KDK-12
NEANDC(OR)146/L Part A
INDC(SWD)-8/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN
APRIL 1976

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN

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CONTENTS

PREFACE

This report contains information from laboratories in Sweden about measurements, compilations and evaluations, which are relevant to obtain nuclear data for research and development in different applied fields of nuclear physics.

Reports are given of neutron cross section and fission product nuclear data measurements relevant to the nuclear energy field. Reports are also given of photonuclear measurements with applications in activation analysis and of charged particle cross section measurements of importance for cyclotrone-produced radioisotopes for medical use.

In some cases reports are also given of measurements aiming to test nuclear models which are commonly used for the calculation of the above type of data.

In general basic nuclear physics research is not included in this report. However the limitation between pure and applied nuclear physics is not strict why reports might be missing or added as a matter of subjective judgements.

The report also contains short information about changes of existing and about new experimental facilities.

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CINDA Type Index of Neutron Cross Section Measurements

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Element S	Element A	Quantity	Type	Energy Min	Energy Max	KDK-12 Page	Lab	Comments
D		DIFF ELASTIC	EXPT-PROG	8.1+6		31	TLU	AMTÉN+
BE		DIFF ELASTIC	EXPT-PROG	9.7+6		9	AE	CORCALCIUC+ TOF DIFF ELASTIC FROM 20° TO 160°
C		DIFF ELASTIC	EXPT-PROG	9.7+6		9	AE	CORCALCIUC+ TOF DIFF ELASTIC FROM 20° TO 160°
O		NONELASTIC γ	EXPT-PROG	7.0+6	1.0+7	28	FOA	NORDBORG+
F		INELASTIC γ	EXPT-PROG	1.6+7	2.3+7	8	AE	CORCALCIUC+ PROD GAMMA IN(n,n') AND (n,2n) REACTIONS
S		DIFF ELASTIC	EXPT-PROG	9.7+6		9	AE	CORCALCIUC+ TOF DIFF ELASTIC FROM 20° TO 160°
CA		DIFF ELASTIC	EXPT-PROG	9.7+6		9	AE	CORCALCIUC+ TOF DIFF ELASTIC FROM 20° TO 160°
CR		DIFF ELASTIC	EXPT-PROG	9.7+6		9	AE	CORCALCIUC+ TOF DIFF ELASTIC FROM 20° TO 160°
FE		DIFF ELASTIC	EXPT-PROG	7.1+6		5	AE	GÖRANSSON+ TOF 20° TO 174°
FE		INELASTIC γ	EXPT-PROG	1.6+7	2.3+7	8	AE	CORCALCIUC+ PROD GAMMA IN (n,n') AND (n,2n) REACTIONS
CO		DIFF ELASTIC	EXPT-PROG	7.1+6		5	AE	GÖRANSSON+ TOF 20° TO 174°
CO		INELASTIC γ	EXPT-PROG	1.6+7	2.3+7	8	AE	CORCALCIUC+ PROD GAMMA IN(n,n') AND (n,2n) REACTIONS
NI		DIFF ELASTIC	EXPT-PROG	9.7+6		9	AE	CORCALCIUC+ TOF DIFF ELASTIC FROM 20° TO 160°
NI	59	(n,p)	EXPT-PROG	2.9-2	4.2-2	14	CTH	MCDONALD+ THR VALUE 4±1b DEDUCED
NI	59	(n,α)	EXPT-PROG	2.9-2	4.2-2	14	CTH	MCDONALD+ THR VALUE 22.3±1.6b DEDUCED

