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International Atomic Energy Agency

INDC(SEC)-36/L

INDC

INTERNATIONAL NUCLEAR DATA COMMITTEE



# CONSOLIDATED PROGRESS REPORT FOR 1973
# ON NUCLEAR DATA ACTIVITIES
# OUTSIDE THE NDS SERVICE AREA

Austria
Belgium
Netherlands
Norway
Switzerland
Turkey



September 1973

IAEA NUCLEAR DATA SECTION, KÄRNTNER RING 11, A-1010 VIENNA

# FOREWORD

This consolidated progress report for 1973 has been prepared for the countries outside the NDS service area. A second report, INDC(SEC)-35/L, covers countries within the NDS service area.

The report is arranged alphabetically by country, and reproduces the content of each individual report as it was received by the INDC Secretariat. Also included in the Table of Contents is a list of each laboratory, institute and university referred to in the report, preceded by its internationally used EXFOR code.

As in all progress reports the information included here is partly preliminary and is to be considered as private communication. Consequently, the individual reports are not to be quoted without the permission of the authors.

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# PROGRESS REPORT TO INDC FROM AUSTRIA

August 1973

O.J.Eder, Editor

Österreichische
Studiengesellschaft
für Atomenergie
Ges.m.b.H.
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Austria

ATOMINSTITUT DER ÖSTERREICHISCHEN HOCHSCHULEN, WIEN

# 1. CROSS SECTIONS

## 1.1 A simple determination of inelastic scattering cross sections for fast neutrons

H.Jasicek, F.Bensch
(to be published)

The total inelastic and the total nonelastic neutron cross sections of Ag, Sb and J have been measured by means of a "spherical shell" scattering arrangement. Ag and Sb have increasing importance in fast reactor physics. The incident monoenergetic (395, 760 and 962keV) neutrons were produced by spherical photoneutron sources. A proton recoil proportional counter has been used to resolve the inelastically scattered neutron groups. The inelastic excitation of states in Ag at 80, 320, 420 and 730keV, in Sb at 30, 160 and 550keV and in J at 60, 200, 410 and 600 keV was observed.

Total nonelastic scattering cross sections $\sigma^t_{nel}$ of Ag and Sb:

| | E (keV) | $\sigma^t_{nel}$ ($10^{-24}cm^2$) |
|---|---|---|
| Ag | 388 ± 9 | 0.88 ± 0.10 |
| | 755 ± 11 | 1.53 ± 0.14 |
| | 959 ± 15 | 1.55 ± 0.13 |
| Sb | 387 ± 9 | 0.68 ± 0.08 |
| | 755 ± 11 | 0.75 ± 0.07 |
| | 958 ± 15 | 0.84 ± 0.07 |

Total inelastic scattering cross sections $\sigma^t_{inel}$ of Sb:

| E (keV) | $\sigma^t_{inel}$ ($10^{-24}cm^2$) |
|---|---|
| 387 ± 9 | 0.55 ± 0.08 |
| 755 ± 11 | 0.63 ± 0.07 |
| 958 ± 15 | 0.72 ± 0.07 |

Hauser-Feshbach calculations were carried out to obtain continuous excitation functions which were compared with the experimental measurements.

# 2. NEUTRON SPECTROMETER

## 2.1 Pseudostatistical spin-flip-chopper with Mezei-coils

H.Rauch, G.Badurek, G.P.Westphal

The installed spin-flip-chopper device (Nucl.Instr.Meth. 98 (1971) 61) where a pulsed radio frequency field was used to obtain chopped neutron bursts with high repetition rates was completed with a pseudostatistical pulse sequence system and now the radio frequency coils will be changed by Mezei-coils. A further increase of the resolution power up to 1μs seems to be possible and a more symmetrical neutron burst shape omits problems by calculating the cross correlation of experimental data. Test measurements of the quasi-elastic broadening of the critical scattering of Ni will be done with periodical and pseudostatistical pulsed neutron beams.

# 3. NEUTRON SCATTERING AND DEPOLARIZATION MEASUREMENTS

## 3.1 Elastic magnetic neutron scattering on MnO and Dy

H.Rauch, A.Zeilinger, H.Leder, W.Schindler

Elastic scattering experiments on MnO- and Dy-single crystals were performed with a two axis spectrometer in the temperature range from 4.2K to room temperature. After correction of extinction and resolution effects, the intensity of the magnetic lines yields information about the sublattice magnetization. For MnO a Néel-temperature of $T_N = 121.69 \pm 0.06$K and a critical exponent of $\beta = 0.328 \pm 0.038$ was determined for the antiferromagnetic range. The quasielastic intensity above $T_N$ was analysed according to de Gennes and yields $T_N =$ $= 121.8 \pm 0.3$K and a paramagnetic Curie temperature $\theta = 619.5 \pm 10.4$K. The elastic magnetic scattering from Dy is investigated to verify a strong magnetic after effect by crossing the antiferro-ferromagnetic transition line.

## 3.2 Neutron depolarization experiments on Dy and Ni

H.Rauch, A.Zeilinger, M.Waldauf, P.Vockenhuber

By means of the neutron depolarization technique the magnetic transitions in Dy and Ni are observed. Measurements on different samples of polycrystalline Dy show a very strong dependence of the sharpness of the AFM-FM transition on the thermal treatment of the sample indicating the large influence of internal stresses on the magnetic properties. The domain wall densities in different crystallographic directions are determined. Further investigations of the magnetic superviscosity in Dy at the AFM-FM transition are made using very pure single crystals. The investigations at the Curie point of Ni show fluctuating ferromagnetic short range order above the Curie point. Influences of impurities and various thermal treatments on the magnetic properties near the Curie point are also under investigation.

## 4. NEUTRON INTERFEROMETRY

H.Rauch, W.Treimer, M.Suda, P.Skalitzky[1)]

The experimental set-up of a Laue neutron interferometer is finished. The adapted interferometer crystal (ideal Si-single crystal, 70x80mm) has been tested to work as X-ray interferometer. The interferometer is based on the dynamical diffraction theory. Numerical calculations of the intensity distribution behind the interferometer are carried out for various dispersive positions of monochromator and interferometer crystal. For strong dispersive positions up to 2000 orders of interference fringes should be visible by using the intensity of the high flux reactor in Grenoble. First measurements will deal with a very accurate determination of coherent scattering amplitudes and with coherence problems of the two interfering beams.

## 5. NUCLEAR PHYSICS

### 5.1 Spin assignment of s-wave resonances in $Cs^{133}(n,\gamma)$ by low energy gamma rays

P.Riehs, B.W.Thomas[2)]

The intensity of gamma rays at 116, 130, 178, 199, 206, 253 and 246keV has been measured for about 30 resonances between 140 and 1000eV using the neutron booster target of the 45MeV electron linac at Harwell. It is intended to deduce the spins of s-wave resonances from the population of low energy levels. The data evaluation is to be continued. Theoretical calculations with a cascade model program were performed to get population rates of low energy levels and information about the fluctuations caused by the random distribution of partial radiation widths of the capture- and subsequent states.

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1) Institut für Angewandte Physik der TH Wien
2) A.E.R.E., Harwell, England

5.2 Rotational and vibrational spectra in $U^{235}(n,\gamma)$ and $U^{235}$, $Pu^{239}(n,f\gamma)$ reactions

W.J.Schindler, C.M.Fleck
Nucl.Phys. A206 (1973),374

Gamma rays of primary fission products in thermal-neutron induced fission of $U^{235}$ and $Pu^{239}$ were investigated. Isotopic assignments of several lines were made by comparing fission yield ratios and relative $\gamma$-ray intensities of the two fissioning nuclei. Differences between $U^{235}$ and $Cf^{252}$ fission product $\gamma$-ray lines are discussed. In the $U^{236}$ nucleus spin and parity of the 1342keV level and a level at 1383keV are deduced.

# 6. REACTOR FUEL AND BURN-UP

6.1 High sensitive detection of rare fission gas release of fuel elements of water cooled reactors

C.M.Fleck, H.Erber, W.Fritsch, H.Böck, P.Brunner
ATKE 20 (1972), 51
(work under contract of IAEA)

The release of gaseous fission products from intact fuel elements is measured after irradiation. The release mechanisms are discussed and it is shown that the Uranium contamination of the surface is responsible for the main part of the gas release. Absolute quantities of the released Xe and Kr isotopes are given and the surface contamination was measured, thus release probabilities for the fission gases could be determined.

6.2 Burn-up measurements for reactor operation and safeguards

C.M.Fleck, H.Bauer, J.Curda

Some new techniques for incore and out-of-core measurements on PWR's and BWR's are studied. Theoretical and experimental investigations are carried out for burn-up measurements on the fuel of LMFBR's.

## 7. MEASUREMENT AND DATA HANDLING

### 7.1 Position sensitive neutron detectors

G.P.Westphal, H.Rauch
Nucl.Inst.Meth. 96 (1971) 333
Nucl.Inst.Meth. 106 (1973) 279

Position resolution of $^{10}BF_3$ proportional counters with 1 atm filling pressure has been improved up to 3,75mm fwhm. Further improvements will be obtained by a raised pressure and by digital position encoding by means of a fast on-line computer. The work on a neutron camera on the base of channel multipliers and Gd-converter foils is still in progress.

### 7.2 Computer based multichannel analyzers

G.P.Westphal

A stored program analyzer based on a Nova 1200 8k machine has been developed. It automatically performs TOF measurements, pulse height analyses and various data reductions both in a manual and in an automatic mode by means of a 40-statements command string interpreter. A fast 12-bit ADC for pulse height analysis has been developed having a conversion time of 15μsec and a differential linearity of less than 0.2%. It is intended for use in a multi-user PHA-system at a recently installed PDP 11/45 computer system.

## FAST NEUTRON WORK IN PROGRESS AT INSTITUT FÜR RADIUMFORSCHUNG UND KERNPHYSIK, WIEN

### 1. Measurements of γ-ray-spectra produced by 14MeV neutron capture

N.Frenes, W.Hofmann, M.Uhl, H.Warhanek

From measurements of the high energy part of the γ-ray spectra for natural Cr preliminary values of the respective cross sections for $^{52}Cr$ have been determined. For an improved evaluation of the experimental results we are developing now a Monte-Carlo code which simulates the experiment.

## 2. Activation analysis applications in archaeology

W.Czerny, G.Winkler

In cooperation with the "Institut für Antike Numismatik" (University of Vienna) and "Österreichisches Archaeologisches Institut" nondestructive activation analysis work with fast neutrons is in progress on ancient bronze coins and ancient pottery. After irradiation $\gamma$-spectra are measured with a highly resolving Ge(Li)-spectrometer.

## 3. Study of the short-lived activities $^{70}Cu$ and $^{67}Ni$

W.Reiter, W.H.Breunlich, P.Hille

Work described in the last report is continued. To reduce background-effects the device for measuring ß-spectra was improved by using a coincidence between a proportional counter and the plastic-scintillation counter. Plastic-NaJ $\beta$-$\gamma$ coincidences were measured. Results will be given in a thesis by W. Reiter.

## 4. Measurement of energy spectra and angular distributions of charged particles emitted in nuclear reactions induced by 14MeV neutrons

P.Hille, M.Uhl, K.Richter, W.Weisz

The tests with the first model of a multiwire chamber are completed. According to the results the final version is constructed. The electronic read out system will be used as described in the last report.

## 5. The Neutron-Neutron Scattering Length $a_{nm}$

W.H.Breunlich, S.Tagesen, W.Bertl, A.Chalupka

A kinematically complete break-up experiment on the reaction D(n,2n)p has been performed detecting the outgoing neutrons at $11.0^{o}$ and $17.8^{o}$ with respect to the incident beam and recording the proton recoil energy. Analysing the correlation spectra with the Amado-Model we arrive at $a_{nm} = -(16.0 \pm 1.2)$ fm. The ratio of experimental and theoretical cross-section is $1.07 \pm 20\%$.

6. $^{58}Ni(n,p)$ for 14MeV neutrons

A.Gatterer, W.H.Breunlich

The energy- and angular distributions of protons from reactions $^{58}Ni(n,p)$ and $^{58}Ni(n,px)$ have been measured using nuclear emulsions. The results are compared to statistical theory. A comparison to other experimental results using counter telescopes gives excellent agreement. The results will be given in the thesis by A. Gatterer.

7. $^{50}Cr(n,\alpha)$ for 14MeV neutrons

R.Jindra, W.H.Breunlich, S.Tagesen

The energy and angular distributions of the $\alpha$-particles emitted have been measured using a counter telescope. The results will be partially given in the thesis by R. Jindra.

8. A pulsed neutron generator

G.Stengl

A pulse width of one nanosecond and 15mA $D^+$-peak current have been achieved. For the moment the post-acceleration system (200kV) and a new high-voltage device are installed.

9. (n,p)-cross section of the reaction $^{14}N(n,p)^{14}C$

H.Friedmann, H.Felber

Measuring the cross section of the reaction $^{14}N(n,p)^{14}C$ for 14MeV neutrons by activation is in progress. Counting the $C^{14}$ activity will be done by a new low-level device.

10. Cross sections for 14meV Neutron Capture

O.Schwerer, M.Wagner, M.Winkler, H.Warhanek

Additional activation cross sections for Neutron Capture at an energy of (14.6 ± 0.2)MeV are being measured relative to $(Al^{27}(n,\alpha)Na^{24})$ = 114.2mb ± 1.2%. Gamma ray spectra are measured with a Ge(Li)-detector. Special attention is being given to taking into account all possible sources of error, especially contributions of lower energy neutrons. The cross sections are being measured - or

are planned to be measured - for the Isotopes:
$Mg^{26}$, $Cl^{37}$, $K^{41}$, $Mn^{55}$, $Ga^{71}$, $Br^{81}$, $Rb^{87}$, $Mo^{100}$, $In^{115}$, $J^{127}$, $Cs^{133}$, $Ba^{138}$, $La^{139}$, $Ce^{142}$, $Ta^{181}$, $Pt^{198}$.

