keV at a pulsed Van de Graaff Generator; a large liquid scintillator was used to detect capture events in the sample. Capture cross sections can be determined in this experiment relative to a known standard cross section.

In the present work all measurements are based on the capture cross section of gold as standard. It can be measured absolutely with good accuracy at certain energies by activation methods, as Pönitz points out in his paper [1]. The capture cross section curve for gold recommended in that paper was used here for normalization of all other capture cross sections.

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1) Work performed within the association in the field of fast reactors between the European Atomic Energy Community and Gesellschaft für Kernforschung mbH, Karlsruhe

2. Experimental Method

The experimental arrangement was similar to that described by Gibbons et.al. [2]. A broad neutron spectrum is produced by the $Li^7(p,n)$ reaction in a thick lithium metal target. Neutron energies are determined by time-of-flight. The well collimated neutron beam is incident on the sample located in a hole at the center of a liquid scintillator tank of 1.1 m diameter. The two samples used for the relative measurement are interchanged at short time intervals controlled by a current integrator for the proton beam. The timing resolution of the detector was 3 ns, accelerator burst width was 10 ns, thus at a flight path of 1.5 m the overall resolution was 7 ns/m. This resolution is sufficient for the present investigations; but it can be improved for future experiments to 2 ns/m by bunching the proton beam to 1 ns pulse width.

The efficiency of the detector for capture events in the sample is

$$\varepsilon = p_{ne} \cdot p_b,$$

where p_{ne} is the probability that not all capture γ-rays of a cascade escape without interaction from the scintillator, and p_b is the probability that a detector signal from a capture event exeeds the discriminator bias level. An exact calculation of p_{ne} would be very complicated and would require detailed knowledge of the γ-ray spectra. However, p_{ne} can be estimated with reasonable accuracy for a scintillator of this size from a calculated efficiency curve for single γ-rays. Such an estimate suffices because of the high average multiplicities of capture γ-ray cascades from heavy nuclei. We estimate $p_{ne} = 0.96 \pm 0.03$, where the uncertainty applies even to unfavourable cases with an appreciable admixture of high energy transitions, such as gold.

For the determination of p_b one has to evaluate the capture pulse height spectra. In the present experiment capture pulse height spectra were taken simultaneously with the time-of-flight spectra. Subtraction of background for the pulse height spectra was performed by means of a time gate set alternately on time regions of capture events and of background. The high background does not allow an exact determination of the pulse height spectra below γ-ray energies of 1 Mev. Only extrapolations with an uncertainty of about 5 % are possible.

The capture cross section measured relative to a standard cross section σ_{st} is

$$\sigma_\gamma = F \cdot \frac{N}{N_{st}} \cdot \frac{\varepsilon_{st}}{\varepsilon} \cdot S \cdot \sigma_{st}$$

where F is a factor which is determined by the two sample thicknesses, N, N_{st} are the two counting rates after subtraction of background, S is the ratio of the multiple scattering corrections [3] made for the two samples. The index st refers to the standard.

For the total error in σ_γ we get the following contributions:

The error in $\varepsilon_{st}/\varepsilon$ based on the above estimate is 8 %.

For sample thicknesses of about 1 mm as used here the relative scattering correction [3] given by S is less than 4 %, its error is estimated to be less than 1 %. Resonance self shielding effects, which are even smaller than the multiple scattering corrections and largely compensate in relative measurements, are neglicted here. This may introduce an error of less than 1 %.

The statistical error in the ratio of the counting rates N/N_{st} is important only in the low energy tail of the neutron spectrum, where we have a poor signal to background ratio. The statistical accuracy below 20 kev was improved by combining channels in the time-of-flight spectra; as a result, the energy resolution is reduced. Then we obtain a statistical accuracy of about 5 % at 15 kev, 2% at 20 kev and better than 1 % above 30 kev for typical runs.

The error in the standard capture cross section of gold σ_{st} quoted by Pönitz [1] is 8 % below 40 kev and increases to 12 % at higher energies.

