NEANDC (E) - 182 U Vol. V
INDC (Ger) - 19/L + Special

PROGRESS REPORT ON NUCLEAR DATA RESEARCH IN THE FEDERAL REPUBLIC OF GERMANY

for the Period January 1, 1976 to March 31, 1977

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Editor:
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P R E F A C E

This report is prepared for nuclear data research information exchange among member states of IAEA and NEA. It brings together reports from the GfK Karlsruhe, the EIT Karlsruhe, the KFA Jülich, the Universities of Hamburg, Kiel, Mainz and Munich, the PTB Braunschweig and from the ZAED Karlsruhe. The publication of this report was supported by the Fast Breeder Project of the Karlsruhe Research Centre.

All contributions are presented under a laboratory heading. Where the work is relevant to requests in the World Request List for Nuclear Data Measurements, WRENDA 76/77 (INDC(SEC)-55/URSF) the corresponding request numbers are listed behind the titles and the authors' names of the contributions.

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INSTITUT FÜR ANGEWANDTE KERNPHYSIK
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1. Isochronous Cyclotron

1.1 Fission Cross Section Ratios of ^{238}U, ^{239}Pu and ^{240}Pu in the Energy Range from 0.5 - 20 MeV

S. Cierjacks, K. Kari, B. Leugers, D. Erbe, G. Schmalz

(Relevant to request numbers: 671203, 691416, 693065, 714020, 732112, 742086, 742136, 754019, 661049, 691439, 691467, 692426, 693070, 714024, 721086, 741125, 742006, 742099, 754009, 762211, 671130, 714030, 721088, 721091, 742008, 742022, 742105, 754003, 762213, 763005, 763006)

The fission cross sections of ^{238}U, ^{239}Pu and ^{240}Pu have been determined in the energy range from 0.5 - 20 MeV (Pu-isotopes) and from 1.2 - 30 MeV (^{238}U) relative to the fission cross section of ^{235}U. The measurements were carried out at the neutron time-of-flight spectrometer using the 57 m-flight path for ^{238}U and the 12 m-flight path for the Pu-isotopes. ^{235}U- and ^{238}U- or Pu-foils were irradiated in series in the same neutron beam. Fission events were measured by gas scintillation counters. The results of the present data for ^{239}Pu and ^{240}Pu are shown in Figs. 1 and 2. The data of the present work characterized by the open circles have a statistical accuracy of better than 2 % in most of the data points. Part of the results were presented at the NEANDC/NEACRP Specialists Meeting on Fast Neutron Fission Cross Sections of U-233, U-235, U-238 and Pu-239 at the Argonne National Laboratory.

In Figs. 1 and 2 our data are compared with recent results obtained in the Lawrence Livermore Laboratory (1) and with evaluated data of Hunter et al. (2). It can be seen that the ^{239}Pu results are in reasonable good overall agreement with the LLL data except in the energy range above $\sim$ 16 MeV. For ^{239}Pu an energy shift between both sets seems to appear. This is most apparent in the decay regions near 6 and 12 MeV.

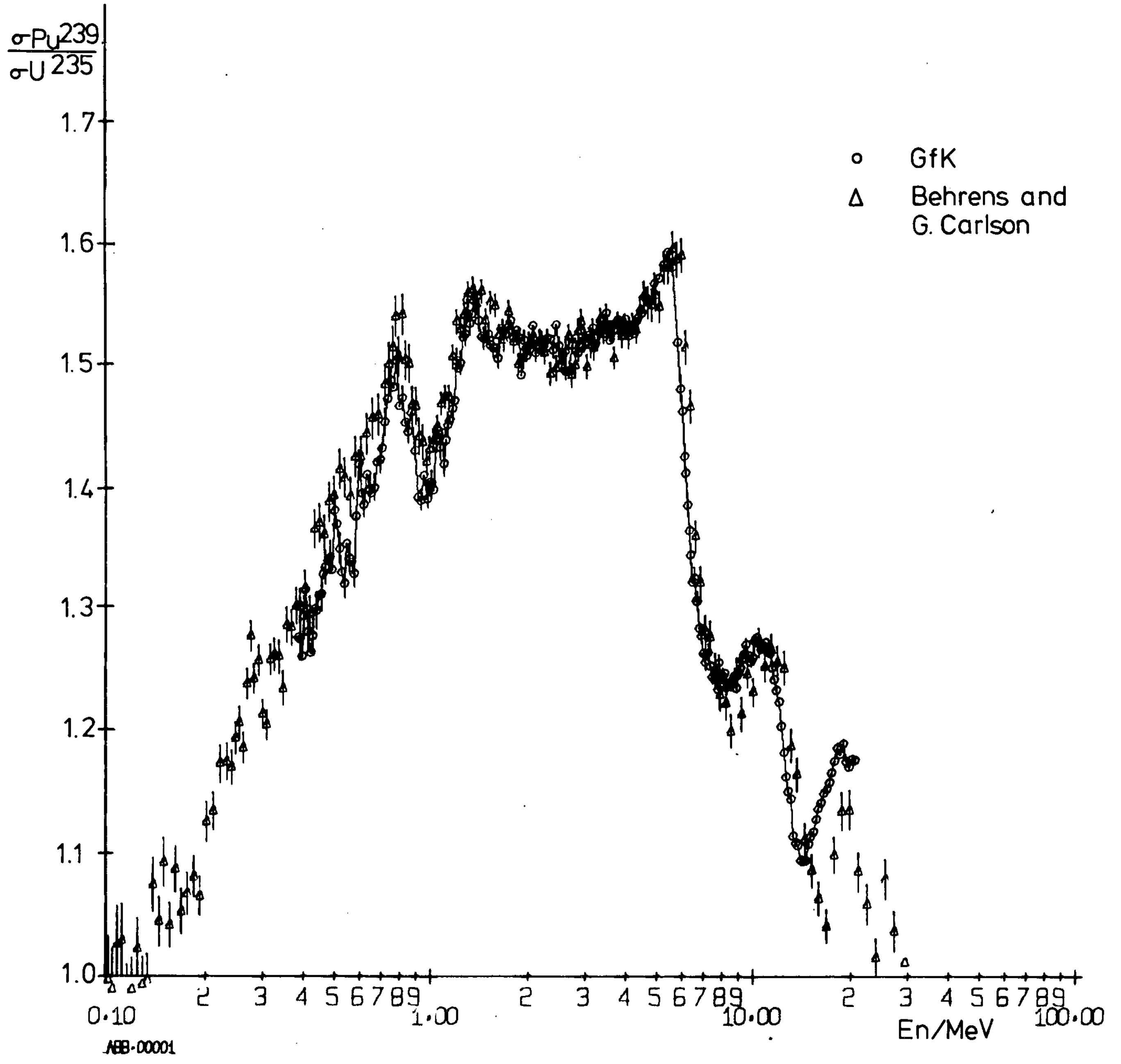

Fig. 1 Fission cross section ratio of $^{239}Pu/^{235}U$. The results of the present work are compared with new data measured in the Lawrence Livermore Laboratory by Behrens and Carlson (ref. 1).

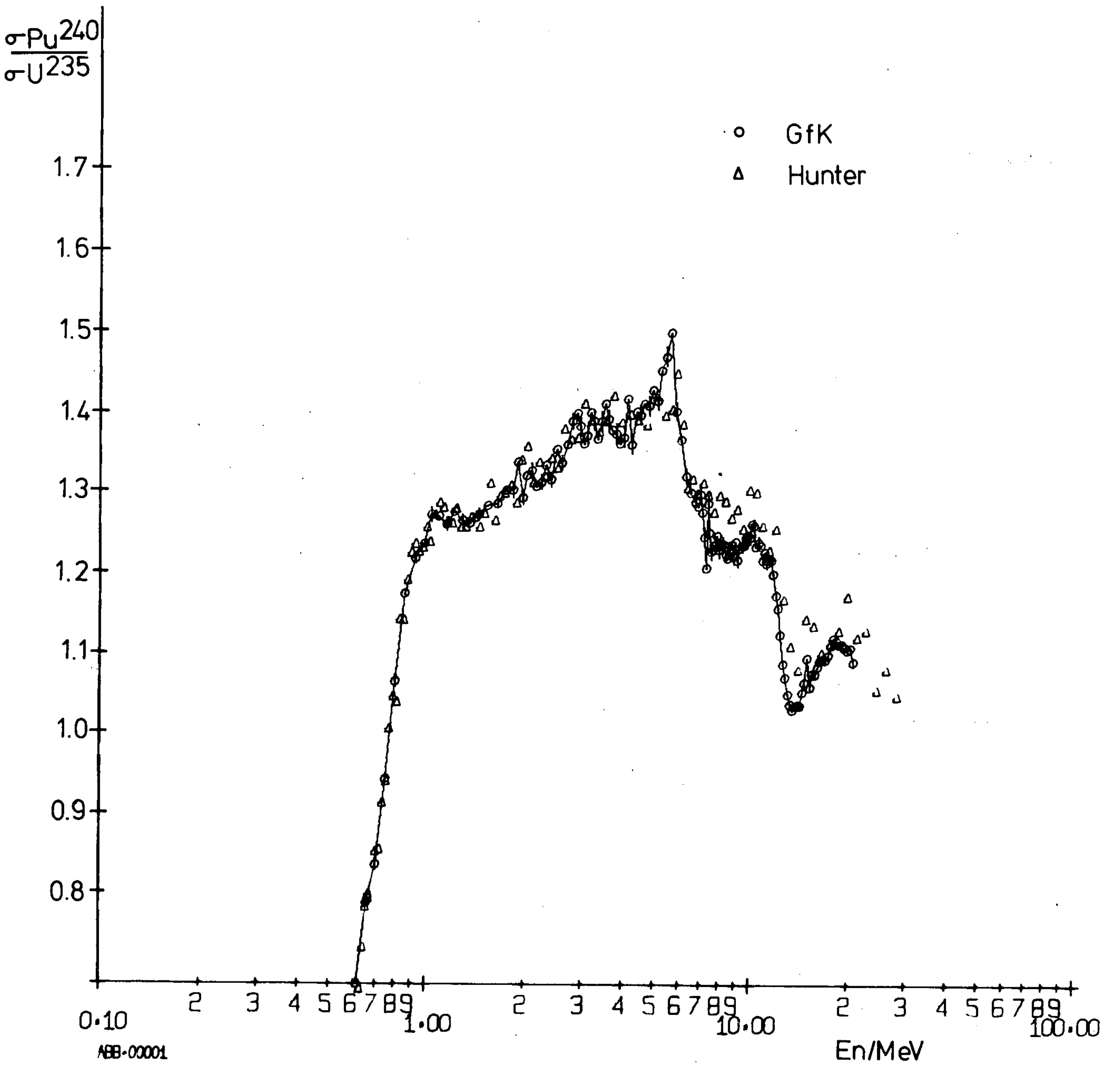

Fig. 2 Fission cross section ratio $^{240}Pu/^{235}U$. Present results are compared with evaluated data from the Los Alamos Scientific Laboratory (ref. 2).

1.2 Absoulte Fast Neutron Fission Cross Sections of ^{235}U, ^{239}Pu and ^{240}Pu

K. Kari, S. Cierjacks, B. Leugers, D. Erbe, G. Schmalz
(Relevant to request numbers: 693765, 714020, 732112, 742086, 742136, 754019, 691439, 691467, 692426, 693070, 714024, 742006, 742099, 754009, 762211, 721088, 721089, 742008, 742002, 742105, 754003, 762213, 763005, 763006)

Absolute fission cross sections of ^{235}U, ^{238}U, ^{239}Pu and ^{240}Pu were determined from the same experiment described in the above section 1.1. This determination was possible since the fast neutron flux was measured simultaneously using a novel fast neutron transmission flux detector described elsewhere (3). Flux determination was accomplished separately between 0.5 and 6 MeV and 5 - 20 MeV with a small interval of overlap. Since the entire transmission of the flux detector is higher than 99 %, flux measurements could be performed simultaneously in the irradiating neutron beam. The ultimately achieved accuracy of the flux determination was better than 3 % in the range from 1 - 20 MeV. A new result for the fission cross section of ^{239}Pu is shown in Fig. 3. For comparison the evaluated data of ENDF/B IV are included in the figure (solid line).

1.3 Γ-ray Production Cross Sections from Inelastic Neutron Scattering on ^{238}U

F. Voß, S. Cierjacks, D. Erbe, G. Schmalz
(Relevant to request numbers: 692393, 742083, 754021, 691270, 714018)

Previous evaluations of the experimental results for the γ-ray production cross sections from inelastic neutron scattering on ^{238}U were continued and have been finalized. The data had been measured by time-of-flight employing the 57 m-flight path of the KIC neutron spectrometer. The γ-rays were detected by a 42 ccm Ge(Li) detector placed at a backward angle of 125°. For the scattering sample a ringe geometry was chosen. As a result of the evaluations the excitation functions between threshold and 5.5 MeV are now available for the following γ-transitions in ^{238}U: 680, 927.931, 997, 1060 and 1061 MeV. As an example for the obtained results Fig. 4 shows the excitation curve for the production of the 635 keV γ-line, deexciting the 680 keV level in the residual nucleus. The error bars assigned to our data include statistical and systematical errors of the measurement. The latter are mainly due to

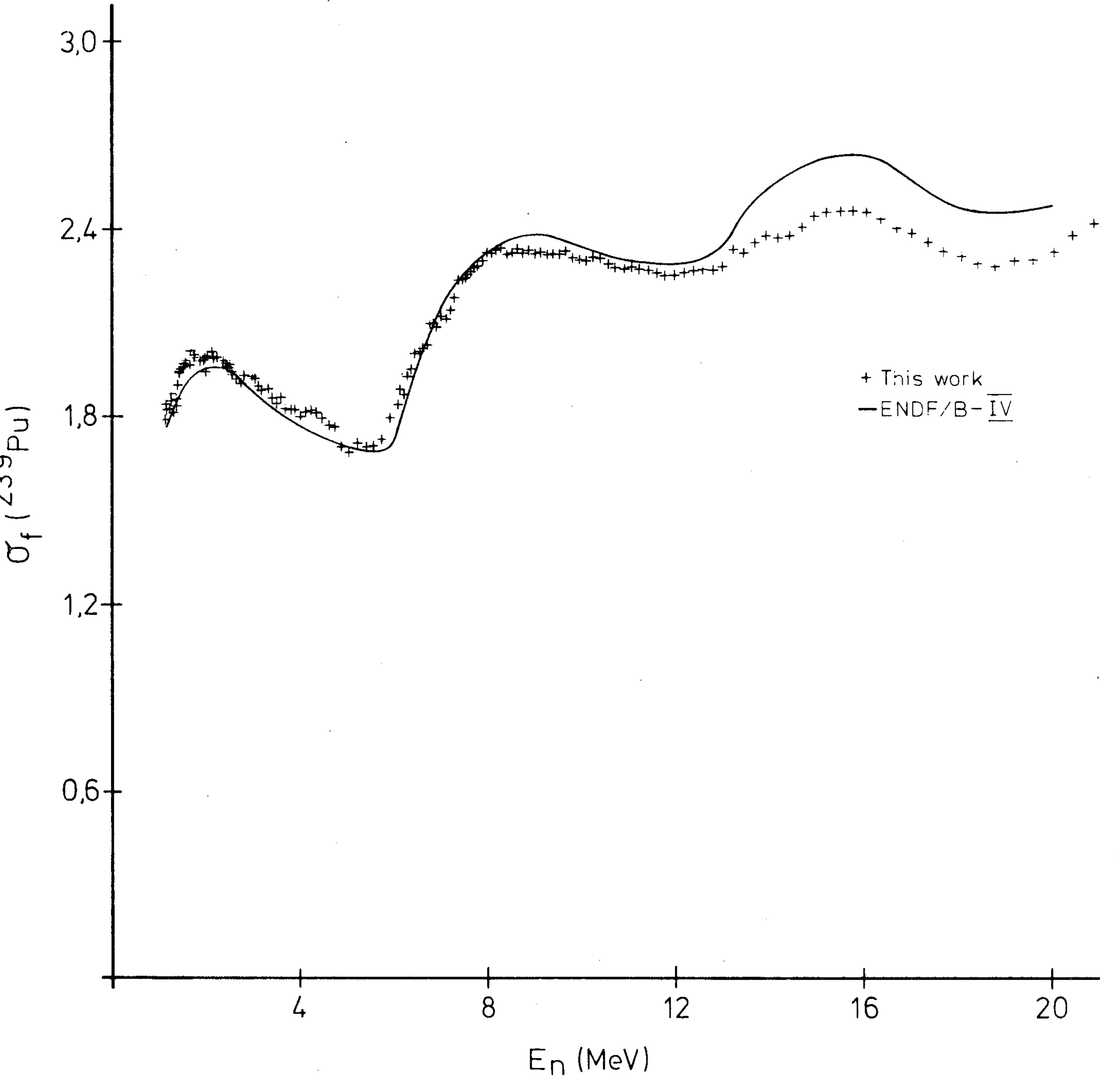

Fig. 3 Fast neutron fission cross section of ^{239}Pu. The data determined in this work are shown together with evaluated data of ENDF/B-IV.

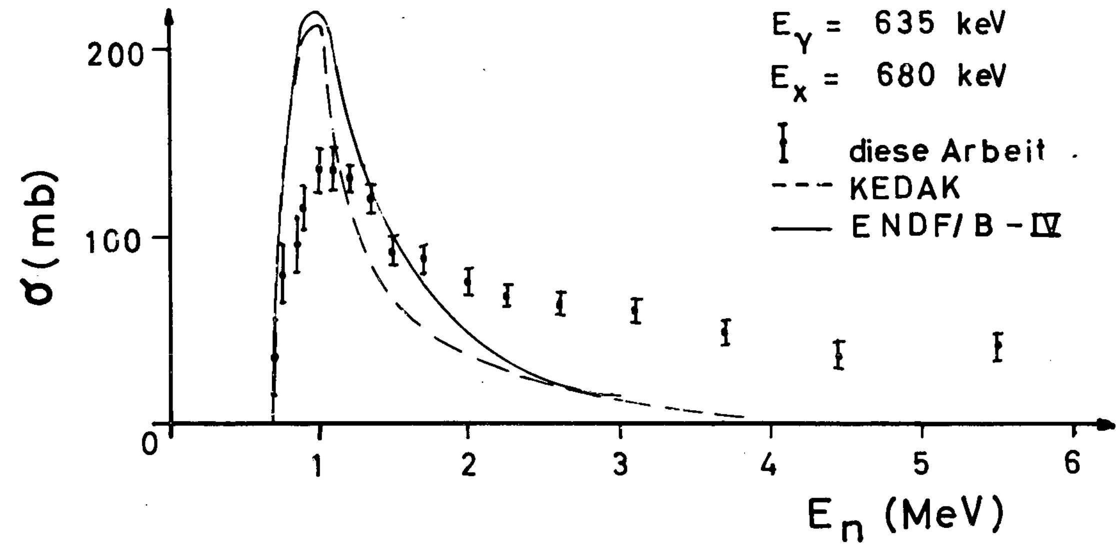

Fig. 4 Cross Section for the production of the 635 keV γ-line from inelastic neutron scattering on ^{238}U. The measured data from the present work are compared with evaluated data from the files KEDAK 3 and ENDF/B-IV.

uncertainties from multiple scattering corrections, background subtraction, flux determination and deflector efficiency calculations. The experimental values are compared in Fig. 4 with evaluated inelastic scattering cross sections. The differences between measured and evaluated data above about 1.5 MeV are mainly due to the feeding from higher levels excited also in inelastic scattering. No corresponding contributions are included in the inelastic scattering cross section given for comparison. At lower energies, however, the presently determined cross sections are up to 30 % lower than the evaluated data. A similar situation was found for the other five excitation functions. This deviation of our results from previous measurements in other laboratories is in qualitative agreement with the results from integral measurements (4) which require a 20 - 30 % reduction of the inelastic scattering cross sections of ^{238}U between about 1 - 3 MeV.

1.4 Precision Measurement of Neutron Resonance Energies in the MeV Region

F. Voß, G. Schmalz, S. Cierjacks

The INDC Subcommittee on Standards and Discrepancies initiated activities to determine accurate energies of neutron resonances, which could be used as recommended standards, in order to remove discrepancies in the neutron energy scales of neutron cross section determinations from different laboratories. As a contribution to this activity some recently measured high-resolution total neutron cross sections were examined and suitable resonances were selected. In the available measurements high accuracy was achieved employing the 190 m flight path of the KIC neutron spectrometer and a 2 ns channel width. As possible candidates for standards, a few narrow neutron resonances of ^{17}O and ^{25}Mg were selected. The corresponding resonance energies are listed in Table 1 for oxygen and Table 2 for magnesium. The errors given in the tables can further be reduced to a few tenth of 2 nsec (the present channel width) by a Gaussian fit to the resonance to determine the accurate peak position. If desired by the users an additional improvement could also be achieved by a new measurement with a further reduced channel width of 250 psec. In this case an accuracy of $\Delta E/E = 10^{-5}$ seems to be achieveable.

Table 1

Position of resonance maxima in the total cross section of oxygen

(E_n in keV)

Present experiment	Cierjacks (5)	Johnson et al. (6)	Davis et al. (7)
1652.5 $\pm$ 0.35	1651 $\pm$ 1	1651 $\pm$ 2	
1835.4 $\pm$ 0.4	1833 $\pm$ 1	1833 $\pm$ 2	
3212.4 $\pm$ 0.6			
3441.3 $\pm$ 0.7			
3768.1 $\pm$ 1.2	3765 $\pm$ 4		3765 $\pm$ 3
5125.0 $\pm$ 1.9	5122 $\pm$ 4		5122 $\pm$ 4
5918.9 $\pm$ 2.4	5906 $\pm$ 7		5914 $\pm$ 5
6402.7 $\pm$ 3.6	6386 $\pm$ 8		6395 $\pm$ 7
7201.3 $\pm$ 3.2	7193 $\pm$ 9		7200 $\pm$ 8

Table 2

Position of resonance maxima (minima) in the total cross section of magnesium

E_n (keV)	ΔE_n (keV)	E_n (keV)	ΔE_n (keV)
1022.7	0.2	2262.6	1.5
1280.9	0.25	2821.9	1.5
1567.4 (min)	0.3	3044.7	0.9
1710.2	0.7	3870.9	1.8
1814.2	0.7	4228.9	1.4
2078.9	0.9	4864.3	1.8

1.5 The Use of ^{237}Np and ^{238}U as Possible Standards for the MeV Region

S. Cierjacks

The aspects of using the fission cross sections of ^{237}Np and ^{238}U as possible standards in the MeV region were considered in an invited contribution to the International Specialists Symposium on Neutron Standards and Applications, NBS, in March 1977. In comparison to other neutron standards their application is particularly advantageous for experiments involving white-source techniques. Major distortions in fast neutron flux measurements due to frame overlap problems and contributions from slow neutron events can be avoided by spectrum cut-off at threshold energies. The present data basis for both nuclei was discussed and critically examined. Some suggestions are made of how to achieve an ultimate accuracy of 2 % in cross section measurements employing ^{237}Np or ^{238}U as secondary standards.

1.6 Investigation of the Level Structure of ^{28}Si

I. Schouky, S. Cierjacks
(Related to request numbers: 762164, 741275)

Although investigated previously, the level structure of ^{28}Si is not yet well known. We, therefore, have made an investigation for this nucleus by analyzing high resolution total and differential elastic scattering cross sections in the range from 0.5 - 3 MeV. High resolution data of this kind provide a good means for unambiguous spin and parity assignments. This is possible by a shape analysis, since resonance shapes as a function of the scattering angle are very sensitive to spins and parities of the nuclear states. In our analysis of the data the experimental resonance shapes were visually compared with the shape of standard resonances, calculated with a single channel, multilevel R-matrix code (8). In the range below E_n = 6 MeV there are only a few partial waves which contribute to neutron resonance scattering. But resonances are already closely spaced, so that the general features of the resonance pattern are partly modified by resonance-resonance interference. Such effects were also studied by calculation of the characteristic resonance behaviour in cases of level-level coherence. With this method J and Π values of 51 levels in ^{29}Si have been determined. A listing of the spin and parity assignments is given in Table 3. Our assignments were compared with previous determinations from other laboratories.

