KDK-6
NEANDC(OR)-140/L
INDC(SWD)-7/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN, SEPTEMBER 1974

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN

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CONTENTS

Preface

This report gives information about nuclear data activities at different laboratories in Sweden. It contains information about nuclear data measurements, compilation and evaluation works in progress. It also contains short information about new experimental facilities.

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1. THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

Status report, Sept 73 - Sept 74

The Swedish Nuclear Data Committee (see KDK-2) has had two meetings during the past year, on September 21, 1973 and on April 19, 1974. At these meetings nuclear data requests have been discussed in relation to measurements, compilation and evaluation activities in progress. Especially, discussions are in progress about the lay-out and organization of request lists for nuclear data in different applied areas. International nuclear data activities at IAEA and OECD-NEA referred to national nuclear data groups for considerations have also been discussed.

Two specialist meetings on selected topics have been organized by the Committee

1) Meeting on evaluated neutron data libraries, February 2, 1973, AB Atomenergi, Studsvik
2) Nuclear Data Needs for Radioactive Waste Burning, (Invited speaker: Dr W C Wolkenhauer, Battelle Pacific Northwest Laboratories) June 13, 1974, Stockholm

List of KDK-reports (with English text):

KDK-2	Progress report on nuclear data activities in Sweden, September 1973.
KDK-3	Requests for neutron data measurements (Sweden), December 1973.
KDK-4	Memorandum of the KDK-panel discussion on radioactive waste burners, to be published.
KDK-6	Progress report on nuclear data activities in Sweden, September 1974.

2. AB ATOMENERGI, STUDSVIK, S-611 01 NYKÖPING

2.1 Neutron Physics Laboratory*

2.1.1 Neutron elastic scattering at forward angles

V. Corcalciuc**, B. Holmqvist and T. Wiedling

Neutron elastic scattering measurements have been performed at angles between 10° and 40° at 7 MeV neutron energy on samples of Fe, Ni, Pb and Bi. The energy and elements chosen are representative for an investigation of the differential elastic scattering functions for which the cross section change is large at forward angles.

The present data were compared with previous Studsvik measurements made at angles above 20° which were extrapolated to smaller angles. Good agreements were obtained between the new data points and distributions obtained by Legendre polynomial fittings to previous "large" angle data.

No attempts have been made to extend the present investigation to angles, close to zero degrees where the Schwinger scattering effects may be observable. The goal has mainly been limited to check previously made measurements by extending the angular range to moderately small angles and to choose a suitable density of data points in the angular interval to be investigated.

It is observed from the numerical values of the coefficients of the Legendre polynomials fitting the angular distributions that there is in general a very good agreement between the results of the forward angle scattering measurements and those based on measurements at angles larger than 20°. The results of the present investigation therefore confirm that the differential cross section measurements published in our previous reports can be used for extrapolation purposes to small angles by means of the Legendre polynomial expansions given.

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* The reports are abstracted from the annual progress report of the Neutron Physics Laboratory, July 1, 1973-June 30, 1974.

** On leave of absence from Institute for Atomic Physics, Bucharest, Romania.

2.1.2 Optical model descriptions of neutron elastic scattering angular distributions

B. Holmqvist and T. Wiedling

The present work is a study of optical model calculations related to experimental neutron elastic scattering angular distributions. Measurements were performed at 8 MeV and scattering was observed from a number of elements ranging in mass from 27 to 209. The optical model computer code at our disposal limited the number of parameters to five. The minimum value of χ^2 was searched for in the U-r_{oU}-a-W-r_{oW} space. The parameters b and U_{SO} were kept constant. This was not considered a serious drawback, even if valuable information on the W-b coupling was lost. The influence of the magnitude of U_{SO} of the spin orbit term is rather small.

One of the serious difficulties in the present search procedure is the occurrence of several minima in the parameter space. The minima may in some cases be comparatively close lying, i.e. there are only small differences between the numerical values of the parameter sets. There may thus be some doubt about the correctness and even usefulness of a calculated set of optical model parameters. The calculations give not only an angular distribution fit but also total elastic and total cross section values. Thus, judgement as to whether a calculated parameter set can be accepted should not only be founded on the minimum value of χ^2 but also on other criteria such as the observed and calculated elastic scattering angular distributions and on comparisons between observed and calculated total elastic scattering and total cross sections, The judgement of calculated data can accordingly be checked with experimental results in more than one way. The study is in progress.

2.1.3 Optical model calculation of fast neutron elastic scattering cross sections for some reactor materials

M.A. Etemad

The purpose of the present work (1) has been to calculate the differential and integral neutron elastic scattering cross sections using the generalized optical model parameters by Holmqvist and Wiedling (2) for some elements important in the field of nuclear reactor technology as well as presenting comparisons with the available experimental data. Twelve elements have been included in the present work, i.e. Na, Al, Si, V, Mn, Fe, Co, Ni, Cu, Y, Nb and Pb. The cross sections are calculated for neutron energies from 1.5 to 8.5 MeV in steps of 0.5 MeV.

The optical model calculations also gave the values of the total and the absorption cross sections. The nonelastic cross sections and compound elastic cross sections were calculated on the basis of the Hauser-Feshbach formalism. Comparisons have also been made between the calculated and measured total cross sections.

In general, the angular distributions calculated in this work agree with the measured ones by better than 20% for all cases except for the elements Na and Si at some neutron energies. The discrepancies between calculated and measured cross sections for these elements, which could be as large as 50%, can be explained by the variation of the total cross section with energy for these elements. These structures can not be described by the optical model and accordingly less satisfactory results will be obtained when calculating elastic scattering cross sections at the neutron energies which correspond to the maxima or minima of the total cross sections.

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(1) Etemad, M.A., Optical Model Calculations of Fast Neutron Elastic Scattering Cross Sections for some Reactor Materials. 1974. (AE-485).

(2) Holmqvist, B. and Wiedling, T., Optical Model Analyses of Experimental Fast Neutron Elastic Scattering Data. 1971. (AE-430).

