EANDC (E) 157 "U"
Volume I

III A

PROGRESS REPORT
ON NUCLEAR DATA RESEARCH IN THE EUROPEAN COMMUNITY

for the period January, 1 to December 31, 1972

Submitted by the Joint European Nuclear Data
and Reactor Physics Committee

(Secretariat: Central Bureau for Nuclear Measurements,
Euratom, Geel, Belgium)

March 1973

EUROPEAN AMERICAN NUCLEAR DATA COMMITTEE

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In reports I - VI the figures in the left margin refer to request numbers listed in RENDA 72 (October 1972) - INDC(SEC)-27/L, in report VII they refer to request numbers listed in WRENDA 73 (March 1973) - INDC(SEC)-32/U.

I N D E X

I. INSTITUT FÜR ANGEWANDTE KERNPHYSIK KERNFORSCHUNGSZENTRUM KARLSRUHE (GERMANY)

1. 3 MV Van-de-Graaff-Accelerator

1.1 A Measurement of the Neutron Fission Cross Section of ^{235}U Between 0.5 and 1.2 MeV.

F. Käppeler

(966, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983)

During 1972 the analysis of the absolute fission cross section measurement of ^{235}U was finished [1]. A new proton recoil detector was used which allowed the neutron flux determination with an accuracy of 2 % [2]. In the energy range from 0.5 to 1.2 MeV 7 absolute and 12 relative values of σ_f have been determined,(see Table I). The total uncertainty of the absolute values lies between 2.6 and 3.4 %. Fig. 1 shows the present results together with measurements published until summer 72. However, this situation improved in the meantime by several other measurements. Especially by the renormalization of the low Poenitz values the discrepancies in Fig. 1 are reduced considerably.

1.2 The Capture Cross Sections of $^{54,57}Fe$, $^{50,52,53}Cr$ and $^{62,64}Ni$

H. Beer, R.R. Spencer

(249, 251, 261, 323, 369, 373, 374, 390, 392)

In the course of a systematic investigation of total and capture cross sections on 12 separated isotopes of structural materials as Ti, Fe, Cr and Ni the capture cross sections were completed by the measurement of σ_γ for $^{54,57}Fe$, $^{50,52,53}Cr$ and $^{62,64}Ni$ in the neutron energy range between 5 and 200 keV. The experiment was performed relative to ^{197}Au by a 800 ℓ liquid scintillator tank with a time resolution of 2 nsec/m [3].

In a first analysis of the data the total radiation widths of the s-wave resonances were determined. For corresponding resonances in the total and the capture cross section a correlation coefficient ρ between the reduced neutron width Γ_n^o and the total radiation width Γ_γ was calculated. From the behaviour of $\rho(\Gamma_n^o, \Gamma_\gamma)$ nonstatistical effects in the neutron capture mechanism can be investigated. Table II shows the results for the analyzed 73 resonances. The quantity P in the last column gives the probability that the correlation coefficient may be caused by statistics only. As can be seen from Table II most isotopes show positive correlations between Γ_n^o and Γ_γ indicating a rather strong contribution of nonstatistical neutron capture.

1.3 The Measurement of the Capture-to-Fission Cross Section Ratio for ^{235}U and ^{239}Pu

R.-E. Bandl

(989, 990, A first measurement of α, the capture to fission cross section ratio, between 8 and 60 keV was concluded /̅4_7. Now an improved
991, 992, measurement with a new technique is planned /̅5_7 which allows
1184, an extension of the energy range up to 400 keV as well as a re-
1185, 1186, duction of the experimental uncertainty to about 10 %. This
1187, measurement will be started in 1973.
1188,
1190)

1.4 The Energy Dependence of $\bar{\nu}$ for ^{235}U and ^{239}Pu Below 1.3 MeV

R.-E. Bandl, F. Käppeler

(993, The existing discrepancies in the shape of $\bar{\nu}$, the average number
995, of fission neutrons, motivated an experiment which is expected to
996, 998, yield relative values of $\bar{\nu}$ for ^{235}U and ^{239}Pu with an uncertainty
1191, of about 1 % /̅5_7. The measurement is performed in the energy
1192, range between 100 and 1300 keV point by point with monoenergetic
1193, 1195, neutrons in steps of 50 keV. Very preliminary results for ^{235}U seem
1196, to confirm a structure in $\bar{\nu}$ but the final analysis is not yet fi-
1197) nished.

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Relative Values		
E_n (keV)	σ_{fU} (barn)	Uncertainty %
513 ± 32	1,210	0,9
580 ± 20	1,193	1,8
678 ± 21	1,208	1,2
767 ± 20	1,165	0,9
795 ± 20	1,178	1,2
872 ± 20	1,120	2,1
920 ± 22	1,141	1,5
930 ± 20	1,172	1,9
945 ± 24	1,206	1,1
966 ± 21	1,213	1,2
1013 ± 20	1,293	1,9
1060 ± 22	1,227	1,2
Absolute Values		
E_n (keV)	σ_{fU} (barn)	Uncertainty %
546 ± 22	1,207	3,4
662 ± 23	1,215	2,6
758 ± 23	1,164	2,6
908 ± 22	1,193	2,9
1057 ± 26	1,248	3,0
1125 ± 25	1,256	3,4
1175 ± 25	1,221	3,4

Table I Numerical results of the present fission cross section measurement of ^{235}U.

Element	J	Number of Resonances	$\rho(\Gamma_\gamma, \Gamma_n^o)$	P %
^{47}Ti	2 3	5 4	+ 0.58 ± 0.70 − 0.20 ± 0.83	76 99
^{50}Cr	$\frac{1}{2}$	4	+ 0.92 ± 0.61	26
^{52}Cr	$\frac{1}{2}$	3	+ 0.98 ± 0.95	32
^{53}Cr	1 2	3 7	+ 0.95 ± 0.82 + 0.77 ± 0.35	41 12
^{53}Cr	2	8	+ 0.76 ± 0.30	9.2
^{53}Cr	1,2	13	+ 0.74 ± 0.23	3.2
^{54}Fe	$\frac{1}{2}$	6	− 0.36 ± 0.44	66
^{56}Fe	$\frac{1}{2}$	4	− 0.32 ± 0.47	61
^{57}Fe	1	4	+ 0.89 ± 0.73	35
^{58}Ni	$\frac{1}{2}$	5	− 0.46 ± 0.81	90
^{60}Ni	$\frac{1}{2}$	9	+ 0.80 ± 0.28	5.7
^{61}Ni	1 2	7 7	− 0.18 ± 0.35 − 0.09 ± 0.42	71 75
^{62}Ni	$\frac{1}{2}$	3	+ 0.94 ± 0.87	28
^{64}Ni	$\frac{1}{2}$	2	+ 1.00 ± 1.18	100
Sum:Even All	-	36	+ 0.53 ± 0.11	0.8
Sum:Even $^{50,52}Cr$ $^{60,62,64}Ni$	-	21	+ 0.78 ± 0.16	0.2
Sum:Odd All	-	37	+ 0.36 ± 0.13	7.6
Sum:All	-	73	+ 0.46 ± 0.08	0.1

Table II Correlation coefficients between reduced neutron widths Γ_n^o and total radiation widths Γ_γ of the observed s-wave resonances.

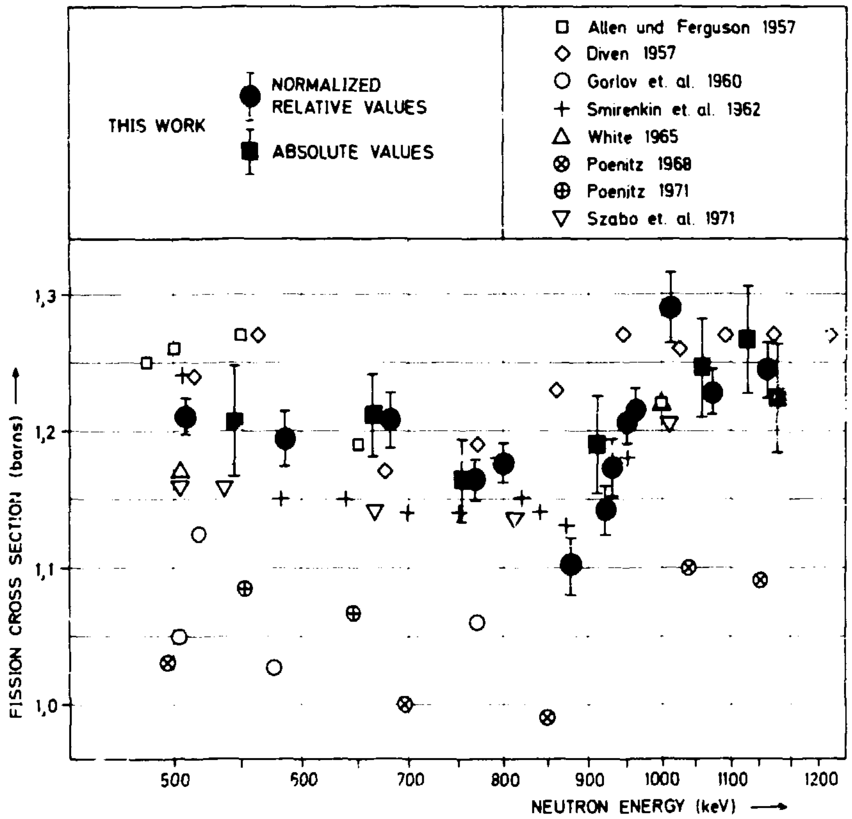

Fig. 1 Present values of the fission cross section of ^{235}U in comparison to previous measurements.

2. Isochronous Cyclotron

2.1 Development of the Fast Neutron Spectrometer

G. Schmalz, S. Cierjacks

Reconstruction of the cyclotron r.f. system and of the "deflection bunching" system for the time-of-flight apparatus resulted in considerable improvements of the KIC-neutron-spectrometer. Internal deuteron beam currents of up to 1 mA can now be achieved. With this improvement it was possible to run experiments on fission cross sections with more than 10 μA average beam current at 100 KHz repetition rate with sustained operation over two long term periods of four weeks. Augmentation of the remote controlled neutron target system to a capability of 25 μA is expected to result in a considerable increase in the source strength. A review of the present status of the fast neutron spectrometer was given at the Budapest conference [1].

The increase in intensity has made it possible to start construction of an improved facility for the investigation of [n,x]-reactions which will be set up at a second flight path of 15 m length. The experience gained in the exploratory experiment carried out on the ^{9}Be[n,α] reaction cross section [2] has provided the design parameters for the new n,x-spectrometer.

2.2 Fast Fission Cross Section of ^{235}U, ^{238}U and ^{240}Pu

S. Cierjacks, P. Brotz, D. Gröschel, I. Schouky, C.M. Newstead, G. Schmalz, R.Töpke, F. Voß

(1075, 1079, 1081, 1239, 1241, 1242, 1243, 1244) Additional measurements for the determination of the fission cross sections of ^{235}U and ^{238}U between 0.8 and 30 MeV were carried out by detecting the fission products of eight thin uranium oxide foils in nine gas scintillation chambers in series. Using the recommended value at 14 MeV preliminary results for the ratio $\sigma_f[^{238}U]/\sigma_f[^{235}U]$ were determined and compared to the results of other authors [fig. 1] [3]. A neutron energy resolution ranging from 20 keV at 1 MeV to 600 keV at 30 MeV was achieved.

By means of a special type of proton recoil detector the shape of the neutron flux was measured so that the fission cross sections normalized at 14 MeV could be determined for ^{235}U and ^{238}U separately. The evaluation for uranium will be finished in the beginning of 1973.

An additional experiment was made to determine the fission cross section $\sigma_f[^{240}Pu]$ and the ratio $\sigma_f[^{240}Pu]/\sigma_f[^{235}U]$. The evaluation is in progress.

2.3 Total Cross Section Measurements

R. Töpke, G. Schmalz, S. Cierjacks, P. Brotz,
D. Gröschel, C.M. Newstead, I. Schouky, F. Voß

(275) The transmission measurements for the determination of high resolution total cross sections of structural materials between 0.5 and 30 keV have been continued at the neutron time-of-flight spectrometer with a flight path of 190 m. Special attention was given to the determination of the deep minima in the total cross sections. Measurements were carried out for the elements O, Mg, Al and Fe. The evaluation of the data is in progress.

2.4 Neutron Elastic and Inelastic Scattering Cross Sections

F. Voß, S. Cierjacks, R. Töpke, J. Nebe

(180) The evaluation and R-matrix analysis of the differential elastic scattering cross sections of ^{40}Ca between 0.5 and 2 MeV has been completed by the publication of the final results [4]. Resonance parameters of about 70 levels in ^{41}Ca have been assigned. Average level distances and strength functions for s-, p- and d-waves were calculated.

The previously used experimental set up has been improved so that the measurements can be extended beyond the threshold for inelastic scattering. In a three parameter experiment the excitation functions will be measured at ten angles simultaneously. Elastic and inelastic scattered neutrons will be discriminated by the pulse height of the recoil protons in the scintillation detectors. First measurements are planned for the beginning of 1973.

(159, 291, 292, 293, 1075, 1058, 1059, 1060, 1061, 1062, 1063, 1064, 1065, 1066, 1067)

The results of a fluctuation analysis of the [n, n'γ]-cross sections of ^{27}Al and ^{56}Fe are now available [5,6]. The average level width of aluminum proved to be significantly dependent on the exit channel. In the excitation functions of both nuclei intermediate structure was found which was in several cases correlated for the elastic and different inelastic channels. The measurement of [n,n'γ]-cross sections of ^{238}U is being prepared for 1973.

2.5 Study of the Optical Potential from Neutron Strength Function Systematics

C.M. Newstead

Previous studies of the neutron strength function [7] carried out at Saclay have been continued in Karlsruhe. The body of data measured at Karlsruhe and Saclay provides convincing evidence for the spin dependence of the s-wave strength function in the energy range investigated and has been interpreted in terms of a spin-spin term in the optical potential [8]. The magnitude of this term is in qualitative agreement with that found from measurements of the spin-spin effect in the total cross section and the depolarisation parameter.

The anomalously deep minima of the s- and p-wave strength functions [see fig. 2 and 3] were found to be described in a natural way by rather small values of the imaginary part of the optical potential W. This reduction in absorbtion was interpreted as resulting from the low density of states in the region of closed shells [9]. The calculation is summarized in table 1.

It has also been shown that the considerable fluctuations in the strength function which occur e.g. for such technologically important materials as the isotopes of Fe and Cr can be related with simple excitations [doorway states] of the compound nucleus. The fluctuations are well described by a doorway state dependent imaginary optical potential W [10].

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Table 1 Comparison of theoretical and experimental results for the s- and p-wave strength functions

TARGET	V	W	β_2	S_o	S_1	S_o	S_1
^{35}Cl	51.04	0.9	0.0	0.15	1.15	0.08 ± 0.07	1.65 ± 0.55
^{37}Cl	48.38	0.9	0.0	0.13	2.07	0.12 ± 0.09	2.87 ± 1.06
^{39}K	48.00	2.5	0.0	0.41	2.40	0.37 ± 0.23	2.71 ± 0.82
^{40}Ca	53.50	1.5	$\beta_2 = 0.00$, $\beta_3 = 0.36$	2.16	0.31	$2.56 ^{+1.20}_{-0.58}$	$0.25 ^{+0.12}_{-0.06}$
^{50}Cr	51.11	1.12	0.22	1.94	0.27	2.18 ± 0.75	0.264 ± 0.152
^{52}Cr	50.40	0.8	0.17	2.06	0.15	2.10 ± 1.05	0.053 ± 0.023
^{54}Cr	49.60	0.44	0.17	0.89	0.076	1.79 ± 1.03	0.042 ± 0.024
^{89}Y	48.97	3.6	0.0	0.44	3.92	$0.39 ^{+0.27}_{-0.12}$	$4.4 ^{+2.0}_{-1.2}$
^{93}Nb	49.15	1.35	0.0	0.15	5.18	0.17 ± 0.06	5.16 ± 0.24
^{98}Mo	48.42	6.2	0.168	0.77	7.21	0.42 ± 0.25	6.8 ± 0.5
^{100}Mo	47.90	4.0	0.253	0.74	4.43	0.55 ± 0.30	$4.6 ^{+0.5}_{-0.4}$
^{103}RH	48.91	3.3	0.264	0.40	5.06	$0.40 ^{+0.05}_{-0.08}$	$5.07 ^{+0.53}_{-0.29}$
^{135}Ba	47.59	4.0	0.150	1.01	1.60	1.0 ± 0.3	
^{137}Ba	47.22	1.82	0.130	0.50	0.84	$0.33 + 0.17$	
^{139}La	47.30	2.12	0.130	0.71	0.83	$0.70 ^{+0.20}_{-0.14}$	$0.70 ^{+0.3}_{-0.2}$
^{141}PR	47.81	4.00	0.110	1.73		$2.04 ^{+0.47}_{-0.35}$	
^{165}Ho	47.5	3.00	0.30	1.82	1.61	1.66 ± 0.24	1.63 ± 0.25
^{209}Bi	46.5	1.5	$\beta_2 = 0.00$, $\beta_3 = 0.20$	0.50	0.29	$0.65 ^{+0.39}_{-0.17}$	$0.25 ^{+0.09}_{-0.05}$

Geometry set for all calculations: r_o = 1.25 f, a = 0.65 f, b = 0.47 f. Potentials strengths in M v.

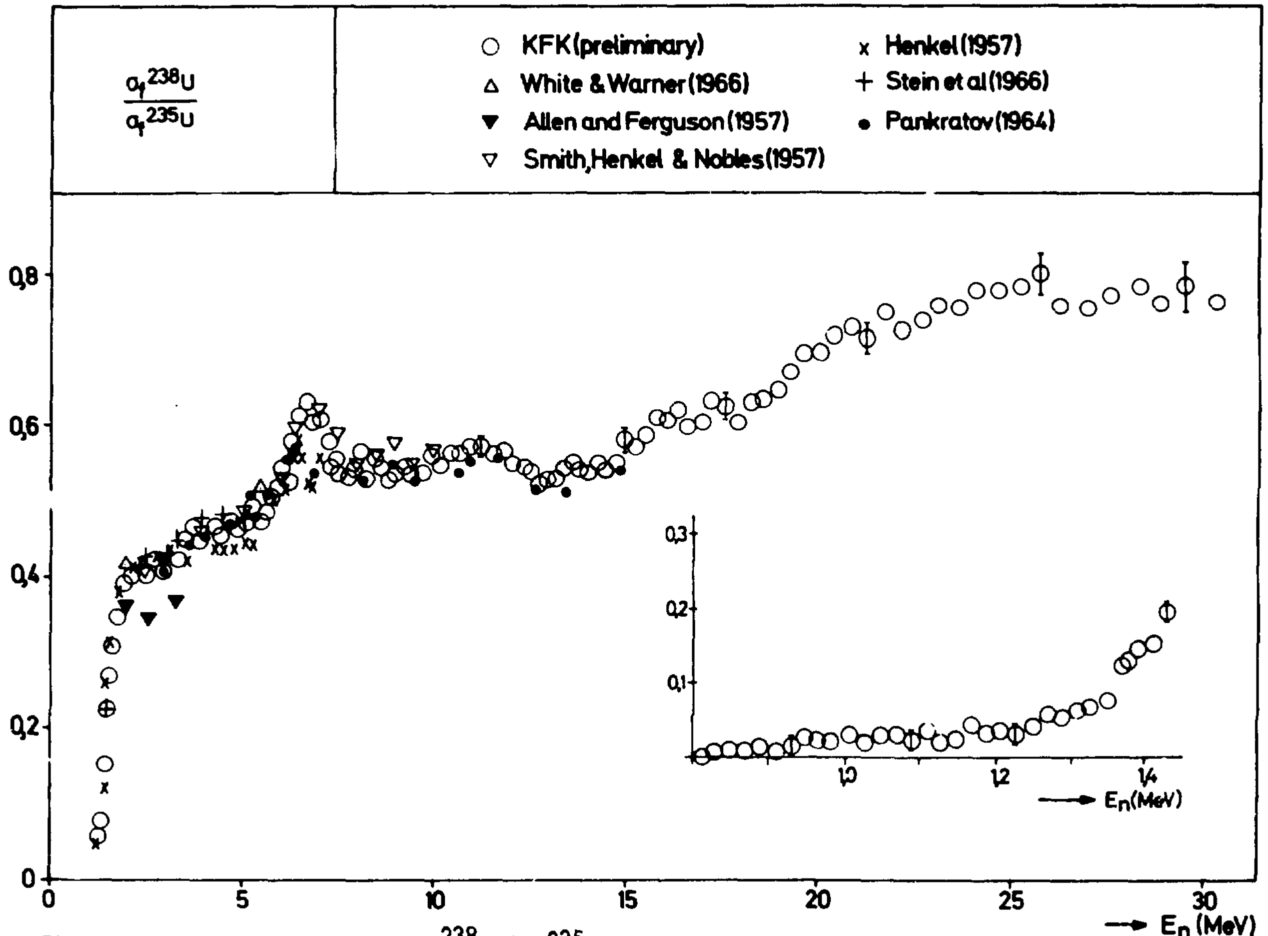

Fig. 1 Fission cross section ratio $\sigma_f[^{238}U]/\sigma_f[^{235}U]$

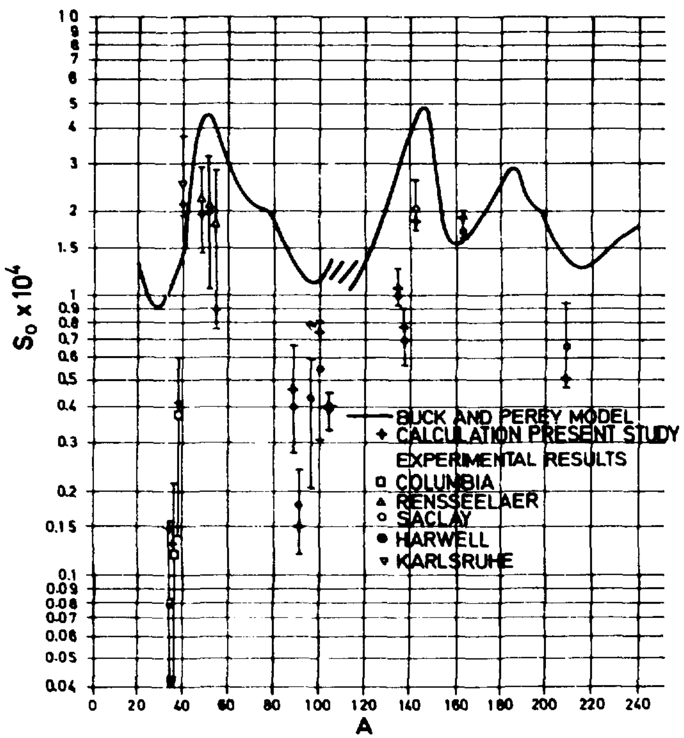

Fig. 2 s-wave neutron strength function

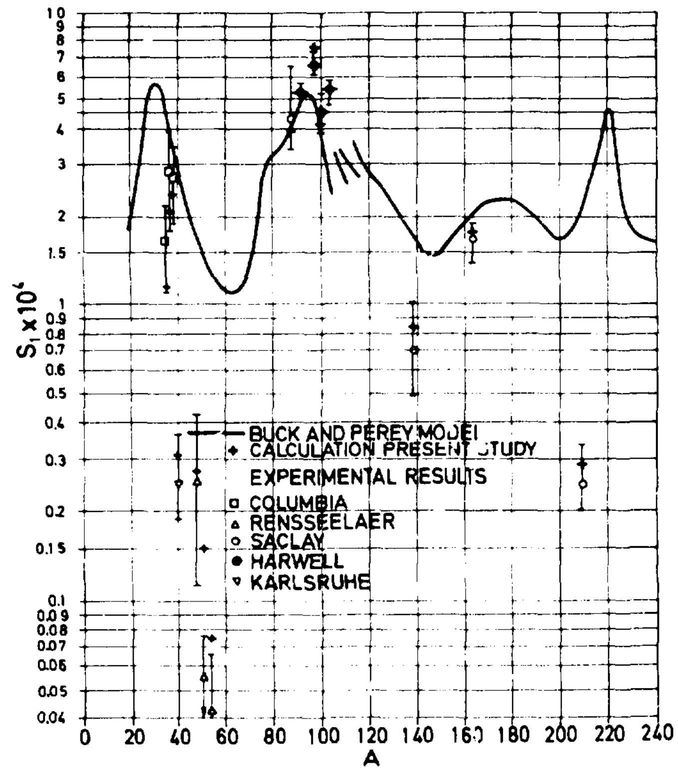

Fig. 3 p-wave neutron strength function

3. Reactor FR 2

3.1 Measurement of Gamma-Ray Spectra from Thermal Neutron Interaction with ^{235}U

P. Matussek, H. Ottmar, I. Piper, C. Weitkamp, H. Woda

Because of the extreme complexity of gamma spectra following neutron interaction of fissionable nuclides two experimental devices were set up and used for the elucidation of the γ spectra from a ^{235}U target. The first consists of a 4 π fission neutron detector which, in coincidence with a γ-ray spectrometer, serves for the detection of prompt fission γ rays, whereas in anticoincidence both neutron capture and fission product γ rays are detected. For the separation of these latter, the neutron beam from the reactor FR 2 is mechanically chopped and the off-beam spectrum considered as mainly delayed, the on-beam spectrum as mainly due to capture events. To ensure optimum energy compatibility, all spectra are recorded simultaneously. Delayed γ rays with half lives between the coincidence resolving time $\tau \approx 25$ ns and the period $T \approx 20$ ms of the chopper appear in the prompt anticoincidence ("capture") spectrum. This difficulty is solved partly by careful comparison of corresponding spectra from different isotopes, partly by using another device based on a totally different experimental approach. This second device consists of a thin uranium foil as the target of a continuous thermal neutron beam, surrounded by a nitrogen-argon gas scintillator which serves to detect and stop the fission products. An adjacent thin plastic scintillator is used as a detector for β particles from fission products, and a large Ge(Li) diode serves as γ spectrometer. Because the efficiencies (except of the Ge(Li)) are close to 100 %, gas-Ge(Li) coincidences indicate prompt fission γ rays and plastic-Ge(Li) coincidences delayed fission gammas. Ge(Li) counts in anticoincidence to both other detectors are likely to be capture events. More experimental details have been [1], or will soon be published [2].

As capture measurements are most difficult and few other experiments have been done with thermal [3,4] and resonance neutrons [5-8] on ^{235}U, only capture γ rays are reported that are prominent and clearly due to capture events. Table I contains a concise list of high (E_γ > 4.6 MeV) and low-energy (E_γ ≈ 0.6 to 1.4 MeV) capture γ rays. Relative intensities were obtained by means of a ^{56}Co decay and ^{14}N (n,γ)^{15}N calibration and converted to absolute values using the 6395 keV intensity of 3.2 ± 0.5 transitions per 1000 captures from a mixed uranium-tetrazole target [9]. This intensity compares favourably with the value of 4.0 for the same line [3]; all of the low-energy intensities are within the error limits quoted by Weigmann and Winter [5] from a measurement in the 6.4 eV resonance of ^{235}U.

The construction of a consistent level scheme of ^{236}U has so far not been successful, partly because of the unusual softness of the capture γ spectrum (most intense primary transition 3 x 10^{-3} per capture). It is our opinion that a precise measurement of very low-energy (< 500 keV) capture γ rays is a prerequisite for the correct assignment of the transitions found. Data in this energy region are under evaluation.

3,2 Study of ^{240}Pu by Thermal and Average Resonance Capture of Neutrons in ^{239}Pu

H. Ottmar, P. Matussek, C. Weitkamp, H. Woda

(1132) In order to study the level structure of ^{240}Pu γ-ray spectroscopy following capture of both thermal and resonance neutrons in ^{239}Pu was applied. For the thermal measurements the fission neutron coincidence-anticoincidence γ-ray spectrometer in combination with the slow chopper as described in paragraph 3.1 was used. Average resonance capture was studied with 2 keV neutrons from the scandium-filtered beam [10] of the reactor FR 2.

As s-wave capture leads to compound states with spin and parity 0^+ or 1^+ and decay studies seemed to indicate even parity for a number of levels around 1 MeV, prominent primary transitions had hitherto been assigned M1 character [11]. This anomalous M1 strength was interpreted as a magnetic dipole giant resonance. Calculations of the M1 γ-ray strength function for some strongly deformed heavy nuclei on the basis of the Nilsson model with pairing force and residual spin-spin interaction [12] show indeed a broad bump of the M1 strength function for γ rays around 6 MeV due to two-quasiparticle excitations shifted upward in energy by a residual interaction.

As the average spacing of s-wave resonances in ^{239}Pu is 2.3 eV, the half-width of 850 eV of the 2 keV beam provides a means of averaging over about 400 resonances, giving a statistical fluctuation of only 8 % for the γ-ray intensities. As shown in Fig. 1, intensities of primary γ rays fall indeed into two well separated groups, and most of the previously observed strong capture γ rays turn out to be of E1 character. The E1's follow nicely the predicted E_γ^5 dependence. M1 transitions do not deviate from the E_γ^3 low either; in particular, no bump can be detected around 6 MeV.

The results of both the thermal and the 2 keV measurements are summarized in Table II and the level diagram of Fig. 2. In addition to the $K^\pi = 0^-$ octupole band with 1^- and 3^- members at 597 and 649 keV (the 5^- state at 742 keV could not be seen in the present experiments), states at 938 keV (1^-) and 959 keV (2^-) were observed that belong probably to another octupole band with $K^\pi = 1^-$; the rotational constant of 5.25 keV compares well with the value of 5.15 keV for the $K^\pi = 0^-$ band.