Summing of all these errors results in a total error varying from 12 % at low energies to nearly 15 % at energies above 40 kev.

3. Measurements and Results

The standard capture cross section of gold is accurately measured by several methods at certain energies as reported by Pönitz [1]. The shape of this cross section is known with less accuracy. Therefore an additional

time-of-flight measurement for the determination of this shape was performed by comparison with the shape of the cross section for the $Li^6(n,\alpha)$ reaction as given by Schwarz et.al. [4]. For this measurement a 1 mm thick glass scintillator with enriched Li^6 was mounted at some distance from the phototube in order to minimize backscattering effects. The resulting capture cross section which was normalized at 30 kev to the value given by Pönitz [1] agrees with other measurements renormalized by Pönitz at low and at high energies. But there are considerable deviations between 30 and 100 kev. In the region of maximum deviations near 60 kev the results of this measurement are about 17 % above those of several other experiments.

The reason of these descrepancies is not yet understood. Therefore Pönitz assumes in his evaluation of several gold cross section measurements (including the present one of the shape) a mean curve with a large error in this energy region which is represented by the solid line in Fig. 1. The points in this figure show the results of the experiment described above, normalized to the smooth curve of Pönitz. This cross section was adopted as standard for the other cross section measurements of this work.

The shape of the capture cross section of gold as observed with the energy resolution of this experiment, is not completely smooth but shows an intermediate structure. This structure should be taken into account in comparing various results at different energies, e.g. the measurements at 24 and 30 kev by several authors. A similar structure can be seen in other cross sections also, but it is most pronounced for elements with a single isotope such as Au and Nb.

Considering the limits of error, we find that the measured capture cross sections of Ta, Mo and In (Fig. 2) agree surprisingly well with the recommended curves which Pönitz has extracted from other experiments after renormalization to the recommended Au cross section. The agreement for W is not quite as good, but is within the limits of error. Ag (Fig. 3) is in rather good agreement with the evaluation of Pönitz. It is interesting to compare Re with the data of Stupegia et.al. [5] since they represent an absolute activation measurement. The agreement is not very good for all energies, but in the region where the largest deviations occur (near 30 kev) the errors of the two measurements still overlap. For two energies, 30 and 65 kev, there exist still other data of Macklin et.al. [6] which are 40 % below the present curve.

The shape of the Re capture cross section shows a steep decrease near 130 kev which must be due to inelastic scattering. A similar effect is observed for W (Fig. 2) near 100 kev. For the capture cross section of Hf given in Fig. 3 no other data in this energy region are known, but the present measurement seems to join well the data of Block et.al. up to 8 kev [7]. The present data for Cd, as well as for Pd and Nb (Fig. 4) show systematic deviations from the values quoted in [8]. They agree quite well below 40 kev, but at higher energies the curves of [8] are almost 20 % below ours. Obviously these discrepancies show a similar tendency as those for Au and must be ascribed to differences in the standard cross sections. For Nb there is still another measurement above 175 kev reported by Diven et.al. [9] which joins the present curve very well. For Cs only one measurement up to 40 kev, made by Popov and Shapiro [10] at the lead slowing down time spectrometer, exists and differs by 30 % from the present results.

Conclusions

The capture cross sections given in this work indicate that the accuracy for relative measurements is rather good. This is obvious from the good agreement with most of the curves recommended by Pönitz, which are all renormalized to the same cross section standard. Nevertheless there are large discrepancies in the absolute cross section values based on different standard cross sections which indicate that probably the differences are mostly due to errors in these standard cross sections. Though the capture cross section of gold has been previously investigated with considerable effort, its shape is known in some regions only with a large uncertainty. Since we hope that this accuracy can be improved by some future experiments which we plan, the absolute cross section data given in the present work should be considered as preliminary. There might be slight changes in the shape of the capture cross section of gold, which would cause a renormalization of the present data.