The agreement between the calculated integrated elastic cross sections and the measured ones is in general very good (better than 10%) except for Na at 2.5 MeV and for Si at neutron energies 4.75, 5.00, 6.35 and 8.54 MeV. In these cases the difference between the calculated and measured cross sections is about 10 - 30%.

The calculated total cross sections in the present work agree well with those measured by Foster and Glasgow except in the case of Na and Si for neutron energies below 4.0 and 6.0 MeV, respectively. For the element Y the calculated total cross sections are systematically smaller than the measured ones by about 10%. For the rest of the elements the measured and calculated data agree within 5%.

2.1.4 Elastic cross section measurements at back-angles

P.Å. Göransson and T. Wiedling

The purpose of the (n,n) back-angle scattering measurement was to find out if the generalized parameters by Holmqvist and Wiedling (1) give a good description for angles above 160°. To do this some modifications of the earlier experimental arrangement were needed. The detector was placed in its maximum backward angle at 158° relative to the charged particle beam. The scattering angle was adjusted by moving the sample along the extension of the axis from the detector and through the normal scatterer position.

Three angles above 158° were examined, namely 164.3°, 169.2° and 171.8°. In order to get an overlapping region for normalization with earlier experiments [1], the differential cross sections were also determined at 155° and 158°.

The measurements were performed using a time-of-flight spectrometer, with γ-ray discrimination properties, and the neutron flux was monitored by a direction sensitive BF_3 long counter. The target neutron energy was 7.05 MeV at zero degrees and 6.90 MeV at the angle corresponding to the largest scattering angle. The examined elements were Fe, Co, In and Bi.

The data are being analyzed.

2.1.5 Neutron elastic scattering at 10 MeV

V. Corcalciuc*, M. Farooque**, B Holmqvist and T. Wiedling

The aim of the present work has been to extend the elastic cross section measurements to 10 MeV. Monoenergetic neutrons were produced with the $^{9}Be(\alpha,n)^{12}C$ reaction which is very suitable for elastic scattering measurements because of the large energy separation between the neutron groups populating the ground state and the first excited state of ^{12}C. This source reaction is furthermore very useful for production of 10 MeV neutrons because of favourable background conditions. Finally the reaction is also very attractive since the target can easily be used with high beam currents, which is not the case for tritium or deuterium gas cell targets.

Elastic scattering cross section measurements have been performed on the elements Be, C, S, Ca, Cr, Co, Ni and Bi. The experimental data are being analysed at present and will be used for optical model comparisons.

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(1) Holmqvist, B. and Wiedling, T., Optical model analyses of experimental fast neutron elastic scattering data. (AE-430). 1971.

* On leave of absence from Institute for Atomic Physics, Bucharest, Romania.

** On leave of absence from Department of Physics, University of Dacca, Bangladesh.

2.1.6 A comparison between experimental and theoretical inelastic neutron cross sections for the first excited states in some even-even nuclei

E. Almén

In a systematic study of inelastic neutron cross sections some even-even isotopes in which the first excited states have spin and parity 2^+ have been studied. These isotopes are $^{46,\ 48,\ 50}Ti$, $^{50,\ 52,\ 54}Cr$, $^{54,\ 56}Fe$, $^{58,\ 60,\ 62}Ni$ and ^{206}Pb. The experimental results have been compared with the cross sections calculated with the Hauser-Feshbach formalism properly adjusted according to Moldauer. For the 2^+ levels in ^{54}Fe, ^{56}Fe, ^{50}Cr and ^{54}Cr a good description of the experimental data for primary energies between 2.0 and 3.25 MeV was obtained using modified transmission coefficients in these calculations ($Q_\alpha \approx \frac{1}{2}$ for the iron isotopes and $Q_\alpha = 1$ for the chromium isotopes) while for the rest of the isotopes the cross sections calculated with unmodified coefficients ($Q_\alpha = 0$) agreed best with the experimental data in this energy range. At higher primary energies the cross sections calculated with the pure Hauser-Feshbach formalism describe the data well. For the first 2^+ levels in ^{52}Cr, ^{54}Fe and ^{56}Fe there is a tendency for the Hauser-Feshbach calculations to underestimate the experimental data at the highest investigated primary energy. This can be due to the commencement of a contribution from direct interaction at this energy.

2.1.7 Comparisons between experimental and theoretical inelastic neutron cross sections for some odd-mass nuclei

E. Almén

In the systematic study of inelastic neutron cross sections which has been going on at the Studsvik laboratory during the last years it has been found that the experimental data in most cases are well described by the cross sections calculated with the

Hauser-Feshbach formalism properly adjusted according to Moldauer and with a set of generalized optical model parameters for the calculations of the transmission coefficients. However, disagreements of the order of a factor of 2 between experimental and theoretical results have been found for some of the investigated odd-mass nuclei, ^{89}Y, ^{93}Nb, ^{115}In and ^{209}Bi.

Some odd-A nuclei can be looked upon as a single nucleon outside and even-even core. De Shalit (1) has pointed out the possibility of describing some of the excited states of such nuclei in terms of excitations of the even-even core. This type of excited states can be found in some of the elements investigated in the present work.

If the excited states of the even-even core are collective in nature the corresponding excited states of the odd-even nuclei will be collective to the same extent. Thus, the odd-mass nuclei ^{89}Y, ^{93}Nb, ^{115}In and ^{209}Bi, for which there are disagreements between experimental and theoretical results, have excited states which are collective in nature. Since wave functions for single-particle states are used in the Hauser-Feshbach calculation, this can be a possible explanation for the discrepancies.

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(1) De Shalit, A., Phys. Rev. 122 (1961) 1530.

