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PROGRESS REPORT ON NUCLEAR DATA RESEARCH IN THE EUROPEAN COMMUNITY

for the period January 1 to December 31, 1975

Central Bureau for Nuclear Measurements,
Euratom, Geel, Belgium

February, 1976

Nuclear Energy Agency Nuclear Data Committee

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1. FAST NEUTRON DATA

1.1. Data Evaluation for the Neutron Source Reaction $^{7}Li(p,n)$ (H. Liskien, A. Paulsen)

This work has now been published in Atomic Data and Nuclear Data Tables 15, 57 (1975) with the following abstract: "Centre-of-mass best values for the normalised Legendre coefficients and the 0° differential cross sections as functions of input energy have been derived from various experimental results for the reactions $^{7}Li(p,n)^{7}Be$ and $^{7}Li(p,n)^{7}Be^{*}$(431 keV). This information has been used to calculate laboratory differential cross sections as functions of the laboratory proton energy and neutron emission angle which are given in tabular form together with the corresponding neutron energies."

1.2. Neutron Induced Fission Neutron Energy Spectra of ^{235}U and ^{239}Pu. (H.-H. Knitter, C. Budtz-Jørgensen, M. Mailly, R. Vogt)

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A paper on the fission neutron energy spectrum of ^{239}Pu has been published in Atomkernenergie 26, 76 (1975) with the following abstract:

"The energy spectrum of prompt neutrons emitted in the fission of ^{239}Pu induced by 0.215 MeV neutrons was measured in the energy range from 0.25 to 15 MeV using nanosecond time-of-flight technique. A pulsed Van de Graaff accelerator was used to produce the primary neutrons. Considerable care was taken to measure the energy dependence of the neutron detector efficiency. The shape of the resulting spectrum agrees with a Maxwellian distribution within the experimental uncertainties. An average fission neutron energy of $\overline{E} = 2.136 \pm 0.045$ MeV was obtained."

In this work the calculated correction to the shape of the spectrum due to secondary interactions of the fission neutrons in the sample was significant relative to the overall accuracy. The same computer code has been used to calculate the corresponding corrections for the experiments carried out by A.B. Atom-Energi, Studsvik, Sweden on ^{235}U and ^{239}Pu and also for the experiment on ^{235}U carried out by AERE, Harwell, UK, and CEN Cadarache, France. The results have been transmitted to AERE, Harwell for the preparation of a common compilation.

1.3. Determination of (n, 2n) Excitation Functions for ^{46}Ti, ^{66}Zn, ^{115}In and ^{197}Au (A. Paulsen, H. Liskien, R. Widera, F. Arnotte)

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Evaluation of the final data was completed and the results were published in Atomkernenergie 26, 34 (1975) with the following abstract:

"Excitation functions have been determined in the 10 to 20 MeV energy region for the reactions $^{46}Ti(n, 2n)^{45}Ti$, $^{66}Zn(n, 2n)^{65}Zn$, $^{115}In(n, 2n)^{114}In^{m}$ (50.1 d) and $^{197}Au(n, 2n)^{196}Au$ by means of the activation technique. There is considerable scatter among existing data for these reactions in the 13 to 15 MeV energy region. Evidence is discussed that these discrepancies are due to deviating assumptions for the decay schemes and insufficient energy resolution of activity detectors in the past. For the reactions $^{115}In(n, 2n)^{114}In^{m}$ and $^{197}Au(n, 2n)^{196}Au$ the present results are confirming the lowest cross-sections from the existing data."

1.4. Measurements of the Fast Neutron Scattering and Total Cross Sections of ^{141}Pr (R. Singh, H.-H. Knitter)

A paper with the following abstract was published in Z. Phys. A 272, 47 (1975):

"The differential elastic neutron scattering cross sections of ^{141}Pr were measured at the incident neutron energies of 1.2, 1.7 and 1.9 MeV in the angular range between 25 and 150 degrees. At 1.7 MeV the differential inelastic neutron scattering cross sections corresponding to Q = -1122 keV, and at 1.9 MeV the ones corresponding to Q = -1122, and Q = -1295 keV were also determined. In a transmission experiment, the total cross section was measured between 0.50 and 2.42 MeV. The total and differential cross sections were calculated using the nuclear optical model. The calculated results were compared with the experimental data."

Further optical model calculations are in progress.

1.5. Status Report for NEANDC (H.-H. Knitter)

On behalf of the NEANDC two reports, each bringing the status of experimental measurements up to date, were written, one on "Average fission cross section of ^{238}U in the fission neutron spectrum of ^{235}U induced by thermal neutrons" and one on "The ratio of the fission cross section of ^{238}U to the one of ^{235}U."

1.6. Determination of Excitation Functions for the Reaction $^{103}Rh(n,n')^{103}Rh^{m}$ and $^{115}In(n,n')^{115}In^{m}$ in the region from threshold to 7 MeV (A. Paulsen, H. Liskien, R. Widera, F. Arnotte)

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Using the activation technique measurements have been made at 100 keV intervals for both reactions in the energy range 0.3 MeV to 4.1 MeV. Metallic rhodium and indium samples (discs 20 mm ∅, 5 mm thick) were irradiated with neutrons produced by the reaction $T(p,n)^{3}He$ (2.5, 3.0, 3.5 MeV proton energy) and the reaction $D(d,n)^{3}He$ (1.0 MeV deuteron energy). Activities have been obtained by counting the 20 keV X-rays of ^{103}Rh and the 336 keV γ-rays of $^{115}In^{m}$ respectively. Using the known angular distribution for each source condition and by irradiating simultaneously samples under various emission directions, sets of relative data have been obtained which were fitted to each other by minimizing the variance at all neutron energies. It is intended to extend these measurements up to 7 MeV neutron energy and to normalise them on an absolute basis.

2. RESONANCE NEUTRON DATA

The following superscripts indicate the affiliations of visiting scientists engaged in collaboration with CBNM programmes: + SCK/CEN, ++ University of Antwerp, +++ University of Catania, * Technische Hochschule, Darmstadt, ** Nationaal Fonds voor Wetenschappelijk Onderzoek, Brussels, *** CNEN-Bologna.

2.1. Resonance Parameters of ^{236}U

The extensive investigations on this isotope have been written in two reports. Titles, authors and abstracts read as follows:

714011 Neutron Cross Section Measurements on ^{236}U (L. Mewissen+, F. Poortmans+, G. Rohr, J. Theobald*, H. Weigmann, G. Vanpraet++)

"Capture, scattering and total cross-section measurements have been performed on ^{236}U, over an energy range from 30 eV up to 1.8 keV. The neutron width Γ_n could be determined for 97 levels and the capture width Γ_γ for 57 among them. The average radiative width is: $\overline{\Gamma}_\gamma = [23.0 \pm 0.3\ (stat.) \pm 1.5\ (syst.)]$ meV. For the s-wave strength function we find: $S_o = (1.05 \pm 0.14)10^{-4}$."

This paper has been presented at the "Conference on Nuclear Cross Sections and Technology" in Washington 1975.

Total neutron cross section measurements of ^{236}U in the energy range from 40 eV up to 4.1 keV. (G. Carraro, A. Brusegan)

"Transmission measurements have been performed on ^{236}U using the time-of-flight technique at a 100 m flight path of the 80 MeV electron linear accelerator of CBNM. Γ_n values have been evaluated for 185 resonances in the energy range from 40 eV to 4.1 keV. Assuming only s-wave contributions in the analysis range the average level spacing $\overline{D}$, the average reduced neutron width $\overline{\Gamma_n^o}$ and the strength function S_o were determined as

$D = (16.2 \pm 0.8)$ eV; $\overline{\Gamma_n^o} = (1.61 \pm 0.18)$meV; $S_o = (1.00 \pm 0.1) \cdot 10^{-4}$

The method of Fuketa and Harvey (NIM 33 (1965)107) was used to consider missed resonances. Finally Dyson's Δ_3- and W-statistics besides the method of Bollinger et al. were applied to put the presence of p-wave resonances in the analysis range into evidence."

This paper has been accepted for publication in Nuclear Physics.

2.2. Resonance Parameters of ^{238}U (E. Cornelis[++], L. Mewissen[+], F. Poortmans[+], G. Rohr, R. Shelley, T. van der Veen, G. Vanpraet[++], H. Weigmann)

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Capture cross section experiments

A series of capture and self indication measurements have been made in the energy range between 10 eV - 6 keV using various sample thicknesses (capture: $1.311 \cdot 10^{-5}$ at/b, $5.53 \cdot 10^{-5}$ at/b, $1.61 \cdot 10^{-3}$ at/b and $1.01 \cdot 10^{-2}$ at/b. Transmission: $6.31 \cdot 10^{-3}$ at/b and $1.10 \cdot 10^{-2}$ at/b). Gamma detection was by means of a pair of C_6F_6 scintillators at a 60m flightpath and the weighting method proposed by Maier-Leibnitz was applied. The neutron flux was measured by replacing the ^{238}U sample with a ^{10}B slab. Absolute calibration of the capture cross section has been achieved by means of the saturated resonance technique, using resonances in Ag. The area analysis of these data has been started. The expected accuracy of the final resonance parameters Γ_n, Γ_γ is between 5 - 10% depending on the energy range and the strength of the resonance.

Total cross-section experiments

A series of transmission experiments has been performed between 9 eV and 4 keV using various sample thicknesses ($7.48 \cdot 10^{-5}$ at/b, $1.609 \cdot 10^{-3}$ at/b, $3.781 \cdot 10^{-3}$ at/b, $1.009 \cdot 10^{-2}$ at/b and $3.481 \cdot 10^{-2}$ at/b). The samples which could be changed automatically, were mounted at 30 meter from the linac target, and the detector, consisting of four ^3He high pressure gaseous scintillators, was placed at 60 meter. Experiments were performed with samples cooled at liquid nitrogen temperature. All the measurements were done with a linac burst width of 23 nsec. The statistical precision on the transmission is better than 1% for most of the measurements. The analysis is nearly completed between 9 eV and 1 keV. For most of the s-wave resonances, the neutron width has been determined to better than 5%. The analysis above 1 keV is continued.

Scattering cross section experiments

Evaluation of the previously obtained data below 1.2 keV is in progress.

2.3. Resonance Parameters of ^{237}Np (A. Angeletti, L. Mewissen[+], F. Poortmans[+], G. Rohr, T. van der Veen, G. Vanpraet[++], H. Weigmann)

This work has been in temporary obeyance during this year.

2.4. Resonance Parameters of ^{226}Ra (H. Ceulemans[+])

The preliminary results on ^{226}Ra mentioned in the previous progress report have been superseded by new values of the resonance parameters obtained from a modified Atta-Harvey type shape analysis. This was done on transmission data obtained with the 5.9 10^{-3} atoms/barn sample, and using a resolution function of the form $R^2(E) = R_o^2 E^3 + R_1^2 E^2 (eV^2)$(energy in eV). Numerical values used are: R_1 = 0.0016 and R_o = 3.16 10^{-5}, 5.0 10^{-5}, 9.22 10^{-5} and 1.80 10^{-4} for the different timing zones covering respectively the energy intervals 600 to 277 eV, 277 to 104 eV, 104 to 33 eV and 33 to 9.4 eV. For the analysis, the value Γ_γ = 30 meV was used, to obtain a value for Γ_n. Variation of the value assumed for Γ_γ would also change, to a variable extent, the resulting Γ_n and the same is true for a variation of the resolution width. Both effects have been taken into account in quoting the fluctuations on the individual results (see table 2.1.)

The transmission results have been extended up to 2.5 keV, with a very noticeable decrease of detail towards the high-energy end.

Table 2.1.

E_o (eV)	Γ_n (meV)	Γ_n^o (meV$^{\frac{1}{2}}$)
24.25 ± 0.01	0.016 ± 0.002	0.0032 ± 0.0004
39.14 ± 0.01	0.07 ± 0.02	0.011 ± 0.003
39.72 ± 0.01	0.42 ± 0.04	0.085 ± 0.008
55.53 ± 0.01	6.4 ± 0.6	0.85 ± 0.08
80.45 ± 0.04	0.15 ± 0.02	0.017 ± 0.002
88.16 ± 0.02	27.0 ± 2.0	2.9 ± 0.2
154.6 ± 0.1	1.65 ± 0.3	0.13 ± 0.02
217.5 ± 0.1	2.4 ± 0.5	0.16 ± 0.03
236.5 ± 0.1	187 ± 20	12.2 ± 1.3
261.9 ± 0.1	15 ± 3	0.9 ± 0.2
290.3 ± 0.1	180 ± 20	10.6 ± 1.2
328.0 ± 0.1	134 ± 15	7.4 ± 0.8
346.6 ± 0.1	250 ± 25	13.4 ± 1.3
375.9 ± 0.1	95 ± 10	4.9 ± 0.5

Table 3.1. (contd.)