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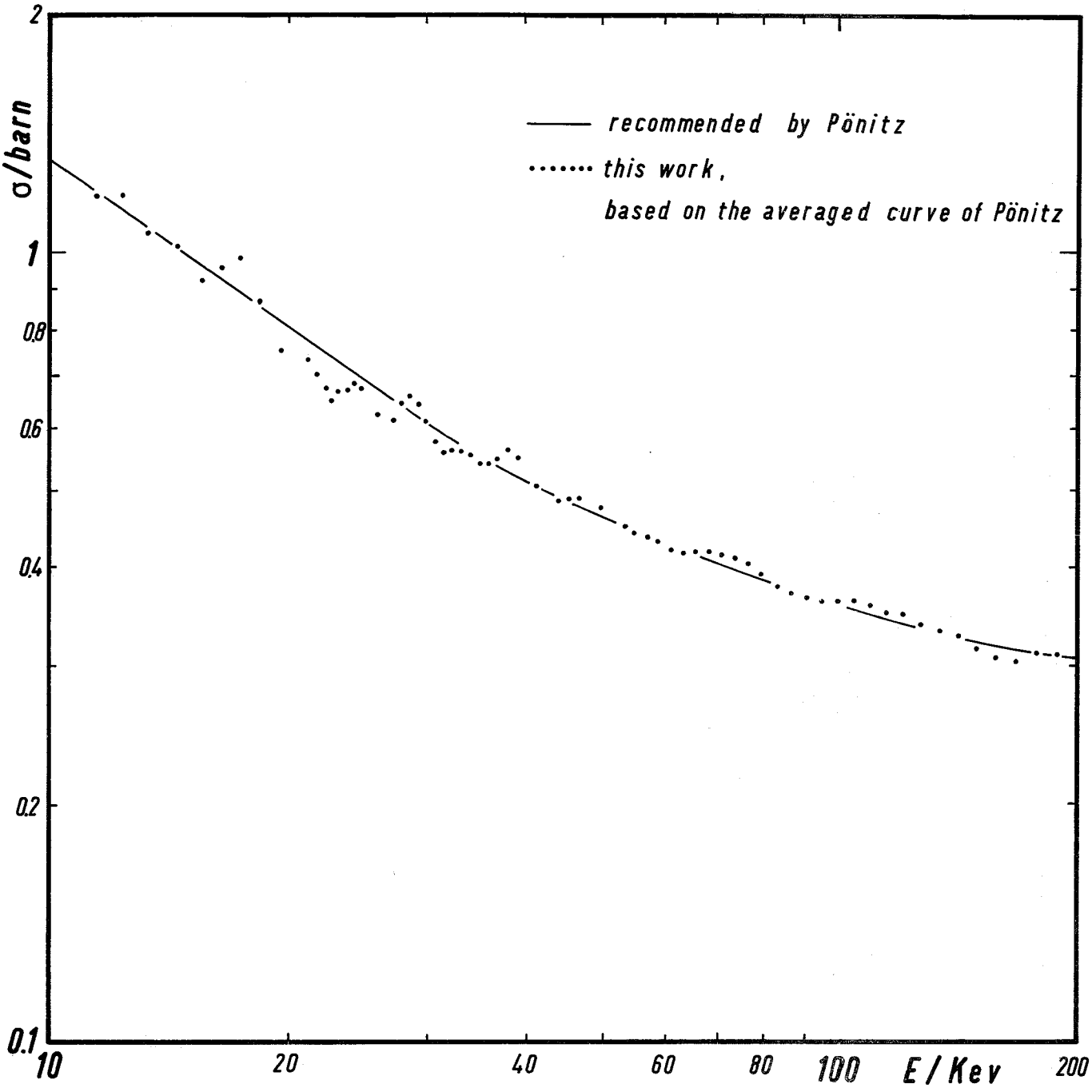

Fig. 1. Capture cross section of Au, normalized at 30 Kev.