PHYSIKINSTITUT DES FORSCHUNGSZENTRUMS SEIBERSDORF, ÖSTERREICHISCHE STUDIENGESELLSCHAFT FÜR ATOMENERGIE

## 1. NUCLEAR PHYSICS

### 1.1 Observation of Parity Violation in Tl 203 by β-γ directional Correlation and a control experiment on Ru 103

F.Dydak, G.Serentschy, P.Weinzierl

The parity violation in Tl 203, given by the term $A_1 \cos\theta$ in the Hamiltonian could be established and gave $A_1 = -(2.7 \pm 0.7).10^{-4}$ with a control value of $(0.7 \pm 0.8).10^{-4}$. In the past year the experiment was repeated to get better statistics on $A_1$ and a further experiment on Ru 103 was planned, which should give no parity violation and thereby enable the experimenter to produce a satisfactory control experiment.

### 1.2 Study of the neutron decay by measuring the recoil proton spectrum

R.Dobrozemsky, E.Kerschbaum, P.Weinzierl

At the tangential beam tube of the ASTRA reactor a proton source has been installed for normalisation experiments, energy resolution and efficiency control of the spherical capacitor spectrometer. A first preliminary neutron-decay proton spectrum has been measured. Final experiments are expected for the middle of next year.

### 1.4 Activation analysis

J.Kaltseis, E.Lanzel

A PDP 11 computer has been programmed to function as a multichannel analyser and an interface between the ADC and the computer has been developed and will be used for automatic activation analysis.

## 1.4 Discussion of fission product yield evaluation methods and a new evaluation

M.Lammer, O.J.Eder
Paper presented at IAEA Symposium on Applications of Nuclear Data in Science and Technology, Paris 1973

Reliable data on fission product yields are necessary for interpretation of gammaspectrometric measurements on burnt fuel elements. Discrepancies among sets of fission yields recommended by different evaluators led to a detailed study of published experimental data. A new evaluation was performed.

After a comprehensive description of the present state of experimental methods for obtaining fission product yields the previously adopted evaluation procedures are critically reviewed. An evaluation procedure is proposed which takes into account sources of experimental errors and accuracies of methods used. Examples of recently evaluated fission product yields for thermal fission of $^{233}U$, $^{235}U$ and $^{239}Pu$ and for fast fission of $^{232}Th$ are presented. Data for $^{238}U$ fast fission and $^{241}Pu$ thermal fission are in preparation.

## 1.5 The Influence of Uncertainties in Fission-Product Nuclear Data on the Interpretation of $\gamma$-Spectrometric Measurements on Burnt Fuel Elements

O.J.Eder, M.Lammer
Paper presented at IAEA Symposium on Applications of Nuclear Data in Science and Technology, Paris 1973

The combination of computer calculations and gamma spectrometric measurements offers new possibilities for investigations on burnt fuel elements. The accuracy of such a method is mainly limited by the accuracy of nuclear data used and uncertainties in the evaluation of measured gamma spectra arising from experimental conditions.

A method is described that combines "forward" calculations and measured activity ratios of fission products and examples of application are given.

The availability of compilations of nuclear data relevant for burnt fuel element analysis is surveyed and improvements are proposed. A set of fuel isotope and fission product nuclear data is presented, that resulted from our own compilation efforts.

Finally uncertainties are reviewed that arise from detector calibration, experimental conditions, nuclear data of fission products and simplifications in calculations. The influence of uncertainties in nuclear data on results of calculations and measurements is demonstrated by some examples.

## 2. NEUTRON SCATTERING

### 2.1 Structure measurements of liquid Aluminium

O.J.Eder, B.Kunsch, G.Pressl

The structure of liquid and solid Al has been measured around the melting point and is now under evaluation. Little structure other than the hard core structure is observed. Around a proposed anomalous change in the viscosity of liquid Al no abnormous structural behaviour could be detected.

### 2.2 Structure of Sulphur around its $\lambda$-$\mu$ phase transition

O.J.Eder, C.Manoussakis

The slow $\lambda$-$\mu$ structural transition in Sulphur as shown most clearly in the viscosity was observed as a slight change in the structure function and is now being interpreted.

## REAKTORINSTITUT DES VEREINS ZUR FÖRDERUNG DER ANWENDUNG DER KERNENERGIE, TECHNISCHE HOCHSCHULE GRAZ

### 1. Contributions to the theory of third order correlation functions in subcritical assemblies

E.Ledinegg, W.Thury
Paper presented at the 1972 meeting of the
Austrian Physical Society

Starting from a method for the calculation of second order correlation functions developed by H.Borgwald and B.Stegemann, an extension towards the analytical formulation of the statistical neutron flux momenta of the order n in reactor configurations was made in a previous investigation. The described procedure is characterized by the fact that it allows the determination of the statistical momenta as a functional of appropriate Green's functions without involving the use of any special field theory. Reference to a special reactor theory is to be made only when the momenta are calculated explicitly.

In this paper the third order correlation functions are calculated and applied to the point reactor model. Whereas the one point response functions can be directly evaluated, the calculation of the two point response functions needed for the determination of the third order correlation functions requires the calculation of special second order correlation functions.

The results are in good agreement with the expression derived by H.Borgwald in a completely different way basing his derivation on the point reactor model from the very beginning. In addition the evaluation of Rossi-$\alpha$ experiments that have been modified following the equations derived in this paper leads to results that correspond to theoretical expectations.

2. <u>The reliability of calculated central reactivity coefficients of structural materials and the sensitivity of Ni, Fe and Cr material worths to uncertainties in the cross section data</u>

M.Heindler
Paper presented at the EACRP Working Group Meeting on "keV Capture of the structural materials" Karlsruhe, May 8 - 9th, 1973

The accuracy requested for integral reactor parameters such as global breeding gain, $k_{eff}$, critical enrichment etc. contrasts with the actual uncertainties with respect to the keV absorption cross section data of structural materials. There is strong evidence that the fairly good agreement between measured and calculated integral reactor parameters specific for stainless steel 72/18/10 (SS 304) is due to compensation of errors and is somewhat artificial, since it is the result of a cross section data adjustment based on these very parameters.

This paper deals with this problem by presenting the results of a study of central reactivity coefficients for a number of fast reactor assemblies of the ZPR III, VERA, MASURCA and ERMINE type. The discrepancies between measured and calculated material worths are discussed.

In view of these discrepancies as well as of recent measurements of absorption cross sections of the cross section library (Cadarache Set Version 2) is suggested. The extent of these modifications suggests that uncertainties regarding the basic data of structural materials have been so far assessed too optimistically.

The influence of this modification on the calculated central reactivity coefficients and as a consequence, on the discrepancies between calculated and measured material worths is discussed.

After a very careful investigation of systematic errors in the calculation procedures, a number of conclusions is drawn and a number of suggestions for future investigations are made.

3. Contribution to the theory of a cylindrical few zone reactor with spherical fuel elements

F.Schürrer
Paper submitted to "Acta Physica Austriaca"

The importance of pebble bed reactors was greatly increased by the investigations performed in Western Germany (AVR reactor). Recently the use of spherical fuel elements was suggested for power reactors cooled by fluids. Thus the advantages of a pebble bed core should be combined with the operating experience gained with water cooled reactors.

In this paper the model of such a liquid cooled pebble bed reactor is presented and the formulae needed for the calculation of the neutron flux distribution in double ring cores and of the corresponding effective multiplication constant is derived in the one group approximation to the diffusion theory. In order to determine a core structure that is satisfactory regarding neutron physics, the neutron flux distribution was determined numerically.

4. Derivation of the diffusion kernel in the two group approximation to the diffusion theory for heterogeneous finite and infinite reactor assemblies in xyz-geometry

M.Heindler
Doctoral thesis, Technische Hochschule in Graz

The diffusion kernel (Green's tensor) corresponding to the diffusion equation in the two group approximation with a diagonal diffusion coefficient matrix having direction independent elements is calculated for different reactor assemblies in xyz-geometry. In all instances the assemblies are supposed to be invariant with respect to translations in two coordinates.

From the multitude of possible source representations of the flux density vector we used the one which leads to a relatively simple system of equations for the elements of the Green's tensor. This was obtained essentially by introducing both a differential operator for decoupling the given system of differential equations and a modified Green's tensor. The partial differential equations derived therefrom are solved by Fourier transformation.

The method presented in this report can be extended to the solution of the diffusion equation in the n-group approximation (arbitrary n).

5. <u>Contributions to the development of several experimental techniques for precision determination of radioactive nuclides</u>

A.Huber
Diplomarbeit, Technische Hochschule in Graz

In the first part of the paper measurement techniques for the precision determination of the wear-off of machine parts in motion by means of radionuclides are described.

The machine parts under investigation are irradiated in the nuclear reactor. A part of the originally stable isotopes is activated by the capture of neutrons (e.g. Fe-59, Cr-51). If this activated machine part is subject to wear-off while turning in an oil bath or lubricated by an oil circuit extremely small radioactive particles are worn off and transported by the oil from the wearing-off machine part to the oil container. The activity of the lubricating oil can be detected in a secondary circuit by a radiation detector and therefrom the mass of worn-off particles can be determined.

In the second part of this paper the experimental set-up and the calibration of a measuring device for the detection of the Argon activity in a reactor hall is described.

6. <u>Contributions to the determination of delayed neutrons at the Siemens Argonaut Reactor</u>

A.Jaklitsch
Diplomarbeit, Technische Hochschule in Graz

The delayed neutrons of the U-235 isotope are measured by means of a rabbit device. Furthermore the influence of the delayed neutrons on the neutron balance as well as the mechanism of delayed neutron formation is described. The time behaviour of the reactor is described taking into account the delayed neutrons.

# PROGRESS REPORT TO THE INDC

on

NUCLEAR DATA RESEARCH IN BELGIUM

during the year

1972




compiled by

M. NEVE de MEVERGNIES

C.E.N./S.C.K.

B - 2400 MOL, BELGIUM

## I. NUCLEAR ENERGY CENTRE (C.E.N./S.C.K.), B-2400 MOL

The main facilities available in Mol are the following :

a) around the *high flux BR2 reactor*

- a Fermi-type chopper for the neutron energy range (0.005 - 0.4 eV);
- a high-intensity, Bi-filtered thermal neutron beam;
- a single-crystal neutron spectrometer for the energy range (0.01 - 10 eV);
- a time-of-flight neutron spectrometer for inelastic cold neutron scattering studies;
- 2 neutron diffractometers

and in the final stage of preparation :

- a bent-crystal diffraction spectrometer for (n,γ) studies;
- a 3-crystal neutron diffraction spectrometer for slow-neutron inelastic scattering studies

b) around the *medium-flux BR1 reactor*

2 fast pneumatic conveyors for the study of short-lived radioisotopes.

In addition to the BR1 and BR2 reactors, several neutron cross-section measurements are performed by C.E.N./S.C.K., in collaboration with CBNM, Euratom, Geel, using the Euratom LINAC pulsed neutron source.

### 1. NEUTRON SPECTROMETRY

#### Total cross-section of $^{226}$Ra - H. CEULEMANS, G. GOEDEME*

The measurements on the 1 g sample of $^{226}$Ra, performed at the R3 crystal spectrometer of the BR2 reactor and mentioned in the previous progress report were extended down to a neutron energy of 0.02 eV and the region around the resonance at 0.539 eV was measured in greater detail. An analysis of all the experimental data showed an anomalous behaviour of the low energy cross-section, which was attributed to the presence of water absorbed in the sample. The data could be fitted over the entire interval of the measurements by assuming a 9 mg water content in the sample and a Ra cross-section determined by the resonance at 0.539 eV for which $\sigma_o\Gamma^2$ = 3.2 ± 0.4. This leads to a capture cross-section of 14 ± 2 barn at thermal energy (0.0253 eV), the difference with the preliminary result of 21 + 4 barn being entirely due to the water content. The final result agrees with the value of 13.5 barn obtained by PEVZNER et al. [J. Nucl. Energy II, 4, 366 (1957)]. This work has been reported at the Budapest Conference [31 July - August 1972].

The measurements will be extended to higher energies by using a 30 m flight path at the Electron LINAC pulsed neutron source of CBNM, Euratom, Geel. The prepara-

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* Present address : Koninklijke Biblioteek Brussel

tory work for these experiments is nearly complete.

**Total cross-section of Nd isotopes - H. CEULEMANS**

The data obtained previously at the Nevis Synchro-cyclotron of Columbia University N.Y. and mentioned in the last progress report were further analysed for neutron resonances in $^{143}$Nd. The thickness range for the $^{143}$Nd samples was extended by using material depleted in the isotope of interest. The thinnest sample contains about $3.10^{-5}$ atoms/barn of $^{143}$Nd, whereas the thickest sample has $3.015.10^{-3}$ at/b. of this isotope. Least-squares shape fitting of the transmission curves with no restriction on the resonance parameters often gives results which are widely different from one sample thickness to another.

One way to avoid this is to make a simultaneous fit for all available sample thicknesses, as is done e.g. at Saclay. The other solution is to use fits with one parameter fixed, e.g. the total width $\Gamma_t$.

A combination of such fits on widely different sample thicknesses yields well-defined areas of convergence for the resonance parameters. Below 500 eV complete sets of data giving the channel spin J, the neutron width $\Gamma_n$ and the total width $\Gamma_t$ could be obtained. At higher energies data from thicker samples are needed for a complete analysis but these are not available unless natural samples (7 isotopes of Nd) are used. At these energies also, the value of $\Gamma_n$ becomes increasingly dependent on an accurate determination of the non-resonant transmission level $T_p$ and the value of $\Gamma_t$ on the detection of incompletely resolved resonances. In the neutron energy range 0 - 1210 eV, a total of 31 resonances have been analysed in $^{143}$Nd, 14 of which are below 500 eV and have complete parameter sets. The comparison of our J-values with those given by other authors gives complete agreement up to 350 eV. The agreement with the $\Gamma_n$ and $\Gamma_t$ values quoted by TELLIER [Note CEA-N-1459 or EANDC-E-138/L] varies from excellent at low energies to moderate and outside quoted errors as one proceeds to higher energies. The analysis of the higher-energy data is still in progress.