The spins of levels at 1410 and 1438 keV were directly measured by Schmorak et al. [11] to be 0 and 2. With the assumption of even parity these states were interpreted as the first two members of a two-phonon octupole vibrational band. The negative parities from our measurement clearly exclude this assignment. A possible interpretation for the 0^- state is a two quasiproton state; the Nilsson arrangement $5/2^-$ [523↓] $5/2^+$ [642↑] is in good agreement with the interpretation of the 1^- isomer of ^{240}Np and the log ft values for β decay to these two states.

3.3 Octupole Bands in ^{242}Pu from Thermal Neutron Capture in ^{241}Pu

P. Matussek, H. Ottmar, C. Weitkamp, H. Woda

(1269) Gamma-ray spectra from the capture of thermal neutrons in ^{241}Pu have been isolated from the prompt and delayed fission γ components by use of the fission neutron detector with mechanical chopper as briefly described in paragraph 3.1 of this report. Many γ rays have been observed, both high-energy (E_γ > 3.8 MeV) and low-energy (0.6 MeV < E_γ < 1.4 MeV). All prominent high-energy lines, but less than 30 % of the low-energy γ rays have been included in the level scheme as shown in Fig.3.

Possible compound state spins in thermal neutron capture are 2^+ and 3^+. Assuming that the strongest primary γ ray leads to the level at 823 keV which, from the deexcitation to the 2^+ and 4^+ members of the ground state band, must have spin 3, the binding energy of the last neutron is calculated to 6309.5 ± 0.7 keV, in fair agreement with Wapstra's value [13] of 6301.4 ± 3.5 keV.

The absence of a primary transition to the 1^- level indicates that thermal capture occurs mainly into a $J^\pi=3^+$ compound state. Taking into account the absence of a transition to the 1064 and 1152 keV states in a (d,d') study just completed [14], this allows only $J^\pi=2^-$ or 4^- for these levels. The unique spin assignment is then possible from the observed deexcitation. Thus the 780 keV 1^-, 882 keV 3^-, 1019 keV 3^- and 1064 keV 4^- states fit well with the 5^- levels at 927 and 1122 keV from (d,d') work to form two octupole bands with $h^2/2\Theta$ = 5.2 and 5.7 keV. The former is assigned K = 0 from γ transition branching ratios. For the latter K = 3 agrees well with the very small Coriolis perturbation; on the other hand, although no primary transition to a 2^- band head was observed, the intense 941 keV γ ray could be interpreted as deexcitation of a 2^- state to the 45 keV level, so K = 2 cannot be excluded. The position of the two bands fit well into the systematics and agree with predictions of RPA calculations properly corrected for particle-phonon coupling [15].

3.4 Investigation of the level structure of ^{87}Sr, ^{92}Zr, ^{190}Os and ^{233}Th using the radiative neutron capture reaction

U. Fanger, D. Heck, R. Pepelnik and H. Schmidt

The level structures of ^{87}Sr, ^{92}Zr, ^{190}Os and ^{233}Th have been studied by means of thermal neutron capture γ-ray spectroscopy. The targets used were enriched to 85 % in ^{86}Sr, to 70 % in ^{91}Zr and to 87 % in ^{189}Os, respectively. High resolution measurements of singles spectra have been performed with Ge(Li) spectrometers operated in Compton-reduction mode at low γ-ray energies. Coincidence relationships of γ-transitions in ^{92}Zr and ^{233}Th have been determined using two-parameter coincidence techniques with Ge(Li) detectors. As a result of these measurements considerably extended transition schemes have been constructed for ^{87}Sr, ^{92}Zr, ^{190}Os and ^{233}Th (ref. 16,17). Several new levels have been firmly established in these nuclei. Angular correlation measurements have lead to unambiguous assignment of new level spins in ^{92}Zr and in ^{190}Os. Some previously determined spin values have been confirmed. Spin and parity assignments to several other levels have been inferred from their deexcitation modes.

The neutron separation energies of ^{87}Sr, ^{92}Zr, and ^{233}Th were found to be 8428.3 ± 1 keV, 8635.1 ± 1 keV, and 4786.6 ± 1 keV, respectively.

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Table I. Energies E_γ and intensities I_γ (in photons per capture) of the most intense γ rays from the reaction $^{235}U(n,\gamma)^{236}U$ with thermal neutrons. The intensity errors do not contain a common 16 % uncertainty from the conversion of relative to absolute values.

E_γ keV	I_γ 10^{-3}	E_γ keV	I_γ 10^{-3}
6395.5 ± 0.3	3.2 ± 0.1	641.8 ± 0.1	58 ± 2
5544.6 ± 1.3	0.4 ± 0.1	655.6 ± 0.4	6 ± 1
5493.4 ± 1.0	0.2 ± 0.1	687.5 ± 1.0	19 ± 5
5373.4 ± 2.0	0.4 ± 0.1	720.2 ± 1.0	3 ± 2
5323.2 ± 1.8	0.5 ± 0.1	814.5 ± 0.5	8 ± 1
5213.7 ± 1.0 p.d.	0.5 ± 0.1	880.0 ± 0.5	6 ± 1
5196.8 ± 2.5	0.3 ± 0.1	910.2 ± 0.3	11 ± 1
4973.0 ± 0.5	0.9 ± 0.1	921.1 ± 0.5	6 ± 1
4902.7 ± 1.9	0.4 ± 0.1	942.5 ± 0.3	15 ± 2
4883.9 ± 1.0 p.d.	0.9 ± 0.1	956.5 ± 0.2	15 ± 2
4648.3 ± 0.6	0.4 ± 0.1	966.7 ± 0.3	8 ± 1
		1005.7 ± 0.3	5 ± 1
		1023.7 ± 0.5	5 ± 1
		1116.0 ± 0.8	2 ± 1
p.d. = possible doublet		1363.2 ± 0.3	4 ± 1

Table II. High energy γ rays from 2 keV neutron capture in ^{239}Pu

E_γ keV	I_γ 10^{-3}	E1/M1	E_x keV	J^π
6534.8	0.37	M1	0	0^+
6492.4	0.51	M1	43.1	2^+
5938.2	2.02	E1	597.3	1^-
5676.2	0.27	M1	859.3	0^+
5636.2	0.26	M1	899.0	2^+
5597.7	1.61	E1	937.8	$(1)^-$
5592.2[a]	0.20		(943.3)	
5576.7	1.72	E1	958.8	$(2)^-$
5445.3	0.24	M1	1090.2	0^+
5399.1	0.26	M1	1136.8	0^+
5313.7	0.19	M1	1221.8	$+$
5294.4	0.82	E1	1241.1	$-$
5200.8	0.25	M1	1334.7	$+$
5124.5	0.91	E1	1410.0	$(0)^-$
5097.0	1.18	E1	1438.5	$(2)^-$
5047.6	0.90	E1	1487.9	$(1)^-$
5009.8	0.22	M1	1525.7	$+$
4996.0	0.79	E1	1539.5	$(1)^-$
4976.5	0.17	M1	1559.0	$(2)^+$
4947.2	0.64	E1	1588.3	$-$
4927.8	0.90	E1	1607.7	$-$
4909.0	0.83	E1	1626.5	$-$
4904.1[b]	0.76		(1631.4)	
4898.9	0.24	M1	1637.4	$+$
4888.1[a]	0.24		(1648.2)	
4826.8[b]	0.25		(1708.7)	$-$
4760.5	0.68	E1	1775.0	

a) identification as capture line uncertain.

b) possible interference from fission γ rays.

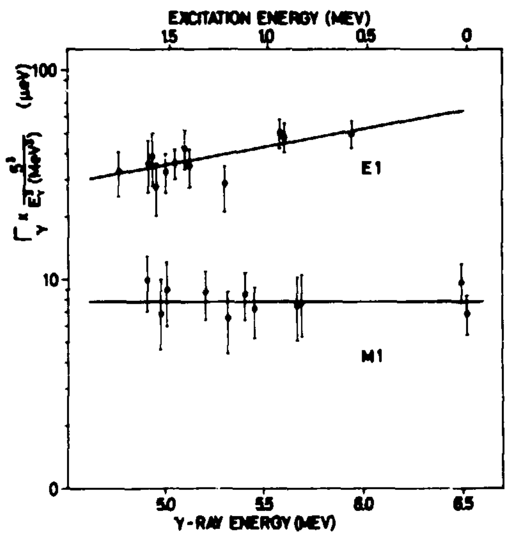
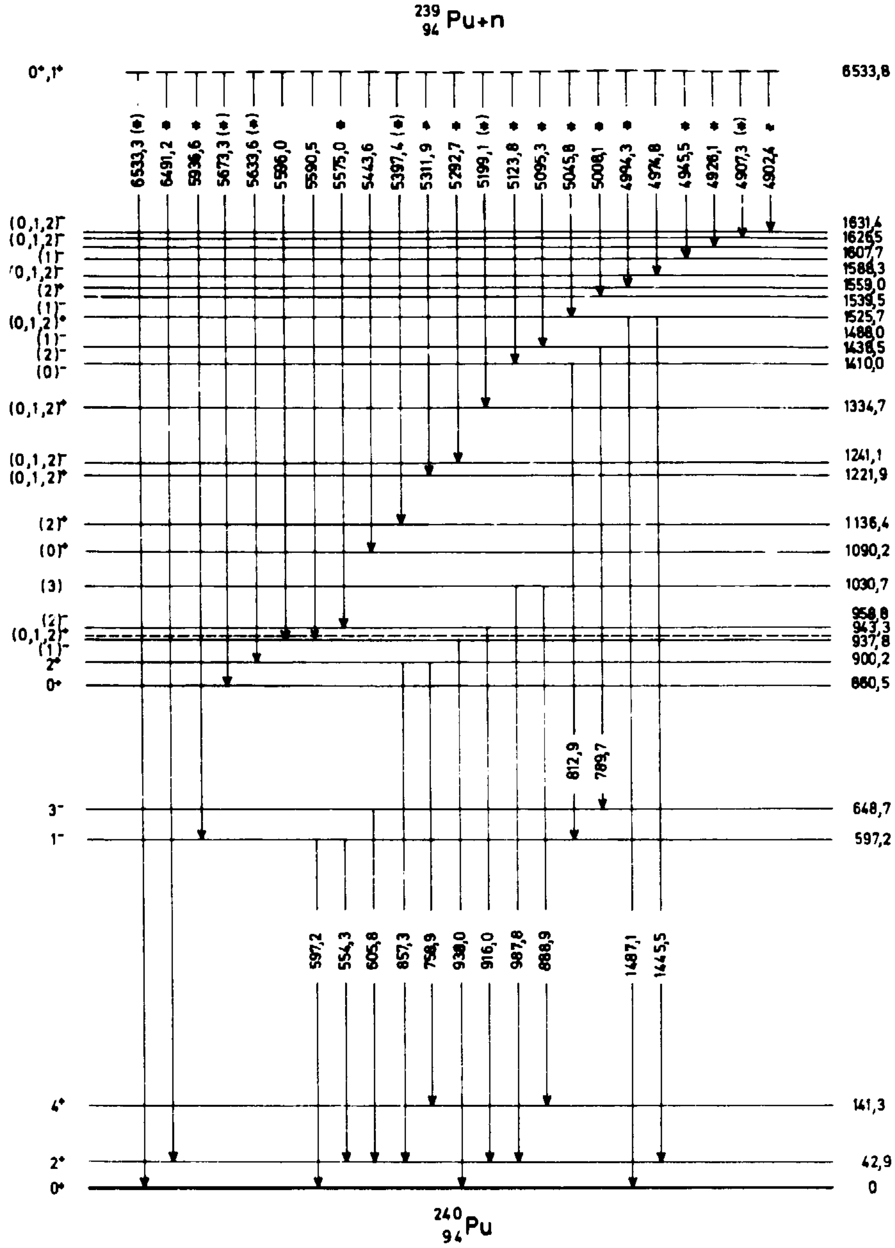


Fig. 1 Average partial radiation widths for γ rays from ^{239}Pu (n_{2keV},γ). The E_γ dependence is normalized to E_γ = 5.0 MeV.



*OBSERVED IN THERMAL NEUTRON AND 2keV NEUTRON CAPTURE

Fig. 2. Level diagram of ^{240}Pu from the reaction $^{239}Pu(n,\gamma)\,^{240}Pu$.

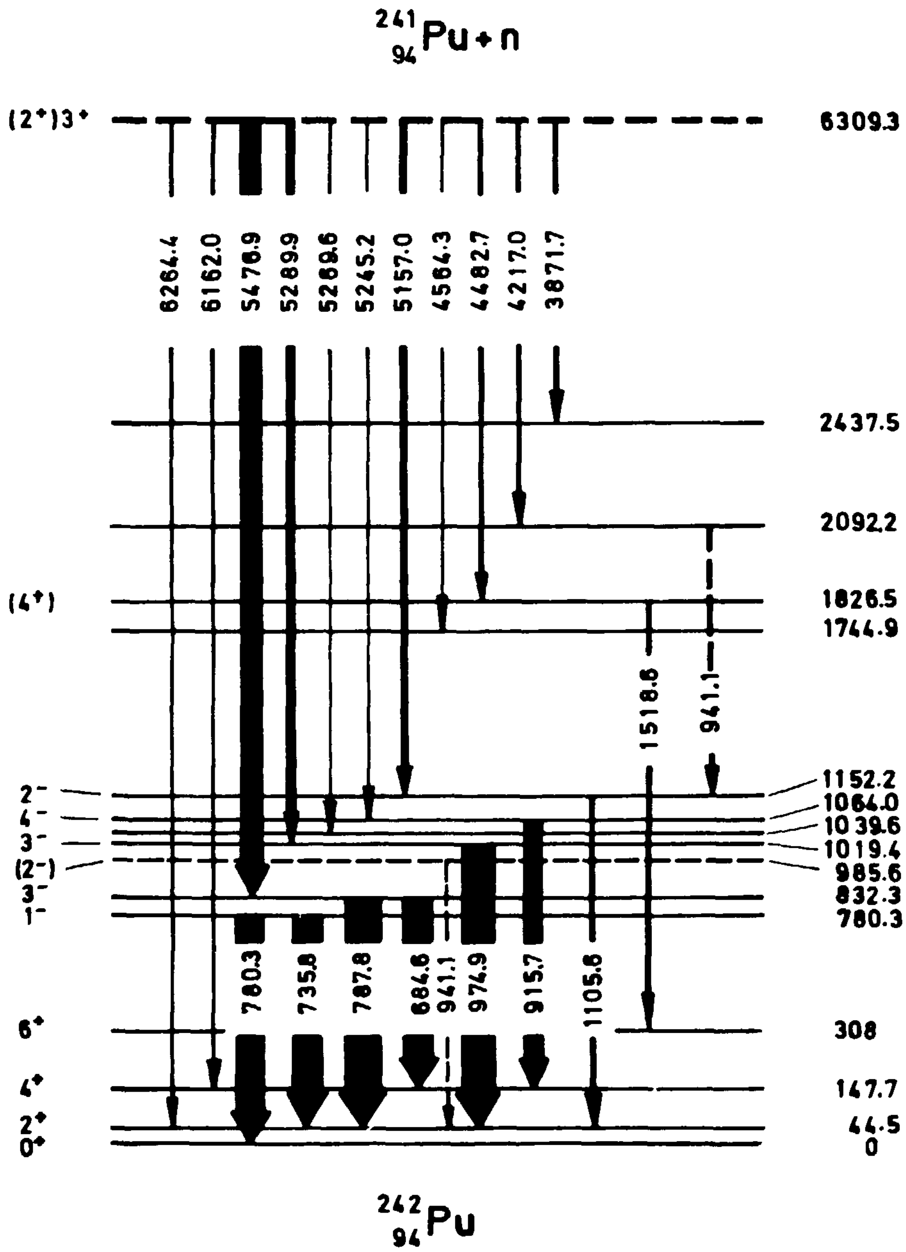


Fig. 3

Level diagram of ^{242}Pu from the reaction $^{241}Pu(n,\gamma)^{242}Pu$.

II. INSTITUT FÜR NEUTRONENPHYSIK UND REAKTORTECHNIK KERNFORSCHUNGSZENTRUM KARLSRUHE (GERMANY)

1. Experimental Neutron Physics

1.1 Prompt fission neutron spectra of ^{235}U, ^{239}Pu and ^{252}Cf

H. Werle, H. Bluhm

(1002, 1003, 1004, 1005, 1006, 1201, 1202, 1203, 1399) Recent integral studies of the thermal-neutron induced fission of ^{235}U and ^{239}Pu with activation detectors [1] indicate that 1) the average energy of the prompt ^{235}U fission neutrons is about 10 % higher and 2) the average energy of ^{239}Pu fission neutrons is remarkable closer to that of the ^{235}U fission neutrons than previously deduced from differential spectrum measurements [2]. Therefore the fission neutron spectra of ^{235}U and ^{239}Pu have been remeasured at the thermal column of the reactor FR2 using two independent methods, proton recoil proportional counters and a ^{3}He-semiconductor-sandwich-spectrometer with γ-n-discrimination. In addition the neutron spectrum of a ^{252}Cf spontaneous fission source was measured [3].

Above 600 keV the spectra measured with both techniques agree rather well (Fig. 1) and below about 6 MeV they are quite well represented by Maxwellian distributions. In table I the present values of Maxwellian energies E_M and their ratios are compared with averages over a series of differential measurements [2] and with activation detector results [1]. The present E_M values for both isotopes agree within 2 % with the differential averages, whereas the high activation detector value of $E_M(^{235}U)$ is in definite disagreement. The present $^{239}Pu/^{235}U$ ratios of Maxwellian energies are not conclusive. The ^{3}He-ratio favours the activation detector value, whereas the proton recoil results confirms the differential average.

1.2 Delayed fission neutron spectra of ^{235}U, ^{238}U and ^{239}Pu

G. Fieg

(999, 1000) 14 MeV neutrons and for ^{235}U also thermal neutrons were used to induce fission. The periodic irradiation was done with a 400 kV(d,t)-neutron generator and proton recoil proportional counters were used to determine the neutron spectra.

The spectra of the various half-live groups were extracted from measurements with different irradiations and counting times.

The group spectra for ^{235}U (thermal fission) are shown in Fig. 2. They agree within the error limits with the Batchelor-Hyder data [4]. The various group spectra are quite similar for the isotopes investigated and are also scarcely dependent on the energy of the neutrons inducing the fission. This can be seen from table II where the average neutron energies of the group and steady-state spectra are compared with published results. The results of this investigations have been published [6].

1.3 Spectrum measurements in a depleted uranium metal block for investigations of discrepant ^{238}U cross sections

H. Bluhm

Neutron spectrum measurements have been performed at several positions in a massive block of metallic uranium, which has been installed at the thermal column of the FR2 research reactor.

The spectra have been measured using spherical proton recoil counters between 10 keV and 1.4 MeV and ^{3}He filled semiconductor sandwich spectrometers between 100 keV and 5 MeV. The ^{3}He-spectrometers differ from other spectrometers of this type by a possibility of γ-discrimination. Good agreement between both methods has been obtained in several intercomparison measurements and their accuracy can be stated to about 10 %.

The neutron spectra have been computed using a 208 group cross section set based on the nuclear data file KEDAK and the one-dimensional transport code DTK [7]. S_8-calculations have been performed to study the sensitivity of spectra aga. ıst changes of the cross sections. Changing all relevant nuclear data within reasonable limits it was found that the spectra are extremely sensitive to changes of Σ_{capt} and Σ_{in} whereas all other data only weakly influence the spectra.

The KEDAK data underlying the computation are shown in Fig. 3 together with an adjusted cross section shape that predicts the spectra much better. It can be shown that this change of the total inelastic cross section is the only reasonable way to get agreement in both the high and the low energy region. But an additional reduction of the capture cross section as shown in Fig. 3 is necessary.

The proposed cross sections also lead to a good agreement between measured and calculated spectral indices.
In Fig. 3 the recommended cross sections are also compared to the KFK-INR-set [8] which recently has been deduced from criticality calculations of a number of different reactors. A report on this topic is in preparation.

(299, 300, 302, 303, 304, 534, 535, 536, 537, 538, 539, 663, 697)

1.4 <u>(n,γ)-cross section measurements of ^{99}Tc, Eu, Sm and Fe between 1 eV and 50 keV with a slowing-down time spectrometer</u>

Jeng-Chang Chou and H. Werle

n-γ-cross sections of some higher yield fission products have been measured because they are of interest in connection with long-time reactivity changes in fast breeder reactors. No experimental results were available for ^{99}Tc. Fe has been studied to remove some unexplained discrepancies in earlier measurements.

Both, the γ- and the neutron detector have been calibrated absolutely, therefore the cross section values rely only on the 1/v-dependance of the ^{10}B(n,α)^{7}Li- and the thermal Au-cross section.

Extrapolated cross sections for infinite thin samples were derived from measurements with different samples and are shown in Fig. 4. In addition p-wave-strength functions and some resonance parameters were determined. A report concerning these measurements has been written [9].

1.5 The neutron continuum from the $^{9}Be+\alpha$ reaction

H. Werle, L. Van der Zwan+) and K.W. Geiger+)

Spectra of the low energy neutron continuum between 0.1 and 2.4 MeV were measured at 5.01, 5.44, 6.37 and 7.44 MeV bombarding energies and different angles of neutron emission with cylindrical proton recoil proportional counters at the 4 MeV Van de Graaff of the National Research Council, Ottawa. Fig. 5 shows the results for 7.44 MeV bombarding energy.
The discrete groups n_3, and n_4 which populate the 9.64 and 10.2 MeV levels in ^{12}C are indicated. The results are consistent with the assumption that the continuum is due to the sequential decay $^{9}Be(\alpha,\alpha')^{9}Be^{*} \rightarrow {}^{8}Be+n$ [10]. By integration of the double differential cross sections (mb · sr^{-1} · MeV^{-1}) over angle and energy a few neutron production cross sections for the break-up continuum above E_n = 0.1 MeV could be established (table III). From these and previously published data [11] the fraction of neutrons below 1.5 MeV was calculated to be $(15\pm4)\%$. This value may be compared with $(17.5\pm4)\%$, which was measured directly using a 740 mCi Am-Be source with known total emission rate.

Results of this work will be published.

+) National Research Council of Canada, Division of Physics, Ottawa

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Table I Maxwellian energies of prompt fission neutron spectra for ^{235}U and ^{239}Pu (thermal fission) and ^{252}Cf

		Maxw. Energies E_M (MeV)			E_M-Ratios	
		^{235}U	^{239}Pu	^{252}Cf	$\frac{^{239}Pu}{^{235}U}$	$\frac{^{252}CF}{^{235}U}$
Present investigation	Proton recoil	1.956	2.136	2.155	1.092	1.102
	^{3}He-spectr.	2.020	2.075	2.130	1.028	1.054
Differential average [2]		1.979	2.084	2.189	1.084	
Activation detectors [1]		2.20			1.039	

Table II Average energies of delayed fission neutrons, group and steady-state spectra (Error ± 10 %)

	Average energies (keV) group 1	2	3	4	5	Steady-State
Present investigation						
^{235}U (thermal)	277	484	447	432	-	435
^{235}U (14 MeV)	286	458	432	480	-	451
^{238}U (14 MeV)	278	468	443	425	382	445
^{239}Pu (14 MeV)	296	481	411	430	-	425
Batchelor [4] ^{235}U (thermal)	250 ±20	460 ±10	405 ±20	450 ±20	-	430
Burgy [5] ^{235}U (thermal)	300 ±60	670 ±10	650 ±90	910 ±90	400 ±70	

Table III Neutron production cross sections σ_b for the continuum of the $^{9}Be(\alpha,n)$ reaction

E_α (MeV)	5.01	5.44	6.37	7.44
σ_b (mb)	62 ± 25	177 ± 50	242^{+} ± 80	356^{++} ± 70

$^{+}\sigma_b$ ($0.1 \leq E_n \leq 1.0$ MeV) only, n_3 included; $^{++}n_4$, n_5 included

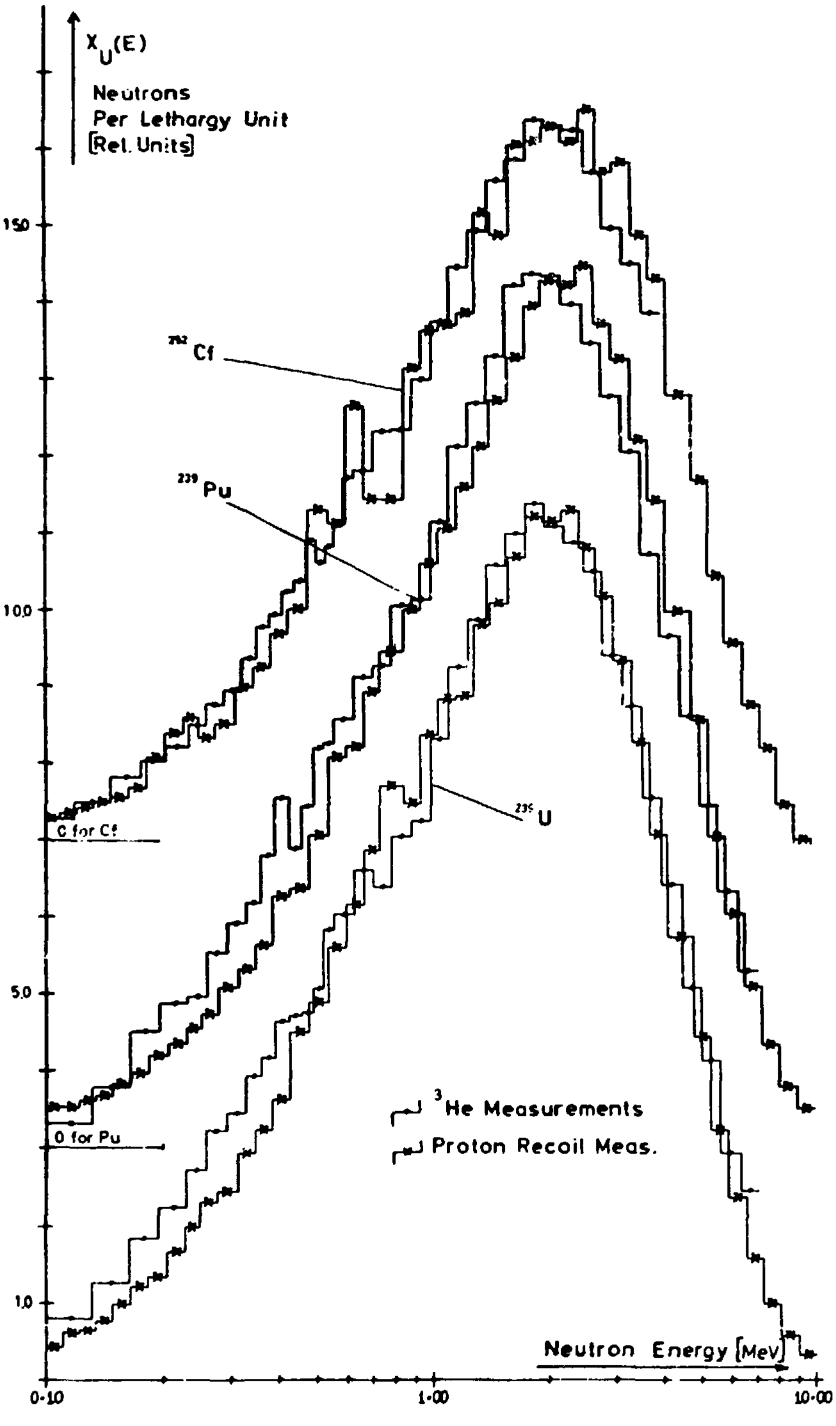

Fig.1 Measured prompt fission neutron spectra (per unit lethargy) of ^{235}U, ^{239}Pu and ^{252}Cf. Measurements with both techniques are normalized in the common energy range.