E_o (eV)	Γ_n(meV)	Γ_n^o (meV$^{\frac{1}{2}}$)
396.8 ± 0.1	240 ± 25	12.0 ± 1.3
460.1 ± 0.2	23.7 ± 3.0	1.1 ± 0.15
470.8 ± 0.2	17 ± 2	0.8 ± 0.1
481.7 ± 0.2	7.7 ± 2	0.35 ± 0.1
522.2 ± 0.2	83 ± 10	3.6 ± 0.4

2.5. Resonance Parameters of ^{91}Zr and ^{96}Zr (A. Brusegan, G. Rohr, T. van der Veen)

Capture cross section measurements have been performed on an enriched ^{96}Zr sample ($4.78 \cdot 10^{-3}$ at/b) using a pair of C_6F_6 de-
691156 741074 tectors and applying the spectrum weighting technique. The flight-path length was 60 m.

The analysis of the capture and self indication data obtained in a previous experiment on ^{91}Zr sample (8.184 at/b) in the same energy range is in progress.

2.6. Resonance Parameters of Nb (L. Mewissen+, F. Poortmans+, G. Rohr, T. van der Veen, J. Winter)

Total cross section measurements (30 eV - 7 keV)

σ_T data were obtained with four high pressure ^3He gaseous scintillators at 60m and 3 samples ($4.23 \cdot 10^{-3}$at/b, $1.27 \cdot 10^{-2}$ at/b and $2.53 \cdot 10^{-2}$ at/b) cooled down to liquid nitrogen temperature. Area analysis is in progress. Shape analysis was possible for 5 resonances below 200 eV yielding Γ_γ values which are in agreement with the values quoted in BNL 325 but which show a smaller spread.

Scattering cross section measurements (30 eV - 4 keV)

Measurements have been performed with 6 high pressure ^3He gaseous scintillators placed at 30 m on two different samples ($4.25 \cdot 10^{-3}$ at/b and $1.27 \cdot 10^{-2}$ at/b). The resolution being sufficient to resolve most of the resonances, the data were normalised relative to the scattering cross section of Pb.

Capture cross section and self indication ratio measurements (30 eV-7keV)

The capture experiments were carried out on a sample, $5.463 \cdot 10^{-3}$ at/b, at 60m with two C_6F_6 scintillators for γ-ray detection.

The neutron flux was measured by replacing the Nb sample with a ^{10}B slab. Saturated Ag resonances served for the normalisation. The self indication ratio data were obtained with a sample thickness of $2.235 \cdot 10^{-2}$ at/b. Data analysis is in progress.

p-wave assignment

The capture data measured with the C_6F_6 detector have been used for parity assignment of resonances, comparing time of flight spectra taken with a high amplitude bias with those with a low bias. The results are in very good agreement with the results of the low population method as reported last year.

2.7. Resonance Parameters of ^{127}I (G. Rohr, R. Shelley)

Motivated by a direct request from RCN Petten (in relation to the STEK-project concerned with integral measurements of the capture cross section of fission products) for Γ_γ values of ^{127}I a series of capture, self indication and transmission measurements have been carried out on PbI_2 samples in the energy range from 20 eV - 5 keV. All measurements have been performed using a pair of C_6F_6-detectors at a 60 m flightpath. For the capture cross section data the weighting method proposed by Maier-Leibnitz has been used. Absolute calibration of the capture cross section has been obtained by the saturated resonance technique using Ag resonances. For the total cross section and the flux measurement the capture sample was replaced by a ^{10}B slab. Area analysis of the capture data has been started. The expected accuracy of the final resonance parameters $g \cdot \Gamma_n$ and Γ_γ is between 7% and 20% depending on the energy range and the strength of the resonances.

2.8. Resonance Parameters of ^{177}Hf (G. Rohr, H. Weigmann)

The results of the ^{177}Hf measurements have been submitted to Nuclear Physics for publication with the title "Short Range Energy-Dependence of the Neutron Widths of ^{177}Hf Resonances". The abstract reads as follows:

"Neutron widths of ^{177}Hf+n resonances have been determined from neutron radiative capture and self-indication measurements. Together with resonance spin classification of Coceva et al. (Proc. Int. Conf. on Stat. prop. of Nuclei, Albany 1971), the data have been used to study spin- and energy dependence of the neutron strength

function. A statistically significant energy dependence of the strength function for spin 4^- has been observed. Various statistical tests show the presence of two narrow structures with a "spreading width" of the order of the level spacing (~ 5 eV)."

2.9. Intermediate Structure in the keV Fission Cross Section of ^{235}U (E. Migneco+++, P. Bosignore+++, G. Lanzano+++, J.A. Wartena, H. Weigmann)

A paper with this title was presented at the Conference on Nuclear Cross Sections and Technology in Washington 1975. The abstract is:

"The relative fission cross section of ^{235}U has been measured up to 200 keV with a nominal resolution of 1.0 ns/m, using a thin foil plastic scintillator detector. The data have been analysed in order to detect nonstatistical effects due to intermediate structure. Statistical tests which have been applied to this fission and similar total cross section data include calculations of the autocorrelation function and Wald-Wolfowitz tests on the cross-sections and on the autocorrelograms. The comparison of the results indicates the presence of intermediate structure effects in the fission cross-section which may be interpreted on the basis of the double-humped deformation potential."

2.10. Sub-Barrier Fission of ^{238}U (E. Migneco+++, J.A. Wartena, H. Weigmann)

A paper was presented at the Conference on Nuclear Cross
691416 Sections and Technology in Washington, 1975. The abstract is:

"Sub-barrier fission in ^{238}U has first been observed by R. Block et al., using ionisation chambers for fission fragment detection. In the present measurements a liquid scintillator was used to detect prompt fission neutrons. Thereby, with a sample of 250 g of ^{238}U, neutron time-of-flight measurements could be performed at a 30 m flightpath with a nominal resolution of 1.3 nsec/m. The result of the present investigation is a full confirmation of the findings of Block et al. This includes a confirmation, by high resolution data, of the fact that the resonances at 721.0 eV and 1210.7 eV contribute most strongly to the observed fission in the two sub-barrier structures at low neutron energies. Their fission widths are found to be (0.85 ± 0.13)meV and (0.25 ± 0.05)meV, respectively (assuming Γ_γ = 23 meV).

For most of the other resonances in these two structures only upper limits for the fission widths are obtained."

2.11. Fission Cross Section Measurements on ^{239}Pu (R. Barthélémy, C. Wagemans**, J.A. Wartena, H. Weigmann)

Preliminary measurements of the ^{239}Pu fission cross section and neutron multiplicity have been carried out with a new liquid scintillator detector. Fission cross section determination via fragment detection has been performed with large areas surface barrier detectors. The analysis range extends from 5 eV to 35 keV. The measurements will be continued after Linac modernisation.

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2.12. Fission Fragment Kinetic Energy and Mass Distributions for the Neutron Induced Fission of ^{235}U (C. Wagemans**, H. Weigmann, G. Wegener-Penning+ and R. Barthélémy)

The capacity of the three-dimensional analysing system has been improved by coupling a 20 bit EMI magnetic tape to the Tridac system. This allows the simultaneous recording of correlated fission fragment pairs (E_1, E_2) in a 128 x 128 channels matrix for 64 time-of-flight addresses. Measurements were performed with two different ^{235}U layers. Three neutron energy regions were selected: from 10 keV to 300 keV and the two strong resonances at 8.79 eV (J=4) and 12.39 eV (J = 3). From these data the total fission fragment kinetic energy (E_K) distributions as well as the mass distributions were calculated as functions of the incident neutron energies. With the actual statistical accuracy no significant differences are found between the mean total fission fragment kinetic energies $\bar{E}_K$ nor between the symmetric-to-asymmetric fission yields for both resonances. In the neutron energy region from 10 to 300 keV a significant and systematic decrease of $\bar{E}_K$ with increasing neutron energy is observed. The symmetric-to-asymmetric fission yields are considerably higher in the keV region than for both resonances considered.

Higher resolution measurements will be performed to determine more precise mass-distributions. At the same occasion several well-resolved resonances with well-known spin values will be measured in order to investigate the correlation between $\bar{E}_K$, symmetric-to-asymmetric fission yields and resonance spin.

2.13. Capture to Fission Ratio α of ^{235}U, from the Measurement of Low-Energy γ-rays (F. Corvi, P. Giacobbe***)

This work was presented at the Conference on Nuclear Cross Sections and Technology in Washington, 1975. The abstract of the paper is as follows:

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"A new technique of α-determination is presented, consisting of measuring with a Ge(Li)-detector low-energy γ-ray spectra following neutron absorption in ^{235}U, as a function of neutron energy. A relative value of α can then be deduced assuming that the intensity of a given capture (fission) γ-ray is proportional to the average capture (fission) cross-section. Such an assumption is thoroughly discussed in the text. More specifically, α was taken proportional to the ratio between the intensity of the 642 keV capture transition and those of the fission γ-rays at 352 keV and 1280 keV. Average α-values with statistical errors less or equal to $\pm$ 5% were determined for 20 intervals in the range 86 eV - 31.6 keV".

2.14. p-Wave Assignment of ^{238}U Neutron Resonances (F. Corvi, G. Rohr, H. Weigmann)

A paper, with the following abstract was presented at the Conference on Nuclear Cross Sections and Technology in Washington, 1975.

"A method of p-wave assignment of ^{238}U resonances is presented, consisting of measuring the fraction of capture γ-rays above 4.3 MeV for neutron resonances in the range 10 - 1600 eV. In this way 57 resonances showing an enhancement of the high energy γ-ray yield, were identified as p-waves. In addition, a capture cross-section measurement was performed on a $6.32 \cdot 10^{-3}$ at/barn thick sample in order to obtain the $g\Gamma_n^1$ values of such small resonances. The derived final estimates of the p-wave strength function S_1 and of the s-wave level spacing D_o are: $S_1 = (2.3 \begin{smallmatrix} +0.5 \\ -0.4 \end{smallmatrix}) \cdot 10^{-4}$; $D_o = (22.4 \pm 1.0)$ eV."

2.15. p-Wave Assignment of ^{232}Th Neutron Resonances (F. Corvi, R. Shelley, T. an der Veen).

The p-wave assignment technique described in 3.14 above was applied also to the ^{232}Th case. The yield of high-energy capture γ-rays above 4.4 MeV from a 6 mm thick metallic sample was measured in the neutron energy range 110 - 2200 eV at a 50 m long

flightpath. This run was then compared to a normalisation run in which γ-rays in the range 3.7 - 4.4 MeV were detected: such a high threshold was chosen in order to cut down the γ-activity from the decay of the daughter product ^{208}Tl. Even so, residual summing effects from this activity contributed more than 50% of the total background.

The ratios R between the resonance areas of the two runs are plotted against $g\Gamma_n\sqrt{E_n}$ in fig. 2.1: the picture is similar to that already found for ^{238}U, with weak resonances showing high R values while most strong levels have values falling below the dotted line at R = 0.59. On the basis of such a plot and of additional calculations, we identify as p-waves those resonances which satisfy the following two conditions: a) $(R - \Delta R) > 0.59$; b) $g\Gamma_n/E_n < 0.15$ meV.

A preliminary list of 46 p-wave assignments based on such requirements are given in table 2.2. It is planned to repeat the measurements with the upgraded Linac at a shorter flightpath (L = 30 m) in order to improve the statistical accuracy and the signal-to-background ratio.

2.16 Controversy on Fission Fragment Energy Variations in ^{235}U Neutron Resonances (R. Barthélémy, C. Wagemans,* J. Wartena, H. Weigmann)

Recently, Felvini et al. (Proc. of the Conference on Nuclear Cross Sections and Technology, Washington 1975, NBS Special Publ. 425, p. 580) observed strong variations of the energy distribution of fission fragments as a function of neutron energy for the resonance neutron induced fission of ^{235}U. Since this would have important consequences on both fission theory and fission cross-section measurements, we undertook a very similar measurement. Under comparable measuring conditions we recorded 8.5×10^5 fission events in the energy range from 0.6 to 23 eV, i.e. five times more than in the case of Felvinci et al. Detailed statistical tests were applied to the data, demonstrating that no fluctuations stronger than should be expected from counting statistics are present.