2.1.8 The sensitivity of the elastic and inelastic neutron scattering cross sections to the values of the optical model parameters

E. Almén

In order to investigate the sensitivity of the inelastic cross sections to changes in the different parameters, Hauser-Feshbach calculations have been performed for ^{27}Al and ^{56}Fe at 3.0 MeV primary energy. These calculations have shown that the inelastic cross sections are rather insensitive to changes of up to 10 per cent in the values of W and r_{oW} while the sensitivity to changes in U and r_{oU} is higher. The cross sections for the higher lying excited states are most sensitive to the changes. However, it has been found from the calculations that changes of U by ±5 per cent will affect the cross sections for the levels from which the neutrons are scattered with an energy larger than 0.3 MeV by less than 10 per cent. Furthermore, changes in r_{oU} of 5 per cent will affect the cross sections for Al and Fe by less than 5 per cent except for the levels from which the neutrons are scattered with an energy less than 1.0 MeV. However, if the product Ur_{oU}^2 is kept constant the inelastic cross section will not change more than 5 per cent. Furthermore, variations of the diffuseness parameters, a, of ±5 per cent will also influence the value of the inelastic cross sections by less than 10 per cent.

2.1.9 Inelastic neutron scattering from ^{238}U

P. I. Johansson

The present measurement has been performed to find an experimental technique and parameters which can possibly improve the knowledge of the 45 keV level of ^{238}U. The detector was an 11 cm diameter photomultiplier of low noise type coupled to a liquid scintillator with pulse shape discrimination properties (PSD). An efficient PSD circuit made it possible to run the detector at a cut off of 50 keV neutron energy. The response function has a steep rise up to about 0.35 MeV where the curve flattens out and then falls slowly as the neutron energy is increased. The source of neutrons was a metallic lithium target bombarded with proton bursts with a duration of 1 ns. The thickness of the target introduced a neutron energy spread of 5 keV at 2 MeV proton energy. The flight path was 300 cm at an angle of 90^{o} relative to the charged particle beam. The scattering sample was a hollow cylinder weighing 100 g at a position 6 cm from the target. The corrections for the flux attenuation and multiple scattering effects were of the order of 10%. For this reason a smaller sample will be used in future experiments.

The excitation function was determined by a relative measurement using carbon as a standard. In order to avoid any uncertainty in the detector response function elastic scattered neutrons from ^{12}C and those inelastically scattered from ^{238}U were choosen to have the same energy by a proper choice of scattering angles.

Preliminary results indicate a differential cross section above the ENDF/B-MAT-1158 data in the 500 keV region. It should be possible to reach an accuracy of about 4 % above 400 keV with increasing errors at lower energies. The uncertainty of the carbon cross section of the order of 5 % is not included in these figures.

2.1.10 Effects of the sample size in fast neutron scattering measurements

E. Almén and P. I. Johansson

To make an accurate test of the Monte Carlo program used at the Neutron Physics Laboratory for corrections of neutron flux attenuation, multiple scattering and finite angular resolution in scattering experiments the program has been applied to neutron elastic angular distribution data recorded with samples of iron and bismuth of two different sizes. Preliminary results of the iron measurements indicated a good agreement after the application of correction factors of the order of 59% for the large scatterer and 11% for the small one.

A standard polyethylene sample was used to get information on the relative efficiency of the organic scintillators detector by n-p scattering measurements at different angles and neutron energies. A measurement of the detector efficiency in the energy range 2 MeV to 6 MeV has been performed to investigate the accuracy of the calculated corrections which has to be applied because of the sample size. Four samples of different geometries and weights ranging in mass from 0.26 g to 9 g were used. The measurements were performed with neutrons of the energy 7 MeV produced by the $D(d,n)^3He$ reaction. Data analysing is in progress.

2.1.11 Prompt fission neutron spectrum measurements

P. I. Johansson, P-Å. Göransson and E. Fredriksson

Studies of prompt fission neutron spectra from isotopes which are of interest from the reactor point of view are in progress to determine the spectrum from ^{239}Pu in order to complete the earlier measurements (1, 2, 3).

The experiments have been performed using the time-of-flight technique with an electronic set up similar to that shown in the block-diagram in reference (4). The samples used consisted of hollow cylinders weighing 100 g positioned 6 cm from the target. The distance between the sample and the detector was 300 cm at a detector angle of 90^o relative to the incident neutron beam. The source neutrons with energies 0.1 and 0.18 MeV were produced by the $^6Li(p,n)^7Be$ reaction. The neutron time-of-flight detector (NE 213 Ø 4"x1", RCA 8854) was biased at 0.05 MeV and its relative efficiency was determined by observing neutron scattering from hydrogen and carbon at different primary neutron energies and angles. The very low energy region (< 300 keV) was measured relative to the angular distribution of the $T(p,n)^3He$ reaction. By the present measurement on ^{235}U we have now determined the fission spectrum over the entire energy range, i.e. from 160 keV to 15 MeV.

The fission spectrum from ^{239}Pu was determined relative to the intensity distribution of fission neutrons from ^{235}U measured under identical experimental conditions. This was achieved by using samples of the same dimensions and by replacing the ^{239}Pu-sample every hour either by the ^{235}U-sample or by a sample of Pd or by an empty can representing the plutonium capsule. The Pd-sample and the empty can were used for background corrections. The neutron spectra measurements were performed at primary neutron energies 0.1 MeV, 0.18 MeV, 0.53 MeV produced by the $^{6}Li(p,n)^{7}Be$ reaction and at 2.1 MeV produced by the $T(p,n)^{3}He$ reaction using a gas target.

The analysis of the experimental data is in progress.

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(1) P. I. Johansson, B. Holmqvist and T. Wiedling
An experimental study of the prompt fission neutron spectrum induced by 0.5 MeV incident neutrons on ^{235}U. EANDC(OR)-115"L".

(2) P. I. Johansson, L. Jéki, B. Holmqvist and T. Wiedling
The prompt fission neutron spectrum of ^{235}U and ^{238}U induced by 2.1 MeV neutrons. EANDC(OR)-135"L".

(3) P. I. Johansson, L. Jéki, B. Holmqvist and T. Wiedling
Angular measurements of fission neutrons from ^{235}U and ^{238}U. EANDC(OR)-135"L".

(4) P. I. Johansson, Recent improvements of the neutron time-of-flight apparatus. S-470 (1973).

