XE 9000301

Commission of the European Communities

JOINT
RESEARCH
CENTRE

NEANDC (E) 312 "U" Vol. III Euratom
INDC (EUR) 024/G

ANNUAL PROGRESS REPORT ON NUCLEAR DATA
1989

EUR--12822 [(NEANDC-E--312) U (V.3) (INDC(EUR)--024-G)]

CENTRAL BUREAU FOR NUCLEAR MEASUREMENTS

GEEL (BELGIUM)

May 1990

EUR 12822 EN

Commission of the European Communities

JOINT
RESEARCH
CENTRE

NEANDC (E) 312 "U" Vol. III Euratom
INDC (EUR) 024/G

ANNUAL PROGRESS REPORT ON NUCLEAR DATA 1989

CENTRAL BUREAU FOR NUCLEAR MEASUREMENTS

GEEL (BELGIUM)

May 1990

EUR 12822 EN

CATALOGUE N°: CD-NA-12822-EN-C

TABLE OF CONTENTS

Editor : H.H. Hansen

Note : For further information concerning the Project Nuclear Measurements (Nuclear Data, Nuclear Metrology), please contact A.J. Deruytter, Project Manager.

EXECUTIVE SUMMARY

A.J. Deruytter

In 1989 the efforts for the improvement of the set of **standard neutron cross sections** and other quantities selected within the INDC/NEANDC Standards File continued. In particular a detailed study of the nuclear mass and charge distribution of the cold and near cold fission of ^{252}Cf yielded understanding of cold mass rearrangements in nuclei. Accuracy of alpha-particle emission probabilities for major transitions in the decay of ^{236}Pu, ^{239}Pu and ^{243}Am was improved to better than 0.5 %.

In the field of **nuclear data for fission technology** work was concentrated on European requests in the NEA High Priority Request List. The number of neutrons emitted per neutron absorbed, η, was obtained for ^{235}U between 2 and 100 meV neutron energy with an overall uncertainty on the shape (energy dependence) between 0.5 % and 1 %. Using the weighting function determined at CBNM for neutron capture detectors, a new value was obtained for the neutron width of the 1.15 keV resonance in ^{56}Fe Γ_n = (62.9 ± 2.1) meV in excellent agreement with the same width determined by transmission measurements Γ_n = (61.7 ± 0.9) meV, hence solving the discrepancy between transmission and capture measurements subject of a NEANDC Task Force.

In the field of **nuclear data for fusion technology**, measurements continued aiming at an improvement of relevant data for neutron transport calculations in the blanket and for prediction of gas production. In 1989 double differential neutron-emission cross-sections for ^{9}Be were analysed and a new measurement performed to extend the data set to higher incident neutron energies. For future measurements of double differential neutron-emission cross-sections at GELINA a new mercury cooled and stainless steel canned heterogeneous U-Be target was tested. The neutron yield from this target exceeds the yield from the rotary targets above 10 MeV neutron energy, by factors 2 to 3.

The **radionuclide metrology** subproject follows three lines: determination of decay-scheme data, preparation of special standards and the improvement of measurement techniques including international comparisons.

The accuracy of peak-analysis in alpha spectrometry with peak-fitting codes has been assessed using synthetic doublets. Also the non-linear response of silicon detectors to particle radiation was studied and attributed to the dependence of the energy needed for electron-hole creation on the stopping power of the particle.

In the area of **neutron metrology** neutron flux and dose determinations were provided for neutron irradiations in radiobiological studies at the Van de Graaff accelerator.

NUCLEAR DATA

NUCLEAR DATA FOR STANDARDS

Neutron Data for Standards

Standard Cross Section Ratio $^{235}U(n,f)/H(n,n)$

F.-J. Hambsch, H.-H. Knitter, G. Willems*

A new effort has been made for improving the determination of the cross section ratio $^{235}U(n,f)/H(n,n)$from the point of view of suited hydrogen layers. It has been shown previously[1,2] that for the above mentioned cross section measurement with an accuracy below 1 % the limiting factor is the sample quality. At present several new chemical compounds with high hydrogen content are under investigation. In the first stage a long term stability test under argon atmosphere has been performed together with homogeneity checks using an electron microscope. However, a definite hydrogen compound could not yet be chosen. Problems are the roughness of the backing material and impurities in the sample materials so that the elemental composition might not correspond to the stoichiometric composition.

Set-up of a Correlation Experiment Between Gamma-Ray Emission and Fission of $^{252}Cf(SF)$

H.-H. Knitter, F.-J. Hambsch, R. Vogt

The investigation of the spontaneous fission of ^{252}Cf has contributed considerably to the improvement of the ^{252}Cf standard fission neutron spectrum[3]. However, because of the complexity of the fission process not all correlations could be recorded simultaneously. In particular the correlations of the fission fragment properties with γ-ray de-excitation and the dependencies of the γ-ray multiplicity and γ-ray energy upon fragment mass and total kinetic energy are in contradiction for different experiments[4]. The present set up is schematically shown in Fig. 1.
A ^{252}Cf source of 1500 fissions per second was used.

---

* Scientific Visitor from KU Leuven, Leuven, Belgium
(1) C. Budtz-Jørgensen and H.-H. Knitter, Nucl. Sci. Eng. 86 (1984) 10
(2) H.-H. Knitter, C. Budtz-Jørgensen and H. Bax, Proc. Nuclear Standard Reference Data, Geel, IAEA-TEC DOC -335 (1985) 470
(3) C. Budtz-Jørgensen and H.-H. Knitter, Nucl. Phys. A490 (1988) 307
(4) P. Glässel et al., HMI-B464 (1989)3

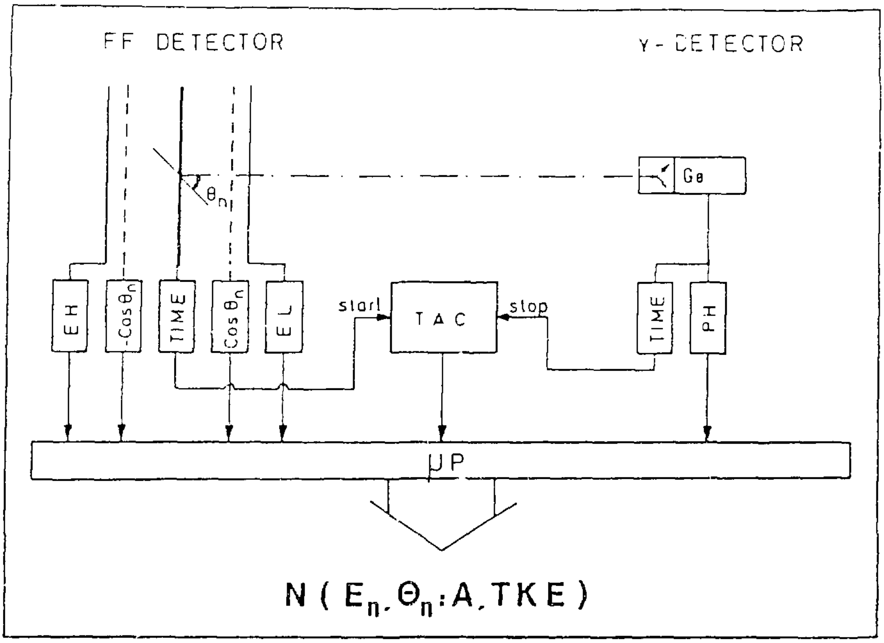

Fig. 1. Schematic experimental arrangements

Because of the high α-background a pile-up rejection circuit has been installed. Only the fission fragment detector part has been tested and calibrated. Recently the γ-ray detector has been added. The test together with the ionisation chamber is in progress.

Cold spontaneous fission of ^{252}Cf

H.-H. Knitter, F.-J. Hambsch

The experimental set-up for the measurement of the standard neutron spectrum of the spontaneous fission of ^{252}Cf gave the opportunity to measure also the nuclear mass and charge distribution in great detail in the cold and near cold fission region. This fission region is of special interest for the understanding of cold mass rearrangements in nuclei and for the recently discovered cluster radioactivity.

Fig. 2 shows in the upper part and with the energy scale on the left hand side the maximum Q values for the different mass splits of the spontaneous fission of ^{252}Cf as calculated from two different mass tables. The thick line through these Q_{max} values is a kind of average between the odd and even mass splits. Parallel to this line in steps of 2 MeV eight fragment total kinetic energy bins are defined as indicated by the thin lines in Fig. 2. The total fission yield in this experiment was $1.4 \cdot 10^8$ events. For each total kinetic energy bin the elemental yields were evaluated. Thus, the elemental yield as function of the total excitation energy available to both fragments is obtained.

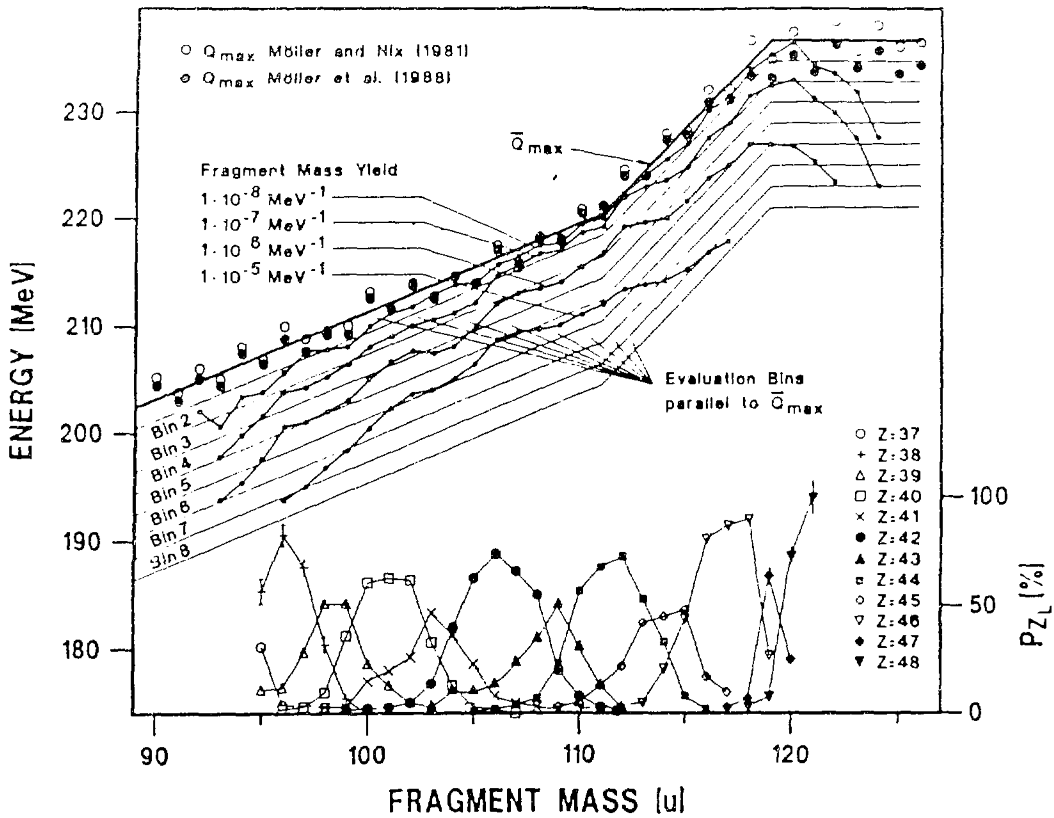

Fig. 2. Maximum Q values, total kinetic energy bins and fragment mass yield levels are shown for the high energy outskirts of the fragment mass distribution of $^{252}Cf(SF)$. The lower part shows the elemental composition for each isobaric split as measured in bin 6

From the isobaric yields for these total kinetic energy bins, it is observed that the mass resolution decreases with increasing difference between Q value and total kinetic energy. This is well understood by the onset of the neutron evaporation with the increasing availability of excitation energy to the fragments. From each isobaric distribution the elemental com-position has been evaluated. In Fig. 2 the elemental yields as obtained from bin 6 are plotted in the lower part with its scale in percent at the right hand side. The same evaluation has been done also for the other energy bins.