A more detailed report on these measurements has been published in Phys. Rev. Lett. 35, 18 (1975)1213 with the following abstract: "Measurements have been made to check recent findings of fission

Table 2.2.

p-Wave Resonances of ^{232}Th

E_n(eV)	R	±	ΔR	E_n(eV)	R	±	ΔR
128.2	0.90		0.15	997.1	0.88		0.17
145.9	1.12		0.11	1044.9	1.11		0.21
167.7	2.15		0.71	1049.8	1.13		0.42
168.2	1.18		0.29	1115.9	1.04		0.11
196.2	1.13		0.11	1117.5	0.86		0.18
201.3	1.10		0.17	1206.2	1.15		0.18
202.7	0.81		0.18	1234.8	1.22		0.34
242.4	1.89		1.00	1347.2	1.74		0.61
299.9	3.12		2.32	1373.9	1.07		0.23
302.7	0.99		0.19	1389.2	0.81		0.13
380.6	1.34		0.31	1408.0	1.01		0.41
392.0	1.03		0.41	1613.4	1.82		0.70
412.2	1.45		0.24	1626.0	1.35		0.54
459.1	1.36		0.47	1645.8	1.68		0.23
476.5	1.63		0.78	1692.9	1.17		0.51
533.9	1.05		0.17	1732.1	1.30		0.27
535.9	1.08		0.12	1787.9	1.21		0.41
574.2	1.58		0.08	1838.8	1.55		0.50
765.2	0.97		0.17	1850.6	0.84		0.14
802.4	1.35		0.46	1876.2	1.46		1.71
821.9	0.80		0.15	1896.6	1.18		0.10
851.6	0.76		0.11	1917.5	2.14		0.80
919.8	1.56		0.58	2104.8	3.62		2.66

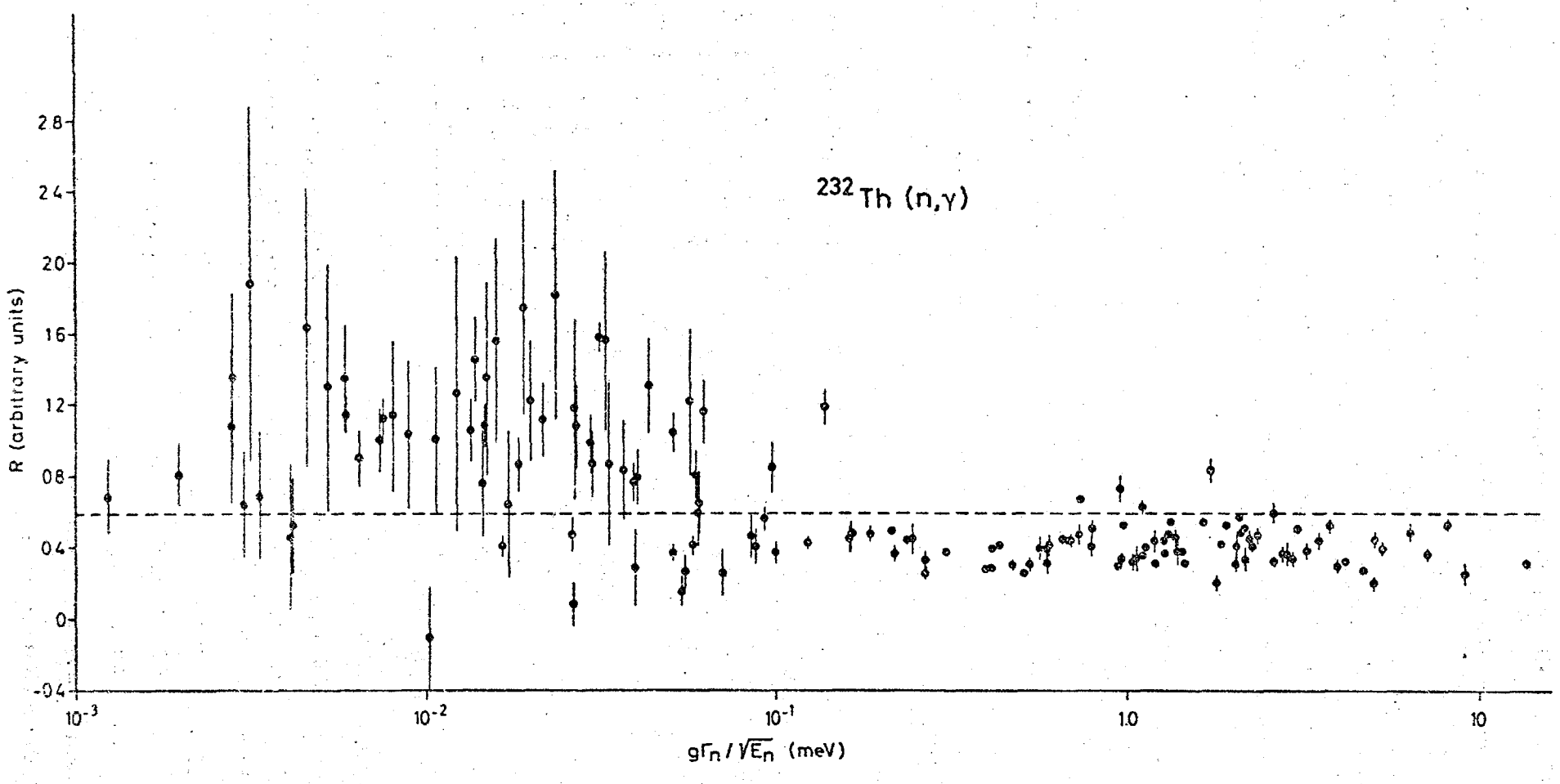

Fig. 2.1. Plot of R values against $g\Gamma_n / \sqrt{E_n}$ for ^{232}Th neutron resonances in the range 110 - 2200 eV.

fragment energy variations in low energy neutron resonances of ^{235}U. The result has been negative."

2.17. Precision Neutron Energy Determination of C, Na, ^{6}Li, ^{7}Li and ^{238}U resonances (K.H. Böckhoff, F. Corvi, A. Dufrasne)

Discrepancies in the neutron energy scales of different laboratories have stimulated an investigation of the neutron energy calibration at our Linac by measuring neutron resonance energies from the MeV range down to the eV range and comparing them with the results of other laboratories.

a) Carbon resonances

Experiment: transmission without moderator
determination of resonance minima

Detector: plastic scintillator viewed by three 60 AVP photomultipliers

Flightpath length: 400 m

Burst and channel widths: 10 ns each

Results: (in keV) compared with results from other laboratories

Karlsruhe 68[1]	Wisconsin 69[2]	NBS 75[3]	Geel 75	BNL 325
Cyclotron	Van de Graaff	Linac	Linac	---
	2079 ± 3	2079 ± 3	2077 ± 3	2077 ± 2
	2819 ± 3	2819 ± 5	2817 ± 3	2818 ± 4
4933±5	4935 ± 4	4940 ± 11	4935 ± 8	4936 ± 6
5369±6	5368 ± 5	5378 ± 13	5368 ± 9	5366 ± 6
6293±8	6294 ± 8	6295 ± 16	6292 ± 11	6293 ± 5

1) S. Cierjacks, Proc. Conf. Nucl. Data, Vol. II, Helsinki, 15-19 June, 15-19 June, 1970, p. 238.

2) J.C. Davis and F.T. Noda, Nucl. Phys. A 134 (1969), 361-368

3) H.T. Heaton II, J.L. Menke, R.A. Schrack, R.B. Schwartz, Nucl. Sci. Eng. 56 (1975), 26-36.

b) Sodium resonances

Experiment for 1602.9 keV resonance: as in case a)

Experiment for 299.4 keV resonance:

- Transmission with moderator
- ^{10}B-NaI detection system
- Flightpath length: 100 m

Results (in keV) compared with results from other laboratories.

Karlsruhe 69[4]	Columbia 73[4]	Harwell(I)74[4]	Harwell(II)74[4]	Geel 75
Cyclotron	Synchrocyclotron	Linac	Synchrocyclotron	Linac
299.5±0.1 1602.9±1.4	298.5±1.0	298.8±2.3	299.19±0.12	299.4±0.4 1603.8±1.2

c) Lithium-6 Resonance (see also chapter 4.1)

The energy of the peak of the ^{6}Li total cross section has been determined from Legendre polynomial least squares fits to the cross section data of 3 independent transmission experiments (with 2 different thicknesses of ^{6}Li enriched samples), each of them performed simultaneously with a transmission experiment on natural Li so that the ^{7}Li contribution could be subtracted directly. The resonance energy as obtained from a Breit-Wigner fit (Knitter) agreed within 0.1 keV with the value from a polynomial fit. Statistical accuracy of the σ_T data points around t peak of the resonance is ~ 1%. The distance between these data points at the peak is 700 eV. Flightpath length was 100 m, burst and channel widths 20 ns each. The measurements were done with the ^{10}B-NaI detector.

Results (in keV)

Linac values

Harwell(I)74[4]	Harwell(II)74[4]	Oak Ridge 75	Geel 75
243.5 ± 1	242.71 ± 0.33	(246.0 ± 0.25)[5]	244.9 ± 0.5 245.1 ± 0.5 245.0 ± 0.5

Van de Graaff values

Argonne 68 (I)[4]	Argonne 68 (II)[4]	Argonne 72 (III)[4]	Geel 75
250	250.6 ± 2	252.5	248.7 ± 3

d) Lithium-7 Resonance

The energy position of the peak cross section was determined by a Legendre polynomial fit applied to the data obtained in experiment (c) on natural Li and was corrected for ^{6}Li. The result is:

$$E_R = 255.2 \pm 0.5 \text{ keV}$$

4) G.D. James, D.B. Syme, P.H. Bowen, P.E. Dolley, AERE Report 7919.

5) Proc. of the Conf. on Nucl. Cross Sections and Technology, Washington DC, March 3-7, 1975, 244-245.

e) ^{238}U Resonances

Experiment: capture

Detector: 7" x 6" NaI crystal

Flightpath length: 50 and 200 m

Burst and channel widths: 20 ns each.

The energy values of ^{238}U neutron resonances deduced from the data of section 2.13. which were taken at a 50 m flightpath display a systematic shift as compared to the data of Rahn et al. (Phys. Rev. C, Vol. 6, Number 5, 1854-1869) performed at a 200 m flightpath. A capture run was therefore made at 200 m to check the Geel 50 m data. There was very good agreement between the two Geel runs. As a further precaution the flight-path for the nominal 200 m run was measured with an Invar tape yielding a precision in linegth of 1 part in 10^5. The energies of a selected number of ^{238}U resonances are compared in a table for the two Geel runs and the Columbia data set. The last column gives the relative differences between the 200 m runs of Columbia and Geel. From the approximate constancy of these differences in energy and its average value of 0.1% one may conclude that the flightpath length determinations of both laboratories differ by about 10 cm.

Energies in eV of ^{238}U neutron resonances

Geel (50 m)	Geel (200 m)	Columbia 1 (200 m)	Relative Difference
2673.9 ± 0.8	2674.0 ± 0.8	2671.3 ± 0.9	+1.00 -0.3
2490.7 ± 0.7	2490.8 ± 0.4	2488.4 ± 0.7	+0.96 -03
2457.2 ± 0.7	2457.3 ± 0.4	2454.8 ± 0.7	+1.02 -03
2428.3 ± 0.7	2428.8 ± 0.4	2425.7 ± 0.7	+1.63 -03
2393.5 ± 0.7	2393.6 ± 0.4	2391.4 ± 0.7	+0.92 -03
2282.2 ± 0.6	2283.2 ± 0.4	2281.7 ± 0.7	+0.66 -03
2146.9 ± 0.6	2146.7 ± 0.3	2144.6 ± 0.6	+0.98 -03
2097.5 ± 0.6	2097.6 ± 0.3	2095.9 ± 0.6	+0.81 -03
2031.7 ± 0.5	2031.9 ± 0.3	2029.8 ± 0.6	+1.03 -03
1809.4 ± 0.5	1809.5 ± 0.2	1807.9 ± 0.5	+0.88 -03
1639.0 ± 0.4	1639.1 ± 0.3	1637.4 ± 0.5	+1.04 -03
1474.6 ± 0.4	1474.6 ± 0.3	1473.4 ± 0.4	+0.81 -03
1444.8 ± 0.3	1445.1 ± 0.3	1443.5 ± 0.4	+1.11 -03
1428.7 ± 0.3	1428.8 ± 0.3	1427.4 ± 0.4	+0.98 -03
	1420.7 ± 0.3	1419.2 ± 0.3	+1.06 -03

3. STANDARD NEUTRON CROSS SECTION DATA AND RELATED INVESTIGATIONS

3.1. Measurements Pertaining to the $^{6}Li(n,\alpha)$ Cross Sections

Measurements on H, C, ^{6}Li and ^{7}Li in the keV-MeV range using a "white" source. (K.H. Böckhoff, A. Dufrasne)

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692005
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713002
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721009
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742024

Since the results of the previous measurement series showed up to 3% deviations from recent literature data, a new series of transmission measurements on H, C, and ^{6}Li and ^{7}Li has been performed at a 100 m flightpath (20 ns burst and channel widths) after modification of some experimental conditions (neutron monitor, collimation, electronics) and careful check of others. Pieces of lead, 3 mm thick, placed between the ^{10}B slab and each of the 4 NaI crystals reduced the γ-flash signal to a 1.5 MeV pulse.