## JOINT S.C.K./C.E.N. - CBNM (EURATOM)- RUCA NEUTRON CROSS-SECTION PROGRAM

(Contract Euratom - S.C.K./C.E.N. N° 002/66/12 - PG PG B/Av. N° 2)

**Resonance Parameters of $^{242}$Pu**

**F. POORTMANS, G. ROHR*, J.P. THEOBALD*, H. WEIGMANN*, G. VANPRAET****

A study of the interactions of low-energy neutrons with $^{242}$Pu was made for the following reasons. The resonance parameters are needed to establish the mass dependence of the s-wave neutron strength function $\bar{\Gamma}_n^o/\bar{D}$ above mass A = 240 and for the interpretation of the subthreshold fission cross-section results obtained at Los Alamos and at Harwell. The neutron cross-sections are also requested by reactor designers and for the calculation of the production of heavier isotopes, es-

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* C.B.N.M., Euratom, Geel
** Rijksuniversitair Centrum, Antwerpen

pecially curium in reactors (cfr. Report EANDC-85-U, 1970).

Capture, elastic scattering and total neutron cross-section measurements on $^{242}Pu$ below 1300 eV were performed, using the CBNM LINAC. The neutron widths $\Gamma_n$ were obtained for 71 resonances and the total radiative widths $\Gamma_\gamma$ for 25 resonances. The s-wave strength function $S_o = 0.89^{+0.1}_{-0.09} \times 10^{-4}$ and the average radiative width $\bar{\Gamma}_\gamma = [21.9 \pm 0.4 \text{ (stat.)} \pm 1 \text{(syst.)}]$. The resonance parameters were used to calculate the fission widths $\Gamma_f$ from the fission cross-section results of Los Alamos. From these fission widths, the height of the second fission barrier is deduced : $E_B = 5.18$ MeV.

A paper describing this work has been submitted for publication in Nuclear Physics.

**Cross-section measurements on $^{237}Np$**

**F. POORTMANS, L. MEWISSEN, G. ROHR*, J.P. THEOBALD*, G. VANPRAET**, H. WEIGMANN***

A new series of total, scattering and capture measurements on $^{237}Np$ below 300 eV are being performed in order to resolve the discrepancies on the $\Gamma_\gamma$ values between earlier Geel measurements and the results from Saclay. Moreover, due to the improvements in neutron-energy resolution, the measurements can now be extended above 50 eV and eventually yield the spin for some more resonances.
Transmission measurements on three different samples were completed. The scattering and capture measurements are in preparation.

**Cross-section measurements on $^{236}U$ below 2 keV**

**L. MEWISSEN, F. POORTMANS, G. ROHR*, J.P. THEOBALD*, G. VANPRAET**, H. WEIGMANN*, R. WERZ***

A study of the reactions of slow neutrons with $^{236}U$ is of interest for various reasons. The neutron cross-sections and resonance parameters are requested by reactor designers (Compilation of Requests for Neutron Data Measurements, Report EANDC 85-U, April 1970), for the calculation of isotope build-up in thermal reactions and for the calculations of $^{237}Np$ production.

Little information has been published on $^{236}U$. Only level parameters obtained from capture and self-indication measurements on $^{236}U$ for neutron energies up to 415 eV, have been published (CARLSON et al., Nuclear Physics, A141, 577, 1970). Therefore a new measurement of the capture, scattering and total cross-sections of $^{236}U$ is justified, using the CBNM-LINAC.

The scattering cross-section was measured on a 30 m flight path station, using the $^3He$ gaseous scintillation detector system, with two different sample thicknesses : $2.15\times10^{-4}$ at/b (99.69 % $^{236}U$) and $1.5\times10^{-3}$ at/b (89.4 % $^{236}U$). The resonance scat-

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tering areas have been obtained for more than 40 resonances. These areas have also been corrected for self-screening and for absorption of the scattered neutrons.

The capture cross-section experiments were performed on the same samples with the CBNM Moxon-Rae detector on a 60 m flight path station. The data have been analysed up to 1 keV for more than 50 resonances and the analysis between 1 keV and 2 keV is in progress.

The transmission has been measured at a 30 m flight path station, using a 1 cm diameter neutron beam and a $^3$He gaseous scintillator as transmission detector. The sample had a thickness of $7.645 \times 10^{-3}$ at/b (99.69 % $^{236}$U). An area analysis of the transmission data was done using a modified version of the Atta-Harvey program (EUR-report 4760 e).

The resonance parameters $\Gamma_n$ and $\Gamma_\gamma$ will be deduced by combining the results from the different measurements. This part of the analysis is still in progress. The number of resonances which can be analysed is sufficiently large for obtaining meaningful values for statistical properties of the resonance parameters, such as the mean level spacing, mean capture width and s-wave strength function.

**Scattering cross-section of $^{238}$U - H. CEULEMANS**

The results obtained previously with $^3$He proportional counters and mentioned in the 1971 progress report were analysed by means of least-squares search and fitting routines adapted to and developed for this purpose. Data from three different sample thicknesses, ranging from $n = 1.3 \times 10^{-5}$ at/barn to $n = 1.9 \times 10^{-4}$ at/barn were analysed. The main difficulty for an accurate calculation of the scattering yield is the correct assessment of the absorption after scattering. The best way to check this is to compare the differences in resonance scattering widths $\Gamma_n$ obtained from different sample thicknesses. Even for predominantly scattering resonances for which, at resonance, the sample thicknesses ranged between 0.1 and 2 mean free paths, the difference was only 10 % in $\Gamma_n$. Our data were normalized to the parameters of the 36.7 eV as given by J.B. GARG et al. [Phys.Rev.134(1964)B 985]. With this normalization good agreement is found with Garg's transmission data for all resonances measured (Table 1) in contrast to previous scattering results where systematic differences exist [M. ASGHAR et al. Nucl. Phys. 85 (1966) 305]. From these studies it can be concluded that the method of analysis gives reliable results which could be used to resolve the systematic differences between sets of resonance parameters of $^{238}$U [J.B. GARG et al. Phys. Rev. 134 (1964) B 985], [G. CARRARO and W. KOLAR, IAEA - STI/PUB/259 Vol. 1 (1970) 403], [F. RAHN et al., Phys. Rev. C 6 (1972) 1854], if the remaining problem of absolute normalization to a proper standard such as Pb is solved. Although the measurements were intended to contribute to a better value of the radiation width $\Gamma_\gamma$ of the resonances, it was found that the sensitivity was insufficient, a 10 % change in $\Gamma_\gamma$ corresponding to a 5 % change in $\Gamma_n$ even in favourable cases. The results of this work have been presented at the Budapest Conference (31 July - 5 August 1972).

TABLE 1

| $E_o$ | Present Results $\Gamma_n$(meV) | J.B. GARG et al $\Gamma_n$(meV) |
|---|---|---|
| 21.0 | 9.5 ± 0.5 | 8.7 ± 0.3 |
| 36.7 | 31.0 ± | 31.15± 1.0 |
| 66.2 | 22.3 ± 1.0 | 25.2 ± 1.0 |
| 102.7 | 61.1 ± 3.0 | 66.0 ± 2.0 |
| 189.6 | 150.2 ± 7 | 150.0 ± 3.0 |

**Capture cross-section detectors - G. VANPRAET*, G. ROHR**, H. WEIGMANN****

A pair of hydrogen-free liquid scintillators (C6F6) have been used as a total energy detector for test measurements with a natural Mo sample. Mo has been chosen because it is well known that the capture gamma ray spectra are quite different from resonance to resonance. These experiments were in fact a good test for the calculated pulse-height weighting function. The results obtained for the capture areas of 12 resonances below 1 keV have been compared with those obtained with the Moxon-Rae detector of CBNM on the same sample. The agreement is satisfactory within the statistical error (< 5%).

In order to keep the bias imposed on the pulse-height below 150 keV electron energy loss, RCA photomultipliers have been ordered in replacement of the Philips XP 1040 tubes, which have a relatively much higher anode dark current, resulting in a too high noise level (≃ 375 keV). The new PM's arrived recently and will soon be put into operation.

**Data acquisition system for capture measurements - L. MEWISSEN, H. CEULEMANS**

A Hewlett Packard Magnetic Tape Unit 7970 A has been installed so that compilation routines and the B.C.S. loading system are rapidly available for Assembler and Fortran programs. Checking the M.T.S. Driver, a timing incompatibility with the HP 2115 A computer was observed. A new version of the driver avoiding timing errors during Fortran compilations was obtained from the HP software center of Cupertino.

A report describing the data acquisition system for two parameter neutron spectrometry has been published (C.E.N./S.C.K. Blg-Report). It contains the detailed

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operating instructions for capture experiments on $^{238}U$ and the Assembler version of this program. It was checked with an A.M.C. 256 K disc during different phases of the supervisor routines.

**Scattering cross-section facility - F. POORTMANS**

A scattering detector system, consisting of six $^{3}He$ high pressure gaseous scintillators (LND type 800, pressure 250 atmospheres) has been installed at a 30 meter flight path station on the CBNM LINAC.

The main advantages of these detectors are high efficiency and good timing properties. The most important factor affecting the time-of-flight resolution is at present the flight path uncertainty, due to the size of the sample. A neutron energy resolution width $\Delta E$ (F.W.H.M.) of the order of $10^{-3} \times E$ can now be obtained below 10 keV.

Selected low-noise photomultipliers (RCA 4516) have been mounted on the detectors. Test measurements performed with an $^{238}U$ sample have shown that the pulse-height discrimination against capture gamma rays is very good. Scattering cross-section measurements performed on $^{236}U$ and $^{242}Pu$ with this equipment are described elsewhere in this report.
A Monte-Carlo program was written which corrects the scattering data for self-screening and for absorption of the scattered neutrons. As multiple scattering is not yet taken into account, this program can only be applied for measurements on thin samples, where the corrections are small. This program will be extended for the more general cases, taking into account multiple scattering and for samples which are made out of different materials (for example an oxide sample in an aluminium canning).

## 2. FISSION PHYSICS AND CHEMISTRY

**Identification of new germanium isotopes in fission - P. del MARMOL, P. FETTWEIS**

After measuring the half-lives of Ge isotopes from mass 79 to 84, the energies and intensities of the main γ-rays were assigned to the longer-lived of these isotopes ($T_{1/2} \geqslant 10$ s) and partial decay schemes were given for the decay of $^{81}Ge$, $^{81}As$ and $^{82}As$.

The relative fission yield measurements give information about the nuclear charge distribution in fission for this mass region and shows evidence for fine structure due to preferential formation of 50-neutron closed shell nuclei. The results were published in Nuclear Physics.

### Thermal neutron fission cross-section measurements for $^{227}Ac$ and $^{227}Th$

P. del MARMOL, F. HANAPPE*, M. MONSECOUR

The number of fissions registered in Makrofol detectors have been counted and analysed for $^{227}Th$, both irradiated in the BR1 thermal column. The resulting fission cross-section was 203 + 16 b, in agreement with a recent 200 ± 20 b value measured by V. VON GUNTEN et al.

In the first type of experiment an upper limit of 350 μb was found for the fission cross-section of $^{227}Ac$, nearly a factor of $10^4$ lower than an upper limit of 2 b fixed earlier by PETERSON and GHIORSO. These results have been submitted for publication to the Journal of Inorganic and Nuclear Chemistry.

### Fission barrier measurements at the Ottignies cyclotron

P. del MARMOL and F. HANAPPE☆
(Association C.E.N./S.C.K. - IISN - UCL, Ottignies)

It is planned to measure the fission barrier of the compound nucleus formed by α particles on $^{181}Ta$, and later on still lighter nuclei, by following the variation of the fission cross-section versus α-energy by means of Makrofol solid state detectors. The experimental set-up has been mounted at the cyclotron and preliminary tests are being carried on.

### 3. JOINT S.C.K./C.E.N. - C.B.N.M. (EURATOM) STUDIES IN FISSION PHYSICS AND STANDARDS

A. DERUYTTER*, W. BECKER**, G. WEGENER-PENNING•, G. WAGEMANS°
(Contract EUR/C/4146/67f)

These studies have included the following items :

- Comparison of the thermal neutron induced fission of $^{239}Pu$ and the spontaneous fission of $^{240}Pu$.
- Ratio of the ternary (LRA)-to-binary fission cross-section induced by resonance neutrons in $^{239}Pu$.
- Total kinetic energy of fission fragments in $^{235}U$-resonances.
- Normalization of fission cross-sections in the resonance region.
- Fission cross-section of $^{235}U$ in the range up to 100 keV.
- $^{6}Li$ (n,α) cross-section in the thermal region.

They are summarized in the contribution from CBNM, Euratom, Geel to the "Progress Report on Nuclear Data Research in the European Community for 1972", EANDC(E)157-U, Vol. I, pp. 64-70.

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° NFWO, erkend navorser, Univ. Gent and S.C.K./C.E.N.

## 4. NUCLEAR LEVEL SCHEMES AND RADIOACTIVE DECAY DATA

### JOINT KATHOLIEKE UNIVERSITEIT LEUVEN - S.C.K./C.E.N. program

P. VAN ASSCHE, J.-M. VAN DEN CRUYCE*, G. VANDENPUT*, L. JACOBS*

### Neutron Capture Gamma Ray Studies

The data reduction of the spectra from the $^{151}$Sm, $^{179}$Hf and $^{182}$Ta nuclei has reached its final stage. A collaboration with foreign laboratories has been started in order to obtain complementary information on the spectroscopy of these nuclei : conversion electron data on $^{151}$Sm (T. von EGIDY et al., Technical University, Munich) and on $^{179}$Hf and $^{182}$Ta (P. PROKOFJEV et al., Riga, USSR) and gamma-gamma coincidence data on $^{182}$Ta (W. DELANG et al., K.F.A., Jülich).