2.1.12 Delayed gamma radiation from fission products

P. I. Johansson

A computer-based on-line system has been developed to measure the time and energy dependence of the delayed gamma rays from thermal induced fission in ^{235}U. Samples enriched to 93% in the form of circular discs 0.15 g in weight are irradiated by thermalized neutrons produced by the $^{9}Be(d,n)^{10}B$ or the $^{9}Be(p,n)^{9}B$ reactions using the Van de Graaff-accelerator. A rabbit system transports the sample after irradiation to a gamma ray detector consisting of one, two or three sodium iodide scintillators. The detector response function will be determined by γ-ray sources as well as by using (p,γ)-reactions. The irradiation, cooling and counting times are handled by the computer which will also automatically store spectra on magnetic tape for analysis. The times can be chosen independently and arbitrarily, but the first study will be concentrated to the gamma ray spectra in the time range 1 to 10^3 seconds after neutron irradiations of 1 to 10^3 seconds.

Data handling is in progress. Future plans involve the replacing of the NaI-scintillator by a Ge(Li)-detector to study the fine structure of the delayed gamma ray spectra.

2.1.13 Measurements of delayed neutron yields following fission

T. Wiedling

In order to investigate the feasibility of the use of the 5.5 MeV type CN Van de Graaff accelerator as a neutron source in experiments on delayed neutron emission, i.e. the measurement of total delayed neutron yields, some introductory experiments have been arranged.

The irradiation facility chosen for this purpose consisted of a water cooled beryllium target (easily standing a thermal load of about 500 W) which was positioned in a moderator assembly. Uranium samples (0.15 g, enriched in U^{235}) were positioned in the moderator, irradiated for a short time (10 sec) and transported by a rabbit system to the centre of a 4π neutron detector. This detector consists of 20 $B^{10}F_3$ tubes each one meter in length arranged in two concentric circles. Moderation of the neutron takes place in concentrically positioned polyethylene tubes surrounding the detector tubes. The whole assembly is shielded by boron plastic, cadmium, paraffin and concrete with a total wall thickness on each side of about one meter.

The net result of the study indicates the usefulness of the experimental arrangements for yield measurements with good accuracy for half-lives down to a fraction of a second.

2.1.14 Measurements of neutron nuclear data of importance in astrophysics

E. Almén and T. Wiedling

The heavier elements in stars are preferably built up through neutron capture processes. Thus it is of interest to investigate different neutron producing reactions which possibly can take place in stellar objects.

In this project investigations of (p,n) and (α,n) reactions are planned. Extensive work has been performed on building a sensitive and reliable neutron detector with low background. To achieve high sensitivity a 4π detector has been constructed. Low background is obtained by choosing counters which are mainly sensitive to neutrons.

The final detector consists of 20 $^{10}BF_3$-tubes, each of them one meter in length, arranged in two concentric circles. The moderation of the neutrons takes place in concentrically positioned polythene tubes surrounding the detector tubes. The neutron target is positioned in the centre of the detector assembly. The whole assembly is shielded from neutrons by boron plastic, cadmium, paraffin and concrete up to a total thickness on each side of about 0.7 m.

The detector efficiency is about 20 per cent. With a background of 0.7 counts per second it is possible to measure total cross sections of about 30 nb with a signal-to-back-ground ratio of 1.3:1 using a beam current of 4μA and a target thickness of about 40 $\mu g/cm^2$.

The neutron producing reactions, which have been studied in this project are the $^{9}Be(\alpha,n)^{12}C$ and $^{13}C(p,n)^{13}N$ reactions.

The $^{9}Be(\alpha,n)^{12}C$ measurement was performed with an "infinitely" thick beryllium target, i.e. the incoming alpha particles are completely stopped in the target. This means that the integrated neutron yield was measured in an energy interval from thermal energy up to the energy of the incoming alpha particles. This technique was used since the lowest potential obtainable with our 5.5 MeV Van de Graaff accelerator is 0.44 MV. The integrated neutron yield was measured for alpha energies from 0.44 to 0.69 MeV in steps of 0.01 MeV. The neutron yield in the energy interval 0 - 0.44 MeV was then found to be less than 1 per cent of the yield in the interval 0 - 0.60 MeV. This latter interval includes the resonance corresponding to the 11.00 MeV level in ^{13}C.

Thus the results show that there are insignificant or no resonance effects in the $^{9}Be(\alpha,n)$ reaction for the 10.75 and 10.81 MeV levels in ^{13}C.

Furthermore the $^{13}C(p,n)^{13}N$ reaction has been studied from threshold, i.e. 3.2372 MeV, up to 4.25 MeV. The cross section for the inverse reaction is of interest in nuclear astrophysics. Resonances have thereby been observed at laboratory proton energies of 3.77, 3.99 and 4.15 MeV, which correspond to levels in ^{14}N at 11.05, 11.25 and 11.40 MeV, respectively. These values are in good agreement with earlier reported results.

2.1.15 Improvements of the Van de Graaff accelerator

L. Norell

Work is in progress to install a heavy ion source at the Van de Graaff accelerator. The ion source will be of the sputtering type and is provided with a tunable deflection magnet.

A new upper platform for the heavy ion source is under construction.

2.1.16 Infinite-dilution resonance-integrals*

H. Albinsson

A compilation is given of infinite-dilution resonance-integrals (1/v contribution included). Most results have been obtained from experiments, though in some cases evaluated data have also been included. The resonance-integral values have been normalized to conform to various standards, mainly those from ^{197}Au and ^{59}Co.

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* to be included in a handbook of cross section data for activation analysis to be published by IAEA (see also Internal report AE-FN-29, April 1974)

3. CHALMERS UNIVERSITY OF TECHNOLOGY, S-40220 GOTHENBURG

3.1 Department of Nuclear Chemistry

3.1.1 Fission product research activities

J. Rydberg, P.O. Aronsson and G. Skarnemark

A rapid continous radiochemical separation technique, called SISAK, based on liquid-liquid extraction has been developed (1, 2). At present it facilitates separation of nuclides with half-lives $\gtrsim$ 4 s (3).