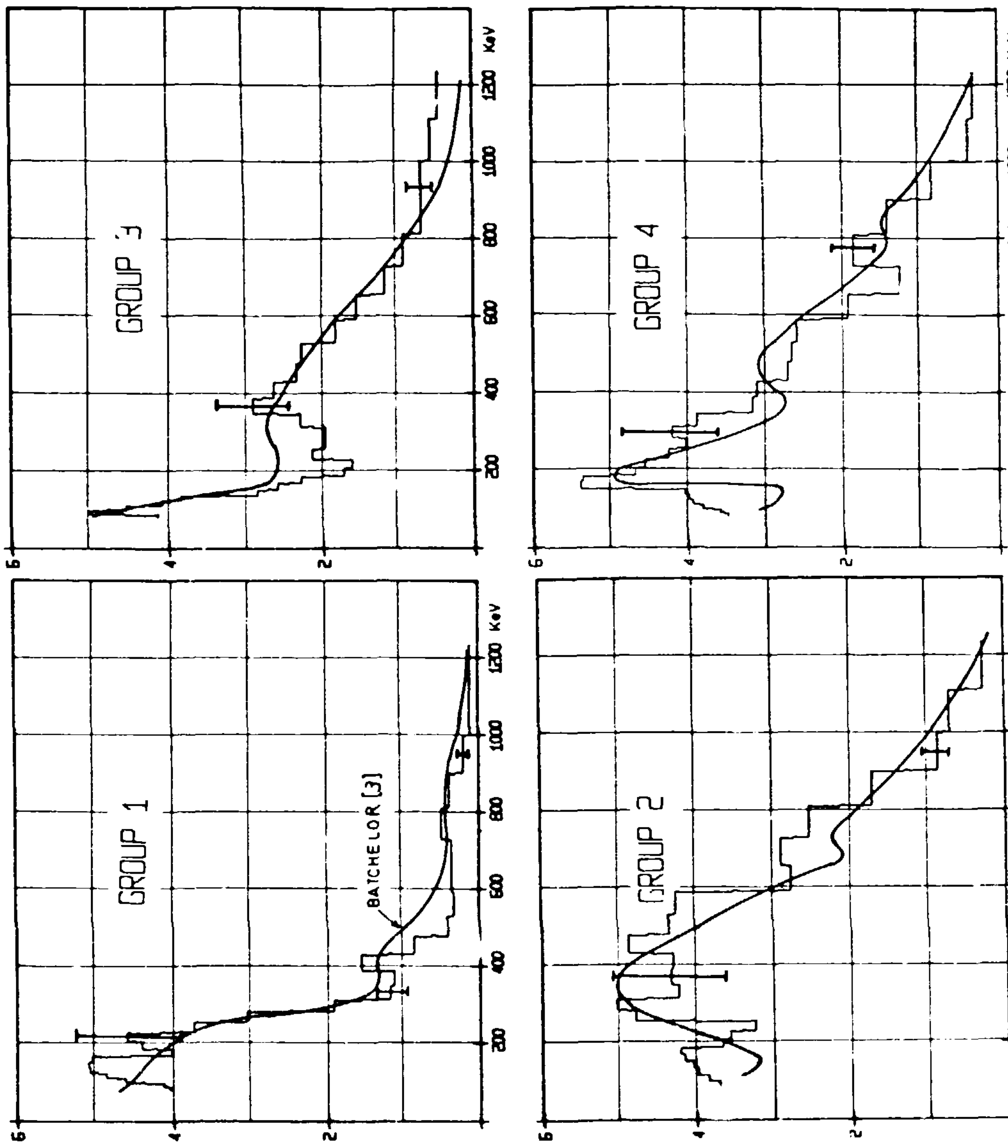

Fig.2 Measured delayed neutron spectra (per unit energy) of ^{235}U (thermal fission).

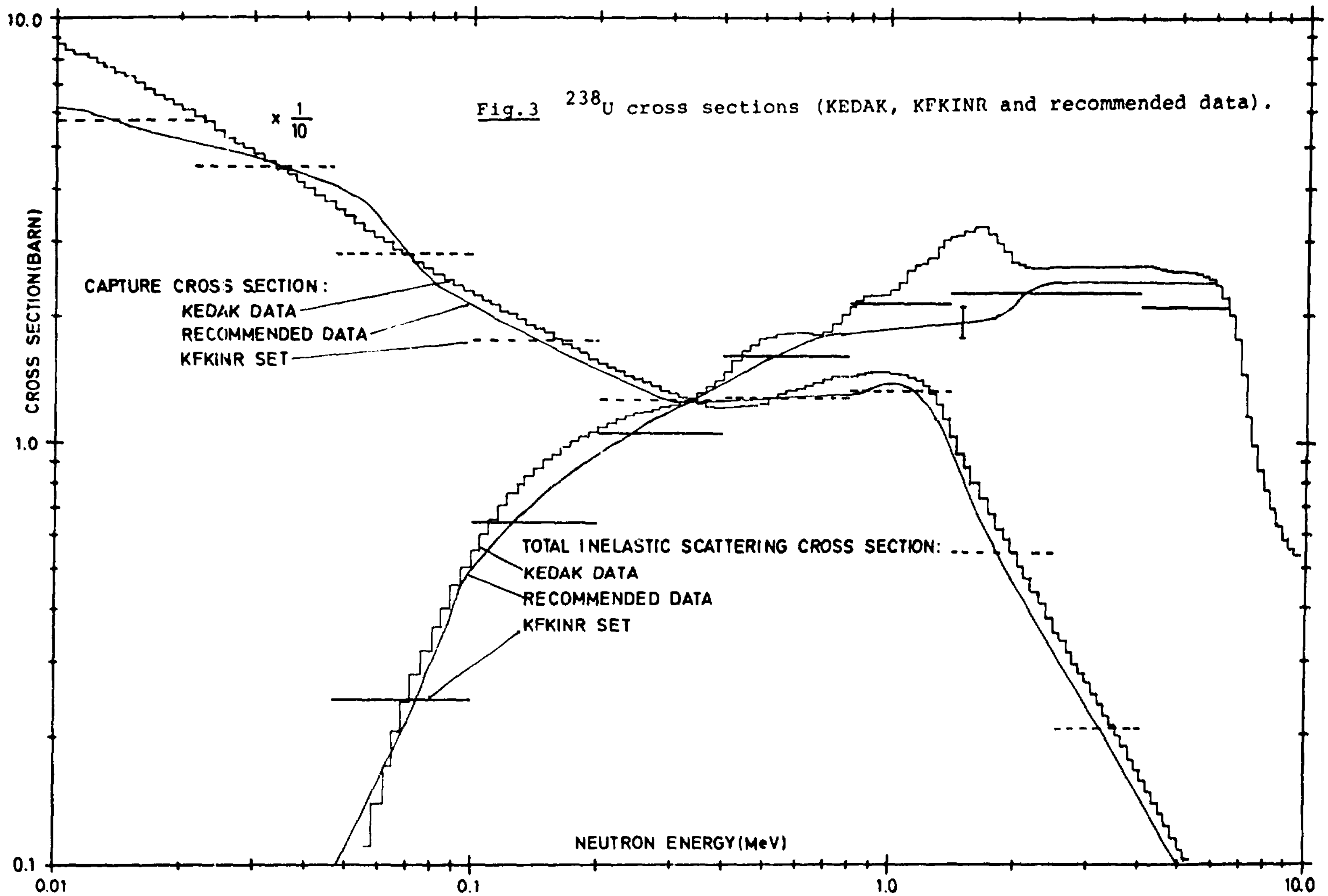

Fig.3 ^{238}U cross sections (KEDAK, KFKINR and recommended data).

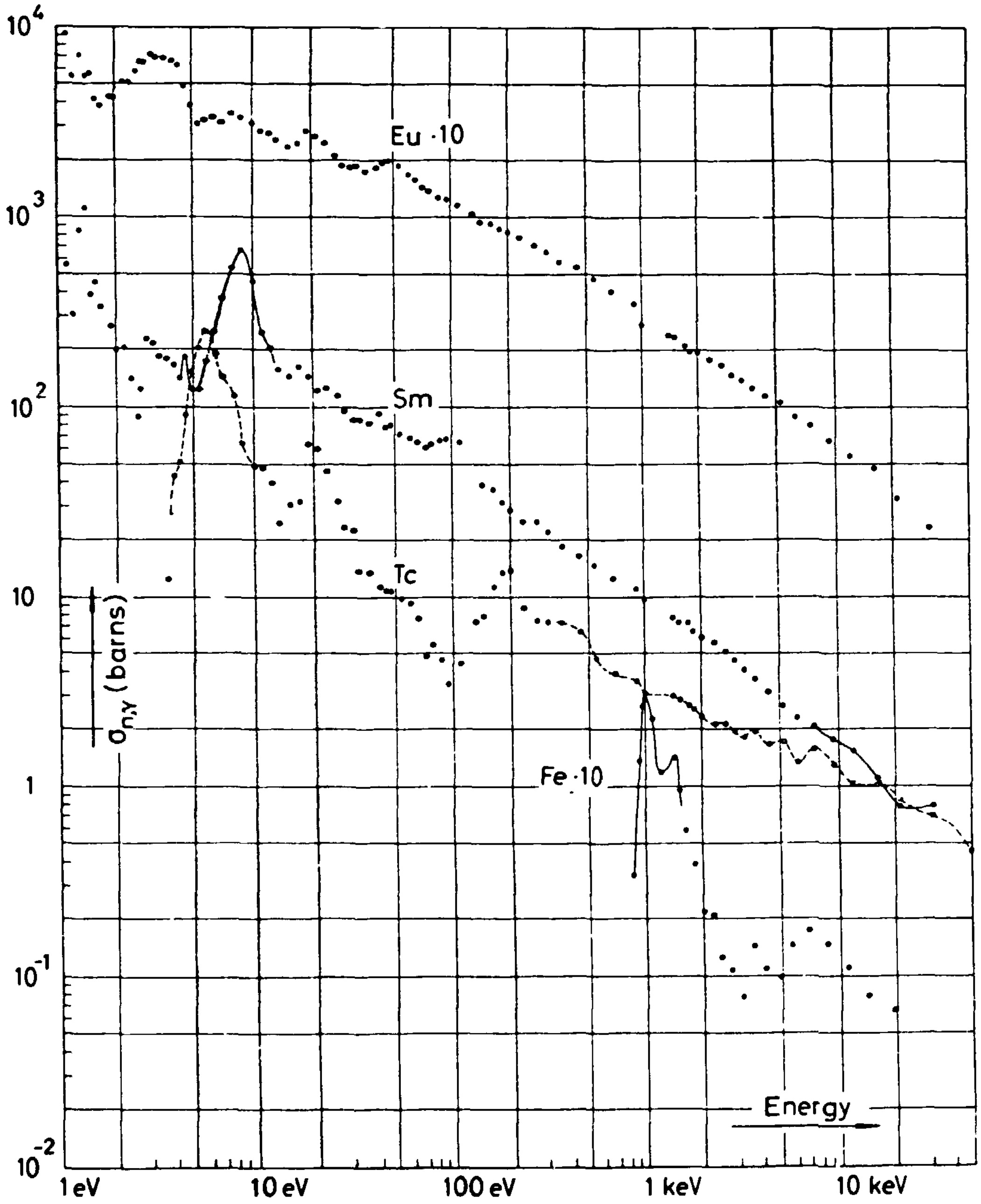

Fig.4 Extrapolated (for zero foil thickness) capture cross sections of ^{99}Tc, Eu, Sm and Fe.

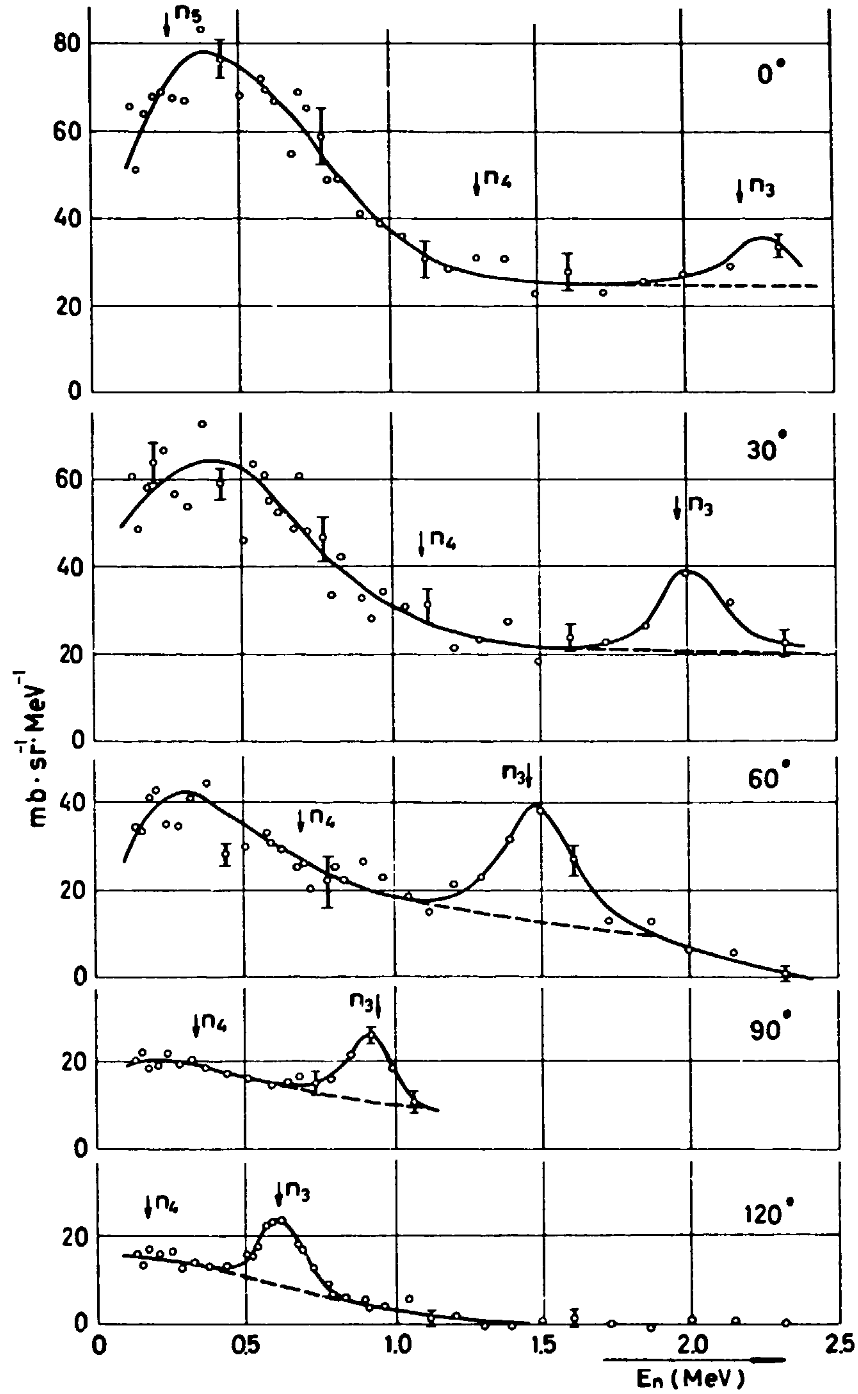

Fig.5 $^{9}Be(\alpha,n)$-neutron spectra at 7.44 MeV bombarding energy.

2. Neutron Nuclear Data Evaluation

R. Meyer, B. Schatz

The cross section data depending on the type σ_f, $\bar{\nu}$, α, σ_T which were evaluated in 1971 have been changed and all revised data were incorporated into the KEDAK-library which will presumably be released as version 3 in the second half of 1973. In addition to these changes the determination of the energy dependence of the average fission width was repeated by fitting the evaluated $\sigma(E)$-curve. The evaluation for U-235 was described in a KFK-report which will be published as KFK 1629 (EANDC (E) 151 "U").
The new measurements for $\bar{\nu}$ (U-238) were reviewed and the KEDAK-values for this type revised, where $\bar{\nu}_p(E)$ is based on the evaluation of Mather et al. [1].
The new evaluations for Pu 240, Pu 241, Pu 242 [2] performed by the group of Prof. Yiftah in collaboration with Karlsruhe were taken over onto the KEDAK-file after verification of the consistency and the resulting necessary corrections.
Data for the threshold reactions (n,p), (n,α), (n,2n) of the stable Cr-, Fe- and Ni-isotopes were incorporated into the KEDAK-library. A review on the present status of the nuclear data for Fe, Cr, Ni and Na was elaborated [3].

A number of materials on the ENDF/B III-file was converted into the KEDAK-format by using the program system BRIGITTE which was developped in Mol [4] in collaboration with Karlsruhe. Among them the data for Li-6 and Pb were tested, corrected and incorporated into the KEDAK-library. Corrections included a modification of the Li-6 inelastic scattering data and consistency corrections, e.g. for σ_{tot}.

The program system for testing and printing nuclear data from KEDAK was considerably extended. The program system KEMA for updating the KEDAK-library was completed and described [5].
The program system SCORE which was taken over from Atomics International for evaluation purposes was modified in order to enable the processing of KEDAK-data instead of ENDF/B-data for which the original version was written.

References

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III. INSTITUT FÜR REINE UND ANGEWANDTE KERNPHYSIK UNIVERSITÄT KIEL [IKK], GEESTHACHT [GERMANY]

Fast Chopper Time-of-Flight Spectrometer

H.H. Jung, H.G. Priesmeyer

1. Total Cross Section Measurements of Gross Fission Products

(1409) Measurements and analysis of cross sections of gross fission products were continued. The results up to 13 eV can be summarized as follows:

From 0 to 13 eV 21 resonances could be resolved [Tabl. 1]; for 20 of them an isotopic identification could be accomplished. All identified resonances belong to isotopes which are either stable or have life times greater than 10^5 a, except for the Pm 147 resonances at 5.33 eV. This means that in the energy range mentioned, no variation of the cross section of samples of gross fission products will occur with increasing cooling time except for the Pm 147 resonance at 5.33 eV.

Fig. 1 shows a comparison between the measured transmission of a gross fission product sample and the transmission which had been calculated from known resonance parameters and known fission product concentrations in the sample.

The analysis above 13 eV is more complicated and more measurements will be necessary, especially on gross fission products of the fission of U 233 and Pu 239, since the mass distribution of their fission products differ from that of the U 235-fission.

2. Lowest lying resonance in Hf and Ta

BRAND et al. have reported a new resonance in Hf at 0.27 eV with a peak cross section of about 10 barn [1]. This result has been checked with the chopper and no resonance was found at that energy. [If there would be a resonance at that energy it is smaller than 2 barn - with 95 % confidence level]. The existence of the 0.43 eV-resonance of Ta [peak cross section ≈ 1 barn], however, could be confirmed.

3. Publications

H.G. PRIESMEYER, H.H. JUNG

Der totale Wirkungsquerschnitt der Rutheniumisotope
99, 100, 101, 102 und 104 im Resonanzbereich ATKE 19 [1972] 111

H.H. JUNG, H.G. PRIESMEYER

Neutronenwirkungsquerschnitte der Spaltprodukt-Nuklide im Resonanzbereich
Paper K 258, Spring meeting of the DPG in Berlin, 1972

References

[1] ATKE 19 [1972] 262

Tab. i

Significant Resonances in the Cross Section of Gross Fission Products up to 13 eV

Resonance Energy E_o [eV]	Isotope
0.29	U 235
3.6	U 235
4.4	? [Nd 145 ?]
4.82	U 235
5.12	U 234
5.33	Pm 147
5.43	U 235
5.45	U 236
5.58	Tc 99
5.79	U 235
5.85	Cs 133
6.16	U 235
6.38	U 235
6.65	U 238
7.04	U 235
8.02	Sm 152
8.74	U 235
9.23	U 235
10.2	U 235
11.7	U 235
12.4	U 235

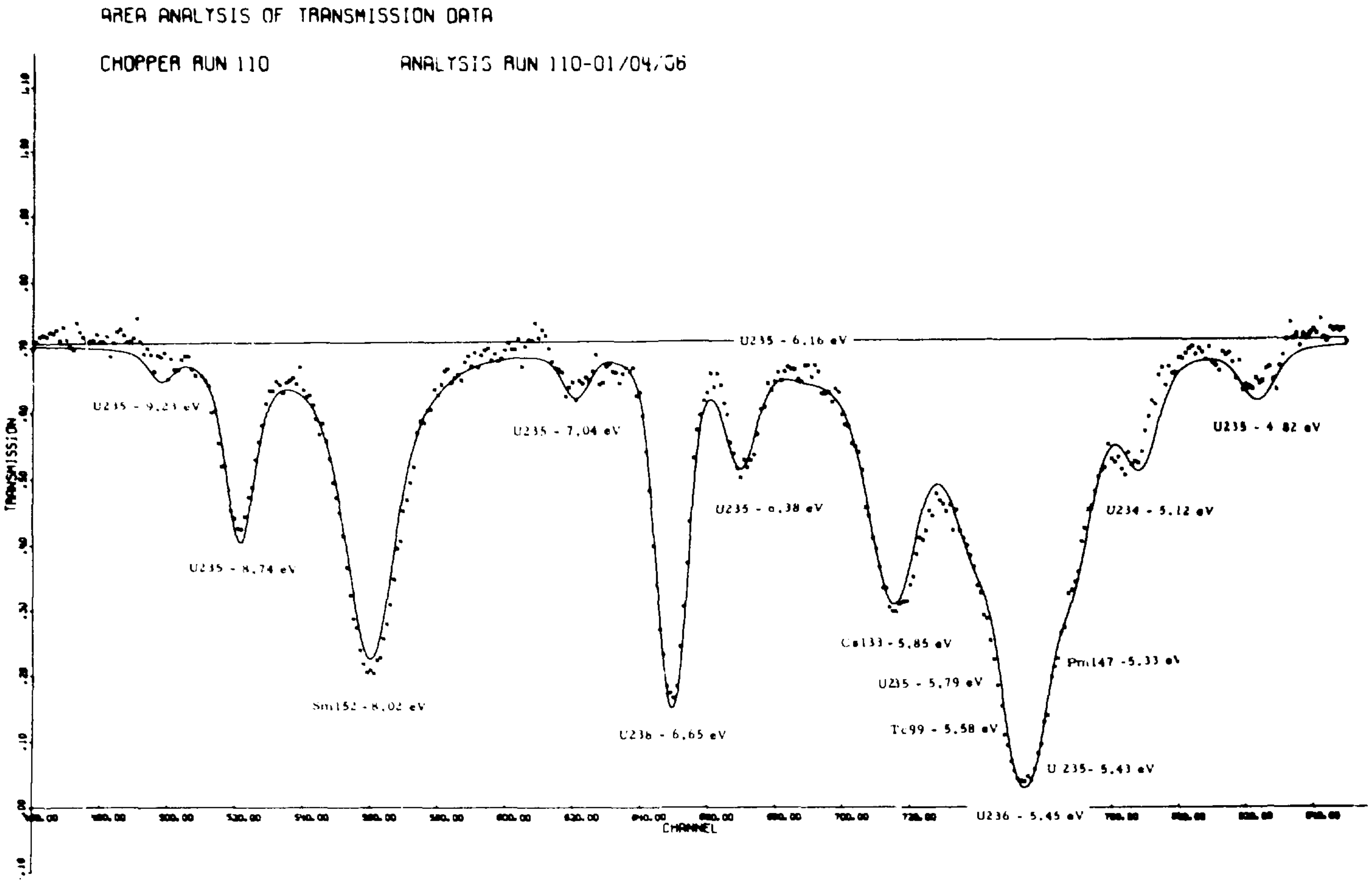

Fig. 1 ***Transmission of gross fission product sample HFR-101 (RCN-Petten)***

IV. I. INSTITUT FÜR EXPERIMENTALPHYSIK, UNIVERSITÄT HAMBURG, [GERMANY]

1. Excitation Function of the Reaction $^{12}C[n,2n]\,^{11}C$ from the Threshold up to 34 MeV Neutron Energy.

B. Anders, M. Bormann, W. Scobel

In connection with measurements concerning the production of the residual nucleus ^{11}C via different entrance channels[1] we have determined the excitation function of the $^{12}C[n,2n]\,^{11}C$ reaction by the activation method.

The neutrons were produced with a self supporting tritium-titanium-target and the 6 - 17 MeV deuteron beam of the Hamburg isochronous cyclotron. Neutron flux measurement was performed with a stilbene proton recoil spectrometer. Because of the Q-value of -18.72 MeV for the $^{12}C[n,2n]\,^{11}C$ reaction, low energy neutrons from tritium break up and deuteron induced reactions in titanium isotopes do not contribute.

The 20.3 min β^+ activity of the carbon samples was detected with a calibrated $\gamma\gamma$-coincidence spectrometer. The resulting cross sections are given in fig. 1 together with the data of Brill et al.[2].

1] B. Anders, H.H. Bissem, M. Bormann, W. Scobel,
Jahresbericht des I. Instituts für Experimentalphysik, Universität Hamburg, Hamburg, [1971] p. 15

2] O.D. Brill, N.A. Vlasov, S.P. Kalinin, L.S. Sokolov,
Soviet Physics - DOKLADY 6 [1961] 24

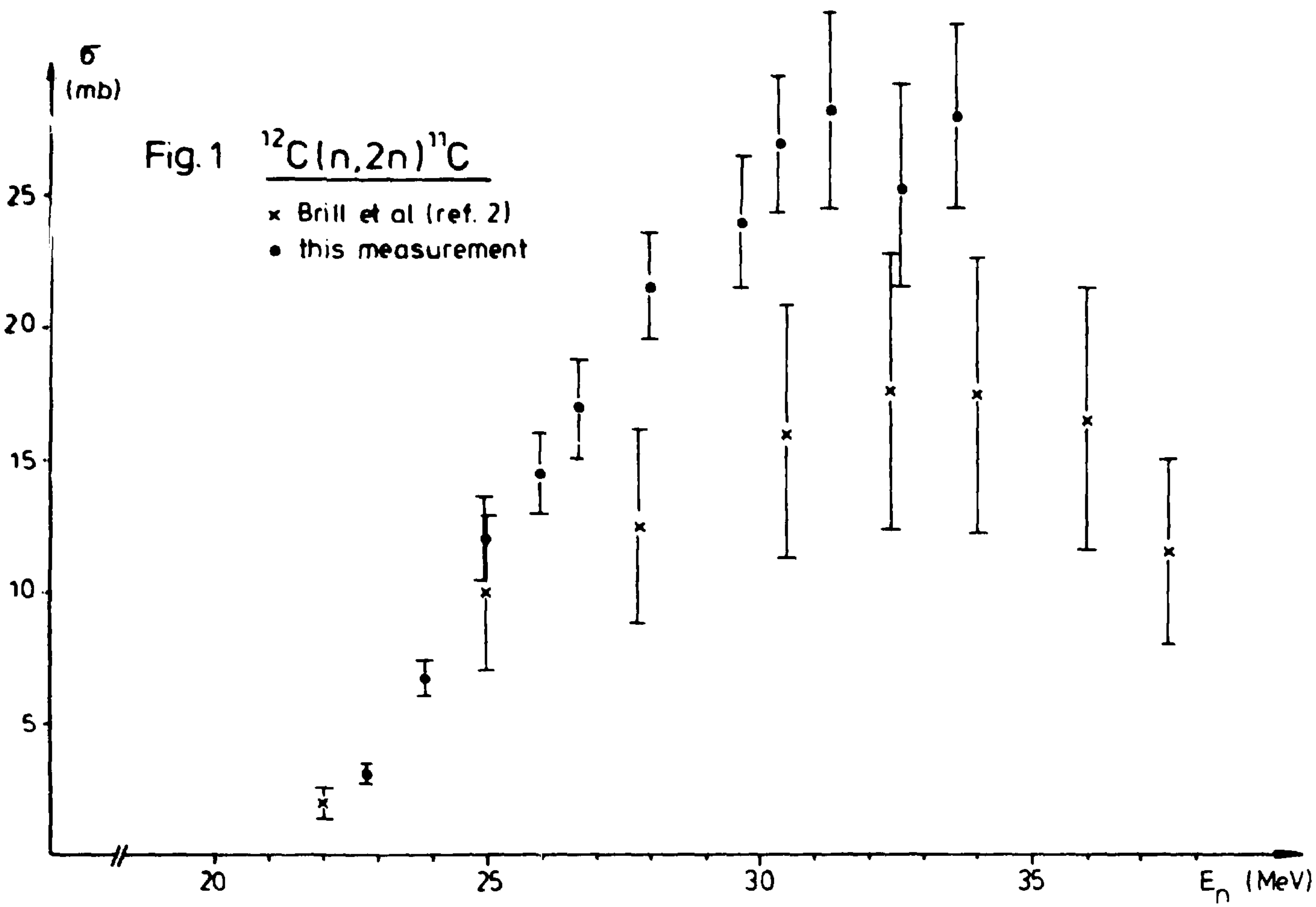

Fig. 1 $^{12}C(n,2n)^{11}C$

IV. PHYSIK-DEPARTMENT DER TECHNISCHEN UNIVERSITÄT MÜNCHEN, E 14 (GERMANY)

1.1 Investigation of Nuclear Structure with Neutron Capture Reactions ^{114}In Level Scheme

D. Rabenstein

The reaction ^{113}In (n,γ) ^{114}In has been studied using a target containing 96 percent of ^{113}In.

A level scheme of ^{114}In has been constructed up to about 1.3 Mev as a result of experimental data extracted from low energy γ-ray singles and coincidence measurements and of pair spectrometer measurements. Because of the lack of other reliable experimental data on the ^{114}In level scheme, at present, our level scheme is less complete than the level scheme of ^{116}In [1] and only half of the observed γ lines with energies below 500 keV are unambiguously placed.
The $\pi(g_{9/2})^{-1}\,\nu(h_{11/2})$ multiplet states have been found between $J^{\pi} = 3^{-}$ and $J^{\pi} = 8^{-}$ and show a similar character as the corresponding states in ^{116}In. The neutron separation energy in ^{114}In has been determined as S_n = 7274.1 ± 1.5 keV.

1.2 Study of γ-γ-coincidences in ^{60}Co, ^{64}Cu and ^{66}Cu

D. Rabenstein

In all three nuclei, which are near the closure of the $f_{7/2}$ proton shell, low energy γ-γ coincidences have not been studied in a satisfactory way up to now. With these coincidence data the level schemes can be completed at low excitation energies and extended up to higher excitation energies. The Co-Data are presently being reduced.
Only natural copper has been used in the Cu(n,γ) study. Therefore, for cross-section reasons, mainly ^{64}Cu has been studied in these measurements. Three new levels below 1 MeV have already been firmly established in ^{64}Cu. Measure-

[1] D. Rabenstein, D. v. Harrach, H. Vonach, G.G. Dussel, R.P.J. Perazzo, Nucl. Phys. A 197 (1972) 129

ments with separated Cu targets are in preparation.