These collaborations have been very fruitful for the $^{182}$Ta nucleus. Seven rotational bands of positive parity and eleven rotational bands of negative parity have been identified in the $^{182}$Ta level scheme.

The spectroscopic study of $^{179}$Hf is almost completed as the number of observed states below 1 MeV has almost the expected value.

The study of the $^{151}$Sm nucleus is more difficult because no regular rotational behaviour is expected here. It is hoped that (n,$\gamma\gamma$) data, to be performed soon, will be helpful.

### The decay of $^{116g}$In - P. FETTWEIS and S. SADASIVAN**

The $\beta$-decay of the $1^+$, 14 s ground state of $^{116}$In produced by neutron capture has been reinvestigated using Ge(Li) detectors. It is found that besides the ground state of $^{116}$Sn, excited levels at 1293.6($2^+$), 1756.9($0^+$), 2225.3($2^+$), 2545.7($0^+$,$1^+$,$2^+$) 2649.8($2^+$), 2790.7($2^+$) and 2844.6($2^+$) keV are populated, while no evidence could be obtained for the population of the $0^+$ and $2^+$ levels at 2030 and 2112.4 keV respectively. The activation cross-section for $^{116m2}$In (2.16 s, $I^\pi$=$8^-$) has been remeasured and a value of 83 ± 8 b has been obtained. The final results have been accepted for publication in "Zeitschrift für Physik".

### The decay of $^{83g}$Se and $^{83m}$Se - P. FETTWEIS and S. SADASIVAN**

The gamma spectrum of the isomeric pair $^{83g}$Se (22.6 min; $I^\pi$=$9/2^+$) and $^{83m}$Se (70 s; $I^\pi$=$1/2^-$) produced by neutron capture in $^{82}$Se has been reinvestigated using straight Ge(Li) and Ge(Li) - Ge(Li) coincidence spectrometry, as well as natural and enriched targets. Out of a total of 73 transitions from the decay of the long lived isomer, 58 (corresponding to 97 % of the total intensity) have been placed in a consistent $^{83}$Br level scheme, as well as 24 transitions out of 32 (corresponding to 97.5 % of the total intensity) from the decay of the short lived isomer. Evidence for 12 previously unreported levels in $^{83}$Br is found. From $\gamma$-ray unbalances and from the known isomeric cross-section ratio of $^{82}$Se, $\beta^-$-branchings

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have been obtained, including a 32 % branching of $^{83m}$Se to the ground state of $^{83}$Br. From this, logft values have been deduced, allowing the proposal of spin and parity values for the various excited $^{83}$Br levels. A final report is being prepared for publication.

**Properties of $^{235}U^m$ - M. NEVE de MEVERGNIES**

A systematic study of the perturbation of the decay rate of $^{235}U^m$ implanted in the (3d), (4d) and (5d) transition metals has been performed and published. The results can be qualitatively understood by means of the "rigid band" and "screened potential" models describing the electronic interaction of an impurity atom with a metallic environment. When the difference in valency between the U impurity (mainly hexavalent) and the host metal is equal to or larger than 2, the screening effect dominates; when this difference is 1 or 0, the valence electrons of U are taken up in the conduction band of the host metal, as described by the rigid band model, and the effect on the decay rate should be due to the detailed interaction of the conduction band on the valence and conversion electron subshells of $^{235}U^m$. A detailed report on the experimental techniques has been prepared for publication in "Nuclear Instruments and Methods".

## II. INSTITUT DE PHYSIQUE CORPUSCULAIRE, UNIVERSITE CATHOLIQUE DE LOUVAIN, B-1348 Louvain-la-Neuve

The main experimental facilities of the Institute are :

- a variable-energy cyclotron, built by C.S.F. (France)

  $E_p$ = 10 to 80 MeV
  $E_\alpha$ = 20 to 80 MeV
  $(I_\alpha)_{max} = (I_p)_{max}$ = 20 µA (external beam)
  ΔE/E < 1 % (external beam)

- a 4.5 MV Van de Graaff built by High Voltage, (USA)

The following charged-particle reactions were studied during 1972 :

(1) Elastic scattering of 22 MeV α's by $^{23}$Na, $^{24,25,26}$Mg, $^{27}$Al, and $^{28}$Si
(J. Lega, P. Macq)

(2) Elastic scattering and reaction cross-sections of 15-21 MeV α's by $^{12}$C
(J. Lega, P. Macq)

(3) $^{20}$Ne(α,d) $^{22}$Na and $^{22}$Ne(α,d) $^{24}$Na at 21.5 MeV incident energy
(E. Labie, P. Macq)

(4) $^{52}$Cr(α,n) $^{55}$Fe and $^{52}$Cr(α,p) $^{55}$Mn at 15 MeV and 22.5 MeV incident energy
(Y. El-Maszi, J. Vervier)

(5) Sb(α,2n) $^{123}I$ at 27.5 MeV incident energy, for medical purposes, using a natural Sb target (Ch. Deglume, J.P. Deutsch, D. Favart, R. Prieels)

(6) Elastic and inelastic scattering of 50 MeV α's by $^{12}C$ (P. Leleux, P. Macq, J.P. Meulders, C. Pirart)

(7) Inelastic scattering of 67.5 MeV α's by $^{208}Pb$ (P. Leleux, J. Lira-Chavez, P. Macq, J.P. Meulders, C. Pirart)

(8) $^{159}Pb(p,4n)$ $^{156}Dy$ for 27-51 MeV protons and $^{159}Pb(^{14}N,5n)$ $^{168}Hf$ for 93 MeV $^{14}N^{4+}$ ions. (Y. El-Masri, P. Monsen, J. Steyaert, J. Verviers)

More detailed information about these studies can be found in the Annual Progress Report for 1972 of the Institute (edited by J. Verviers).

## III. INSTITUUT VOOR NUCLEAIRE WETENSCHAPPEN, RIJKSUNIVERSITEIT TE GENT, B-9000-GENT

The main facility of the Institute is a 60 MeV Electron Linear Accelerator which is mainly used as a Bremsstrahlung source for photonuclear research.

The following studies in the field of photonuclear reactions and decay schemes have been performed in 1972.

### 1. STRUCTURE IN THE GIANT RESONANCE OF $^{55}Mn$

R. CARCHON, J. DEVOS, R. VAN de VIJVER, C. VAN DEYNSE and H. FERDINANDE)

The $^{55}Mn(\gamma,xn)$ cross-section was measured from 10 to 23 MeV, using the Bremsstrahlung photon beam from the Linac. As a target we have used natural manganese powder with a purity in excess of 99.8 % and with a grain diameter smaller than 150 μm, contained in a perspex holder of 1 mm wall thickness. The photoneutrons were detected using a Helpern-type detection system, with a total efficiency of 8.8 %.
The neutron yield curve as a function of Bremsstrahlung endpoint energy was measured in energy steps of 125 keV between 10 and 15 MeV, and with an interval of 250 keV between 15 and 23 MeV. The reproducibility error of maximum 4 °/oo was normally somewhat higher than the statistical error of about 1 °/oo; the latter one was always used in the analysis. Penfold and Leiss' analysis, including the variable bin method, as well as Cook's program were applied and the results for the photoneutron cross-section were found to be in very good agreement with each other.

The leading edge of our photoneutron cross-section reveals peaks in the neighbourhood of (10.7), 11.3, 12.4, 13.0, 13.75, 14.5 and 15.4 MeV. Only those at 13.75 and 15.4 MeV are very pronounced. The giant dipole resonance, which should have its maximum at about 18.75 MeV, as predicted by the hydrodynamic model, shows to be split up into several peaks. We observe maxima at 16.4, 16.9, 17.9, 19.0 and 19.75 MeV; finally there exists a less striking bump around 22 MeV. The fine structure found in a photoproton spectrum measurement by Shoda and coworkers, is amazingly similar to our measurement. As a conclusion, the dynamic collective theory of Huber, shifted in energy over 0.3 MeV, is in reasonably good agreement with our experimental results.

## 2. THE DECAY OF $^{81}As$

M.C. CHACKO, L. DORIKENS-VANPRAET, K. HEYDE and M. DORIKENS

The isotope $^{81}As$ has been produced by ($\gamma$,p) reaction on enriched $^{82}Se$. The gamma-radiation is the Bremsstrahlungspectrum of the electron LINAC. The decay of 33 s $^{81}As$ is studied with high resolution Ge(Li) detectors.

33 gamma transitions were found, most of which can be placed in a decay scheme that is in accordance with neutron capture and reaction work. Conclusions are drawn about spin and parity of the $^{81}Se$ levels.

The experimental results are compared to two types of shell-model calculations, one using surface delta interaction, the other with realistic forces (Kuo and Brown matrix elements).

Nuclear Energy Research Center
CEN/SCK - Mol, Belgium

# PROGRESS REPORT TO INDC IN THE FIELD OF NUCLEAR DATA COVERING THE PERIOD January 1 - July 31, 1973

Compiled by
M. Nève de Mevergnies
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# 1. NEUTRON SPECTROMETRY

## Total Cross Section of $^{226}Ra^+$

H. CEULEMANS

The 1 g Ra sample has been installed in the target room of the CBNM (Euratom) Linac. The measuring and control system based on the HP 2115 B on-line computer and the sample steering system used at the BR2 reactor have been installed at the Linac and brought into operation. Preliminary test runs were made with simplified HP2115B programming. Tests to exchange magnetic tapes between the IBM 360/44 and our on-line system have been successful. Improved on-line programs are prepared and experiments will start after the Linac shutdown, i.e. beginning of September 1973.

## Resonance Parameters of $^{242}Pu^+$

F. POORTMANS, G. ROHR*, J.P. THEOBALD*, H. WEIGMANN*, G. VANPRAET**

The results have been published in "Nuclear Physics", A207 (1973) 342.

## Cross Section Measurements on $^{237}Np^+$

F. POORTMANS, L. MEWISSEN, G. ROHR*, J.P. THEOBALD*, G. VANPRAET**, H. WEIGMAN*

The analysis of the transmission data is in progress. The scattering cross section measurements are completed and the analysis of the data will be started soon. These experiments were done between 7 eV and 250 eV on a 30 meter flight path using six $^3He$ gaseous scintillators as neutron detectors. As compared to the old data (F. Poortmans et al., Third Conference on Neutron Cross Sections and Technology, Knoxville 1971, Vol. 2 (1971), p. 667) the time-of-flight resolution is much improved and the statistical accuracy is about a factor of 4 better.

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+ Joint CBNM (Euratom, Geel)-CEN/SCK-RUCA Program

* CBNM, Euratom, Geel

** Rijksuniversitair Centrum, Antwerpen (RUCA)

## Cross Section Measurements on $^{236}U$ below 2 keV+

L. MEWISSEN, F. POORTMANS, G. ROHR*, J.P. THEOBALD*, G. VANPRAET**, H. WEIGMANN*, R. WERZ*

The analysis of the capture, scattering and transmission experiments has been completed. In the energy range from 30 eV up to 1800 eV, the neutron widths $\Gamma_n$ have been deduced for 99 resonances and the capture widths for 56 resonances.

Supposing that all the detected levels are due to s-wave interaction, and that no resonances are missed we find, from the data below 1200 eV the following preliminary results:

mean level spacing $\bar{D}$ = 17.3 ± 0.5 eV
mean capture width: $\bar{\Gamma}_\gamma$ = [22.3 ± 0.5 (stat.) ± 1.0 (syst.)] meV
s-wave neutron strength function: $S_o$ (1.05 ± 0.15) $10^{-4}$

## Capture Cross Section Facility+

G. VANPRAET**, G. ROHR*, H. WEIGMANN*

The development of a hydrogen free $C_6F_6$ liquid scintillator detector for measurements of prompt γ-rays following neutron capture is completed. The total energy detector consists now of four identical, cylindrical cells (3" x 4" diam), each viewed by an RCA 4522 photomultiplier.

A first set of capture measurements on a $^{238}U$ sample has just been made in the energy region between 10 eV and 4.5 keV at a flight path station located at 30 m from the neutron source. The measurements will be extended to higher energies with the detectors located at the 100 m station.

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+ Joint CBNM-SCK/CEN-RUCA Program

* CBNM, Euratom, Geel

** Rijksuniversitair Centrum, Antwerpen

## Total Cross Sections of $^{143}Nd$

The analysis of the transmission data of the separated isotope samples obtained at the Nevis Cyclotron of Columbia University were extended to the resonance at 2128 eV (see table 1).

In view of the longer computing times needed at higher energies, possible improvements in calculation speed were investigated. In particular the Doppler-broadening subroutine W which is based on the solution of the complex probability integral, was compared with a subroutine QUICKW which uses tables of this integral and a six-point interpolation formula in the complex plane. Random tests revealed that the results of the faster QUICKW routine were within very close limits of the regular routine except for the region near the origin where the imaginary part of the integral is going through zero. Here, large percentage deviations were observed for the values calculated by the fast routine.