The total cross section data of hydrogen was obtained from transmission experiments on two research grade polyethylene samples of different thicknesses and one reactor grade graphite sample employed in the same sample changer sequence. Fig. 3.1 shows how a least squares fit to the data deviates from the corresponding fit to the ENDF/B IV data. Fig. 3.2. displays the percentage deviations of least squares fits to the carbon total cross section data of this and other experiments.

In a transmission experiment using 20 cm of iron in the beam a total cross section for carbon of 4.650 barns was found at the "neutron windows" near 24 keV, which agrees within 0.7% with the value obtained in a similar experiment by Block et al. (CINDA 75).

The total cross sections of ^{6}Li and ^{7}Li obtained from quasi-simultaneous transmission experiments on three ^{6}Li enriched samples and one natural Li sample are plotted in Fig. 3.3. The ^{6}Li peak cross sections as determined from the experiments with the two thinner samples and polynomial least squares fits yielded the same value of $\sigma_T = 10.7 \pm 0.1$ b. The energy of the maximum of σ_T in the resonance is 245.0 ± 0.5 keV.

The total cross section results presented here still show unexplained systematic deviations in parts of the analysed energy range from the results of other authors. An explanation has not yet been found.

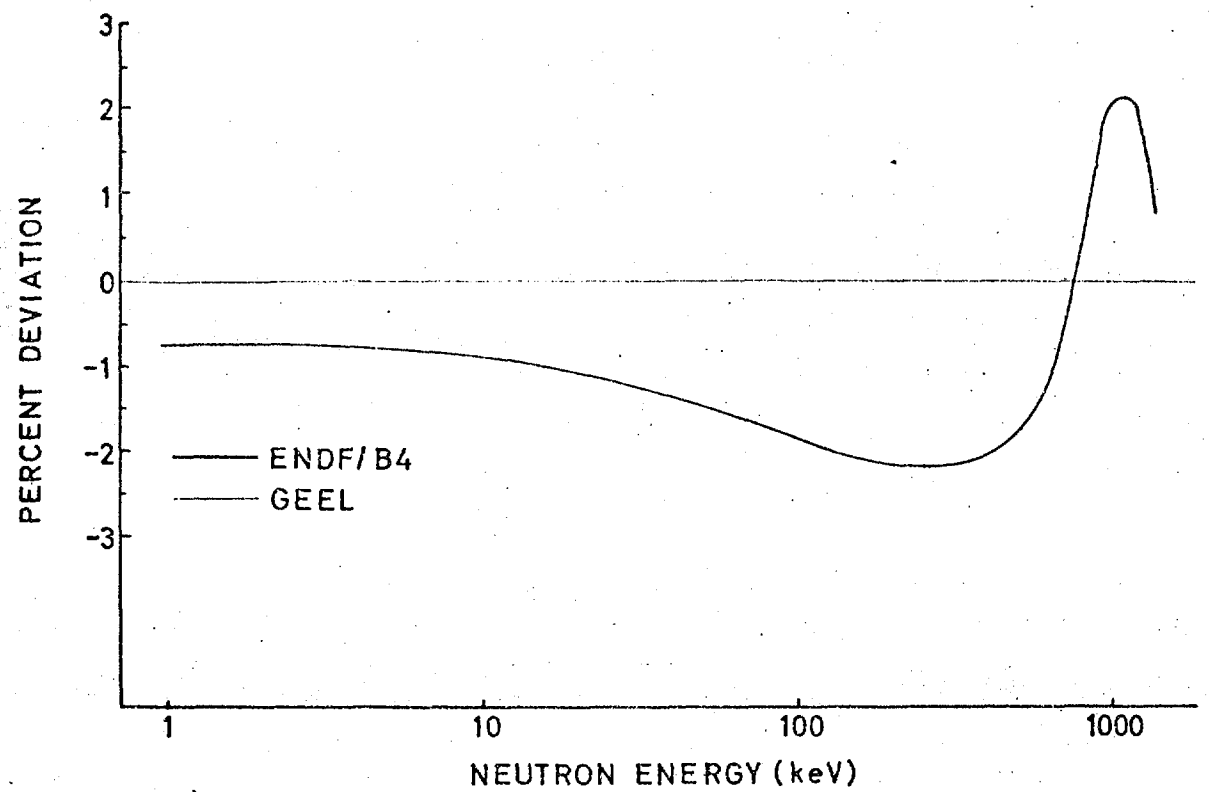

Fig. 3.1

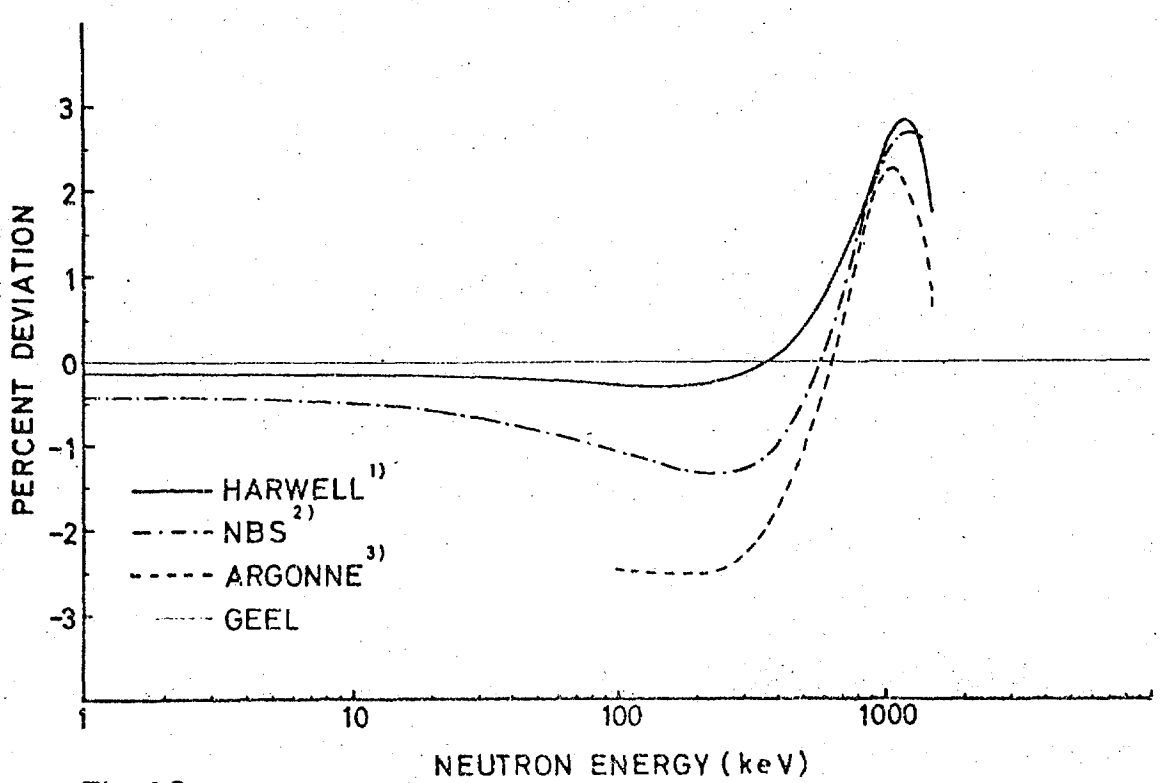

Fig. 3.2

1) C.A. Uttley, K.M. Diment, Proc. Symp. Neutron Standards and Flux Normalisation, Conf. 701002, p 201, US Atomic Energy Commission (1971).

2) H.T. Heaton II, J.L. Menke, R.A. Schrack, R.B. Schwartz Nucl. Sci. Eng. 56, 27-36 (1975).

3) J.W. Meadows and J.F. Whalen, Nucl. Sci. Eng 41, 351 (1970).

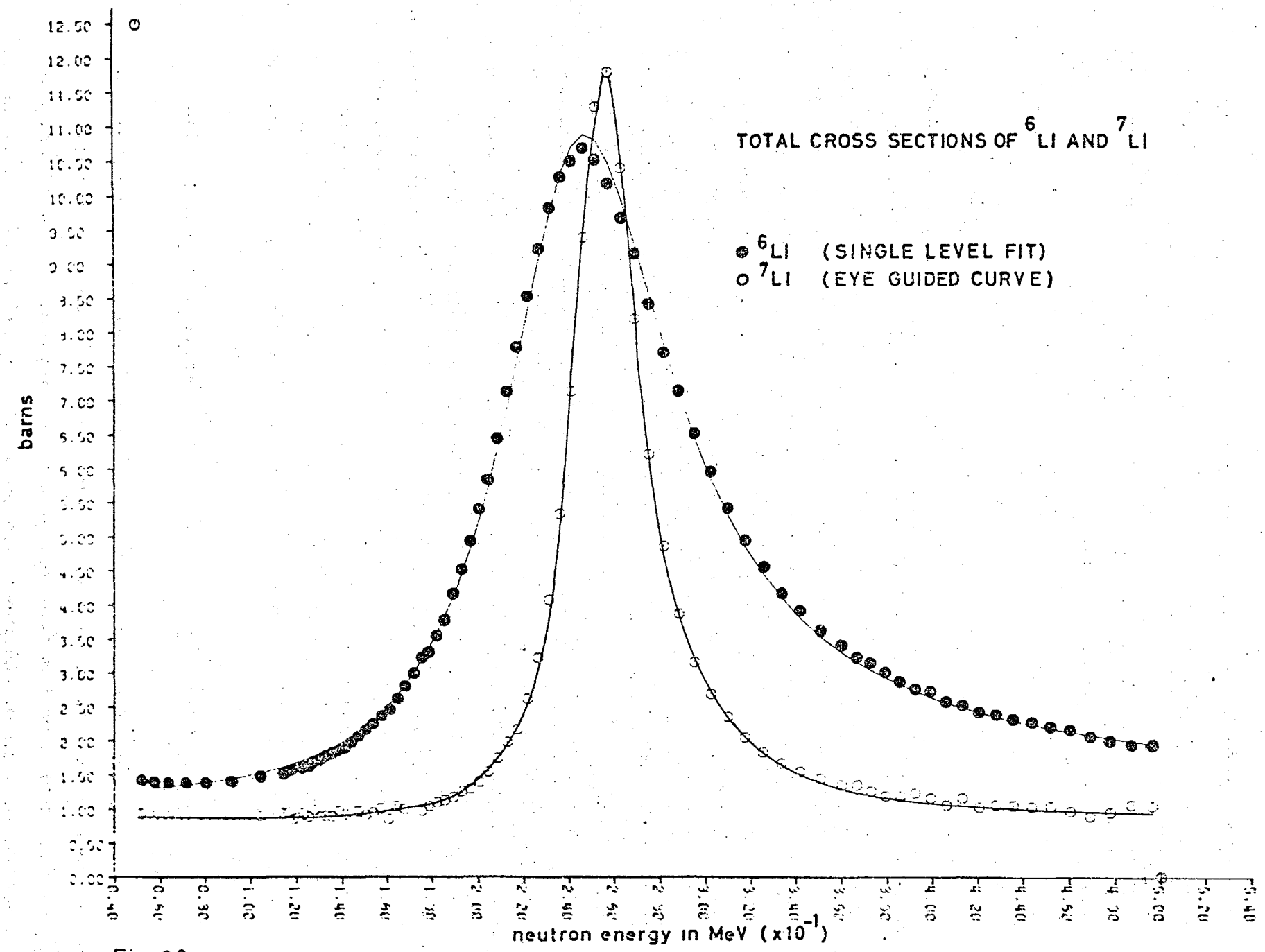
TOTAL CROSS SECTIONS OF ^{6}LI AND ^{7}LI
● ^{6}LI (SINGLE LEVEL FIT)
○ ^{7}LI (EYE GUIDED CURVE)
barns
neutron energy in MeV (x10^{-1})

Fig. 33

At present it cannot be excluded that the 2.2 MeV γ's from neutron capture in the polyethylene moderator have a higher influence on the results than assumed.