The present research program is focused on fission products in the region of the light lanthanides, mainly La, Ce and Pr (4). The studies are extended to decay scheme studies via γ-γ coincidence measurements (5, 6).

The SISAK-equipment is portable and may be installed at any suitable irradiation and data collecting facility. The project is operated in close cooperation with professor A.C. Pappas' group in Oslo. The irradiation source is a 14 MeV neutron generator. The experiments of reference (6) have been performed in cooperation with professor G. Herrmann's group in Mainz, at their 14 MeV neutron generator.

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(1) P.O. Aronsson, E. Ehn and J. Rydberg, New Isotope of Palladium, ^{116}Pd. Phys. Rev. Letters 25 (1970) 590.

(2) P.O. Aronsson, B.E. Johansson, J. Rydberg, G. Skarnemark, J. Alstad, B. Bergersen, E. Kvåle and M. Skarestad. SISAK - - A New Technique for Rapid (Radio) chemical Separations. J. Inorg. Nucl. Chem. 36 (1974)

(3) P.O. Aronsson, G. Skarnemark and M. Skarestad. The Half-life of ^{150}Ce Determined by SISAK-technique. Inorg. Nucl. Chem. Letters 10 (1974) 499.

(4) P.O. Aronsson, G. Skarnemark and M. Skarestad. Short-lived Isotopes of Lanthanum, Cerium and Praseodymium Studied by SISAK-technique. J. Inorg. Nucl. Chem. 36 (1974) 1689-1692.

(5) P.O. Aronsson, G. Skarnemark, E. Kvåle and M. Skarestad. Decay Characteristics of some Neutron-rich Lanthanide Nuclides Obtained by SISAK-technique. Inorg. Nucl. Chem. Letters 10, (1974) 753.

(6) To be published in 1975.

3.2 Department of Physics

3.2.1 A facility for production of monoenergetic neutron beams in the epithermal energy region at the R2 reactor at Studsvik.

H. Albinsson and N. Ryde

At a tangential through-hole in the reactor a facility for production of monoenergetic beams in the energy region 0.1 - 150 keV is being built up based on the principles of using either a continuous scatterer near the core combined with an energy-selecting neutron filter or a resonance scatterer near the core combined with an appropriate absorption filter. The filters are installed in a 3-position rotary collimator in which the filters are mounted in order to give a flexible arrangement consisting of rapidly interchangeable filters. Based upon the principle first mentioned a filter using the resonance window at 2 keV in iron has been designed. It consists of 25 cm of Fe, 39 cm of Al and 7 cm of S. The half-width is about 1 keV. The number of filters using the energy-selecting principle that can be realised with reasonable economical in-put is, however, limited.

The use of resonance scatterers seems very promising especially for the energy region 0.1 to 10 keV in which a large number of appropriate scatterers are available. Table 1 contains calculated intensities of some neutron beams in the R2 tangential beam tube for a few scattering materials using the resonance-scattering technique.

In some cases it may be possible to install a second scatterer in the beam taken out from the reactor in which case the background from fast neutrons and gammas will be reduced to a very low level.

Table 1.

Scattering material	Energy in the "neutron window" (keV)	Calculated intensity ($n/cm^2 \cdot s$)
Ni	4.2	4×10^6
Na	2.5	2×10^6
^{144}Nd	0.35	10^6
^{59}Co	0.12	10^6
^{186}W	0.017	2×10^6

3.3 Department of Reactor Physics

3.3.1 Measurement of the $^{59}Ni(n,\alpha)$ cross section

J. McDonald and N.G. Sjöstrand

Nickel enriched to 99% in Ni-58 was irradiated for 4 months in the R2 reactor. After chemical treatment to remove Co-58, mass spectrometry was used to determine that a relative atomic percentage of 0.8% Ni-59 had been formed, the remainder of the material being mainly Ni-58. A thin target of this material was prepared by vacuum deposition on an Al foil backing. At the same time a similar target of non-irradiated Ni-58 was made, as well as three targets of LiF.

The targets were placed in a vacuum chamber at 45° to an incoming collimated beam of thermal neutrons, and a Si surface barrier detector was used to study charged-particle emission from neutron-induced reactions. The neutron beam was derived from a double-crystal monochromator, and measurements were made at three different neutron energies in the region 0.029 - 0.042 eV.

In all of the measurements with the Ni-59 enriched target a peak was observed in the spectra corresponding to the detection of alpha particles with an energy of 4.74 ± 0.01 MeV, in good agreement with the value derived from the Q-value for alpha emission from Ni-60 to the ground state of Fe-56. This peak, which was well separated from the background, did not appear in measurements with the non-irradiated target, and can therefore be assigned to the $^{59}Ni(n,\alpha)^{56}Fe$ reaction.

Cross sections were deduced by comparison of the 4.75 MeV peak area with the areas of the triton peak from the $^{6}Li(n,\alpha)T$ reaction. Within the experimental errors the cross section ratio of Ni-59 to Li remained constant for the three neutron energies used, suggesting that the Ni-59 cross section follows the 1/v law. If this is so, then our preliminary data analysis indicates a somewhat higher value for the 2200 m/s cross section than that recently reported by Eiland and Kirouac (1), who used alpha particle track detectors.

A full report of the present work will be published in due course.

(1) H.M. Eiland and G.J. Kirouac, Nucl. Sci. Eng. 53, 1 (1974)

4. LUND UNIVERSITY AND LUND INSTITUTE OF TECHNOLOGY, S-22007, LUND 7

4.1 Department of Nuclear Physics

Neutron Physics

4.1.1 Fast neutron capture cross section measurements with improved activation techniques.

K. Ponnert, G. Magnusson and I. Bergqvist

The cross section of the $^{115}In(n,\gamma)^{116m}In$ reaction at an incident neutron energy of 15 MeV has been determined by measuring the γ-rays following the decay of the metastable ($T_{1/2}$=54 min) first excited state of ^{116}In. By systematically varying the geometrical arrangement the corrections due to secondary low energy neutrons could be determined. Numerical estimates of the multiple reaction corrections have been made and a comparison with the experimental results indicates a good agreement. The corrected activation capture cross section at 15 MeV is 0.7 ± 0.3 mb which is an order of magnitude lower than previous activation measurements on the same reaction. Measurements are completed and published in Physica Scripta 10 (1974) 35.