TABLE 1

| $E_o$(eV) | Present results | $2g\,\Gamma_n$ Tellier* |
|---|---|---|
| 1433.1 ± 0.5 | 765 ± 50 | 980 ± 50 |
| 1463.5 ± 0.5 | 140 ± 15 | 175 ± 10 |
| 1472.7 ± 0.5 | 660 ± 60 | 754 ± 30 |
| 1511.1 ± 0.6 | 290 ± 30 | 255 ± 10 |
| 1557.5 ± 0.7 | 390 ± 30 | 660 ± 20 |
| 1583.5 ± 0.8 | 1490 ± 100 | 1920 ± 100 |
| 1653.0 ± 0.8 | 600 ± 60 | 945 ± 30 |
| 1667.4 ± 0.8 | 2650 ± 250 | 3390 ± 100 |
| 1724 ± 1 | 520 ± 50 | 790 ± 40 |
| 1760.3 ± 1 | 1000 ± 100 | 1270 ± 60 |
| 1849.6 ± 1 | 770 ± 50 | 2000 ± 100 |
| 1910 ± 1 | 910 ± 150 | 1510 ± 80 |
| 1963 ± 2 | not measured | 120 ± 20 |
| 2004 ± 1 | 1160 ± 100 | 1855 ± 80 |
| 2088 ± 1 | 340 ± 40 | 460 ± 25 |
| 2128 ± 1 | 6700 ± 600 | 8400 ± 400 |

* Note CEA-N-1459

## 2. FISSION PHYSICS AND CHEMISTRY

### Fission barrier measurements at the Ottignies Cyclotron

P. del MARMOL and F. HANAPPE*
(Joint CEN/SCK-IISN-UCL Program)

A series of experiments was started, using the Cyclotron of Louvain-la-Neuve, to measure the fission cross section of $^{181}$(Ta+$\alpha$) as a function of excitation energy.

About 10 fission cross sections for $^{181}Ta + \alpha$ have been measured ranging from 80 MeV down to 37 MeV $\alpha$-energies. Irradiation times varied from 10 min to 60 hr. The resulting $\sigma_f$ versus energy curve shows the expected exponential dependence.

### $^{110}$Ru Fission Isotope

P. del MARMOL

The study of a radiochemical procedure for fast separation of Ru (as $RuO_4$) from the other fission products, was started. The aim is to try to identify $^{110}$Ru (the heaviest Ru isotope known at present is $^{109}$Ru, T 1/2 = 35 sec.).

The separation method for Ru from other fission products, investigated so far, consists of the formation of $RuO_4$ in basic medium by passing $Cl_2$ gas through the solution. The Ru is recovered in $CCl_4$; the only contaminants observed are I and Br. Although these contaminants are only present in feeble amounts, the decontamination factors should be improved owing to their high fission yield with respect to Ru. So modifications to this procedure are being investigated.

### $^{239}$Pu Fission Products - Mass Distribution

P. VAN ASSCHE

A study of the mass distribution of fission products from the $^{239}$Pu fission at the 0.290 eV neutron resonance has been carried out, using only the gamma activity of the fission products. A significant change with respect to the $^{239}$Pu fission, induced by thermal neutrons, has been observed.

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## 3. NUCLEAR LEVEL SCHEMES AND RADIOACTIVE DECAY DATA

### Neutron Capture γ-ray Studies with a Diffraction Spectrometer

P. VAN ASSCHE, L. JACOBS*, J.M. VAN DEN CRUYCE*, G. VANDENPUT*,
(Joint K.U.L.-S.C.K./C.E.N. Program)

$^{182}$Ta - In order to get better information from the Jülich (n,γγ) coincidence spectra, these data have been analyzed by the SAMPO program here at Mol.

$^{151}$Sm - The reaction data from McMaster University, Ontario(Canada) are at our disposal now; a mutual improvement of the analysis of these data and of our (n,γ) information is expected.

The assembling of the bent crystal diffraction spectrometer for (n,γ) spectroscopy at BR2 is in its final stage.

A study of diffracting Si- and Ge- single crystals has been started in collaboration with Dr. M. Hart at the Bristol University (U.K.). These dislocation-free crystals with very homogeneous structure should yield a far better energy resolution and a gain in total reflectivity as compared to quartz crystals.

### Neutron Capture γ-rays with Ge(Li) Detectors

P. FETTWEIS

A Bi-single crystal has been installed in the outer shielding of the R5 beam-hole of the BR2 reactor in order to serve as a filter for thermal neutrons. Three filter lengths (30, 50 and 80 cm) have been tested. The best compromise between γ-background (< 100 mR/h) and neutron flux ($3 \times 10^6$ n/cm$^2$,s) has been obtained for the 50 cm filter. Detector calibrations by means of the N(n,γ), C(n,γ), Na(n,γ), Fe(n,γ) reactions are in progress. An energy resolution of 5.2 keV at 5 MeV is obtained.

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Properties of $^{235m}U$

M. NEVE de MEVERGNIES, P. del MARMOL

A study of the true "Chemical effect" on the decay rate was started. The preliminary results obtained with chemically prepared sources are the following:

$UO_2$ (18 meas.) : T1/2 = 24.68 ± 0.26 min
$U_3O_8$ (15 meas.): T1/2 = 25.89 ± 0.13 min
$UO_3$ (13 meas.) : T1/2 = 26.03 ± 0.10 min.

As a check of these results, the decay rate of $^{235m}U$ recoils implanted in thick $UO_2$ and $U_3O_8$ deposits was measured. The half-life associated with $U_3O_8$ is (2.6 ± 0.4)% longer than the half-life associated with $UC_2$, thus the same trend is found as for chemically prepared sources. However, the absolute values of the half-lives are systematically longer, due probably to incomplete exchange of the $^{235m}U$ recoils and the inactive U host atoms.

The decay rate of $^{235m}U$ implanted in a thick $UC_3$ layer will be measured soon.

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# Progress Report on
# Nuclear Data Activities in
# The Netherlands

REACTOR CENTRUM NEDERLAND, PETTEN, THE NETHERLANDS.

1. FOM-RCN Nuclear Structure Group

(K. Abrahams)

1.1. General

Much interest was paid to the effect of channel interference in thermal neutron capture. It became clear that the present 3 facilities at the HFR at Petten complement each other reasonably well.
For the $^{59}Co(n,\gamma)$ reaction a satisfying agreement was reached between measurements with oriented target nuclei and measurements of the circular polarization.
For the $^{39}K(n,\gamma)$ and the $^{57}Fe(n,\gamma)$ reactions it appeared that a combination of $\gamma$-$\gamma$ angular correlation measurement and a $\gamma$ circular polarization measurement can be sufficient to determine the channel interference.
The study of the partial $(n,\gamma)$ widths could be concluded with the result that a positive correlation exist between the reduced width and the (d,p) spectroscopic factors for the $p^3/_2$ levels of all studied nuclei in the region A = 40 - 70.

1.2. Gamma spectroscopy and angular correlations

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

The facility uses a thermal neutron beam ($3 \times 10^7$ $cm^{-2}s^{-1}$) with a cooled quartz-bismuth filter, two 5" × 5" NaI detectors, two Ge(Li) (23 and 50 $cm^3$ active volume), a 16 window apparatus for coincidence studies, two 3" × 3" NaI detectors which in combination with one of the Ge(Li) detectors function as a pair spectrometer.
Preparations are being made for the multiparameter Ge(Li) - Ge(Li) system which will be connected to an on-line computer.
The analysis of the $^{37}Cl(n,\gamma)$ spectrum resulted in 79 $\gamma$ transitions of which 64 could be fitted in a $^{38}Cl$ decay scheme.
For nuclei in the mass range A = 30 - 50 the correlation between (d,p) and $(n,\gamma)$ strengths is being studied.
Present research is on the reactions $^{64}Zn(n,\gamma)$, $^{66}Zn(n,\gamma)$ and $^{68}Zn(n,\gamma)$.

### 1.3. Capture of polarized thermal neutrons

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

The facility used consists of a neutron polarizing focussing mirror system giving a 90% polarized beam of $3 \times 10^7$ $cm^{-2}$ $s^{-1}$ flux density, two cobalt-iron gamma-ray polarimeters, two Ge(Li) detectors (40 and 60 $cm^3$ active volume), a 4096 multi-channel analyser connected to an on-line computer. There are plans to install a new minor system in the present thermal column of the HFR which would produce a ten fold higher flux of polarized neutrons.
Measurements have been performed with the target nuclei: $^{29}Si$, $^{63}Cu$, $^{72}Ge$ and $^{183}W$. Present research is on $^{64}Zn$, $^{66}Zn$ and $^{68}Zn$.
In the period under review a contribution has been made to resolve the existing uncertainty in the capture cross section of $^{23}Na$ by determining the spin interference in the capture state.
Gamma-ray spectroscopy with the Ge(Li) detectors and the measurements of the circular polarisation of 12 primary transitions in the $^{23}Na(n,\gamma)$ reaction support the $J^{\pi} = 1^+$ assignment for the 2.85 keV resonance.

### 1.4. Neutron capture γ rays of oriented nuclei

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

This facility uses a mono-energetic polarized neutron beam obtained by diffraction from a magnetized Co-Fe single crystal.
By a $^3He$-$^4He$ dilution refrigerator we are able to cool samples to 0.03 K for periods of several days without interruptions.
Two Ge(Li) detectors are available (6.4 and 40 $cm^3$ active volume) of which the biggest can be used as central detector for pair spectrometry.
A super conducting magnet has been ordered to increase the magnetic field on the samples to 50 KG.
The $^{59}Co(n,\gamma)$ work has been finished and the capture of polarized neutrons in a polarized Ho target is being studied now.

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Fission of Aligned $^{233}U$ nuclei by Neutrons from 0.4 - 2000 eV.

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Subthreshold Neutron-Induced Fission of Aligned $^{237}Np$ Nuclei.

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## 2. R.C.N. Reactor Physics Group

### 2.1. Integral measurements of fission product cross sections

(M. Bustraan et al.)

#### General

The integral measurements of cross sections of fission product nuclides are performed in STEK in 4 different neutron spectra (see fig. 1) by use of the central reactivity worth method.
Measurements have been performed now in the 4 STEK cores mainly for samples of mixtures of actual fission products from thermal fission of U235 contained in "burned" U-Al alloys.
Also one so-called mock-up sample has been used which consists of a mixture of elements such that the fission products of a fast reactor are more or less simulated.
Since March 1972 we dispose also of gram quantities of enriched isotopes on loan from the US-AEC loan pool for stable isotopes. These isotope samples have been thoroughly dried and packed in thin wall welded stainless steel capsules of pin shape. Measurements with these in STEK cores 4000, 3000 and 1000 are finished now. Final measurements in STEK-2000 are to be finished in spring 1973.
An extension of the loan period until December 1973 could be obtained with the consequence that now also measurements in a fifth core, STEK-500, with a "hard" neutron spectrum will be performed, for obtaining some data above 50 keV.
According to the present time schedule final results on the mixed fission products are foreseen for autumn 1973 and final results for the isotopic samples for autumn 1974.

#### Interpretation of measurements

The central neutron spectra in STEK are being measured by all conventional means including time of flight. The evaluation of these measurements is not yet final. There seems, however, to be a reasonable agreement between calculated and measured spectra.
Many of the earlier measurements at STEK were badly disturbed by traces of $H_2O$ absorbed in the samples. This has been remedied now by rigorous drying and packing procedures.

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

Evaluation of fission product cross sections and adjustment

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

Other measurements

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

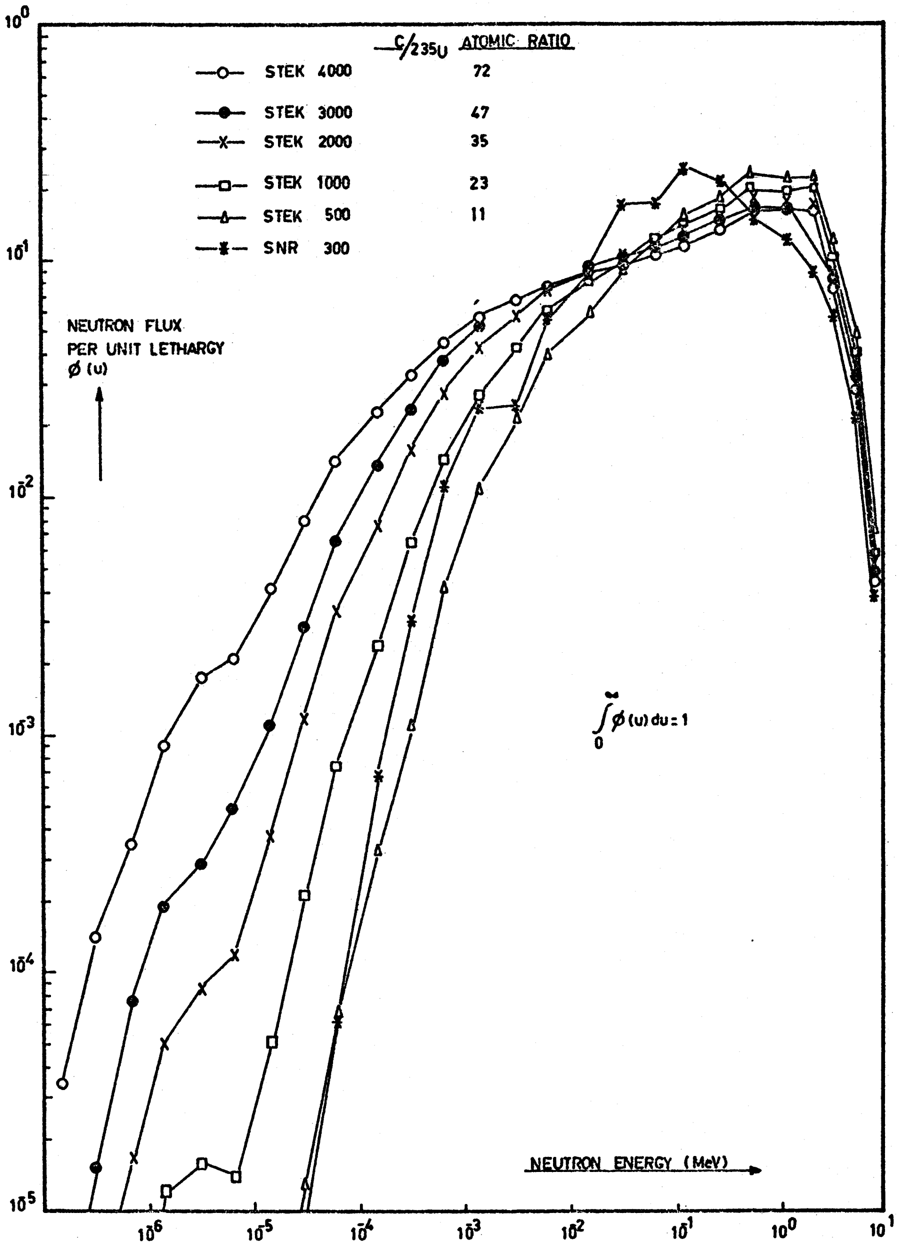


Fig. 1. Neutron spectra in STEK and SNR 300.