Measurements of neutron total and elastic scattering cross section of ^{6}Li with the monoenergetic beam technique (H.-H. Knitter, C. Budtz-Jørgensen, M. Mailly, R. Vogt)

The total cross section measurements of ^{6}Li have been completed in the energy range from 0.1 to 3.0 MeV neutron energy using the transmission method and the monoenergetic beam technique. Since the total cross section changes by about a factor of 10 over the resonance near 250 keV incident neutron energy, three different samples were used in the measurements in order to keep the transmission between 0.5 and 0.7. Corrections due to the inscattering effect, isotopic content of ^{7}Li, electronic deadtime and due to the energy spread of the incident neutrons were applied to the raw experimental data.

Elastic neutron scattering angular distributions were measured at the following incident neutron energies: 0.22, 0.25, 0.27, 0.30, 0.32, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80, 2.90 and 3.00 MeV. Analysis of the data is nearly complete. In the energy range from 1.0 to 2.3 MeV the data agree with those obtained previously (Knitter and Coppola, EUR 3454.e 1967).

A fit with a single Breit-Wigner level and a background was made to the total cross section data only. This gave a maximum value at 248.7 ± 3.0 keV and a value of 3.27 ± 0.14b for the peak(n,α)cross-section. When analysis of the elastic scattering cross section data is completed, the whole data set will be treated using the S-matrix formalism and it is hoped to obtain the integrated cross section as well as the angular distributions as a function of the incident neutron energy of the reaction $^{6}Li(n,t)^{4}He$.

Measurement of the ^{6}Li to $^{10}B(n,\alpha)$ cross-section ratio (C. Bastian, G. Le Dez).

Apparatus for carrying out this measurement as described in the
642001 previous report is in an advanced stage of construction. The gas scin-
682004
691022 tillation technique has been tested with the α-particles from a uranium deposit in a small container through which purified Xenon is circulated.

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754025

Two quartz window photomultipliers view the gas. Good separation of the α-particle scintillations from background is obtained; the pulse amplitude decreases noticeably in about 2 days after disconnecting the container from the purification loop.

3.2. Determination of $^{197}Au(n,\gamma)$ Cross Sections in the 0.2 to 3.0 MeV Region (A. Paulsen, H. Liskien, R. Widera, F. Arnotte)

This work was finished and published (A. Paulsen, R. Widera, H. Liskien, Atomkernenergie 26 (1975) 80 with the following abstract:

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"Cross sections for the standard capture reaction $^{197}Au(n,\gamma)^{198}Au$ were measured between 0.2 and 3.0 MeV neutron energy with an accuracy better than ± 5% by means of the sample activation technique. Quasi-monoenergetic neutrons were produced at the 3.7 MV Van de Graaff accelerator of the CBNM and the neutron fluences were determined by a proton recoil proportional or telescope counter."

In addition the following information is given here: The neutron fluence determinations are based on the integral and differential n-p scattering cross sections as given in ENDF/B-IV. The induced activities were measured by means of a Ge(Li) gamma spectrometer in comparison with ^{198}Au calibration sources which resembled the activation samples with respect to material and geometry. Corrections were applied for neutron beam attenuation within the sample, for neutron in-scattering by target backing and holder and for thermal and epithermal neutrons. When compared with earlier measurements published since 1969 the present results are not systematically higher than the corresponding results of the prompt γ detection measurements.

3.3. Measurements Pertaining to Absolute Fission Cross-Section Data

Measurement and normalisation of the relative ^{241}Pu fission cross-section in the thermal and low resonance region. (C. Wagemans**, A.J. Deruytter****, R. Barthélémy)

A report has been written and is accepted for publication in Nucl. Sc. Eng. The abstract is:

"The neutron induced fission cross-section of ^{241}Pu has been measured at an eight meter flightpath of the CBNM Linac from 50 eV to 0.01 eV, allowing a direct normalisation to the 2200 m/sec reference cross section. The fission reaction rate and the neutron flux

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****University of Ghent

were determined simultaneously with surface barrier detectors placed on each side of back-to-back ^{241}Pu and ^{10}B layers. The fission cross-section was determined assuming a 1/v behaviour of the $^{10}B(n,\alpha)^{7}Li$ cross-section. Several fission and resonance integrals were calculated from the normalised σ_f-curve and compared with other results. Also the 20.44°C Westcott factor was calculated, yielding $g_f = 1.046 \pm 0.006$."

Measurement of the fission cross section of ^{235}U in the energy region from 5 eV to 30 keV (C. Wagemans**, R. Barthélémy, J. Van Gils)

The neutron induced fission cross-section of ^{235}U was measured
6601043 et al. on pages 70, 71, 72 of WRENDA LIST relative to the $^{10}B(n,\alpha)^{7}Li$ reaction. In addition the flux determination was verified using also the $^{6}Li(n,t)^{4}He$ reaction. Fission fragments and α particles were detected with Si-surface barrier detectors and the black-resonance technique was used for the background determination. The data have been normalised to the fission integral $\int_{7.8eV}^{11\ eV} \sigma_f(E)dE = (240.1 \pm 2.1)$ b·eV determined in a previous measurement (JNE 25 (1975) 263), which was itself normalised to the absolute 2200 m/s fission cross-section value (587.6 ± 2.6)b determined by Deruytter et al. (JNE 27 (1973)645). A critical analysis of published cross section data shows that discrepancies may be explained to a large extent by the very different normalisation methods.

Determination of the fission cross-section of ^{233}U from 0.002 eV to 0.15 eV and its reference value at 2200 m/s (R. Buyl, J. Van Gils, E. Wattecamps)

The purpose of the experiment is to determine σ_f of ^{233}U relative to $^{10}B(n,\alpha)^{7}Li$ from 0.002 eV to 0.15 eV and to determine
621035 621036 692342 753025 in particular the reference value σ_f° at 2200 m/s in absolute units to within 0.5% accuracy. The slow chopper facility at the BR-2 reactor of the SCK laboratory is being used. Since σ_f° of ^{235}U is already known and since ^{235}U causes less radiation damage to the semi-conductor detector, preliminary measurements are being made on σ_f ^{235}U relative to ^{10}B. To discover and reduce as far as possible systematic errors, three ^{235}U samples and four ^{10}B samples were investigated, thus allowing cross-checks. The accuracy obtained so far for σ_f° of ^{235}U is 2%, but the poor accuracy is mainly due to poor statistical accuracy and bad pulse height resolution of the α and ^{7}Li peaks. New detectors

with 25 keV pulse height resolution (for 1.5 MeV α) have now been incorporated and means for increasing the flux and thus improving the statistical accuracy are under study.

3.4. Participation in the International Fast Neutron Fluence Intercomparisons by BIPM (H. Liskien, A. Paulsen, R. Widera)

The series of intercomparison done in 1974 have been completed in May 1975 by irradiating about 80 mg/cm^2 thick iron foils in known 14.8 MeV neutron fluxes. The "saturated" β-emission rate at the end of the irradiation serves as a basis for interlab comparison. No correction for selfabsorption is applied; "saturated" means that the results are corrected for the finite irradiation time applied. CBNM fluxes were determined via proton recoil telescopes. Final results are:

Foil	Weight (g)	"Efficiency" (β/n/cm^2)	Stat. uncert. (%)	Syst/uncert. (%)
Fe-44	0.4128	$3.22 \cdot 10^{-4}$	0.8	2.5
Fe-45	0.4057	$3.22 \cdot 10^{-4}$	0.9	2.5
Fe-46	0.4085	$3.18 \cdot 10^{-4}$	0.9	2.5

The foils were received from NPL Teddington and have been passed on to ETL, Tokyo.

4. NON-NEUTRON NUCLEAR AND ATOMIC DATA

4.1. Half-lives of Actinides

Status Report for NEANDC. (R. Vaninbroukx)

On behalf of the NEANDC a status file on the half-life of ^{239}Pu is kept and updated. From some new values which became available in 1975, and a consideration of older data, it seems very probable that the values previously adopted are too high. Until the results of several measurements, which are presently in progress, are available, a value of $(2.42 \pm 0.01)10^4$ years is recommended.

Determination of the half-life of ^{233}U. (R. Vaninbroukx, P. De Bièvre, Y. Le Duigou, V. Verdingh)

A paper reporting on these measurements has been accepted for publication in Phys. Rev. C. The abstract is as follows:
"Combining different methods, all based on the measurement of the specific activity of a large number of samples from two different
741115 batches of uranium oxides, both enriched to nearly 100% ^{233}U, a new determination of the half-life of ^{233}U was made. The activities of the samples were determined by α-counting techniques: low geometry, liquid scintillation, and 4π proportional counting. The uranium content of the samples was determined by isotope dilution-mass spectrometry technique and by controlled potential coulometry. The half-life was measured as $(1.5925 \pm 0.0040) \cdot 10^5$ years. The uncertainty quoted is the overall uncertainty at the 99.7% confidence level, taking into account both statistical and systematic effects. This result is in close agreement with the value published recently by Jaffey et al. (Phys. Rev. C 9, 1991, 1974) and with the new recommended value, evaluated by Lemmel (NBS Spec. Publication 425, 1975, pp. 286-293).

Determination of the half-life of ^{239}Pu. (R. Vaninbroukx, J. Broothaerts, B. Denecke, M. Gallet, G. Grosse, F. Hendrickx, A. Loopmans, W. Zehner)

Measurements have been performed using the NBS certified reference material 949d: metallic Pu with (99.99 ± 0.05)% Pu. The ^{239}Pu enrichment was determined to be (97.624 ± 0.007) atom % by mass spectrometry. The α-radioactivity concentration of a solution containing a known quantity of the Pu was determined by two different methods: α counting in a defined low geometry solid angle (LG) and α counting by liquid scintillation (LS).

The ^{241}Am activity, which had grown in from the ^{241}Pu, was determined by γ-ray spectrometry using a Si(Li) detector; its contribution to the total α-count rate was (0.43 ± 0.01)%. The ^{238}Pu content as determined by α-ray spectrometry, with the ^{241}Am contribution in the 5.5 MeV α peak subtracted was (33±2)ppm, which is in agreement with the mass spectrometric value of (35 ± 10) ppm. From the isotopic composition and from the α and γ-ray spectrometric determinations, the contribution to the total α-count rate from all other impurity radionuclides was calculated to be (9.32 ± 0.19)%. The results of the measurements are summarised in Table 4.1.

Table 4.1. Specific activity and half-life of ^{239}Pu

Method of counting	^{239}Pu specific activity	^{239}Pu half-life	Uncertainty*
LG	2 284 $s^{-1}\mu g^{-1}$	2.4225×10^4 yr	± 0.5%
LS	2 292 $s^{-1}\mu g^{-1}$	2.4143×10^4 yr	± 0.4%

* Quadratic sum of all individual statistical uncertainties involved plus the linear sum of the systematic uncertainties.

The weighted mean of both values is:

$$T_{\frac{1}{2}}(^{239}Pu) = (2.417 \pm 0.010)\cdot 10^4 \text{ years.}$$

It is planned to make further measurements on a sample containing 99.98 % ^{239}Pu.

Determination of the half-life of ^{241}Pu. (P. De Bièvre, M. Gallet, J. Broothaerts)

Mass spectrometer measurements of the ^{241}Pu/^{240}Pu ratio as a function of time on a sample initially containing 92.806% ^{241}Pu and 4.011% ^{240}Pu have started. Similar measurements will also be made on two samples which have previously been used for half life measurements at Harwell, U.K.

4.2. Other Half-lives

The half-lives of ^{58}Co and ^{60}Co. (R. Vaninbroukx, G. Grosse)

The half-life of ^{58}Co has been redetermined by observing the decay of three Ni foils, irradiated in the reactor BR2. With a Ge(Li) detector the correction for the ^{60}Co and especially of ^{57}Co contribution can be determined with much higher accuracy than in the past.

The final value for the half-life of ^{58}Co is 70.81±0.10 days, which confirms the result of 70.78±0.13 days published recently by Lagoutine et al. (Int. J. Appl. Radiat. Isotopes 26, 131 (1975)).