Element S	A	Quantity	Type	Energy Min	Max	KDK-12 Page	Lab	Comments
NI	61	(n,α)	EXPT-PROG	2.9-2	4.2-2	14	CTH	MCDONALD+ THR VALUE < 2mb
Y		(n,γ)	EXPT-PROG	4.5+6	1.5+7	32	TLU	LINDHOLM+
RB	94	DELAYD NEUTS	EXPT-PROG			29	RCL	LUND+
RB	95	DELAYD NEUTS	EXPT-PROG			29	RCL	LUND+
IN		DIFF ELASTIC	EXPT-PROG	7.1+6		5	AE	GÖRANSSON+ TOF 20^{o} TO 174^{o}
IN	115	(n,γ)	EXPT-PROG	1.4+7		19	LTH	MAGNUSSON+ ACT TECHNIQUE
CE		(n,γ)	EXPT-PROG	4.5+6	1.5+7	32	TLU	LINDHOLM+
BI		DIFF ELASTIC	EXPT-PROG	7.1+6		5	AE	GÖRANSSON+ TOF 20^{o} TO 174^{o}
BI		DIFF ELASTIC	EXPT-PROG	9.7+6		9	AE	CORCALCIUC+ TOF DIFF ELASTIC FROM 20^{o} TO 160^{o}
TH	232	FISSION	EXPT-PROG	5.0+6	1.0+7	27	FOA	NORDBORG+, REL TO U235 FISSION
U	235	SPECT FISS N	EXPT-PROG	1.0+5	2.0+6	4	AE	JOHANSSON TOF SPECT FISS N
U	235	FISS PROD γ	EXPT-PROG	THR		3	AE	JOHANSSON+ DELAYED GAMMA AFTER FISSN
U	236	FISSION	EXPT-PROG	5.0+6	1.0+7	27	FOA	NORDBORG+, REL TO U235 FISSION
U	238	FISSION	EXPT-PROG	5.0+6	1.0+7	27	FOA	NORDBORG+, REL TO U235 FISSION
U	238	EVALUATION	EVAL			13	AE	HÄGGBLOM BWR AND PWR INTEGRAL DATA COMPARED WITH ENDF/B-III
PU	239	SPECT FISS N	EXPT-PROG	1.0+5	2.0+6	4	AE	JOHANSSON TOF SPECT FISS NEUTR

1. THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

Status report, Sept 74 - Dec 75

The Swedish Nuclear Data Committee has had three meetings during the time period, on September 13, 1974, April 18 and September 24, 1975. At these meetings nuclear data requests have been discussed in relation to measurements, compilation and evaluation activities in progress. Compilations of request lists for nuclear data in different applied areas are in progress. Lists of data needs in the nuclear energy field and for neutron reference standards have been compiled and transmitted to CCDN for inclusion in the WRENDA file.

International nuclear data activities at IAEA and OECD-NEA referred to national nuclear data groups for considerations have also been discussed.

A panel discussion about the situation in Sweden concerning breeder reactor developments was arranged by the Committee on November 15, 1974 in Stockholm.

Publications

KDK-4 Transmutation of High-Level Radioactive Waste, Notes from the KDK panel discussion in Stockholm, June 13, 1974 (November 1975)

KDK-6 Progress Report on Nuclear Data Activities in Sweden (September 1974)

KDK-7 List of Nuclear Data Needs in the Nuclear Energy Area. (December 1975) (In Swedish)

KDK-8 Report on Nuclear Reference Data Needs (January 1976) (In Swedish)

KDK-9 Report from the Specialist Meeting on Sensitivity Studies and Shielding Benchmarks, 7-10 Oct 1975, Paris (November 1975) (In Swedish)

KDK-10 Report from "CINDA Readers" seminar, 17-18 November 1975, CCDN, Paris (January 1976) (In Swedish)

KDK-11 Report from IAEA Advisory Group Meeting on Transactinium Isotope Nuclear Data, 3-7 November 1975, Karlsruhe (January 1976) (In Swedish)

KDK-12 Progress Report on Nuclear Data Activities in Sweden (April 1976)

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

2.1 Neutron Physics Laboratory

2.1.1 Measurement of delayed gamma rays from fission products

P.I. Johansson and J. Lorenzen

A facility for thermal neutron irradiation of fission samples using the 6 MeV VdG-accelerator of the Neutron Physics Laboratory and a spectrometer for the study of delayed gamma rays from fission products have been built. The irradiation time is 1 to 100 seconds and the gamma ray emission is followed from a few seconds up to about 30 minutes after fission.

The accelerator delivers ion beams of protons or deuterons with currents up to 100 µA. Neutrons emitted in the $^{9}Be(d,n)\,^{10}B$ or $^{9}Be(p,n)^{9}B$ reactions are subsequently thermalized using a large cubic-shaped moderator of paraffin. The thermal neutron flux available at sample position is about 10^{9} n/(s cm^{2}).

The fission rate in the irradiated samples is determined by an absolute-calibrated fission chamber as well as by measurements of the gamma ray yields from fission fragments. The delayed gamma rays are measured with a well shielded and collimated NaI(Tl) crystal of diameter 12.5 cm and length 12.5 cm.

The transportation of the uranium samples in cylinders of polythene by means of a pneumatic system between the different positions is as well as the irradiation and counting times handled by means of a PDP-15 computer. An automatic cycle can comprise an irradiation time and various counting and cooling times, exceeding 2 s. The spectra are automatically stored on magnetic tape for off-line data analysis. Measurements of delayed gamma-rays from thermal fission of ^{235}U are in progress.