1.3 n,γ Studies of ^{51}V, ^{142}Pr and ^{104}Rh

D. Harrach

A lower limit of $\sigma_{thermal\ n,\gamma}(^{50}V) = 19 \pm 4$ b could be established and $S_n(^{51}V)$ was determined to 11051.1 ± 0.5 keV. Spin and parity assignments of levels up to 5.6 MeV previously found in (p,p') and (d,p) experiments were possible by observation of primary gammas and by determination of their decay modes by coincidence experiments.

The studies of ^{142}Pr and ^{104}Rh by (n,γ) are not complete and will be continued.

2.1 Coherent Scattering Amplitudes Measured by Small Angle Scattering of Neutrons

L. Koester, K. Knopf (FRM 1972)

The data given in the last report were published [1]. New measurements on elements in paramagnetic compounds yielded the following amplitudes of the bound atoms (given in 10^{-13} cm and with standard errors):

a(Co) = 2,35 ± 0,05	from	CoF_2, $CoCl_2$, $CoSO_4$
a(Rh) = 5,88 ± 0,03	from	$RhCl_3$ (diamagnetic)
a(Ru) = 7,21 ± 0.07	from	$RuCl_3$
a(Dy) = 17,0 ± 0,2	from	$Dy_2(SO_4)_3$

These experiments were not affected by the magnetic behaviour of the investigated powders.

Experiments on anhydrous compounds of alkaline earth metals resulted in:

a(Mg) = 5,33 ± 0,02	from	MgF_2, $Mg(NO_3)_2$
a(Ca) = 4,80 ± 0.06	from	CaF_2, $CaCO_3$

[1] L. Koester, K. Knopf, Z. Naturforschung 27a, 901 (1972)

a(Sr) = 7,08 ± 0.07 from SrF_2, $SrCO_3$, $Sr(NO_3)_2$
a(Ba) = 5,28 ± 0.03 from BaF_2, BaW_3, $Ba(NO_3)_2$
a(N) = 9,38 ± 0.03 from NH_4Cl, $CsNO_3$, KNO_3, $Pb(NO_3)_2$

New investigations on rare earth metals and on lanthanides are in progress.

2.2 Absolute Values for Scattering Amplitudes of Hydrogen and Carbon and of Some Halides

L. Koester, W. Nistler (FRM 1972)

Preliminary results of these measurements utilizing the Neutron-Gravity-Refractometer, were published in a letter [1].
Additional measurements on liquid compounds of C, H and Cl were performed. They gave results for the coherent scattering amplitudes of the molecules:

$C_2H_4Cl_2$: a = 17,500 ± 0,006 fm and
C_2Cl_4: a = 51,617 ± 0,008 fm

in best agreement with the published preliminary numbers for C, H and Cl.

2.3 Precise Measurements of Total Cross-Sections at 1.25 eV and 5.2 eV Neutron Energies

L. Koester, W. Waschkowski (FRM 1972)

Utilizing resonance detectors for the neutron energies 1.25 and 5.2 eV we measured total cross sections of some elements by transmission experiments. The results are of interest in connection with precise numbers of coherent scattering amplitudes. They could have some importance in interpreting experiments on neutron-electron-interaction by precise measuring of neutron cross-sections of different elements.

The experiments yielded for:

Be: σ_{tot} (1,25 eV) = 6,149 ± 0.008 barn
(5,2 eV) = 6,149 ± 0.007 barn

[1] L. Koester, W. Nistler, Phys. Rev. Letters 27, 956 (1971)

(860)

Mg: σ_{tot} (1,25 eV) = 3,425 ± 0,003 barn
(5,2 eV) = 3,415 ± 0,002 barn

S: σ_{tot} (1,25 eV) = 1,045 ± 0,004 barn
(5,2 eV) = 1,014 ± 0,003 barn

SiO_2: σ_{tot} (1,25 eV) = 9,617 ± 0,006 barn
(5,2 eV) = 9,600 ± 0,003 barn

Measurements on samples of liquid Bi and Pb are in preparation.

3. Total Neutron Cross Section Measurements on Gold and Cobalt in the 0.0014 - 0.005 eV Range

W. Dilg, W. Mannhart, E. Steichele, P. Arnold

A new thermal neutron TOF spectrometer at the FRM, mainly designed for high resolution diffraction work [(1)], was used to determine thermal standard cross-sections with high accuracy. The facility consists of a 150 m long guide tube used as flight-path and three synchronized choppers near the reactor, distant by 1.5 m and 17.7 m. The velocity of the first chopper was chosen to give a TOF-resolution of ~ 2.8 μsec/m, i.e. $\Delta\lambda \sim 0.010$ Å. By variable reduction of the velocities and phases, respectively, of the second and third chopper the width of the transmitted wavelength spectrum was changed between 1.4 Å and 2.7 Å, and the centers of the spectra were selected between 4 and 7 Å, respectively. The TOF wavelength calibration was checked by comparison with the well known Bragg cutoffs of polycrystalline samples of Be, Pb, Fe, Mg and Si between 3.9606 Å and 6.2708 Å and was found to be consistent within 0.002 Å.

Measurements were performed on gold and cobalt which are the most widely used thermal standards for activation work. Two samples of gold (nominal purity 99.999 %) were used in the 4 - 7.5 Å range and one sample of cobalt (spec. pure) in the 5.5 - 7.5 Å range. From the gold transmission data above 4.7 Å (111-Bragg-cut-off) the subthermal limit σ_{abs}/λ of the absorption cross section was evaluated using the same corrections as in [(2)] for incoherent elastic and inelastic scattering and for the slight deviation from 1/v caused

by the 4.9 eV resonance. Combining the 4.7 - 7.5 Å data of the two samples and different runs we obtained σ_{abs}/λ = 54.35 ± 0.05 b/Å (2 σ error) . This agrees with the previous measurements of Gould et al. [(2)] in the 5 - 11 Å range and those of Als-Nielsen and Dietrich [(3)] above 7 Å. However, our
(333, data do not support the trend to lower values seen by [(3)] at 6.35 A and
844) 5.17 A. With a correction of 0.96 % for the non 1/v resonance contribution at thermal energy we obtain σ_{abs} (2200 m/s) = 98.68 ± 0.10 b (2 σ error) to be compared with the previous results 98.8 ± 0.3 b [(2)], 98.6 ± 0.2 b [(3)] and 98.9 ± 0.3 b [(4)].

The evaluation of the cobalt data yields the preliminary value σ_{abs} (2200 m/s) = 37.17 ± 0.2 b, assuming an effective scattering correction above the Bragg cut-off of 6 b (incoherent elastic and magnetic scattering). The incoherent scattering correction is uncertain due to discrepancies of the available rather old total cross section measurements in the low eV region. We intend to remove this uncertainty by a measurement on Co at 1.2 eV (rhodium resonance detector method).

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(1) E. Steichele, P. Arnold, to be published

(2) F. Gould et al., Nucl. Sci. and Engng. 8 (1960) 453

(3) J. Als-Nielsen, O. Dietrich, Phys. Rev. 133 (1964) B 925

(4) H, Teutsch et al., Nukleonik 4 (1962) 165

VI. CENTRAL BUREAU FOR NUCLEAR MEASUREMENTS, Euratom, Geel (Belgium)

I. NEUTRON MEASUREMENTS DIVISION

1.1. General Developments
A.H.W. Aten, Jr. *

1.1.1. Gamma flash suppression
J. Wartena

A target moderator shielding assembly with reduced γ -flash has been installed.

The target is a conventional mercury cooled uranium target with a diameter of 34 mm. Two semicircular moderator slabs of 75 mm radius and 40 mm thickness of polyethylene are placed in a vertical plane above and below the target. Three concentric lead rings surround the target in a horizontal plane, to shield the flight paths from direct γ -radiation. The lead rings shield also the unmoderated neutrons, going directly from the target to the flight paths.
The dimensions of these lead rings are given in table 1.

Table I

	inner radius (mm)	outer radius (mm)	height (mm)
inner ring	75	125	34
middle ring	175	225	38
outer ring	175	325	40

The construction is so, that, looking through the collimators from the flight paths, only the moderator and the outer surface of the biggest lead ring are seen. All structure materials (cooling pipes, supports etc.) and the target are either outside the lines of the sight, or shielded by the rings. Compared with the old version of the target where already some shadow cones have been used, the gamma flash is only reduced by a factor three. But the gammas which reach the flight paths are now lower in energy. 511 keV annihilation quanta originated from the target are degraded in energy by Compton effect in the moderator before they leave the target system. Therefore it is now possible to use a γ -filter in the beam. Such a filter of lead with 8.5 mm thickness for example reduces again the γ-flash by a factor 10 at the expense of 25% of the neutron flux.

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* in charge of this activity

A time of flight experiment indicates that the lead shielding reduces the background by a factor 1.5. We assume that this is due to the shielding of the unmoderated neutrons. Compared to the old target version, the neutron flux is unchanged up to a neutron energy of 100 keV. Beyond these are less neutrons because of:

1. the shielding of the fast neutrons by the lead rings
2. only large angle scattered neutrons in the present moderator reach the flight paths.

Because of the new position of the moderator in one plane the resolution of the time of flight experiment is improved.

If one shifts the moderator parallel to its plane by 40 mm it is possible to reduce the γ-radiation by a factor 2 and to decrease the energy of the gammas in the flash. By doing this, the γ-flash is harder in the opposite flight path.

Table 2 gives the energy absorption in a 50 x 50 mm NaI(Tl) at 9 m from the target for the γ-flash of a linac pulse of 3.3 Joule and 60 MeV electron energy:

Table 2

Target version	Energy absorption (GeV)
1. mercury cooled uranium target	1600.
2. same as 1. with lead rings	0.9
3. same as 2. with moderator	29.
4. same as 3. moderator shifted 40 mm away from the detector	13.
5. old configuration	78.

1.2. Data Handling

F. Colling (until 31.7.72), H. Horstman*, W. Kolar (until 11.9.72), R. Werz, C. Cervini, U. Meloni, J. Deckx-Van [illegible]elen, D. De Pooter; full participation : A. Idzerda++++ [illegible]ty participation : T. Babeliowsky, A. Brusegan++++

1.2.1. [illegible]chnical Improvement of the Data Processing Equipment : [illegible] number of multichannel analysers interfaced to the IBM [illegible]800 computer has been increased by one (8 in total). Due to growing demands of disk storage capacity for experimental neutron data the disk capacity of the IBM 1800 has been doubled.

++++ Euratom bursar

1.2.2. Data Reduction for Neutron Cross Section Measurements: The set of programs for data reduction of scattering and fission cross section measurements has been extended and improved. Optimalization calculations of background functions in total cross section experiments have been performed.

1.2.3. Calculations for Fission Neutron and Gamma Multiplicity Measurements: A computer program has been developed which permits the calculation of the probability of a s-fold coincidence of n particles impinging on k detectors with a total efficiency of ϵ per particle. The program and results of the calculations have been published. [1]

1.2.4. Modification of Programs for Cross Section Analysis: The IBM 7090 programs MOULD and MAGGIE (AWRE Aldermaston) for the calculation of multiple scattering corrections of differential elastic and inelastic neutron scattering cross sections have been changed to be compatible with the IBM 370/165 computer system of CETIS. The programs are included in the CBNM disk program library.

1.2.5. Programming Assistance for General Data Analysis Problems: Programming assistance for the following problems has been given: background corrections, comparisons, and fittings for total cross section data, least squares fits for various experimental data sets, and format conversions of measured spectra for several data reduction programs.

1.2.6. Programming for the Extended Disk Capacity for Experimental Neutron Data: The computer routines controlling the disk storage for experimental data have been modified and extended in order to serve the new IBM 2311 disk unit. The disk capacity shared by all data acquisition stations interfaced to the IBM 1800 computer has been increased to 240 spectra of 4096 channels and 480 blocks of 256 channels for spectra of variable length.

1.2.7. Improvement of the IBM 1800 Multiprogramming System: The disk controlling capabilities of the IBM 1800 operating system have been improved by the generation of a new multiprogramming system (V3L2). A magnetic tape spooling system has been developed which increases the efficiency of batch processing and reduces the rental costs of the IBM 1443 line printer.

1.2.8. Analyser Computer Interface Units:
According to the requests of the experimental groups the set of routines for data transfers and interactive data reduction has been extended, especially for the purpose of automatic data reduction and modification of experimental data stored on the IBM 1800 disk. Two reports have been published. [2] [3]

1.2.9. Satellite Computer for Multiparameter Experiments:
The software of the GA 18/30 satellite computer of the IBM 1800 is being debugged. Programs for two-parameter experiments with windows on both parameters and three-parameter experiments have been developed. Utility routines have been added to the system facilitating the planning for the storage of experimental data on the IBM 1800 disk. EUR reports about the system are being prepared.

1.2.10. Satellite Computer for the Radionuclides Group:
The configuration of a data acquisition and control system for the radionuclides group has been determined.
The system is based on a GA 18/30 computer to be operated as satellite of the IBM 1800 system. The source of the data to be processed are standardization measurements with about 100 counters located in up to 15 stations. The software planning has been made for on-line control of the experimental equipment, checks on the incoming data, transfers of data to the disk storage of the IBM 1800, and remote control of evaluation programs on the IBM 1800.

A communication program for data transfers between the IBM 1800 and a GA 18/30 satellite has been developped.

1.3. Linear Accelerator

C. Allard*, J. M. Salomé. R. Cools, R. Forni, F. Massardier, F. Menu, R. Pijpstra, P. Schweitzer, P. Siméone, F. Van Reeth, C. Waller

1.3.1. Operation of the linear accelerator: The high number of beam hours obtained in 1971 has been maintained in 1972 (see Table 3 and Fig. 1).

Table 3: Operating hours of the linac

	1971 (11 months)	1972 (11 months)
Number of klystron hours	3878	3852
Number of beam hours	3817	3817
Number of maintenance hours and other stops	465	544

Also the utilisation coefficient of the flightpaths has still been improved in 1972, four to seven flightpaths have been used during 80% of the time (see Fig. 2).

1. 3. 2. Collaboration with other laboratories: The better use of the linac is mainly due to the increase of participation of other laboratories:

1) CEN Mol: used two more flightpaths in 1972 in total 5 flightpaths used with the following time: 1190 - 1375 - 1557 - 2006 and 3196 hours.
2) CNEN: 2 flightpaths during 1353 and 3103 hours

1. 3. 3. Targets: A ^{238}U target with reduced dimensions has been used up to 3 kW, associated with a polyethylene moderator (e = 4 cm) placed vertically in the axis of the target. The detectors were better protected against the γ-flash by the lead shielding surrounding the target. The gamma radiation was reduced considerably (at least by a factor 10, depending on the flightpath and the detectors used). In this way it is possible to enlarge the neutron energy range from a few keV up to about 100 keV. (Cf. 1. 1. 1.).

A new 4 kW target with reduced dimensions has been studied at CBNM and ordered. It will be put into operation during the first quarter of 1973.

A preliminary plan for a rotative mercury cooled target and also for a rotative mercury and vacuum tight joint (p = 5 bars) has been studied by the firm CERCA following the instructions of CBNM.
Tests with this joint will be done during 1973.

1. 3. 4. Improvement of the accelerator: Fast PIN diode modulators have been tested on the micro-wave lines between the pilot oscillator and the klystrons. They are able to switch the microwave power at the input of the big klystron ($\sim$ 200 W) within 20 ns in such a way that the pulse shape at the klystron output is very well defined. Rise and fall times of less than 100 ns can be obtained on the 20 MW microwave pulses which can have only the duration of the filling time of the sections. The Joule losses in the accelerator can be largely

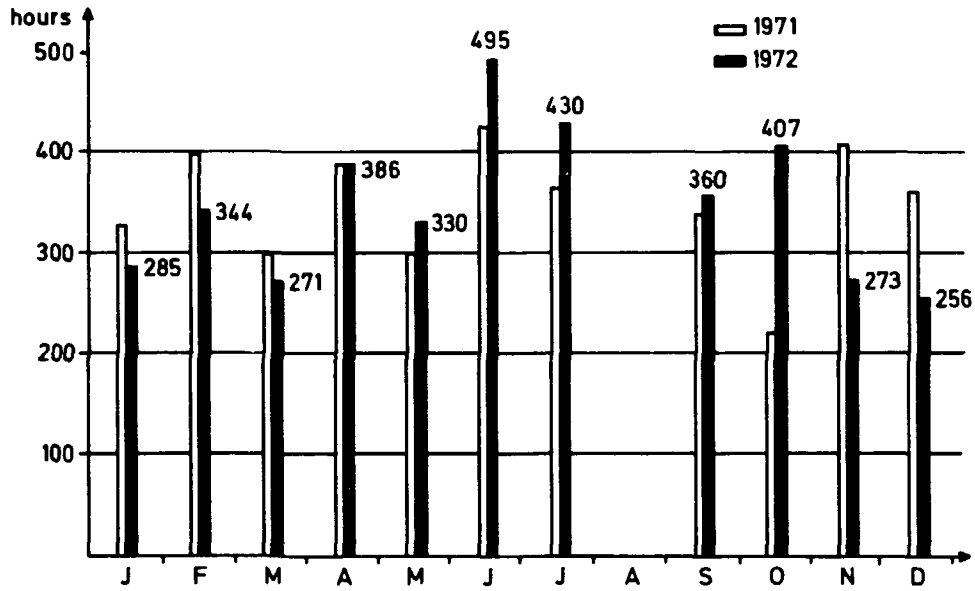

Fig.1 Linac operation

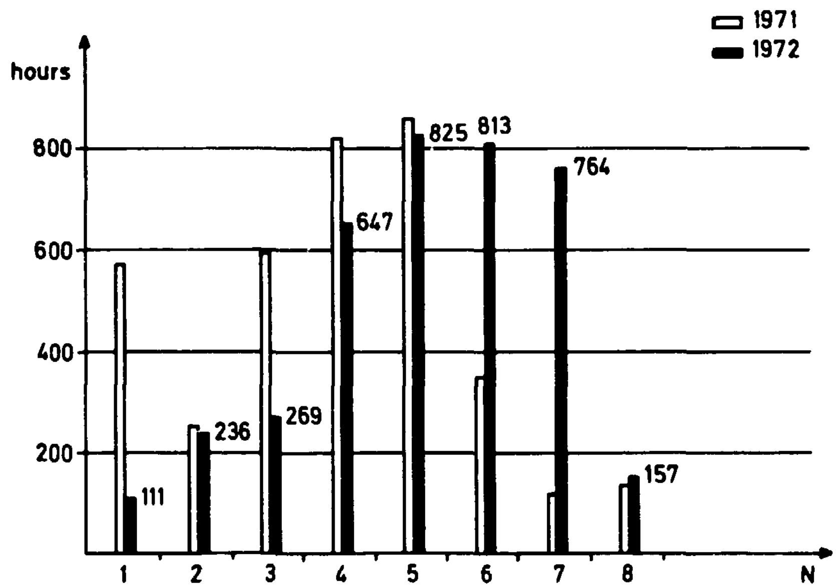

Fig. 2 Number of flightpaths simultaneously used

reduced (50%) or can be modified in order to change the tuning frequency of each section separately. Up to now, this system has been tested as a prototype and works satisfactorily. It will be adapted on the two sections and improved to fulfill the normal working conditions.

Project to replace the spark gaps by a big thyratron has been brought out and studied with the firms English Electric Valve and ITT. Many advantages can be expected with such tubes as a better phase stability, smaller impedance and easier maintenance. Two racks have been set up and a new tube EEV CX1521 has been tested by the specialists of the firm in August on our modulator. These measurements were useful to improve the prototype, and the firm has the intention to retest it in 1973.

The F2011 klystron used as a master oscillator will be no longer produced in 1975 by the firm Thomson CSF, which was engaged to provide these tubes for 10 years. Thus we are looking after another generator to drive the big klystron. A specification book has been written and sent to the different manufacturers of the world. This generator will consist of a low level constant wave oscillator, modulated by a fast switch and driving an amplifier klystron supplied by a DC voltage. Such a system will perform a good frequency stability during the pulses and will be the cheapest one. The proposals are expected for the beginning 1973.

1.4. Total Cross Section Measurements

K.H. Böckhoff*, A. Brusegan+, G. Carraro, A. Dufrasne

1.4.1. Precision Total Cross Section Measurements on ^{6}Li, ^{7}Li and C in the keV and MeV Range: After the subcritical experiment of the CEA (Cadarache) the equipment for neutron total cross section experiments has been re-assembled and re-aligned and transmission measurements on the 3 isotopes were started at new. Data with high statistical accuracy have been obtained on three ^{6}Li, two ^{7}Li and two carbon (reactor grade graphite) samples between 2 keV and 2 MeV neutron energy.

The main problem is the background determination since the usually applied black resonance technique affects the quantity to be measured and since the small number of suitable black resonances may be not sufficient to trace the shape of the background curve.

One of the background evaluation methods which was tried consists of a least squares fit parameter determination of a suitably constructed mathematical form of the background

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+ Research fellow - Università di Padova curve comparing our own transmission results on carbon with those derived from an evaluated "best" curve (JAERI 1218) for σ_T which comprises most of the information on σ_T of carbon available so far. The background function is then applied to the Li transmission results obtained "simultaneously" (in the same sample changer turn) with the carbon data after normalising it via a black resonance common to all spectra. In this way the Li total cross section determination is linked to the standard carbon total cross section which is assumed to be fairly well systematic error compensated.

Measurements have been finished and evaluation is proceeding.

1.4.2. Resonance Parameters of the ^{59}Co Resonance at 132 eV.

(329) The analysis of the transmission data obtained with 4 different sample thicknesses has been terminated. Fig. 3 shows the $\Gamma_n - \Gamma_\gamma$ diagram calculated with the Atta-Harvey program.

1.4.3. Total Cross Section of ^{236}U: Transmission measurements have been performed on a $^{236}U_3O_8$ (89.38 at. % ^{236}U)

(1024, 1025) sample covering the energy ranges 100 eV - 800 eV, 400 eV - 2400 eV and 1500 eV - 6000 eV. Sample thickness was $0.898 \cdot 10^{-2}$ at/b.

Preliminary results presented at the Conference on Nuclear Structure Study with Neutrons (Budapest 1972) have been revised and completed after a new evaluation of the experimental data and reported at the 58th National Congress of the Societa Italiana di Fisica (Cagliari 1972).

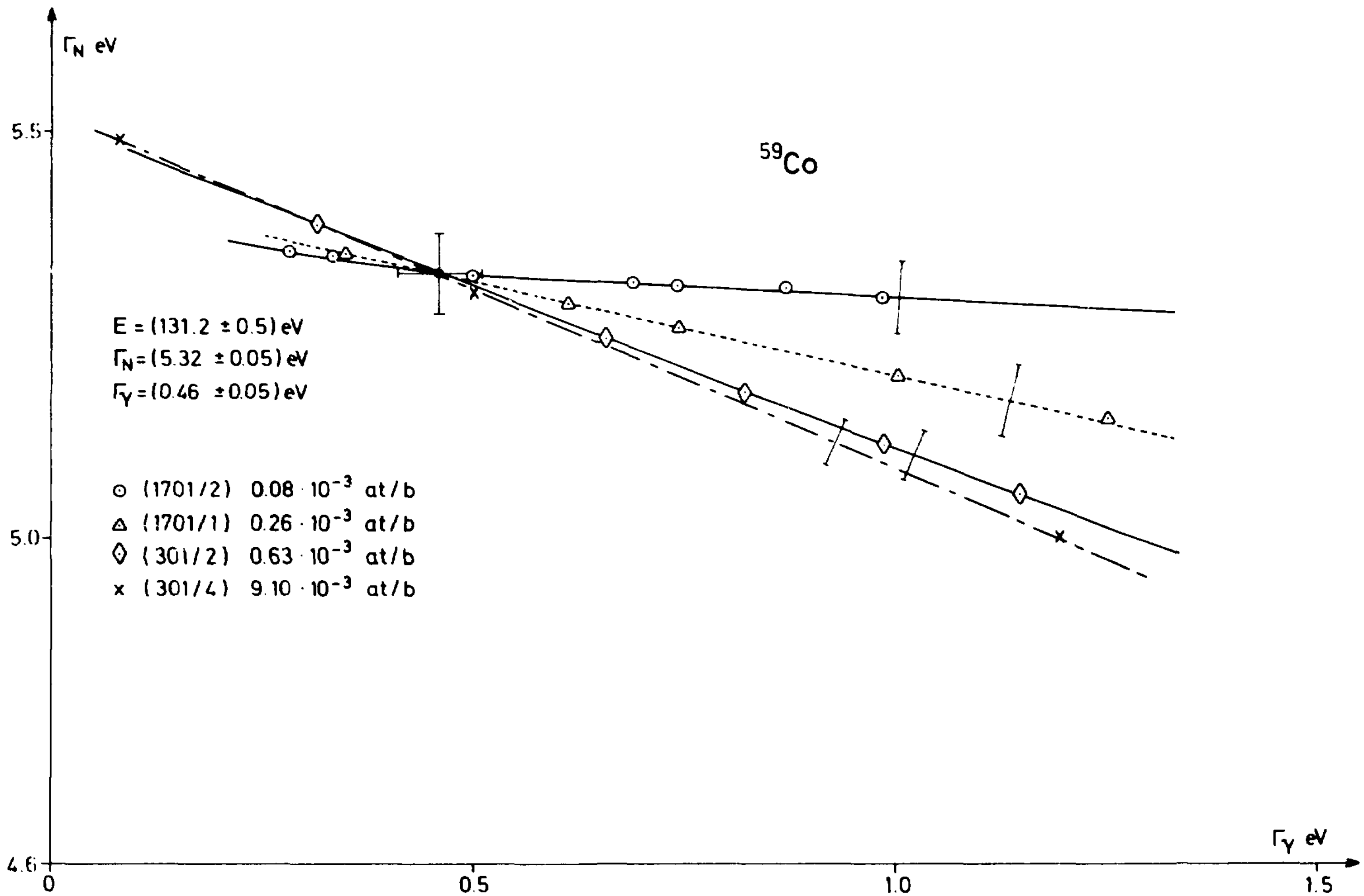
New measurements with a different sample thickness scheduled for 1973 will experimentally compensate the rather large ^{235}U and ^{238}U contributions in the sample by putting corresponding amounts of these parasitic isotopes into the "open beam" runs.

1.5. Fission- and Scattering Cross Section Measurements

J.P. Theobald*, J.A. Wartena, M. Merla in cooperation with L. Mewissen+, F. Poortmans+

1.5.1. Subthreshold Fission Cross Section of ^{236}U: Fission widths of ^{236}U neutron resonances have been determined in the energy range between 5.45 and 415 eV. They show small variations in this range and have an average of $\langle\Gamma_f\rangle = 0.35$ meV. Consequences of these results on fission barrier parameters of ^{237}U are discussed in a paper published in "Nuclear Physics" under the title "Fission Components in ^{236}U Neutron Resonances" [4].

+ SCK-CEN, Mol



Γ_N eV
5.5
5.0
4.6
^{59}Co
E = (131.2 ± 0.5) eV
Γ_N = (5.32 ± 0.05) eV
Γ_γ = (0.46 ± 0.05) eV
⊙ (1701/2) $0.08 \cdot 10^{-3}$ at/b
△ (1701/1) $0.26 \cdot 10^{-3}$ at/b
◊ (301/2) $0.63 \cdot 10^{-3}$ at/b
× (301/4) $9.10 \cdot 10^{-3}$ at/b
Γ_γ eV
0
0.5
1.0
1.5

Fig. 3

1.5.2. Subthreshold Fission Cross Section of ^{241}Am: The
(1325) experimental set up for this experiment has been completed. The sample preparation for the multi-spark-chamber-detector will be ready in February 73.

1.5.3. Fission Cross-Section Measurement on ^{235}U in the
1 - 500 keV Range of Neutron Energy: For this measure-
(966, ment a new flight path station at 30 m distance from the
968, neutron source has been equiped with copper for colli-
970, mation. The thin foil plastic scintillator fragment detector[+]
971, developed at the CBNM has turned out to be an useful and
972, efficient instrument for fission cross section measurements
973, on ^{235}U up to several 100 keV. In a preliminary experiment
974, the cross section fluctuations between 20 and 30 keV ob-
975, served previously by C. D. Bowman (Livermore) have been
976, confirmed. A serious problem remains the neutron flux
977, measurement in the keV - 500 keV range. Boron slab
979, detectors and BF_3 proportional counters have an energy
980, dependent efficiency ranging below 10 μs TOF equivalent
981, after the γ-flash of the neutron source. Therefore a
982, semiconductor detector for the (n, α) reactions on ^{10}B
983, or ^{6}Li has been installed. The first test results are
984) satisfactory. A flux measurement up to about 1 MeV does
not show the strong efficiency drifts after the γ-flash
like the other detectors. However, small drifts below
5% have still to be ruled out.

1.5.4. Fission Neutron Multiplicity Measurements: The experimental technique for this type of work has been discussed in a special report). The measurements on ^{239}Pu summarized in the progress report 1971 have been extended to ^{235}U. Neutron induced fission events emitting 2, 3, 4 or 5 neutrons have different contributions to fission yields recorded with double and triple neutron coincidence signals as a function of incoming neutron energy. This fact can be used to search for variations of neutron multiplicities in fission resonances, in particular in resonances of different channel spins.
In the case of ^{235}U no difference in fission neutron numbers for 3^- and 4^- levels has been detected above the experimental error of $\pm$ 1.5%. A paper has been submitted to the "Journal of Nuclear Energy" [7].

Table 4 gives for several resonances ratios R_i of resonance integrals conditioned by double and triple neutron coincidences. These ratios are given in units of $\langle R_i \rangle$.