Fig. 3 shows as a function of ($\bar{Q}_{max}$-TKE) the yields in each bin for fission into fragments with even-even, odd-odd, even-odd and odd-even proton and neutron numbers. It is evident that the proton odd-even effect is strong and decreasing with ($\bar{Q}_{max}$-TKE), whereas the neutron odd-even effect is much smaller.

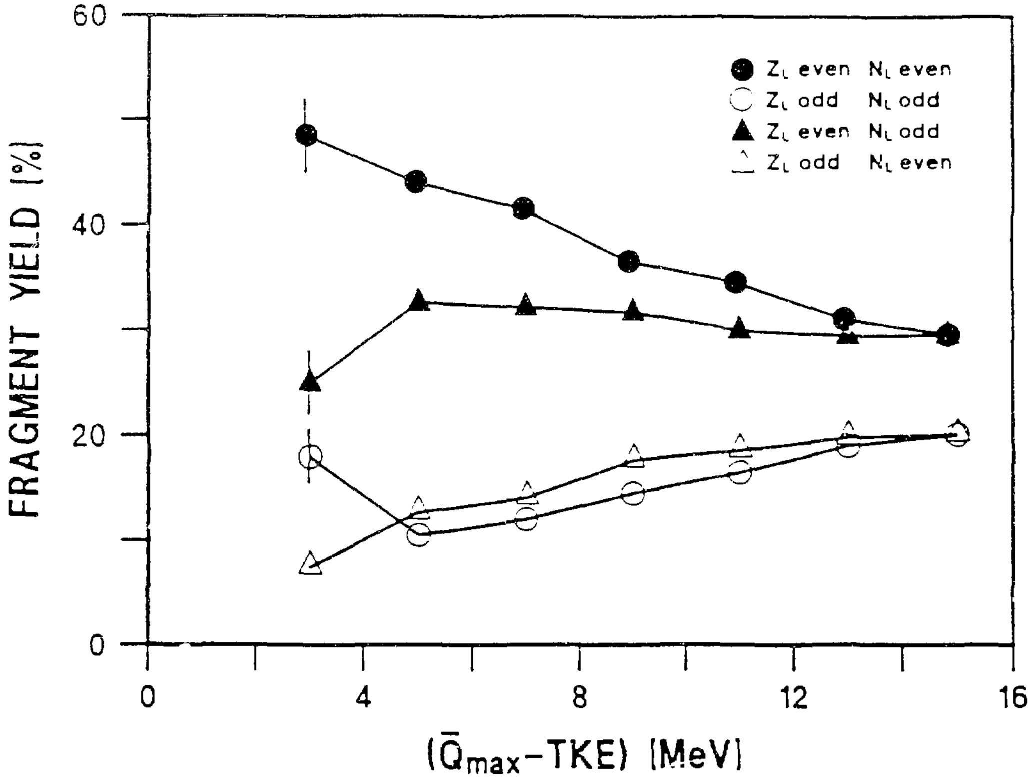

Fig. 3. The yields of fragments with even-even, odd-odd, even-odd and odd-even proton-neutron number are plotted versus ($\bar{Q}_{max}$-TKE)

Non-Neutron Nuclear Data for Standards

Half Life of ^{125}I

T. Altzitzoglou

Half-life uncertainties influence considerably the accuracy of the calculated standard source activity after a period of several half-lives. Uncertainties of less than 0.03 % might be necessary. In the case of ^{125}I a more accurate determination of the half-life has been requested[1].
Several ^{125}I sources were prepared and sealed in standard aluminium containers (diameter 15 mm, thickness 3 mm). They were counted at regular intervals using both a NaI(Tl) and a germanium detector. Data reduction and evaluation are in progress.

---

[1] P. Christmas, A.L. Nichols, A. Lorenz, INDC (NDS)-221/GE (1989)

Alpha-Particle Emission Probabilities

G. Bortels, D. Mouchel

High-resolution alpha-particle spectra from highly enriched ^{236}Pu, ^{239}Pu and ^{243}Am have been measured to improve the present accuracy of the alpha-particle emission-probability data to better than 0.5 % for the major transitions. Very thin vacuum-evaporated sources were used. The measurements are finished and the evaluation of the spectra is in progress.

Evaluations of X- and Gamma-Ray Emission Probabilities

W. Bambynek

In the frame of an IAEA Coordinated Research Project (CRP) on X- and Gamma-Ray Standards for Detector Efficiency Calibration the X-ray emission probabilities of the radionuclides ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{57}Co, ^{58}Co, ^{65}Zn, ^{75}Se, ^{85}Sr, ^{88}Y, ^{93m}Nb, ^{109}Cd, ^{111}In, ^{113}Sn, ^{125}I, ^{137}Cs, ^{133}Ba, ^{139}Ce, ^{152}Eu, ^{154}Eu, ^{198}Au, ^{203}Hg, ^{207}Bi, ^{241}Am were re-evaluated[(1)].

---

(1) W. Bambynek, CBNM Internal Reports GE/R/RN/05/89 and GE/R/RN/12/89.

NUCLEAR DATA FOR FISSION TECHNOLOGY

Neutron Data of Actinides

Subthermal fission of ^{241}Pu

C. Wagemans*, P. Schillebeeckx**, A.J. Deruytter, R. Barthélémy, J.Van Gils

Results of the subthermal fission cross-section measurements for ^{233}U, ^{235}U and ^{239}Pu have been reported elsewhere [1]. Since especially for ^{241}Pu the σ_f-data base in the subthermal energy region appeared to be very poor, the same experimental set-up at GELINA has been used to measure the ^{241}Pu(n,f) cross-section down to 2 meV.

For these measurements, a liquid nitrogen cooled methane moderator has been installed at GELINA to enhance the neutron production for $E_n < 20$ meV. The accelerator was operated at a 40 Hz repetition frequency with 2 µs burst width and with an average electron current of 15 µA. An evaporated layer of 25 µg ^{6}LiF/cm^2 for the neutron flux determination and a 9 µg ^{241}Pu/cm^2 layer (prepared by solution spraying of Pu-acetate) were mounted back-to-back in the centre of a large vacuum chamner. The fission fragments and the particles from the ^{6}Li(n,α)t reaction were detected with two 20 cm^2 large surface barrier detectors placed outside the neutron beam.

For the ^{6}Li(n,α)t reaction cross-section, a 1/v-shape was assumed in the energy region below 20 eV. The ratio of the background corrected fission and (α+t) counting-rates yields the $\sigma_f(E)\sqrt{E}$-shape, which still needs to be normalized. This normalization was done in the thermal region relative to the $\sigma_f°$-value of 1012.7 b proposed for the ENDF B6 file. Fig. 4 shows the preliminary $\sigma_f(E)\sqrt{E}$ data in the neutron energy range from 1 meV up to 1eV. Fig. 5 compares the $\sigma_f(E)\sqrt{E}$ data for ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu in the neutron energy range from 2 meV up to 100 meV, clearly demonstrating the 1/v-shape of these cross-sections below 10 meV. In the specific case of ^{241}Pu, our preliminary data follow a 1/v-shape up to about 50 meV, which is not the case for most of the data sets available in the literature. The difference is probably due to absorption and/or self-absorption effects and needs to be further investigated.

The 1/v-shape of the present ^{241}Pu subthermal fission cross-section data has a strong impact on the Westcott g_f-factor calculated from these data.

---

* SCK/CEN, Mol and Rijksuniversiteit Gent, Belgium

** Now at JRC Ispra

(1) C. Wagemans, P. Schillebeeckx, A.J. Deruytter, R. Barthélémy, Proc. Conf. on Nuclear Data (1988), p. 91