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# Progress Report on Nuclear Data Activities in Norway

Contribution from Norway to INDC Progress Report 1973.
(Submitted by E. Andersen, Institutt for Atomenergi, August 1973)

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# THE (n,p) REACTION CROSS SECTION OF $^{116}Cd$ AT 14.7 MeV

by

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Radiochemical and Radioanalytical Letters, in press July 1973

During the authors investigation of the decay of $^{116}Ag$ (1) a study of the cross section for its formation by fast neutron irradiation of $^{116}Cd$ was undertaken.

In the study of the decay of $^{116}Ag$ the authors confirmed the existence of $^{116m}Ag$ and proposed a decay-scheme including both $^{116m}Ag$ and $^{116g}Ag$ and measured the respective halflines to (10.5±0.5) sec and (2.65±0.06) min (1).

For production of $^{116}Ag$ a Philips Neutron Generator, type PW 5320, with a total neutron output of about $3 \cdot 10^{10}$ n $sec^{-1}$ was used.

The results of the measurements gave

$$\sigma_{n,p} \approx (2.2 \pm 0.5) \text{ m b}$$

for the (n,p) cross section of $^{116}Cd$ at 14.7 MeV.

The only measured value to the authors knowledge was that of Yu and Gardner (2) published in 1967, of (0.2 ± 0.1) m b.

Predictions of the measured cross sections from empirical and semiempirical equations are discussed in detail in the paper. The measured value is in fair agreement with the semiempirical prediction of Gardner and Rosenblum of 1.4 m b (3).

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# Progress Report on

# Nuclear Data Activities in

# Switzerland

## PREFACE



## CONTENTS

## I. Institut de Physique Nucléaire, Université de Lausanne

(Dir.: Prof. Dr. Ch. Haenny)

### 1. (n, t) and (n, α) reactions on $^{9}Be$ at 14 MeV

J.P. Perroud and Ch. Sellem

The measured $^{9}Be(n, \alpha_o)\ ^{6}He$ cross section agrees to -20% with the results of Paic and coll. [1]. The angular distribution can be well interpreted in terms of a HPS mechanism in PWBA calculation, in which $^{9}Be$ has been considered as a $\alpha$-$^{6}He$ cluster with L = 0 relative angular momentum.

The angular distribution of the differential cross section for the reaction leading to the first excited state in $^{6}He$ has been measured up to $145^{o}_{CM}$. Its shape, characteristic of a direct reaction process, could not be interpreted by simple calculation. The integrated cross section is $17.5 \pm 1$ mb.

No $^{6}He$ level higher than 1,8 MeV up to 10 MeV is excited appreciably ($\sigma < 5$ mb).

The $^{9}Be(n, t_o)\ ^{7}Li_{GS}$ and $^{9}Be(n, t_1)\ ^{7}Li^*$ differential cross sections were measured up to $90^{o}_{CM}$. The integrated cross section, assuming the hypothesis of a compound nucleus reaction, is $5.5 \pm 0.46$ mb for the second reaction in agreement with the results of Benveniste and coll. [2].

A paper has been submitted to Nuclear Physics and another one on "Identification of charged particles in reactions induced by 14 MeV neutrons" will be submitted to Nuclear Instruments and Methods.

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## 2. $^{10}B$(n, Charged Particles) Reactions at 14 MeV

Ch. Sellem, J.P. Perroud

Results of the simultaneous measurements of the angular distribution of light and heavy particles emitted in reactions induced by 14,0 MeV neutrons in $^{10}B$ were reported last year [1].

The analysis of the experimental results has been continued. It shall give the angular variation of the differential cross sections for the following reactions:

$(n, t_o)$ ; $(n, t_1)$
$(n, d_o)$ ; $(n, d_1)$
$(n, p_o)$ ; $(n, p_1)$ ; $\left[ n, (p_2\ p_3\ p_4) \right]$ ; $\left[ n, p_5 \right]$
$(n, (\alpha_o + \alpha_1))$ ; $(n, \alpha_2)$

The difficult separation between $\alpha_o$ and $\alpha_1$ will be attempted.

Besides the differential cross sections also the corresponding integrated cross sections will be obtained.

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## II. Institut de Physique, Université de Neuchâtel

(Dir.: Prof. Dr. Jean Rossel)

### Depolarisation factor D in the D(nn) Elastic scattering at 2.45 MeV and phase shift analysis*

D. Bovet, S. Jaccard, J. Piffaretti and J. Weber

D has been measured at two angles and at an incident neutron energy of 2.45 MeV. The preliminary results are

$\Theta_{cm}$ : 90° D : (46,0 ± 8.4) %
$\Theta_{cm}$ : 40° D : (39,2 ± 8.0) %

The errors are statistical and experimental.

Phase shift analysis in the framework of the J-degenerate model [1] have been made, each one using as a "starting point" one of some of the many phase shift sets published up to now. Fig. 1 shows that, without inclusion of any experimental values of D, the results of these phase shift analysis are widely scattered especially with regards to the doublet phases. The situation improves a lot when one includes in the analysis our two preliminary results, as it is shown in Fig. 2.

The measurements of an angular repartition of D at 2.45 MeV and other energies are currently being prepared for the purpose of solving the problem of the doublet phases at low energy, below the breakup threshold.

* A more detailed paper has been submitted for publication in Helv. Phys. Acta.

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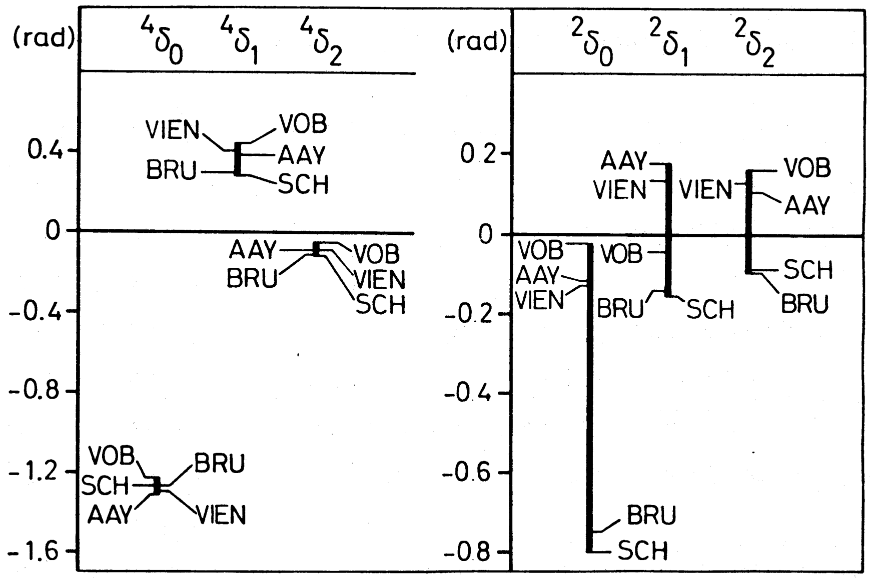
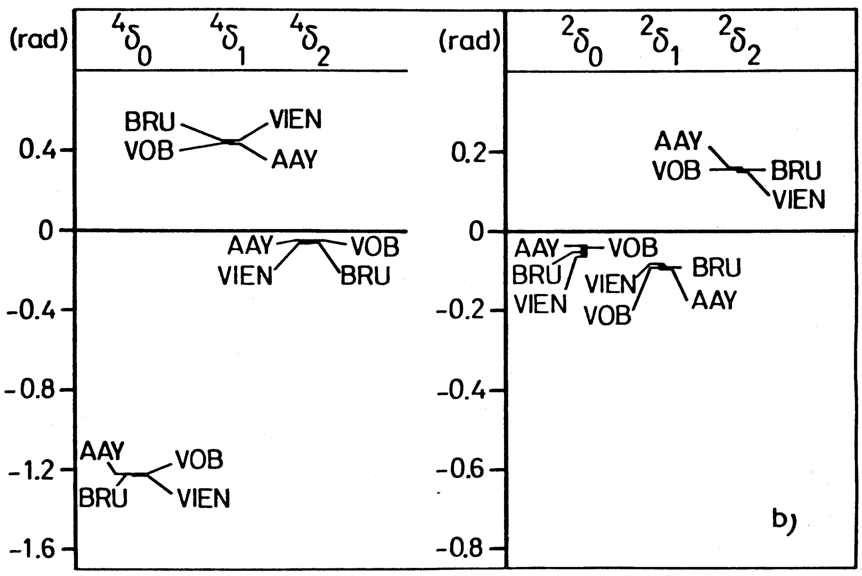



Fig. 1: Ranges of variation of our phase shift analysis results without any D values included in the analysis starting points (see text):

| | |
|---|---|
| AAY | Aaron et al [2] |
| VOB | Van Oers et al [3] |
| BRU | Brüning [4] |
| VIEN | Viennet [5] |
| SCH | Schmelzbach et al [6] |




<u>Fig. 2:</u> same as Fig. 1 but with our two experimental values of D included in the analysis.

## III. Laboratorium für Kernphysik, Eidgenössische Technische Hochschule, Zürich

### 1. Deuteron Breakup in the Fields of Heavy Nuclei

J. Lang, D. Balzer, L. Jarczyk*, R. Müller,
P. Viatte and P. Marmier
Laboratorium für Kernphysik, ETH, 8049 Zürich,
Switzerland

Measurements of cross sections of the deuteron breakup in the fields of heavy nuclei at bombarding energies, where off-shell effects may be neglected, can be useful in testing the quality of different 3-body reaction theories. Such experiments were carried out using the ETH Tandem Van de Graaff accelerator to bombard gold and lead targets with deuterons of energies between 7 and 12 MeV. Outgoing protons and neutrons were detected simultaneously in a semiconductor counter and a liquid scintillator respectively, recording for each coincidence event the proton energy and the flight time difference. By monitoring with the well known Rutherford scattering at $20^{\circ}$, absolute cross sections $d^5\sigma/d\Omega_n d\Omega_p dE_p$ were obtained [1]. An example of an angular correlation, calculated by integration over the proton energies, is depicted in fig. 1.

To date, no exact 3-body calculations on deuteron breakup with realistic potentials have been published. Landau and Lifshitz [2] have shown 25 years ago that an analytical expression for the transition matrix element in the post representation can be obtained by assuming a zero range approximation for the n-p-potential, pure Coulomb wave functions for the proton and the deuteron and a plane wave for the neutron. The results of such a calculation, given in the form of a dashed curve in fig. 1, show unexpected big discrepancies. (The theory of Gold and Wong, which is even worse, shall not be discussed here.) As these differences cannot be due to the zero range approximation, they must result from neglecting the nuclear interaction. Also the experiments were performed below the Coulomb barrier. Therefore, the influence of the nuclear field was included by calculating the d-, p- and n-wave functions using a simple optical potential [3] . The agreement achieved with this method [4] (solid line) is excellent.

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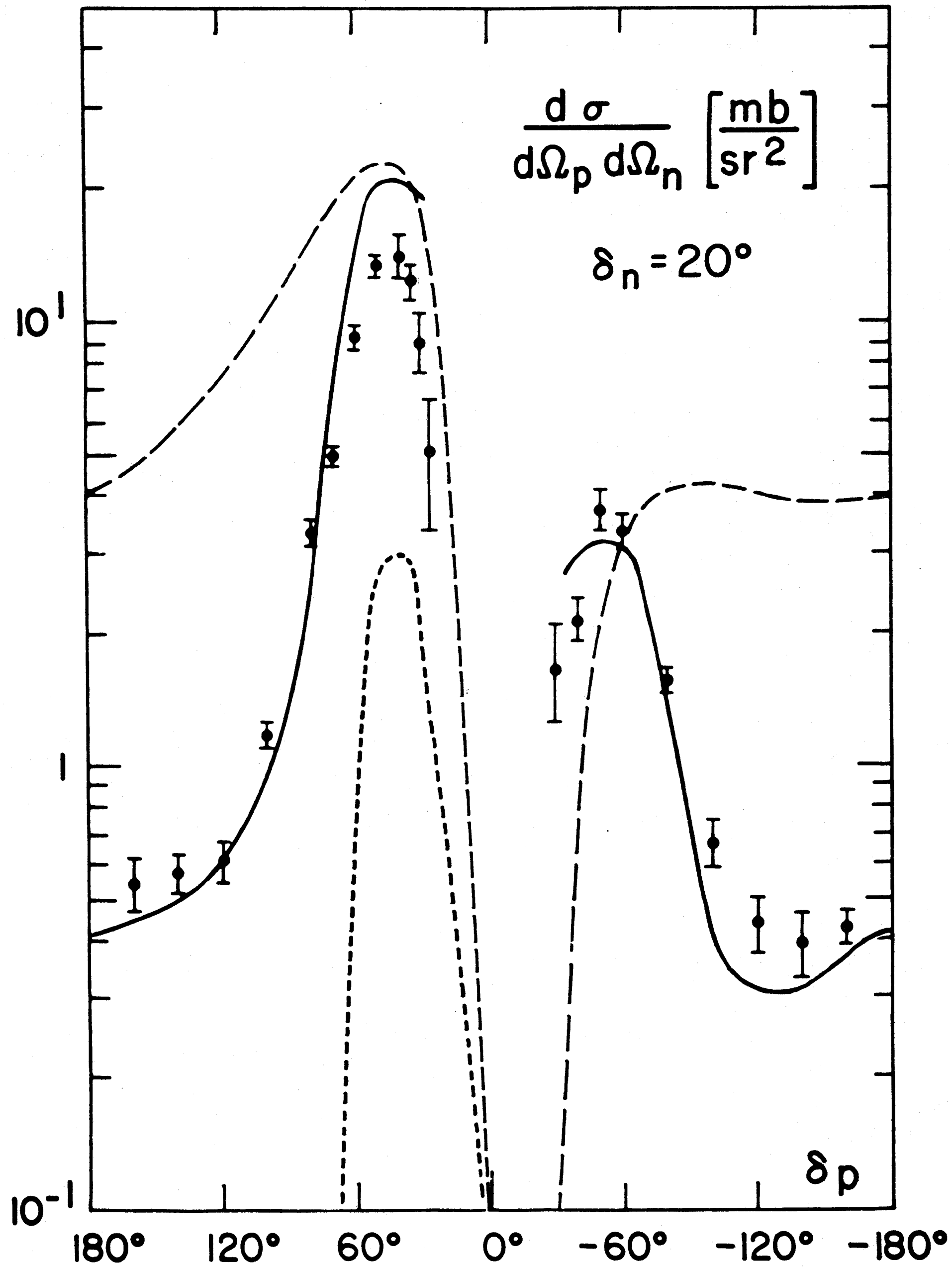
* On leave from Jagellonian University, Cracow, Poland




<u>Figure Caption</u>

Fig. 1: Angular correlations $d^4\sigma/d\Omega_p\, d\Omega_n$ for the reaction Au(d, pn) with $E_d$ = 12 MeV and neutron emission angle $\delta_n = 20^o$ as a function of the proton emission angle $\delta_p$. The curves show different theoretical calculations: ——— present paper; ------ Landau and Lifshitz; ······ Gold and Wong.