Table 3

Spin and parity assignments for neutron resonances of $^{28}Si+n$

	$E_{lab.}$ (MeV)	$E_{exc.}$ (MeV)	J^{π}		$E_{lab.}$ (MeV)	$E_{exc.}$ (MeV)	J^{π}
1	0.5321	8.988	$5/2^+$	27	1.804	10.216	$3/2^+$
2	0.562	9.017	$3/2^-$	28	1.850	10.260	$3/2^-$
3	0.5867	9.041	$1/2^-$	29	1.860	10.270	$5/2^+$
4	0.5904	9.044	$1/2^-$	30	1.918	10.326	$3/2^-$
5	0.7711	9.219	>1/2	31	1.926	10.334	>1/2
6	0.812	9.258	$3/2^-$	32	1.971	10.377	$3/2^+$
7	0.8441	9.289	$1/2^-$	33	2.038	10.442	$1/2^+$
8	0.9096	9.352	$3/2^-$	34	2.059	10.462	$1/2^-$
9	0.974	9.415	$1/2^-$	35	2.084	10.486	$3/2^-$
10	1.016	9.455	>1/2	36	2.115	10.516	$3/2^+$
11	1.042	9.480	$3/2^+$	37	2.171	10.570	$1/2^+$
12	1.163	9.597	$1/2^+$	38	2.226	10.623	$3/2^+$
13	1.186	9.619	$1/2^+$	39	2.288	10.683	3/2
14	1.203	9.636	1/2	40	2.300	10.695	$5/2^+$
15	1.255	9.686	$1/2^+$	41	2.373	10.765	$3/2^+$
16	1.263	9.694	$1/2^-$	42	2.439	10.829	$1/2^+$
17	1.408	9.834	$3/2^-$	43	2.456	10.845	$3/2^-$
18	1.478	9.901	$3/2^+$	44	2.490	10.878	$1/2^-$
19	1.5104	9.933	>1/2	45	2.495	10.883	$5/2^-$
20	1.527	9.949	$3/2^+$	46	2.657	11.040	$5/2^+$
21	1.579	9.999	$3/2^+$	47	2.696	11.077	$3/2^-$
22	1.595	10.014	$3/2^-$	48	2.778	11.156	$1/2^-$
23	1.628	10.046	$1/2^-$	49	2.854	11.230	$3/2^+$
24	1.636	10.054	$5/2^+$	50	2.937	11.310	$5/2^+$
25	1.650	10.067	$5/2^+$	51	2.971	11.343	$1/2^+$
26	1.783	10.196	>1/2				

1.7 T = 3/2 Isobaric Analog Resonance in ^{29}Si

S. Cierjacks, S.K. Gupta*, I. Schouky

Since the neutron decay of T = 3/2 analog states in T_z = 1/2 nuclei is isospin forbidden, it can proceed only via isospin impurities in the initial or the final state. Thus, the investigation of the neutron widths of T = 3/2 resonances together with the widths of T = 1/2 resonances of the same spin and parity provides a good means to obtain information about the isospin purity of the analog states. In Si the lowest T = 3/2 state is below the neutron separation energy and, therefore, cannot be seen in neutron scattering. However, the isobaric analog of the first excited state in ^{29}Al ($J = 1/2^+$) should appear at an energy of E_n = 1.262 MeV. In order to identify this member of the multiplett, resonance parameters were determined for four neutron-resonances in Si in the region between 1.05 and 1.4 MeV. This was done by analyzing the measured differential neutron scattering cross sections combined with the total neutron cross sections and applying R-matrix single channel, multilevel theory. The resonance at 1254 keV has been identified as the s-wave analog of the 1262 keV first excited state in ^{29}Al. The identification took also into account experimental radiative neutron capture data (9) and shell model calculations for the radiative width (10). The experimental results and calculated cross sections obtained by the Nebe-Kirouac code are shown in Fig. 5. The final fit was chosen by visual comparison of measured and calculated curves. The simultaneous fit to the total cross section (top curves) and the scattering data for all ten angles (lower curves) seems to be quite satisfactory. From the reduced width of all T = 1/2 and the T = 3/2 s-wave resonances isospin mixing matrix elements were derived.

1.8 Study of Mass- and Energy Distributions and Neutron Yields from the ^{233}U(d,pf)-Reation

S. Cierjacks, Y Patin+, J. Lachkar+, J. Sigaud+, C. Humeau+ and Y. Chardine+

The study of dynamical aspects of the fission process, which includes inertial and damping (or viscosity) effects has received increasing attention in fission physics. Effects of this kind play an important role for a proper description of the fissioning system during the crossing of the fission barrier and in the descent from the saddle point to scission. Information about the nature and the influence of dynamical effects on the fission process can, in

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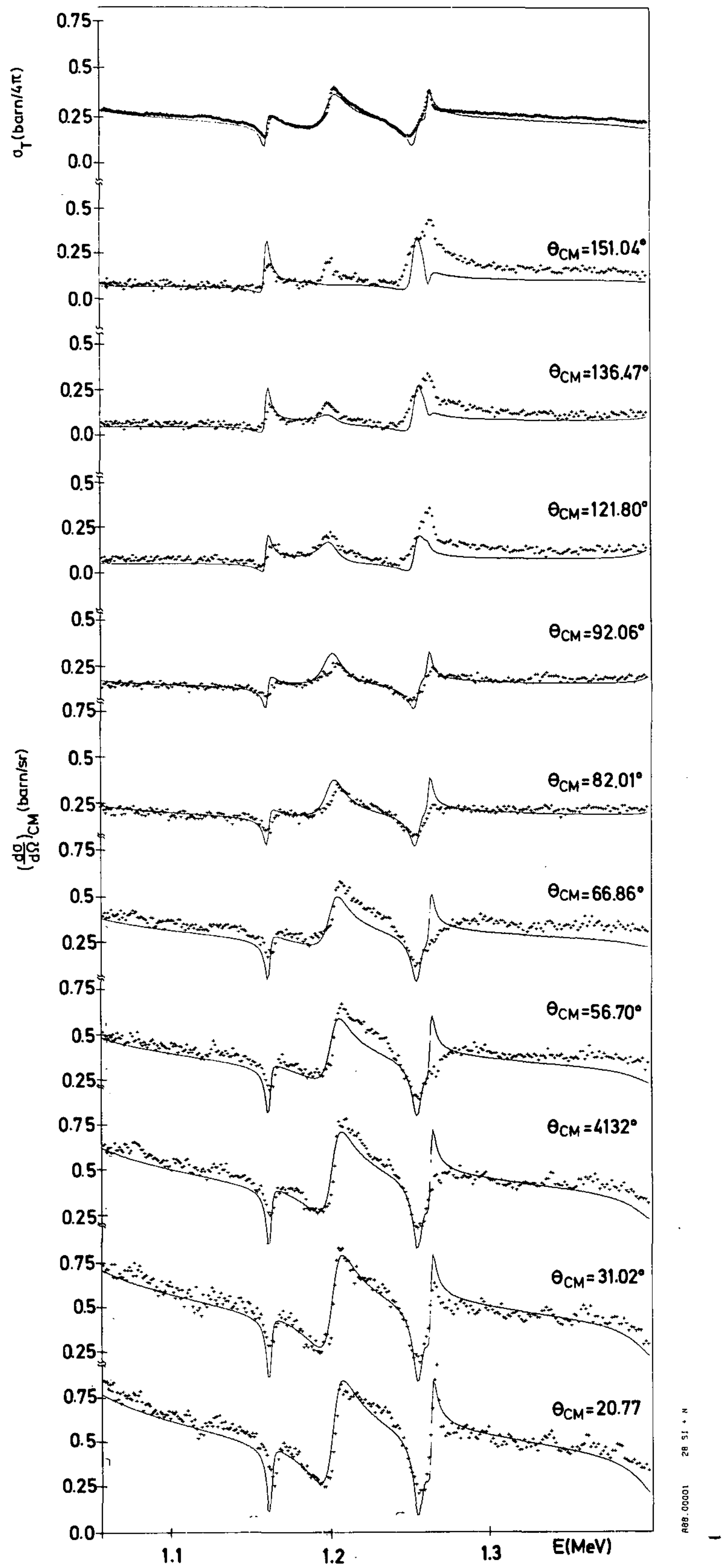

Fig. 5 Total and differential elastic neutron scattering cross sections of silicon between 1.05 and 1.40 MeV. The solid lines represent a simultaneous single channel multilevel R-matrix fit.

principle, be obtained from experimental studies of the variation of fragment masses and energies and neutron yields with the excitation energy of the fissioning system. Experimental information of this type has in the past, however, been very scarce due to intensity problems arising in kinematically complete experiments. The $^{233}U(d,pf)$-experiment carried out in 1975 and described elsewhere (11) has partially been analyzed in the period covered by this report. In the analysis pre-neutron mass distributions and energies were calculated from the fragment velocities. For an independent determination of pre-neutron masses and energies it was necessary to replace the initial pre-neutron emission velocities of the fragments by the measured final average velocities. Such a treatment is reasonable, since neutron emission is symmetric around 90^o in the centre-of-mass system of the fragment. The calculation of post-neutron emission quantities involved a modified version of the Schmitt-method (12). Neutron yields as a function of the fragment mass were derived by the energy ratio method and directly by the time-of-flight method. Some preliminary results are shown in Fig. 6. The upper diagram shows the fragment mass distribution obtained for a wide range of excitation energies between $\sim$ 6 and 9 MeV. In the bottom curve the fragment kinetic energy, E_K^* before neutron emission is shown.

1.9 Isospin-Mixing in Low Lying T = 3/2 Resonances of ^{17}O and Investigations on an Isospin-Dependence of the Electromagnetic Interaction

S. Cierjacks, D. Erbe, B. Leugers, G. Schmalz, F. Hinterberger+,
P. v. Rossen+

In continuation of the program on the study of isospin mixing in T = 3/2 resonances of T_z = 1/2 nuclei ultra high-resolution transmission meausrements were performed for oxygen between 3 and 30 MeV. For this nucleus only little information exists from previous work about low lying T = 3/2 states: Information on four T = 3/2 resonances comes from a study of the $^{13}C(\alpha,n)$-reaction (13). Five additional T = 3/2 resonances are predicted from studies of the level structure in the mirror nucleus ^{17}F (14,15). In the ultrahigh resolution measurement of the total neutron cross section five extremely narrow resonances were observed at exactly the energies predicted for the T = 3/2 analog states.

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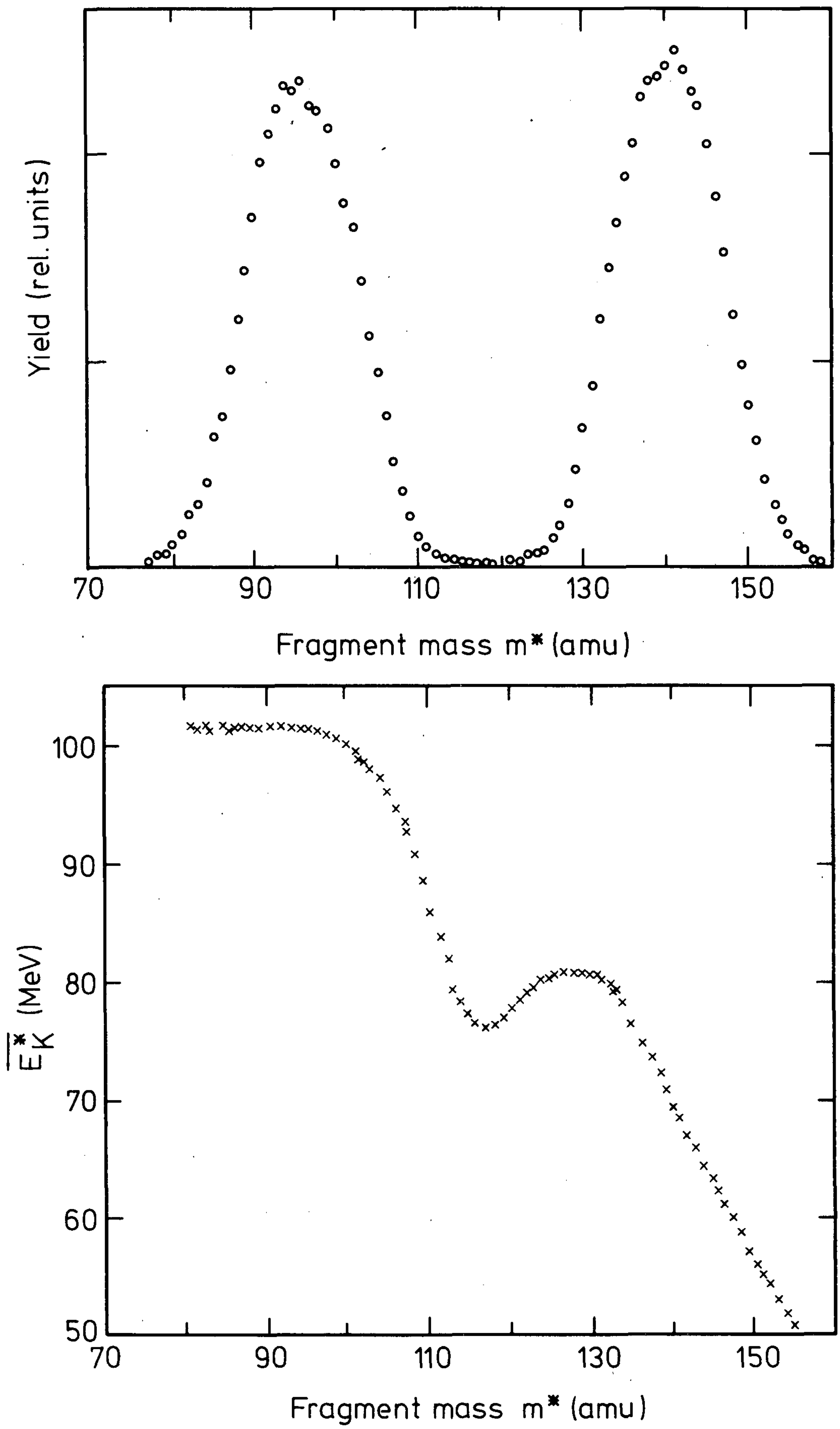

Fig. 6 Top: Mass distribution of fission fragments from the $^{233}U(d,pf)$-reaction before neutron emission. Bottom: Fragment kinetic energy before neutron emission. Observation in the direction of the ^{234}U-recoil axis.

For a test of the possible existence of an isotensor component in the electromagnetic interaction, it has been suggested (16) to compare decay widths of T = 3/2, $\Delta T=1$ γ transitions in mirror nuclei. An isotensor component would reveal itself by a different decay widths for the two nuclei, the difference of which being predicted to be of the order of 10 % (16). Recent investigation of this kind have largely concentrated on the study of the ^{13}C - ^{13}N mirror pair. Despite numerous experiments no decise conclusions about the existence of an isotensor component could be drawn. Presently sufficiently precise values exist only for Γ_{γ_o} of ^{13}N and for the ratio Γ_{γ_o}/Γ of ^{13}C. Thus an accurate measurement of the total width of ^{13}C from neutron scattering was considered to be most valuable. In order to study the 15.11 MeV T = 3/2 resonance of ^{13}C, an ultrahigh resolution measurement ($\Delta t/\ell$ = 0.005 ns/m) was performed with the further improved KIC fast neutron spectrometer. Under these conditions a statistically significant resonance excursion was first observed in a transmission experiment. A preliminary estimate of the resonance height indicated that the earlier suggested value for Γ_n/Γ = 0.07 is still too large. The analysis of the data is in progress.

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2. 3 MV Van-de-Graaff-Accelerator

2.1 Structural Materials

2.1.1 Study of keV-Resonances in the Total Cross Sections of ^{63}Cu and ^{65}Cu

H. Beer and G. Rohr⁺

Neutron total cross sections of ^{63}Cu and ^{65}Cu have been determined in the energy range 34 - 150 keV by means of transmission measurements (1). With an R-matrix shape fit analysis of the transmission data, s-wave and $\ell > 0$ wave resonance parameters were derived. The s-wave resonance parameters were used to calculate strength functions and to establish width and spacing distributions. A previously reported spin dependence of the strength function could not be confirmed. In the case of ^{63}Cu indications for intermediate structure were found.

2.1.2 Neutron Capture Cross Section of ^{58}Fe in the Energy Range from 15 to 160 keV

L.D. Hong, H. Beer and F. Käppeler

(Relevant to request numbers: 691104, 762179)

For the discussion of the astrophysical nucleosynthesis in the Fe-region, ^{58}Fe plays an important role. For an estimate of the s-process (slow neutron capture) contribution to the formation of this isotope the capture cross section was measured in the neutron energy range from 15 to 160 keV. In this energy range the capture cross section is - of course - also of interest for reactor physics. The experiment has been carried out by the time-of-flight-technique using a large liquid scintillator tank to detect the prompt γ-rays from capture events. With a neutron flight path of 2 m an energy resolution of 2 nsec/m was achieved. Capture events were accumulated in a two-dimensional matrix with 1024 time-of-flight and 16 pulse height channels. The measurement turned out to be rather difficult because only a relatively

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⁺ Present address: CBNM-Euratom Geel (Belgium) small amount of sample material with only moderate enrichment in ^{58}Fe was available. The data analysis is nearly completed; presently resonance parameters of the resolved resonance structures are determined.

2.2 Main Fissile and Fertile Isotopes

2.2.1 Capture to Fission Ratio of ^{235}U

H. Beer and F. Käppeler

(Relevant to request number: 621249, 692373, 714008)

The analysis of the capture to fission ratio measurement on ^{235}U between 10 and 500 keV has been completed. In the experiment a large liquid scintillator tank was used to detect capture and fission events from a thin metallic sample. In addition a fission neutron detector was placed near the sample in a vertical tank channel which allowed to discriminate fission and capture events. The neutron energy range was covered in several runs with overlapping energy regions. With the present experimental method for the first time the capture to fission ratio could be determined in the keV range with reasonable energy resolution. Fig. 1 shows the data from 10 to 30 keV. For comparison the results of Gwin et al. (2) for the neutron energy intervals from 10-20 and 20-30 keV are included. The present data exhibit considerable structure which reflects the influence of the double humped fission barrier of ^{236}U on the fission channel. Structures in α are also observed at higher energies up to 300 keV. If the results are averaged over 10 keV intervals, an accuracy of better than 10 % was achieved.

2.2.2 The Energy Gap at the Saddle Point Deformation of ^{236}U

F. Käppeler and F. Dickmann

A steep increase in the fission cross section of ^{235}U at 0.95 MeV neutron energy was interpreted as due to the onset of quasi particle excitations in ^{236}U. Together with the result of a recent evaluation of the ^{236}U fission barrier an improved value of the energy gap at the saddle point deformation $2\Delta_s = 1.79 \pm 0.2$ MeV was determined. This value is discussed with respect to current assumptions on the deformation dependence of the pairing force parameter G (3).

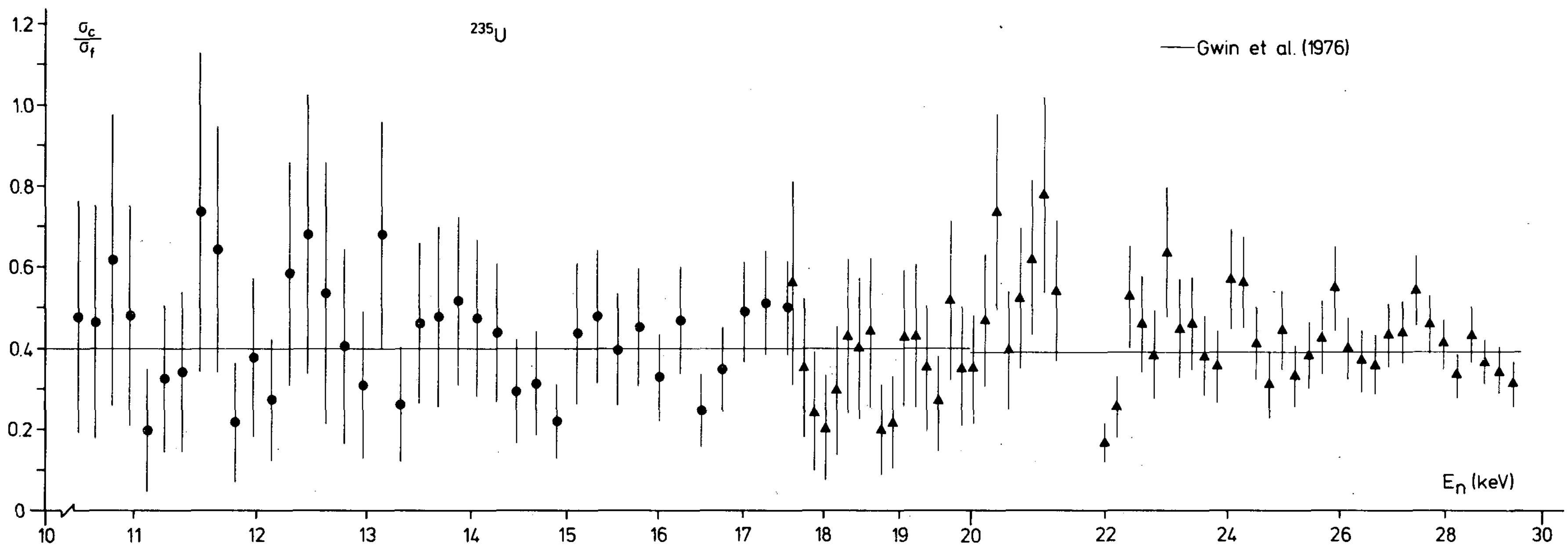

Fig. 1 The experimental points show a strong energy dependence for the capture to fission ratio, α, of ^{235}U which is caused by fluctuations in the fission channel. For 10 keV averaged values the accuracy is better than 10 %.

2.3 Actinide Cross Sections

2.3.1 Neutron Capture Cross Section Ratios of ^{240}Pu, ^{242}Pu, ^{238}U and ^{197}Au in the Energy Range from 10 to 90 keV

K. Wisshak and F. Käppeler

(Relevant to request numbers: 682071, 691389, 692451, 692452, 692453, 714032, 754006, 762214, 712102, 721098, 721142, 742010, 754014, 762223, 722043, 732128, 691419, 692403, 692404, 692405, 692406, 702032)

The neutron capture cross sections of ^{240}Pu and ^{242}Pu have been determined in the energy range from 10 to 100 keV relative to ^{197}Au and ^{238}U (4). The measurement was using the ^{7}Li(p,n) reaction as a kinematically collimated neutron source. Capture events were detected by a Moxon-Rae detector. Three sets of $\sigma(n,\gamma)$ ratios have been evaluated from the experimental data: two, measured at different flight paths relative to ^{197}Au and one relative to ^{238}U. The accuracy achieved amounts to 4-10 % for the ^{240}Pu cross section ratio and 6 - 12 % for ^{242}Pu. The cross section ratio of ^{238}U and ^{197}Au, determined as a cross check of the measurement, agrees very well within the experimental uncertainty of 4 % with recent measurements of other authors (5,6) and with evaluated files (KEDAK 3 and ENDF/B-IV). Fig. 2 shows the cross section of ^{240}Pu determined by multiplying the experimental ratios with the evaluated cross section of the reference samples. For comparison the data of other authors (7,8) are given, too.

In a further experiment data have been taken in the energy range from 50 to 250 keV using the T(p,n) reaction.