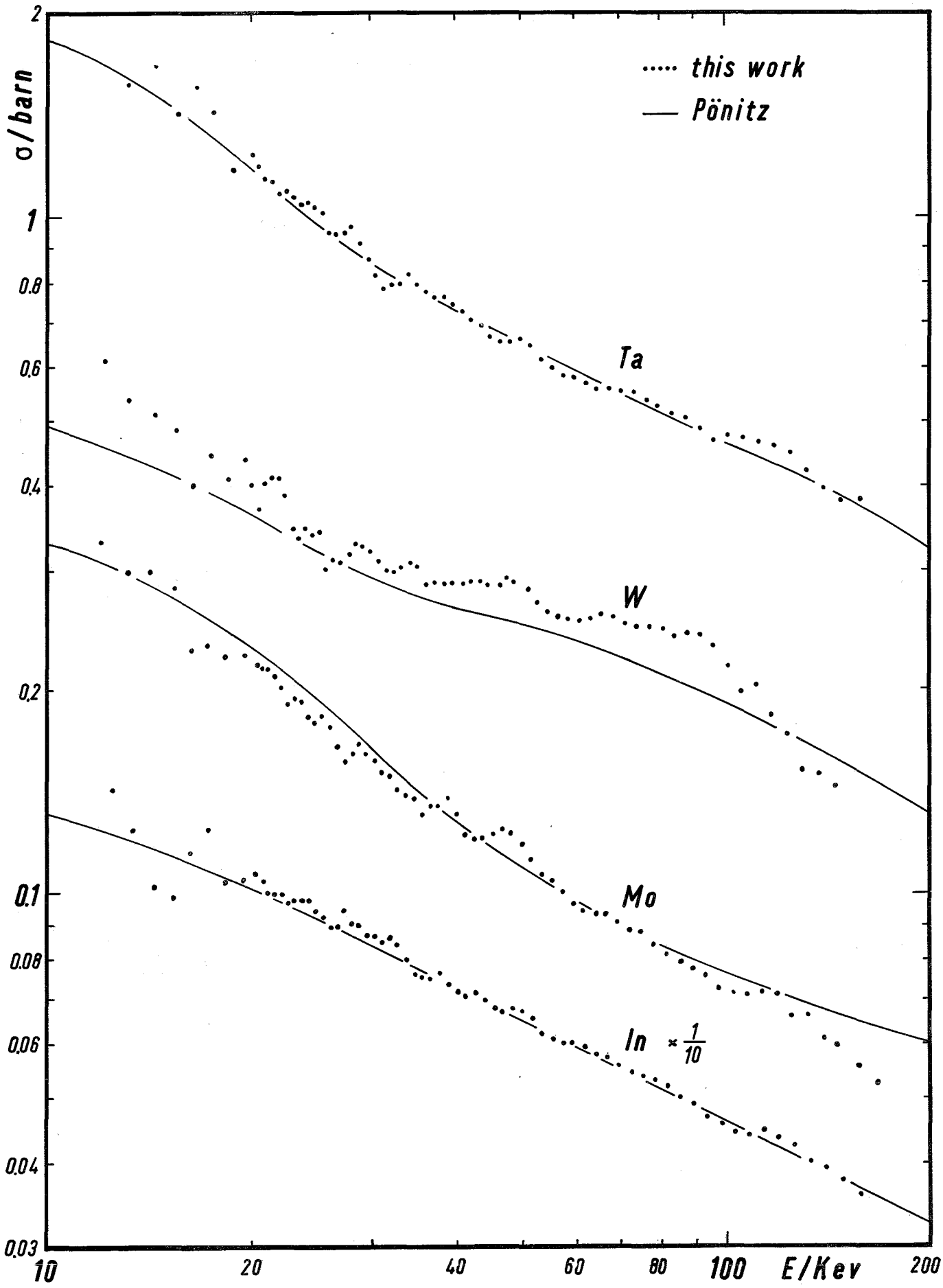

Fig. 2. Capture cross sections of Ta, W, Mo, In.