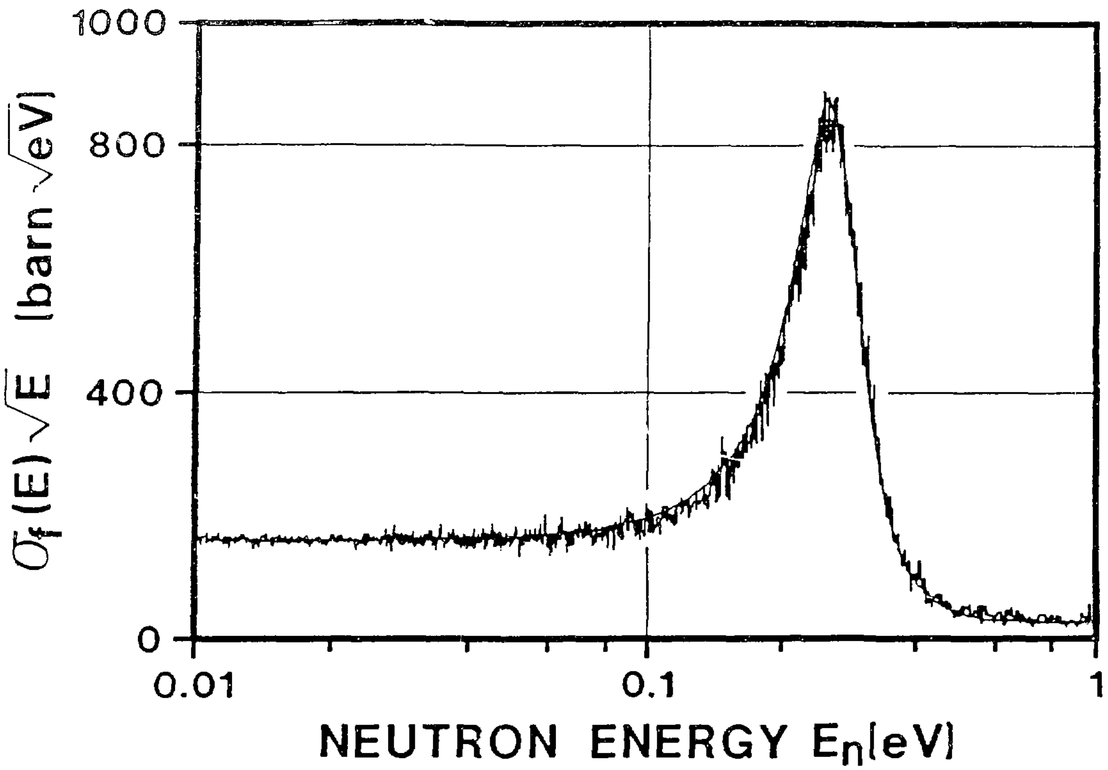

Fig.4. Fission cross section of ^{241}Pu as function of neutron energy

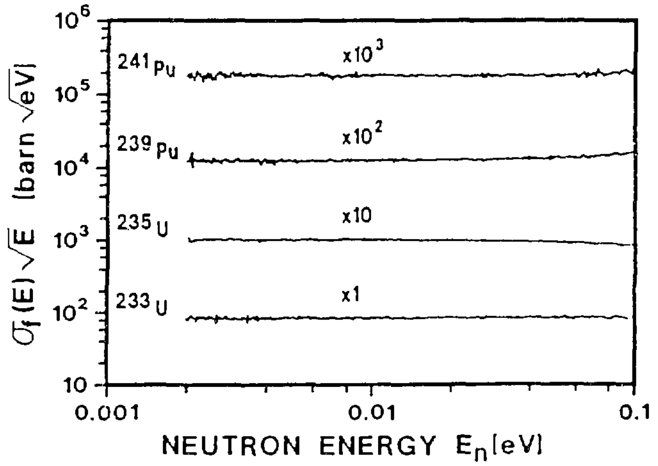

Fig.5. A Comparison of $\sigma_f(E)\sqrt{E}$ data for various nuclides

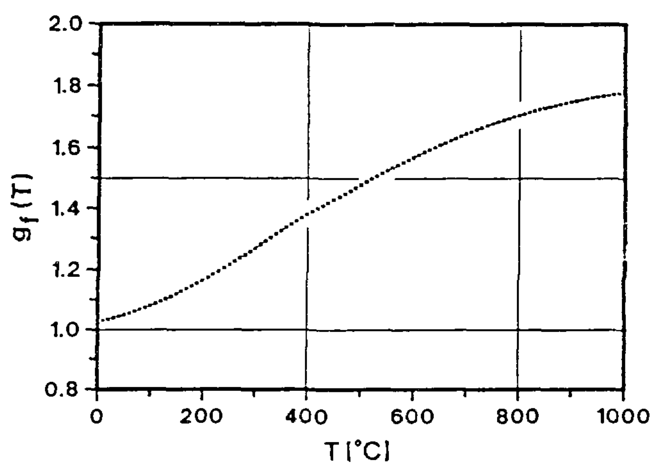

Fig.6. Westcott factor for ^{241}Pu as function of the temperature

Fig. 6 displays the Westcott g_f-factor calculated as a function of the temperature. The important g_f-factor at T = 20.44 °C yields a preliminary value of 1.036, which is about 1 % lower than the most recent evaluated values.

Eta of ^{235}U

B. Keck*, J.A. Wartena, H. Weigmann, C. Bürkholz, P. Geltenbort**,
K. Schreckenbach**

Earlier measurements of η, the number of fission neutrons emitted per neutron absorbed, of ^{235}U, executed at the GELINA pulsed white neutron source have indicated that the energy dependence of η may deviate from the constant assumed in ENDF/B-5 in the sub-thermal region by up to 2 %.
In order to confirm this indication, a similar experiment has been performed at a neutron beam of the ILL high flux reactor, with the conditions being improved as compared to the GELINA measurement in two ways: (1) the neutron spectrum is much more suited due to less high energy neutrons which in the time-of-flight experiment are the source of the background problems at lower energies and (2) by the installation of two choppers essentially a pulsed monoenergetic beam is produced, and background events in the detectors due to scattered neutrons are separated in time from true events. Details of the experimental arrangement and the measurements at the ILL have been described in the previous progress report[1].
A number of corrections has to be applied to the measured data: apart from backgrounds and dead-times, the data have to be corrected for incomplete absorption and scattering of the incident slow neutrons in the "black" uranium sample and in the capture sample, the relative number of secondary fission events induced by these neutrons, and the fraction of all fission neutrons that are detected in the liquid scintillator, must be taken into account. The latter fraction depends on the spatial distribution of primary fission events within the "black" uranium sample, and thereby on the energy of the incident slow neutrons. Finally, the self-absorption of the γ rays in the capture sample has to be considered. These corrections have been calculated by approximate analytical expressions as well as by Monte-Carlo techniques.

---

* Scientific Visitor from TH Darmstadt, Darmstadt, Germany
** ILL, Grenoble, France
(1) CBNM Annual Progress Report 1988, EUR 12267 EN

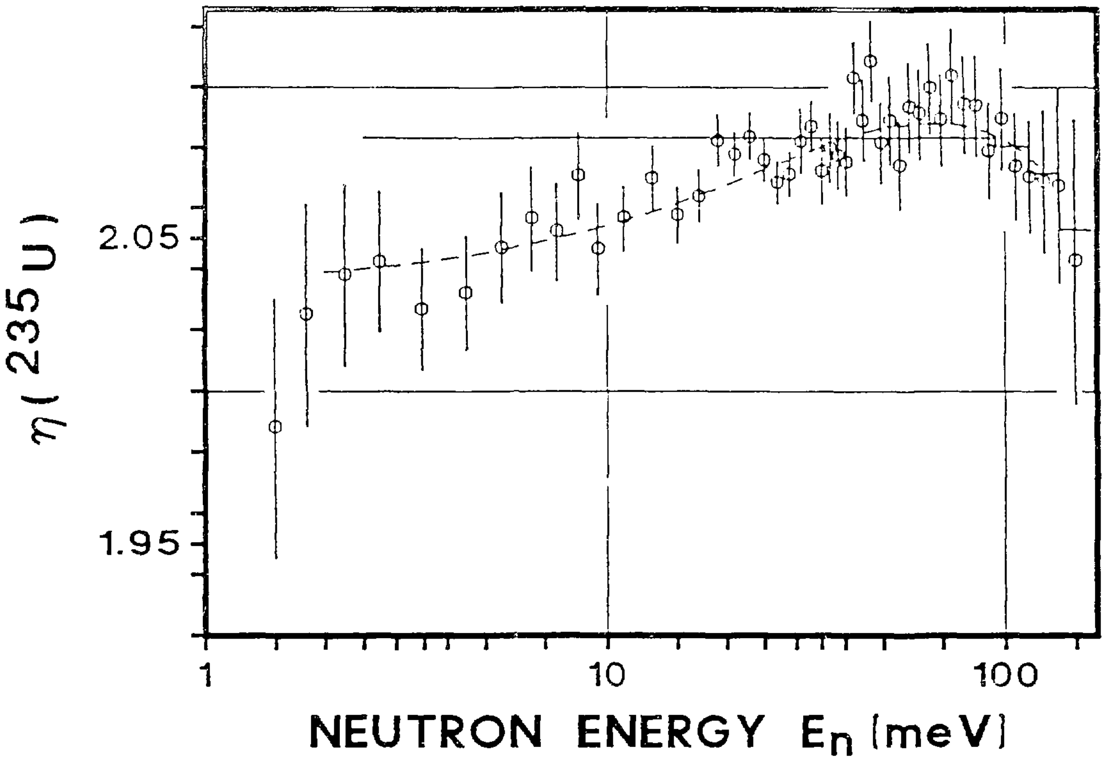

Fig. 7. Energy dependence of η of ^{235}U in the sub-thermal region as obtained from the measurements at the ILL reactor

The overall uncertainty of the resulting shape of the energy dependence of η is between 0.5 and 1 % in most of the energy range between 2 and 100 meV. The results from both experiments at the GELINA pulsed white neutron source and the ILL reactor show the same general trend, i.e. a gradual decrease of η for subthermal energies: η values below 5 meV neutron energy are about 2 % smaller than at 25 meV. This is in rough agreement with the proposal by Santamarina et al.[1] Fig. 7 shows the results obtained at the ILL reactor.

---

(1) A. Santamarina, C. Golinelli, L. Erradi : ANS Topical Meeting on Advances in Reactor Physics, Chicago (1984)

Neutron Data of Structural Materials

The ^{56}Fe 1.15 keV Resonance Task Force

F. Corvi, G. Fioni*, F. Gasperini, P.B. Smith**

The results obtained in the frame of this Task Force study have shown[1] that the weighting function to be applied in the pulse-height spectrum of total energy detectors used before the year 1988 was uncorrectly known. Thus, most of the neutron capture cross-section data obtained with the pulse-height weighting method prior to that date contain a systematic error which depends on the difference between the shape of the capture spectrum of the nuclide under investigation and that of the normalizing nuclide, typically gold or silver. The error is considered particularly serious for structural materials. However, before starting the revision of all data in this field, it was felt neccessary to repeat the experimental determination of the weighting under conditions as close as possible to the neutron capture setup.

The (p,γ) method used for the determination of reponse functions and efficiencies of monochromatic γ-rays has been described before[1]. The present experimental setup consists of two cyclindrical C_6D_6 liquid scintillators placed symmetrically at 90° with respect to the proton beam direction. Each scintillator viewed by a EMI 9823 KQB photomultiplier is supported by a light aluminium frame fixed to a movable platform. An improvement as compared to the previous measurement is the increase of the length of the end cap of the beam line from 15 to 50 cm : in this way the wobbling part to which the cap is connected and which consists of a rather massive metallic object is now too far away to influence the measurement in an appreciable way. The high-resolution detector is a coaxial high-purity Ge crystal of 30 % relative efficiency placed at 0° with respect to the beam direction. Besides the items described above no other material is present within a range of 40 cm around the target. The geometry of the experiment and in particular the position of the two detectors, their mutual distance and orientation with respect to the beam as well as the type of support reproduce exactly the conditions of the neutron capture measurements performed at CBNM. Also as in neutron capture, the detectors are unshielded and free from any other nearby surrounding material with the exception of their support.