2.3.2 Measurement of the Neutron Fission Cross Section of ^{241}Am via Fragment and Neutron Detection

W. Hage+, H. Hettinger+, S. Kumpf+, F. Käppeler and K. Wisshak

(Relevant to request numbers: 712103, 732115, 742018, 742107, 762225, 702080)

Fission cross section measurements on ^{241}Am are complicated by the high α-background from natural decay ($>10^8$ α/mg sec). Below the threshold at about

+Euratom Ispra, Italy

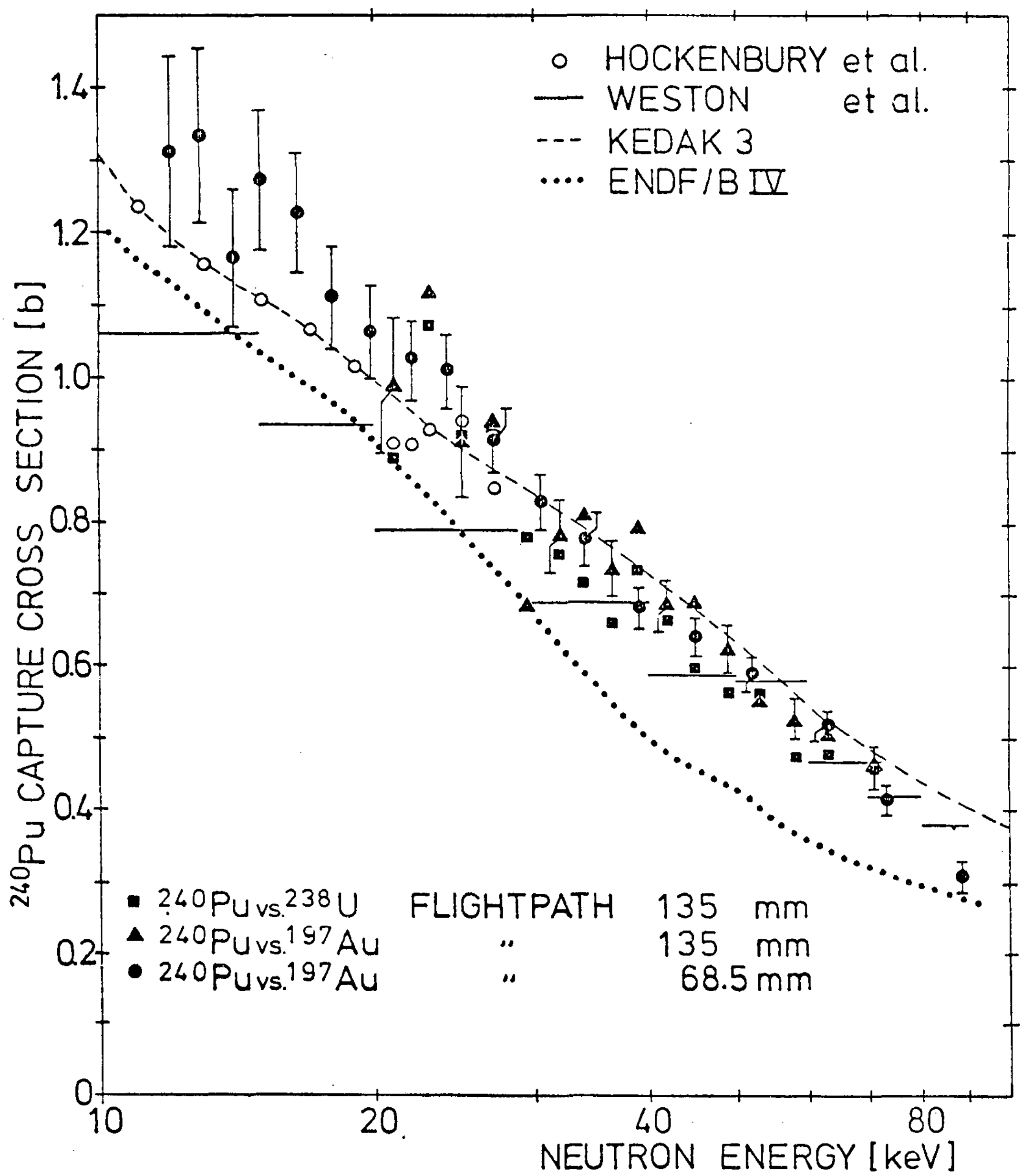

Fig. 2 The neutron capture cross section of ^{240}Pu. The black points and triangles show our results. For comparison the values of other authors are given together with evaluated cross section curves. In the present data the accuracy was considerably improved.

800 keV, the fission cross section of ^{241}Am decreases rapidly until a rather flat subthreshold value of less than about 50 mb is reached at 200 keV; above threshold cross section values of about 2 b are reported. As we intended to cover the neutron energy range from 10 to 1200 keV it seemed reasonable to use different techniques because the cross sections are too different at the lower and upper end of the energy range.

a: Neutron detection

At present a cross section measurement by fission neutron detection is under analysis. This measurement was made relative to ^{235}U for neutron energies from 10 to 1000 keV. The fissile samples were located very close to the neutron target to achieve a good signal-to-background ratio. Monoenergetic neutrons were produced by the $^{7}Li(p,n)$ reaction. The time-of-flight technique was used to measure the neutron energies and to further reduce the time independent background. The method was sensitive enough to establish accurate cross section values even in the subthreshold region, where uncertainties of less than 6 % are expected.

b: Fragment detection

The more common technique for fission cross section measurements is based on the detection of fission fragments. We are preparing an experiment with a gas scintillation counter which yields a good time resolution and thus a good signal-to-background ratio in time-of-flight measurements with monoenergetic neutrons. Again the ^{241}Am fission cross section will be measured relative to the fission cross section of ^{235}U. Up to now there are still problems with the high α-background of the Am sample. For improved discrimination, a He-N-mixture is used as a counter gas in which the ranges of α-particles are considerably larger than the counter dimensions, thus cutting off that part of their range where the specific ionization is high. Further α-suppression is achieved by a coincidence between both fragments of a fission event. Aluminium was found to be a suitable backing foil which can withstand the high α-dose sufficiently long. As the fragment absorption losses in the backing foil (about 20 % in 4 π measurements) make an accurate determination of the detector efficiency difficult, we are intending to use the "threshold cross section method" suggested by Behrens and Carlson /9/ for the determination of the cross section ratio. The measurements with this technique will start late in 1977 and will cover the neutron energy range from about 500 to 1200 keV.

2.4 Fission Products

2.4.1 Capture Cross Sections of Krypton Isotopes

F. Hensley

(Relevant to request numbers 671190, 742040)

Capture cross section measurements on noble gas isotopes are mainly motivated by astrophysical needs for the discussion of nucleosynthesis. In the case of Krypton these interest overlaps with request from reactor physics.

For these measurements an apparatus was designed to produce liquid samples of noble gas allowing the investigation of one liter gas of separated isotopes at standard conditions. The gas is condensed into a sample chamber of 1.9 cm^3 volume. The temperature in the cryostat is kept constant by a regulation circuit and determined independently by measuring the vapour pressure of the sample. With the knowledge of the density and the geometric size of the sample, one can determine the irradiated amount of material. In the capture cross section measurements with the neutron time-of-flight method the capture γ-rays will be detected with a C_6D_6 liquid scintillator using the pulse height weighting technique. In a preliminary run the cross section of the natural isotopic composition was measured relative to ^{197}Au. Further measurements of enriched samples of ^{84}Kr and ^{86}Kr are planned for the second quarter of 1977.

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INSTITUT FÜR NEUTRONENPHYSIK UND REAKTORTECHNIK
KERNFORSCHUNGSZENTRUM KARLSRUHE

1. Nuclear Data Evaluation

The work on the improvement of the nuclear data library KEDAK-3 (ref.1-3) was continued. In particular the following new evaluations were performed during the last 15 months.

1.1 Evaluation of Fission and Capture Cross Sections for ^{241}Pu

B. Goel
(Relevant to request numbers: 682071, 691389, 692451, 692452, 692453, 714032, 721137, 754006, 762214, 671130, 714030, 721088, 721089, 721090, 742022, 742105, 754003, 762213)

The data on the KEDAK-2 originated from an evaluation of Caner and Yiftah (4). The evaluation was first performed in 1967 and updated in 1973. The data for σ_f were based on nuclear theory and from 40 keV to 10 MeV they followed the 1968 evaluation of Davy (5). During the period covered by this report σ_f and σ_c above the resolved resonance region to 1 MeV are reevaluated.

1.1.1 Fission Cross Section

The measurements of the fission cross section in the eV and low keV range are made predominantly with the time of flight technique using pulsed neutrons. The experimental data reported after 1968 are from Harwell (6), Geel (7), ORNL (8) and Saclay (9). These data are normalised to different sources. Thus a normalisation uncertainty is expected in these data. It is estimated to be of the order of 4 %. The experimental errors quoted vary between 3 and 6 %. Fig. 1 shows the data reported by different labs together with the result of the present evaluation for the energy interval 100 eV to 30 keV. The spread of the data is much larger than the errors quoted. The Saclay and Geel data seem to be systematically lower than the data of the other three laboratories.

1.1.2 Capture Cross Section

The only new measurement available for this cross section is that of Weston and Todd (8). They have measured the capture-to-fission ratio from 10 eV up to 250 keV. The recommended KEDAK-3 data correspond to these data. Weston and Todd give an uncertainty of 20 % below 20 keV and 10 % above 20 keV in their alpha values. Between 0.3 and 300 keV the presently recommended data are lower than the evaluation of Caner and Yiftah.

1.2 Evaluation of Total and Fission Cross Sections for ^{235}U above 1 MeV

B. Goel

(Relevant to request numbers: 691245, 691246, 691449, 692366, 692368, 693054, 714007, 741209, 742073, 752025, 754008)

In revision of the 1973 KEDAK evaluation (11) the total and fission cross sections for ^{235}U are reevaluated in the energy range 1 MeV to 15 MeV.

1.2.1 Total Cross Section

The 1973 evaluation was primarily based on the data of Cabé et al. (12). These data are systematically 3 - 5 % higher than other published data. For the present evaluation the data of Cabé et al. are reduced by 3 % and combined with the experimental data of Foster and Glasgow (13) and Schwartz et al. (14). The experimental data and the presently and previously recommended data are shown in Fig. 2. The main difference between the old and the new data on KEDAK is in the energy region from 1.5 to 6 MeV with a maximum deviation of 4.5 % at 4 MeV.

1.2.2 Fission Cross Section

In the previous evaluation of σ_f for ^{235}U above 1 MeV preference was given to the data of Hansen, McGuire and Smith (15). However, these data are found to contain some inconsistencies. The new evaluation is mainly based on the data of Czirr and Sidhu (16), Diven (17) and White (18).

In Fig. 3 the new and old evaluations are shown together with the experimental data which in the case of Czirr and Sidhu are averages over certain energy intervals. The main difference between the two evaluations is in the energy region of 9 MeV to 13 MeV which reflects the difference between the data of Hansen et al. and those of Czirr and Sidhu amounting to about 12 % at 11 MeV.

To assess the quality of the evaluated KEDAK-3 data in reactor physics calculations, their effect on the k_{eff} of a large variety of critical assemblies is studied. The result of some of the critical assemblies are given in Table 1. It is seen that the experimental k_{eff} values are reasonably well reproduced with the KFKINR-set modified with KEDAK-3 data, without requiring any adjustment of the group cross sections.

1.3 Evaluation of Structural-Material Cross Sections

F.H. Fröhner

(Relevant to request numbers 741033, 741034, 691081, 741035, 741043, 741046, 741049, 741056, 741059, 691128, 741062, 741065, 741068)

Resonance parameter data for $^{50,52,53,54}Cr$, $^{54,56,57}Fe$ and $^{58,60,61,62}Ni$ were evaluated with special consideration of recent capture and transmission results from Oak Ridge (19,20,21) and Karlsruhe (22,23,24). Multi-level point cross sections (σ_γ, σ_n, $\sigma_{n'}$, σ_T) up to 300 keV were calculated for natural iron and temperatures of 300, 900, 1500 and 3100 K for the KEDAK file. Fig. 4 shows the 300 K total cross section as an example. The iron "windows" (1) below 200 keV were found to be reproduced within few percent without introduction of a "smooth" component. Analogous calculations for Cr and Ni are in progress.

1.4 Improved Estimation of Level-Statistical Parameters

F.H. Fröhner

A new maximum-likelihood technique was developped for the estimation of strength functions and average level spacings from statistical samples of neutron widths and resonance energies. In contrast to conventional methods (25) no assumptions on experimental observabilities are needed, the essential information being extractable from the resonance energy sample. This makes the technique especially useful in evaluation work where normally composite samples from several experiments must be used. Examples of automatic fits with confidence bands are shown in Figs. 5,6,7.

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Table 1: Effect of the evaluated data on the calculation of k_{eff} for some of the critical assemblies studied.

No	Critical Assembly	k_{eff} Experiment	k_{eff} Calculated KFKINR 2D	k_{eff} Calculated KFKINR 0D	δk KFKINR 2D–0D	k_{eff} modified KFKINR 0D	k_{eff} calculated 0D+δk	$\frac{C-E}{E}$ %
1	SNEAK 3A1	1.0	1.0035	0.9948	+0.0087	0.9941	1.0028	+0.28
2	SNEAK 3A2	1.0	1.0008	0.9896	+0.0112	0.9892	1.0004	+0.04
3	ZPR III 55	1.0	1.011	0.9952	+0.0158	0.9836	0.9994	−0.06
4	ZPR IX 25	1.0	0.9950	0.9953	−0.0003	1.0115	1.0112	+1.12
5	SNEAK 8	1.0065	0.9970	0.9987	−0.0017	1.0165	1.0148	+0.82
6	SNEAK 7A	1.001	1.012	1.0175	−0.0055	1.0060	1.0005	+0.05
7	SNEAK 7B	1.0016	1.0088	1.0538	−0.045	1.0448	0.9998	−0.18
8	VERA 11A	1.0	1.0064	0.9537	+0.0527	0.9449	0.9976	−0.24
9	ZPR III 48	1.0	1.0065	0.9762	+0.0303	0.9680	0.9983	−0.17
10	ZEBRA 3	1.0	0.9972	1.0017	−0.0045	1.0111	1.0066	+0.66
11	ZEBRA 2	1.0	0.9874	0.9822	+0.0052	0.9818	0.987	−1.3
12	ZPR III 6F	1.0	1.0021	1.0017	+0.0004	1.0118	1.0122	+1.22
13	ZPR III 56B	1.0	1.0037	1.0057	−0.002	0.9953	0.9933	−0.67

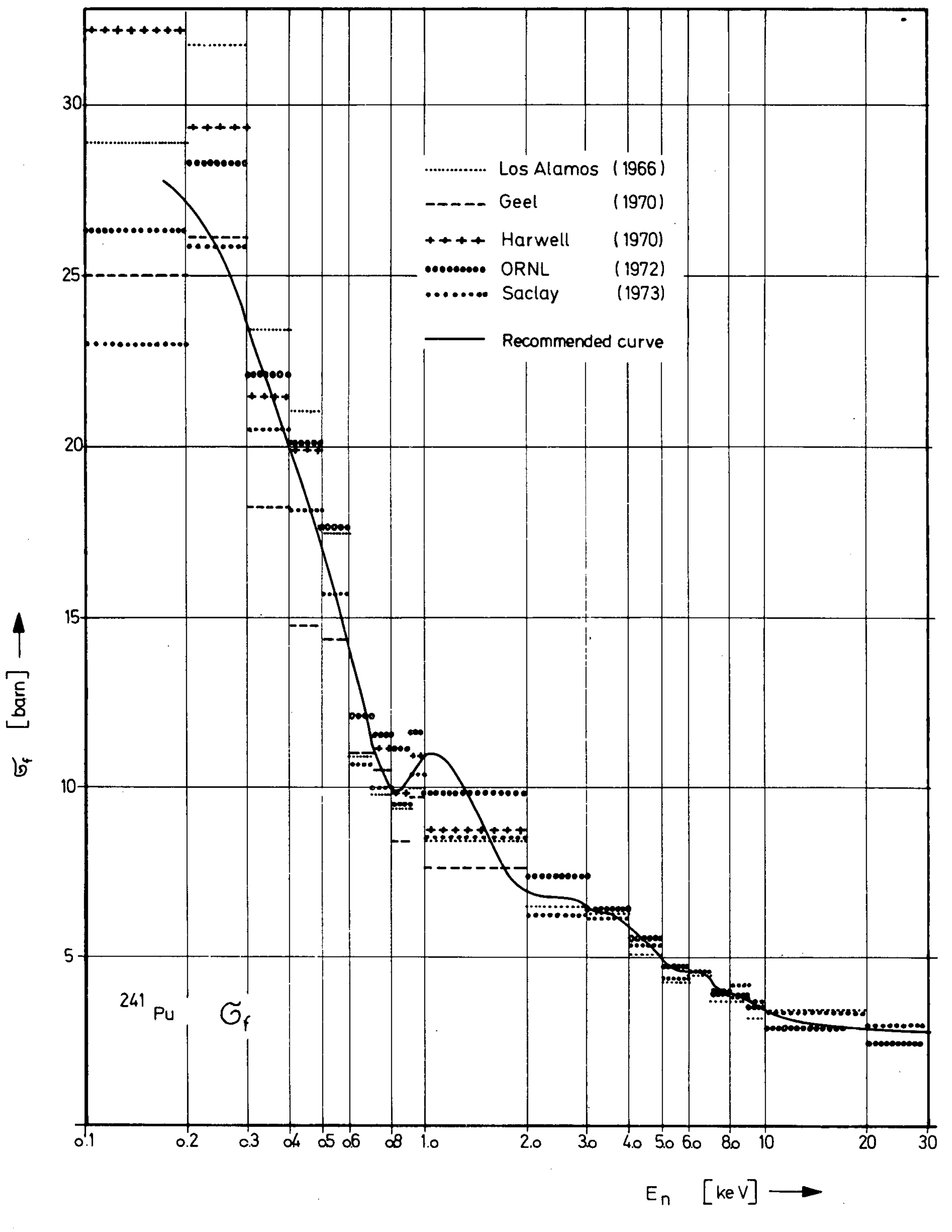

Fig. 1: Comparison of the fission cross section of ^{241}Pu from different authors in the energy range 100 eV to 30 keV.

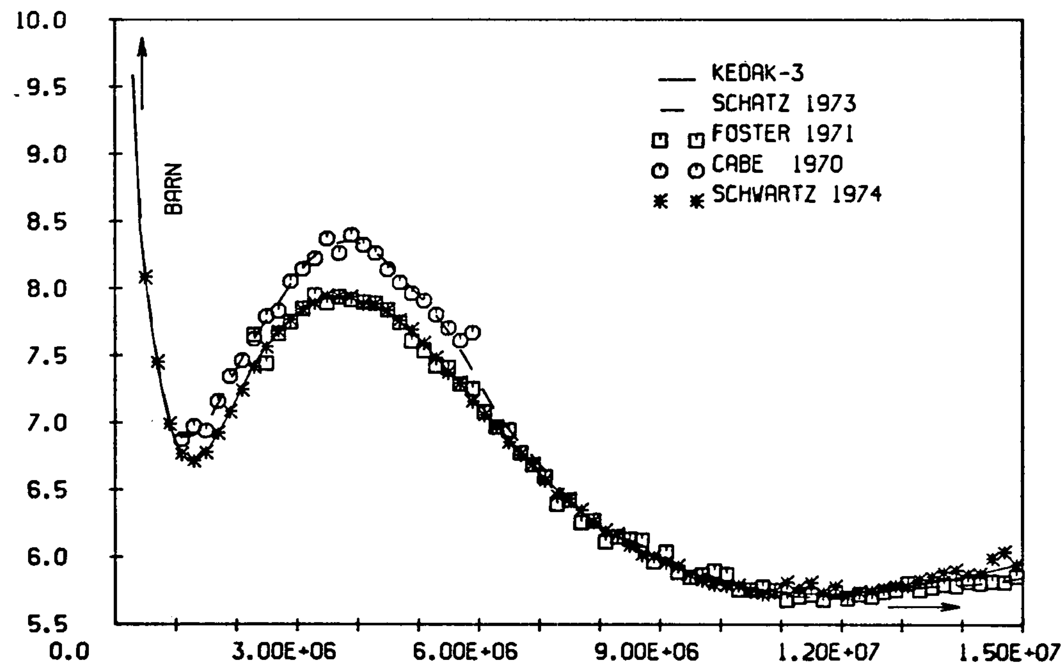

Fig. 2: Total cross section for ^{235}U from 100 keV to 15 MeV.

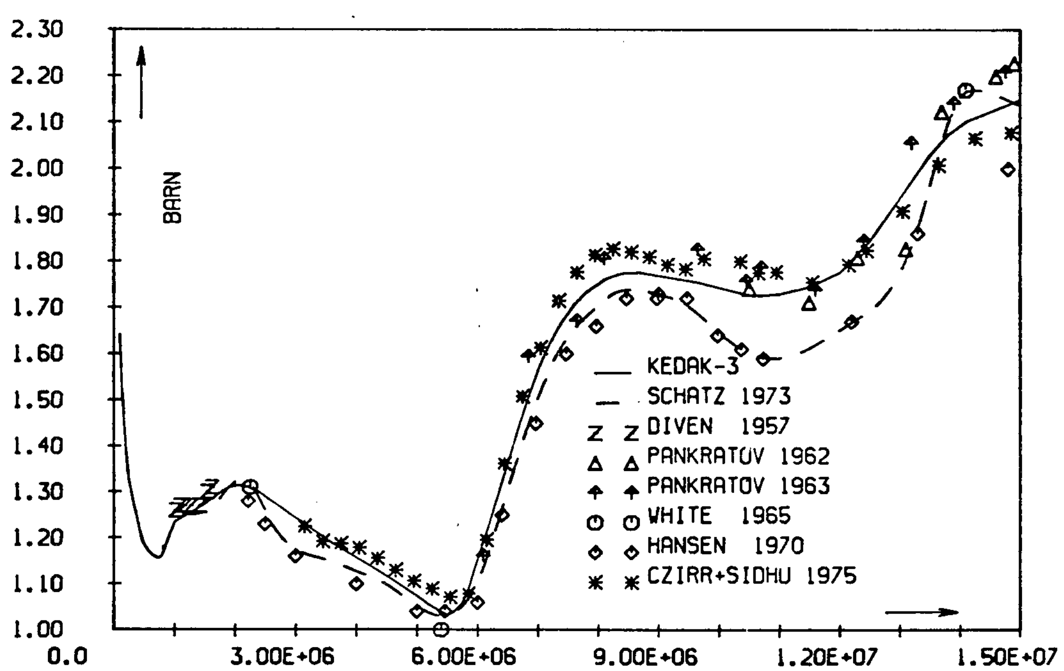

Fig. 3: Fission cross section for ^{235}U in MeV-range. Experimental data from ref. 16-18.