Some of the ^{60}Co sources which were prepared at CBNM 13 years ago, have been used during the subsequent years to test the long-term stability of several γ detectors. After more than two half-lives, these measurements have now been used to compute the half-life of ^{60}Co. The result obtained is 5.283±0.008 years, which is in good agreement with the value 5.279±0.008 years of J.S. Merritt and J.G.V. Taylor (AECL-3333 (1969), p. 32), but is higher than the recent values 5.2719±0.0011 years by K.F. Walz and H.M. Weiss (Z. Naturforsch. 25a (1970), 921) and 5.270±0.003 years by A. Rytz (Procès verbaux des séances du Comité International des Poids et Mesures, 40 (1973)).

Determination of the half-life of ^{95}Nb. (R. Vaninbroukx, G. Grosse)

The half-life of ^{95}Nb has been redetermined. In order to correct for admixtures of ^{95}Zr the sources, some with known added amounts of ^{95}Zr were examined with a Ge(Li) γ spectrometer. All sources were γ counted 20 times at regular intervals during a period of 210 days, using a 3"x3" NaI(Tl) detector. The final value obtained for the half-life of ^{95}Nb is 34.967 ± 0.034 days. The uncertainty quoted is the overall uncertainty at the 99.7% confidence level, taking into account both statistical and systematic effects.

4.3. Studies on the Decay of ^{139}Ce

The nuclide ^{139}Ce is one of the most suitable reference nuclides for the efficiency calibration of γ-ray detectors in the energy range below 200 keV. The following studies have been performed.

Determination of the half-life. (R. Vaninbroukx, G. Grosse)

The decays of three sources with initial activities 1, 2 and 4μ Ci, respectively, have been followed for one year with a 3"x3"NaI(Tl) detector under three different geometrical conditions (efficiencies ranging from about 3 to 20%). The radiochemical purity of the source material was checked by a Ge(Li) spectrometer. The value obtained for the half-life of ^{139}Ce is 137.66±0.13 days. The uncertainty quoted is the over-all uncertainty at the 99.7% confidence level, taking into account both statistical and systematic effects.

Internal conversion coefficient of the 165 keV γ ray in ^{139}La.
(H.H. Hansen, D. Mouchel)

The determination of the internal conversion coefficients, described in the Annual Report 1974 has been finished. The following results were obtained: the probability for internal conversion in the K-shell $\varkappa_K = 0.1719 \pm 0.0020$ and the conversion ratios $K/(L+M+...) = 5.84 \pm 0.17$, $K/L = 7.45 \pm 0.20$, and $L/(M+...) = 3.63 \pm 0.29$. The internal conversion coefficients deduced are $\alpha = (0.2520 \pm 0.0050)$, $\alpha_K (0.2151 \pm 0.0033)$ and $\alpha_L = (0.0289 \pm 0.0012)$. The results are in good agreement with previous experimental values and with theoretical data calculated for an M1 transition of 165.8 keV in ^{139}La.

Determination of the total internal conversion coefficient. (I.W. Goodier, E. Celen)

An accurate value of the total internal conversion coefficient for the de-excitation of the first excited level of Lanthanum-139 has been measured by the 4π(AX)-γ coincidence counting extrapolation technique. The value obtained was $\alpha_T = 0.2522$ with a random uncertainty of ± 0.0005 and a systematic uncertainty of ± 0.001. This is in excellent agreement with the value of Hansen and Mouchel.

Determination of the K-shell electron capture probability P_K
(H.H. Hansen, D. Mouchel)

This work is finished and published (Z.Physik A 274, 335, 1975) with the following abstract: "A new coincidence procedure for the determination of the K-shell electron capture probability in simple EC decays is described. By measuring γ-rays and K-shell conversion electrons separately and in coincidence with the K X-rays, the K capture probability can be deduced from counting rates only. The method has been applied to ^{139}Ce. The result of $P_K = 0.726 \pm 0.010$ is in fairly good agreement with other experimental values reported previously.

4.4. The 145 keV γ-Ray Intensity in the ^{141}Ce Decay (R. Vaninbroukx, I.W. Goodier, E. Celen, G. Grosse)

In addition to ^{139}Ce the nuclide ^{141}Ce would be very suitable for the efficiency calibration of γ-ray detectors provided that the intensity of its γ ray is well established. Values between 0.45 and 0.51 have been reported. The intensity has been remeasured counting the γ-rays with a well calibrated Si(Li)detector from a source whose activity was measured by 4π β-γ coincidence counting.

The source contained about 1% ^{139}Ce impurity. A preliminary value of $I_\gamma = 0.475 \pm 0.010$ was obtained, but it is believed that the error could be reduced by up to a factor of two if a pure ^{141}Ce source is used.

4.5. Measurement of the Total Internal Conversion Coefficient of the First Excited Level of ^{203}Tl (I.W. Goodier, E. Celen, W. Zehner)

Measurements of the disintegration rates of sources of ^{203}Hg by the $4\pi\beta$-γ coincidence counting extrapolation technique give results from which the total internal conversion coefficient of the first excited level of ^{203}Tl can be calculated. The value obtained is 0.2310 with a random uncertainty of $\pm$ 0.0008 and a systematic uncertainty of $\pm$ 0.001. Sources were prepared by precipitation of the Mercury-203 as mercuric sulphide on carbon films, to obviate such effects as volatilisation, diffusion, amalgamation etc. which could give rise to a loss or variable distribution of the radioactivity during the measurements of the sources.

4.6. Review on Orbital Electron Capture by the Nucleus (W. Bambynek)

The final draft of the survey is finished and will be sent to the editor at the end of this year.

4.7. Isotope Abundances and Atomic Weights of the Elements (P. De Bièvre, M. Gallet)

Best estimates of isotope abundances were contributed to Nuklidkarte, 4. Auflage, Gersbach und Sohn Verlag, München, 1975.

4.8. K-Shell Internal Ionization Probabilities in Nuclear β^- Decay (H.H. Hansen)

This work is finished and a paper with the following abstract has been submitted for publication in Phys. Rev. C. "Total K-shell internal-ionization probabilities per β^- decay of the isotopes ^{63}Ni, ^{143}Pr and ^{204}Tl have been determined by x-ray spectroscopy with a high-energy-resolution Si(Li) detector.

The number of emitted K X-rays was deduced and compared with the absolute β^--decay rate. The results of $(4.6 \pm 0.4) \cdot 10^{-4}$ for ^{63}Ni, $(2.92 \pm 0.16) \cdot 10^{-4}$ for ^{143}Pr and $(1.12 \pm 0.11) \cdot 10^{-4}$ for ^{204}Tl are compared with previous experimental values and recent theoretical calculations of Law and Campbell (Nucl. Phys. A 185, 529, 1972). Good agreement is found between this theory and the present experimental results."

4.9. Photon Interaction Cross-Sections

Total photon interaction cross sections for photons of energies between 60 and 1333 keV. (H.H. Hansen, K. Parthasaradhi °)

The total photon interactions at several energies between 60 and 1333 keV have been measured for V, Cu, Mo, Sn and U. They were found to agree with those calculated by E. Storm and H.I. Israel (Nucl. Data 7, 565 (1970)).

Determination of the total and sub-shell photoelectric cross sections by a direct method. (K.W.D. Ledingham °°)

A 4π well type plastic scintillation spectrometer has been designed and constructed to detect photoelectrons of up to 300 keV while minimising the detection of γ rays. A heavily collimated ^{141}Ce source (γ energy 145 keV) of strength about 1mCi has been used as the source of photons. A fine beam of γ rays strikes various foils of thickness about 5 mg/cm^2 placed at the foot of the well in the scintillator. The electrons resulting from the photoeffect in the various foils are detected with almost 100% efficiency in the surrounding scintillator. Knowing the incident γ flux and the number of photoelectrons, the cross sections may be determined. Preliminary total photoelectric cross sections have been determined for Cu, Sn, and Au while the K and L+M sub-shell yields have been obtained for Au.

° Department of Nuclear Physics, Andhra University, India

°° On sabbatical leave from the Department of Natural Philosophy, University of Glasgow, Scotland

4.10. Metrology of Radionuclides

International intercomparison and standardization of radionuclides. (I.W. Goodier, R. Vaninbroukx, E. Celen, G. Grosse)

Measurements of the disintegration rates of sources of ^{139}Ce have been carried out using the $4\pi(AX)$-γ coincidence counting extrapolation technique with high efficiency sources. A simple theory has been developed to explain the discrepancy in the values of "Gradient/Intercept" obtained by the $4\pi(AX)$-γ coincidence extrapolation technique for ^{139}Ce in a small intercomparison held as a forerunner to the full scale international intercomparison to be organised by BIPM.

In order to support the measurement of $Rh(n\,n')Rh^{m}$ described in Section 2.6, sources of the parent-daughter equilibrium mixture $^{103}Ru/^{103}Rh$ have been measured by $4\pi\beta$-γ coincidence counting. These measurements are also of interest as they involve the study of a "mixed β decay". The parent Ruthenium-103 decays by β^- emission giving rise to a typical β^- spectrum energy distribution while the daughter decays by almost total internal conversion of its 40 keV transition giving rise to K conversion electrons and L conversion electrons with energies of 17 keV and 35 keV, respectively.

Investigation of count rate dependent corrections for $4\pi\beta$-γ coincidence counting. (I.W. Goodier, E. Celen, R. Vaninbroukx)

A detailed examination of the coincidence equations used by standardising laboratories has been made. An intercomparison, arranged by BIPM, is in progress to asses experimentally the validity of approximations made in coincidence counting and to check the range of counting rates over which they are applicable. A series of sources of ^{60}Co with activities ranging from 2×10^{3} to 10^{5} s^{-1} has been distributed to several standardising laboratories. A round robin programme is then envisaged with each set of sources being measured by each laboratory. Preliminary results at CBNM indicate that sources of ^{60}Co with disintegration rates of 8×10^{4} s^{-1} can be measured by $4\pi\beta$-γ coincidence counting with an accuracy of better than 0.15%. Further measurements and detailed analysis of data are in progress.

4.11. Improvements of Techniques to Measure Nuclear and Atomic Radiations

Ionisation Chamber. (G. Bortels)

A 4π pressurised ionisation chamber has been brought into operation for accurate secondary reference measurements of γ activity. Repeat measurements on one source have shown that the internal standard deviation is about 0.005%, but larger systematic errors are introduced when comparing sources with widely different activities.

Ge(Li) γ-ray spectrometer. (D. Mouchel, H.H. Hansen)

A spectrometer has been built for the determination of γ-ray intensities and for purity measurements of radioactive samples. It consists of an encapsulated Ge(Li) crystal (coaxial type) with an active volume of 18 cm^3 and a sensitive area of 7.5 cm^2 cooled at 85°K. The energy resolution of the system is 2.48 keV at FWHM for the 1.372 MeV γ-ray peak. A reproducibility of $\pm$ 0.2% has been achieved for any source manipulation in the possible 7 different source to detector positions. A calibration curve for the photopeak efficiency has been established in the energy range of 122 to 1332 keV.

Solid state detector sandwich spectrometer. (D. Reher, W. Bambynek)

The Solid State Detector Sandwich Spectrometer (SSDSS), has now been set up and tested. A new kind of slow-fast-strobed coincidence chain has been installed which has the advantage of high energy resolution in conjunction with excellent timing qualities. The dead time corrections in the single channels are better than $\pm$ 0.1% below 10^4 cps. The dead time correction in the coincidence channel is difficult to calculate due to the extending dead times in the single channels, which may vary between 5 µs and 100 µs and so measurements have been carried out to find an empirical relation. The deduced correction formula gives good results for singles count rates below 5000 cps and dead times smaller than 50 µs.

With two CBNM made Si(Li) detectors of about 700 mm^2 and each having an energy resolution of about 2 keV at 33 keV,

a time resolution of 35 ns in the coincidence channel is obtained. The electronics, disregarding the preamplifier, contributes less than 1 ns to this value.

Automatic control and data acquisition of magnetic β-ray spectrometer measurements. (E. Sattler, H.H. Hansen, K. Hofmans, D. Mouchel, H. Nerb, H. Schipke)

A paper has been published in Nucl. Instr. Methods 124 (1975), 131 with the following abstract:
"The development of a versatile electronic system for control and data acquisition in connection with a goniometer-type magnetic β-ray spectrometer is described. Beside the commercially available transistorised power supply the electronic system consists of a magnet current control unit including an automatic demagnetisation routine and a read-out control unit. Use has been made of CAMAC standard equipment as much as possible. Experimental tests are performed on stability and reproducibility of the complete installation."