---

* EC Fellow

** Rijksuniversiteit Groningen, Groningen, The Netherlands

(1) F.Corvi et al., Nucl Instr. Meth. A 265 (1988) 479

The efficiency values measured for 20 γ rays in the range from 0.2 to 8.4 MeV are plotted in Fig. 8 where the continuous line is a fit to the data of the type $f(E) = aE^2 + bE + c/E^3 + d$. The efficiency at low γ ray energies could be better described due to additional measurements made with some radioactive sources.

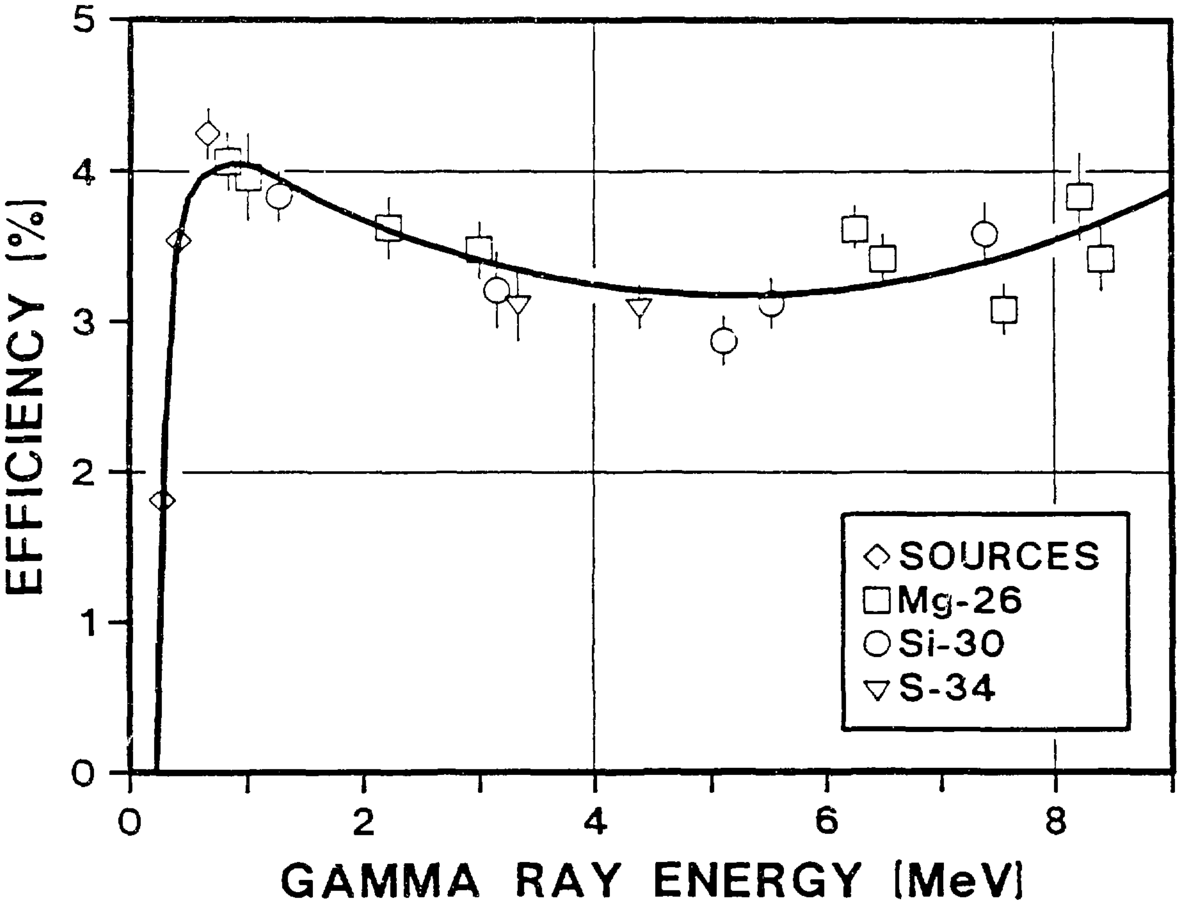

Fig. 8. Experimental values of the absolute efficiency of the two C_6D_6 scintillators operated in sum mode with a detection threshold of 100 keV. The full line is a fit to the data.

From the set of these efficiencies and the corresponding response functions a weighting function W has been derived such that its convolution with the response function of a given γ ray equals its energy in MeV. Since the weighting is very similar to that determined previously[1], it should be concluded that it is rather insensitive to such parameters as the source-to-detector distance, the angle between proton beam and detector axis, the number of detectors and even a limited amount of extra material in the vicinity of the γ ray source.

---

(1) F. Corvi et al., Nucl Instr. Meth. A 265 (1988) 479

The value of the neutron width of the 1.15 keV resonance obtained with the present weighting is Γ_n = (62.9 ± 2.1) meV, in good agreement with Γ_n = (63.4 ± 2.3) meV and with Γ_n = (61.7 ± 0.9) meV from transmission. The present exercise gives further confidence for applying the experimentally determined weighting function to neutron capture measurements.

Development of a Telescope Detector

C. Coceva*, A. Mauri**, A. Spits***

A capture experiment in ^{60}Ni resonances below 100 keV has been planned. In order to measure gamma spectra from capture of relatively high energy neutrons, a Ge crystal with 30 % relative efficiency was set up on a 25 m flight path.

The crystal is provided with a 4π telescope, composed by a NaI(Tl) annulus and two Ge crystals, as illustrated in Fig. 9.

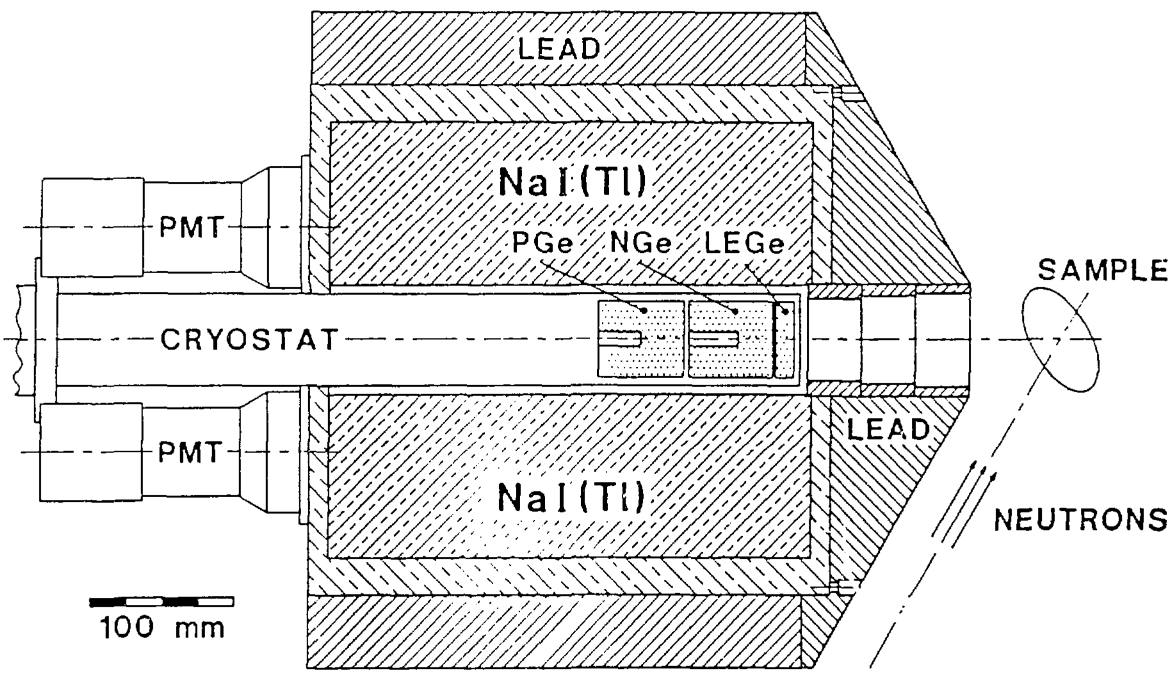

Fig. 9. Sample and detector set-up for measurement of gamma-ray spectra from neutron capture in single resonances. The central Ge detector (N type) is in anticoincidence with the two other Ge crystals and with four NaI(Tl) scintillators

---

* Scientific Visitor from ENEA, Bologna, Italy
** National expert from ENEA, Bologna, Italy
*** Scientific Visitor from SCK/CEN, Mol, Belgium

When the system is operated with the central Ge crystal in anticoincidence with any of the other detectors, around 6 MeV the double escape peak for gamma rays is reduced by a factor of 50 and the single escape peak by a factor of 7, approximately. The reduction of the Compton background can be seen in Fig. 10.

These improvements are obtained in exchange of a lower detection efficiency, since the Ge crystal has to be moved away from the sample.