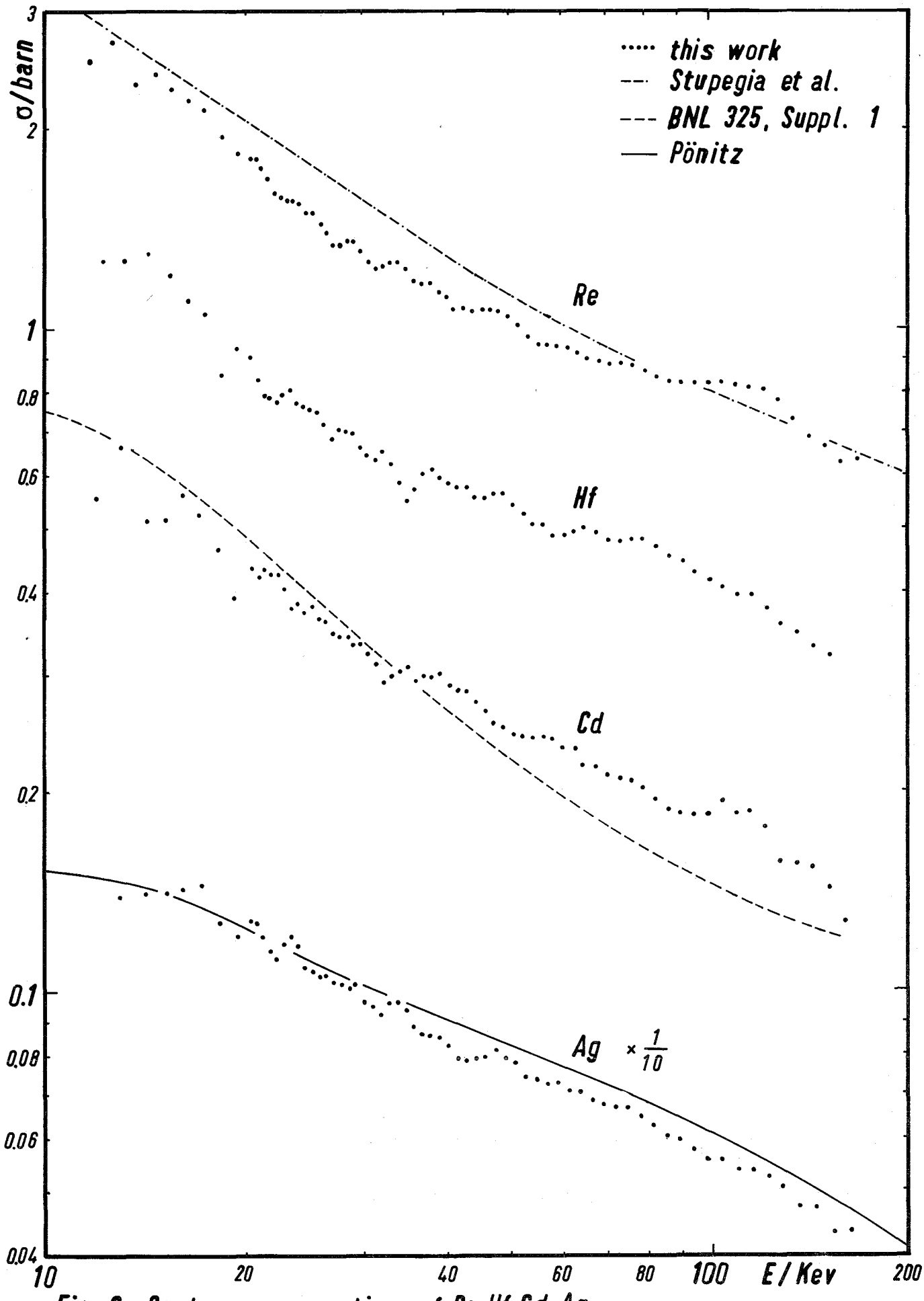

Fig. 3. Capture cross sections of Re, Hf, Cd, Ag.