Numerical methods to evaluate α-ray spectra. (G. Bortels)

The procedure for the numerical evaluation of the total area of ^{238}Pu and (^{239}Pu+^{240}Pu) peaks in α-ray spectra has been modified. All parameters for the peak region in the ^{238}Pu group can now be optimized in one computer programme. A second programme calculates the parameters of the ^{238}Pu tail under the (^{239}Pu+^{240}Pu) group and a third one computes the areas of both groups. This modification gives an increase of accuracy and a gain in computing time.

Radioactive source preparation. (I.W. Goodier, D. Reher, W. Oldenhof, W. Zehner)

A study of various techniques for the preparation of high efficiency sources for 4πβ-γ coincidence counting has been made. Early results show that freeze drying and electrospraying of solutions and suspensions are most promising. A simple device has been made for measuring the conductivity of metallised plastic films and carbon foils.

Techniques for the preparation of quantitative sources of α-emitting actinides, with high resolution, have been studied. These sources will be used in the analysis of Plutonium samples by α spectrometry.

A technique to prepare very thin sources of extremely low self-absorption has been developed. The radioactive material is evaporated under vacuum by flashing onto thin metallised plastic films. Sources of this type are needed in investigations of low energy electrons and X rays.

Statistical evaluations of multichannel spectra using their Walsh transform. (C. Bastian)

The quality of a multichannel spectrum strongly depends on the number N of counting channels into which the range of variation of the parameter has been divided. Choosing N too low may cause significant evolutions to be integrated to zero over one single channel. Choosing N too large will bury them into a blur of counting fluctuations. However, in the latter case, it is possible to optimise the signal to fluctuation ratio by condensing groups of contiguous channels into less numerous, broader channels. The condensation factor can be determined rationally on the basis of integrals of the Walsh transform of the record. The method has been applied successfully to several time-of-flight spectra taken at the Linac of Geel.

5. SAMPLE AND TARGET PREPARATION

5.1. Special Preparations (M. Aerts, E. Freistedt, W. Lycke, J. Mast, H. Mast, F. Michiels, G. Müschenborn, M. Parengh, J. Pauwels, F. Peetermans, J. Tjoonk, J. Triffaux, J. Van Audenhove, J. Van Gestel, V. Verdingh, J. Waelbers)

During 1975 we have continued to supply special samples and targets for CBNM groups and for outside users. The total number of samples was 4660 covering 120 orders. About 45% of these orders are for bulk samples not requiring support on a backing and used mainly as materials with certified composition in solid state physics and analytical chemistry. These samples are listed in table 5.1. The remainder are very thin samples usually requiring a backing and used mainly as targets for nuclear measurements. The list of these samples is given in table 5.2.

Table 5.1

Bulk Samples delivered in 1975

Materials	Applicants (a)	Number of Samples	Def. Meth. (b)	Prep. Meth. (c)
Sc	(1)	1		M; C
^{235}U	(2)	1	IA-DC-MD	R
Mo/Ni/Fe alloys	(3)	4	QA-DC	LM; R
Au/Ta/Cu	(2)	16	MD-DC	R
^{6}Li, In, Pb	(4)		MD-DC	C; R;
S, Al, Au, Cu,		82		M;
Pt, Rh, Nb, Ta				
Zr	(2)	2	DC-MD	R
U/Fe alloys	(2)	4	QA	LM; M; C
Cu/Fe alloys	(5)	3	QA	LM; R
Al/Co alloys	(5)	3	QA	LM; R

Table 5.1 (continued)

Materials	Applicants (a)	Number of Samples	Def. Meth. (b)	Prep. Meth. (c)
Al/Cu alloys Al/Ag alloys	(6)	30	QA QA	LM;R LM;R
C	(14)	10	--	M
Ti, TA6V, W, Mo, Mo, Ta, Pb, Cu Al, Ni	(3)(10)(4)(5) (14) to (42)	3648	DC	M
Cu-12 and 1.2 ppm Pt Cu-12 and 1.2 ppm Pd	(17)(36)(10) (43)(44)(35) (45)(46)(3)	71	QA	LM;M; R;WD
Nb	(51)	5	MD	CS
Au, Al, Pt Ta, Ni, Cu, Vyns	(4)	230	MD	Miscell.
Zr	(2)	2	MD	VD
Be	(4)	6	MD	VD
ZnO_2 Ga activated	(4)	2	MD	ES
^{96}Zr	(4)	1	MD	ES

Table 5.2

Thin samples delivered in 1975

Layers	Applicants (a)	Number of Samples	Def. Meth. (b)	Prep. Meth. (c)
^{235}U	(1)(3)(4)(7)(8)(9) (10)(13)(14)(20) (48)(53)	434	MD α count. XRF IDMS	ES; VD
^{238}U	(4)(10)	9	MD-XRF	ES
Nat. U	(1)	4	MD-XRF IDMS	ES
^{239}Pu	(1)(20)(4)(2)(31)	20	α count.	ES
^{252}Cf	(49)(50)(10)(3)	16	Count.	ST
^{237}Np	(20)(1)(31)(4)	9	MD	ES
^{233}U	(1)(10)	11	α count.	ES
^{241}Am	(3)(4)	7	α count.	ES
^{232}Th	(10)(2)	15	MD-XRF	ES
^{6}Li, ^{7}Li	(4)(18)	9	MD	VD
^{10}B, ^{11}B B nat.	(49)(52)	4	MD	ES; VD
^{182}W ^{184}W ^{186}W	(51)	6	MD	ES

(a) List of Applicants

(1) I.A.E.A., Vienna, A
(2) S.C.K. - C.E.N., Mol, B
(3) C.C.R. Ispra, I
(4) C.B.N.M. Geel, B
(5) K F Jülich, BRD
(6) Univ. Milano, I
(7) Univ. Catania, I
(8) CEA Grenoble, F
(9) Johannes Gutenberg Univ., Mainz, BRD
(10) CEN Saclay, F
(11) Univ. Louis Pasteur, Strasbourg, F
(12) Inst. Reaktorforschung, Würenlingen, Switz.
(13) Lab. Chemie Nucl., Gradignan, F
(14) INW, Univ. Gent, B
(15) NPL, Teddington, UK
(16) Centre Recherche Aluminium Péchiney, Voreppe, F
(17) BAM, Berlin, BRD
(18) Inst. Phys. Nucl., Univ. Liège, B
(19) Metallgesellschaft AG, Frankfurt, BRD
(20) CEN Bruyères-le-Châtel, Montrouge, F
(21) CEN Valduc, Is-sur-Tille, F
(22) Max-Planck Inst. Metallforschung, Schwäbisch Gmünd, BRD
(23) Metallurgie Hoboken-Overpelt, B
(24) CEN Fontenay-aux-Roses, F
(25) Centre de Recherche Vallourec, Aulnoye, F
(26) Soc. Ind. Combustribles Nucléaire, Veurey, F
(27) Krupp Forschungsinstitut Essen, BRD
(28) CEN Grenoble, F
(29) Imperial Metals Industries, Kynoch, UK
(30) Ugine Aciers, Ugine, F
(31) Gesellschaft für Kernforschung, Karlsruhe, BRD
(32) Groupe de Physique Nucl. de l'École Norm. Sup., Paris, F
(33) Staatliches Materialprüfungsamt Nordrhein-Westf., Dortmund, BRD
(34) Inst. für Radiochemie der Univ. Köln, BRD
(35) Univ. Vlaude Bernard, Inst. Phys. Nucl., Villeurbanne, F
(36) CNRS, Lab. du Cyclotron, Orléans, F
(37) CNR-TNI, Milano, I
(38) CNRS, Lab. de Métallurgie, Vitry-sur-Seine, F
(39) Mullard Res. Lab. Redhill, UK
(40) Metallwerk, Plansee, Reutte, Austr.
(41) Ugine Carbone, Grenoble, F
(42) Inst. f. Radiochemie der Techn. Univ. München, BRD
(43) Bundesanstalt f. Ernäherung, Karlsruhe, BRD
(44) Comptoir Lyon Allemand, Paris, F
(45) Ugine Kuhlmann, Levallois, F
(46) C.R.A.A., Pavia, I
(47) Univ. Tübingen, BRD
(48) CEN Cadarache, F
(49) Univ. Darmstadt, BRD
(50) Univ. Heidelberg, BRD
(51) U.L.B., Bruxelles, B
(52) Univ. Louvain, B
(53) Univ. Karlsruhe, BRD

(b) Definition Methods

XRF	:	X-ray fluorescence
MD	:	Mass definition
αcount.	:	α counting
IDMS	:	Isotope Dilution - Mass Spectrometry
Count.	:	Counting
IA	:	Isotope Analysis
DC	:	Dimensional Control
QA	:	Quantitative alloying

(c) Preparation Methods

ES	:	Electrospraying
VD	:	Vacuum deposition
ST	:	Self transfer
CS	:	Cathodic sputtering
C	:	Canning
R	:	Rolling
LM	:	Levitation melting
M	:	Machining
WD	:	Wire drawing

5.2. The Preparation of ^{241}Am Samples (F. Michiels, H. Ruts, H. Silvester, V. Verdingh)

In order to measure fission cross sections of ^{241}Am at energies up to 1 MeV and especially the shape below threshold, two ^{241}Am samples each of large surface area were requested for assembly in a spark chamber (see section 9.1.). The specifications of the layers were 200 x 200 mm with a layer thickness of about 1 mg · cm^{-2} Am on each side of a stainless steel backing. The layers have now been fabricated by the techniques of suspension spraying of americium oxide.

Both samples of ^{241}Am are also required for transmission and capture measurements with the Linac. As a total activity of 60 Ci for ^{241}Am is involved, every step of this project is studied from the point of view of contamination and radiation hazard. The samples will be prepared by vacuum-canning and a double containment will be employed. An attempt is being made to make these samples equally useful for measurements in other Community laboratories and in this respect collaboration is maintained with AERE, Harwell and GfK, Karlsruhe.

In addition special containers which are fire proof, shock resistant and which provide sufficient shielding have been constructed for safe transportation.

5.3. Procurement of Special Isotopes (H. Ruts, V. Verdingh)

The isotope procurement for neutron measurements from USA was continued. A contract was made for the procurement of a 100 g sample of ^{239}Pu, to be used at CBNM for σ_f and ν measurements. For the same purpose a 12g sample of ^{239}Pu was received on a sub-loan contract from GfK Karlsruhe.

Recovery and final accounting were made for ^{91}Zr, ^{96}Zr and ^{236}U isotopes on loan from the USAEC Research Pool. In a subcontract with the USERDA about 200 mg of the ^{236}U isotope stock held at CBNM was shipped to CEN, Bordeaux.

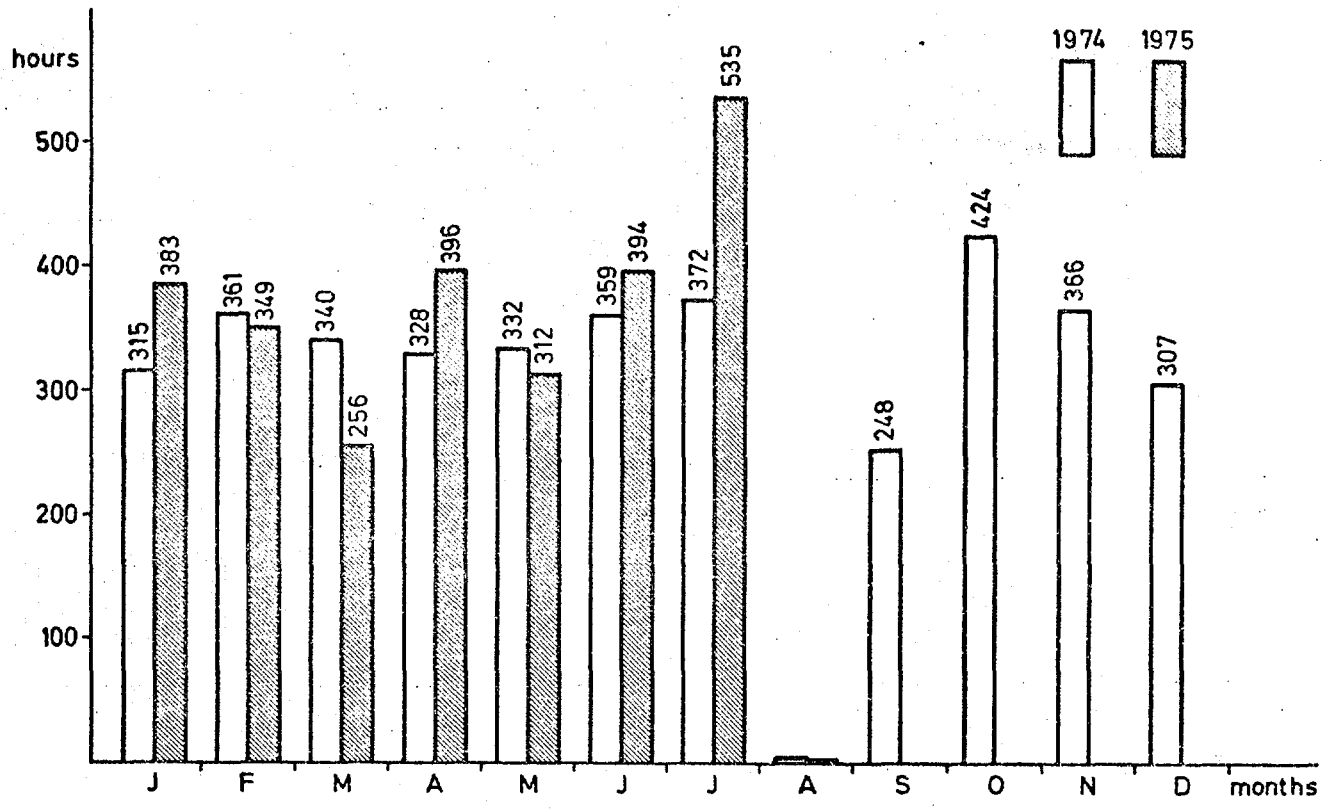

Fig. 6.1. Linac operation: Useful electron beam hours per month.