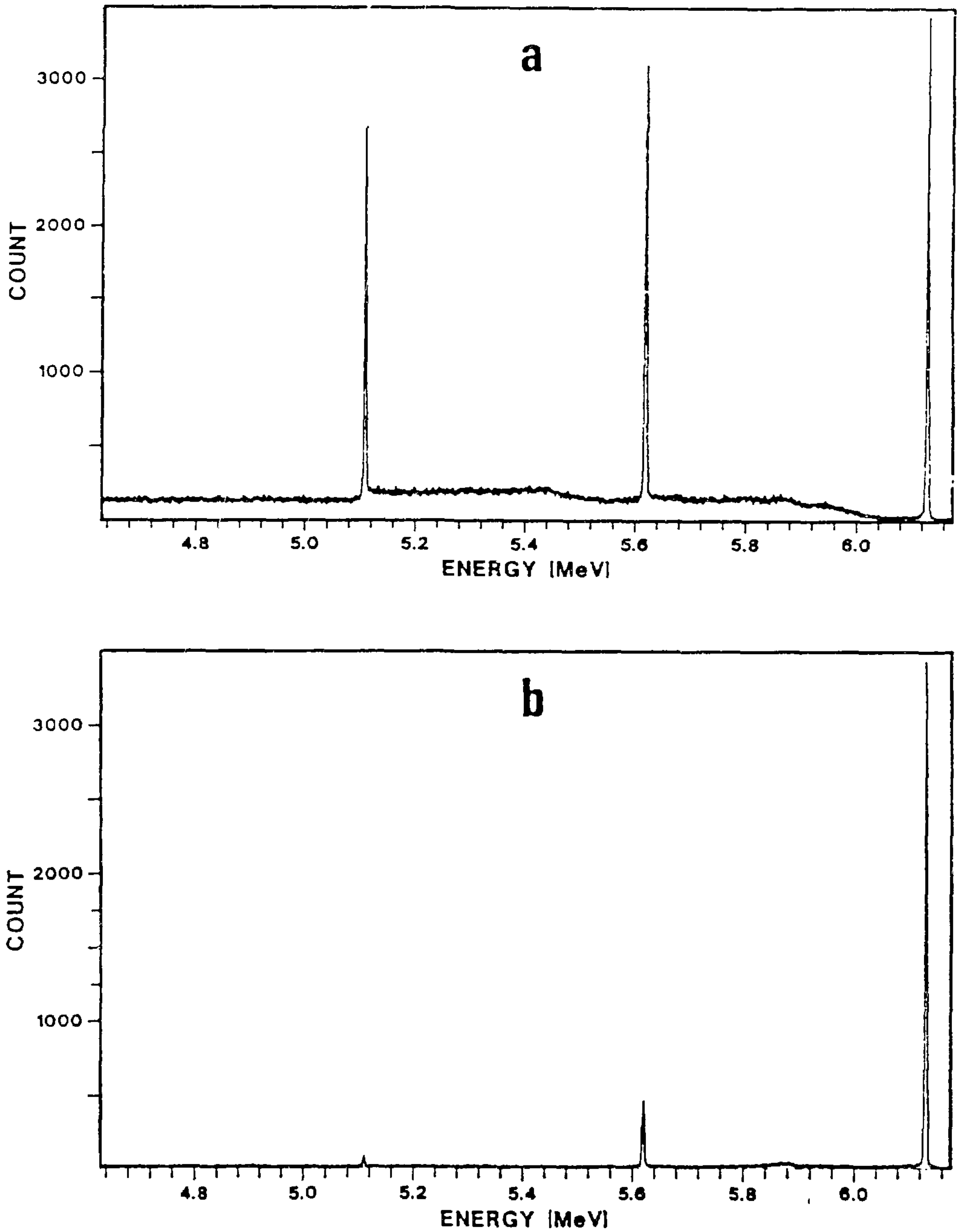

Fig. 10. Spectrum of monochromatic gamma rays at 6.13 MeV, detected by the central Ge crystal: a) without anticoincidence, b) with anticoincidence

The Distribution of the Intensity Spectrum Behind a Combined $^{238}U/Ge/Mn/W$ Neutron Beam Filter in the Energy Range 17.35 eV to 102.1 keV.

A.Brusegan, C.Baracca*, C. Van der Vorst

Beams of intense monoenergetic neutrons are applied in the fields of neutron physics, health physics, dosimetry and radiobiology(1).
Although a modest resolution is required, it is important that these beams have a low contribution from other energy neutrons. This has led to the development of the combined neutron filters.
The transmitted neutron spectra for a composite uranium filter have been measured at GELINA with the time-of-flight technique in the energy region from 10.4 eV to 1.0 MeV.
The uranium filter (16.4 cm) transmits neutrons at approximately 185 eV, whereas a germanium sample (3 mm) and a powder manganese sample (8.1g/cm^2) are used to remove the 100 eV peak and to reduce some satellite peaks.
An additional tungsten filter (1.5 mm) attenuates the wanted 185 eV line, but it leaves almost unchanged the other peaks in the neutron spectrum transmitted by the combined filter(2).
The experiment was carried out at the 50 m flight distance of the neutron total cross section facility of GELINA running with a repetition frequency of 100 Hz and an electron burst width of 14 ns.
The neutron detector consisted of a 0.5 cm thick sintered B_4C slab (92 % enriched in ^{10}B) viewed by four 10 cm x 7.5 cm NaI(Tl) scintillators: the assembly was screened with lead and borated paraffin.
A barium gamma ray source placed in the vicinity of the scintillators proved that the average variation of the photomultipliers' gain could be kept within 3 %. The measurement consisted of the determination of the transmitted neutron spectra applying various sample combinations. From each spectrum the constant background, normalised to the effective measuring time, was substracted, then the remaining part below 102 keV was fitted and subtracted.
In particular the background for the 'unperturbed' beam was calculated in the minima of the black resonances lying in the energy range from 18.4 eV up to 102 keV, renormalised in the cobalt resonance minimum (at about 132 eV) and then corrected for the attenuation (6.1 %) of the background due to the cobalt filter itself.

---

* EC Fellow

(1) R.C.Block, R.M.Brugger, Filtered Neutron Beams, Ch.8, Neutron Physics and Nuclear Data (Cierjaks, ed.),Vol. 2,p.177

(2) Filters supplied by PTB, Braunschweig, Germany

The systematic error introduced by this technique is on the average 2 %. This error plus that due to the gain variation of the PM's raises to 5 % the total average systematic deviation of the final transmission values. In Fig.11 the transmissions of 3 filters are shown in the energy interval 176 eV - 193 eV. In Table 1 the average properties for the U/Ge/Mn filter and for the filter difference spectrum are given.

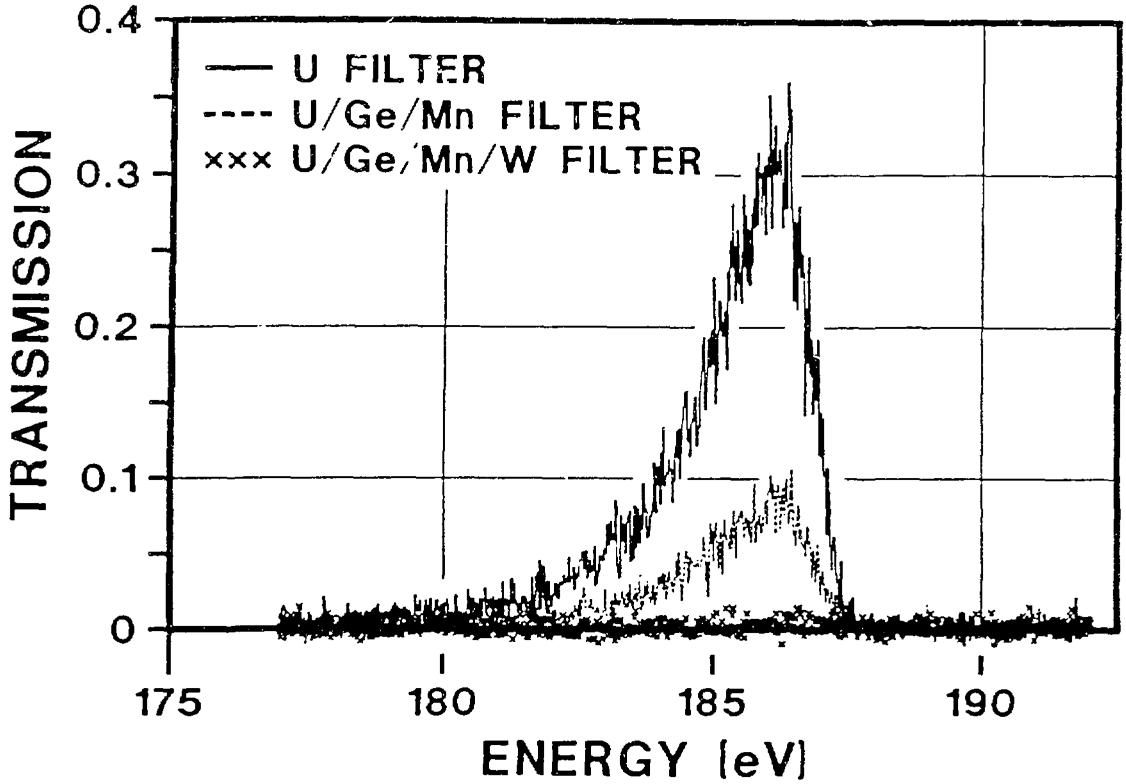

Fig. 11. Transmission spectra as function of neutron energy for various filters

Table 1. Average filter properties (given error are statistical standard deviations).

Filter	U/Ge/Mn	U/Ge/Mn and U/Ge/Mn/W difference
Integral : 176.46 eV - 187.85 eV 17.35 eV - 102.1 keV	10.01 ± 0.20 15.89 ± 0.93	9.38 ± 0.14 9.37 ± 0.17
Ratio	0.630 ± 0.039	1.001 ± 0.024
Average energy [eV]	184.98	185.10
Width [eV]	1.80	1.53

NUCLEAR DATA FOR FUSION TECHNOLOGY

Double-Differential Neutron-Emission Cross-Sections

H. Liskien, L. Mewissen*, F. Poortmans*, J. Wartena, H. Weigmann, C. Bürkholz

The basis and concept for experimental work to determine double-differential neutron-emission cross-section data for neutron-transport calculations have been described previously[1].

A first series of measurements on the reaction ^{9}Be(n,2n) had been done end 1986. During 1989 a second measurement campaign has been conducted, including measurements on ^{12}C which serve for normalization of the data obtained for ^{9}Be, to the differential elastic scattering cross section of ^{12}C below 2 MeV.

The data from both experiments are being analysed at present. Apart from the unfolding of the experimental pulse height distributions the correction for multiple scattering events has to be introduced. This is done by Monte Carlo calculations. In the case of ^{9}Be they must take into account, besides elastic scattering, also (n,2n) events, for which a rough estimate of the relevant cross sections is used.

For future measurements of double-differential neutron-emission cross sections at GELINA a new target consisting of uranium and beryllium plates in a sandwich arrangement, has been realized. The neutron yield from this target exceeds the yield from the rotary targets above 10 MeV neutron energy by a factor of 2 to 3, whereas at lower energies the yield from the U-Be target is smaller by a factor of about 0.65.

Excitation Functions of (n,p) and (n,α) Reactions on Molybdenum and Titanium Isotopes

H. Liskien, N.I. Molla**, S.M. Qaim**, R. Widera, R. Wölfle**

Molybdenum and titanium are important components of structural materials used in fission and future fusion reactors. The molybdenum experiment has been decribed previously.[1]

---

* SCK/CEN, Mol, Belgium

** KFA, Jülich, Germany

(1) CBNM Annual Progress Report 1988, EUR 12267 EN

The analysis is meanwhile finalized and an article is in press in the International Journal of Applied Radiation and Isotopes. Cross sections were measured for the reactions $^{92}Mo(n,\alpha)^{89}Zr$, $^{92}Mo(n,p)^{92m}Nb$, $^{92}Mo(n,np)^{91m}Nb$, $^{95}Mo(n,p)^{95g}Nb$, $^{95}Mo(n,p)^{95m}Nb$, $^{96}Mo(n,p)^{96}Nb$, $^{98}Mo(n,\alpha)^{95}Zr$, $^{100}Mo(n,\alpha)^{97}Zr$. Use was made of the activation technique in combination with high-resolution γ-ray spectroscopy. The neutron fluence rates were determined using two independent methods, viz. proton recoil and $^{27}Al(n,\alpha)^{24}Na$ monitor reaction. The present work concentrates on activation products with half-lives in the range of (0.7 - 70) days and provides excitation functions in the (12.5 - 19.6) MeV region.