Johansson, P.I. and Lorenzen, J., Measurement of the Energy Released as Gamma Rays in Radioactive Decay of Fission Products of ^{235}U. Conference on Nuclear Cross Sections and Technology, Washington D.C., March 3-7, 1975.

2.1.2 Prompt fission neutron spectra of ^{235}U and ^{239}Pu

P.I. Johansson

The aim of the study, is to measure the shape of the fission neutron spectrum of ^{235}U with as high a degree of accuracy as possible with present day techniques. With this spectrum as a standard it is comparatively easy to measure also the shapes of other fission neutron spectra. Thus measurements of fission spectra of ^{235}U and ^{239}Pu have been performed at the 6 MeV Van de Graaff accelerator using time-of-flight technique (TOF). The spectra were measured at the energies 0.10, 0.18, 0.53 and 2.07 MeV using the $^{7}Li(p,n)^{7}Be$ reaction as a neutron source except in the 2.07 MeV measurement, where the neutrons were produced by the $T(p,n)^{3}He$ reaction.

Since an accurate determination of the fission neutron spectrum is dependent on a good knowledge of the relative detector efficiency as well as of the energy scale of the TOF spectrometer, these quantities have been measured very carefully using different methods.

The observed fission neutron spectra of ^{235}U and ^{239}Pu were interpreted in terms of the Watt and Maxwellian type distributions expressed by the relations $\chi(E) \sim \exp(-AE)\ \sinh(BE)^{1/2}$ and $\chi(E) \sim E^{1/2}\exp(-E/T)$ (E is the outgoing neutron energy and A, B and T are constants). The numerical values of the constants were derived by a least squares fit procedure. The results were reported to the Conf on Nucl Cross Sections and Technology, Washington D.C., March 1975 and to the Specialist Meeting on Inelastic Scattering, Harwell, April 1975. Futher studies of the fission neutron spectrum of ^{235}U in the low energy part of the spectrum is under discussion as a collaboration with a group from Harwell.

Johansson, P.I., Holmqvist, B. and Wiedling, T., An Experimental Study of the Prompt Fission Neutron Spectrum Induced by 0.5 MeV Incident Neutrons on ^{235}U. Neutron Standard Reference Data, IAEA Vienna 1974.

Johansson, P.I., Adams, I.M. and Ferguson, A.T.G., Fission Neutron Spectrum Measurements of ^{235}U at 0.5 MeV Indicent Neutron Energy. Conference on Nuclear Cross Sections and Technology, Washington D.C., March 3-7, 1975.

Johansson, P.I., Holmqvist, B., Wiedling, T. and Jeki, L., Precision Measurements of Fission Neutron Spectra of ^{235}U, ^{238}U and ^{239}Pu. Conference on Nuclear Cross Sections and Technology, Washington D.C., March 3-7, 1975.

Johansson, P.I., Precision Measurements of Fission Neutron Spectra of ^{235}U, ^{238}U and ^{239}Pu. Specialist Meeting on Inelastic Scattering, Harwell, April 14-16, 1975.

2.1.3 Neutron elastic scattering cross section measurements at back-angles

P.Å. Göransson, E. Ramström and T. Wiedling

Measurements of angular distributions for neutron elastic scattering have been going on at our laboratory for several years using time-of-flight technique. Hitherto these measurements have been confined to angles in the region 20° to 160°. In the present work the studied angular range has been extended to 174° for Fe, Co, In and Bi at a primary neutron energy of 7.05 MeV. The purpose of this experiment has been to examine whether the Legendre polynomial expansions, based on experimental data in the angular region up to 174°, differ from those obtained using experimental data from the angular range below 160°. To make such measurements possible the experimental arrangement had to be modified. Thus, the detector was placed at 158° relative to the direction of 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.

Differential cross sections were measured at the angles 158°, 164°, 168°, 172° and 174°. For normalization with earlier measurements at this laboratory in the angular region 20° to 160° (1), measurements were also performed at 130°, 140° and 150°.

The results of this investigation show good agreement between the Legendre polynomial curve obtained by a least square fit to the experimental data in the angular region 20° to 160° and the one obtained when data in the range 20° to 174° are taken into account

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

for all the studied elements. This indicates that the previous measurements, at angles from 20^{o} to 160^{o}, give a satisfactory description of the angular distribution even above the investigated angular interval.