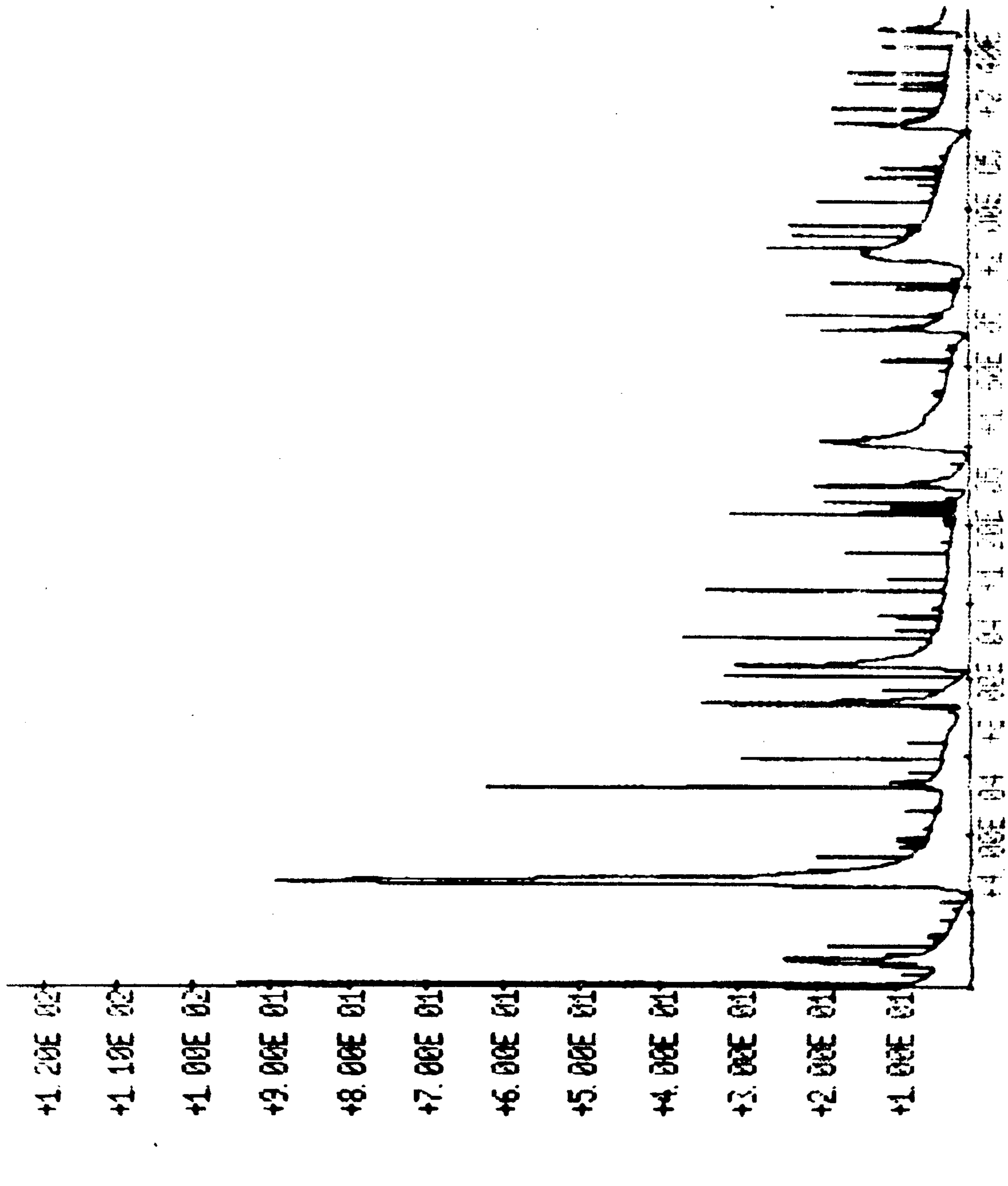

Fig. 4 Total cross section of Fe between 3-3oo keV. STRUMA

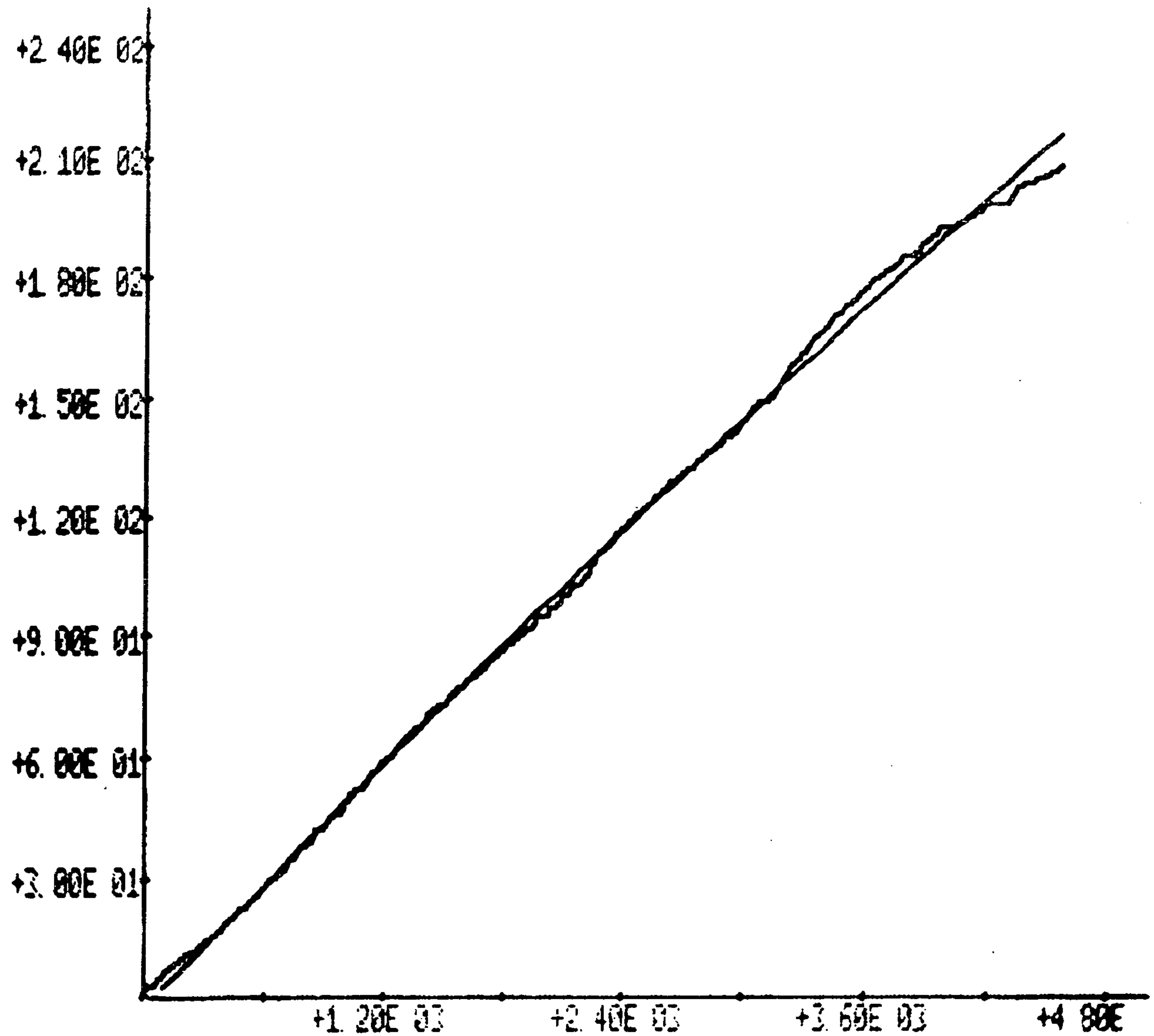

Fig. 5 S-wave level spacing diagram, ^{238}U+n

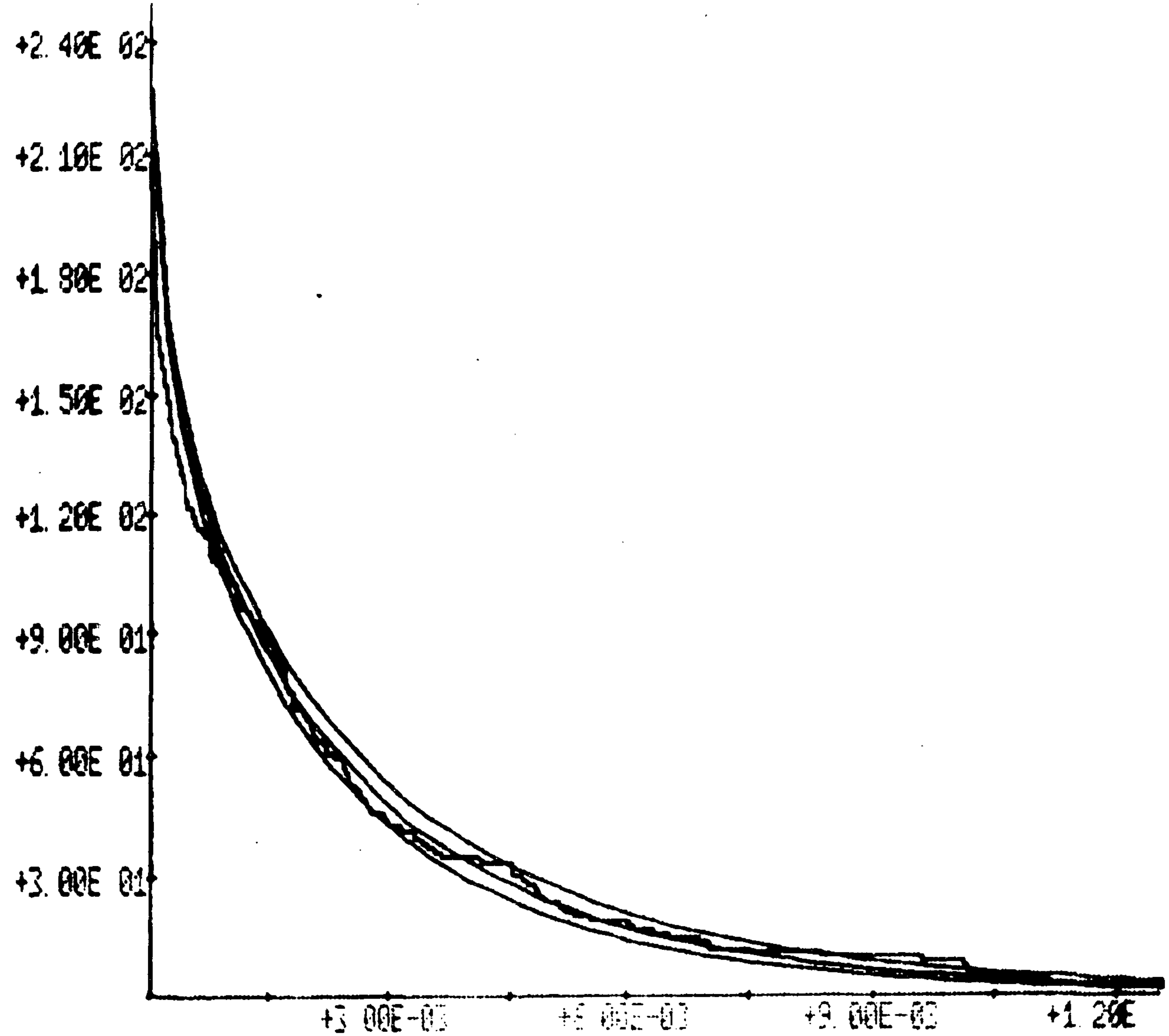

Fig. 6 S-wave levels, reduced width distribution, $^{238}U+n$

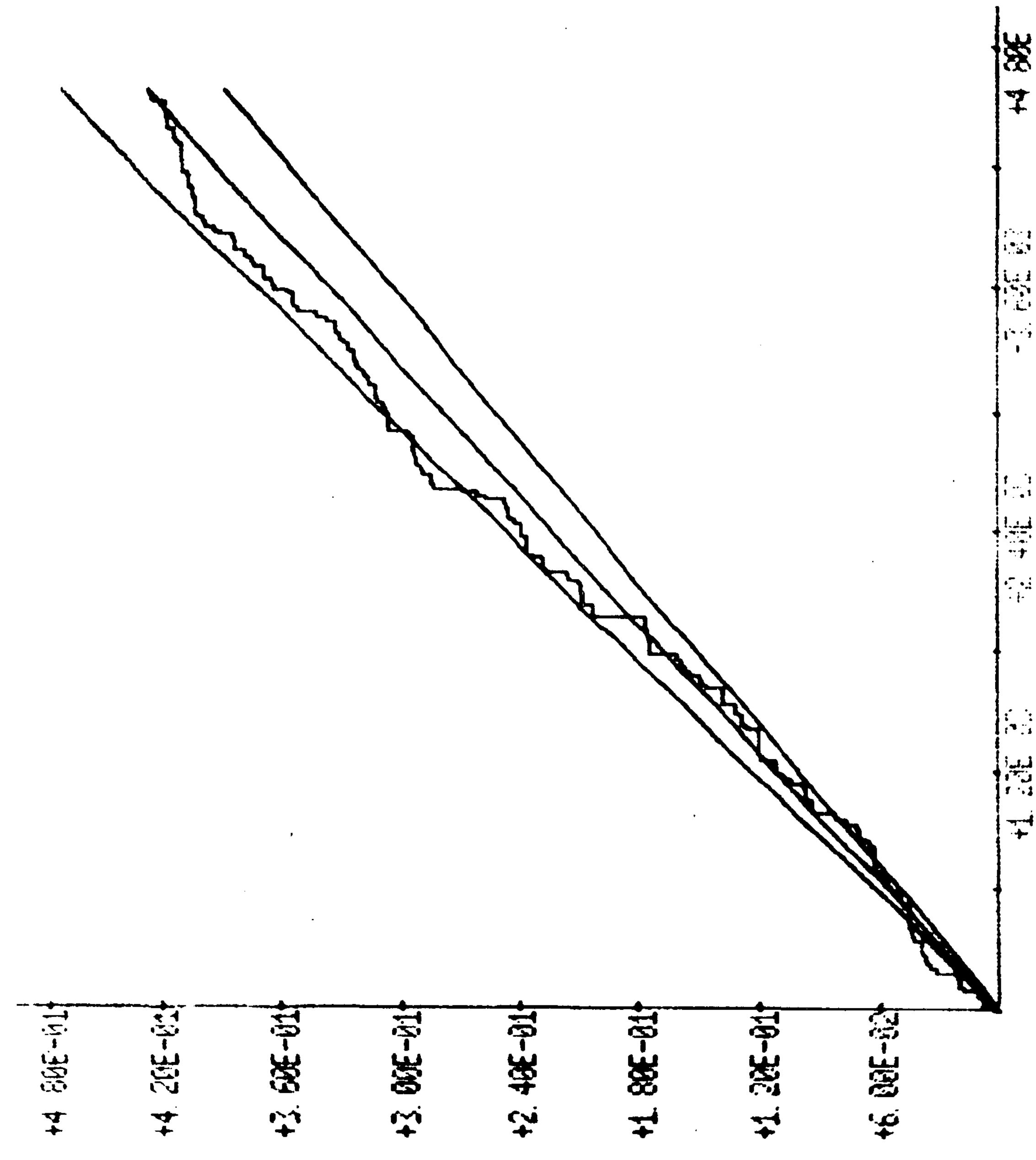

Fig. 7 S-wave strength function diagrams $^{238}U+n$

2. (n,α)-Cross Sections for the Prediction of Radiation Damage in Stainless Steel

B. Goel

It is well established that helium formed in stainless steel by various (n,α) process has a pronounced effect on its mechanical and dimensional properties. There has been strong discrepancy between the helium contents measured in irradiated stainless steel and that calculated on the basis of known (n,α)-cross sections on the stable constituents of stainless steel. This discrepancy can be resolved by attributing the excessive helium to the two step process; $^{58}Ni(n,\gamma)^{59}Ni(n,\alpha)^{56}Fe$. However, a large discrepancy exists between the value of the thermal cross section for the $^{59}Ni(n,\alpha)^{56}Fe$ process used to calculate the helium production data and that obtained out of the direct measurements of this cross section.

In a study (1) the role of the (n,α) cross section is investigated on the irradiation-induced swelling as an example. It is known that insoluble gases like helium do influence swelling by way of nucleating and stabilising voids. It is further shown that helium produced via ^{59}Ni constitutes a substantial amount of helium produced in stainless steel under thermal as well as under fast reactor conditions. In fast reactors helium produced via ^{59}Ni gains its importance at high neutron fluences (Fig. 1). A linear extrapolation of helium production data measured at low fluences to the fluences of the order of $1.5 \cdot 10^{23}$ n/cm^2 is not justified. The study also shows that the usual practice to relate helium production data to thermal and fast neutron fluence is inadequate. The details of the neutron spectrum are necessary to reliably predict the helium production rate. A measurement of the $^{59}Ni(n,\alpha)^{56}Fe$ cross section in the keV and MeV range is recommended.

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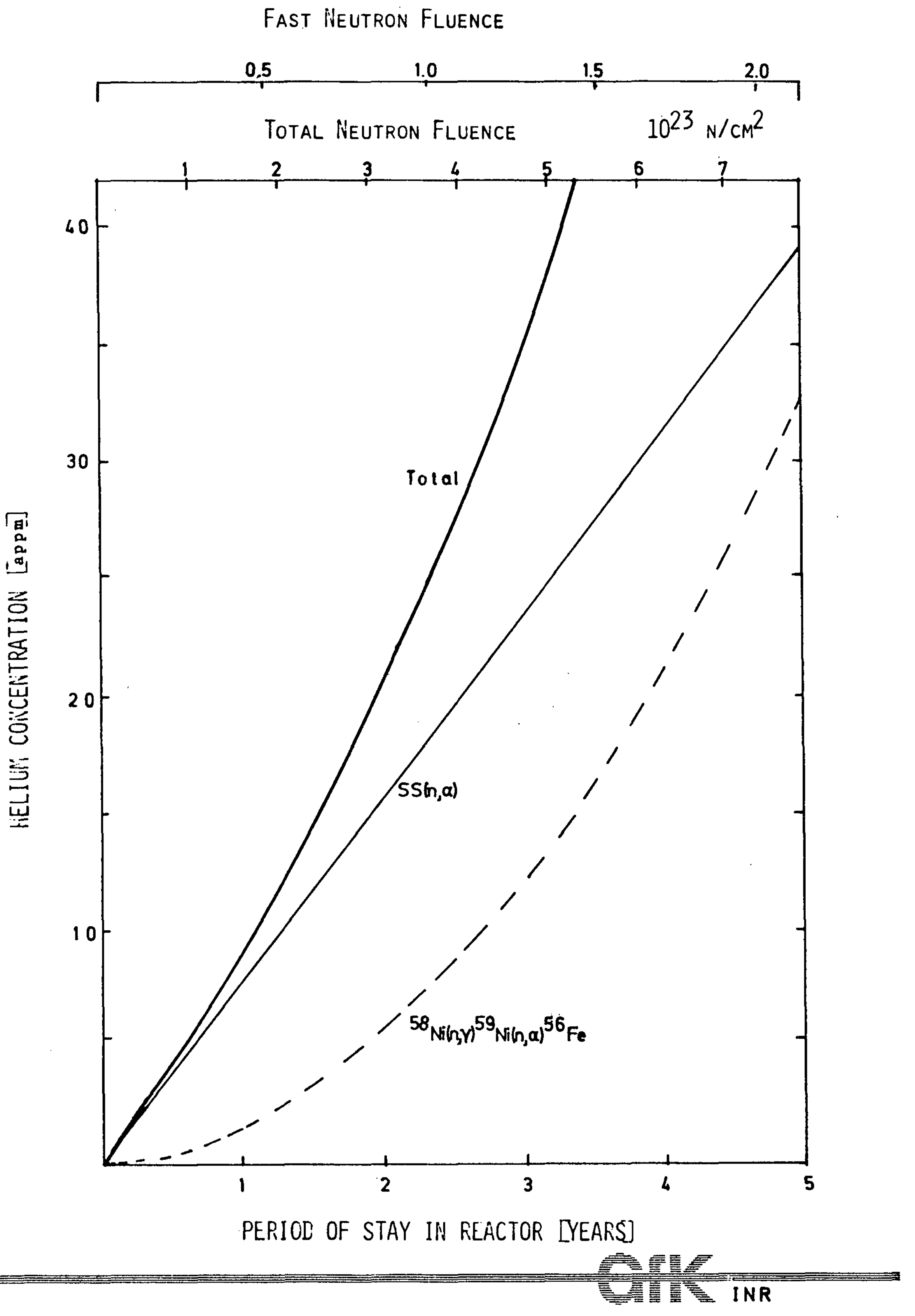

Fig. 1: Helium generation in stainless steel. Thin solid line denotes helium generation in the absence of two step process (dashed line)

3. Absolute Value Calculations of Pre-equilibrium Processes of Inelastically Scattered Neutrons

H. Jahn, C.H.M. Broeders and I. Broeders

(Related to request numbers: 661016, 661018, 702007, 712022, 714004, 661012, 732040, 661024, 702008, 724044)

New attempts to reproduce the absolute values of the observed angle integrated energy distributions of the inelastic 14 MeV neutron cross sections by means of calculations using Blanns geometry dependent hybrid model have now been fully successful (1). The reason is that the realistic Fermi gas single-nucleon state density has been used to evaluate the emission rate into the continuum instead of the equidistant single-nucleon state density as used in our previous calculations (2). In this way the full geometry dependence could be taken into account for the 3-exciton component and no extra direct term had to be added as in ref. (2). Consequently the direct term should be considered as contained in the 3-exciton component. This is consistent with the fact that the angular distribution averaged over 1 MeV intervals that was measured by the Dresden group (3) can be reproduced quite well by our calculations for the case of iron without any fit parameter other than the optical model information as shown in Fig. 1. The same is true for the angle integrated energy distributions for the cases of iron (see ref. (1)) as well as ^{52}Cr, ^{55}Mn, ^{58}Ni and ^{93}Nb presented at the Lowell Conference (4). In all these cases the absolute value calculations of the equilibrium part have been carried out by means of a Hauser-Feshbach term for continuous channels (5) using the level density formulae of Gilbert and Cameron (6). Only the one-neutron channel contributions have been taken into account in the Hauser-Feshbach denominator. This worked well for the cases of Fe, ^{52}Cr and ^{55}Mn as can be seen in Figs. 2a and 2c. But for the case of ^{58}Ni the contribution of the (n,p)-channel cannot be neglected in the Hauser-Feshbach denominator because of its exceptional low negative Q-value. Therefore our calculated equilibrium part is too large compared with measured values of the Dresden group (3) for the case of ^{58}Ni. On the other hand the Q-value of the (n,2n)-processes for ^{93}Nb shows that the (n,2n)-processes cannot be neglected for this case which we have done. Therefore our calculated equilibrium part is too small compared to the measured values of the Dresden group for the case of ^{93}Nb as shown in Fig. 2e. The completion of our calculations in this respect is under way.

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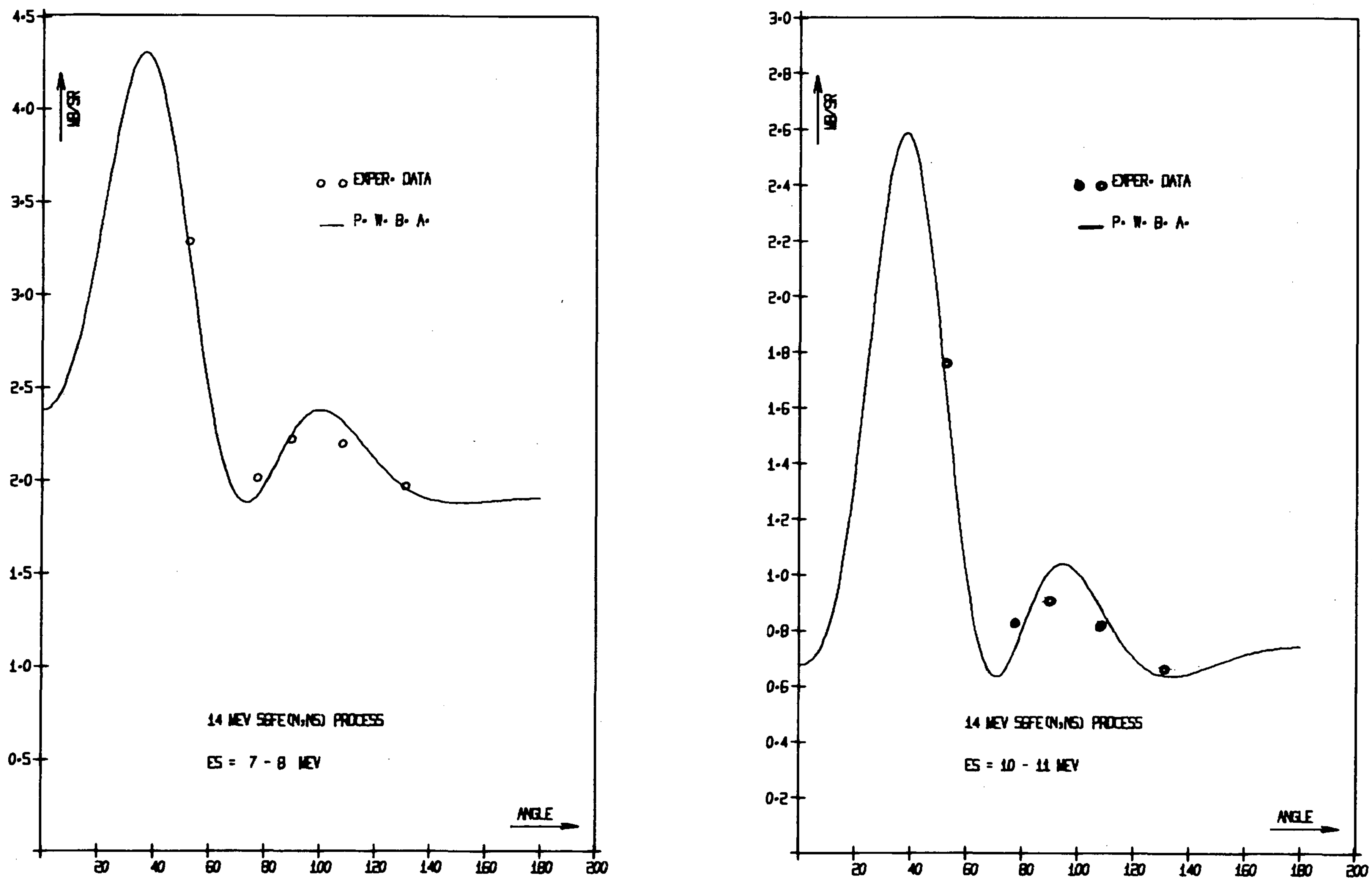

Fig. 1 Angular distribution of 14 MeV neutrons scattered inelastically on ^{56}Fe. The curves represent a PWBA distribution with equilibrium + $n \geq 5$ pre-equilibrium background where the angle integrated PWBA component is equated with the $n_o=3$ component of the geometry dependent Hybrid model.