The titanium experiment is conducted along the same line. Two sample irradiations took place with neutron fluence rates of $5 \cdot 10^7$ $sr^{-1} \cdot s^{-1}$ (for 0°). Presently γ-ray counting is performed. Sample preparation for additional β-ray counting is going on.

A lecture on "Improved Neutron Fluence Accuracies in Activation Experiments" has been presented at the NEANDC Specialists' Meeting on Neutron Activation Cross Sections for Fission and Fusion Energy.

The Excitation Function for the Reaction $^{52}Cr(n,2n)^{51}Cr$

H. Liskien, M. Uhl*, M. Wagner*, G. Winkler*

Chromium is contained in candidate materials for future fusion reactors, ^{52}Cr being the main isotope. Above the neutron binding energy, elastic scattering and the (n,2n) reaction are the main neutron interaction processes.

The experiment has been decribed in the previous progress report. It was meanwhile finalized and an article is in press in Annals of Nuclear Energy. The excitation function for the (n,2n)-reaction on the main isotope of the structural material has been determined from threshold to about 20 MeV using the activation technique. Quasi-monoenergetic neutrons were produced via the $T(d,n)^4He$ reaction making use of the neutron energy variation with emission angle. The neutron fluences seen by the 24 symmetrically arranged samples were determined relative to the well-known angular distribution of the source neutrons and the (n-p)-scattering cross section using a recoil-proton telescope. In addition they were checked around 14 MeV against the well-evaluated Nb(n,2n) cross section.

---

*IRK, Vienna, Austria

The induced ^{51}Cr ($T_{1/2}$ = 27.7 d) γ-ray activities were measured by means of an intrinsic solid state Ge detector and a carefully calibrated NaI(Tl) well-type scintillator. The results agree at 14 MeV with the many experimental results published earlier. However, they disagree above 15 MeV with two earlier experimental excitation functions, one of which published very recently. Theoretical calculations also have been performed based on direct inelastic scattering, on pre-equilibrium emission and on sequential evaporation from the equilibrated compound nucleus. Results show satisfying agreement with the experimental data and similar theoretical results obtained elsewhere.

Systematic Studies of Excitation Functions of (n,t) Reactions on Medium and Heavy Mass Nuclei

R. Wölfle*, S.M. Qaim*, H. Liskien, R. Widera

The (n,t) reaction is known to occur mainly in the light mass region; major efforts were devoted so far to the study on ^{6}Li, ^{7}Li[1], and ^{9}Be[2]. In the medium mass region the excitation functions of aluminium, cobalt and niobium[3] have been determined in the 14 to 20 MeV region. This work has been performed to cover a more extended mass region. Cross sections were measured for (n,t) reactions on beryllium, vanadium, indium, lanthanum, tantalum and bismuth with the incident neutron energy in the range between 16 and 19.6 MeV using the activation technique and low-level tritium counting. The (n,t) cross section increases with increasing neutron energy. At the maximum incident neutron energy used (i.e. about 5 MeV above the reaction threshold) the (n,t) cross section shows very little change between vanadium and bismuth. Hauser-Feshbach calculations on the first chance emission of tritons from target nuclei with $A \geq 51$ give results which are appreciably smaller than the experimental data. The contribution of statistical processes appears to decrease with the increasing mass of the target nucleus. A paper has been accepted for publication in Radiochimica Acta.

---

* KFA, Jülich, Germany

(1) S.M. Qaim, R. Wölfle, H. Liskien, Phys.Rev C25, 203 (1982)

(2) H. Liskien, R. Wölfle, S.M. Qaim, Int.Conf.on Nucl.Data for Science and Technology, Antwerp (1982) p.349

(3) H. Liskien, R. Widera, R. Wölfle, S.M. Qaim, Nucl. Sci. Eng. 98, (1988)266

Automation and Test of a dE-t-E Alpha Particle Telescope

E. Wattecamps, G. Rollin

An alpha particle telescope was developed at the Van de Graaff laboratory to measure neutron induced charged particle production cross section data of structural materials for fusion reactors. First tests of the telescope were described in the previous annual progress report[1].

More recently the operation with the telescope was automated by implementing a commercial robot, which sets any of four possible samples in the irradiation position. To perform repeatedly sequential irradiation of foreground-, background- and calibration-samples, and to get data acquisition in listing mode with adequate on-line monitors as well, specific software was developed and tested.[2]

Preliminary tests with the automated system were performed at 7 MeV neutron energy with samples of nickel and natural lithium. Two-dimensional foreground distributions of Li(n,x) reactions have been registered.

Off line analyses of listing mode spectra, N(E,t,ΔE), were performed. The method of acquisition and analysis is specific and redundant, the background is very small and the counting rate is quite large.

---

(1) CBNM Annual Progress Report 1988, EUR 12267 EN

(2) G. Rollin, E. Wattecamps, CBNM Internal Report GE/R/VG/63/89

SPECIAL STUDIES

Study of Sub-Nucleonic Interactions

G. Rohr

According to the present understanding the spacings of neutron resonances are distributed like a Wigner function in agreement with Bohr's compound nucleus model. Based on the independent particle model it is found however that in order to study the dynamics of nucleons in nuclei one has to be limited, in a nearest-neighbour spacing distribution, not only to levels with a given spin and parity but also to levels of low seniority number (s). The levels of lowest seniority are doorway states (2p-1h states, s = 3) which can be understood as being created by a single collision of an incoming neutron with one of the target nucleons, exciting the nucleus to its lowest mode of nucleon-nucleon interaction. More complex states (s > 3) are created in a multiple collision process which is accompanied by additional nuclear states changing the spacing distribution of the lowest mode, with no possibility to correct for it. According to the level density parameter systematics, doorway resonances are expected at neutron separation energy for A < 38 and closed shell nuclei[1].

The following α-cluster nuclei ^{28}Si, ^{32}S and ^{40}Ca as well as the closed shell nuclei ^{52}Cr and ^{96}Zr have been studied and non-statistical effects indicating sub-nucleonic interaction are observed. The main result is a Gaussian-like distribution of the nearest level spacings which points to the existence of phonons in particle excitations and permits the nucleus to be represented by a multiple harmonic oscillator.

Table 2 Phonon properties

	two-oscillators phonons	three-oscillators phonons
ε_q [1. keV]	310 ± 40	31 ± 9
τ_q $[10^{-2}s]$	1.6 ± 0.45	7 ± 1.2

In Table 2 the phonon properties of two different phonons are collected.

---

[1] G. Rohr, Z. Phys. A318, 299-308 (1984)

The energy is calculated from the average level spacing

$$\bar{D} = \varepsilon_q = \hbar\omega_q$$

and the lifetime

$$\tau_q = \hbar/\Delta\varepsilon_q$$

is based on the standard deviation $\Delta\varepsilon_q$ of the Gaussian distribution. The two-oscillator and three-oscillator phonons are based on resonance data of ^{32}S (and ^{28}Si for $\Delta\varepsilon_q$) and ^{52}Cr respectively. There is a reasonable agreement between lifetime of phonons and of nuclear states.

The results are in disagreeemnt with a two-body nucleon-nucleon interaction and indicate a sub-nucleonic many-body interaction. An analogy between nuclear and solid state physics can be observed.

Nonstatistical Effects Observed with ^{52}Cr + n Resonances

G. Rohr, R. Shelley, A. Brusegan, F. Poortmans*, L. Mewissen*

The neutron total and neutron capture cross sections of ^{52}Cr have been measured using the neutron time-of-flight technique at the pulsed electron linear accelerator (GELINA) of CBNM, Geel. Data analyses have been performed in the energy ranges 1 to 500 keV to 1 MeV, respectively, for capture and transmission, with R-matrix multilevel multichannel codes and with resonance shape fitting procedures, to determine the resonance parameters E_0, $g\Gamma_n$, $g\Gamma_\gamma$, J and l. Subsequent values for the average resonance parameters for s-wave and p-wave neutron resonances are: D_0 = (41.5 ± 4.4) keV and S_0 = (2.85 ± 0.25) x 10^4 up to 1 MeV, and D_1 = 14.7 keV and S_1 = (0.30 ± 0.05) x 10^4up to 200 keV. The following non-statistical effects are indicated in the resonance parameter set: two gaps are observed in the s-wave level distribution, where at least two resonances for each gap are missing; a strong discontinuity in the level spacing is observed for p-wave resonances whereby three energy ranges, up to 500 keV, with different level spacings may be distinguished. This energy-dependent behaviour of the p-wave level density shows that the level density parameter (a) strongly depends on the excitation energy and causes parity dependence of nuclear states in the neutron energy range (200-600) keV. These deviations of the resonance parameters from statistical behaviour may be explained by doorway structures with a small spread of states, as has been observed for ^{28}Si and ^{32}S which, like ^{52}Cr, have a multipler of four nucleons in the target nucleus.

---

*SCK/CEN, Mol, Belgium

NUCLEAR METROLOGY

RADIONUCLIDE METROLOGY

Assessment of Accuracy in Alpha-Particle Spectrometry

G. Bortels, D. Mouchel, E. Garcia-Toraño*, M.L. Aceña*

The problem of the accuracy of peak analysis with peak-fitting codes has been assessed for spectra with strongly overlapping peaks. Synthetic doublets were produced by adding two high-resolution ^{234}U spectra, one of which had been shifted numerically over an energy distance corresponding to 0.5, 1 and 2 full width at half maximum (FWHM). Various peak ratios in the doublets were obtained from the least-squares fit to the doublets and compared with the values known from the analysis of the spectra before addition.

It was found that an accuracy of 1 % or better can be obtained for peak ratios close to 0.5 and peak separations down to about one FWHM. Larger uncertainties may occur outside these regions. Detailed information is in the course of being published.

Nonlinear Response of Silicon Detectors to Particle Irradiation

P. Bauer**, G. Bortels

When used for energy spectrometry of charged particles, semiconductor detectors have a nonlinear response as a result of energy losses in the source, the detector entrance window, and in the sensitive volume due to nuclear collisions, recombination of electron-hole pairs and dependence of the energy needed to create an electron-hole pair on the stopping power.

The latter effect was investigated for two particle-implanted passivated silicon detectors by measurement of the detector response to alpha particles from a mixed ^{239}Pu, ^{241}Am, ^{244}Cm source and to conversion electrons from ^{109}Cd, ^{237}Np-^{233}Pa and ^{137}Cs sources.

Recombination of charge carriers can be neglected for electrons and alpha particles. The thickness of the entrance window was measured by means of slow hydrogen ions and nuclear losses were calculated by the TRIM.T2D code.