+ Nucl. Instr. and Methods, 45, 1966, 233

Table 4

$E_{o\,i}$ eV	R_i / < R > A	R_i / < R > B	J
8.79	1.04 ± 0.05	1.01 ± 0.05	3
12.39	1.00 ± 0.02	1.00 ± 0.02	3
15.40	1.00 ± 0.03	0.99 ± 0.03	4
16.08	1.04 ± 0.03	1.01 ± 0.03	4
16.69	1.05 ± 0.03	1.04 ± 0.03	
18.07	0.99 ± 0.03	.94 ± 0.03	
19.31	0.99 ± 0.02	1.00 ± 0.02	4
21.08	1.03 ± 0.04	1.03 ± 0.04	4
22.94	1.00 ± 0.02	1.04 ± 0.02	4
23.42)	0.97 ± 0.03	.95 ± 0.03	4
23.65)			4
24.32	0.98 ± 0.03	.96 ± 0.03	3
25.20)	0.95 ± 0.04	1.00 ± 0.04	
25.50)			
26.48	0.99 ± 0.03	1.00 ± 0.03	
27.84	1.07 ± 0.04	1.01 ± 0.04	
30.6)	0.93 ± 0.04	.99 ± 0.04	
30.85)			4
32.07	0.98 ± 0.03	1.01 ± 0.03	4
33.53	0.98 ± 0.03	.98 ± 0.03	4
35.20	1.06 ± 0.03	1.05 ± 0.03	4
39.40	1.00 ± 0.03	1.00 ± 0.03	3

the columns A and B differ in the way the "background" has been subtracted.

J is the resonance channel spin.

1.5.5. Neutron Resonance Parameters of ^{242}Pu: We have performed elastic scattering and total cross section measurements on ^{242}Pu below 1300 eV. The results

(1319) of these measurements together with those of capture cross section measurements yielded the neutron widths Γ_n for 71 resonances and the total radiative widths Γ_γ for 25 resonances.

The s-wave strength function $S_o = 0.89 {}^{+0.1}_{-0.09} \times 10^{-4}$ and the average radiative width $\bar{\Gamma}_\gamma = [21.9 \pm 0.4$ (stat.) $\pm$ 1. (syst.)$]$. The resonance parameters were used to calculate the fission widths Γ_f from the fission cross section results of Los Alamos. From these fission widths, the height of the second fission barrier is deduced: E_B = 5.18 MeV.

Preliminary results have been published during the Budapest Conference on "Nuclear Structure Study with Neutrons" [6]. The final results are submitted for publication in "Nuclear Physics" [7].

1.5.6. Neutron Resonance Parameters of ^{236}U: In order to

(1024, 1025) obtain resonance parameters of ^{236}U the partial and total cross sections have been measured.
The scattering cross section was obtained on a 30 m flightpath station, using the ^3He gaseous scintillator detector system, with two different sample thicknesses: 2.15 10^{-4} at/b and 1.50 10^{-3} at/b. The resonance scattering areas have been deduced for more than 40 resonances. These areas also have been corrected for self screening and for absorption of the scattered neutrons.

Transmission has been measured at a 30 meter flight-path station, using a 1 cm diameter neutron beam and a ^3He gaseous scintillator as transmission detector. The sample thickness was 7.645 10^3 at/b. An area analysis of the transmission data was done using a modified version of the Atta-Harvey program.
The resonance parameters Γ_n and Γ_γ will be de-duced by combining the results from the different measurements including capture data
This part of the analysis is still in progress.

1.5.7. Scattering Cross Section of ^{240}Pu: After a renorma-lization of the radiative capture data of this isotope

(1231) the scattering cross section data have been re-evaluated.

The old discrepancies on Γ_n values obtained from total cross section work on one side and partial on the other have been eliminated. The final data have been published in the "Journal of Nuclear Energy" [8] (CS. 1.6.2.).

1.5.8. Neutron Resonance Parameters of ^{237}Np: A new series of total, scattering and capture cross section measurements on ^{237}Np below 300 eV are being prepared in order to resolve the discrepancies on the Γ_γ values between our older measurements and the Saclay results. Moreover, due to the improvements in energy resolution, the measurements can now be extended above 50 eV and eventually yield the spin for some more resonances.

(1112, 1114)

The transmission measurements on three different samples have been finished. We have used for these experiments a ^3He high pressure gaseous scintillator as transmission detector. The flightpath length was 30 meter and the beam diameter 11 mm. The ^{237}Np sample for the partial cross section measurements is in preparation.

1.5.9. Detector Development: A δ-electron detector has been constructed consisting of a δ-electron converter foil, a three lens electrostatic focussing electron optic and a channeltron plate. After tests this detector is designed for future fission cross section measurements using fragment detection methods.

1.5.10. Systematic Behaviour of Barrier Parameters: A systematic study of fission barrier parameters on the basis of near barrier fission and isomeric half-life data has been completed and a paper on this subject published [9].

1.6. Capture Measurements

G. Rohr, H. Weigmann*, J. Winter in cooperation with G. Vanpraet+

1.6.1. Resonance Parameters of ^{177}Hf: Resonance area analysis of neutron radiative capture and self indication ratio measurements on ^{177}Hf has been completed. Using the resonance spins as given by Coceva et al. ++ the following average resonance parameters are obtained:

(800, 801)

$S_o(J=3^-) = 2.7 \pm 0.6$ $\quad\quad$ $<\Gamma_\gamma>_{J=3^-} = 72. \pm 6.$

$S_o(J=4^-) = 1.8 \pm 0.4$ $\quad\quad$ $<\Gamma_\gamma>_{J=4^-} = 56. \pm 5.$

\+ Rijksuniversitair Centrum Antwerpen

++ C. Coceva, F. Corvi, P. Giacobbe and M. Stefanon Proc. of the Intern. Conf. on statistical Properties of Nuclei, Albany, 1971, s. 447

A small difference in average radiative widths may qualitatively be understood as being due to the fact that $J = 3^-$ resonances may decay by E1 transitions to 2^+ - and 4^+ members while 4^- resonances may decay only to 4^+ members of $K = 0^+$ rotational bands.

A preliminary report on these measurements has been presented at the Conference on Nuclear Structure Study with Neutrons, Budapest [10].
A more detailed paper is in preparation.

1.6.2. Resonance Parameters of ^{240}Pu: A remeasurement of the 20 eV resonance in ^{240}Pu by Moxon et al. [+++] has shown that the parameters assumed for this resonance
(1229, until recently have been vastly in error. As the para-
1230, meters of this resonance had been used for normali-
1231, zation of our capture cross section measurements on
1232) this isotope done in 1967 [°] a re-analysis of these measurements on the basis of the new parameters of the 20 eV-resonance has become necessary. The results of this re-analysis have been published [8]. The average radiative width obtained now for ^{240}Pu is $\langle \Gamma_\gamma \rangle = (32. \pm 2.)$ meV. (Cf. 1.5.7.).

1.6.3. Capture Cross Section of ^{242}Pu: Neutron radiative
(1319) capture measurements on a sample of 4.5 g of ^{242}Pu have been completed. Results of a resonance area analysis have been combined with corresponding results from transmission and scattering measurements to yield resonance parameters. Preliminary results have been presented at the Conf. on Nuclear Structure Study with Neutrons [6], and a final paper is in preparation [7].

1.6.4. Capture Cross Section of ^{236}U: Measurements of
(1036, neutron radiative capture on two samples of ^{236}U
1037, (one sample with 58 g of U_3O_8 enriched in ^{236}U to
1038, 89 %; another with 5.4 g of U_3O_8 enriched in ^{236}U
1039, to 99.7%) have been performed in the neutron energy
1040, range from 5 eV to 2000 eV. The data will be com-
1041, bined with elastic scattering and transmission data
1042) for resonance analysis.

1.6.5. Gamma Ray Spectra from Resonance Neutron Capture in ^{143}Nd: A paper describing this work has been published [11] [12].

+++ M.C. Moxon, J.E. Jolly and D.A.J. Endacott, report EANDC(UK)140 AL

°) H. Weigmann and H. Schmid, J. Nucl. Energy 22 (1968) 317.

1.6.6. Capture Cross Section Detectors: A pair of hydrogen free liquid scintillators (C_6F_6) has been used as a total energy detector for tests measurements with
(509, a natural Mo sample. Mo has been chosen because
510, it is well known that the capture gamma ray spectra
511, are quite different from resonance to resonance.
512, These two parameter experiments were in fact a
513) good test for the calculated pulse-height weighting function. The results obtained for the capture areas of 12 resonances below 1 keV have been compared with those obtained with the Moxon-Rae detector of CBNM on the same sample. The agreement is satisfactory within the statistical error ($< 5\%$).
In order to keep the bias imposed on the pulse heights, below 150 keV electron energy loss RCA photomultipliers have been ordered in replacement of the Philips XP1040 tubes, which have a relative much higher anode dark current, resulting in a too high noise level ($\approx$ 375 keV). The new PM's are recently arrived and will soon be put in operation.

1.6.7. The Ge(Li)-Detector-two-Parameter-System: The Ge(Li)-Detector-two-Parameter-System used for the measurements of γ-ray spectra of neutron capture resonances has been completely redesigned and is partly rebuild in order to improve the system.
In more details the following is done:
1. A new detector station has been built at flightpath no. 5 permitting measurements at distances which can be varried from 8 to 14 m from the target. Additionally a new and better collimator/system has been designed and will be constructed.

2. Analog Signalway: In order to eliminate the underswing of pulse signals after heavy overloading by the γ-flash of the linear accelerator a direct DC-coupled signal path from the Ge(Li-)-detector to the amplitude-to-digital converter (ADC) was realised. For doing this it was necessary to modify our two cryostats and to adapt them for an isolated (from ground) mounting of the Ge(Li)-crystals. The capacitor for injecting the calibration pulses was mounted in this cryostat. It is to be expected that the stability of the measuring chain will now be nearly independent of the ambient temperature.
For the interconnection of amplitude converter, time coder, analog windows, stabilisation generator etc. with the satellite computer (GA 18/30), logic networks are needed. Two different versions of these logic networks have been designed and realised. The more simple type operates satisfactorily. The more complex unit which also permit the gating of the γ-flash by a pulse compression system [+] is not yet ready.

[+] J. Winter, Proc. of the Symposium on Semiconductor Detectors for nuclear Radiation, Munich, 11-1[illegible] May, 1970, p. 188

3. The magnetic tape unit used for the storage and sorting of the digital signals delivered from the amplitude and time coders has been replaced by a satellite computer. After temporarily storaging and sorting the signals are transferred via the central computer to a magnetic disk unit. This system including the software was extensively tested. The test period is not yet finished.

1.6.8. Empirical Formula for Radiative Widths of Neutron Resonances: An activity has been started with the aim to fit experimental radiative widths of neutron resonances throughout the periodic table with a semi-empirical formula. Although up to now little succes has been obtained in general, it has turned out that the radiative widths of actinide isotopes, if treated separately, may be rather well approximated by the simple formula:

$$\Gamma_\gamma = 1.414 \cdot 10^{-5} \cdot U^{2.6} \cdot A^{2/3} \, [eV] \text{ with}$$

$$\begin{array}{lll} U = B - 1.46\,\Delta & (\text{even-even} & \\ U = B - \Delta & \text{for } (\text{odd A} & \text{compound nuclei} \\ U = B & (\text{odd-odd} & \end{array}$$

where B is the neutron binding energy in MeV and $\Delta = (1.68 - 0.0042A)$ MeV is the pairing energy gap. In table 5 radiative widths calculated with this formula are given for a number of isotopes and compared to experimental data where there are available. The average deviation of the calculated from the experimental values is 8.8%.

1.7. Standard Data (Linac and BR2)

A.J. Deruytter*, W. Becker+, G. Le Dez, R. Barthélémy, J. Van Gils * in cooperation with C. Wagemans++, G. Wegener-Penning+++

1.7.1. Precise 2200 m/s Fission Cross-Sections: The IAEA (Vienna) formed a consultants group to review the values for the 2200 m/s neutron constants for the four fissile nuclides in which we take part for the fission cross sections. For the consultants meeting (Vienna 15-17 November 1972) two papers [13] [14] were prepared, concerning the CBNM work. Both papers were extensively discussed at the Consultants

+ W. Becker, Euratom bursar

* J. Van Gils, Contract with SCK-CEN Mol

++ C. Wagemans, NFWO and SCK-CEN Mol

+++ G. Wegener-Penning, IWONL and SCK-CEN Mol

Table 5: Comparison of calculated and experimental radiative widths of actinide isotopes

Compound nucleus	Bind. energy (MeV)	s-wave radiative width (eV) calculated (10^{-3})	experimental (10^{-3})	Deviation (%)
RA-223	5.150	24.5		
RA-224	6.501	42.2		
RA-225	4.888	21.1		
RA-226	6.389	40.5		
RA-227	4.565	17.3		
RA-228	6.311	39.4		
AC-226	5.384	41.7		
AC-227	6.528	50.8		
AC-228	5.035	35.2		
TH-228	7.129	57.4		
TH-229	5.237	26.7		
TH-230	6.790	50.0		
TH-231	5.129	25.3	24.0	5.6
TH-232	6.434	42.9		
TH-233	4.787	20.7	21.5	3.2
TH-234	6.179	38.2		
PA-231	6.818	58.8		
PA-232	5.562	46.2	48.0	3.6
PA-233	6.517	52.0		
PA-234	5.197	38.9		
PA-235	6.120	43.7		
PA-236	4.850	32.7		
PA-237	5.920	40.0		
O-231	5.900	38.5		
O-232	7.270	62.3		
O-233	5.743	35.9		
O-234	6.841	52.3	54.0	2.9
O-235	5.306	28.6	25.0	14.7
O-236	6.545	46.2	45.0	2.8
O-237	5.125	26.1	24.0	8.8
O-238	6.144	38.5		
O-239	4.803	21.7	24.0	9.5
O-240	5.933	34.9		
NP-236	5.691	49.6		
NP-237	6.619	55.5		
NP-238	5.480	45.2	52.0	12.9
NP-239	6.227	46.9		
NP-240	5.170	39.1		
NP-241	5.970	41.8		
PU-237	5.859	38.8		
PU-238	6.998	57.3		
PU-239	5.656	35.3	38.0	6.8
PU-240	6.534	47.0	42.0	12.1
PU-241	5.241	28.5	30.5	6.5
PU-242	6.301	42.6	47.0	9.3
PU-243	5.037	25.5	22.0	16.3

Table 5: Comparison of calculated and experimental radiative widths of actinide isotopes (continued)

Compound nucleus	Bind. energy (MeV)	s-wave radiative width (eV) calculated (10^{-3})	experimental (10^{-3})	Deviation (%)
PU-244	6.018	37.4		
PU-245	4.720	21.2		
PU-246	5.940	36.3		
AM-242	5.528	46.8	40.0	17.0
AM-243	6.377	51.2		
AM-243	6.425	52.3		
AM-244	5.363	43.5		
AM-245	6.047	44.3		
AM-246	5.050	37.4		
CM-243	5.703	36.9		
CM-244	6.799	54.3		
CM-245	5.520	33.9	37.5	9.5
CM-246	6.451	46.8		
CM-247	5.157	28.0		
CM-248	6.210	42.1		
CM-249	4.713	21.6		
BK-248	5.560	48.2		
BK-249	6.220	49.0		
BK-250	4.969	36.2		
CF-249	5.593	35.9		
CF-250	6.619	51.7		
CF-251	5.114	27.9		
CF-252	6.166	42.2		
CF-253	4.793	23.2		
ES-252	5.400	45.2		
ES-253	6.220	49.9		
ES-254	5.088	38.9		
FM-253	5.540	35.6		
FM-254	6.511	50.3		
FM-255	5.185	29.6		

Meeting and will now be submitted to a Journal. Especially the higher σ_f^o -value for ^{235}U will influence the final set of 2200 m/s-parameters. Fission cross-section measurements from other laboratories, α-half-life values used for their determination as well as standard cross-sections used for the same purpose were reviewed. This work is not yet finalized but continues in 1973. It will be finalized and published by the IAEA for the ENDFB4-version. A preliminary summary of the Consultants Meeting was presented at the Second IAEA Standards Panel [15].

We further took part in an evaluation working group meeting at AERE Harwell to discuss the evaluation of ^{235}U, ^{238}U and ^{239}Pu cross-sections. The report of the meeting was edited by B. H. Patrick and M. G. Sowerby (AERE Harwell) as EANDC-90"L".

1.7.2. $^6Li(n,\alpha)$ Cross-Section in the Low Energy Region:
The time-of-flight transmission experiments with the BR2 slow chopper on the quartz-cells filled with He, D_2O, D_2O + $^6Li_2SO_4$, D_2O + $^{nat}Li_2SO_4$, were finalized. The analysis of the data was performed
(25) and all known corrections were applied. In this way the total cross-section of $^6Li_2SO_4$ and $^{nat}Li_2SO_4$ were calculated and represented by $\sigma_{tot} = a\tau + b$, where a gives the 1/v-component and b is a constant resulting from the scattering cross-section of Li and the total cross-sections of sulphur and of oxygen. However no agreement was found for the absorption cross-section of ^6Li from the natural composition and the highly enriched solution. The result from the highly enriched solution for the 2200 m/s-value was substantially different from the generally accepted one. For this reason we are planning new transmission experiments on ^6LiF-layers (completely different preparation technique) to try to resolve this discrepancy.

1.7.3. Normalization of σ_f (^{239}Pu) in the Resonance Region:
(1157, 1158, 1159, 1160, 1161, 1162, 1163, 1164, 1165, 1166, 1167, 1168, 1169) This work was published in Journal of Nuclear Energy [16].

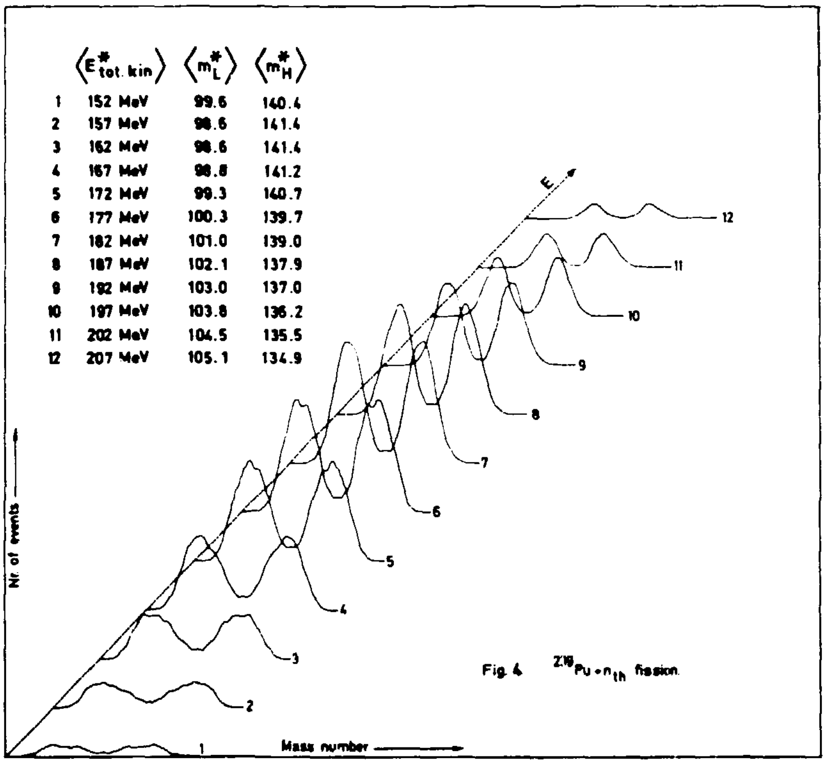
1.7.4. Normalization of σ_f (^{233}U) in the Resonance Region:
The measurements on ^{233}U in the low resonance region were continued. After the analysis of all sets of data still some doubt exists about the background in
(908, 909) the very low energy region. In order to have full confidence in the low energy end of the data a new low energy run is planned early 1973 to be able to publish the results and recommend resonance integrals for further normalization of σ_f.

1.7.5. Fission Cross Section of ^{235}U in the Range up to 100 keV: Measurements were performed at a 30 m flight path sta-
(968, 969, tion with 4 solid state detectors out of the neutron beam
970, 971, on each side of a back-to-back ^{235}U-^{10}B layer. Pulses
972, 973, in the solid state detectors were sufficiently fast and
974, 975, well-resolved. Data-taking is however time-consuming.
976, 977, No special difficulties were encountered due to the γ-
978, 979, flash with the solid state detectors outside the neutron
980, 981, beam. The neutron beam in front of the detection cham-
982, 983, 984) ber has however to be very well collimated, to reduce the background. The black resonance technique with several filters of different thicknesses is used.

1.7.6. Branching-Ratio in the α-Decay of ^{235}U: These results were used as part in a doctoral thesis presented at the University of Ghent by Mrs. Wegener. The results will now soon be published.

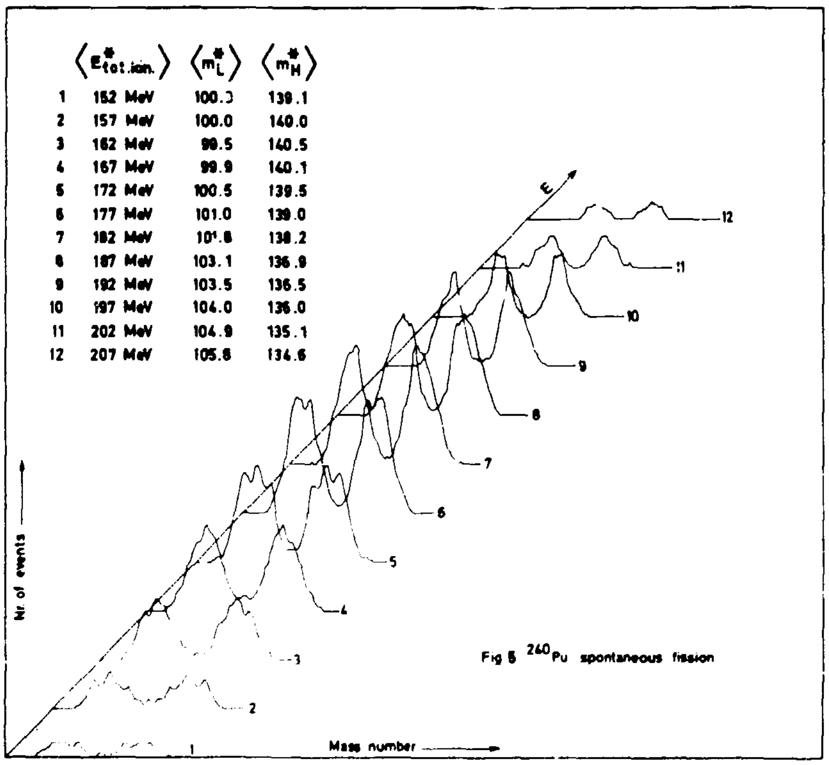
1.7.7. Comparison of the Thermal Neutron Induced Fission of ^{239}Pu and the Spontaneous Fission of ^{240}Pu: The ana- lysis of this work was finalized in 1972. The mass-
(1205, distribution of the fission fragments were calculated
1206, for groups of kinetic energies. The fine structure in
1207, these distributions is pronounced at low total kinetic
1208, energy, decreases and disappears at higher kinetic
1209) energies. The structure is more pronounced in spontaneous fission than in the induced fission but follows the same trend. The widths of the mass-distributions decrease when moving towards higher total fragment kinetic energies as does the amount of symmetric fission. Also the average light and heavy primary masses move closer together when moving towards higher total kinetic energies. Figures 4 and 5 show these primary mass distributions as a function of total kinetic energies of the fragments for ($^{239}Pu+n_{th}$) and spontaneous fission of ^{240}Pu respectively.

This work was used for partial fulfilment of a doctor degree at the University of Ghent by Mrs. Wegener[17]. The results and methods used will be published in 1973.



	$\langle E^*_{tot.kin} \rangle$	$\langle m^*_L \rangle$	$\langle m^*_H \rangle$
1	152 MeV	99.6	140.4
2	157 MeV	98.6	141.4
3	162 MeV	98.6	141.4
4	167 MeV	98.8	141.2
5	172 MeV	99.3	140.7
6	177 MeV	100.3	139.7
7	182 MeV	101.0	139.0
8	187 MeV	102.1	137.9
9	192 MeV	103.0	137.0
10	197 MeV	103.8	136.2
11	202 MeV	104.5	135.5
12	207 MeV	105.1	134.9

Fig. 4 $^{239}Pu + n_{th}$ fission



	$\langle E^*_{tot.ion.} \rangle$	$\langle m^*_L \rangle$	$\langle m^*_H \rangle$
1	152 MeV	100.3	139.1
2	157 MeV	100.0	140.0
3	162 MeV	98.5	140.5
4	167 MeV	99.9	140.1
5	172 MeV	100.5	139.5
6	177 MeV	101.0	139.0
7	182 MeV	101.8	138.2
8	187 MeV	103.1	136.9
9	192 MeV	103.5	136.5
10	197 MeV	104.0	136.0
11	202 MeV	104.9	135.1
12	207 MeV	105.8	134.6

Fig 5 ^{240}Pu spontaneous fission

1.7.8. Ratio of the Ternary-to-Binary Fission Cross Section Induced by Resonance Neutrons in ^{235}U: This work was presented at a European Physical Society Meeting on Fission Heavy Ions and High Energy Physics [18] (Aix-en-Provence) and published in detail in Nuclear Physics [19].

1.7.9. Ratio of the Ternary-to-Binary Fission Cross Section Induced by Resonance Neutrons in ^{239}Pu: At a 8 m flight path of the Linac two sets of data were obtained with different sets of surface-barrier detectors of the ratio of binary-to-ternary fission (Low Range Alpha Particle) in ^{239}Pu. The measurements were performed with a bias in the ternary α-spectrum of 15 MeV (aluminium foil + electronic bias). About 15 resonances could be analysed (intensity sufficient for the LRA detection). The covered range was from 0.5 eV to 50 eV. The broad 0^+ level at 15.5 eV has a significant larger value for T/B. Resonances with low and high T/B-values were grouped.

We also performed a T/B-ratio measurement in the low energy range from below thermal (a few meV) to 15 eV especially to measure through the first large resonance at 0.3 eV. Also the ternary α-particle spectrum with the 15 MeV bias-level was checked in detail at BR2. All data are being analysed at present.

1.7.10. Total Kinetic Energy of Fission Fragments in ^{235}U-Resonances: Several tests with detectors and 4π VYNS-foils were performed in the expectation of the completion of the two-parameter analysis system.

1.7.11. Collaboration with CEN Cadarache (I. Szabo, J. L. Leroy, J. P. Marquette): Systematic discrepancies between fission cross-sections of ^{235}U measured in the 1 MeV-
(979, range with a White chamber and a similar Cadarache
1169, chamber filled with a CBNM foil were brought to our
1170, attention. Because of the importance of this cross-sec-
1171, tion in the high energy range it was agreed to perform
1172, several comparative measurements with our equipment
1173, at BR2. The following comparisons with neutron energy-
1177) selection were performed May 1972:

1. U^{235} chambers White and Cadarache (CBNM foil)
2. Chamber White ^{235}U, chamber Cadarache ^{239}Pu (CBNM foil)
3. Chamber Cadarache ^{235}U, chamber Cadarache ^{239}Pu (CBNM foils)
4. Chamber Cadarache ^{235}U and a boron chamber (foils CBNM)

in order to compare with the ^{10}B 2200 m/s reference cross-section. Part 4. was withdrawn because of the high sensitivity of the 2π boron ionization chamber to γ-rays. The pulse height spectrum was distorted in such a way that no accurate measurements of the $^{10}B(n,\alpha)$-rate could be made. Nevertheless from parts 1., 2. and 3. it was possible to deduce the different ratios of the chamber counting-rates and σ_f^9/σ_f^5 at thermal energy. Details of the results as well as the influence of these measurements on the interpretation of published preliminary σ_f data in the high energy-range were presented by I. Szabo at the second IAEA Panel on Neutron Standard Reference Data (Vienna 20 to 24 November 1972). +

1.8. <u>CNEN-CBNM Cooperation for Nuclear Data Measurements</u>

C. Coceva, F. Corvi, P. Giacobbe, M. Stefanon

1.8.1. Spin of ^{235}U Neutron Resonances: Low-energy prompt gamma-ray spectra in the range 95-670 keV have been measured for forty-one ^{235}U neutron resonances selected by time-of-flight in the neutron energy range 1.5 - 58 eV. Discrimination against the natural gamma-activity of ^{235}U has been obtained by means of a coincidence tech-
(947, nique. The spectra show a very complicated structure
948) due to few capture and to many fission gamma rays.
The ratios of the intensities of the 160.3 keV and 642.4 keV capture gamma-rays have been used for spin assignments of fourteen resonances with small fission widths. Some conclusions are drawn about the spin dependence of average fission widths, anisotropy of fission fragments and symmetric fission yields in a paper accepted for publication in Nuclear Physics. [20] [21]

1.8.2. Statistical Properties of Level Spacings in ^{156}Gd+n: A 10 g sample of separated A-156 isotope of Gd was used for capture and transmission measurements on
(736) 50 m and 100 m flightpaths, for neutron energies up to 3100 eV. Scope of the measurements is to find a complete series of $J = 1/2^+$ levels with little contamination of p-wave resonances in order to study the statistical properties of the level spacings.