2.1.4 Calculations of the compound elastic cross sections

E. Ramström

The use of the Hauser-Feshbach (HF) and Moldauer (MHF) formalisms makes it possible to estimate the compound elastic scattering contribution to the experimentally observed elastic scattering cross section. Thus the experimental angular distributions can be corrected for this effect before the distributions are compared with the shape elastic scattering cross sections calculated with the optical model. Therefore it is of importance to know the effect of the Moldauer corrections on the calculated compound elastic scattering cross sections. A comparison between the cross sections calculated with the MHF formalism with $Q_{\alpha} = 0$ and those calculated with the HF formalism is most interesting in this connection, since it has been found in a systematic study of inelastic scattering at this laboratory (1) that the inelastic scattering cross sections calculated with the MHF formalism with $Q_{\alpha} = 0$ give the best agreement with the experimental data.

For compound elastic scattering, contrary to inelastic scattering, the cross sections calculated with $Q_{\alpha} = 0$ in the MHF formalism are always larger than those calculated with the HF formalism. Furthermore the ratio between the compound elastic scattering cross sections calculated with those two formalisms increases with increasing incident neutron energy in the investigated energy range, and thus with an increasing number of open decay channels for the compound nucleus. With about 15 open channels this ratio varies between 1.4 and 2.4 for the investigated elements. Furthermore the results from the calculations performed in the present work show that the ratios obtained for the odd-mass nuclei are all lower than those for the even-even nuclei.

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(1) Almén-Ramström, E., A Systematic Study of Neutron Inelastic Scattering in the Energy Range 2.0 to 4.5 MeV. 1975. (AE 503).

2.1.5 General conclusions from the results of a systematic study of neutron inelastic scattering in the energy range 2.0 to 4.5 MeV

E. Ramström

During several years fast neutron inelastic scattering cross sections from eighteen elements covering the atomic mass region 27 to 209 has been measured with time-of-flight technique at our laboratory for incident neutrons in the energy range 2.0 to 4.5 MeV. The experimental results of this systematic study have been compared with those calculated with the Hauser-Feshbach (HF) formalism properly adjusted according to Moldauer (MHF). The transmission coefficients used in these calculations have been obtained using a set of generalized optical model parameters, which have been derived from experimental elastic scattering data. In most cases the inelastic cross sections calculated in this way describe the experimental data well within the quoted experimental uncertainties. Exceptions are a few levels in some odd-mass nuclei such as ^{69,71}Ga, ^{89}Y, ^{93}Nb, ^{115}In and ^{209}Bi, for which the calculated cross sections differ as much as a factor of 2 from the experimental data.

It is obvious from a comparison between the experimental and theoretical cross sections that in those cases where there are few open competing decay channels for the compound nucleus, the cross sections calculated with the MHF formalism with $Q_\alpha = 0$ as a rule give the best description of the experimental data. Furthermore it is clear from the theoretical results of this investigation that the inelastic cross sections calculated with the MHF formalism with $Q_\alpha = 0$ are lower than those calculated with the HF formalism by at most 45 per cent at the lowest primary neutron energy. This figure decreases when the number of open decay channels for the compound nucleus increases with increasing primary neutron energy. Thus with, for instance, 17 open channels, the cross sections calculated according to MHF with $Q_\alpha = 0$ are less than 20 per cent lower than those calculated with the HF formalism.

Almén-Ramström, E., A Systematic Study of Neutron Inelastic Scattering in the Energy Range 2.0 to 4.5 MeV. Dissertation, University of Lund, 1975, (AE-503).

Almén-Ramström, E., A Systematic Study of Neutron Inelastic Scattering in the Energy Range 2.0 to 4.5 MeV. Specialist Meeting on Inelastic Scattering, Harwell, April 14-16, 1975.

2.1.6 A study of the Fe(n,n'γ) and Fe(n,2nγ) reactions in the energy interval 16 - 23 MeV

V. Corcalciuc[x)], G.A. Prokopets[xx)] and B. Holmqvist

The (n,n') and (n,2n) reactions are very interesting to study since they are the dominating ones for medium-weight nuclei when the incident neutron energy is in the interval from about 12 MeV to 23 MeV. The experimental information regarding these reactions is, however, very limited because of experimental difficulties. The aim of the present work has been to study the energy dependence of the cross sections for the production of discrete γ-ray lines induced by 16 to 22 MeV neutrons interacting with some medium-weight nuclei, i.e. F, Fe and Co. For this purpose samples (diameter 8.5 cm, height 1.0 cm) were irradiated. The γ-rays following (n,n') and (n,2n) processes were observed with a 100 cm^3 Ge(Li) detector using time-of-flight technique to separate γ-rays from neutrons. The γ-ray interval of interest in the measurements was from 0.2 MeV to 3.0 MeV. The analyses of the experimental data are in progress.