---

* CIEMAT, Madrid, Spain
** Scientific Visitor from the Johannes Kepler Universität, Linz, Austria

This investigation confirms the validity of the model proposed by Lennard et al.[1]. Quantitative results compare well with those in the literature for surface-barrier detectors.

Low-Energy X-Ray Standards

B. Denecke, C. Ballaux*, W. Bambynek, G. Grosse, A. Srivastava**, U. Wätjen

Fluorescence sources were prepared and their KX-ray emission rates certified with an accuracy of better than 2 %. The sources were standardized using a gas-flow proportional counter in a defined low-solid angle set up. They were used for the efficiency calibration of a Si(Li) detector at the characteristic KX-ray energies of aluminium, phosphorus, sulfur, chlorine, calcium and titanium. Improvement of the source preparation is in progress.

Measurement of K-Shell Fluorescence Yields

A. Solé***, W. Bambynek

The study of K-shell fluorescence yields has been a subject of investigation for many years. Only in recent years it became possible to calculate fluorescence yields with some degree of confidence. Nevertheless, evaluations still show inconsistencies in the reported K-shell fluorescence yields for atomic numbers between 20 and 30.
The possibility to measure K-shell fluorescence yields for these elements by the method of fluorescence excitations of solid targets has been investigated. It is estimated that this method will not yield results of better than 5 % accuracy with the presently available input data[2].

Determination of the Count Rate to Mass Ratio of Two Series of $^{237}NpO_2$ for Neutron Dosimetry

T. Altzitzoglou

The relative specific activity of two sets of $^{237}NpO_2$ spheres, used for

---

* SCK/CEN, Mol, Belgium

** Scientific Visitor from the Institut für Kernchemie der Universität Mainz, Mainz, Germany

*** EC Fellow

(1) W.N. Lennard, K.B. Winterbon, Nucl. Instr. and Meth. B 24/25 (1987) 1035

(2) A. Solé, CBNM Internal Report GE/R/RN/13/89

neutron dosimetry, was measured, in order to check the hcmogeneity within each set and the probability that the spheres of the two sets belong statistically to the same population.

The measurements were carried out using a germanium detector and the data analysis was based on the 86.5 keV line in the decay of ^{237}Np and the 300.2, 311.9 and 340.5 keV lines of its daughter, ^{233}Pa. Corrections for the self-absorption and different measurement geometries were applied. The spheres within the individual sets were found to be homogeneous, but the two sets do not belong statistically to the same population[1].

---

[1] T. Altzitzoglou, CBNM Internal Report GE/R/RN/01/89

METROLOGY OF NEUTRON FLUX AND DOSE

International Fluence Comparison

H. Liskien, Li Linpei*, R. Widera

In 1986 the Van de Graaff laboratory of CBNM participated in an international fast neutron fluence intercomparison organized by BIPM which used two uranium-loaded parallel-plate fission ionsation chambers (^{235}U and ^{238}U) as transfer instruments.[1] Meanwhile this round-robin exercise has been finalised. Only NBS (now NIST) used for the participation at 565 keV both a quasi-monoenergetic and a white source. The only other white source included is that of AERE Harwell, where unfortunately only relative measurements were performed.

The pair of fission chambers have proven to be suitable transfer instruments for the accurate intercomparison of fast neutron fluence rates available on all the accelerator-based neutron sources used in neutron metrology. Although the participants used a variety of methods to determine these fluences none of them suffered from significant unknown systematic errors. The results can also be used to determine accurate standard fission cross sections. Results obtained support the new values of ENDF/B-6. The conclusions from this exercise were submitted to Metrologia for publication.

At CBNM a pair of chambers has been built and tested[1]. Unfortunately the 260 mg ^{235}U material used contained 1.67 atom% ^{234}U. This resulted in an α-particle decay rate of $\approx 10^6$ s^{-1} which did not allow a proper separation from fission fragments.

---

* Scientific Visitor from the National Institute of Metrology, Beijing, PR of China

(1) H. Liskien, A. Paulsen, R. Widera, S. Bao, CBNM Internal Report GE/R/VG/51/86; Li Linpei, CBNM Internal Report GE/R/VG/61/89

TECHNICAL APPENDIX

LARGE FACILITIES

Electron Linear Accelerator

J. M. Salomé

Neutrons are produced in a rotary uranium target via (γ,n) and (γ,f) reactions. According to the requested neutron energies, moderators of water or liquid CH_4 are placed on both sides of the target. Twelve flight paths are equipped for neutron time-of-flight experiments. On the average, 2.5 neutron beams were used simultaneously when GELINA was operated at very short bursts and one when operated at 40 Hz with the methane moderator.

The new mercury cooled and stainless steel canned heterogeneous U-Be target was set up in March. This target was designed to enhance the neutron yields at energies above 10 MeV. Operating the Linac at 5.5 kW (1 ns, 800 Hz), the temperatures registered at three positions in the U-Be core remained below 120° C. Due to the comparatively low bremsstrahlung absorption in this target, the radioactivity of air measured in the ventilation-stack was close to the authorized limits. To reduce it sensibly, several empty barrels were placed beyond the target to trap most of the activated air in the room.

Study of Transition Radiation

X. Artru*, P. Goedtkindt**, F. Poortmans***, J.M. Salomé, F. Van Reeth, C. Waller, L. Wartski*, N. Maene***

Transition Radiation (TR) is generated when energetic electrons cross the boundary between two media. The radiation can extend from microwave to X-ray frequencies.

Both optical and X-ray TR are being measured, with more effort on X-ray beam characterization. An optical system will allow observation of the visible light emitted from thin foil radiators, installed in two different places, with a sensitive CCD camera set up outside the target room.

The X-ray spectra emitted by various stacks of foils have been calculated. In view of reducing some non relevant bremsstrahlung during the experiment, the magnetic deviations have to be slightly modified. In addition GELINA must be operated with an increased rf power in the prebunching cavity to reduce the electron beam energy spectrum.

---

* Université de Paris XI, Orsay, France
** EC Fellow
*** SCK/CEN, Mol, Belgium

Van de Graaff Accelerators

A. Crametz

CN - 7 MV : Neutrons from the $^{9}Be(d,n)$ reaction with a 6.3 MeV, 9 µA DC deuteron beam have been produced for irradiations asked by the SCK/CEN radiobiology Department. Furthermore a $^{14}N^{+}$ beam (2.5 MeV, 3 µA DC) has successfully been produced. For this purpose, however, the 30° analyzing magnet in the high voltage terminal had to be removed;
KN - 3.7 MV : 1) in view of the installation of a microbeam in the target hall of this accelerator, an air compressor has been transferred to a more remote place : vibrations on the beam extensions are now eliminated.

Operation of Central Computer System and User Support

C. Cervini, H. Horstmann, J.J. Soro

The central computer (4381/P2) as part of the integrated system for scientific data processing and office automation (Ethernet)has mainly been used for the analysis of experimental data (Projects Nuclear Measurements and Reference Materials).
CBNM has become a member of the DFN-Association, has installed the UCLA/Mail400 message handling system (CCITT X400) and uses the DFN gateway at GMD (Bonn) to EARN and BITNET.
An APL2 package for the stock management of fissile material at CBNM has been developed on the basis of the EURATOM Safety Regulations.

TGS Filing Control Utilities For Multiparametric Data Acquisition

C. Bastian, C. Cervini, C.A. Nazareth

TGS was developed as a file format capable of holding a variable number of spectra of variable size in one file. In this way all spectral results belonging to a multiparametric measurement may be transferred as a single file from the acquisition system via CBNM's Ethernet to the IBM 4381 mainframe.
TGS filing utilities allow the user to combine (PACK) spectra into a TGS file, to inspect (SCAN) a TGS file, or to retrieve (UNPACK) spectra from a TGS file.
TGS control utilities can monitor measurements performed by cycles of acquisition by checking automatically the corresponding parameters.

Special Electronic Equipment for Laboratory Use

S. de Jonge, E. De Roost, H. Nerb, W. Stüber, C. Teuling, H. Mensch

Several electronic units have been developed, constructed and installed, among others buffer units, ADC-analyser interfaces, fast time coders, analog spectrum stabilizers, interval digitizers, and NIM crate monitors.

LIST OF PUBLICATIONS

CONTRIBUTION TO CONFERENCES

BORTELS, G., MOUCHEL, D., GARCIA-TORANO, E., ACENA, M.L.
Synthetic doublets from ^{234}U alpha spectra for assessing accuracy in peak fitting.
Intern. ICRM Symp. Nucl. Decay Data: Spectrom. Meth., Meas. and Eval., Braunschweig, June 6-8, 1989; Nucl. Instr. and Methods Phys. Res. A286 (1990)429

BUDTZ-JØRGENSEN, C., KNITTER, H.-H
Simultaneous investigation of fission fragments and neutrons in $^{252}Cf(SF)$.
Physics of Neutron Emission in Fission, Proc. IAEA Consultants' Meeting, Mito; INDC (NDS)-220(1989), p. 181

DENECKE, B., BALLAUX, C., BAMBYNEK, W., GROSSE, G., WÄTJEN, U.
A set of X-ray fluorescence reference sources for the intrinsic efficiency calibration of Si(Li) detectors down to 1 keV.
5th Intern. Conf. on Particle Induced X-Ray Emission and its Analytical Appl., Amsterdam, August 21-25, 1989

DENECKE, B., GROSSE, G. WÄTJEN, U. BAMBYNEK, W., BALLAUX, C.
Efficiency calibration of Si(Li) detectors with X-ray reference sources at energies between 1 and 5 keV.
Intern. ICRM Symp. Nucl. Decay Data: Spectrom. Meth., Meas. and Eval., Braunschweig, June 6-8, 1989; Nucl. Instr. and Methods Phys. Res. A286 (1990)474

DERUYTTER, A.J., FREHAUT, J.
Les méthodes expérimentales actuelles : mesures des sections efficaces et ν.
Le Cinquantenaire de la Découverte de la Fission, Société Française d'Energie Nucléaire, Paris, 21 juin 1989

FUDGE, A.J., PAUWELS, J., VAN AUDENHOVE, J.
Neutron dosimetry materials used in European Community Countries.
Reactor Dosimetry: Methods, Applications and Standardization, Proc. 6th Symp., Jackson Hole; H. Farrar IV and E.P. Lippincott (eds.), ASTM-STP 1001 (1989), p. 627

HAMBSCH, F.-J., KNITTER, H.-H., BUDTZ-JØRGENSEN, C., THEOBALD, J.P.
Interpretation of fluctuations of $\bar{\nu}$ and E_γ in resonances of ^{235}U (n,f).
Physics of Neutron Emission in Fission, Proc. IAEA Consultants Meeting, Mito;
INDC (NDS)-220 (1989), p. 129