1.8.3. Spin of Low-Lying Bound States of ^{178}Hf: Measurements have been performed of the relative populations of the low-lying states of ^{178}Hf when neutrons are captured in different resonances of ^{177}Hf. The population ratios
(799, for J = 4 and J = 3 resonances were used to deduce
800) the spins of 24 low-lying states [22]. The results are
in agreement with those obtained by conversion electrons and gamma-gamma coincidence measurements, thus confirming the reliability of the method which had already been applied to ^{105}Pd + n. (Cf. 1.8.4.2.).

\+ Proceeding in press

1.8.4. High-Energy Gamma Rays from Capture in Neutron Resonances.

1. ^{115}In: A first account of the analysis of 31 gamma transitions in 30 resonances of ^{115}In was given at the Budapest Conference [23]. Values of the average E 1 and M 1 reduced widths are given. Estimates of spin and parity of the low-lying bound states of ^{116}In are obtained up to an excitation energy of 1.4 MeV.

2. ^{177}Hf: High-energy gamma rays from neutron
capture in single resonances of ^{177}Hf have been
(799, measured with a Ge-Li detector at a neutron flight
800) distance of 13 m. The gamma spectra of the resonances
up to about 200 eV have been determined in the range
5.2 - 7.6 MeV. (Cf. 1.8.3.).

1.8.5. Resonance Parameters of ^{91}Zr: Transmission mea-
surements have been performed on an enriched sample
of 20 g of ^{91}Zr, at a 100 m flightpath. Neutron ener-
(447) gies up to about 15 keV have been explored. The mea-
surements are to be completed.

1.9. <u>Van de Graaff Accelerator</u>

A. Crametz,* D. Bassetti, P. Falque, J. Leonard

1.9.1. During 1972, 2130 hours of 2775 working hours were utilized for neutron experiments, including 164 hours for a work executed in cooperation with PTB-Braunschweig and 703 hours for physicists of the CCR-Petten, the SCK-Mol, the IKO-Amsterdam, the PTB-Braunschweig and the Technische Hogeschool Eindhoven.
185 hours were needed to prepare, to condition and to calibrate the accelerator.
195 hours were utilized for tritium decontamination, (protection of the floor of the target hall with a plastic layer to prevent a further distribution of the contamination) and the installation of an automatic positionning system of three detectors around the 1 nanosecond extension.
265 hours were used for maintenance, namely to change twice the ion source and to repair the 1 and 200 Mc/sec oscillator.

1.9.2. A CBNM-built ion source was installed beginning of March and ran satisfactorily during 670 hours. The life-time of the second ion source (HVEC) was excellent and greater than 1200 hours. This result is certainly due to the good performance of the two turbo-molecular pumps for which a remote control system is ordered.

19.3. Up to now the regulation of the high voltage terminal was realized by the ion beam hitting the slits behind the analyzing magnet. A more precise voltage stabilizer unit was installed and variations in terminal voltage are electronically sensed and used through feedback loops to correct these voltage fluctuations by regulating the corona current.

19.4. Most of the integrated circuits of the project concerning the automatic adjustment of voltages of the accelerator were re-designed and rebuilt, and all the interconnections between plates were rewired, in order to have a better technical presentation. Due to last modifications and a long delivery time, the installation of the reducer gearboxes (HVEC) of the stepmotors will be only possible with the first opening of the tank next year.
The principle of this device consists in keeping the target current between an upper and lower limit. When level detectors indicate that one of these limits is passed, the system gives order, following a pre-selected sequence of the parameters to turn the potentiometer by the corresponding stepmotor successively 10 sec forwards, 20 sec backwards and 10 sec forwards. During each voltage exploration, the maximum of the target current is memorized and the potentiometer is finally positionned to that maximum. Then another parameter is selected for an exploration up to the moment the mean value of the target current is recovered.

1.10. Activation Measurements

H. Liskien*, A. Paulsen*, R. Widera

1.10.1. Precision Determination of Neutron Fluxes

1.10.1.1. Associated Particle Counting[+]: Flux density measurements for 250 keV neutrons from the T(p, n) source reaction were successfully carried out by counting the associated ^{3}He particles. The experimental technique and a comparison with proportional counter

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[+] Study done in collaboration with Dr. Cosack, PTB/Braunschw measurements was described in a publication [24]. Two different discrimination methods were applied to separate the ^{3}He particles

1. from the huge number of elastically scattered protons by means of an electro-static deflection field and
2. from spurious protons with degraded energy by time-of-flight discrimination.

The flux density of the associated 250 keV neutrons was simultaneously measured by means of a proton recoil proportional counter with pulse shape discrimination against gammas. Agreement within the estimated uncertainties was found between the two measuring techniques.

1.10.1.2. Pulse Shape Discrimination at Proton Recoil Proportional Counters: A gamma-neutron discrimination based on pulse rise time differences was used to eliminate the gamma-background from recoil spectra measured with proton recoil proportional counters. The major part of the background could be removed in this way. Spectra were taken for neutrons of 80, 60, 30 and 10 keV from the $^{7}Li(p,n)^{6}Be$ reaction. Different tests show that the gamma-neutron discrimination gives good quantitative results. A cooperative contribution from CBNM-Geel and PTB-Braunschweig was submitted to a conference [25].

1.10.2. Cross-Sections for Neutron Induced Reactions:

1.10.2.1. $^{63}Cu(n,\alpha)^{60}Co$: In view of the discrepancy between experimental fission neutron average cross-sections and the corresponding calculations from differential data for the reaction $^{63}Cu(n,\alpha)^{60}Co$ a check on the consistency of the involved differential data was performed [26] by irradiating a Cu-Al (95 - 5% in weight) alloy sample for 38 h in a flux of 2.10^{7} n/s. These neutrons had energies between 7.7 and 8.3 MeV where the fission neutron response functions of both (n,α) reactions on ^{63}Cu and ^{27}Al have their maximum. The neutrons were produced by bombarding a thin Be-Target with 2.3 MeV α-particles from the CBNM 3 MV Van de Graaff accelerator. Only the γ-intensities at 1332 keV (for ^{60}Co) and at 1368 keV (for ^{24}Na) observed with a Ge-Li detector were used for evaluation. In this way necessary corrections are minimized. The result of $\sigma_{Cu}/\sigma_{Al} = (0.472 \pm 0.017)$ at (8.00 ± 0.30) MeV is in good agreement with published differential data. This consistency of differential Al and Cu data in the peak of the response function and the fact that there is concurrence for integral and differential results in the case of $^{27}Al(n,\alpha)$ leads to the conclusion

(398, 399)

that there must be something wrong with the integral $^{63}Cu(n,\alpha)^{60}Co$ measurements. Further effort will therefore be spent on this subject.

1.10.2.2. $^{197}Au(n,\gamma)^{198}Au$: Activation measurements between
(847, 848, 0.1 and 1 MeV neutron energy were prepared with
849, 850, special effort to reduce the experimental uncertain-
851) ties and necessary corrections.

1.10.2.3. (n, 2n) Excitation Functions: The measurements on ^{66}Zn, ^{115}In and ^{197}Au were finished, but the evaluation of the results was delayed due to a complete recalibration of
(843) the Ge-Li gamma detection system.

1.10.3. Fission Data

^{252}Cf Spontaneous Fission Neutron Spectrum: Several tests showed that a ^{252}Cf source sandwiched between
(1399, two thin plastic scintillator foils would be best suited
1400) for a time-of-flight spectrum measurement using the fission fragments for the timing. The spectrum measurement is in progress.

1.10.4. Cross Section Compilations and Evaluations

1.10.4.1. Neutron Induced Threshold Reactions: A cross check between our file and the CCDN experimental data file performed during the past two years has lead to the completion of the CCDN file with respect to data covered by the EUR 119.e compilation. This means at the same time that these data are generally available to all interested users due to the four centre cooperation (NNCSC, CCDN, NDS, CJD) in the neutron data field. Therefore it has been decided to stop the issue of further supplements to the EUR 119.e compilation, while the CCDN has agreed to perform a pilot study aiming in a CCDN publication which could be regarded as a successor for EUR 119.e.

1.10.4.2. Neutron Standard Cross-Sections: Using the reciprocity theorem for nuclear reactions differential cross-sections
(11, 12, for the reactions $^{3}He(n,p)T$ (see Figure 6) and $^{3}He(n,d)D$
13, 14, were deduced from the corresponding $T(p,n)^{3}He$ and
15, 16, $D(d,n)^{3}He$ data. At the same time new best curves for
17) the total $^{3}He(n,p)T$ and $^{3}He(n,d)D$ cross-sections are resulting from this conversion. The data were distributed as a report EANDC(E) - 153"L" and a revised version will be published [27].

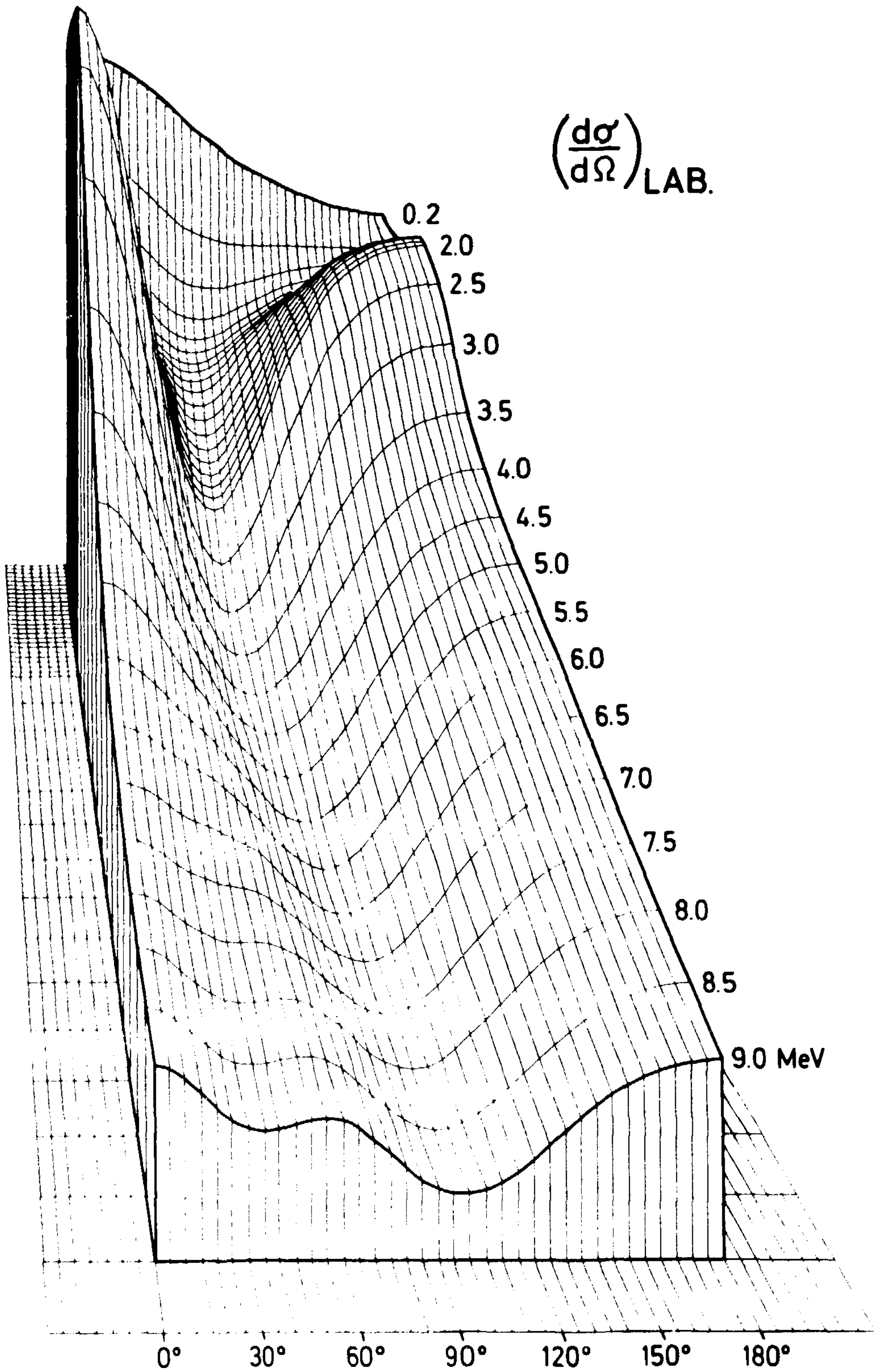

Fig 6 The differential LAB cross-sections for the reaction $^3He(n,p)T$ as deduced from the inverse reaction

1.10.4.3. Neutron Producing Reactions: Evaluations of cross-sections for the $T(d,n)^4He$ and $T(p,n)^3He$ reactions were carried out and distributed as EANDC reports[28) 29)] Due to the receipt of new data a reevaluation for the three reactions $T(p,n)^3He$, $D(d,n)^3He$ and $T(d,n)^4He$ was started. All data will be published in Nuclear Data.

1.11. Fast Neutron Time-of-Flight Measurements

M. M. Islam[+], H.-H. Knitter[*], M. Mailly, R. Vogt

1.11.1. Measurements on ^{235}U: Neutron Scattering Cross Sections, Energies and Angular Distributions of Fission Neutrons: The evaluation of the time-of-flight spectra of neutrons emitted from ^{235}U, when bombarded with monoenergetic neutrons of 1.50, 1.90, 2.30, 4.00, 4.50, 5.00 and 5.50 MeV energy, measured at 20 different angles between 20 and 150 degrees with respect to the direction of the incident neutrons was completed. Neutron elastic scattering cross section angular distributions, integrated elastic scattering cross sections, angular distributions of fission neutrons, average fission neutron energies under the assumption of a Maxwellian energy distribution and inelastic neutron scattering cross sections due to inelastic neutron energy groups of 200 keV width were determined. The elastic neutron scattering angular distribution did not show good agreement with cross sections calculated by Agee and Rosen using a spherical optical model with average parameters. It was, however, already observed in the case of ^{239}Pu and ^{238}U, that a spherical optical model does not give a good representation of the experimental data. Rather an optical model which takes into account the deformation of the nucleus gives a better agreement, both, for the shape of the angular distributions and for the magnitude of the integrated elastic cross sections of ^{239}Pu. The same might be true also for ^{235}U. The energy distribution of the inelastically scattered neutrons could be fairly well represented by an expression derived from the Fermi gas model of the nucleus. A part of these results was communicated at a Conference[30)] and a final paper is published[31)].

(952, 953, 958, 959, 960, 961, 962, 963, 1006, 1007)

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1.11.2. Measurements of Fission Neutron Energy Spectra of ^{235}U at E_n 0.40 MeV: The knowledge of the fission neutron energy spectrum is important for neutronic calculations of reactors. Moreover, the ^{235}U spectrum is regarded, besides the ^{252}Cf-fission neutron spectrum, as a "standard neutron
(1005, spectrum" and therefore it should be known as good
1006) as possible. Experiments were performed using samples of two different dimensions in order to control the correction calculations due to effects emanating from finite size of the samples. The corrected experimental data were fitted, using a Maxwellian and a Watt form for the neutron energy distribution. The numerical values for the coefficients of these distributions as obtained from the best fit and the average energy values $\bar{E}$ resulting from these coefficients are given in table 6.

Table 6

Watt Distribution			Maxwellian Distribution	
A(MeV^{-1})	B(MeV^{-1})	$\bar{E}_w$(MeV)	T(MeV)	$\bar{E}_m$(MeV)
0.990±0.027	2.132±0.274	2.06±0.05	1.375±0.034	2.06±0.05

Although the $\bar{E}$-values of the two fits are the same, the chi-square was 20% smaller for the Watt distribution. The present data were compared with integral measurements of the fission neutron spectrum in a contribution to a Conference [32], and a detailed paper about this subject is in press [33].

1.11.3. ^{252}Cf-Spontaneous Fission Neutron Spectrum: At the "Consultants Meeting on Prompt Fission Neutron Spectra" of the IAEA held in Vienna, August 1971 it was recommended to measure the shape of the fission neutron energy spectrum of ^{252}Cf from a few keV up to at least 10 MeV. The quality of the results
(1399, should be such as to make it a "standard" fission
1400) neutron spectrum. The aim of the present effort is to contribute to the establishment of such a standard.

An experiment was set up which consists of a fission fragment detector and a calibrated neutron detector. The fission fragment detector consisted of a ^{252}Cf-compound encapsulated between two plastic scintillation foils mounted on an AVP 56/03 photomultiplier which allowed to extract a fast timing signal. The neutron detector consisted of a liquid scintillator mounted on a RCA-8850 photomultiplier. The neutron detection threshold of this detector is at 50 keV. The relative detector efficiency was measured from 50 keV up to 8.5 MeV and from 12.4 up to 19.5 MeV using the n-p scattering and several angular distributions of neutron producing reactions. Between 8.5 and 12.4 MeV the detector efficiency was interpolated. Also this detector allowed to extract a fast timing signal. The detectors were separated by a distance of 162.3 cm from each other. The two timing signals were used to record a time-of-flight spectrum. Such a preliminary spectrum is shown in Fig. 7.

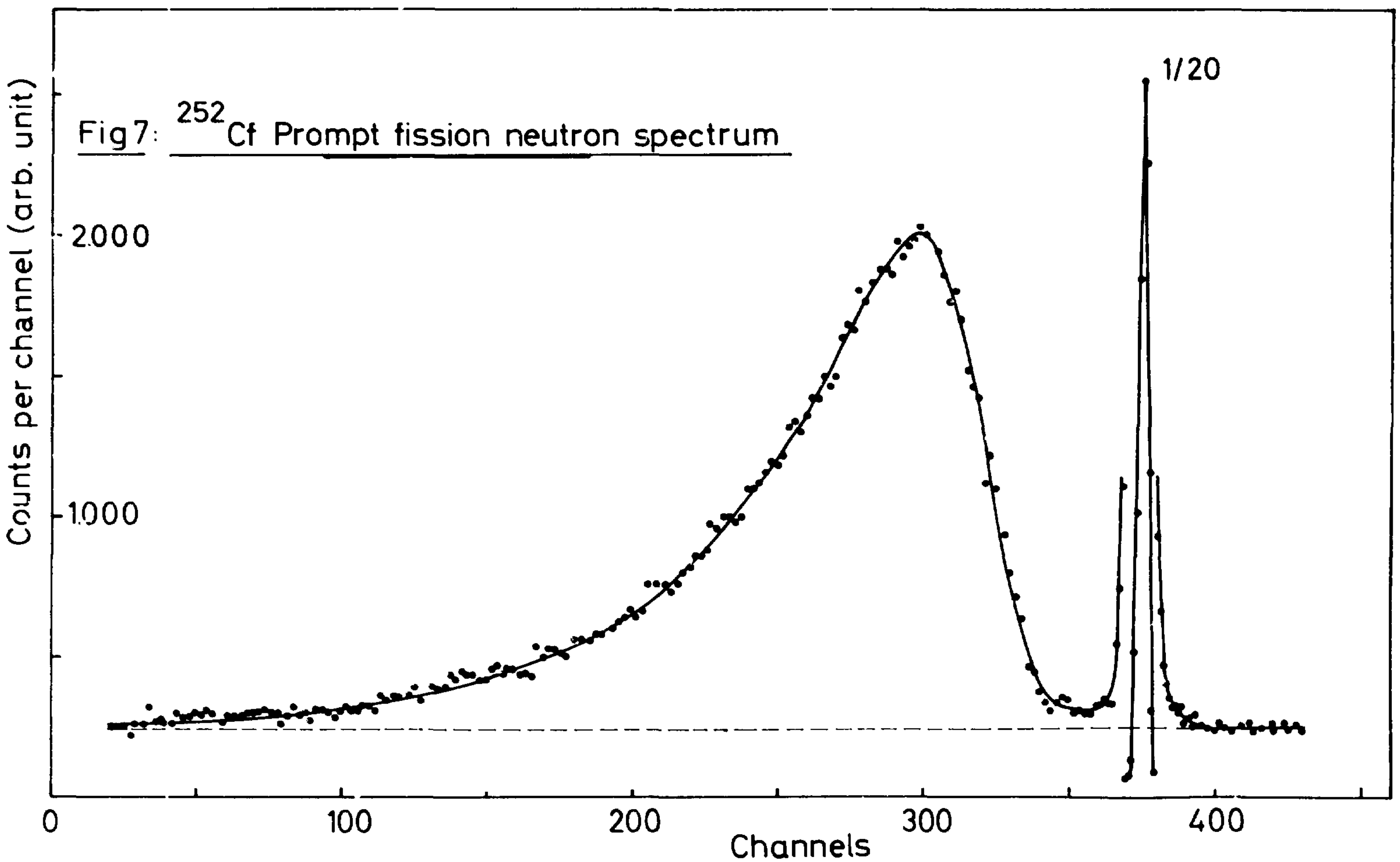

Fig 7: ^{252}Cf Prompt fission neutron spectrum

2. NUCLEAR METROLOGY

2.1. Mass Spectrometry: Constants

G.H. Debus*, A. Loopmans, W. Oldenhof (part time)

2.1.1. Ratio determinations have been performed on different enriched isotopes of Eu, Pd, Ho, Hf, Yb, U and Pu. Some measurements have been performed on ^{241}Pu for the determination of the half life.

2.1.2. The performance of the M.S. 5 mass spectrometer has been improved by changing some components by new ones, e.g. an electronmultiplier, an amplifier, two high voltage supplies, two filament power supplies and a baffle.

After these improvements a systematic study was made to define the minimum sample amount needed for an isotopic analysis. The integrated current obtained from Plutonium samples of 1µg, 0.1µg and 0.01µg indicates that the overall transmission (ions collected/atoms on filament) is only 10^{-4}. A 0.01µg Pu sample with an isotope ratio of 40 has been measured with an accuracy of 1%, and 1µg Pu samples has been measured with a precision of 0.1%. The precision of these measurements is mainly defined by the statistics of the ions impinging on the collector.

2.1.3. In the field of safeguards extensive collaboration has been given:

1. as a chairman of the first meeting for the organization of the international intercomparison test IDA-72 a general lay-out of the experiment has been presented
2. an IAEA symposium on safeguards studies has been attended
3. a theoretical study on the optimal conditions for inventory determinations in reprocessing plants has been drafted [34)]
4. as an invited expert of the IAEA the specifications of a mass spectrometer (to be used for safeguards) have been given

2.2. Mass Spectrometry of Solids
P. De Bièvre ×, G. Ehrenfreund, M. Gallet, W. Oldenhof (part time), M. D'Angelantonio +

2.2.1. Reference Isotope Analyses: The laboratory continued to certify high accuracy isotopic compositions and assays by isotope dilution for e.g.

- nuclear fuel certification prior to delivery to nuclear reactors
- reception verification of USA enriched uranium delivered to the Community
- the Community's Safeguards System
- settlement of disputes between nuclear companies, organizations, etc. in the Community
- burn up determinations, irradiation experiments and neutron measurements

249 registered Certificates have been issued.

2.2.2. Measurement support for the Community's Safeguards system (Luxembourg): The 7 years old measuring support to the Community's Safeguards Authority (Contrôle de Sécurité) has been continued. 50 registered Certificates have been delivered. A new procedure has been developed and tested to assay accurately reprocessing plant input and output solutions. It is now possible to certify concentration and isotopic composition of fissile elements at place and time of sample-taking in the reprocessing plant rather than at time and place of analysis as usual. With regard to previous measurements, the procedure requires much less sample, is more accurate, offers no radiation risks, is much cheaper, does not require close geographical location of reprocessing plant and CBNM and allows to detect accidental or other errors from the moment of sample-taking up to the certification of the final results. The procedure is now operational.

+ fellowship, Commission of the European Communities

2.2.3. Safeguards Analytical Laboratory Evaluation (SALE) Program: On the basis of the results submitted to the USAEC Umpire Qualification Program, the laboratory has been asked by the USAEC SALE Program to certify referee values for the isotopic composition and assay by isotope dilution of a variety of Uranium and Plutonium materials on a cost paying basis. About 12 different materials are involved. This Program intends to distribute on a regular basis samples of these materials to nuclear laboratories interested in submitting themselves to periodic analytical tests and evaluation of their performance. A first series of certified values has already been achieved and mailed (Uranylnitrate).

Another request has been received and accepted: UF_6 isotopic definition in the framework of the USAEC UF_6 General Analytical Evaluation Program (purpose: same as above).

Certification functions in the above Programs are performed to provide the necessary confidence basis for the measurement support to the Community's Safeguards system in Luxembourg.

2.2.4. CBNM Uranium and Plutonium T1/2 Programs: The isotopic composition of base material, layers and solutions used in the ^{233}U determination have been defined. The accuracy of the concentration determination of Uranium solutions has been improved to 0.15% using two different mass spectrometers and careful calibration procedures.

Same performance is available for half-life determination of any Uranium and Plutonium nuclide.

2.2.5. Isotopic definition of samples for nuclear measurements, prepared at CBNM

Samples	Applicant	Program
^{235}U	CEN Bordeaux	--
$^{235}UF_4$	CBNM	international fission foil exchange program
^{235}U	CEN Bordeaux	--
^{233}U	CBNM	^{233}U T1/2
Li	Max Planck Institut Mainz	absorption measurements
Li	CBNM	total cross section measurements
^{240}Pu	KFK Karlsruhe	fission cross section
^{235}U	KFK Karlsruhe	" " "
^{238}U	" "	" " "
Al/Pu	PTB Braunschweig	fission detectors
^{233}U	Ispra	spike solution
^{242}Pu	Ispra	spike solution
U	PTB Braunschweig	burn-up measurements
^{233}U	CEN Fontenay	fission cross section
U	PTB Braunschweig	burn-up measurements
^{233}U	CBNM	normalization fission cross section
^{235}U	CEN Bordeaux	--
^{6}Li	CBNM	total cross section measurements
^{236}U	CBNM	cross section measurements
^{242}Pu	CBNM	capture, fission, scattering cross sections
Li	CBNM	standard absorption cross section
^{6}Li	CBNM	standard absorption cross section

2.2.6 Mass spectrometric quantitative definition by isotope dilution

Samples	Applicant	Program
1 mg U/g solution	CBNM	T1/2 ^{233}U
285µg U/g "	RCN	Umpire intervention
67µg U/g "	RCN	" "
200mg U/g "	European Commission	Safeguards+Umpire intervention
1 mg Pu/g "	" "	Safeguards+Umpire intervention
30µg/g ^{233}U "	SCK-Mol	spike for burn-up meas.
1 mg/g ^{233}U "	CBNM/GfK Karlsruhe	spike for IDA-72 Program
30µg ^{242}Pu/g "	CBNM/GfK Karlsruhe	spike for IDA-72 Program
50µg ^{240}Pu/g "	SCK-Mol	spike for burn-up meas.
3µg ^{142}Nd/g "	" "	" " " "
20µg ^{242}Pu/g "	CCR Ispra	spike solution

2.2.7. Isotopic Standards and Reference Materials:

2.2.7.1. Plutonium

All necessary equipment is ready since 18 months to establish secondary Pu Isotopic Standards with high ^{240}Pu content. The CBNM committed itself towards the CCR and Safeguards Luxembourg to provide these.

2.2.7.2. Uranium

Uranium samples with high ^{236}U content are available for isotopic certification and would meet a number of requests.

2.2.7.3. Lithium

Very limited work could be done, but it was possible to eliminate the isotopic composition of samples as a possible cause of 5% discrepancy in high accuracy standard cross-section measurements on natural and ^{6}Li enriched samples.

2.2.8. Miscellaneous :

- Highly stable magnet power supplies have been built at our request and 4 units delivered by the electronics group.
- Practical help (suggestions, laboratory assistance, well known samples) was given to the IAEA mass spectrometer laboratory at Seibersdorf (20 Dec. 1972).
- The proposal for a noble metals Standard Reference Program, made before an international panel in Nov. 1971 and agreed upon, was started to be worked out at a first meeting in Brussels with industries and laboratories concerned.

Invited papers were given in Heidelberg[35] and in Ispra[36].
An invited seminar was held at the Badische Anilin und Sodafabrik, Ludwigshafen (Rhein) on "Atomgewichte und Isotopenhäufigkeit der natürlichen Elemente und ihre zukünftige Bedeutung für den analytischen Chemiker" (Ludwigshafen, 20 November 1972).

2.3. Mass Spectrometry of Gases

T. Babeliowsky*, E. Bouwmeester, W. De Bolle

2.3.1. Routine Gas Analysis : The number of sample and calibration runs was 290 : 231 on request of third organizations, 7 on demand of other groups of the CBNM and 52 for our own programs.

2.3.2. D_2O Analysis : Three calibration measurements have been performed on our stock of heavy water :

D_2O content : 99.781 mole %
99.784 "
99.783 "

The mean value of all calibrations up to now did not change: 99.7828±0.0010 mole %.

Three water samples have been measured to correlate density and isotopic composition:

D_2O content	density d(25°C), g/cm^3
99.9535 ±0.0015	1.104422_5
99.7519 ±0.0011	1.104200_2
99.7955 ±0.0010	1.104257_0

The extrapolated density of 100% D_2O with normal air oxygen composition is 1.104474 g/cm^3. This value is somewhat larger than cited in literature.
Some additional points are being measured on highly purified waters. The three stage purification with addition of $KMnO_4$ and BaO to oxidize volatile organic impurities in the first stages and passing the water vapour over hot CuO was improved to give a contamination of 0.002 mole % on a 50 ml sample.

Influence of addition of deuterium, fumaric acid and PtO_2 catalyst was reduced a d proved to be of no detectable influence on D_2O content results

The D_2O program is finished by a report on method and experimental results 37).