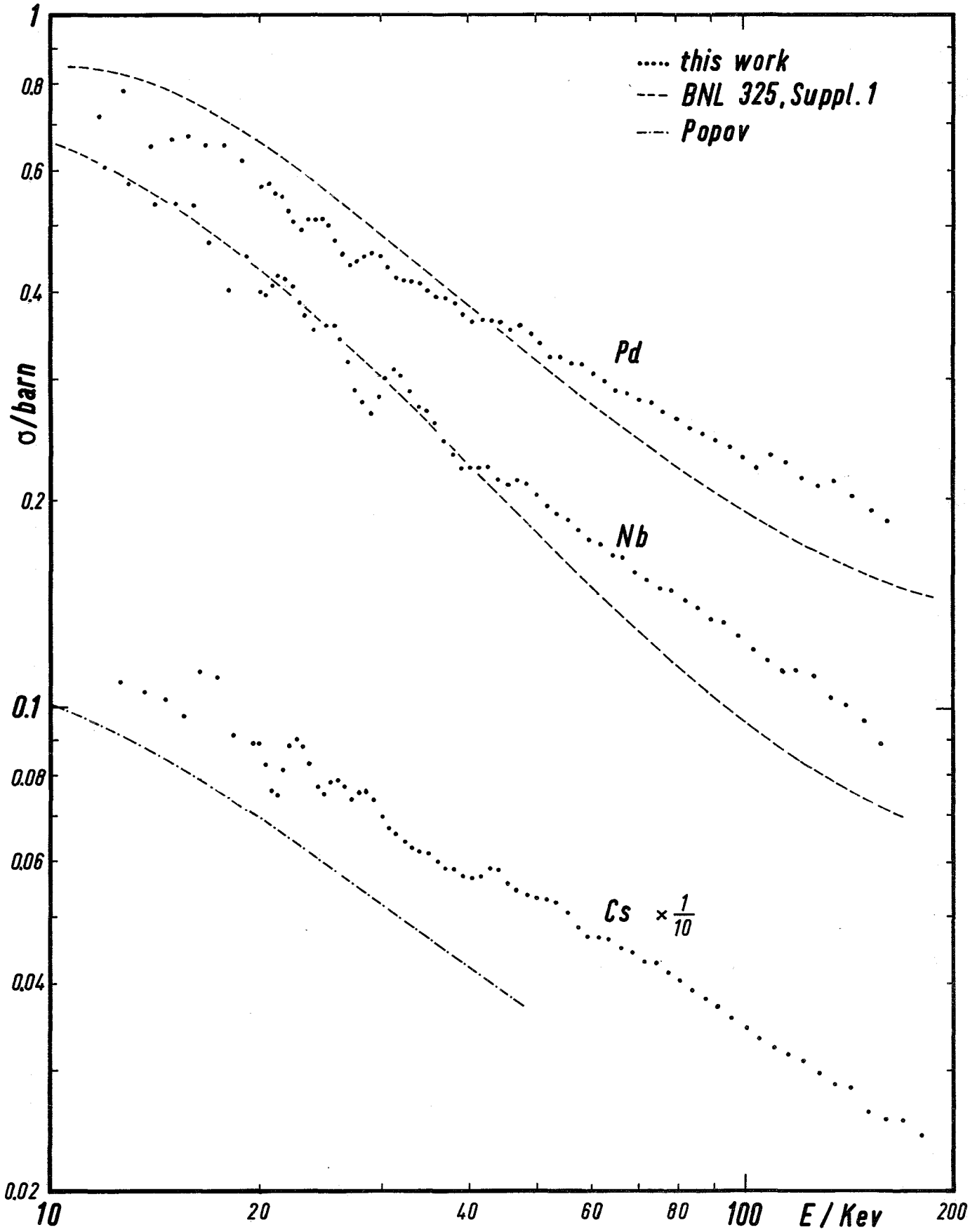

Fig. 4. Capture cross sections of Pd, Nb, Cs.