A new target system has been constructed in an attempt to further minimize the contributions of low energy secondary neutrons. This construction has been made on basis of the present results. Both target and sample are placed in a vacuum chamber of aluminium. With this arrangement the backing plate for the tritium target can be made very thin (~ 0.02 mm). With this improved activation technique we are planning to measure neutron capture cross sections for several nuclei with 15 MeV neutrons. Measurements at lower neutron energies are also planned.

4.1.2 Neutron capture reactions in the giant resonance region

I. Bergqvist and P. Pålsson
J. Eriksson, AB Atomenergi
A. Lindholm and L. Nilsson, Tandem Accelerator Laboratory

(see 8.1)

Photon Induced Reactions

4.1.3 A review of intermediate energy photofission

B. Forkman and B. Schröder

The photofission process at intermediate energies is reviewed and comparison is made with fission processes induced by pions, nucleons and heavy ions. The photofission cross section in medium-heavy and heavy elements is discussed at photon energies both below and above the photomeson threshold. Single fragment kinetic energy spectra, fragment mass distributions and the angular distribution of fission fragments are treated and discussed from simple interaction models.

Physica Scripta 5 (1972) 105.

4.1.4 An experimental study of mass asymmetry in subbarrier photofission of ^{238}U

A. Alm and T. Kivikas

A measurement of symmetric and asymmetric photofission yields of ^{238}U in the energy region from 4.5 MeV to 6.5 MeV has been performed. Some structures in the yield curves at about 5.3 MeV and a pronounced maximum at about 6.0 MeV in the valley-to-peak ratio in the fission fragment yield distribution are observed. It is suggested that these effects are connected with the double-hump fission barrier concept and indicate differences between fission barriers for symmetric and asymmetric fission.

Nucl. Phys. A215 (1973) 461.

4.1.5 Subbarrier photofission of ^{238}U

A. Alm, T. Kivikas and L.J. Lindgren

Experimental yield curves for symmetric and asymmetric photofission of ^{238}U in the subbarrier energy region are analysed in the framework of a double-hump fission model. The asymmetric yield can be described by one dominant 1^-, 0 channel with a resonance at 4.6 MeV and one 2^+, 0 channel. The information about the symmetric fission is however very limited, except that a strong resonance at about 5.8 MeV is clearly observed. The maximum at 6 MeV in the valley-to-peak ratio is interpreted as an effect of this resonance in the symmetric yield and not as an effect of neutron competition.

Physics and Chemistry of Fission 1973, Vol I, IAEA-SM-174/36.

4.1.6 Compilation and analysis of intermediate- and high-energy photon and electron induced spallation yields

G.G. Jonsson and K. Lindgren

Available intermediate- and high-energy photon and electron induced spallation yields have been compiled and analysed with the five-parameter formulae given by Rudstam. The mass and energy dependence of the parameters are discussed. With appropriate parameters the CDMD-formula is then used to estimate spallation yields and cross sections.

Physica Scripta 7 (1973) 49.

4.1.7 Photonuclear cross sections

B. Bülow and B. Forkman

This article gives a compilation of photon induced reaction cross sections in the giant resonance region.

IAEA publication 1974.

4.1.8 Proton hole states excited by monoenergetic gamma quanta

C-O. Wene

This report contains experimental cross sections for separate photon-proton transitions induced by 17.62 MeV gamma quanta. Targets have been ^{45}Sc, ^{51}V, ^{59}Co, ^{58}Ni, ^{63}Cu and natural Ni. Cross sections are correlated with spectroscopic factors from pick-up reactions.

LUNP 7410 April 1974.

4.1.9 Experimental Facilities

R. Hellborg

The budget has been allocated for a 6 MeV tandem-pelletron to be installed in spring 1975. The machine will be equipped with a duo-plasmatron-ion-source for the acceleration of p, d and He-ions. The machine will replace the old 3 MeV van de Graaff accelerator. The research program will include nuclear structure and reaction studies and also neutron physics.

5. RESEARCH INSTITUTE OF NATIONAL DEFENSE, S-104 50 STOCKHOLM 80

5.1 Studies of the fission threshold structure for ^{232}Th and ^{231}Pa

M. Holmberg and L-E Persson.

Measurements of the fission cross section and of the angular distributions of the fission fragments have been made for ^{232}Th and ^{231}Pa in the fission threshold region. The measurements have been made at the 5.5 MeV Van de Graaff at Studsvik. The "Macrofol" technique was used in the measurements of the angular distributions. The results are to be published shortly.

5.2 Fission cross sections

H. Condé and L-G Strömberg
C. Nordborg, Tandem Accelerator Laboratory, Uppsala

Measurements are in progress at the tandem accelerator at Uppsala of the fission cross section ratios $\sigma_f(x)/\sigma_f(^{235}U)$ for $^{236,\,238}U$ and ^{232}Th between 5 and 10 MeV in energy steps of about 0.3 MeV. The neutrons are produced by the $^3H(p,n)$ and $^2H(d,n)$ reactions in gas targets (1). The pulsed fast neutron beam was monitored with a plastic scintillator in a time-of-flight arrangement. The monitor was in turn calibrated against a proton recoil telescope.

A back-to-back fission ionization chamber with four separate outputs has been used (1). The fission chamber was run in a time-of-flight arrangement to reduce the background caused by thermal neutron induced fission and by the α-activity of the fissile material. The time resolution was about 5 ns. The fissile material (0.5 mg/cm^2) was deposited on 0.1 mm Al-plates. The ^{235}U foils have been supplied by BCMN, Geel and the $^{236,\,238}U$ and ^{232}Th foils by AB Atomenergi, Studsvik. Measurements have been made for ^{236}U and ^{238}U and data handling is in progress together with measurements on ^{232}Th.