## 2. Measurements of the Tensor Analysing Powers in the $T(\vec{d},d)T$ Elastic Scattering

A.A. Debenham, V. König, W. Grüebler, D.O. Boerma,
R. Risler and P.A. Schmelzbach

Work is in progress to measure angular distributions of the deuteron tensor analysing powers in the $T(\vec{d},d)T$ elastic scattering in the energy range from 5 to 11.5 MeV for the incident deuterons. The aim of this work is to provide further experimental information on the five nucleon system. Specifically, it is hoped that these results, together with those obtained for the $He^3(\vec{d},d)He^3$ scattering [1], could be used in conjunction with theoretical work on the five nucleon system [2] to provide conclusions about Coulomb effects in the system. At present, preliminary results have been obtained at 6, 8 and 10 MeV for the moments $T_{20}$, $T_{21}$ and $T_{22}$.

Two types of target* have been used for this experiment. The first consisted of a 1.2 $mg/cm^2$ gold foil 10 mm in diameter with a 0.3 $mg/cm^2$ layer of titanium evaporated onto it. The titanium layer was then loaded with tritium at a temperature of around $400^o$ C. The second target was similar except that a 0.2 $mg/cm^2$ aluminium backing was used in place of the gold. This was found to be advantageous especially at forward angles where the elastic scattering of deuterons from gold was very high. Both elastically scattered deuterons and recoil tritons were detected although, owing to hydrogen contaminant in the target, the latter were mixed with recoil protons from d-p scattering at laboratory angles greater than about $32^o$.

Use of a particle identification system would therefore solve this problem as well as allow the possibility of measuring the tritons at angles less than $17^o$ lab. The method of particle identification proposed in [3] and carried out on line with the PDP 15 computer [4] was found to be successful for this purpose.

Recently, Heiss [5] has furnished polarization equations for two particle reactions, treating the long ranged part of the Coulomb interaction separately. As a result, it is apparently now possible [6]to make theoretical computations of our observables.

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* Provided by Nuklearchemie und -metallurgie, Hanau.
We are grateful to Dr. D. Balzer for preparing the gold foils.

## IV. Eidgenössisches Institut für Reaktorforschung, Würenlingen

### 1. Spontaneous-fission decay constant of $^{235}U$

A. Grütter, H.R. von Gunten and V. Herrnberger
B. Hahn*, U. Moser* and H.W. Reist*
G. Sletten**

The partial spontaneous fission half-lives of odd-A and doubly-odd actinides are observed to be orders of magnitude longer than for even-even nuclides with the same fissility parameter. For $^{233}U$ and $^{235}U$, however, this difference in half-life is reported to be much smaller than for other even-odd actinides. This deviation from systematics could be due to inaccuracies in the measurements or special features of the fissioning systems.

An attempt was made to remeasure the spontaneous fission decay constant for $^{235}U$ using the "spinner" technique. The principle of this detector is based upon producing negative pressure by centrifugal forces in a liquid containing the fissionable material. The metastable state created in this way in the solution can be destroyed as in normal bubble chambers. Very low background and a one hundred percent efficiency even for gram quantities of fissionable material are the main features of this fission counter.

About 8 grams of uranium with an isotopic composition of 99.7% $^{235}U$ were dissolved in ethyl alcohol. Since $(\alpha,n)$-reactions in the alcohol influence the fission rate, "spinner" vessels with different diameters were used in order to enhance the escape probability for neutrons. In chambers of 8 cm and 4 cm diameter count rates of $(2.43 \pm 0.05)$/h and $(0.98 \pm 0.03)$/h, respectively, were obtained. These count rates are compared to those predicted by neutron transport calculations for the contribution of the $(\alpha,n,f)$-reaction. Since the spinner was operated 15 m below rock, the contribution by cosmic interactions is estimated to be negligible.

After correction for the contribution of the spontaneous fission of $^{234}U$, $^{236}U$ and $^{238}U$ (using the published values for the decay constants) an upper limit for the decay constant of $^{235}U$ of $3.65 \cdot 10^{-19}$ $y^{-1}$ was obtained. This limit is about 10 times lower than the value of Segrè (Phys. Rev. 1952) whose determination dates back to pre 1945. It is about 6 times lower than a more recent measurement performed by Aleksandrov et al in 1966 (Atomnaya Energiya 1966). Therefore, we conclude that the deviation in fission hindrance of $^{235}U$ compared to other even-odd actinides was at least partly due to an inaccuracy in the measurements.

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** Niels Bohr Institutet, Tandem Accelerator Laboratoriet, Risø 4000 Roskilde, Danmark

## 2. Independent yields of $^{150}Pm$ in the thermal neutron fission of $^{233}U$, $^{235}U$ and $^{239}Pu$

H. Gäggeler* and H.R. von Gunten

The recent availability of fast separation procedures for rare earth elements makes these elements accessible for determinations of independent fission yields. The rare earth region is of special interest in the investigation of charge distribution because it is complementary to the region of light fragments which are influenced by the 50 neutron shell. Furthermore, the rare earth fission products furnish results for charge distribution in very asymmetric fission.

The shielded nuclide $^{150}Pm$ is very suitable for such measurements due to its half-life and well known gamma-ray spectrum. It has already been determined indirectly in the thermal neutron fission of $^{235}U$ through a measurement of stable $^{150}Sm$ (Chu, 1959, unpublished) and in the spontaneous fission of $^{252}Cf$ by radiometric techniques (von Gunten, 1969). The distribution of charge for $^{233}U$ and $^{239}Pu$ is very poorly known in the region of the 50 neutron shell.

Promethium was separated from irradiated targets by a carrier-free ion exchange procedure followed by two reversed phase chromatographic separations with di-(2-ethylhexyl) orthophosphoric acid (HDEHP) on a diatomaceous silica column. The promethium fraction was counted on a calibrated GeLi-gamma spectrometer. Three photopeaks of 1165 keV, 1324 keV and 1736 keV, respectively, were used to compute the absolute activity of the $^{150}Pm$ formed. The decay of these photopeaks was followed for radiochemical purity. The activity of the peaks of $^{150}Pm$ was compared to the activity of the 340 keV photopeak of $^{151}Pm$ in the same sample.

The independent fission yields for $^{150}Pm$ in the thermal neutron fission of $^{233}U$, $^{235}U$ and $^{239}Pu$ were found to be $(7,3 \pm 0,4) \cdot 10^{-4}$ $(5,4 \pm 0,3) \cdot 10^{-4}$, $(1,10 \pm 0,05) \cdot 10^{-3}$, respectively. The corresponding fractional chain yields lead to empirical Zp (most probable charge) values of 58,67 ± 0,18, 58,62 ± 0,18 and 58,75 ± 0,17 for $^{233}U$, $^{235}U$ and $^{239}Pu$, respectively, if a Gaussian charge dispersion function with a $\sigma$ of 0,59 ± 0,06 is used. The Zp-value for $^{235}U$ is in agreement with the Zp-function proposed by Wahl. However, for $^{233}U$ and $^{239}Pu$ the Zp-values calculated for $^{150}Pm$, using $\nu_A$-values of 1,7 neutrons, deviate significantly from the Zp-function constructed with the light fragments available in this region.

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## 3. $^{153}Eu(n,p)$, $(n,\alpha)$ and $(n,2n)$ Cross-Sections for 14.5 MeV Neutrons

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Cross sections for the $^{153}Eu(n,p)^{153}Sm$, the $^{153}Eu(n,\alpha)^{150}Pm$ and the $^{153}Eu(n,2n)$ $^{152m2}Eu$ reactions have been measured relative to the $^{153}Eu(n,2n)$ $^{152m1}Eu$ reaction cross section.

Neutrons were produced by the $^{3}H(d,n)^{4}He$ reaction in the EIR 150-kV accelerator. The decrease in the intensity of the neutron flux due to burn-out of the target was monitored and the decay curve was fitted to an exponential to obtain the neutron flux decay constant $\Delta$. Samples consisting of 350 mg of $Eu_2O_3$ (enrichment 98.8% $^{153}Eu$; obtained from ORNL) were irradiated for about 3 hours. After the end of the irradiation, the $\gamma$-ray activities were counted with a 40 $cm^3$ coaxial Ge(Li) detector, and successive $\gamma$-ray spectra were recorded by a 4096-channel analyser. The irradiations were repeated three times. In Fig. 1 a typical $\gamma$-ray spectrum is given.

The following equation was used to calculate the cross sections:

$$\sigma = \sigma_m \cdot \frac{\lambda - \Delta}{\lambda_m - \Delta} \cdot \frac{1 - e^{-(\lambda_m - \Delta)t}}{1 - e^{-(\lambda - \Delta)t}} \cdot \frac{\lambda_m}{\lambda} \cdot \frac{A}{A_m}$$

where subscript m stands for the monitor and $\sigma$ is the cross section under investigation. A is the activity at the end of the irradiation; $\lambda$ is the decay constant and t is the duration of the irradiation. The activity A is given by:

$$A = \frac{C \cdot s\,(1 + \alpha)}{\varepsilon \cdot p}$$

where C is the photopeak counting rate at the end of the irradiation; s is the self-absorption correction; ε is the photopeak detection efficiency; p is the decay probability for the transition under investigation and α its internal conversion coefficient. The counting rate C was calculated from an exponential fit to the measured decay curve.

The following decay parameters were used for the reactions [1],[2]:

| | |
|---|---|
| $^{153}Eu(n,p)^{153}Sm$ (47 h); | $E_\gamma$ = 103 keV, p = 77 %, α = 1.8 |
| $^{153}Eu(n,\alpha)^{150}Pm$ (2.7 h); | $E_\gamma$ = 334 keV, p = 74 %, α = 0 |
| | $E_\gamma$ = 1165 keV, p = 17 %, α = 0 |
| | $E_\gamma$ = 1324 keV, p = 19 %, α = 0 |
| $^{153}Eu(n,2n)^{152m2}Eu$ (1.6 h); | $E_\gamma$ = 90 keV, p = 100 %, α = 0.34 |
| $^{153}Eu(n,2n)^{152m1}Eu$ (9.3 h); | $E_\gamma$ = 842 keV, p = 11.1%, α = 0 |
| | $E_\gamma$ = 963 keV, p = 9.9%, α = 0 |

For the monitor reaction $^{153}Eu(n,2n)^{152m1}Eu$ cross section values of 750 ± 200 mb [3] and 652 ± 90 mb [4] are reported in the literature. A value of 650 mb was used.

Table I lists the results of the cross section measurements. The error limits quoted in Table I are composed of the error in the neutron flux decay constant, the error in the photopeak detection efficiency, the statistical error in the counting rate and the error in the self-absorption correction. The errors in the monitor cross section and in p,α and λ of the decay data are not included in the reported error.