The analyses of the γ-ray spectra (observed for iron) in the neutron energy range 16 MeV to 22 MeV show that the main contributions of γ-rays are emitted in connection with (n,n') and (n,2n) reactions. The contributions of γ-rays following neutron capture and (n, charged particle) reactions have a much smaller probability.

Corcalciuc, V., Prokopets, G.A. and Holmqvist, B.,
Neutron Interaction with Iron Atoms in the Energy Range,
16 - 22 MeV (in Russian). Sov. J. Nucl. Phys. 20(1974)1096.

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x) On leave from Institute for Atomic Physics, Bucharest, Rumania

xx) On leave from Kiev State University, Kiev, USSR

2.1.7 <u>Elastic scattering of 9.74 MeV neutrons</u>

V. Corcalciuc[x)], M. Farooque[xx)], P.Å. Göransson and B. Holmqvist

Differential cross sections for elastic neutron scattering from Be, S, C, Ca, Cr, Co, Ni and Bi have been measured at an incident neutron energy of 9.74 MeV. All the examined elements had natural isotopic abundances.

Measurements were performed by the time-of-flight technique in the angular region 20° to 160°. In the forward angular range, i.e. from 20° to 60°, measurements were made at every 5°. In that way a good description was obtained of the steeply sloping distributions in this angular region.

The high-energy neutron group from the $^{9}Be(\alpha,n)^{12}C$ reaction ($Q = 5.704$ MeV) were used as a source of neutrons. For our 6 MV Van de Graaff accelerator this is the most prolific reaction for production of neutrons in the energy region around 10 MeV. The neutron group from the first excited state of ^{12}C at 4,43 MeV excitation energy is well separated from the high-energy group. Furthermore, the reaction produces relatively small amounts of γ-radiation, which reduce the influence of the background.

After being analysed the experimental data will be used for optical model comparisons.

2.1.8 <u>The study of the $^{13}C(\alpha,n)^{16}O$ reaction in the energy interval 0.6 to 1.2 MeV</u>

E. Ramström and T. Wiedling

In stars the build-up of elements takes place during various burning phases in the stellar evolution. During these phases different nuclear reactions are of special interest. Thus the $^{13}C(\alpha,n)^{16}O$ reaction is, for instance, important during the hydrostatic helium burning as well as during the hydrostatic and explosive carbon burning. These processes occur at temperatures in the range 10^{8} to 10^{9} K. Because of the high Coulomb barrier between the

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x) On leave of absence from Institute for Atomic Physics, Bucharest, Rumania

xx) On leave of absence from the Atomic Energy Centre, Dacca, Bangladesh alpha particles and the ^{13}C nuclei, the cross sections in the lower parts of these regions are too low to measure at the present time. However, the cross section at low energies can be extrapolated by using the so called cross section factor, $S(E_L) = a+bE_L$, derived at higher energies.

In this work the neutron yield from a thick ^{13}C target (88 $\mu g/cm^2$) was measured for α-particles in the energy range 0.6 to 1.2 MeV with a 4 π neutron detector. It consists of concentric cylindrical shells of polythene as moderators. The neutron counters, 20 $^{10}BF_3$ tubes, each one metre in length, are positioned in the space between the shells. The neutron target is positioned in the centre of the detector assembly. The whole detector 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 observed neutron yield curve from the $^{13}C(\alpha,n)$ reaction shows a smooth shape. However, at 1.056 MeV there is a narrow resonance. Above about 0.900 MeV there is an increase in the neutron yield which might be attributed to some broad resonance. Outgoing from the observed smooth neutron yield curve in the α-particle energy range 0.600 to 0.900 MeV the parameters a and b in the expression for $S(E_L)$ given above have been determined.

Wiedling, T. and Ramström. E., Neutron Reaction Yields and Carbon Burning in Stars, Conference in Physics, Göteborg, June 10-12, 1975.