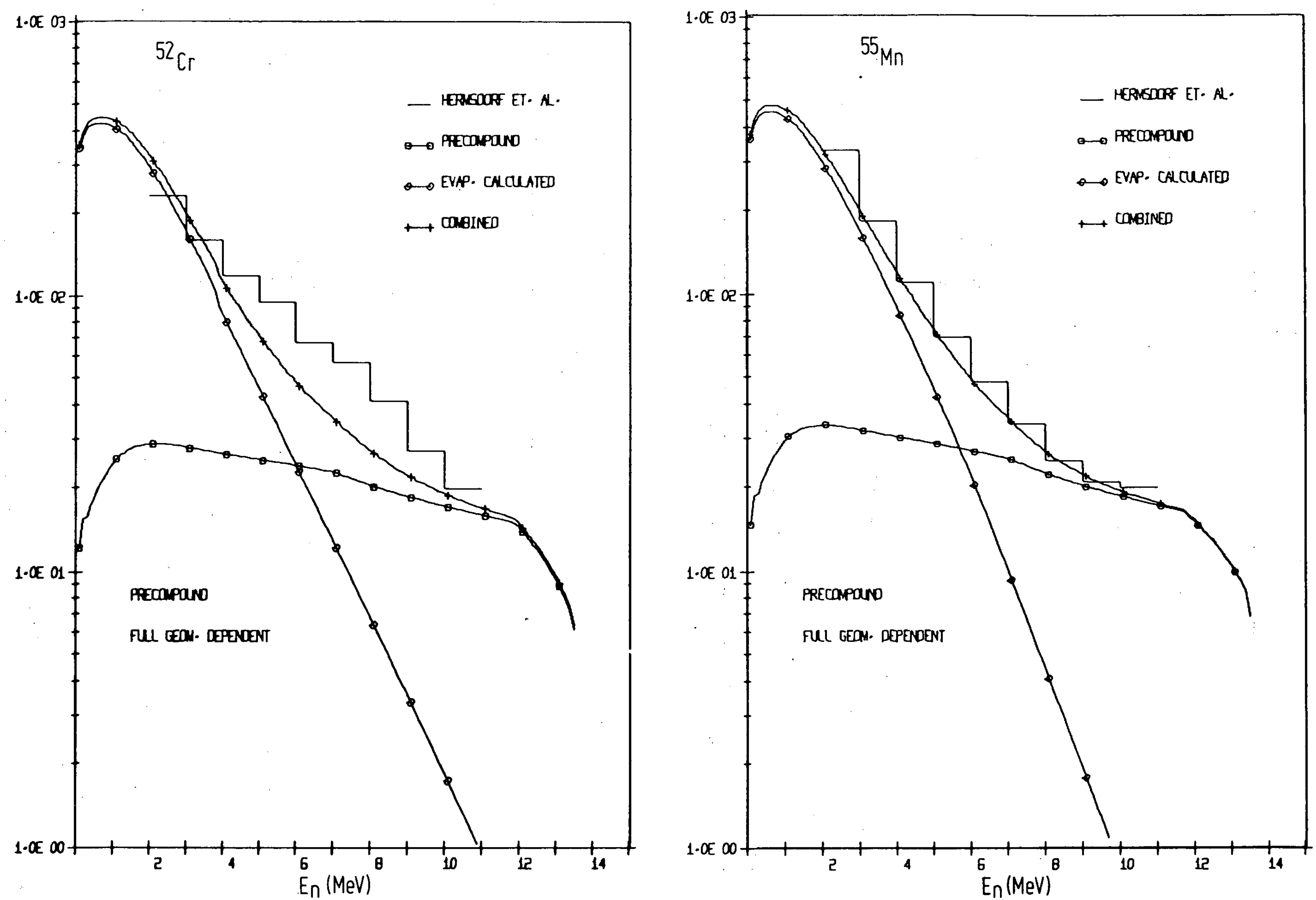

Fig. 2a,b Comparison between measured and calculated angular integrated inelastic cross sections of ^{52}Cr and ^{55}Mn. For precompound contribution see text.

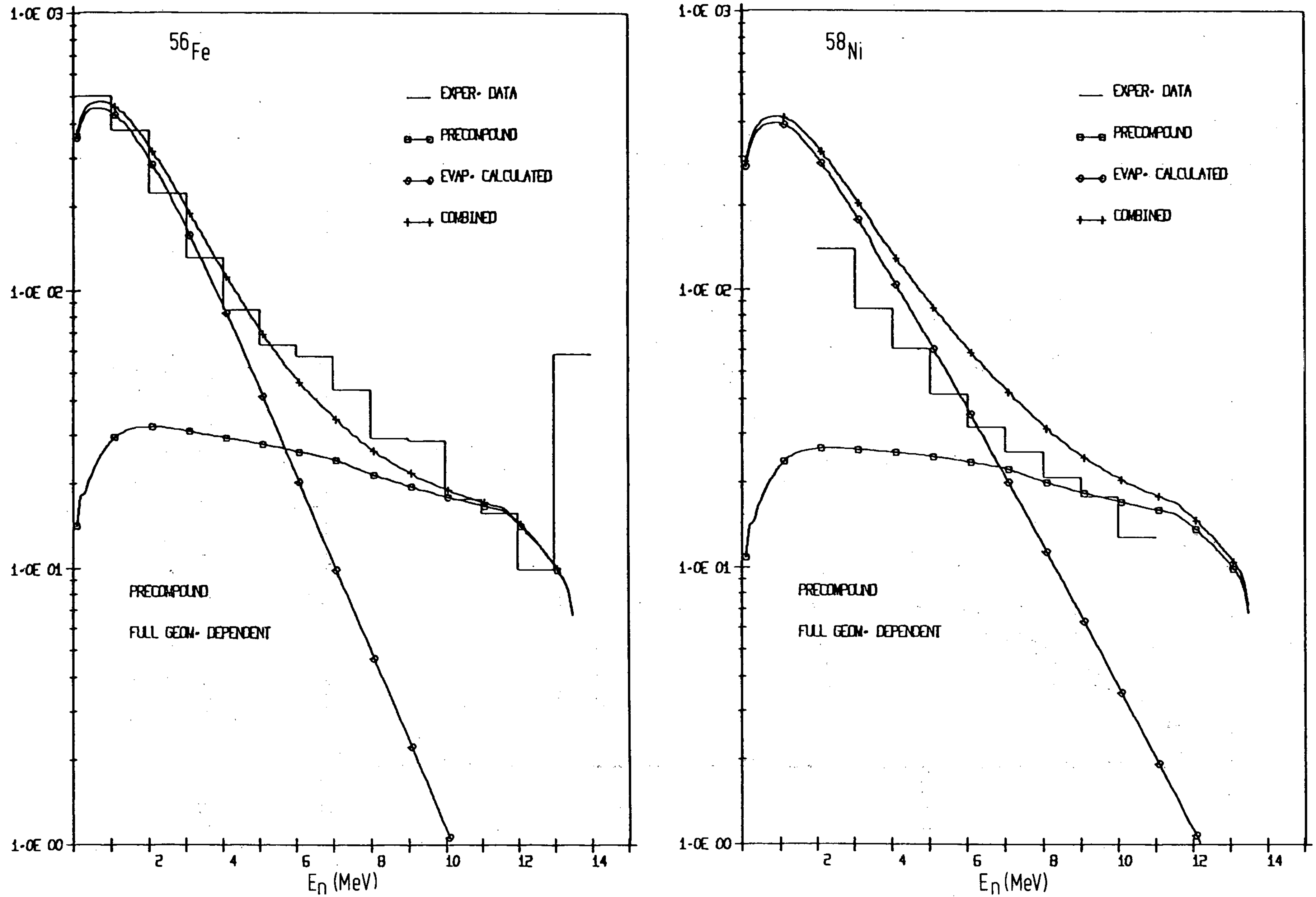

Fig. 2c,d Comparison between measured and calculated angular integrated inelastic cross sections of ^{56}Fe and ^{58}Ni. For precompound contribution see text.

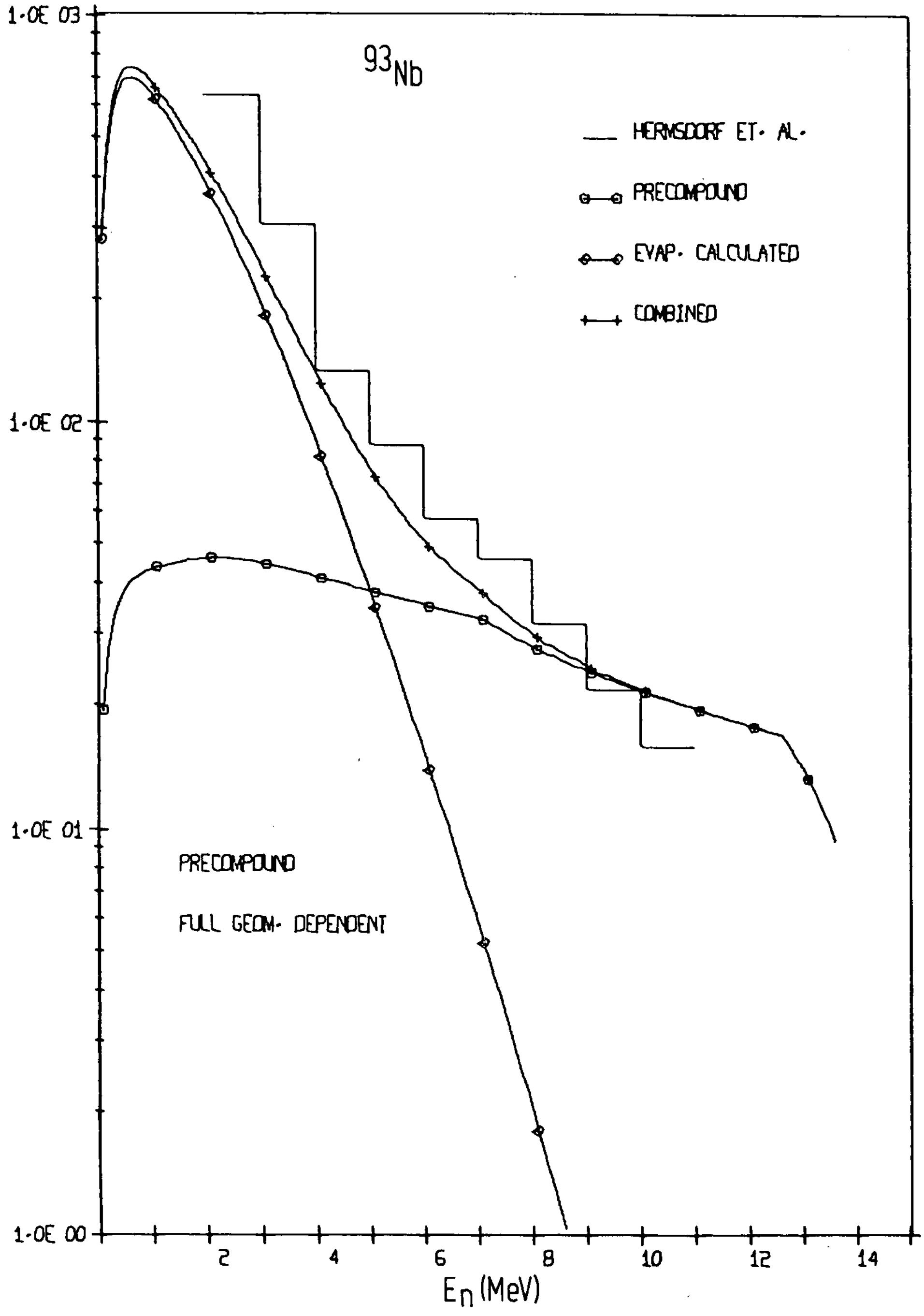

Fig. 2e Comparison between measured and calculated angular integrated inelastic cross sections of ^{93}Nb. For precompound contribution see text.

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KACHAPAG-File for Integral Charged Particle Reaction Data

H. Münzel, H. Klewe-Nebenius, J. Lange, G. Pfennig

The Karlsruhe Charged Particle Group (KACHAPAG) continued (see NEAND(E)-172U Vol. 5) to collect integral charged particle nuclear data (ICPND), i.e. cross sections and thick target yields for the formation of nuclides (ground and metastable states). The work is now part of an international cooperation, initiated and coordinated by NDS/IAEA. The NNDC (Brookhaven) publishes every year a cumulative bibliography for ICPND and the Karlsruhe group is responsible for handling the master file of the data, e.g. merging the input from contributing groups and distributing copies of this file every half year.

The data are now stored on magnetic tape in an extended EXFOR-format developed for the compilation of ICPND, but which is now also accepted for handling Neutron Reaction Data. The entries contain information about

- the bibliography (Author, Journal, Institution, ...)
- the investigated type of data and their numerical values,
- the analysis as well as values of the error, and
- other relevant quantities (decay data of the nuclide produced, experimental arrangement used, ...).

It is expected that this compilation contains in general all information needed for futher application of the data. The following sample page (Fig. 1) shows a slightly modified, 'edited' version of the content of the KACHAPAG-file for one reaction.

By the end of 1976 the KACHAPAG-file contained data for about 400 reactions. Retrievals on the file are available from ZAED (Karlsruhe), Neutron Data Centers (Brookhaven, Saclay, Vienna) and Kurchatov Institute (Moskow).

In 1977 the compilation activity will be continued with special emphasis on proton reactions. In addition, a printed version of the file is in preparation and will be published.

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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * PAGE     13  * *
*                                                                            *
*        REACTION    (79-AU-197(A,2N)81-TL-199,,SIG,,,EXP)                   *
*                                                                            *
* * * * * PUB: B       2.003  * * * * * * * * * * * * * * * * * * * * * * * * *

     TITLE        MEASUREMENT AND EQUILIBRIUM STATISTICAL-MODEL
                  CALCULATION OF EXCITATION FUNCTIONS OF THE AU-197(A,XN)
                  REACTIONS IN THE ENERGY RANGE FROM 16 TO 103 MEV
     AUTHOR       (H.E.KURZ, E.W.JASPER, K.FISCHER, F.HERMES)
     INSTITUTE    (2GERBON)
     REFERENCE    (J,NP/A,168,129,71)
                  (T,JASPER,69).MORE DETAILS AND ADDITIONAL VALUES FOR
                  THE FORMATION OF THE GROUNDSTATE AND METASTABLE STATE
     METHOD       (STTA,EXTB,EDEG,BCINT)
                  STACKS WITH UP TO 80 FOILS WERE IRRADIATED. THE MEAN
                  ENERGY OF THE ALPHA-PARTICLES IN EACH FOIL WAS
                  CALCULATED FROM THE TABLES OF WILLIAMSON AND BOUJOT,
                  CEA-R-2189(1962).
     FACILITY     (ISOCY,2GERKFK)
     DETECTOR     (GELI)
     SAMPLE       GOLD-FOILS WITH THICKNESS OF 20 OR 40 MG/CM**2
     ERR-ANALYS   THE ERRORS ESTIMATED FOR THE CROSS SECTIONS ARE LESS
                  THAN 10 PER CENT AND THOSE FOR THE ENERGY ARE LESS
                  THAN 1 MEV
     ADD-RES      (COMP)
                  FOR CROSS SECTIONS OF AU-197(HE3,XN)-REACTIONS GIVEN
                  IN THE THESIS SEE ENTRY B0033
     STATUS       (CURVE)
     HISTORY      (750127C)M2LA
     REACTION     (79-AU-197(A,2N)81-TL-199,,SIG,,,EXP)
     RAD-DET      (81-TL-199,DG)
     DECAY-DATA   (81-TL-199,7.4HR,DG,208.,0.119)
     EN           DATA
       MEV          MB
  1    18.6         11.
  2    20.8         85.
  3    21.9        152.
  4    22.9        200.
  5    24.8        390.
  6    25.9        396.
  7    26.7        540.
  8    28.5        654.
  9    29.5        650.
 10    32.9        450.
 11    36.1        203.
 12    39.1        107.
 13    42.0         71.
 14    47.4         50.
 15    52.4         37.5