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(1) H. Condé, L-E Persson, L-G Strömberg, A. Lindholm, G. Lodin, L. Nilsson and C. Nordborg, TLU 9/73, Tandem Laboratory Report, Uppsala 1973.

5.3 Fission fragment angular distributions

H. Condé, L-G Strömberg
C. Nordborg, Tandem Accelerator Laboratory, Uppsala

A measurement has been made of the fission fragment angular distributions at 4 different energies in the neutron energy range 5-10 MeV for $^{235,\ 236,\ 238}U$ and ^{232}Th. The fragment angular distributions are measured with a scattering chamber containing "macrofol" plastic detectors. Preliminary results give a relatively large anisotropy close to the threshold for second chance fission in accordance with previous measurements.

5.4 Study of the gamma-ray production in neutron scattering on Oxygen

H. Condé, L-G Strömberg
C. Nordborg, L. Nilsson, Tandem Accelerator Laboratory, Uppsala

Measurements have been completed for the gamma-ray production in neutron scattering on ^{16}O.

The experiment has been performed in the energy region $6.5 \leq E_n \leq 10.5$ MeV with water as the scattering sample using a large NaI(Tl) crystal (Ø9" x 8") for gamma-ray detection at 90^o relative to the incident neutrons. To produce neutrons in this energy range two types of gas targets have been used, deuterium [$^2H(d,n)$ reaction] to produce neutrons with energies in the range 6.5 - 9.5 MeV, and tritium [$^3H(p,n)$ reaction] for neutron between 8 and 10.5 MeV.

To reduce the background when using the tritium target the entrance foil in the gas cell as well as the beam stop were made of highly enriched ^{58}Ni.

At these neutron energies only a limited number of gamma-rays are produced in the scattering on ^{16}O, the most prominent one being the 6.13 MeV gamma-ray from the 3^- level to the 0^+ ground state. The excitation function for this gamma transition has been studied throughout the whole energy region in steps of about 50-100 keV. Preliminary treatment of the data reveals a prominent structure of the cross-section with energy. The final data will be reported shortly. Besides the excitation function angular distribution have been studied at two energies; preliminary data indicates an almost isotropic distribution in both cases. The 3.09, 3.68 MeV and the 3.85 MeV gamma transitions in the $^{16}O(n,\alpha\gamma)^{13}C$ reaction have also been studied and in the higher part of the energy region the contributions from the 6.92 MeV and 7.12 MeV gamma-rays produced by the $^{16}O(n,n'\gamma)$ reaction.

5.5 Studies of scattering and gamma-ray production of neutrons on Nitrogen

H. Condé and L-G Strömberg
C. Nordborg and L. Nilsson, Tandem Accelerator Laboratory, Uppsala

Studies of the gamma-ray production in neutron scattering on Nitrogen have been started in the energy region 8-11 MeV. The gamma-rays are measured with a large Ge(Li)-detector. Apart from the study of the gamma-ray production, the elastically scattered neutrons will also be observed in an effort to verify a measurement by Perey and Kinney (1) which shows that the earlier reported discrepancy around 8 MeV in the relation $\sigma_{tot} - \sigma_{el}$ and σ_{nonel} is removed.

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(1) F.G. Perey and W.E. Kinney, Nucl. Sci. Eng. 46 (1971) 428.

6. RESEARCH INSTITUTE FOR PHYSICS, S-104 05 STOCKHOLM

6.1 Research activities

C.J. Herrlander

The nuclear research programme at the Research Institute for Physics (AFI) is centred around the 225-cm cyclotron. Alpha-particle beams as well as $^{12}C^{4+}$ beams are used for producing high-spin states in neutron-deficient nuclei. The γ-ray decay of these states is studied in-beam with the help of Ge(Li) high-resolution spectrometers and suitable auxiliary arrangements. Information is thus primarily obtained on the energy, spin and decay properties of such levels, but also quantities like lifetimes and magnetic moments are studied. The investigations concern nuclei over a very wide range of the periodic table, but with emphasis on problems in the tin region, the rare earth region and the lead region. The cyclotron beam is also used for producing short-lived radio-isotopes for medical applications. - An isotope-separator on-line makes it possible to study the decay of very short-lived activities, both neutron-deficient (produced in (HI,xn) reactions) and neutron-rich (produced in particle-induced fission) radio nuclei. The research programme is to a large extent carried out in close cooperation with scientific groups from other laboratories in Northern Europe.

6.2 Experimental facilities

C.J. Herrlander

After a two-year improvement period, the 225-cm cyclotron has been in operation since July 1973, and alpha-particle beams as well as $^{12}C^{4+}$ beams have been produced. Other kinds of heavy ions ($^{7}Li^{3+}$, $^{14}N^{5+}$, $^{16}O^{5+}$, etc) will be tested in the near future. The cyclotron is found to perform reliably and a second, smaller, improvement programme is now being started. This aims mainly at increasing the efficiency of the ion extraction from the machine. Also, a new experimental area has recently been proposed but, so far, no funds have been given to meet this urgent need.

7. THE SWEDISH RESEARCH COUNCILS' LABORATORY, STUDSVIK, S-611 01 NYKÖPING

7.1 Studies on short-lived fission products

B. Grapengiesser, E. Lund, G. Rudstam, S. Shalev

7.1.1 Survey of short-lived fission products obtained using the isotope-separator-on-line facility at Studsvik (B. Grapengiesser, E. Lund and G. Rudstam, Swedish Research Council's Laboratory Report LF-47, 1973).

Half-life data in the range from about 1 second to about 10 minutes have been determined for 85 fission products.

7.1.2 Evaluation of half-life data for short-lived fission products (G. Rudstam, B. Grapengiesser and E. Lund, to be published in the Proceedings of the IAEA Panel on Fission product Nuclear Data, Bologna, 26-30 November 1973).