2.3.3. UF_6-Analysis: In the last quarter of the year a UF_6 mass spectrometer Varian MAT 511 was installed. The instrument will be operated by a General Automation SPC 18 Processor. Interfacing apparatus is now almost finished. Software was prepared.

2.3.4. Other Subject:

- A demand was accepted from NPL to analyse pure natural Argon for its isotopic composition. The NPL Argon arrived but ^{36}Ar ordered in USA was not yet received.

By removing some baffles in the CH5 analyser tube, it proved possible to do ratio recording of the $^{36}Ar/^{40}Ar$ isotope ratios.
The reproducibility of H_2 determination in Ti metal, determined by the isotope dilution method was found to be 8-10ppm for a H_2 content of 60 ppm.
Some computer programs of general use were written or adapted and improved : card read function and minor changes in GUS (general utility and service program), reusable card loader, core load builder to be executed in GA 18/30 machines, core load builder for GA 18/30 core loads to be executed in IBM 1800, program for interactive and/or programmable desk simulating calculations, program to fit data with functions containing more than one independent variable, program to determine gas sample composition from spectrum and calibration runs on a mass spectrometer (25 unknowns, 40 equations). Several of these programs were put at the disposal of other groups.

2.4. Neutron Dosimetry

B. J. Mijnheer

2.4.1. Calibration of Radioactive Neutron Sources : In close collaboration with van der Eijk (2.14) one RaBe and two ^{252}Cf sources were calibrated by means of the CBNM $MnSO_4$-bath system. The source strength of the RaBe source will be compared with older measurements carried out at CBNM. by means of gold foils. The Cf-sources have also been calibrated at the Institute for Nuclear Physics Research, IKO Amsterdam, using the same method. The relative activities of the sources as well as the absolute source strength determined in both laboratories, will be used to investigate possible systematic errors in the $MnSO_4$-method.

One of the ^{252}Cf-sources (about 0.4 μg) had formerly already been calibrated at IKO, and the new measurements in combination with the older ones, have been used to determine the half-life of ^{252}Cf 39). The other Cf-source has been constructed at CBNM , and will among other things be used for the calibration of neutron dosimeters.

2.4.2. The Construction of a Personnel Neutron Dosimeter using Track Registration: At CBNM, ^{252}Cf-samples are now handled in water shielded glove boxes. In order to determine the neutron dose on the hands of the operators, a dosimeter consisting of thin sheet of thorium in contact with a plastic foil, has been constructed. The number of holes in the plastic, which originate from the fission induced by fast neutrons in the thorium, is proportional to the neutron dose. The holes can be counted, after etching in a NaOH solution, by an electrical sparking method as described in the literature. Two electrical track counters (ETC) were built and tested. One is now in use at the Health Physics Service for the counting of personnel neutron dosimeters. A second one has been designed for improving some of the properties of the ETC like the reproducibility and the maximum number of countable tracks, by varying the pressure and type of gas between the electrodes. In order to determine the sensitivity of the system before the californium-252 arrived at CBNM, the dosimeter was tested at the Institute for Transuranium Research in Karlsruhe, using a strong Cf-source. Also the angular response and the influence of the presence of the hands on the sensitivity were determined.

The influence of the walls of the glove box on the sensitivity was tested by comparing the efficiency of the dosimeter in a scatter-free surrounding with that obtained inside the glove box. For the conversion of the measured neutron fluence into neutron dose, knowledge of the spectrum of neutrons inside the box is necessary. This has been determined by means of indium - and gold-spheres surrounded by a ^{10}B-sphere. The thermal neutron flux density has been determined by means of gold foils, and gave only a small contribution to the neutron dose.

The angular dependence of the efficiency was also measured with mono-energetic neutrons at different energies, with the CBNM Van de Graaff accelerator.The angular response of the relatively thick thorium layer was compared with that measured for dosimeters with very thin layers of ^{238}U, ^{235}U and ^{237}Np, at the same neutron energies.

2.5. Radionuclides, Standardization

W. Bambynek*, G. Bortels, D. Reher

2.5.1. Fluorescence Yields : Measurements of the K-shell fluorescence yield of Sr after electron capture decay of ^{88}Y, which were performed in 1971, have been evaluated. The final value is $\omega_K(Sr) = 0.699 \pm 0.013$. A publication is in preparation.

A review article on "X-Ray Fluorescence Yields, Auger, and Coster-Kronig Transition Probabilities" written in collaboration with American and German scientists has been published[38]. The present status of the field of fluorescence yields, radiationless and radiative transition probabilities is summarized. Tables of experimental and theoretical results are included, and tables of "best values" of important quantities are presented.

An invited paper on "K-Shell Fluorescence Yields" has been presented in Atlanta, Georgia, April 17-21, 1972 [39]. A review is given of our knowledge on K-shell fluorescence yields. The most important experimental methods of measurements are summarized and discussed. A set of most reliable ω_K values is evaluated and compared with recent theoretical predictions .

2.5.2. Proportional Counters : An invited lecture "On Selected Problems in the Field of Proportional Counters" has been given in Herceg Novi, Yugoslavia, August 21-September 1, 1972 [40]. The following topics has been discussed : gas amplification, space charge, recombination, ion and electron transit times, efficiencies of counters operated at high pressure.

2.5.3. Evaluation of Radionuclides Decay Data : A panel (February 8, 1972) of the Working Group on Evaluation of Radionuclides Decay Data took place at Geel. The group consisting of several physics from LMRI (Saclay) IKO (Amsterdam), PTB (Braunschweig) and CBNM (Geel) has established recommendations for the evaluation of decay data. Preprints are available. The evaluation of ^{58}Co has been brought to a final form.

2.5.4. Gamma Spectrometer : Calibrations of the following nuclides have been performed : ^{7}Be, ^{51}Cr, ^{56}Mn, ^{57}Co, ^{60}Co, ^{88}Y, ^{95}Nb, ^{144}Ce. Improvements of the measuring technique (excentricity of the source, cut-off energy, dead time) resulted in a higher accuracy.
A computerized listing of references concerning gamma ray spectroscopy has been prepared. It contains approximately 450 references.

2.5.5. Solid State Sandwich Detector : First plans for the construction of a solid state sandwich detector have been made. Such a system contains a matched pair of Si(Li) or Ge(Li) detectors with a source between them. A solid angle of 4π should be approximated as far as possible. The possibility to change the detector distances very accurately inside the evacuated cryostat should be provided. Such a system will allow to measure electrons, X or γ rays, in singles and coincidence mode.

2.5.6. Satellite Computer : The interfaces between the GA 18/30 and the peripheral input-output equipment have been obtained. The unit has been used off-line for elementary calculations of a large number of liquid scintillation spectra.

2.5.7. Calculation of Solid Angles : The solid angle of a coaxial circular disc subtended by a diaphragm is usually calculated by a series of approximations. At medium geometries the involved errors become too large. It is found that for homogeneous sources the solid angle can be approximated with much higher accuracy by the mean value of the solid angles of two point sources in the plane of the disc, one situated in the center, the other on the periphery of the disc.

2.6. Radionuclides, Constants A

H.H. Hansen*, D. Mouchel, K. Parthasaradhi +

The study on the photon spectrum emitted by β^- -decaying isctopes has been continued :

a) the measurements on ^{147}Pm have been accomplished and described in a paper prepared for presentation at the Atlanta Conference in April 1972 [41]. The final results are : a weak γ-transition in ^{147}Sm with an energy of $E_\gamma = (121.10 \pm 0.14)$ keV and an intensity of $p_\gamma = (3.0 \pm 0.3) \cdot 10^{-5}$ γ-rays per decay; the feeding of the 1. excited level at 121 keV in ^{147}Sm of $p_\beta(exc.) = (6.0 \pm 0.6) \cdot 10^{-5}$ of all decays; the probability for internal K-shell ionization of $p_{II} = (8.1 \pm 0.9) \cdot 10^{-5}$ per β^- -particle ;

+ EURATOM Research Fellow

b) the measurements on ^{99}Tc using seven sources of different activities have been performed with Si(Li) detectors from TMC as well as Q&S. A preliminary value for the internal K-shell ionization probability of $p_{II}=(4.6\pm0.4)\cdot 10^{-4}$ per β^--particle agrees very well with results from earlier investigations;

c) measurements of $^{90}Sr/^{90}Y$ isotopes with six quantitatively prepared sources of different strength have been executed. The necessary calculations are under performance. Experiments with ^{63}Ni have just been started.

As low energy electron detector a channeltron has been mounted in the β^--spectrometer. The detection efficiency has been determined in the range of $50eV \leq E_e \leq 6keV$ using an electron gun and for $20keV \leq E_e \leq 60keV$ with an ^{241}Am source of known decay rate. Also these experiments and their results have been prepared for presentation at the Atlanta Conference [42]. - Using the channeltron as detector the spectrum of low energy electrons emitted by ^{7}Be (specially prepared sources from the isotope separator of NPL, Teddington) has been measured with the magnetic β-spectrometer ($E_e \leq 200eV$) and the retarding field spectrometer ($E_e \leq 100eV$). Results from both methods indicate that most of the electrons emitted have energies below 60eV.

Extensive preparation of the ^{115m}In experiment for the determination of the most interesting decay properties and first tests were made. Special treatment of irradiated Cd and preparation of the original ^{115g}Cd material has been discussed and agreed during a visit at TCR, Amersham.

The planning, development, construction and set-up of a Ge(Li) γ-ray spectrometer has been settled An intense study of the performance problems has been made with detailed discussion of cooling, evacuation, shielding, mounting and security control. First tests with the total device using γ-rays of ^{137}Cs and ^{60}Co indicate that the specifications quoted by the supplier of the Ge(Li) probe can be reached.

Calculations for a $^{95}Zr/^{95}Nb$ standardization requested by the SCK/CEN, Mol, have been performed. Measurements made with Ge(Li)- , NaI(Tl)- and $4\pi\beta$-γ-coincidence devices were used in order to obtain information on the age of the radioactive solution, its activity, impurities and on some decay properties. A report on the whole subject has been written [43].

Planning for the experimental part of a study on photo-electric cross section has been started. The selection of suitable γ-emitters and the choice of appropriate absorber materials have been accomplished. Some training and study on weighing and accurate source preparation has been performed.

2. 7. Radionuclides, Constants B

E. Celen, B. Denecke, E. De Roost, M. Mutterer [+], A. Spernol [x]

About 500 calibrations have been performed for others, especially by $4\pi\beta$-γ coincidence and α-low-geometry counting and GeLi and Si surface barrier spectrometry. Special attention has been given to $^{95}Zr/^{95}Nb$, $^{106}Ru/^{106}Rh$ and $^{144}Ce/^{144}Pr$.

A review paper on "some general aspects of radioactivity measurement methods" [44] has been prepared for the first international summer school on radionuclides metrology. For the same purpose a paper on "problems and possibilities of bremsstrahlung counting" has been written [45], which contains also our results of $4\pi\beta$-bremsstrahlung coincidence experiments on pure β-emitters. The investigations on internal bremsstrahlung were finished [46, 47, 48]. Some smaller improvements were achieved in α-low-geometry counting, especially concerning source problems.

The first series of measurements of the ^{233}U half life (in collaboration with several other units) yields $1.586 \cdot 10^5 y \pm 1\%$ ($\sim 3\sigma$, including possible systematic errors). The half life of ^{95}Nb was determined by the $4\pi\beta$-γ coincidence method to (34.986 ± 0.019)d. The measurements on the ^7Be-decay were continued. New high efficiency sources, prepared by NPL with their isotope separator, were used. The evaluation of the results is in progress.

+ EURATOM research fellow

The decay scheme of ^{65}Zn has been published [49]. Evaluations were made of the decay schemes of ^{37}Ar, ^{51}Cr, ^{65}Zn and ^{198}Au. A paper on "rules proposed for evaluations of decay properties of radionuclides" [50] was written with Mr. Legrand of LMRI for the evaluation group.

An IAEA consultants meeting on evaluation problems, the first international summer school on radionuclide metrology and the meeting of the BIPM consultative committee II for measurement of ionizing radiations were attended. The edition of the proceedings of the summer school is under way. A lecture on ω_K and L/K capture ratio in the ^{37}A decay was given to the Int. Symposium on Inner Shell Atomic Phenomena in Atlanta/Georgia, but we could not find the time to prepare a written contribution.

2.8. <u>Radionuclides, Methods</u>

G. Grosse, I. Stanef [+], R. Vaninbroukx [x]

2.8.1. Liquid Scintillation Counting: The specific α-activity of ^{233}U solutions (material 278; 99.9986% ^{233}U) has been determined. Corrections of 0.1% and 0.06%, respectively, for the α- and β-contribution from the daughter products and other uranium isotopes were applied. The obtained result for 12 samples from 5 different dilutions was 3.868 10^5 dps/g parent solution. The standard deviation was ±0.05% and the overall error ±0.14%. The agreement with the results obtained from 4πP-measurements and α-low geometry measurements was -0.04% and +0.11% respectively. From this figure and the amount of ^{233}U per gram solution, obtained from ID measurements and CPC measurements the ^{233}U half-life was calculated, yielding a value of 1.585×10^5y±0.3% (1σ).

In the frame of a program for the preparation of several standardized solutions in sealed ampoules for the Chemistry Department of the SCK/CEN-Mol, absolute measurements on $^{106}Ru/^{106}Rh$, $^{144}Ce/^{144}Pr$ and ^{137}Cs were performed. Due to the equilibrium between low energetic β-emitters (^{106}Ru and ^{144}Ce) and high energetic β-emitters (^{106}Rh and ^{144}Pr) or to the presence of the conversion electrons and γ-rays from ^{137m}Ba in the case of ^{137}Cs, and because of the presence of radiochemical impurities in the

+ Institute for Atomic Physics, Bucharest, Romania; temporarily guest research fellow at CBNM solutions, prepared from fission products, the obtained results are less accurate than normally obtained. The results of these measurements and of a ^{32}P standardization for internal use (bremsstrahlung measurements) are compared to the results from other methods in the following table. The stated errors are the estimated overall errors.

Nuclide	dps/g parent solution		
	Liq.Scint.Count.	4πβ-γ coinc. (2.12)	4πP(2.14)
^{32}P	$1.622\cdot10^{8}\pm0.5\%$	--	$1.625\cdot10^{8}\pm0.5\%$
$^{106}Ru/^{106}Rh$	$1.655\cdot10^{7}\pm0.3\%$	$1.650\cdot10^{7}\pm0.3\%$	$1.645\cdot10^{7}\pm0.8\%$
^{137}Cs	$1.539\cdot10^{7}\pm1.5\%$	--	$1.542\cdot10^{7}\pm2.1\%$
$^{144}Ce/^{144}Pr$	$2.430\cdot10^{7}\pm1.6\%$	--	$2.390\cdot10^{7}\pm1.8\%$

At the Herceg Novi Summer School on Radionuclide Metrology an invited review paper on the present status of liquid scintillation counting has been presented [51].

2.8.2. γ-Spectrometry: The ^{229}Th (daughter of ^{233}U) content in the ^{233}U material 278 has been determined by measuring the γ-intensity of the daughter products, especially the 440 keV γ of ^{213}Bi. The ratio $^{229}Th/^{233}U$ in May 1972 was (0.00020±0.00004). The error is mainly due to the uncertainty of the γ-branching in the decay of ^{213}Bi.

After the replacement of the 3"x3" crystal at the end of 1971 a recalibration of the spectrometer has been started. The calibration and testing procedures together with an investigation on suitable nuclides for calibration purposes have been described in an internal CBNM report (February 1972). The spectrometer was calibrated, for different kinds of sources and for different β- and X-ray absorbers using following nuclides: ^{22}Na, ^{32}P (bremsstrahlung), ^{51}Cr, ^{56}Mn, ^{57}Co, ^{60}Co, ^{65}Zn, ^{88}Y, ^{95}Nb, $^{95}Zr/^{95}Nb$, $^{106}Ru/^{106}Rh$, ^{137}Cs and $^{144}Ce/^{144}Pr$.

The specific ^{95}Zr activity of a $^{95}Zr/^{95}Nb$ solution, for SCK-CEN Mol, was determined. The accurate standardization of such a solution is rather difficult due to the special equilibrium conditions caused by the comparable half-lives of ^{95}Zr and ^{95}Nb. The obtained result, with an overall error of $\pm 0.6\%$, agreed within 0.3% with the 4πβ-γ coincidence result. For 2.14. eight different ^{56}Mn solutions have been standardized; the error on the results was $\pm 0.3\%$, the reproducibility was of the order of $\pm 0.1\%$. Standard sources of special size of following nuclides: ^{51}Cr, ^{60}Co, ^{65}Zn, ^{95}Nb, ^{137}Cs, and ^{144}Ce, have been prepared and calibrated for 1.9.

From these measurements, and from some earlier measurements too, redeterminations of half-life values have been performed with following results:

^{56}Mn : (2.5785±0.0036)h
^{58}Co : (70.78 ±0.12)d
^{95}Nb : (34.97 ±0.06)d

The results of the investigations, mainly performed earlier, on the decay of ^{65}Zn (together with 2.12) have been published [49].

A preliminar calibration of the Philips Si-Li detector was performed using ^{57}Co- (6.4 keV, 14.4 keV, 122 keV, and 136 keV), ^{88}Y- (14.6 keV), and ^{241}Am- (26 keV and 60 keV) sources. This detector was used for low energy impurity determinations (e.g. for the solutions standardized for SCK-CEN) and for the determination of the ^{241}Am content in a Pu-sample for 3.4.

2.8.3. Developments of Methods: A program for searching optimal conditions for liquid scintillation counting of low energetic β-emitters e.g. ^{3}H and ^{14}C was started (I. Stanef). Different scintillators and photomultipliers have been investigated. Methods based on the extrapolation of the integral energy spectra to zero energy and on the direct calculation of the disintegration rate from differential spectra, applying a correction for zero-detection probability, have been used. The results obtained till now, using only a approximative estimation of the correction for zero detection, are very promising. The reproducibility is of the order of ±1%, and even better in some cases, and the maximum obtained efficiency for ^{3}H is about 90% under the best conditions (BIBUQ -scintillator and RCA-C31000D photomultiplier).

2.9. Radionuclides, Services
W. Oldenhof (part-time), W. van der Eijk [x], W. Zehner

2.9.1. Services: About 270 sources have been prepared by precipitation, electrodeposition and electrospraying from several nuclides (^{7}Be, ^{32}P, ^{51}Cr, ^{55}Fe, ^{56}Mn, ^{57}Co, ^{59}Ni, ^{60}Co, ^{90}Sr-^{90}Y, ^{95}Zr-^{95}Nb, ^{99}Tc, ^{106}Ru-^{106}Rh, ^{109}Cd, ^{115m}In, ^{137}Cs, ^{144}Ce-^{144}Pr, ^{170}Tm, ^{193}Pt, ^{210}Pb, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{241}Am).

400 Au coated VYNS foils have been prepared.

Solutions of ^{32}P, ^{51}Cr, ^{56}Mn, ^{95}Zr-^{95}Nb, ^{106}Ru-^{106}Rh, ^{137}Cs and ^{144}Ce-^{144}Pr have been calibrated.

100 $2\pi\alpha$ and $4\pi\beta$ measurements have been made.

From 25 $MnSO_4$ solutions quantitative samples for Mn concentration determination have been taken.

2.9.2. Improvement of methods: In the frame of the Bureau International de Poids et Mesures working group "Problems in microweighing" an investigation on the performance of the M5- and MPR5-microbalance and the attainable accuracies in mass determinations has been done. The results have been published as EUR report [52]. In the same frame an intercomparison of small masses has been carried out, in which we took part.

Investigations on the preparation of well defined thin drop sources for α-low-geometry counting and α-spectrometry have been started.

2.9.3. Decay schemes: The ^{235}U solution n° 1265 has been calibrated by $4\pi\alpha$ counting, for the U half-life program.

Some preliminary experiments on source preparation for the investigation of the ^{115m}In decay scheme have been done.

2.9.4. Neutron sources: The $MnSO_4$ solution became unstable at the beginning of the year, probably due to hydrolysis and oxidation. By addition of H_2SO_4 until a pH=2 was reached (the original solution had a pH=4) and addition of some H_2O_2, the solution became clear and stable again.

The impurities in the bath have been determined in order to be able to correct for interfering bivalent cations in the Mn-concentration determination by complexometric titration and to correct for neutron absorption by B, Cd and rare earth elements.

The efficiency of the NaI detector for the ^{56}Mn radiation in the bath has been determined 5 times, with a standard deviation of 0.2 %.

The CBNM ^{252}Cf source (1.5 μg) has been calibrated 7 times, the Kooi ^{252}Cf source 3 times and the CBNM Ra-Be source 4 times.

3. SAMPLE PREPARATION AND DEFINITION

3.1. Chemistry A

K.F. Lauer*, H. Silvester, M. Aerts

The Interlab Test "Isotope Dilution Analysis" (IDA 72) has been organized and the first results are now being evaluated in close co-operation of different working units and the organizing services of GfK Karlsruhe.

A research program in the field of precise atomic absorption analysis has been initiated. The first studies will be made in connection with the Li- and Co-measurements.

Work was done as consultant for the IAEA on the subject of "reference materials for nuclear industry and research" (a report is in preparation).

3.2. Chemistry B

Le Duigou Y.*, W. De Spiegeleer, W. Leidert, H. Mast

3.2.1. Sample Preparation: Corresponding to internal and outside requests the following solutions have been prepared and defined by different methods:

Type	n°	starting material	application
Pu nitrate	5	NBS Pu metal	Reference solutions
Pu nitrate	2	99.8% enriched ^{242}Pu oxide	Spike solutions
U nitrate	15	99.99% enriched ^{233}U oxide	Half-life-spike solutions
U nitrate	2	97.8% enriched ^{233}U oxide	IDA experiments
U nitrate	4	NBS U oxide	Reference solutions
U nitrate and Pu nitrate	5	^{233}U + ^{242}Pu oxides	Mixed spike solution

3.2.2. Participation to IDA-72 experiment: IDA-72 is the code name of an international safeguards interlaboratory test for the determination of U and Pu in active feed solutions by isotope dilution analysis.
This experiment has been executed in close collaboration with the Institut für Angewandte Systemtechnik und Reaktorphysik in Karlsruhe and Eurochemic in Mol.
About 250 samples including ^{233}U and ^{242}Pu spike solutions, spiked and unspiked U and Pu reference solutions, spiked and unspiked active feed solutions have been prepared and distributed to 23 participating laboratories.

Reference and spike solutions have been prepared and defined in collaboration with different groups. The mixed spike solution has also been used for additional experiments on spiking procedures (dry spike and aluminium capsules techniques) and for aging effect studies. Measurements on these samples are still in progress and evaluation of the results will take place in Karlsruhe in 1973.

3.2.3. Other activities:

1. preparation, distribution, spiking and analysis of ^{233}U solutions for the half-life program;

2. development of a method for traces of boron analysis in a manganese sulfate solution (spiking technique and separation procedure);

3. preparation of lithium solutions and lithium fluoride compounds and determination of their lithium contents;

4. gravimetric and coulometric determinations of U and Pu contents in various oxides and solutions;

5. test of a new "home-made" equipment (potentiostat and integrator) for controlled potential coulometry. A paper on the determination of U by this method has been published[53].

6. test of equipment for boron pyrohydrolysis and constant current coulometric determination of the resulting boric acid solution.

3.3. <u>Chemistry C</u>
Verdingh, V.*, R. Besenthal, A. Michiels, H. Ruts, G. Strack, J. Tjoonk

3.3.1. Preparative Chemistry

Metallic layers up to 20 mg/cm^2 were prepared by suspension spraying. The same method was applied to prepare isotopic layers with very small quantities of starting material. Large surface $^{241}AmO_2$ layers are being prepared by this method. The deposition of uranium oxide on graphite by high tension electrophoresis was continued.
A new cell was constructed for the deposition of layers on the innerside of tubes. Layers of up to 5 mg U_3O_8/cm^2 could be deposited on graphite and stainless steel tubing. An extensive study was made of the parameters of this method. In parallel to the electrophoresis a new start was given to the electrohydrolysis of uranium in view of the deposition of layers on the inside of metallic tubing.

Table 7 lists the samples delivered in 1972.

TABLE 7

Method	Applicant	Sample Material	Support	Amt.
electro-spraying	Inst. Langevin Grenoble	^{235}U	Cu	2
	TH-München	^{236}U	Al	1
	CBNM	^{235}U	Vyns+Al	3
	KFA-Jülich	^{235}U	Ti	6
	CEA-Saclay	^{235}U	Vyns+Al	6
	CEA-Saclay	^{235}U	" "	6
	CBNM	^{233}U	Quartz+Pt	4
	KFZ-Karlsruhe	^{240}Pu	Vyns+Al	7
	CEA-Cadarache	^{233}U	Pt	1
	CBNM (T1/2)	^{233}U	Quartz+Pt	4
	CBNM	^{235}U	Scint. foil	2
	CEA-Saclay	^{235}U	Pt	5
	CEA-Saclay	^{235}U	Pt	5
	KFZ-Karlsruhe	^{235}U	Stainless steel	[illegible]
	CBNM	^{233}U	Al	1
	Univ. Bordeaux	^{235}U	Al	1
	Univ. Berlin	^{234}U	Al	2
	Univ. Catania	^{239}Pu	Stainless steel	1
	Univ. Catania	^{234}U	Stainless steel	1
	Univ. Catania	^{235}U	" "	1
	Univ. Catania	^{233}U	" "	1
	Aerojet USA	^{235}U	" "	2
	Aerojet USA	^{235}U	" "	2
	KFZ-Karlsruhe	^{238}U	" "	3
	Nucl. Inst. Taiwan	^{235}U	Vyns+Al	5
	Univ. Catania	^{240}Pu	Stainless steel	1
	Univ. Catania	^{233}U	Stainless steel	5
	CBNM	^{233}U	Al	1
	KFZ-Karlsruhe	$^{235}U+^{252}Cf$	Vyns+Al	4
	CEA-Saclay	^{239}Pu	Pt	4
	CEA-Saclay	$^{240}Pu/^{239}Pu$	Al	1
	Nucl. Inst. Taiwan	^{239}Pu	Vyns+Al	4
	KFZ-Karlsruhe	^{239}Pu	Stainless steel	3
Suspension spraying	Inst. Langevin Grenoble	$^{235}U_3O_8$	Cu	3
	KFA-Jülich	$^{235}U_3O_8$	Ti	2
	CBNM	$^{241}AmO_2$	Al	2
	KFZ-Karlsruhe	$^{238}U_3O_8$	Vyns+Al	6
	KFZ-Karlsruhe	$^{238}U_3O_8$	Stainless steel	2
	KFZ-Karlsruhe	$^{235}U_3O_8$	Vyns+Al	5
	KFZ-Karlsruhe	$^{235}U_3O_8$	Stainless steel	1
	CEA-Saclay	ThO_2	Pt	6
	CEA-Saclay	$^{238}U_3O_8$	Pt	4
	KFA Jülich	$^{235}U_3O_8$	Ti	4
	TH München	$^{48}TiO_2$	Al	2
	IPN Orsay	W metal	AL	1
	KFZ-Karlsruhe	^{239}Pu	Pt	3
	CBNM	^{233}U	Al	1
	KFZ-Karlsruhe	$^{238}U_3O_8$	Stainless steel	1
	CBNM	$^{241}AmO_2$	" "	2
Electrophoresis	KFA-Jülich	$^{235}U_3O_8$	Ti	6

Settling	CNEN-CBNM	CsF	Al-canning	1
	CBNM	^{151}Eu	" "	1
	CNEN-CBNM	^{10}B	" "	1
	CBNM	^{236}U	" "	1
	CBNM	^{242}Pu	" "	1
	CNEN-CBNM	^{96}Zn	Al-Be canning	2
	CNEN-CBNM	^{91}Zn	Al-Be canning	3
	CBNM	^{236}U	Al canning	1
	CBNM	^{287}Np	Al canning	3
	CNEN-CBNM	NaF	Al canning	1
	CNEN-CBNM	$^{10}B_4C$	Al canning	1
Prepa-ation of thin supports			Vyns	160

3.2.2. Analytical Chemistry

3.3.2.1. Polarographic analysis:

1. determinations of trace quantities of Cd in $MnSO_4$ were performed.
2. both by oscilloscopic and integrating polarography high precision analysis of Co in Co/Al alloys was studied in NaOH electrolyte using sucrose as complexant.

3.3.2.2. Elemental analysis: A new equipment for the macro-analysis of C and H was installed in view of the definition and standardization of hydrogen containing layers.

3.4. Chemistry D

Del Bino G.*, W. Wolters

3.4.1. Californium sample preparation: The preparation of thin ^{252}Cf sources by self-transfer and other methods has been continued. The needs of applicants in the field go more and more in the direction of high fission-rate sources.
Nine samples have been delivered for use inside and outside the CBNM in 1972.
Particular attention has been devoted to the preparation of a "neutron source" of about 2 µg of ^{252}Cf to be used by the CBNM dosimetry service. For this project special equipment was needed to handle microgramquantities of the isotope. The source was prepared on a gold foil which was pressed and shaped into a sphere and encapsulated in a cylindrical copper container.

3.4.2. Chemical separations and purifications: different separations (mainly Pu/Am) and purifications (U, Pu, Cf) have been performed on materials to be used for nuclear measurements and for the preparation of defined samples, including the chemical treatment and the spiking in view of the isotope dilution analysis of special Pu samples (e.g. ^{241}Pu).