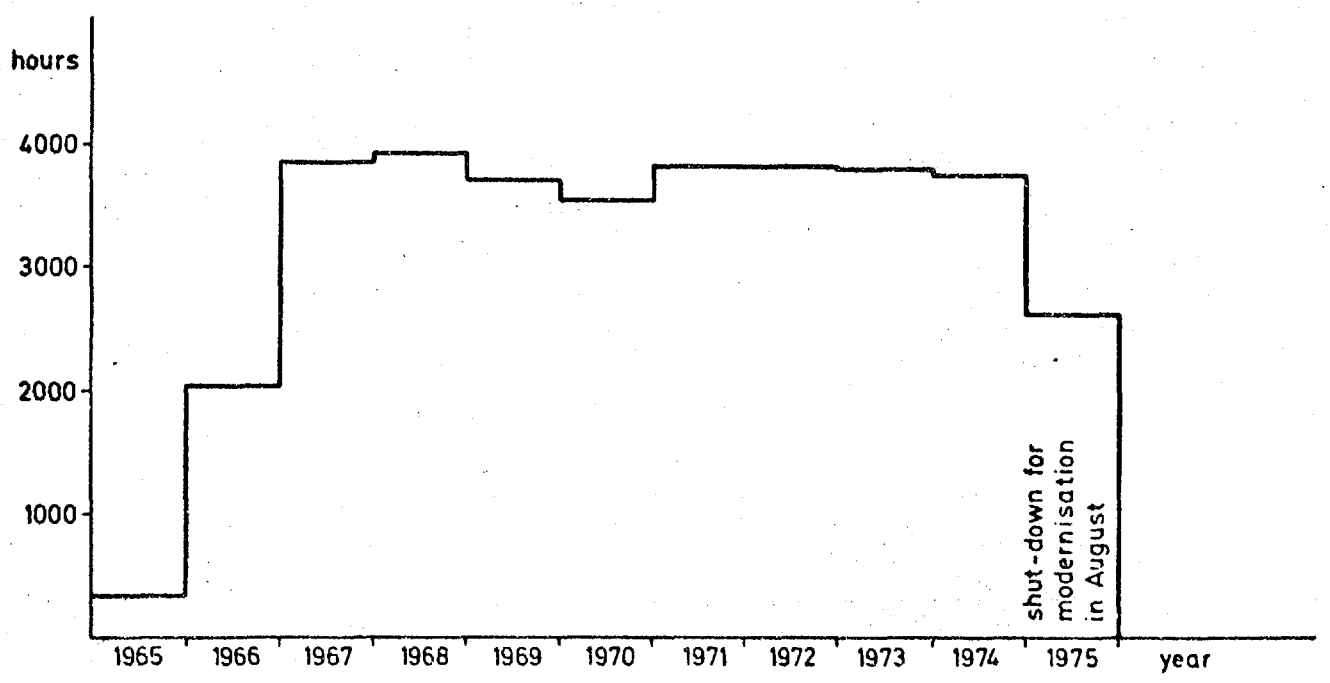

Fig. 6.2. Linac operation: Useful electron beam hours per year.

6. ACCELERATORS AND INSTRUMENTATION

6.1 Electron Linear Accelerator and Experimental Equipment

Operation of the linear accelerator. (J.M.Salomé, R.Cools, R.Forni, F.Massardier, F.Menu, R.Pijpstra, P.Siméone, F.Van Reeth, C.Waller)

In 1975, the Linac was operated for 2 619 hours from January to the end of July . Operations were then stopped in order to carry out the modernisation programme. Details on klystron hours, useful beam and maintenance time are listed in Table 6.1 and Fig. 6.1 .

Table 6.1

	1974	1975 (7months)
Klystron hours	3870	2689
Electron beam hours	3750	2619
Hours for maintenance and other interruptions	552	294

The accelerator was almost entirely used as a pulsed neutron source with an average number of 5.8 flightpaths. Three experiments for activation analysis were carried out which took 29 hours, mainly for conditioning . For this purpose a platinum target was bombarded by an electron beam of 2 kW mean power at 30 MeV .
EEV thyratrons CX 1529 were installed in the modulator in March and were operational for 1700 hours up to the shut-down .
In Fig. 6.2 the number of useful electron beam hours per year over the last ten years is given.

Modernisation of the linear accelerator . (J.M.Salomé, R.Cools, R.Forni, F.Massardier, F.Menu, R.Pijpstra, P.Siméone, F.Van Reeth, C.Waller)

Delivery to CBNM of the components of the modernised linac is expected in January 1976 . It is hoped that the installed machine will be tested in May 1976 and will be operational the following month. The new gun is now under test. Glass was finally chosen for isolation rather than ceramics since with glass it is easier to provide a long electrical path for high voltage and very short connectors for the grid can be made. The modulator and the buncher are completed and are now being checked.

Many modifications of the building are being made in order to install the main new parts of the machine. Special attention has been paid to the development of a new cooling circuit for the accelerating sections and the focusing coils. Some apparatus in the target room which suffered from radiation damage is being renovated. A magnetic deflection system for 20 to 30 MeV with a 50% bandwidth will be installed to provide an electron beam for activation analysis, without disturbance to the neutron target.

Development of targets and moderators (J. M. Salomé, J. Wartena, R. Cools, P. Siméone)

The uranium target of 26 mm diameter has been used for 7000 hours between 4 and 5 kW without difficulties. Two similar targets, 30 mm in diameter, one in natural uranium, the other partially made of 93% enriched uranium are available together with water moderators in metallic beryllium cans and it is expected that these could operate with an electron beam of up to 7 kW.

In order to have a target compatible with the expected maximum power of the modernised machine, rotary targets are under development with either the target alone or both target and exchanger rotating, although the latter idea seems to be the more feasible. In addition an efficient mercury cooling system is being studied. The possibility of using uranium carbide as a target is also being considered.

Development of a spark chamber for fission cross section measurements of ^{241}Am. (A. Brusegan, M. Merla)

The new chamber with stainless steel electrodes was assembled and fitted with the large area ^{241}Am layers on stainless steel backings mentioned in section 8.2. The gas filling which gave most successful operation was pure N_2 at 500-600 torr but even then the performance deteriorated quickly with time. On opening the counter radiation damage effects were observed, although on this occasion there was no noticeable migration of the ^{241}Am layer and no formation of a chemical compound on the electrodes.

Development of a δ-electron counter (R. Werz, P. Rietveld)

For the measurement of fission cross sections of highly α-active isotopes, a fission fragment detector, insensitive to the α-particles and to the γ-flash of the Linac accelerator, would be desirable. Charged particles traversing a thin foil eject a certain number of secondary electrons (so-called δ-electrons) from the surface of the foil. For a fission fragment, the total number of electrons released is about 50 times greater than for an α-particle. With the aid of electrical and magnetic fields it is possible to separate the secondary electrons from the fission fragments and α particles and to reject the α-counts by pulse height discrimination.

Out of the different possible configurations, a sample foil of spherical form, 100 mm diameter and a cylindrical accelerating grid at a potential of about 20 kV, followed by a 180° deflection magnet has been chosen. It can be shown that such an electron optical system is able to focus the secondary electrons into a point sufficiently off axis (to be off line from the neutrons and γ-flash).

A detector based on this principle has now been designed and constructed. It will be tested first by a thermionic electron source and then with ^{252}Cf source, each placed at the sample position.

Avalanche counter for neutron flux measurements at the Linac. (J. Wartena)

Some investigations on the possible applications of parallel plate avalanche counters for flux measurements have been made. Such a counter, loaded with a ^{10}B layer and a quenching gas, was tested on a 30m flight path. The output pulses had a rise time of about 3 ns, the counter didn't respond to the γ-flash and it gave a good neutron spectrum, although the efficiency function could not be properly understood. A telescope arrangement consisting of two parallel plate avalanche detectors is now being tested with a ^{252}Cf source.

6.2. Van de Graaff Accelerator and Experimental Equipment

Operation and maintenance of the 3.7 MV Van de Graaff Accelerator. (A. Crametz, P. Falque, J. Leonard, R. Smets)

During this year the operations of the 3.7 MV Van de Graaff suffered from the fact that the building of the new Van de Graaff tower has been in progress. The machine was operated

for 1880 hours of which 1665 hours were for experimental work and 215 hours to condition the machine. In addition maintenance required 390 hours to exchange two ion sources (having a lifetime of 1200 and 550 hours respectively), one coil of the analysing magnet and to verify the alignment of the beam handling supports. Using insulating gas containing about 7% SF_6, an experiment with a 3.9 MeV proton beam was performed successfully in March. The experimental time was divided between 1400 hours for neutron physics and the rest mainly for Rutherford backscattering. A few irradiations and flux measurements were made for outside organisations.

The accelerator could not be operated during day time (890 hrs.) because of the construction of the new tower for the CN accelerator.

Modernisation of the Van de Graaff accelerator. (A. Crametz, P. Falque, J. Leonard, R. Smets

Delivery of the klystron bunched Van de Graaff accelerator model CN with an upgraded tube supplying 7 MV (High Voltage Engineering Corporation, Burlington) is scheduled for end of January 1976. Preparative work is related to the necessary changes in the infrastructure and to the design of the beam handling system, for which CBNM is responsible. Studies concerned the vacuum, the water cooling system, the gas transfer, the electrical power distribution, the heating of the tower, and the service platform. The required orders for work are being placed and in some cases delivery has been effected.

Development of a reaction chamber for the measurement of (n, p) and (n, α) reactions. (A. Paulsen, H. Liskien, F. Arnotte, R. Widera)

For the determination of cross sections for fast neutron-induced reactions producing hydrogen and helium the activation technique is often not applicable and instead a direct detection technique for the emitted charged particles has to be used.

The design of a suitable reaction chamber for measurements of this type is nearly finished. The chamber consists of five telescope detectors covering almost the angular range 0 to 180°, so that an integrated cross-section can be obtained in one run. In order to make maximum use of the available neutron flux, a solid neutron producing target is placed as near as possible to the sample and makes part

of the instrument.

Development of a fission ionisation chamber (C. Budtz-Jørgensen, H.-H. Knitter, M. Mailly, R. Vogt)

A double gridded ionisation chamber has been constructed. One of the grids, placed at 3 mm distance from the source plate, is used to derive a fast timing signal from an ionizing event and the second grid is operated as a Frisch grid, whereby energy proportional pulse neight response is ensured. The detector has been tested using a weak ^{252}Cf-source. With a preliminary electronic set-up a time resolution (FWHM) of 2 ns was found for a coincidence from the fast timing signal of a fragment pulse and the fission γ-rays as detected by a liquid scintillation detector. The pulse height-ratio between the alpha- and the low energy fragment peak was measured to be 1 : 15. The detector will now be tested under accelerator conditions.

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HANSEN H.H. and MOUCHEL D. Determination of the K-shell Electron Capture Probability P_K in the Decay of ^{139}Ce , Z. Physik , 274 , 335 (1975)

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WAGEMANS C. and DERUYTTER A.J. Measurements and Normalization of the Relative Pu-241 Fission Cross-Sections in the Thermal and Low Resonance Region , Nucl. Sc. Eng.

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