* END * REACTION    (79-AU-197(A,2N)81-TL-199,,SIG,,,EXP)
```

Fig. 1: Sample page of a slightly modified 'edited' version of the content of the KACHAPAG-File for one reaction

EUROPEAN INSTITUTE FOR TRANSURANIUM ELEMENTS
KARLSRUHE, F.R. GERMANY

Cumulative Fission Yields of Pu-239 and Pu-240 in a Fast Reactor Neutron Flux

L. Koch, G. Cottone, Kl. Kammerichs
(Related to request numbers: 671125, 671126, 671128, 711803, 704020, 704023)

In continuation of the experiment TACO, described previously (1), the cumulative fission yields of Pu-239 and Pu-240 have been measured and evaluated. The results stem from the analysis of three Pu-239 and two Pu-240 containing capsules, which have seen different parts of the RAPSODIE neutron spectrum because of different positions in a standard fuel bundle.

The cumulative fission product yields for the heavy mass range above the mass number of 117 were determined by normalizing the fission product abundance to 200 %. Through the use of isotope dilution mass-spectrometry and gamma spectrometry selected fission products were determined. Yields for the masses in the range of 116.8 to 124, 126 to 130, 138 to 142, and 147 were interpolated with the aid of thermal yields in the case of Pu-239 (2) and of predicted yields in the case of Pu-240 (3).

The data (Table 1) are corrected for the contribution of the grown-in daughter fission source, which is only significant for Pu-240. The fission yields of Pu-241 used for this purpose will be published soon (4).

It should be pointed out that the fission yields pertaining to Pu-239 fission agree well with recently published data for ERB-II (5), but disagree with the recommended IAEA data-set (6). In particular the difference in the Nd-148 yield of 4 % will be reflected to the same extent in the burn-up analysis. In the case of Pu-240, no experimentally determined fission yields have been published. However the results obtained within the TACO-experiment agree fairly well with the straight-forward extrapolations of SIDEBOTHAM, even within the requested accuracies (6).

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MASS	Pu-239 TACO CAPS 35	Pu-239 TACO CAPS 36	Pu-239 TACO CAPS 37	Pu-239 average ± dev. %	Pu-239 EBR II (5)	Pu-240 TACO CAPS 45	Pu-240 TACO CAPS 46	Pu-240 average ± dev. %	Pu-240 prediction (3)
125	0.09	0.09	0.11	0.10±12%	0.125	0.03	0.13	0.08±62%	0.06100
126	0.19	0.20	0.20	0.20±2.9%	0.27	0.15	0.29	0.22±32%	0.14000
127	0.49	0.46	0.48	0.48±3.2%	0.52	0.38	0.47	0.43±9.3%	0.36000
128	0.83	0.80	0.82	0.82±1.9%	0.95	0.60	1.04	0.82±27%	0.70000
129	1.56	1.49	1.45	1.50±3.7%	1.61	1.33	1.59	1.46±8.9%	1.36000
130	2.54	2.59	2.42	2.52±3.5%	2.54	2.55	2.43	2.49±2.4%	2.17000
131	4.29	4.09	4.31	4.23±2.9%	3.84	4.24	3.83	4.03±5.1%	3.35000
132	5.87	5.56	5.76	5.73±2.7%	5.27	5.60	5.77	5.68±1.5%	4.83000
133	7.16	7.15	7.31	7.21±1.2%	6.99	6.91	6.84	6.87±0.5%	6.73000
134	8.08	7.54	7.87	7.83±3.5%	7.39	8.17	7.81	7.99±2.3%	7.65000
135	7.70	7.49	7.62	7.60±1.4%	7.57	7.29	7.18	7.23±0.8%	7.25000
136	7.05	6.96	7.12	7.04±1.1%	6.99	6.86	6.50	6.68±2.7%	6.84000
137	6.41	6.38	6.50	6.43±1.0%	6.61	6.42	6.22	6.32±1.7%	6.55000
138	5.49	5.65	5.52	5.55±1.5%	6.12	6.03	6.10	6.06±0.5%	6.42000
139	5.39	5.60	5.42	5.47±2.1%	5.51	5.62	6.17	5.89±4.7%	5.98000
140	5.19	5.41	5.32	5.31±2.1%	5.39	5.34	5.68	5.51±3.1%	5.72000
141	4.93	5.17	4.93	5.01±2.8%	5.15	5.04	5.38	5.21±3.3%	5.51000
142	4.63	4.88	4.55	4.69±3.7%	4.89	4.60	4.81	4.70±2.2%	4.80000
143	4.26	4.34	4.22	4.27±1.4%	4.37	4.23	4.17	4.20±0.7%	4.50000
144	3.56	3.60	3.59	3.58±0.6%	3.70	3.68	3.41	3.54±3.7%	3.94000
145	2.95	3.03	2.94	2.97±1.6%	3.01	2.95	2.92	2.93±0.5%	3.08000
146	2.42	2.48	2.43	2.44±1.3%	2.46	2.47	2.43	2.45±0.8%	2.58000
147	2.02	2.05	2.03	2.03±0.7%	1.99	1.98	2.00	1.99±0.5%	2.13000
148	1.62	1.66	1.63	1.64±1.3%	1.65	1.67	1.68	1.68±0.3%	1.78000
149	1.25	1.25	1.24	1.25±0.5%	1.23	1.31	1.32	1.32±0.7%	1.40000
150	0.96	0.99	0.97	0.97±1.6%	0.98	1.01	1.01	1.01±0 %	1.07000
151	0.77	0.80	0.82	0.79±3.1%	0.78	0.86	0.83	0.85±1.8%	0.94000
152	0.64	0.64	0.63	0.64±0.9%	0.59	0.70	0.63	0.67±5.3%	0.66000
153	0.47	0.44	0.50	0.47±6.4%	0.44	0.56	0.36	0.46±21.7%	0.46000
154	0.29	0.28	0.36	0.31±14.1%	0.26	0.43	0.25	0.34±26.4%	0.33000

Table I: Cumulative Fission Yields for ^{239}Pu and ^{240}Pu in the mass range 125-155

INSTITUT FÜR CHEMIE (1): NUKLEARCHEMIE
KERNFORSCHUNGSANLAGE JÜLICH

1. Neutron Data

1.1 Investigation of Trinucleon Emission Reactions

S.M. Qaim, G. Stöcklin, R. Wölfle

In continuation of earlier radiochemical studies (1) on fast-neutron induced trinucleon emission reactions, (n,t) cross sections were measured at $E_n \approx 22.5$ MeV (53 MeV deuteron break-up neutrons) for B, N, O, F, Ne, Na etc. using vacuum extraction of tritium followed by gas phase β^--counting. Cross sections were also measured for 25 target nuclei by γ-ray spectroscopic analysis of the radioactive activation products. These values, however, gave a sum of the (n,dn), (n,p2n) and (n,t) reaction cross sections. The latter cross sections were much higher than those obtained via tritium counting and led to the conclusion that the (p2n) and (dn) emission is much more probable than ^3H emission.

1.2 Nuclear Data Measurements on FR-Wall and Structural Materials

N.I. Molla, S.M. Qaim
(Relevant to request numbers: 722106, 722107, 724030, 724031, 732010, 732011, 732012, 732014, 732015, 732016, 732019, 732020, 732022, 732023, 732026, 732027, 741228, 741283, 741299, 762080, 762081, 762082, 762085, 762086, 762087, 762097, 762101, 762102, 762106, 762107, 762239, 762240, 762241, 762242, 762243)

In connection with the determination of nuclear data using radiochemical methods (2,3), especially for CTR-related first wall and structural materials, activation cross sections were measured at $E_n = 14.7 \pm 0.3$ MeV for several (n,2n), (n,p) and (n,α) reactions on Ti, V, Cr, Fe and Ni (4). Measurements were also carried out on seventeen reactions induced by fast neutrons produced in the break-up of 30 MeV deuterons (4).

The study of (n,n'p) reactions was continued further and cross sections for this type of reactions were measured (4) at $E_n = 14.7$ MeV on $^{47,48,50}Ti$, $^{53,54}Cr$, ^{57}Fe, $^{61,62,64}Ni$.

1.3 Precision Measurements of Nuclear Reaction Cross Sections at 14 MeV

N.I. Molla, S.M. Qaim

(Relevant to request numbers: 724035, 741305)

Cross sections for (n,p) reactions at 14.7 $\pm$ 0.3 MeV on eighteen stable nuclides of the rare-earth elements Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Er and Lu were measured (5) by the activation technique using high-pressure liquid chromatography. Similarly cross sections for (n,p) reactions on about thirty other nuclides of the elements Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, I, Re, Os, Ir, Pt and Tl were also measured (6).

1.4 Cross Section for the Formation of ^{37}Ar in Fission Reactors

S.M. Qaim, A. Rusheed, G. Stöcklin, R. Wölfle

^{37}Ar occurs to some extent in the gaseous effluents from fission reactors. Since it emits very soft radiations, its detection is not easy. The source of ^{37}Ar in nuclear reactors is believed to be the reaction ^{40}Ca(n,α)^{37}Ar, which takes place on the calcium impurity present in the carbon moderator. Integral cross section measurements of this reaction in a fission neutron spectrum as well as for 14.6 MeV neutrons were carried out (7) using the activation technique involving the separation and gas phase counting of ^{37}Ar. The values obtained are σ_{FS} = 28.5 $\pm$ 5.5 mb and $\sigma_{14.6}$ = 141 $\pm$ 21 mb.

1.5 Measurement of Neutron Capture Cross Sections

A.J. Blair, H. Michael, A. Neubert, R. Wagner

Thermal neutron capture cross section and resonance integral of ^{138}La were determined by mass spectrometry. The final results have now been published (8).

1.6 Evaluation, Compilation and Systematics of Fast Neutron Induced Data

N.I. Molla, S.M. Qaim, G. Stöcklin, R. Wölfle

Statistical model calculations using the Hauser-Feshbach method were carried out for the target nuclides ^{23}Na, ^{27}Al, ^{28}Si, ^{31}P, ^{32}S, ^{39}K, ^{40}Ca, ^{45}Sc, ^{46}Ti and ^{59}Co. The results show that at 14.6 MeV the major reactions (n,n'γ), (n,p) and (n,α) as well as the rare reaction (n,t) proceed mainly via compound nucleus formation; the mechanisms of the (n,d) and (n,^{3}He) reactions, however, are difficult to interpret.

The trends in the (n,p) cross sections at 14 MeV in the region of rare earths were investigated in detail (5) and are shown in Fig. 1. Our earlier results on the (n,2n) cross sections in the rare earth region are also given in Fig. 1. It is evident that in this mass region whereas the (n,2n) cross sections increase very slowly with the increasing (N-Z)/A, the (n,p) cross sections decrease rather sharply as a function of this parameter. From the magnitudes of the (n,2n) and (n,p) reaction cross sections it is apparent that, in the region of rare earths at a compound nucleus excitation energy of about 20 MeV, proton emission is a rather weak process.

The systematics of (n,n'p) reaction cross sections at 14 MeV was also investigated (4) and the results are shown in Fig. 2. For comparison the gross trend in the (n,p) cross sections is also shown and is based on a large number of data points. It is apparent that for many light mass nuclei the (n,n'p) cross sections are comparable to those of the corresponding (n,p) reactions.

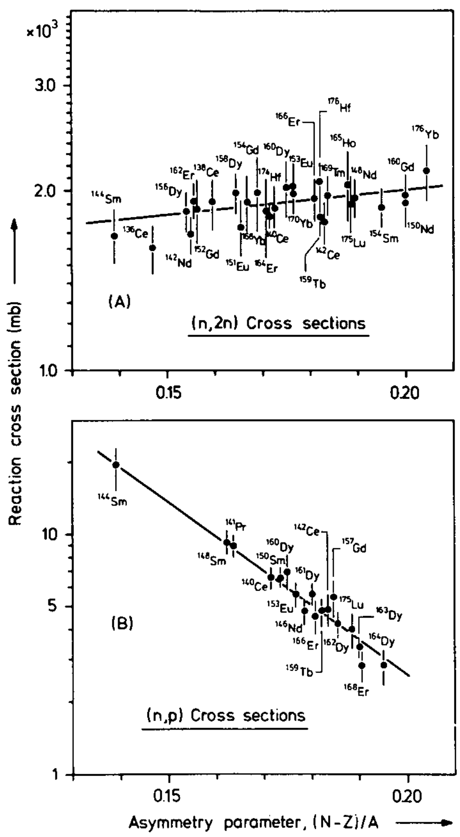

Fig. 1: Systematic trends in (n,2n) and (n,p) reaction cross sections at 14.7±0.3 MeV in the region of rare earths

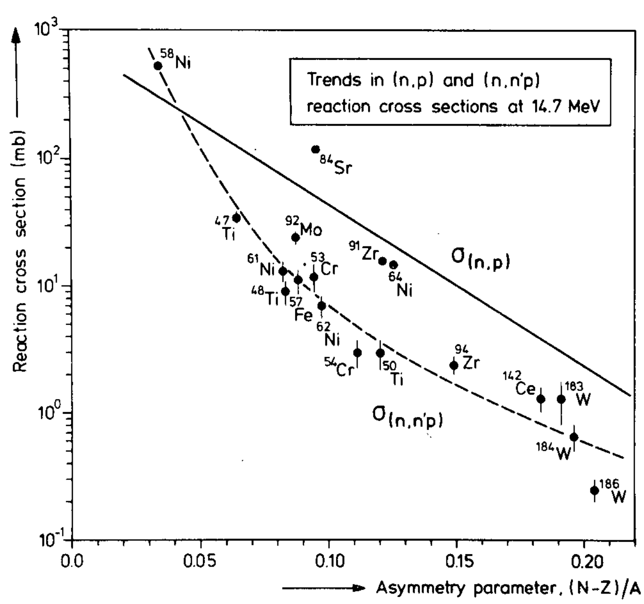

Fig. 2: Trends in (n,p) and (n,n'p) reaction cross sections at 14.7 MeV

2. Charged Particle Data

S.M. Qaim, G. Stöcklin, R. Weinreich

For optimizing the conditions of production of medically important radioisotopes, in continuation of the work described (9) in last year's report, excitation functions of several high-energy nuclear reactions were determined (10,11). Thus, for the production of halogen radioisotopes data were measured for the reactions $^{35}Cl(p,pn)^{34m}Cl$, $^{79,81}Br(d,xn)^{76,77}Kr \xrightarrow{\beta^+,EC} {}^{76,77}Br$ and $^{127}I(\alpha,p7n)^{123}Xe \xrightarrow{\beta^+,EC} {}^{123}I$. Out of these the excitation functions for the production of $^{76,77}Br$ via the decay of $^{76,77}Kr$ precursors are of considerable interest since both ^{77}Br and ^{76}Br appear to have great potential for use in nuclear medicine. The results are shown in Fig. 3. By a careful choice of the energy of the incident deuterons, the thickness of the target as well as the decay time of the krypton precursors, it is possible to produce either ^{76}Br of ^{77}Br with < 1 % contamination from the undesired isotope.

The status of available nuclear data for biomedical purposes was reviewed and the importance of accurate data emphasized (12).

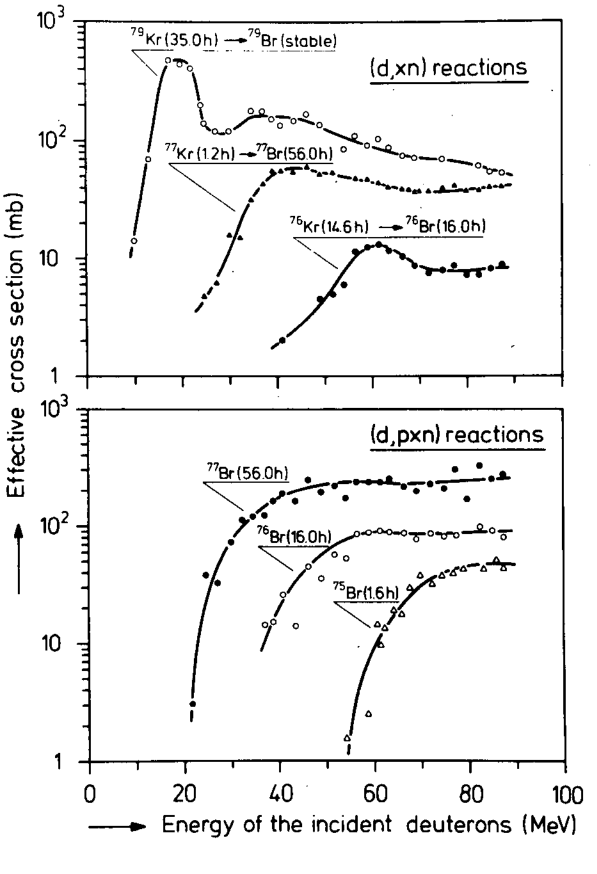

Fig. 3: Excitation functions for the formation of some radioisotopes of Kr and Br in the interactions of high-energy deuterons with natural bromine

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INSTITUT FÜR EXPERIMENTALPHYSIK
UNIVERSITÄT HAMBURG

1. The (n,2n) Reaction of 14.1 MeV Neutrons with ^{127}J and ^{209}Bi

H. Mennekes, V. Schröder, W. Scobel and L. Wilde
(Relevant to request numbers: 742134, 724060)

The study of (n,2n) reactions so far performed in our laboratory with activation techniques (see e.g. (1)) has been continued with an experiment providing energy spectra, angular distributions and correlations of coincident neutrons emitted in the (n,2n) reaction of 14.1 MeV neutrons with ^{127}J and ^{209}Bi. The outgoing neutrons were observed with two time-of-flight (TOF) detectors under several angles between 10^o (for ^{127}J: 28^o) and 150^o (^{127}J: 140^o) with respect to the projectile neutron direction. The TOF start signals were obtained from the associated α particles of the TD neutron source reaction. Fast coincidence, n-γ- discrimination and pile-up rejection requirements had to be fulfilled and a minimum energy E_n^{th}= 0.75 MeV to be exceeded by events from both TOF paths to be accepted as (n,2n) events. The random coincidence rate being determined in background runs with an ^{27}Al target (σn,2n < 1mb) was fairly small. Details of the experimental set-up are given elsewhere (2). Some typical spectra are shown in figure 1.

Integration of the fourfold differential cross-sections $d^4\sigma/d\Omega(\theta_1)d\Omega(\theta_2)dE_{n1}dE_{n2}$ over θ_2 and E_{n2} yields the neutron energy spectra shown in figure 2a for three values of θ_1. Whereas the backward angle spectra agree with the predictions of the statistical model (level density parameters a = 13 MeV^{-1}for ^{209}Bi and 16 MeV^{-1} for ^{127}J) as does the integral spectrum (fig. 1a), the foreward energy spectra show high energy neutrons in excess of the evaporation calculation. They require a preequilibrium contribution (for ^{209}Bi: 16%) in quantitative agreement with the hybrid model predictions and in support of the trend (3) tentatively deduced from 14 MeV activation data of (n,2n) reactions.

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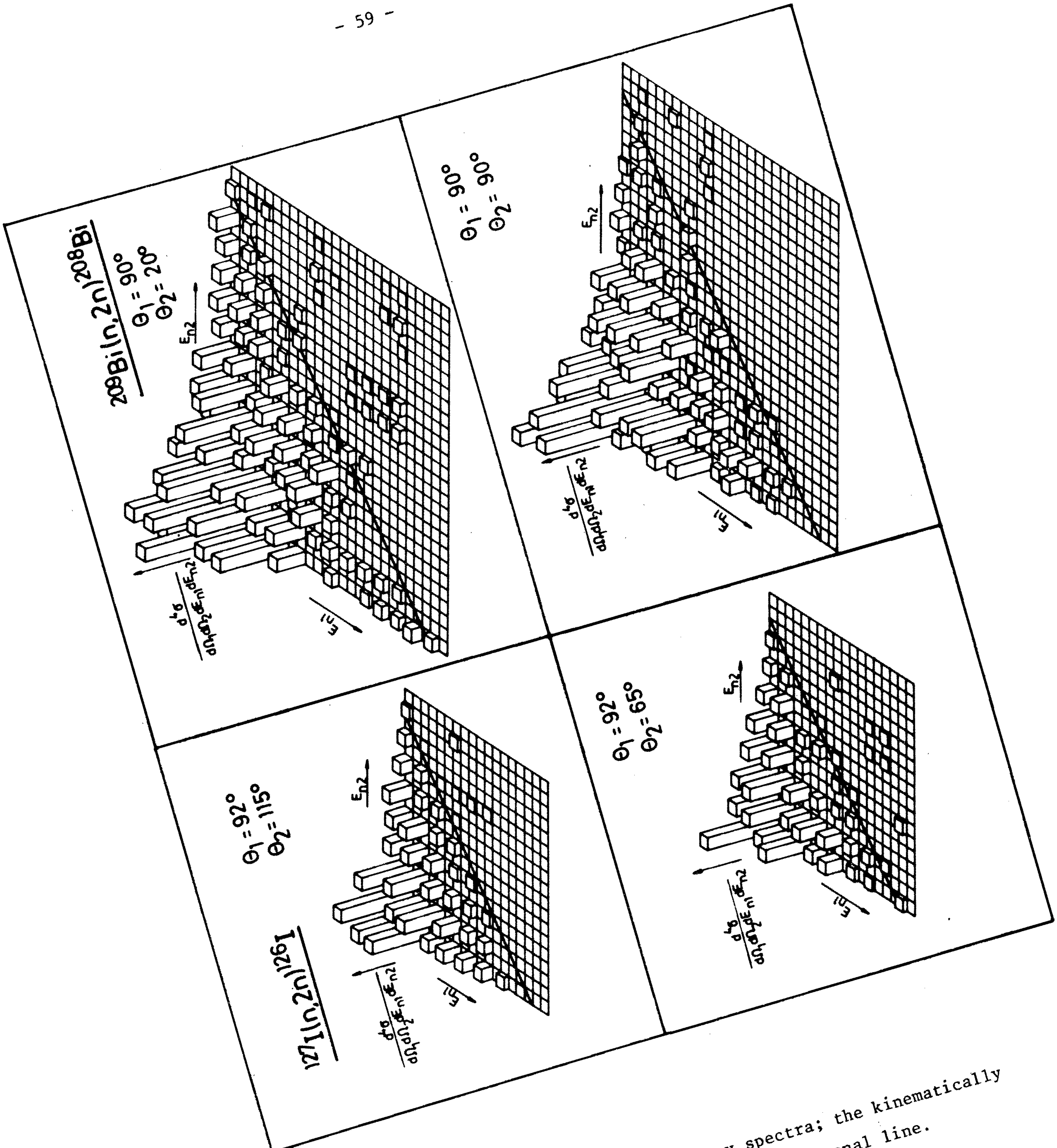

Fig. 1 Some typical neutron energy spectra; the kinematically allowed area is below the solid diagonal line.

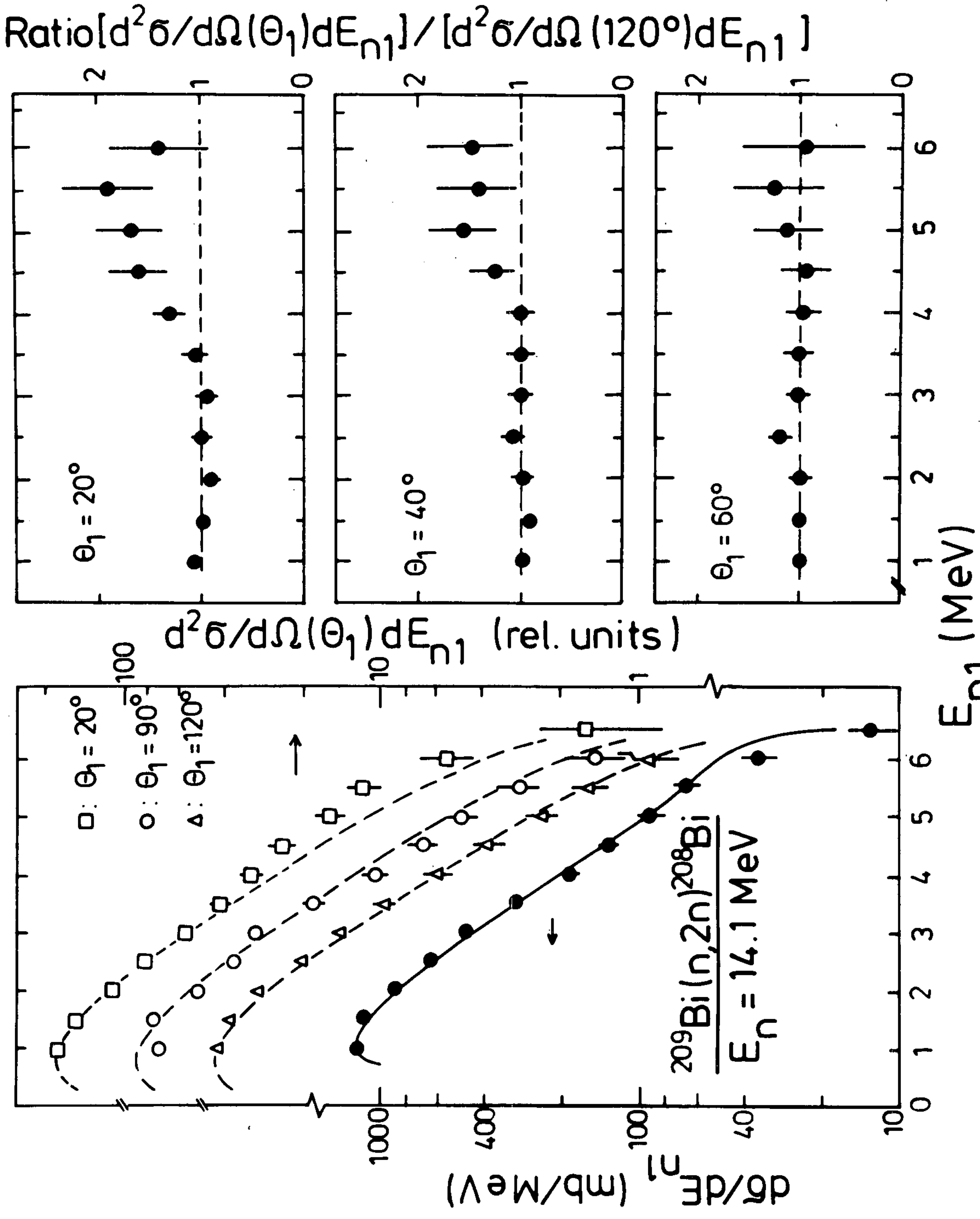

Fig. 2 Left: Spectra obtained for different angles 20°, 90°, 120° of detector 1, and the spectrum resulting from integration over Θ_1. Dashed line: Statistical model calculation; Solid line: Ewing-Weißkopf plus hybrid model result.
Right: Absolute spectra obtained under foreward angles Θ_1, divided by the experimental spectrum at Θ_1 = 120°.

INSTITUT FÜR REINE UND ANGEWANDTE KERNPHYSIK
UNIVERSITÄT KIEL, FORSCHUNGSREAKTOR GEESTHACHT

Fast Chopper Time-of-Flight Spectrometer and Crystal Spectrometer

H.G.Priesmeyer, U.Harz, K.Freitag, P.Podewils

1. Measurements on Cd isotopes

(relevant to request number 752002)

The measurements on the ^{114}Cd enriched sample have been analysed and are being published. Resonance parameters are listed in Table 1. These measurements proved to be very useful for isotopic identifications of resonances in ^{106}Cd and ^{108}Cd, since the sample was prepared from a reactor poison rod, after all of the ^{113}Cd had been converted to ^{114}Cd. Measurements on ^{106}Cd (88.4% enrichment, 2.4g CdO) and on ^{108}Cd (73.7% enrichment, 4.1g CdO) have been completed. The transmissions are shown in Figure 1.
Both samples were on loan from USERDA. Analysis is in progress. Nine new resonances were found. Their energies are listed in Table 2.

Table 1: List of resonance parameters

	E_0 /eV/	$g\Gamma_n$ /meV/	Γ_γ/meV/
^{110}Cd	89.1	130 ± 10	110 ± 20
	369.2	25 ± 5	-
^{111}Cd	27.5	3.4 ± 0.4	-
	85.7	1.8 ± 0.35	-
	99.0	10 ± 1	85 ± 20
	102.5	0.7 ± 0.25	-
	137.5	6.5 ± 1	-
	163.5	48 ± 5	-
	232.2	68 ±10	-
	275.2	14 ± 4	-
	310.0	34	-
^{112}Cd	66.5	7.5 ± 0.5	75 ± 25
	83.0	0.32± 0.1	-
	441	60 ± 10	-
^{114}Cd	56.0	0.086± 0.01	-
	119.6	50 ± 5	70 ± 30
	391.0	880 ± 60	-
	672.5	-	-

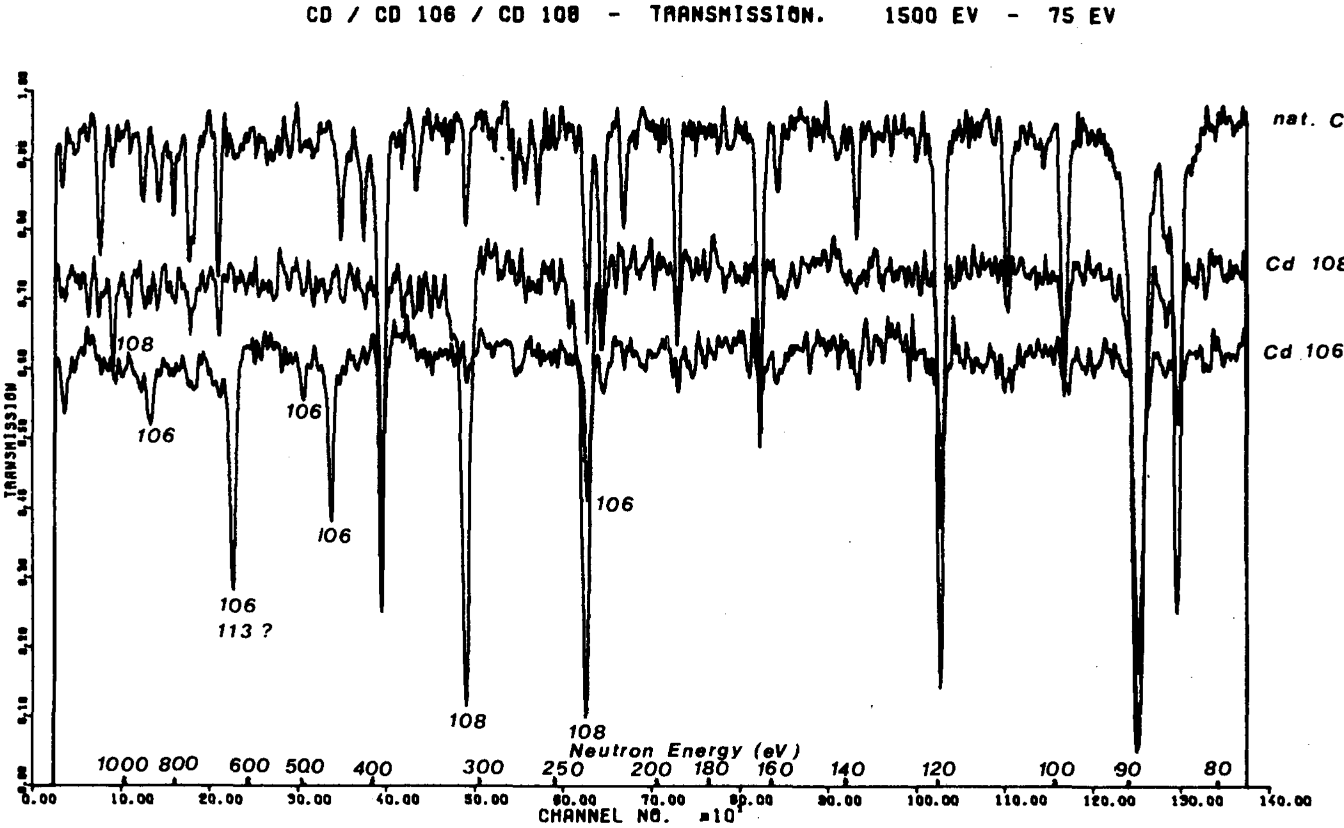

Fig.1: Neutron transmissions of three different samples between 1.5 keV and 75 eV (natural Cd, enriched ^{106}Cd, enriched ^{108}Cd)

Table 2: Resonance energies /eV/

^{106}Cd	^{108}Cd
879	1043
633	311
499	233
454 +	54 +
232	

\+ these resonances were known prior to this experiment, but not isotopically identified

2. Fission Product Cs Mixture

The conclusions drawn from the transmission measurement on the Cs 133/135/137 mixture are not unique as to what the 41.8 eV resonance identification is concerned. The sample will be remeasured, after some cooling time has elapsed.