Table I

Results of cross section measurements

| Reaction | Cross-Section (mb) | | Refs. |
|---|---|---|---|
| | Measured | Literature values | |
| $^{153}Eu(n,p)^{153}Sm$ | 9.2 ± 1.8 | 7.4 ± 0.7 | [5] |
| $^{153}Eu(n,\alpha)^{150}Pm$ | 2.6 ± 0.3 | 9 ± 2 | [6] |
| $^{153}Eu(n,2n)^{152m2}Eu$ | 140 ± 40 | 91 ± 12 | [4] |

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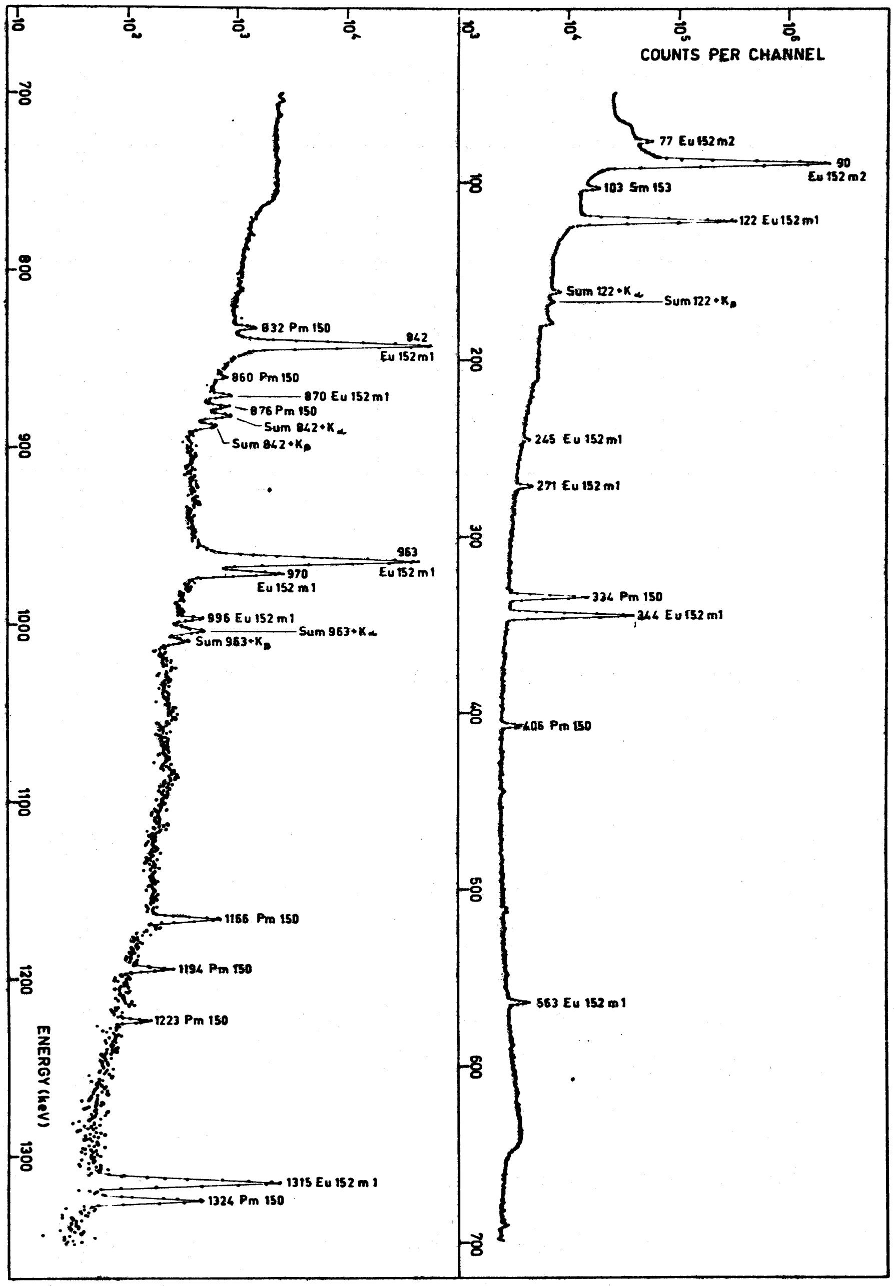


Fig. 1

Gamma ray spectrum of 14.5 MeV neutron irradiated $^{153}$Eu measured with a Ge(Li) detector.

## V. Physikalisches Institut der Universität Basel

### 1. $^{238}U(n,2nf)$-reaction time at 14.3 MeV

U. Noelpp*, R. Abegg and R. Wagner

The $^{238}U(n,2nf)$-reaction time has been measured with the technique presented in EANDC (OR)-116"L". An $UO_2$ single crystal** is cut, ground and etched in a (110)-plane. The quality and orientation of the surface is checked by means of proton-blocking patterns [1]. In the arrangement shown in Fig. 1 the crystal is irradiated by 14.3-MeV neutrons with a total flux of $1.7 \cdot 10^{14}$ n in 4 π. Fission fragments emerging from a circular surface of 1 mm diameter (defined by a 40 μ thick Al-mask) are registered in two glass plates [2]. After etching in HF, the track-density is measured under an optical microscope***. Fields through the center of the shadows of the two <111> -axes are integrated over azimuthal angles, giving the angular distribution of Fig. 2. The difference in shadow-depth can be deduced to $\Delta_\chi = .16 \pm .07$. Considering the relatively short reaction time of $^{238}U(n,f)$ and $^{238}U(n,nf)$ ($1.0 \cdot 10^{-17}$s and $5.0 \cdot 10^{-17}$s respectively) and applying the formulas presented by Gibson and Nielsen [3], we obtain as the final result for the $^{238}U(n,2nf)$-reaction time

$$\tau = (4.9 \begin{smallmatrix} +\ 3.4 \\ -\ 2.8 \end{smallmatrix}) \cdot 10^{-16}\,s$$

As the prefission neutrons deteriorate the depth of the blocking shadows recoiling the compound nucleus, the upper limit of the reaction time can be estimated. The mean recoil distances resulting from the two emerging prefission neutrons are calculated by a simple Monte Carlo-program as a function of the displacement of the compound nucleus.

In Fig. 3, semiempiric calculations on the base of reaction width ratios ( --- ) and a theoretical approach (Hauser-Feshbach calculation [4], -.-.-) are compared with results from Moscow [5] and Aarhus-Studsvik [6] for the $^{238}U(n,f)$-reaction in a similar excitation energy range as our result.

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** We are grateful to Dr. J.L. Whitton, Chalk River Nuclear Laboratories, Canada, for loaning us such crystals

*** Dr. Schaefer of Wild AG, Heerbrugg, Switzerland, made us the M501-sampling-microscope disposable.

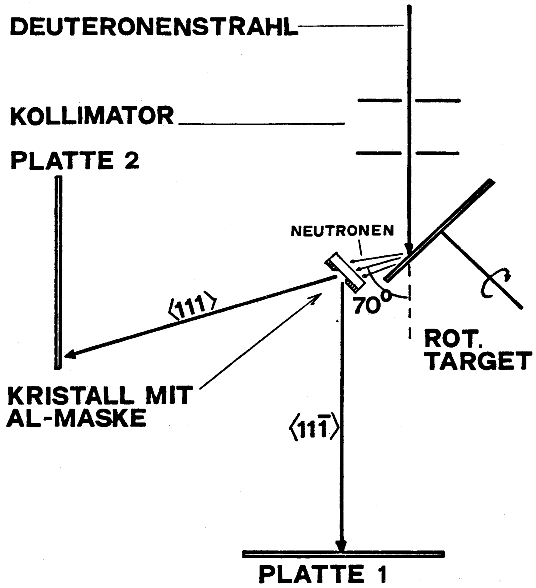


Fig. 1

Experimental arrangement for the measurement of the $^{238}U(n,2nf)$-reaction time. 14.3-MeV neutrons are produced by the $T(d,n)\,^4He$-reaction. The distance between the T-target and the $UO_2$-crystal is 12 mm, the distance between the crystal and the glass plates 200 mm.

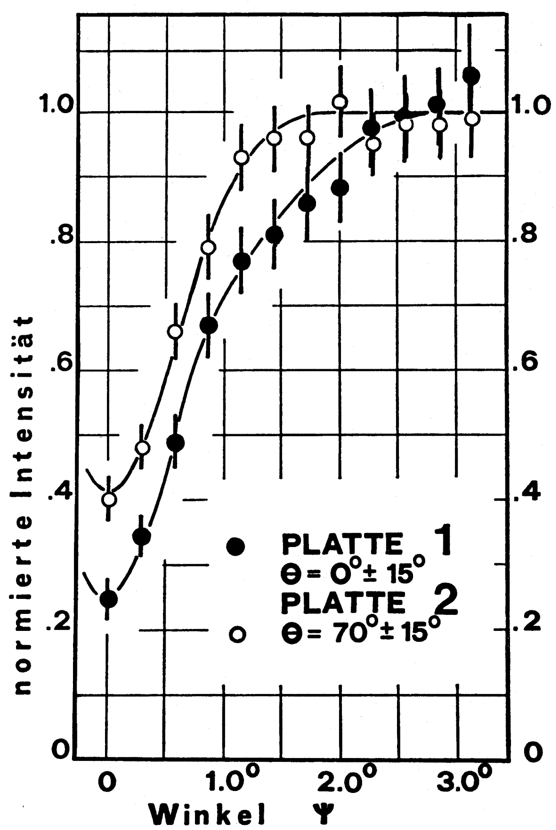


Fig. 2

Angular distribution of the fission fragments emerging from the $UO_2$-single crystal bombarded with 14.3-MeV neutrons, integrated over azimuthal angles near two < III >-axes and normalized for large emission angles.

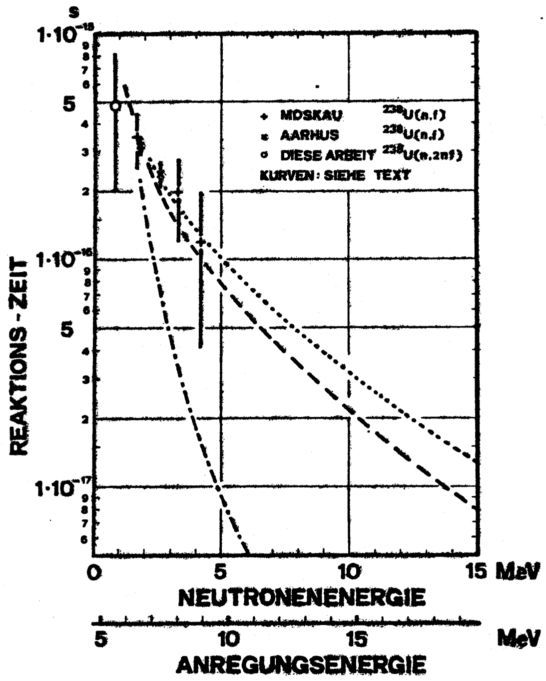


Fig. 3

Comparison of measured and calculated reaction times for neutron-induced fission of $^{238}U$. For literature and curves see text.

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# TOTAL NEUTRON CROSS SECTION OF TERBIUM IN THE THERMAL AND EPITHERMAL ENERGY REGIONS AND DETERMINATION OF THE POTENTIAL SCATTERING CROSS SECTION

Çetin CANSOY, Hâmit ATASOY and Şehsuvar ZEBITAY'AN

The total neutron cross section of $^{159}Tb$ has been measured for different seventy neutron energies in the energy range from 0.062 to 1 eV with a crystal spectrometer using the Be($10\bar{1}1$) crystal plane as monochromator. This energy interval falls in left wing of the first neutron resonance of terbium.

Since a detailed description of the ÇNAEM spectrometer appears elsewhere[1,2] only a few pertinent characteristics are listed here. The neutron beam is collimated by a pair of Soller collimators placed symmetrically before and after the monochromator. Each of these collimators has an angular divergence of 7 minutes of arc, giving a net angular-resolution width of 5 minutes of arc. The spectrometer resolution was 1.405 μ sec/m using the Be($10\bar{1}1$) plane as monochromator.

A sample was made by mounting the oxide $Tb_2O_3$ in an aluminum cell. This sample had an inverse thickness 1/N of 87.92 ± 0.44 b/atom. In calculations of the neutron cross section of the oxide $Tb_2O_3$ the cross section of the oxygen atoms in it was taken into account and subtracted from the total cross section. According to the data given in BNL-325 this correction term was to be almost constant and equal to 5.5 b.

For the total cross section one should consider the influence of the absorption peaks in higher energies, which contribute with an additional term $A/(E)^{1/2}$ in lower energies, where A is a constant that can be estimated for the far away resonances.

The data in the left wing of the first neutron resonance in $^{159}Tb$ were fitted directly to the one-level Breit-Wigner formula using the method of least squares. The quantities obtained from analysis of the data are listed in following table:

$$\sigma_p = 7.96 \pm 1.33 \text{ b}$$
$$A = 5.50 \pm 0.86 \text{ bx(eV)}^{1/2}$$
$$\Im = 2.11 \pm 0.24 \text{ bxeV}$$
$$R = 7.96 \pm 0.66 \text{ fm}$$

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# INVESTIGATION OF SLOW NEUTRON SCATTERING FROM $U^{235}$ ISOTOPE

F. BAYVAS

In this work, scattering of slow neutrons from uranium-235 isotope will be studied.

The coherent scattering of slow neutrons from various isotopes of a given element, give different nuclear scattering amplitudes. In the case of uranium 235, fission phenomenon is predominant for slow neutrons, but neutron scattering is also important. It is also interesting to investigate the scattering process from the point of view of the screened events and the crystallography of the uranium metal.

In this study, scattering phenomena of enriched metallic uranium rods will be examined by using double crystal neutron spectrometer.

ÇNAEM Spectrometer has been designed by MAN for studying both single and powder crystals. It is installed in front of the beam tube no.4 which is 15 cm in. diameter and 2.80 m long. A Soller slit collimator having a divergence of 30' is placed in this tube for the collimation of neutrons coming from the reactor.

Cu and NaCl crystals are being used as a monochromator. After the monochromator, there is a second collimator having a rectangular inlet with a horizontal divergence of $1^{o}32'$. Another collimator, having 21' divergence, can be inserted within this collimator, in case it is required.

The spectrometer is so facilitated that the sample can be rotated either independently or with a ratio of 1/2 with respect to the counter.

The sample is placed between the second collimator and the third collimator which has a rectangular opening. The $BF_3$ counter is placed at the and of the third collimator.

The spectrometer is so designed that the monochromator angle $\theta_B$ can be set up at a maximum $30^\circ$. The $BF_3$ counter table can retate around the second crystal axis from $-10^\circ$ to $+120^\circ$. It rotates stepwise, with steps of 6 minutes in the horizontal plane. The resolution of the spectrometer is 0.035 at 0.0384 eV.

Countings from the monitor and counting from the channels were made semi automatic by two sets of electronic equipment. Data are printed on a paper strip.