KNITTER, H.-H., HAMBSCH, F.-J., BROSA, U., BUDTZ-JØRGENSEN, C.
New results in fission: fission modes and bifurcation points - inhomogeneous elasticity of a prescission nucleus - scission neutron production mechanism in ^{252}Cf(SF).
Int. Conf. Fifty Years Res. in Nuclear Fission, Berlin, April 3-7, 1989

KNITTER, H.-H., HAMBSCH, F.-J., BUDTZ-JØRGENSEN C.
Nuclear mass and charge distributions for cold and near cold spontaneous fission of ^{252}Cf.
50th Anniversary of Nuclear Fission, Leningrad, USSR, October 16-20, 1989

LISKIEN, H.
Improved neutron fluence accuraciesin activation experiments.
Specialists' Meeting on Neutron Activation Cross Sections for Fission and Fusion Energy, ANL, Argonne, September 13-15, 1989

ROHR, G.
Clustering in nuclei and the level density parameter.
Specialists' Meeting on Nuclear Level Densities, Bologna, November 13-17, 1989

ROHR, G.
Neutron resonances and single particle treatment.
Ibidem

WAGEMANS, C., SCHILLEBEECKX, P., DERUYTTER, A.J.
Investigation of neutron shell effects and fission channels in the spontaneous fission of the Pu-isotopes.
50 Years Research in Nuclear Fission, HMI, Berlin, April 3-7, 1989;
Nucl.Phys. A 502 (1989) 287C

WEIGMANN, H., KNITTER, H.-H., HAMBSCH, F.-J.
Light particle and photo induced fission.
50 Years Research in Nuclear Fission, Berlin, April 3-7, 1989;
Nuclear Physics A502 (1989) 177C

WEIGMANN, H.
Subthreshold fission and barrier effects.
50 Years with Nuclear Fission, Gaithersburg, April 25-28, 1989

SCIENTIFIC OR TECHNICAL ARTICLES

CORVI, F., FIONI, G., GASPERINI, F.
The weighting function of a neutron capture detection system.
Nucl. Sci. Eng. (to be published)

COURSEY, B.M., VANINBROUKX, R., REHER, D., HUTCHINSON, J.M.R., MULLEN, P.A., DEBERTIN, K., GEHRKE, R.J., ROGERS, J.W., KOEPPEN, L.D., SMITH, G.
The standardization of niobium-93m for use as a reference material for reactor neutron dosimetry.
Nucl. Instr. and Methods Phys. Res. A (to be published)

HAMBSCH, F.-J., KNITTER, H.-H., BUTDZ-JØRGENSEN, C., THEOBALD, J.P.
Fission mode fluctuations in resonances of $^{235}U(n,f)$.
Nucl. Phys. A491 (1989) 56
INGELBRECHT, C., PEETERMANS, F., PAUWELS, J.
A study of the homogeneity of aluminium-cobalt alloys for neutron dosimetry.
Nucl. Instr. Methods Phys. Rev. A 282 (1989) 217

KLOPF, P. (†), STÜBER, W.
A linear mixer and shape normalizer for 50 ms tail pulses.
Nucl. Instr. Methods Phys. Res. A (to be published)

KNITTER, H.-H.
Fission fragment angular distributions.
The Nuclear Fission Process, CRC-Press Inc.

KNITTER, H.-H., BROSA, U., BUTDZ-JØRGENSEN, C.
Neutron and Gamma emission in fission.
Ibidem

LISKIEN, H., UHL, M., WAGNER, M., WINKLER, G.
The excitation function for the reaction $^{52}Cr(n,2n)^{51}Cr$.
Annals of Nuclear Energy 16 (1989) 563

MAST, H., EYKENS, R., PAUWELS, J., WAGEMANS, C.
^{243}Am targets for nuclear fission experiments: requirements and realization.
Nucl. Instr. Methods Phys. Rev. A 282 (1989) 107

PAUWELS, J., INGELBRECHT, C., EYKENS, R.
Samples and targets for nuclear measurements delivered by CBNM during 1989.
INTDS Newsletter 16 (1989) 16

PAUWELS, J., LIEVENS, F., INGELBRECHT, C.
Uranium-238 dioxide for reactor neutron dosimetry.
EUR-12438 EN (1989)

ROHR, G., SHELLEY, R., BRUSEGAN, A., POORTMANS, F., MEWISSEN, L.
Non-statistical effects observed with ^{52}Cr + n resonances.
Phys. Rev. C39 (1989) 426

RYVES, T.B.
A simultaneous evaluation of some important cross sections at 14.70 MeV.
EUR-11912 EN (1988); European Appl. Res. Reports, Nucl. Sci. and Techn.
Sect. 7 (1989), n° 8

RYVES, T.B.
A simultaneous evaluation of some important cross sections at 14.70 MeV.
(letter to the editor)
Ann. Nucl. Energy 16 (1989) 307

STÜBER, W.
Eine einfache Anordnung zur Eichung von Hochfrequenzoszillatoren mit Hilfe des Senders DCF77.
Funkschau, (to be published)

WEIGMANN, H.
Fission barriers.
The Nuclear Fission Process, CRC Press

WEIGMANN, H.
Neutron induced fission cross sections.
Ibidem

WÖLFLE, R., QAIM, S.M., LISKIEN, H., WIDERA, R.
Excitation functions of (n,p) and (n,α) reactions on molybdenum isotopes.
Appl. Radiat. Isot., Int. J. Radiat. Appl. Instrum., Part A (to be published)

WÖLFLE, R., QAIM, S.M., LISKIEN, H., WIDERA, R.
Systematic studies of excitation functions of (n,t) reactions on medium and heavy mass nuclei.
Radiochimica Acta (to be published)

SPECIAL PUBLICATIONS

HANSEN, H.H. (ed.)
Annual Progress Report on Nuclear Data 1988.
NEANDC (E) 302 "U", Vol. III Euratom; INDC (EUR) 023/G (1989)

GLOSSARY

A E R E	Atomic Energy Research Establishment, Harwell (GB)
A N L	Argonne National Laboratory, Argonne (USA)
B I P M	Bureau International des Poids et Mesures, Sèvres (F)
C B N M	Central Bureau for Nuclear Measurements (JRC-Geel), Geel (B)
C E A	Commissariat à l'Energie Atomique, Paris (F)
C E C	Commission of the European Communities
C E R N	Centre Européen pour la Recherche Nucléaire
C I E M A T	Centro de Investigación Energética, Medio Ambiental y Tecnología
C R N S	Centre National de la Recherche Scientifique
C R P	Coordinated Research Programme
D F N	Deutsches Forschungsnetz
D G	Direction Générale
D P S V	Differential Pulse Stripping Voltametry
E C	European Community
E C N	Energieonderzoek Centrum Nederland, Petten (NL)
E N D F	Evaluated Nuclear Data File
E N E A	Comitato Nazionale : Energia Nucleare e Energia Alternative
E T L	Electrotechnical Laboratory, Ibaraki (Japan)
E W G R D	European Working Group on Reactor Dosimetry
F W H M	Full Width at Half Maximum
G E L I N A	Geel Electron Linear Accelerator
H M I	Hahn-Meitner Institut, Berlin (D)
I A E A	International Atomic Energy Agency, Vienna (A)
I C R M	International Committee for Radionuclide Metrology
I L L	Institut Laue-Langevin, Grenoble (F)
I N D C	International Nuclear Data Committee
I R K	Institut für Radiumforschung und Kernphysik, Wien (A)
J E F	Joint European File
J E N D L	Japanese Evaluated Data Library
J R C	Joint Research Centre
K F A	Kernforschungsanlage, Jülich (D)
K F K	Kernforschungszentrum Karlsruhe, Karlsruhe (D)
K U	Katholieke Universiteit, Leuven (B)
N B S	National Bureau of Standards, Gaithersburg (USA)
N E A	Nuclear Energy Agency, Paris (F)
N E A N D C	Nuclear Energy Agency's Nuclear Data Committee
N I S T	National Institute of Standards and Technology, Gaithersburg (USA)
N P L	National Physical Laboratory, Teddington (GB)

P T B	Physikalisch-Technische Bundesanstalt, Braunschweig (FRG)
S C K/ C E N	Studiecentrum voor Kernenergie/ Centre d'Etudes Nucléaires, Mol (B)
T H	*Technische Hochschule*
T O F	Time of Flight
T R	Transition Radiation
W R E N D A	World Request List for Neutron Data Measurements

CINDA ENTRIES LIST

ELEMENT		QUANTITY	TYPE	ENERGY		DOCUMENTATION		LAB	COMMENTS
S	A			MIN	MAX	REF VOL PAGE	DATE		
CF	252	SFN	EXPTL-PROG			INDC(EUR)024G004	90	GEL	KNITTER + Q-VALUES, MASS, EN OF FRACT
PU	241	NF	EXPTL-PROG	20-3	10 + 1	INDC(EUR)024G008	90	GEL	WAGEMANS + LINAC WESTCOTT FACTORS
U	235	ETA	EXPTL-PROG	20-3	20 + 0	INDC(EUR)024G010	90	GEL	WEIGMANN + CORR MONTE CARLO
FE	56	NG	EXPTL-PROG	11 + 3	11 + 3	INDC(EUR)024G012	90	GEL	CORVI + WEIGHTING FUNCT C6DG DETECT
BE	9	N2N	EXPTL-PROG	20 + 6	10 + 7	INDC(EUR)024G018	90	GEL	WEIGMANN + COMPAR C12 ELASTIC
MO		NP	EXPTL-PROG		20 + 7	INDC(EUR)024G018	-90	GEL	LISKIEN + EXCITATION FUNCTION
MO		NA	EXPTL-PROG		20 + 7	INDC(EUR)024G018	90	GEL	LISKIEN + EXCITATION FUNCTION
TI		NP	EXPTL-PROG		20 + 7	INDC(EUR)024G012	-90	GEL	LISKIEN + EXCITATION FUNCTION
CR	52	N2N	EXPTL-PROG		20 + 7	INDC(EUR)024G019	-90	GEL	LISKIEN + EXCITATION FUNCTION
CR	52	NG	EXPTL-PROG	10 + 3	50 + 5	INDC(EUR)023G023	-90	GEL	ROHR + RESONANCE STATISTICS
CR	52	NT	EXPTL-PROG	10 + 3	10 + 6	INDC(EUR)024G023	-90	GEL	BRUSEGAN + RESONANCE STATISTICS

European Communities - Commission

EUR 12822 - Annual Progress Report on Nuclear Data of the
Central Bureau for Nuclear Measurements

H.H. Hansen (ed.)

Luxembourg: Office for Official Publications of the European Communities

1990 - pag. 38 - 21.0 x 29.7 cm

EN