3. ^{240}Pu Resonance at 1.056 eV

A transmission measurement on material enriched to 8% in ^{240}Pu is prepared, in order to clarify the significant differences in the resonance parameters of the large resonance at 1.056 eV, as stated by the Advisory Group on Transactinium Isotope Nuclear Data (see Technical Document IAEA - 186, Vol.II, p. 30 & 31)

4. Total Neutron Cross Section of Zirconiumhydride at 77 K

Some years ago, measurements on ZrH_x at different temperatures above room temperature have been made with the University of Kiel crystal spectrometer (Bröcker, Schmidt). In order to make these measurements more complete, a low temperature experiment has been made at 77 K. The hydrogen concentration was 192 at%. The energy resolution was between 1 and 3%. The results for both room temperature and liquid nitrogen temperature are shown in Fig. 2 together with a Fermi - model calculation.
The sharp minima are well approximated by the data at 77 K.
One may conclude that the Fermi model does describe the experimental findings in this energy range quite well.

5. Recent Publications

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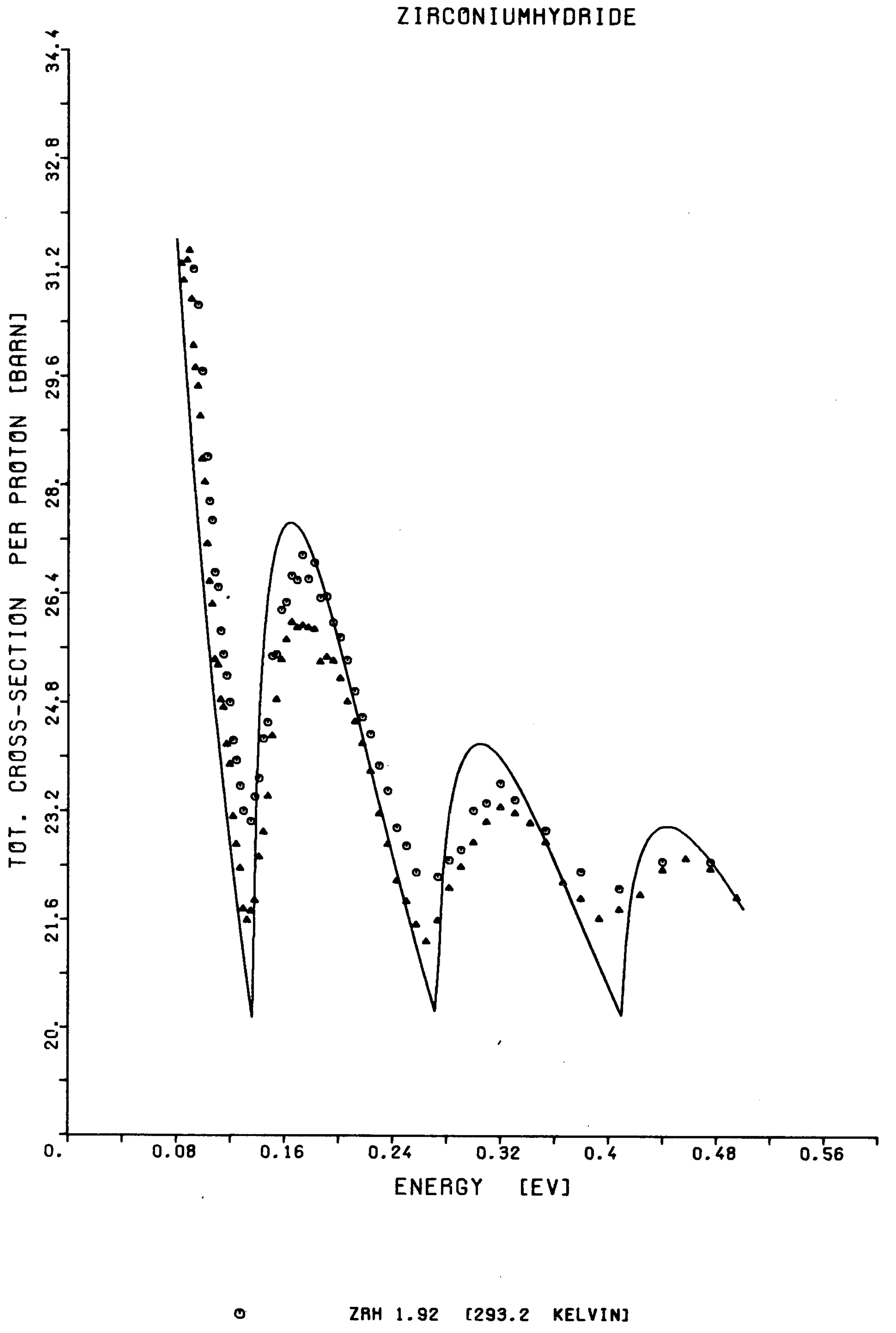

Fig. 2: Low-Energy Total Neutron Cross Section of $ZrH_{1.92}$

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JOHANNES GUTENBERG-UNIVERSITÄT MAINZ

1. Charge Distribution in Thermal Neutron Induced Fission Reactions

H.O. Denschlag, G. Fischbach, H. Meixler, G. Paffrath, W. Rudolph, M. Weis, K. Wolfsberg+

Radiochemical measurements of independent and cumulative yields of fission products have been continued. Various fission reactions of practical [U-235(n_{th},f), Pu-239(n_{th},f)] and of more theoretical interest [Cf-249(n_{th},f), Cf-250(sp,f)] have been studied.

The values obtained are listed in Table 1. For the presentation of the data the form introduced by Meek and Rider (74 MEE 1, 77 MEE 1) has been adopted where applicable.

The values given in Table 1 of this report supersede those of Table I in 76 NEA 1.

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Table 1

Fission yields

Measured Nuclide	Fission Reaction	Meas. Type	Value	Error (1σ)	Norm. Nuclide	Norm. Fission Reaction[2)]	Norm. Value	Ref.
89 Kr	CF249T	FC	77.6	1.5	89 Sr		100	77MEI1
91 Kr	CF249T	FC	32	3	91 Sr		100	77MEI1
91 Kr	CF250S	FC	36	4	91 Sr		100	77MEI1
92 Kr	CF249T	FC	9.5	1.3	92 Sr		99	77MEI1
92 Kr	CF250S	FC	11	3	92 Sr		99	77MEI1
99 Y	U235T	FC	31.4	3.9	99 Mo		100	76WEI1
99 Zr	U235T	FI	56.9	4.3	99 Mo		100	76WEI1
99 Zr	U235T	FC	88.3	2.8	99 Mo		100	76WEI1
99 Nb m	U235T	FI	10.8	2.9	99 Mo		100	76WEI2
99 Nb m	U235T	FC	36.4	4.5	99 Mo		100	76WEI1
99 Nb g	U235T	FI	0.9	0.5	99 Mo		100	76WEI2
99 Nb g	U235T	FC	63.6	4.5	99 Mo		100	76WEI1
99 Nb(m+g)	U235T	FI	11.7	2.8	99 Mo		100	76WEI2
101 Zr	U235T	FC	53.4	2.5	101 Tc		100	77WEI1
101 Nb	U235T	FI	45.2	2.5	101 Tc		100	77WEI1
101 Nb	U235T	FC	[98.6	3.5]	101 Tc		100	77WEI1
101 Mo	U235T	FI	1.4	3.5	101 Tc		100	77WEI1
102 Zr	U235T	FC	52.4	4.9	102 Mo		100	77WEI1
102 Nb h	U235T	FI	41.0	3.0	102 Mo		100	77WEI1
102 Nb l	U235T	FI	<3		102 Mo		100	77WEI1
104 Nb h	U235T	FC	5	5	104 Tc		100	77WEI1
104 Nb l	U235T	FC	42.5	3.0	104 Tc		100	77WEI1
105 Nb	U235T	FC	29	6	105 Tc		100	77WEI1
131 Sn	Pu239T	CU	0.45[1)]	0.07	131 Sn	U235T	0.97	76PAF1
132 Sb h	U235T	RE	0.44	0.05	132 Sb l		1.00	76PAF1
132 Sb h	U235T	RE	0.39	0.06	132 Sb l		1.00	76RUD1
132 Sn	Pu239T	FC	9.0	1.7	132 Te		98	76PAF1
132 Sn	Pu239T	CU	0.44	0.23	132 Sn	U235T	0.56	76PAF1
132 Sb h	Pu239T	RE	0.33	0.05	132 Sb l		1.00	76PAF1
132 Sb h	Pu239T	FI	12.5[3)]	2.5	132 Te		98	76PAF1
132 Sb l	Pu239T	FI	37.9[3)]	4.7	132 Te		98	76PAF1
132 Sb(h+l)	Pu239T	FI	50.4	2.5	132 Te		98	76PAF1
132 Sb(h+l)	Pu239T	IN	2.6	0.16	132 Sb(h+l)	U235T	2.0	76PAF1

Table 1

Fission yields continued

Measured Nuclide	Fission Reaction	Meas. Type	Value	Error (1σ)	Norm. Nuclide	Norm. Fission Reaction[2)]	Norm. Value	Ref.
132 Te	Pu239T	FI	39.6	1.2	132 Te		98	76PAF1
132 Sn	Cf249T	CU[1)]	0.14	0.06	132 Sn	U235T	0.56	76PAF1
132 Sb(h)	Cf249T	RE	0.47	0.05	132 Sb l		1.00	76PAF1
132 Sb(h)	Cf249T	IN	1.1[3)1)]	0.2	132 Sb(l+h)	U235T	2.0	76PAF1
132 Sb(l)	Cf249T	IN	0.5[3)1)]	0.2	132 Sb(l+h)	U235T	2.0	76PAF1
132 Sb(l+h)	Cf249T	IN	1.62[1)]	0.29	132 Sb(l+h)	U235T	2.0	76PAF1
133 Sb	Pu239	CU	1.06[1)]	0.39	133 Sb	U235T	1.7	76PAF1
133 Sb	Cf249T	CU	1.79	0.41	133 Sb	U235T	1.7	76PAF1
134 Sb g	U235T	FC	6.15[4)]	0.40	134 I		11.6[5)]	77RUD1
134 Sb m	U235T	FC	1.23[4)]	0.08	134 I		11.6[5)]	77RUD1
134 Sb(m+g)	U235T	FC	7.38	0.50	134 I		11.6[5)]	77RUD1
134 Sb g	Pu239T	CU	0.28[1)]	0.10	134 Sb	U235T	0.38	76PAF1
134 Sb g	Cf249T	CU	0.31	0.18	134 Sb	U235T	0.38	76PAF1
135 Sb	U235T	FC	2.37	0.14	135 I		47.1[5)]	77RUD1
135 Sb	U235T	FC	2.30	0.18	135 I		98.7	77RUD1
135 Sb	Pu239T	CU	0.07	0.03	134 Sb		0.28	76RUD1
139 Xe	Cf249T	FC	32	4	139 Ba		100	77MEI1
139 Xe	Cf250S	FC	28	8	139 Ba		100	77MEI1
140 Xe	Cf249T	FC	12.5	2	140 Ba		99	77MEI1
141 Xe	Cf249T	FC	4.0	0.3	141 Ba		97	77MEI1
140 Xe	Cf250S	FC	18	7	140 Ba		100	77MEI2
142 Xe	Cf249T	FC	1.2	0.3	142 Ba		91	77MEI1
144 Ba	U235T	FC	[83	8]	144 La		100	77FIS1
144 La	U235T	FI	17	8	144 La		100	77FIS1
145 La	U235T	FC	92	9	145 Ce		100	77FIS1
146 La	U235T	FC	80	4	146 Pr		100	76FIS1
146 Ce	U235T	FC	98	2	146 Pr		100	76FIS1
146 Ce	U235T	FI	[18	5]	146 Pr		100	76FIS1
148 Ce	U235T	FC	94	9	148 Pr		100	77FIS1
149 Ce	U235T	FC	71.5	5.0	149 Nd		100	77FIS1

Footnotes to Table 1

1) Value was given in Table I 76 NEA 1 as a fractional yield. The present form is the direct experimental result.
2) If different from fission reaction studied.
3) Value as stated in Table I of 76 NEA 1 is incorrect due to an arithmetic error.
4) The yields of the single isomeric states have been calculated from the experimentally determined sum of both isomeric states (7.38 %) according to the isomeric ratio of m:g = 1:5 given in 72 KER 1; the (unknown) uncertainty in the isomeric ratio has not been included in the errors indicated. Due to the experimental conditions it would affect mainly the yield of 134-Sb m. The yield of 134-Sb g could at most be raised to 6.36 ± 0.39 % if no yield of 134-Sb m was assumed.
5) Fractional independent yield, other normalizing values are cumulative yields.

Explanation of symbols used in Table 1

U235T	Thermal neutron induced fission of U-235
Pu239T	Thermal neutron induced fission of Pu-239
Cf249T	Thermal neutron induced fission of Cf-249
Cf250S	Spontaneous fission of Cf-250
FI	Fractional independent yield (%)
FC	Fractional cumulative yield (%)
IN	Absolute independent yield (%)
CU	Absolute cumulative yield (%)
RE	Yield relative to normalizing value
g	Ground state
m	Metastable state
h	High-spin state
l	Low-spin state
[ ]	Value derived from other given data (FC-FI etc.). In the other cases when FI and FC are given for one nuclide they are based on separate measurements.

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2. Delayed-Neutron Emission Following Decay of $^{93-97}Rb$, ^{136}Te, ^{138}I and $^{141-146}Cs$ +)

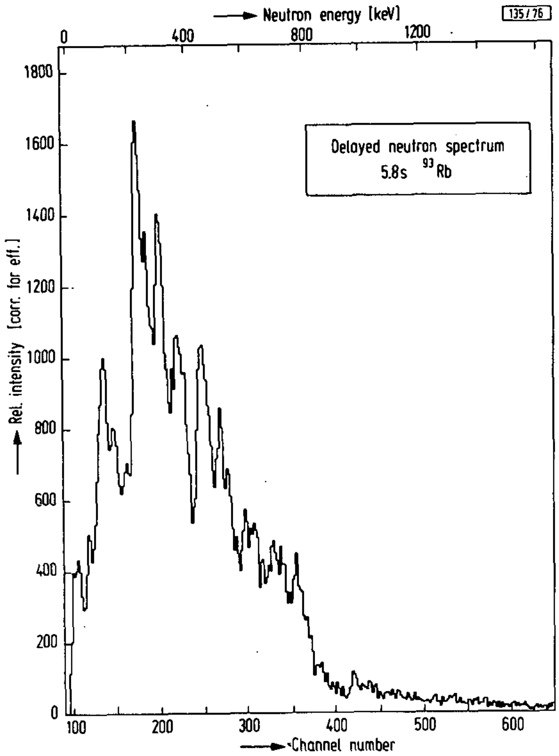
K.-L. Kratz, H. Ohm, W. Rudolph, H. Sümmerer, M. Zendel

The recently measured delayed-neutron spectra from fission product precursors show more or less pronounced peak structure (1-8). In addition, in most of the spectra a marked lack of high-energy neutrons is noted indicating preferential neutron emission from intermediate emitter levels to excited states in the final nucleus, contrary to what is expected from the compound nucleus model (4,9). Moreover, a systematic variation of the spectrum shape with mass-number within an isotope sequence is observed.

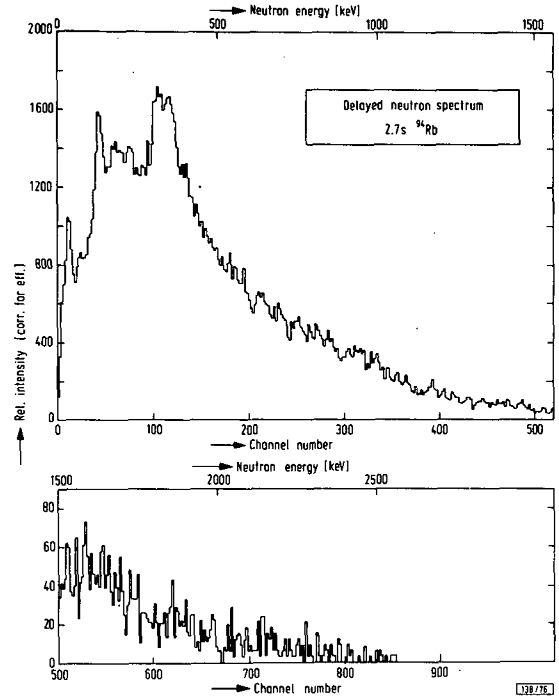
As an example, the neutron spectra following β^--decay of $^{93-97}Rb$ are shown in Fig. 1. Spectra of odd-mass Rb precursors decaying into even-even Sr final nuclei exhibit prominent line structure accounting for about 60 % (^{93}Rb), 50 % (^{95}Rb) and 30 % (^{97}Rb), respectively, of the total neutron intensity. On the other hand, even-mass Rb precursors decaying into odd-mass Sr isotopes show a larger continuous neutron distribution superimposed by peaks containing about 15 % (^{94}Rb) and 20 % (^{96}Rb), respectively, of the total intensity.

Through γ-ray studies we have been able to demonstrate that the above mentioned absence of appreciable high-energy neutron intensity and the variation in the spectrum shape are due to neutron emission to excited states in the final nuclei (1,6,9). The partial neutron emission probabilities $P_n^i(\gamma)$ and the total P_n-values obtained by γ-spectroscopic measurements of five Rb precursors are given in Table 2 indicating strong neutron feeding of excited states in $^{93-96}Sr$. As an example, Figure 2 shows the decay of ^{93}Rb and ^{94}Rb to levels in ^{92}Sr and ^{93}Sr. It is clearly seen that in the case of the even-even final nucleus ^{92}Sr neutron emission can only lead to a maximum of 5 excited states which are widely spaced, whereas in the case of the final nucleus ^{93}Sr a total of 16 narrow spaced levels at low excitation energies are available for neutron decay. Thus, many neutron branches with comparable intensities superimposed lead to the complex neutron spectrum of the even-mass precursor ^{94}Rb with only a few strong neutron lines well resolved. Similar results were obtained for the partial neutron feeding of excited states in $^{94-96}Sr$. This "odd-even effect" in neutron spectra is also

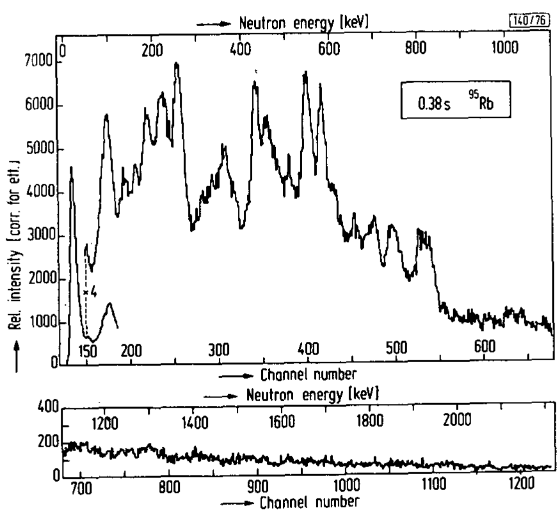
+) Part of these results have been obtained with K.D. Wünsch, G. Jung, R. Decker, H. Wollnik, C. Ristori and J. Crancon at the on-line separator OSTIS installed at the high-flux reactor in Grenoble a)



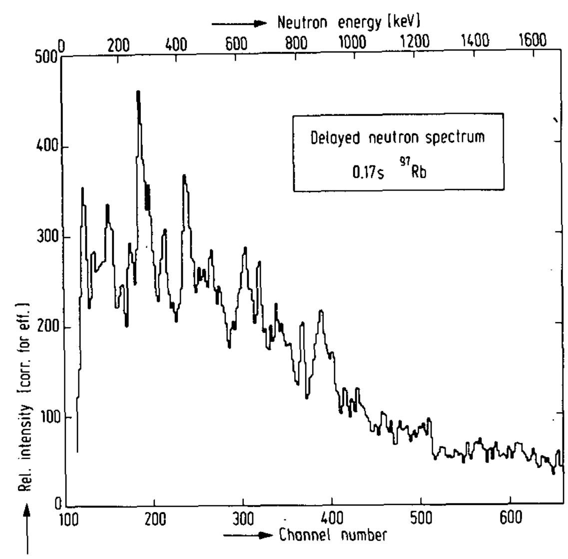
b)



c)



d)



e)

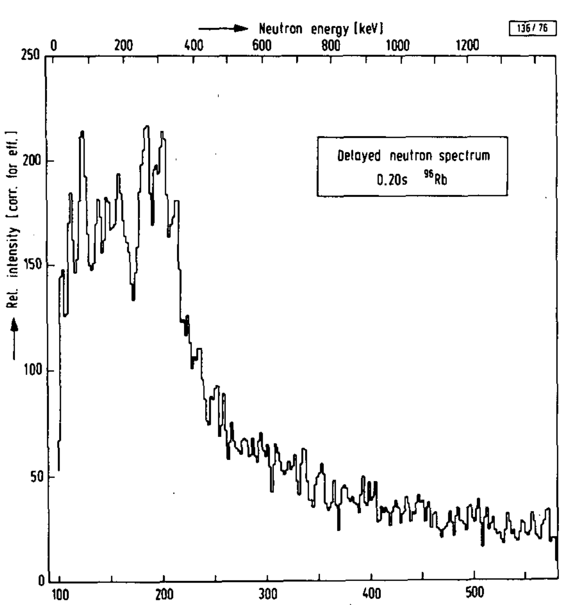


Figure 1: Delayed-neutron spectra from $^{93-97}$Rb decay after correction for detector efficiency, thermal neutrons and background:

a) 5.8 s ^{93}Rb spectrum.
b) 2.7 s ^{94}Rb spectrum.
c) 0.38 s ^{95}Rb spectrum.
d) 0.20 s ^{96}Rb spectrum.
e) 0.17 s ^{97}Rb spectrum.

Table 2

Neutron decay to excited states in the final nucleus, $P_n^i(\gamma)$, and total neutron emission probabilities, $P_n(\gamma)$, obtained from $^{93-97}$Rb γ-ray spectra

Precursor	$P_n^i(\gamma)$ in % of $P_n(\gamma)$	$P_n(\gamma) = \frac{I_\gamma(\text{mass A - 1})}{I_\gamma(\text{mass A})}$
^{93}Rb	9.0 $\pm$ 1.0	1.32 $\pm$ 0.03
^{94}Rb	59.9 $\pm$ 9.3	10.1 $\pm$ 1.3
^{95}Rb	46.0 $\pm$ 3.5 +)	8.6 $\pm$ 0.4
^{96}Rb	58.6 $\pm$ 4.6	13.4 $\pm$ 2.6
^{97}Rb	90 $^{+10}_{-25}$	25.3 $\pm$ 4.8

+) Under the assumption that all levels in the final nucleus deexcite via the first 2^+-state.

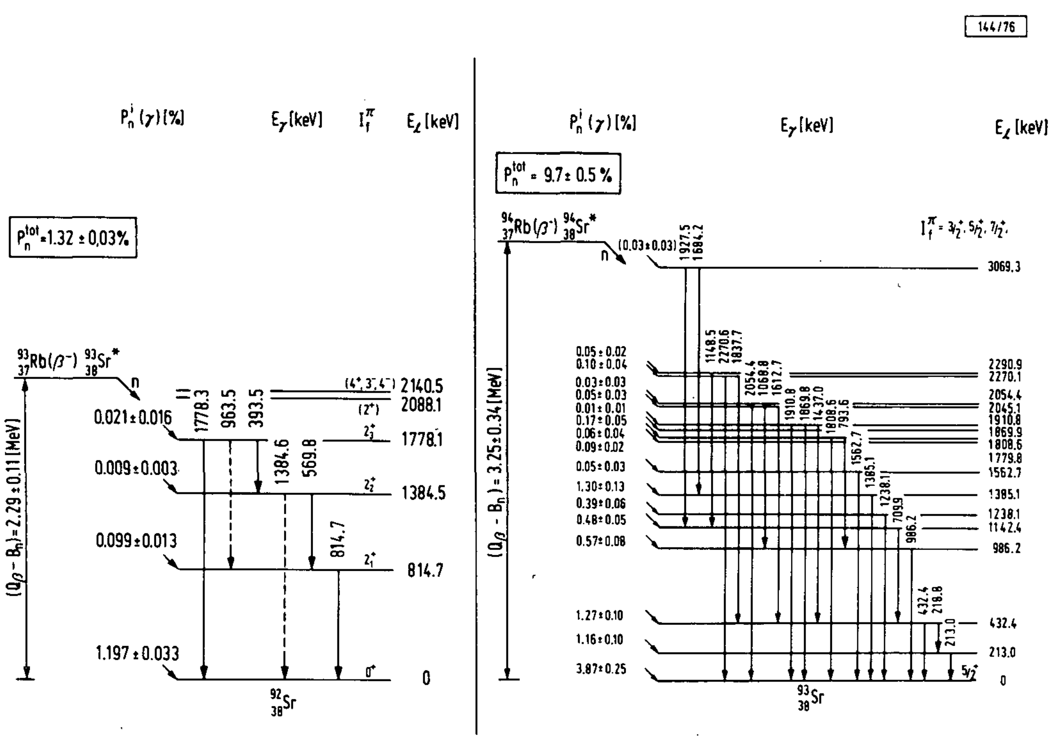


Figure 2: Neutron emission to excited states in ^{92}Sr and ^{93}Sr

observed for the bromine, iodine and cesium precursors. High-resolution β^--strength functions were constructed combining informations from neutron data with the γ-decay schemes of the emitter nuclei. In the cases where neutrons lead to excited states in the final nucleus, unfolding of the neutron spectra is necessary. Due to technical difficulties with nγ-coincidence measurements, this unfolding was done so far via the $P_n^i(\gamma)$ and correlations between neutron transition energies and differences in level energies in the final nucleus (4,9). However, in the case of ^{95}Rb delayed-neutron decay we recently succeeded to measure - for the first time - a high-resolution neutron spectrum in coincidence with its γ-ray spectrum. Though severe difficulties due to the long charge collection time in the ^{3}He ionization chamber - a time window of 20 μs was used for the neutron coincidence branch - and due to the low overall efficiency of about 10^{-7} for the Ge(Li)-^{3}He detector arrangement had to overcome, the neutron spectrum in coincidence with the 837 keV γ-line ($2^+ \rightarrow 0^+$ transition) in the ^{94}Sr final nucleus, shown in the lower part of Fig. 3, indicates that besides others also very low energy neutrons feed the first excited state or higher lying levels in ^{94}Sr.

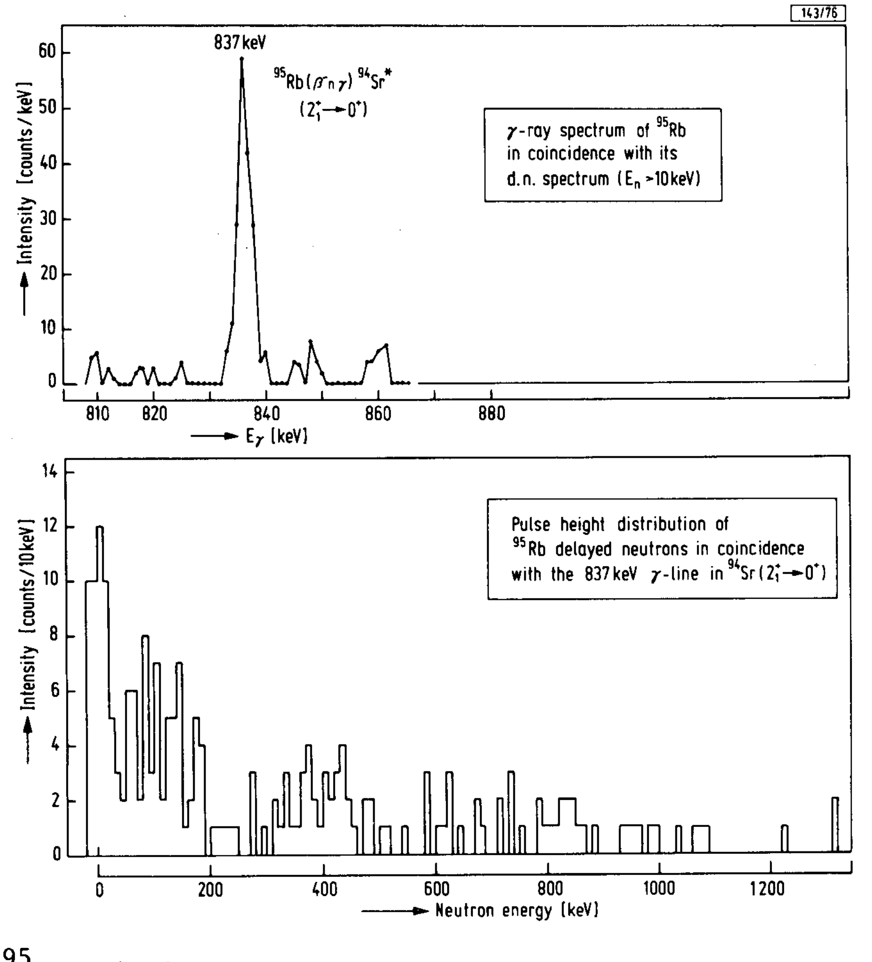


Fig. 3: ^{95}Rb coincidence spectra: 5 μs time-window, random coincidences subtracted; part of the γ-ray spectrum in coincidence with the neutron spectrum (upper part), pulse height distribution of delayed neutrons in coincidence with the 837 keV γ-line ($2^+ \rightarrow 0^+$) in ^{94}Sr (lower part)

Theoretical investigations of the delayed-neutron spectra have so far been limited to the predictions of envelopes of the energy distribution (2,3,10), or to attempts at predicting the location of resonances in these envelopes (11). Based on the results for β^+-delayed proton emission (12,14), and on the predictions of the gross theory of β-decay (11) it was reasonable to assume that slowly varying β-strength functions should be the key to calculations of β^--delayed neutron spectra. However, the above mentioned features of the neutron spectra, the preferential neutron decay from emitter levels to excited states in the final nuclei, and the occurrence of clear resonances in the deduced β^--strength functions, their locations varying only slowly with mass number, point to appreciable selectivity in β^--decay to levels in the vicinity of 5-7 MeV in the emitter nuclei (4-6).

The knowledge on a structure of the Gamow-Teller giant resonance existing from investigation of the isovector M 1 γ-decays of IAS (15), and the configurations (AIAS, CPS and SFS) being responsible for this structure which become energetically accessible to β^--decay in very neutron-rich nuclei may explain this selective β^--feeding of states in the neutron emitter nuclei (16,17).

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3. Decay Studies on Neutron-rich Isotopes of the Light Lanthanides

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The SISAK Collaboration

A detailed knowledge of the decay systematics of neutron-rich La-, Ce- and Pr-isotopes, being situated in the shape transition region (N = 82-92) between spherical and deformed nuclei, is of considerable interest for nuclear structure interpretations.

For studying the decay properties of these nuclei, produced by thermal-neutron induced fission of ^{235}U and ^{239}Pu, a fast on-line operating solvent extraction system consisting of several H-centrifuges - SISAK (1) - in combination with high resolution γ-ray spectroscopy has been used. The transport of the fission products from the production site to the chemical apparatus has been performed with a gas jet system (2).

The chemical separation of the lanthanides from the other fission products is based on their extractibility into di(2-ethylhexyl)orthophosphoric acid from different aqueous solutions (3) after dissolution of the fission products from the clusters which are necessary to transport the radioactivity long distance through narrow capillaries. In the specially designed centrifuges complete phase separation takes place and the measurements can be carried out directly either on the aqueous or the organic phase.

The results of our investigations are summarized in Table 3.

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Table 3

Nuclide	Half-life	Strongest γ-rays (keV)	Ref.
La-143	14.2 ± 0.2 min	620.6, 621.7, 643.9, 798,3;	(4,5)
La-144	42.1 ± 0.7 sec	397.5, 541.3, 585.1, 844.9;	(5,6)
La-145	25.3 ± 2.6 sec	70.2, 118.4, 189.0, 918.2;	(5,6)
La-146	8.5 ± 1.0 sec	258.5, 410.0, 503.2, 515.0;	(5,6)
La-147	2.2 ± 0.4 sec	117.9, 187.1, 215.5, 399.7;	(5)
La-148	∿ 1 sec	158.5, 295.8, 537.7;	(5)
Ce-145	3.0 ± 0.1 min	62.7, 423.6, 724.3, 1147.9;	(5,7)
Ce-146	14.2 ± 0.2 min	133.7, 218.5, 264.9, 317.1;	(5,7)
Ce-147	56.7 ± 2.3 sec	92.9, 269.1, 374.4, 467.3;	(5,7)
Ce-148	50.5 ± 1.6 sec	98.5, 121.2, 195,7, 291.8;	(5,7)