3.4.3. Complexometric analysis: Twenty well defined Nd reference solutions have been prepared and defined by EDTA complexometric analysis with 0.2% accuracy.
By the same method the Mn-content of $MnSO_4$ baths used for neutron source calibration has been determined with accuracies at the 0.1% level. Twenty-three samples have been analysed.

3.4.4. Non dispersive X-ray fluorescence and routine counting: The non-dispersive X-ray fluorescence method of analysis has been started. A 15 mci ^{241}Am γ-source is used for the excitation of samples by means of different targets. Alpha measurements by semi-conductor and low-geometry counting have been continued in the frame work of the actinide preparative and analytical chemistry.

3.5. Spectrochemical Analysis

Berthelot Ch.*, S. Hermann, T. Mencarelli

3.5.1. Analysis of U compounds and preparation of new standards: Analyses of trace elements have been performed with different carriers: Ga_2O_3, AgCl, AgF, NaCl, NaF, LiF and SrF_2.

3.5.2. Impurities in ^{239}Pu nitrates (T 1/2 Program): The metallic impurities in Pu nitrates, after conversion into Pu oxides, have been determined by carrier distillation.

3.5.3. Analysis of B layers: The B layers on Pt-plates have been analysed by the arc, in the presence of graphite as spectroscopic buffer. The addition of 10% LiF markedly improves the limits of detection for many elements, especially of the refractory elements.

3.5.4. Analyses of Mn sulphate solutions for calibration of neutron sources: Different buffers (Li carbonate, graphite) are used for the determination of Cd, Na, Ca, Mg and other elements. However, B must be analysed with high resolution of the spectra, owing to the interference of Mn lines.
Traces of rare earths are separated from Mn by coprecipitation as fluorides with Y added as carrier. Radiotracers $^{152+154}Eu$ are used to monitor the recovery of the lanthanons by γ ray counting.

3.5.5. Development of preconcentration methods: Traces of Co (less than 1 ppm in Ni) are separated by means of anion exchange in HCl medium. The diethyl ether method is used for the preconcentration of Mn, Cr, Ni, Co, Al, Ti and other elements in Fe.

3.5.6. Analyses with the new emission direct-reader SM 150: Simultaneous analyses of 26 chemical elements have been performed on U oxides by dc arc using Ga_2O_3, AgCl and NaF as carriers, on B carbides, on Mn compounds, on graphite and Li carbonates samples.

3.6. Classical Metrology

Moret H.*, J. Brulmans, B. Dijckmans, F. Hendrickx, E. Louwerix, J. Verdonck, F. Verheyen

3.6.1. Intercomparison: In the standardization of radioactive solutions, the determination of drop weights is a limiting factor in the standardization accuracy. Together with the Bureau International des Poids et Mesures (BIPM) an intercomparison of mass metrology was organized.
CBNM made and calibrated the sets. Each set contained metal weights of 20, 50 and 100 mg. The calibrations were checked by BIPM and PTB (Physikalisch-Technische Bundesanstalt) by calibrating independently 2 of the six sets. This was done before and after the intercomparison.

Six laboratories which are specialized in standardization of radioactive solutions (BIPM, National Bureau of Standards (NBS) PTB, IBK (Yougoslavia), CBNM, LMRI) received a set. After mass determination, the results were sent to BIPM. The samples returned to CBNM for post-calibration.

The calibrations were of excellent quality, as shown by the parallel calibrations of BIPM and PTB. Providing extreme care in handling the samples an accuracy of $\pm$ 1 μg is achieved. In-house calibration of reference weights (tracing back to BIPM-checked standard kilogrammes) was applied by each laboratory and seems to be a necessity.

The 6 participating laboratories applied several methods (all on Mettler M5 balances) : direct reading from the balance dials and scale without special calibration, reading of calibrated balance indications and substitution weighing. From the evaluation report (the draft is being written by CBNM) it follows that uncalibrated balances produce errors up to 17 μg, whereas calibrated balances and substitution weighing are about equivalent i.e. $\pm$ 5 μg.

3.6.2. Improvement of drop weight determinations: A test report of Mettler M5 balances was edited. NPL purchased a CBNM designed balance for drop weight determination.
Investigations started to improve drop dispensing. At the same time the manipulation of pycnometers is being improved. It is attempted to realize an improved installation for drop weight determination, based on a commercial balance, with simplified operation and digital reading.
If this design could interest balance firms, future requests to CBNM could be passed on to these firms.

3.6.3. Vacuum balance: The balance was exhibited at Nuclex 1972. A pan brake was developed, tested and installed in one of the balances.
A few modifications were tested in view of the increase of the capacity to 5 or 10 grams. A capacity of 5 grams is possible but the standard deviation is still a few micrograms.

3.6.4. X-ray fluorescence: A sample holder for layer thickness assay was designed and the accuracy of comparison of uranium samples with standards will be investigated. Energy-dispersive fluorescence seems to offer the best possibilities as the geometry requirements are less stringent than in the case of wave-length dispersive techniques.

3.6.5. Talystep: This stylus instrument for layer thickness measurement has proven its quality and usefulness. Standards have been made with the vacuum evaporation/weighing technique.
The relationship between mass per unit area and geometrical thickness was established for Au layers in the region where bulk density may be assumed. Strict linearity was found.
Outside this region (i.e. below 200 Å) the density may thus be determined.
A rotating sector chopper, designed to be placed in front of the substrate during vacuum evaporation, will allow to make step-type standards.

3.6.6. Autoradiography: In the preparation of sources for radionuclide standardization, the distribution of material over the support foil is an important factor.
Autoradiographs are frequently requested. The interpretation, however, is difficult and uncertain. A technique is being developed to evaluate autoradiography in conjunction with the isodensitometer. It is attempted to obtain a (quantitative) topography of the sources.

3.6.7. Substrate temperature: In order to assess substrate temperatures during evaporation and/or bake-out cycles, a technique was worked out to make vacuum-evaporated thermocouples.
First results are promising as reliable thermo- e.m.f. curves are obtained. The very low thermal insertion is a valuable asset.

3.6.8. Ellipsometry: Literature investigations showed ellipsometry to be an attractive tool for quantitative analysis (coverage).
The relatively easy experimental handling was experienced with a few tests on an ellipsometer which could be borrowed for a few months from the Petten establishment.

3.7. Vacuum Techniques

Eschbach H. L.*, G. Müschenborn, W. Dobma,
E. W. Kruidhof, W. Lycke, P. Rietveld, J. Van Gestel

3.7.1. Samples Prepared by Vacuum Evaporation: A considerable number of requests were fulfilled for the production of thin metallic coatings on various materials. Mostly gold and aluminium layers were demanded on plastic foils or glass substrates to give electrically conducting or optically reflecting films. The following targets and reference samples (table 8) were prepared by vacuum evaporation or cathodic sputtering during 1972:

TABLE 8

Material	Backing	Number	Applicant
^{9}Be	Ag, Cu	6	CCR, Ispra
Ni	C	6	Univ. Groningen
Ta	C	3	SCK, Mol
Au	C	2	SCK, Mol
Al	Plastic	2	CBNM
Au	SiO_2	7	CBNM
Cu	SiO_2	6	CBNM
CaF_2	Stainless steel	1	CBNM
Quaterphenyl	SiO_2	2	CBNM
Stearic acid	Stainless steel	3	AERE, Harwell
Y	C and Al	10	SCK, Mol
C	Self-supp.	10	Univ. Utrecht
B(nat)	Stainless steel	3	Univ. Leuven
^{10}B	Al	3	KFZ, Karlsruhe
^{10}B	Stainless steel	3	Univ. Leuven
^{50}Cr	Au	1	Univ. Wien
LiF	Cu	3	SCK, Mol
$^{235}UF_4$	SiO_2/Pt	15	NBS
$^{238}UF_4$	SiO_2/Pt	11	NBS
UF_4 (nat)	SiO_2/Pt	13	NBS
$^{235}UF_4$	SiO_2/pt	14	Fission foil exchange (Joint Programme)
C	Self-supp.	5	SCK, Mol
$^{235}UF_4$	Al	3	Res. Inst. Stockholm
^{6}LiF	Stainless steel	3	GfK, Karlsruhe
V	Ta	2	CBNM
LiF	Scint. Foil	1	CBNM
C	Self-supp.	3	CBNM
LiF	Stainless steel	5	Univ. Leuven
^{6}LiF	Stainless steel	5	Univ. Leuven
Zr	C	4	
Y	C	2	SCK, Mol

3.7.2. Reference samples[54]: A series of experiments were carried out in order to improve the evaporation of metallic uranium by high frequency levitation. In addition the evaporation of UF_4 by resistance heating and UO_2 by electron bombardment has been employed extensively. $^{235}UF_4$-layers are being prepared in a vacuum unit installed in a glove box. Mass determinations are carried out by vacuum balances and/or quartz crystal monitors.

3.7.3. Measurements on Thin Foils: Due to an urgent request the preparation procedure for carbon foils has been improved. Large selfsupporting foils with a thickness of more than 300 μg cm^{-2} can be made.
Systematic thickness measurements using a stylus method have been carried out. A standard test procedure was adopted to find out at what loads of the stylus permanent damage to thin gold layers occurred. At loads of about 10 mg on the stylus first scratches appear. These could also be seen in a scanning electron microscope.
Two different arrangements have been tested to measure stress in thin evaporated layers. The sensing element in both is a linear differential voltage transformer. A paper has been prepared and is ready for submission to describe the characteristics of the two devices and to discuss first results on gold layers[55]. The method will be extended to boron layers and to foils prepared by cathodic sputtering. Very small thin film thermocouples (Au-Ni) have been made and tested. They are used to determine surface temperature of substrates and thin layers.
A report has been prepared reviewing problems in the exact measurement of low pressures and discussing the proposals of standardizing calibration methods [56].

3.8. <u>Metallurgy</u>
Van Audenhove J.*, E. Freistedt, J. Joyeux, J. Mast, M. Parengh, F. Peetermans, J. Waelbers

3.8.1. Samples Preparation and Assay: The sample orders fulfilled during 1972 are given in table 9. In total 94 orders for about 2.000 samples are fulfilled.

3. 8. 2. Development

1. H. F. Levitation alloying: The levitation technique used for the quantitative preparation of alloys had to be adapted and improved to meet the requirements of the applicants. A special levitation equipment for the preparation of 10 g amounts of Zr-alloys has been developed and supplied to the Danish Atomic Energy Commission at Risø (Work performed in the framework of the License contract with Automation Chemique et Nucléaire Bruxelles).

2. Vacuum Manipulator: A standard commercial manipulator for hazardous materials handling has been transformed for use in high vacuum. The firm "La Calhène" (Bezons, France) obtained a license contract from the Commission to manufacture and commercialize this realization.

TABLE 9: Samples delivered in 1972

Material	Special Characteristics		Applicant (2)
	Composition (1)	Form	
Al-Th	(1.00±0.01)wt % Th (0.100±0.001)wt % Th (10.0±0.1)wt % Th	disc disc wire	(a) (a) (d)
Al-Pu	(0.100±0.001)wt % Pu	discs	(a)
Al-Cd	(0.200±0.004)wt % Cd	wire	(b) (d)
U canned	in Al	foil	(a)
Ni-Co	(0.100±0.001)wt % Co (0.500±0.005)wt % Co (1.00±0.01)wt % Co (5.000±0.025)wt % Co (10.00±0.05)wt % Co	rod rod rod, wire rod rod, wire	(c) (c) (c) (t) (c) (c) (t)
Al-Ag	(1.00±0.01)wt % Ag	wire	(d)

Al-Au	(0.100±0.001)wt % Au (0.500±0.005)wt % Au (1.00±0.01)wt % Au (5.00±0.05)wt % Au	wire, disc wire, disc wire, disc wire, disc	(d) (q) (u) (i) (d) (q) (d) (j)
Al-Co	(0.100±0.001) wt % Co (1.00±0.01)wt % Co (2.00±0.02)wt % Co	wire, disc wire, disc wire, disc	(d) (r) (j) (l) (i) (u)
Al-Hf	(5.00±0.05)wt % Hf (0.100±0.002)wt % Hf	wire disc	(d) (q)
Al-In	(1.00±0.01)wt % In	disc, wire	(f) (d)
Al-Ir	(1.00±0.01)wt % Ir	disc, wire	(f) (d)
Al-Mn	(1.00±0.01)wt % Mn (4.00±0.04)wt % Mn (0.100±0.001)wt % Mn	wire, disc disc, foil disc	(d) (f) (q) (f) (j) (q)
Al-Ni	(1.00±0.01)wt % Ni	wire	(d)
Al-Rh	(1.00±0.01)wt % Rh	wire	(d)
Al-Zr	(5.00±0.05)wt % Zr	wire	(d)
Al-W	(0.500±0.010)wt % W (1.00±0.01)wt % W	wire disc	(d) (f)
Ni-Ga-Fe	Ni_{75} Ga_{25} Ni_{75-x} Ga_{25} Fe_x x = 0.00 at % Fe = 0.01 at % Fe = 0.02 at % Fe = 0.05 at % Fe = 0.10 at % Fe	rod	(e)
Al-Dy	(1.00±0.01)wt % Dy (5.00±0.10)wt % Dy	disc disc	(f) (f)
Al-La	(5.00±0.05)wt % La (10.0±0.1)wt % La	disc disc	(f) (f)
Al-Eu	(2.50±0.02)wt % Eu (5.00±0.05)wt % Eu (0.250±0.005)wt % Eu	disc wire wire	(f) (f) (q)
Al-U	(10.0±0.1)wt %	disc	(f) (m)

Al-Ge	(1.33±0.01)wt % Ge (0.803±0.008)wt % Ge (0.268±0.003)wt % Ge (0.201±0.002)wt % Ge (0.134±0.001)wt % Ge (0.0470±0.0005)wt % Ge	wire wire wire wire wire wire	(g) (g) (g) (g) (g) (g)
Al-Cu	(1.00±0.01)wt % Cu	wire	(v)
Pt-Cu	(24.57±0.25)wt % Cu	foil	(h)
Pt-Co	(23.19±0.23)wt % Co	foils	(h)
Pt-Cu-Co	(12.39±0.12)wt % Cu (11.49±0.15)wt % Co	foil	(h)
Pt-Cu-Co	(16.47±0.16)wt % Cu (7.642±0.076)wt % Co	foil	(h)
Pt-Cu-Co	(8.286±0.083)wt % Cu (15.37±0.15)wt % Co	foil	(h)
Ni-Mo	(62.05±0.30)wt % Mo (37.94±0.30)wt % Ni	button	(q)
	(35.27±0.30)wt % Mo (64.72±0.30)wt % Ni	button	(q)
	(29.01±0.30)wt % Mo (70.98±0.30)wt % Ni	button	(q)
Al-Sb	(1.00±0.01)wt % Sb	disc, wire	(q) (v)
Al-In-Co-Au	(2.00±0.02)wt % In (1.00±0.01)wt % Co (50.0±0.5)ppm Au	disc	(q)
Pb-Ag	(2.50±0.2)wt % Ag	wire	(r)
Pb-Ag-Sn	(1.75±0.01)wt % Ag (0.75±0.01)wt % Sn	wire	(r)
Cu, Ni	Pure metals	wire	(r)
Cd	Pure metal	tube	(r) (s)
^{235}U	40 $mg.cm^{-2}$	foil	(o)
Be		tube	(k)

EB welding		Beam monitor Linac	(k)
Co	pure metal	cylinder	(p)
Li canned in Al	---	rod	(n)
Zr, W, Na, Al	high purity	miscellaneous	(x)(w)(d)(l) (k)(y)(z)(z_1) (z_2)(z_3) (z_4)
Ti, V, Zn, Mo, Cd, In, Mn, S, Ge, Fe, Th, Al_2O_3, Ag, Pb, Au, Li, Nd, U, Vacromium	high purity	miscellaneous	(z_5)
Cu-Al	(5.000±0.025)wt % Al	disc	(z_5)

(1) The compositions of the alloys are certified by quantitative levitation melting.

(2) Applicants :

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(b) Interuniversitaire Reactor Instituut, Delft, Nederland
(c) Université de Nantes, lab. de Physique de Métal, France
(d) CNRS Laboratoire d'Analyse par Activation "Pierre SUE", France
(e) K.F.A. Jülich, Deutschland
(f) Chiminport, Bucarest, Roumanie
(g) IAEA, UN Development Program, Greece
(h) Rijksuniversitair Centrum Antwerpen, België
(i) Akademisch Ziekenhuis, Inwendige Ziekten, Gent, België
(j) RCN, Petten, Nederland
(k) Natuurkundig Laboratorium INW Gent, België
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(n) Max Planck Inst. für Chemie, Mainz, Deutschland
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(q) CCR Ispra, Italia
(r) S.A. Cockerill Ougrée, Providence et Espérance, Longdoz, Seraing, België
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(t) National Bureau of Standards, Washington U.S.A.
(u) Yoneyama Chemical Industries, Osaka, Japan
(v) Soc. CODILAB , Lille, France

(w) CEN Saclay, France
(x) Metallgesellschaft AG, Frankfurt, Deutschland
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VII. REACTOR CENTRUM NEDERLAND, PETTEN, THE NETHERLANDS.

1. FOM-RCN Nuclear Structure Group

(K. Abrahams)

1.1. General

Much interest was paid to the effect of channel interference in thermal neutron capture. It became clear that the present 3 facilities at the HFR at Petten complement each other reasonably well.

For the $^{59}Co(n,\gamma)$ reaction a satisfying agreement was reached between measurements with oriented target nuclei and measurements of the circular polarization.

(282) For the $^{39}K(n,\gamma)$ and the $^{57}Fe(n,\gamma)$ reactions it appeared that a combination of γ-γ angular correlation measurement and a γ circular polarization measurement can be sufficient to determine the channel interference.

The study of the partial (n,γ) widths could be concluded with the result that a positive correlation exist between the reduced width and the (d,p) spectroscopic factors for the $p^3/_2$ levels of all studied nuclei in the region $A = 40 - 70$.

1.2. Gamma spectroscopy and angular correlations

(J. de Boer, A.M.J. Spits, A.M.F. Op den Kamp)

The facility uses a thermal neutron beam (3×10^7 $cm^{-2}s^{-1}$) with a cooled quartz-bismuth filter, two 5" × 5" NaI detectors, two Ge(Li) (23 and 50 cm^3 active volume), a 16 window apparatus for coincidence studies, two 3" × 3" NaI detectors which in combination with one of the Ge(Li) detectors function as a pair spectrometer.

Preparations are being made for the multiparameter Ge(Li) - Ge(Li) system which will be connected to an on-line computer.

The analysis of the $^{37}Cl(n,\gamma)$ spectrum resulted in 79 γ transitions of which 64 could be fitted in a ^{38}Cl decay scheme.

For nuclei in the mass range $A = 30 - 50$ the correlation between (d,p) and (n,γ) strengths is being studied.

(375) Present research is on the reactions $^{64}Zn(n,\gamma)$, $^{66}Zn(n,\gamma)$ and $^{68}Zn(n,\gamma)$.

1.3. Capture of polarized thermal neutrons

(K. Abrahams, J. Kopecký, F. Stecher-Rasmussen)

The facility used consists of a neutron polarizing focussing mirror system giving a 90% polarized beam of 3×10^{7} cm^{-2} s^{-1} flux density, two cobalt-iron gamma-ray polarimeters, two Ge(Li) detectors (40 and 60 cm^3 active volume), a 4096 multi-channel analyser connected to an on-line computer. There are plans to install a new minor system in the present thermal column of the HFR which would produce a ten fold higher flux of polarized neutrons.

Measurements have been performed with the target nuclei: ^{29}Si, ^{63}Cu,
(757)(375) ^{72}Ge and ^{183}W. Present research is on ^{64}Zn, ^{66}Zn and ^{68}Zn.

In the period under review a contribution has been made to resolve the existing uncertainty in the capture cross section of ^{23}Na by determining the spin interference in the capture state.

Gamma-ray spectroscopy with the Ge(Li) detectors and the measurements of the circular polarisation of 12 primary transitions in the
(101,102,103) $^{23}Na(n,\gamma)$ reaction support the $J^{\pi}=1^{+}$ assignment for the 2.85 keV resonance.

1.4. Neutron capture γ rays of oriented nuclei

(J.J. Bosman, E.R. Reddingius, H. Postma)

This facility uses a mono-energetic polarized neutron beam obtained by diffraction from a magnetized Co-Fe single crystal.

By a ^{3}He-^{4}He dilution refrigerator we are able to cool samples to 0.03 K for periods of several days without interruptions.

Two Ge(Li) detectors are available (6.4 and 40 cm^3 active volume) of which the biggest can be used as central detector for pair spectrometry.

A super conducting magnet has been ordered to increase the magnetic field on the samples to 50 KG.

The $^{59}Co(n,\gamma)$ work has been finished and the capture of polarized neutrons in a polarized Ho target is being studied now.

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2. R.C.N. Reactor Physics Group

2.1. Integral measurements of fission product cross sections

(M. Bustraan et al.)

General

The integral measurements of cross sections of fission product nuclides are performed in STEK in 4 different neutron spectra (see fig. 1) by use of the central reactivity worth method.

(1352, 1354) Measurements have been performed now in the 4 STEK cores mainly for samples of mixtures of actual fission products from thermal fission of U235 contained in "burned" U-Al alloys.

Also one so-called mock-up sample has been used which consists of a mixture of elements such that the fission products of a fast reactor are more or less simulated.

Since March 1972 we dispose also of gram quantities of enriched isotopes on loan from the US-AEC loan pool for stable isotopes. These isotope samples have been thoroughly dried and packed in thin wall welded stainless steel capsules of pin shape. Measurements with these in STEK cores 4000, 3000 and 1000 are finished now. Final measurements in STEK-2000 are to be finished in spring 1973.

An extension of the loan period until December 1973 could be obtained with the consequence that now also measurements in a fifth core, STEK-500, with a "hard" neutron spectrum will be performed, for obtaining some data above 50 keV.

According to the present time schedule final results on the mixed fission products are foreseen for spring 1973 and final results for the isotopic samples for spring 1974.

Interpretation of measurements

The central neutron spectra in STEK are being measured by all conventional means including time of flight. The evaluation of these measurements is not yet final. There seems, however, to be a reasonable agreement between calculated and measured spectra.

Many of the earlier measurements at STEK were badly disturbed by traces of H_2O absorbed in the samples. This has been remedied now by rigorous drying and packing procedures.

The most troublesome aspect in the evaluation of the reactivity worth measurements is the self-shielding of the samples.
Well defined (pin type) geometries are being used now and most material is packed in two or three pins of different diameters to be able to extrapolate to zero dimensions. Also refined calculational methods will have to be employed to correct for and to check this self-shielding.

<u>Evaluation of fission product cross sections and adjustment</u>

Parallel to the experimental work an evaluation has started on fission
(1353) product cross sections for two reasons.
Firstly to get better and more detailed cross section values for comparing to the experimental results.
Secondly for use in an adjustment procedure. A scheme for adjusting fission product cross sections to the effects measured in STEK has been worked out in which the evaluated cross sections together with their errors and the cross-correlation of these errors will be used.
In this evaluation, capture cross sections below ± 1 keV are derived by the single level Breit-Wigner formalism using resonance parameters, as far as known.
Errors are derived by the error propagation formula using the experimental errors in the parameters Γ_n, Γ_γ and J.
Above ± 1 keV (unresolved region) a normal statistical approach is followed. Two types of errors arise: <u>a)</u> errors due to the uncertainty in the average resonance parameters, as s-, p-, d-strength functions, $\bar{\Gamma}_\gamma$, $\bar{D}_{obs}$; <u>b)</u> errors due to statistics. For calculating the second moment of the cross section the level repulsion effect has to be taken into account e.g. by using a two level correlation function borrowed from random matrix theory.
This delivers complete co-variance matrices for the fission product cross sections derived from the parameters used for calculating the cross sections. A more refined procedure is being worked out now based on the program FISPRO of prof. Benzi. A width fluctuation correction factor has been introduced in this program. This results e.g. for Pd105 in a 30% lower value for $\sigma(n,\gamma)$ at 4 keV up to ± 500 keV.

Other measurements

For calculation of the inelastic- and the absorption cross sections a good knowledge of excitation energies, spins and parities of levels in the region of 0.1 to 3 MeV for the target nucleus is necessary.
It is planned to perform some measurements of these parameters for a number of even even target nuclei by capture γ-ray techniques (measurements of the circular polarization of the γ-rays after capture of polarized thermal neutrons or measurements of the angular correlation of γ-rays due to capture of thermal neutrons as mentioned in the preceding contribution of the FOM-RCN Nuclear Structure Group).

Stable and long lived fission product nuclides used in the integral measurements in STEK

Nuclide	WRENDA 1973 regquest nr.	Nuclide	WRENDA 1973 request nr.
Zr 90	407	Xe131	547, 548
Zr 91	418	Cs133	558
Zr 92	425	Cs135	561, 562, 563
Zr 93	428	Cs137	-
Zr 94	433	La139	567, 568
Zr 96	438	Ce140	-
Mo 92	-	Ce142	-
Mo 94	-	Pr141	570
Mo 95	471, 472	Nd142	-
Mo 96	-	Nd143	573, 575, 576, 577
Mo 97	476, 477	Nd144	-
Mo 98	-	Nd145	578, 580, 581
Mo100	-	Nd146	582
Tc 99	482, 483, 484, 485	Nd148	-
Ru101	488, 489, 490, 491	Nd150	-
Ru102	492, 493, 494	Pm147	586, 591, 592, 593
Ru104	497, 498	Sm147	610
Rh103	504, 505	Sm148	611
Pd104	-	Sm149	612, 614, 615
Pd105	512, 513	Sm150	616, 619
Pd106	-	Sm151	620, 622, 623, 624
Pd107	517, 518	Sm152	625, 628
Pd108	519, 520	Sm154	632
Pd110	-	Eu151	641
Ag107	-	Eu153	650, 653
Ag109	524, 525, 526	Gd156	678
Cd111	-	Gd157	685
Te128	-	Tb159	-
Te130	-		
J127	-		
J129	-		

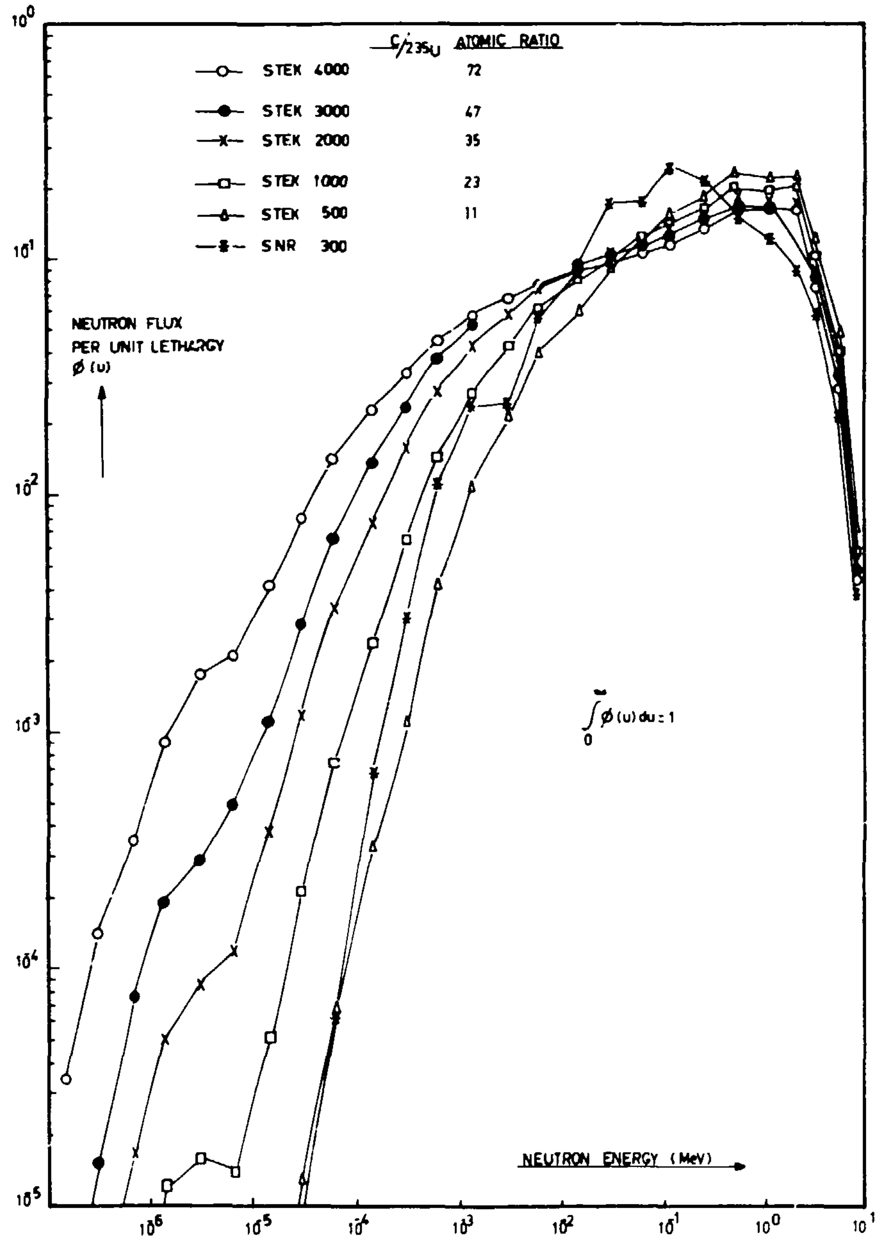

Fig. 1. Neutron spectra in STEK and SNR 300.