An evaluation has been carried out taking the new half-life data given in the report LF-47 into account.

7.1.3 Energy spectra of delayed neutrons from separated fission products.

Part I. Experimental techniques (G.Rudstam, S. Shalev and O.C. Jonsson, The Swedish Research Councils' Laboratory Report LF-54, 1974);

Part II. The precursors ^{85}As, ^{87}Br, ^{135}Sb, ^{136}Te and ^{137}I (S. Shalev and G. Rudstam, The Swedish Research Councils' Laboratory Report LF-55, 1974);

Part III. The precursors ^{89}Br, ^{91}Br, ^{93}Rb, ^{95}Rb, ^{139}I, $^{141}(I+Cs)$ and ^{143}Cs (G. Rudstam and S. Shalev, The Swedish Research Councils' Laboratory Report LF-56, 1974).

In this series of articles energy spectra of delayed neutrons are reported. Delayed neutron spectra for a further set of 12 precursors have been measured.

7.1.4 Beta-decay properties of strongly neutron-rich nuclei (K.A. Johansson, G. Nyman and G. Rudstam, The Swedish Research Councils' Laboratory Report LF-58).

Experimental beta-strength functions for about 50 neutron-rich mass-separated products with half-lifes between 0.8 and 30 s have been obtained. They are found to increase strongly with excitation energy of the daughter in contrast to the approximately energy-independent beta strength found for EC decay.

In addition to the studies mentioned above the total beta decay energy has been determined for a large number of fission products. Another extensive series of measurements concerns the half-life of delayed-neutron precursors. The half-life are measured using a sensitive neutron counter consisting of 30 ^{3}He-neutron detectors.

8. TANDEM ACCELERATOR LABORATORY, BOX 533, S-751 21 UPPSALA

8.1 Neutron capture reactions in the giant resonance region

L. Nilsson and A. Lindholm
I. Bergqvist and B. Pålsson, Department of Physics, University of Lund.
J. Eriksson, AB Atomenergi, Studsvik

The main features of radiative capture of nucleons in the giant resonance region have been described with considerable success by a semi-direct capture model. For example, the model accounts well for both the shapes of the gamma-ray spectra and the cross sections from 14 MeV neutron capture in a number of nuclei. Also the spectrum shapes and cross sections observed in the $^{208}Pb(n,\gamma)$ reaction over the entire range of the giant resonance are well described. On the other hand, the model fails to describe the experimental observations from the $^{40}Ca(n,\gamma)$ reaction. This situation motivates further experimental and theoretical investigations. Our present program within this field concerns studies of the neutron capture process in light nuclei (Si and S) and in other nuclei with closed neutron shells (Y and Ce).

The experiments are performed at the EN tandem accelerator at Uppsala, which is equipped with a pulsed ion source. Monoenergetic neutrons of energies between 3 and 11 MeV can be produced by means of the $^{3}H(p,n)^{3}He$ reaction. Time-of-flight techniques are used to reject background. A NaI(Tl) crystal, 22.6 cm in diameter and 20.8 cm long, is used for gamma-ray detection.

For Si and S, capture gamma-ray spectra have been recorded at seven neutron energies between 4.7 and 10.9 MeV and at 15 MeV. Cross sections for transitions to individual levels or groups of levels have been evaluated and are compared with predictions of the semi-direct capture model. It turns out that the model is not capable of describing neither the detailed structure of the gamma-ray spectra nor the excitation functions. It is evident, that additional reaction processes are required to account for the observed cross sections at least at the lower neutron energies.

Gamma-ray spectra from neutron capture in Y and Ce have been recorded at six neutron energies between 6.2 and 10.9 MeV. For these nuclei the semi-direct capture model gives satisfactory description of the shapes of the gamma-ray spectra and also of the energy dependence of the cross sections. Especially good fits to the excitation functions are obtained with the use of complex coupling between the incident neutron and the vibration of the target nucleus, proposed recently by Potokar[1].

As indicated in the proceeding paragraph our code to calculate semi-direct capture cross sections has been modified to allow calculations with complex coupling interaction between the incident neutron and the vibrations of the target nucleus according to the proposal by Potokar[1].

A considerable improvement in the description of the excitation function of $^{40}Ca(n,\gamma)$ has been achieved by introducing into the semi-direct capture formula the parameters of the $T_<$ component of ^{41}Ca giant resonance instead of the giant resonance parameters of ^{40}Ca[2]. This exchange of giant resonance parameters is motivated by the requirement of isospin conservation.

Preliminary results of the studies of neutron capture reactions in Si and S and in Y and Ce are presented in two contributions[3,4] to the Second International Symposium on Neutron Capture Gamma-Ray Spectroscopy and Related Topics in Petten, September 2. - 6. 1974.

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1. M. Potokar, Phys. Letters 46B (1973) 346
2. L. Nilsson and J. Ericsson, Phys. Letters 49B (1974) 165
3. L. Nilsson, A. Lindholm and I. Bergqvist, Gamma Rays from Fast Neutron Capture in Silicon and Sulphur, Contribution to the Second International Symposium on Neutron Capture Gamma-Ray Spectroscopy and Related Topics, Petten, September 2. - 6. 1974.
4. A. Lindholm, L. Nilsson, I. Bergqvist and B. Pålsson, Gamma Rays from Fast Neutron Capture in ^{89}Y and ^{140}Ce, Contribution to the Second International Symposium on Neutron Capture Gamma-Ray Spectroscopy and Related Topics, Petten, September 2. - 6. 1974.

8.2 Fission cross sections

C. Nordborg

H. Condé and L-G Strömberg, Research Institute of National Defense.

(see 5.2)

8.3 Fission fragment angular distributions

C. Nordborg

H. Condé and L-G Strömberg, Research Institute of National Defence.

(see 5.3)

8.4 Study of the gamma-ray production in neutron scattering on light nuclei

C. Nordborg and L. Nilsson

H. Condé and L-G Strömberg, Research Institute of National Defence.

(see 5.4)