Ce-149	5.7 ± 0.5 sec	57.9, 145.2, 380.1;	(5)
Ce-150	4.1 ± 0.6 sec	103.9, 109.5	(5)
Pr-147	12.0 ± 0.2 min	86.5, 314.7, 577.9, 641.4;	(5,8)
Pr-148	2.2 ± 0.1 min	301.8, 697.8, 1023.2, 1357.9;	(5,8)
Pr-149	2.9 ± 0.3 min	108.5, 138.4, 165.0, 332.8;	(5,8)
Pr-150	6.2 ± 0.2 sec	130.2, 804.4, 852.7, 931.5;	(5,8)

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REAKTORSTATION GARCHING, FACHBEREICH PHYSIK
TECHNISCHE UNIVERSITÄT MÜNCHEN

1. Coherent Neutron Scattering Lengths

1.1 Neutron Refractometer

L. Koester, W. Waschkowski, E. Mathiak

Previous studies of the reflection of slow neutrons on liquid mirror of molten metals have shown that the reflection process was disturbed by invisible vibrations and by oxidation of the liquid metal surface. After installation of a new vacuum oven and an improved damping system new determinations of the scattering lengths for lead and bismuth were performed. Typical results for the scattering lengths per bound atom b_c are

$b_c(Pb) = 9.4003 \pm 0.0014$ fm and $b_c(Bi) = 8.5321 \pm 0.0015$ fm.

The present preliminary value for Bi is larger than the previous result $b_c(Bi) = 8.524(2)$ fm.

1.2 Christiansen Filter Technique

L. Koester, K. Knopf

Improvements of the preparation and handling of Christiansen-filters and the design of a special small-size filter made possible the determination of scattering lengths for powders of compounds of separated isotopes.

The experiments led to the coherent scattering lengths for the bound atoms as follows:

$$
\begin{aligned}
b_c\ (^{11}B) &= 6.69 \pm 0.03 \text{ fm} \\
b_c\ (^{35}Cl) &= 11.70 \pm 0.09 \text{ fm} \\
b_c\ (^{37}Cl) &= 3.08 \pm 0.06 \text{ fm} \\
b_c\ (^{50}Cr) &= -4.84 \pm 0.09 \text{ fm} \\
(^{52}Cr) &= 4.80 \pm 0.09 \text{ fm} \\
(^{53}Cr) &= -4.19 \pm 0.04 \text{ fm} \\
(^{54}Cr) &= 4.73 \pm 0.17 \text{ fm} \\
b_c\ (Ti) &= -3.363 \pm 0.013 \text{ fm} \\
b_c\ (^{48}Ti) &= -5.85 \pm 0.03 \text{ fm} \\
b_c\ (^{55}Mn) &= -3.73 \pm 0.02 \text{ fm}
\end{aligned}
$$

Moreover it was found that previous experiments on "natural" lithium compounds must be corrected because of a depletion of the ^{6}Li content. Corrected and redetermined values are:

$$b_c\ (5.4\ \%\ ^6\text{Li} \pm 94.6\ \%\ ^7\text{Li}) = -2.086 \pm 0.013\ \text{fm}$$
$$b_c\ (^7\text{Li}) = -2.29 \pm 0.02\ \text{fm}$$
$$b_c\ (^6\text{Li}) = 1.3 \pm 0.5\ \text{fm}.$$

1.3 Verification of the Equivalence of Gravitational and Intertial Mass for the Neutron*

L. Koester

A comparison of neutron scattering lengths measured dependent on and independent of gravity leads to a value γ for the ratio of gravitational to intertial mass for the neutron. We obtained $\gamma = 1.00016 \pm 0.00025$. This means the first verification of the equivalence for the neutron with an uncertainty of only 1/4000.

1.4 Measurement of the Neutron-Electron Interaction by the Scattering of Neutrons by Lead and Bismuth**

L. Koester, W. Nistler, and W. Waschkowski

The atomic scattering length of lead and the nuclear scattering lengths of lead and bismuth were measured with high accuracy. From the results we obtained b_c(Pb atom) = 9.4003 ± 0.0014 fm, b_N(Pb nucleus) = 9.5121 ± 0.015 fm, b_N(Bi nucleus) = 8.6412 ± 0.0015 fm, and from the previously reported b_c(Bi atom) we obtained two new values for the neutron-electron scattering length: $b_{n,e} = -(1.364 \pm 0.025) \cdot 10^{-3}$ fm from the Pb experiment, and $b_{n,e} = -(1.393 \pm 0.025) \cdot 10^{-3}$ fm from the Bi data.

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*) Work published in Phys. Rev. D14 (1976) 4

**) Work published in Phys. Rev. Lett. 36 (1976) 1021

1.5 The Scattering of Slow Neutrons by Phosphorus and Nitrogen*

L. Koester, K. Knopf, and W. Waschkowski

The coherent scattering lengths b and the free cross sections for the scattering of slow neutrons by P and N were measured on powdered samples. From the results we derived data for the incoherent cross sections and for the spin state scattering lenghts. We found for phosphorus:

$b = 5.13 \pm 0.01$ fm, $\sigma_{free} = 3.134 \pm 0.010$ b and
$\sigma_{inc} = 0.006 \pm 0.016$ b,

and for nitrogen:

$b = 9.36 \pm 0.02$ fm, $\sigma_{free} = 10.03 \pm 0.08$ b and
$\sigma_{inc} = 0.4 \pm 0.1$ b.

Derived values for resonance parameters of N are given.

2. Free Neutron Cross Sections

2.1 Rotating Resonance Detector Transmission Measurements

L. Koester, W. Waschkowski

By means of rotating resonance detectors transmission measurements were performed on samples containing powders of compounds of natural elements or separated isotopes. The same substances as for the Christiansen filter measurement were used. From the measured total cross sections at 1.2 eV and 5.2 eV neutron energy the free scattering cross section at "zero energy" was derived for the element or isotope of interest.

These values combined with the corresponding coherent scattering lengths allow for the determination of the spin state scattering amplitudes and an estimate of the potential scattering radius of the nuclei if some resonance parameters are known. Results were obtained for the Li-isotopes, the Cl-isotopes, for ^{53}Cr and for Mn.

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*) Work published in Z. Physik A277 (1976) 77

2.2 Precision Measurement of Free Cross Sections for Neutrons*

W. Waschkowski and L. Koester

Rotating activation foils with resonance energies of 1.26 eV and 5.19 eV have been applied for exact measurements of neutron cross sections. The detector consisted of a sandwich of two rotating foils and was suitable for determining exactly the neutron flux at the resonance energy and energy changes in the neutron beam. The cross sections of polycrystalline samples showed uncertainties greater than the statistical error. The more accurate measurements on liquid samples yielded the following scattering cross sections of free atoms for neutrons of zero energy:

Lead: $\sigma_o(Pb) = (11.261 \pm 0.006)$ b,

Bismuth: $\sigma_o(Bi) = (9.300 \pm 0.003)$ b, and

Sulfur $\sigma_o(S) = (0.985 \pm 0.004)$ b.

These data are of interest for an investigation of the neutron-electron interaction.

*) Work published in Z. Naturforsch. 31a (1976) 115

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT
BRAUNSCHWEIG

1. Radioactivity Group

1.1 Fission Product Yields in ^{235}U Fission by Fast and Thermal Neutrons

K. Debertin

Uranium samples enriched to 93 % ^{235}U were irradiated with thermal neutrons in the reactor FMRB of the Physikalisch-Technische Bundesanstalt and with ^{252}Cf-fission neutrons in an open-air low scatter arrangement. Gamma-ray spectra of the irradiated samples were repeatedly taken with an accurately calibrated Ge(Li)-spectrometer at cooling times between half an hour and 100 days. Because the number of fissions was not determined absolutely, only relative cumulative yields could be derived. Fast/thermal yield ratios with respect to ^{95}Zr were obtained for 22 mass numbers. When forming such ratios any errors due to γ-ray self-absorption in the sample, to the efficiency calibration, to γ-ray emission probabilities and to real summing corrections cancel. The uncertainties (68 % confidence level) of the yield ratios are of the order of 1 % to 2 %.

Our results reflect the energy dependence of fission yields in particular on the wings of the mass yield curve. A comparison with the 1974 Meek and Rider tabulations makes evident that ^{235}U fission yields in reactor fast neutron spectra clearly differ from the yields in the harder neutron spectrum of ^{252}Cf.

1.2 Gamma-Ray Emission Probabilities per Decay

K. Debertin, U. Schötzig, K.F. Walz
(Relevant to request numbers: 722002, 722003, 722004, 722005, 722007, 722008, 722009, 722010, 722011, 722012, 704013, 704016)

Gamma-ray emission probabilities per decay were determined directly from activity measurements by 4πß-γ- coincidence counting and from emission rate measurements by means of calibrated Ge(Li) and Ge spectrometers. Results for ^{95}Zr, ^{106}Rh, ^{144}Ce and ^{144}Pr were already publised in Annals of Nucl. Energy 2 (1975) 37. New results were obtained for ^{75}Se, ^{103}Ru, $^{110}Ag^{m}$, ^{133}Ba, ^{134}Cs, ^{140}Ba and ^{140}La. The uncertainties at the 68 % confidence level are of the order of ± 1 % for the main lines.

In addition, relative emission probabilities were determined for ^{182}Ta.

1.3 Half-Lives

K. Debertin, U. Schötzig, K.F. Walz

Half-lives of ^{103}Ru, ^{106}Ru, ^{131}I, ^{140}Ba and ^{140}La were determined by following the radioactive decay with an open air ionisation chamber and a high pressure argon filled chamber. Ge(Li) measurements were carried out for ^{131}I, ^{132}Te and ^{140}Ba. Results are given in Table I.

Table I: Half-lives $T_{1/2}$

Nuclide	$T_{1/2}$
^{103}Ru	(39.276 ± 0.009) d
^{106}Ru	(371.63 ± 0.17) d
^{131}I	(8.02 ± 0.01) d
^{132}Te	(76.9 ± 0.3) h
^{140}Ba	(12.746 ± 0.010) d
^{140}La	(40.272 ± 0.007) d

2. Neutron Metrology Group

2.1 Measurement of Average Cross Sections with Regard to the Low and High Energy Part of the Californium-252 Neutron Spectrum

W. Mannhart

(Related to request numbers: 721105, 732117, 692180, 692194)

To investigate the low energy part of the ^{252}Cf-neutron spectrum the reactions ^{197}Au(n,γ)^{198}Au and ^{115}In(n,γ)^{116}In^{m} were used. The resulting averaged cross sections are (76.2 ± 1.8) mb and (124.1 ± 3.6) mb respectively. The fair agreement between these measurements and calculated averaged cross sections confirms that there is probably no intrinsic structure in the neutron spectrum. Above 8.1 MeV, the neutron spectrum was tested by the reaction ^{197}Au(n,2n)^{196}Au. The cross section obtained is (5.50 ± 0.14) mb and in good agreement with an adopted pure Maxwellian neutron spectrum with a temperature parameter of (1.41 ± 0.01) MeV.

Moreover, the average cross sections for ^{113}In(n,n')^{113}In^{m} of (160 ± 4) mb and for ^{115}In(n,n')^{115}In^{m} of (195 ± 5) mb were measured. The latter value is comparable to the earlier PTB-value of (198 ± 5) mb (1), determined by a slightly modified method for the activity measurement.

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ZENTRALSTELLE FÜR ATOMKERNENERGIE-DOKUMENTATION (ZAED)

An Information System for Physics Data in the Federal Republic of Germany

Status Report

H. Behrens and G. Ebel

1. Introduction

As mentioned earlier in this report series (NEANDC (E) - 172U, Vol. 5), the Zentralstelle für Atomkernenergie-Dokumentation (ZAED) at the Karlsruhe nuclear research center, on the suggestion of the German Physical Society (DPG), has started to establish an information service for physics data in early 1975 with a view to its future functions as a sectoral information center for energy, physics and mathematics. The present state of this project will be discussed below.

2. New data compilations

A major objective of the ZAED is the publication, at regular intervals, of data compilations from those fields of physics where there is a need for up-to-date compilations. During the last year and acting on a suggestion by the ZAED, several groups agreed to set up such data compilations which will be published in the framework of a ZAED series "Physics Data".

The following issues have been published so far:

1-1 (1975):	Survey Index of Pion-Nucleon Scattering Data. K.H. Augenstein, G. Höhler, E. Pietarinen and H.M. Staudenmaier
2-1 (1976):	Stopping Cross Section of Elements with Z=2 to 87 for Li Ions with Energies between 80 keV and 840 keV. W. Neuwirth, W. Pietsch and U. Hauser
3-1 (1976):	Datensammlungen in der Physik. Data Compilations in Physics. H. Behrens and G. Ebel
4-1 (1976):	Compilation of Coupling Constants and Low Energy Parameters. 1976 Edition. M.M. Nagels, J.J. de Swart, H. Nielsen, G.C. Oades, J.L. Petersen, B. Tromborg, G. Gustafson, A.C. Irving, C. Jarlskog, W. Pfeil, H. Pilkuhn, F. Steiner and L. Tauscher (Reprinted from Nuclear Physics B)

5-1 (1976): Gases and Carbons in Metals (Thermodynamics, Kinetics and Properties).
Part I: Alkali Metals, Alkaline Earth Metals, Light Metals (Li, Na, K, Rb, Cs, Ca, Sr, Ba, Be, Mg, Al).
E. Fromm, H. Jehn and G. Hörz

6-1 (1976): Shapes of Beta Spectra.
H. Behrens and L. Szybisz

Other publications now in preparation:

Datensammlungen in der Physik. Data Compilations in Physics.
H. Behrens and G. Ebel
(Supplement to No. 3-1 (1976))

Photoproduction of Pions.
W. Pfeil et al.

Optical Properties of Some Insulators in the Vacuum Ultraviolet Region.
R.-P. Haelbich, M. Iwan and E.E. Koch

Survey Index on Pion-Nucleon Scattering Data.
G. Höhler et al.
Revision and update of No. 1-1 (1975)

Gases and Carbon in Metals (Thermodynamics, Kinetics and Properties)
Part II: Group IIB to VB Metals
(Zn, Cd, Ga, In, Tl, Ge, Si, Sn, Pb, Bi)
H. Jehn, E. Fromm and G. Hörz

Bibliography of Microwave Spectroscopy 1945-1975.
A.N. Boggs, M. Botskor, M. Jones, K. Kettermann, R. Mutter, C.H. Spreter, B. Starck

There are also other groups working on the establishment of data compilations in the following fields: Internal conversion coefficients, fluorescence yields for X-ray transitions, adsorption and desorption characteristics of solid surfaces, properties of superconductors, radiative properties of hadronic atoms.

3. Bibliography of existing data compilations

The bibliography of Data Compilations in Physics (Physikdaten/Physics Data 3-1, 1976) gives a worldwide survey of all existing physics data compilations. It contains the bibliographic data of some 1450 compilations; a supplement to be published soon will list some 500 more. All but a few of these compilations are part of a ZAED reference library.

4. International cooperation

At an IAEA meeting held in May, 1976, international cooperation in the field of evaluation of nuclear structure data has been agreed upon. As a result of this agreement, a worldwide network of participant organizations has been established. In the framework of this cooperation, the ZAED will compile and evaluate nuclear structure data of the mass chains between A=81 and A=100. For this purpose, the ZAED has set up a special evaluation group which started work in February, 1977. Its first task, up to autumn 1977, will be a pilot evaluation for the mass A=86. The results of this evaluations will be stored on the so-called ENSDF files (Evaluated Nuclear Structure Data File), a preliminary version of which is already available in Oak Ridge.

In this connection, it should also be noted that the ZAED participates in the network for Charged Particle Nuclear Data (CPND), also coordinated by the IAEA, where it will act as distributing center for these data for the Federal Republic of Germany. These activities will be discussed in some more detail elsewhere in this report.

Furthermore, the ZAED intends to become more active in the field of atomic and molecular data, where the IAEA organizes a similar network of data centers, and to publish a data index in cooperation with other institutions.

5. Computerized data services

In the framework of its data information service, the ZAED also has the intention to make physics data, stored on magnetic tape, available in the Federal Republic and to supply information on the basis of these tapes. So far, the British Cambridge Crystallographic Data Files are available which contain the crystal structure data (in most cases the exact positions of the atoms) of 14 000 organic and organometallic compounds. Next, the ZAED has begun to implement the above-mentioned magnetic tapes of the nuclear structure data (ENSDF) from Oak Ridge, USA. Finally, the ZAED acts as a referral center for the Federal Republic of Germany.

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