2.1.9 Modifications of the fast neutron time-of-flight spectrometer

E. Ramström and T. Wiedling

The fast neutron time-of-flight spectrometer, which has been described in earlier reports from this laboratory, has been modified during the past year. Thus, measurements can now be performed simultaneously at two different angles, separated 5° from each other, by using two identical organic liquid scintillator detector systems. The two detectors are placed in a shielding made of lead, iron and paraffin mixed with lithium carbonate. The weight of this shielding is about 15 tons. With this new arrangement the signal-to-background ratio for the detector which is best shielded from direct target neutrons in the forward direction, is about 3:1 at an angle of 15^{o}, 6:1 at 20^{o} and 11:1 at 25^{o} at a neutron energy of 7.0 MeV when using a hollow iron cylinder with a height of 3.0 cm, an inner diameter of 0.95 cm, an outer diameter of 1.8 cm and a weight of 50 g. For the other detector the signal-to-background ratio at the same neutron energy and with the same scatterer is 4:1 at a detection angle of 25^{o} and 13:1 at 30^{o}. A better shielding from the target neutrons of the latter detector in the forward direction may be obtained by increasing the distance between the target and the scatterer.

2.1.10 Installation of a heavy ion source for materials research experiments

L. Norell and B. Holmqvist

A gas-cooled heavy ion source, including a lens system and a 6^{o} deflection magnet of the Harwell type has been installed in the terminal of the Van de Graaff accelerator. The ion source is of the sputtering type. The deflection magnet makes it possible to choose one kind of ions for acceleration, thus avoiding loading of the accelerator tube with undesired ions not required for the experiment.

Electrical and mechanical devices necessary for the operation of the ion source have been designed at the laboratory.

The different electrode voltages and currents necessary for optimum working conditions of the ion source were studied in a test bench. During these tests analysed beams of $^{40}Ar^{+}$(6 μA), $^{58}Ni^{+}$(3 μA) and Xe^{+}(10 μA) were extracted.

The heavy ion source has also been tested together with the Van de Graaff accelerator and was found to work properly. In a test run the source was used to produce Ni^{+} ions for implantation studies into pure nickel for the materials research group at the laboratory. The energy of Ni^{+} ions was 2.8 MeV and a beam current of about 3 μA was extracted for the experiment.

2.2 Nuclear Chemistry Section

2.2.1 A proton semi-microbeam device for surface analysis

D. Brune, U. Lindh[x)] and J. Lorenzen

A proton semi-microbeam arrangement has been developed to study the distribution of elements in surfaces. Proton microbeams with square cross-sections of 25 μm and currents of the order of 1 nA have been produced. Focusing is achieved by means of 4 quadrupole lenses. Collimation is adjustable with the aid of two sets of micrometer-screw arrangements. The sample is mounted on a target holder which affords X and Y translations in steps of 1 μm by means of a step motor.

The point of impact of the beam on the sample is located using proton X-ray technique.

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x) Department of Physical Biology, The Gustaf Werner Institute, Uppsala

2.3 Reactor Physics Section

2.3.1 Neutron data adjustment calculations based on integral measurements on BWR and PWR lattices.

H. Häggblom and M. Edenius

With the ENDF/B-III library as the starting point, reactor physics calculations have been made on BWR and PWR lattices for which experimental data were available. Adjustments in the neutron data were made in order to achieve agreement between experimental and calculational results. The most important changes in the data were as follows.

a) The resonance cross section for ^{238}U was reduced by about 0.26 barns independently of the self shielding.

b) The inelastic scattering cross section for ^{238}U was reduced by 20-30 per cent, depending on the energy groups. This result is in agreement with adjustment calculations made earlier for fast reactors.

Edenius, M., Adjustment of the Effective ^{238}U Resonance Integral to Force Agreement with Integral Data. Seminar on ^{238}U Resonance Capture, Held at the National Neutron Cross Section Center, Brookhaven National Laboratory, March 1975 BNL-NCS-50541, p 87.

Häggblom, H., Use of Data from Fast Assemblies for Adjustments of Neutron Data. National Topical Meeting on New Developments in Reactor Physics and Shielding, September 1972 at Kiamesha Lake, CONF-72 0901, Book 2, p 599.

3. CHALMERS UNIVERSITY OF TECHNOLOGY, S-402 20 GOTHENBURG

3.1 Department of Physics

3.1.1 A facility for production of monoenergetic neutron beams in the epithermal and intermediate energy region at the R2 reactor at Studsvik

N. Ryde

The facility described in the proceeding Progress Report has been moved to a radial reactor channel. Measurements have been performed on the iron filter giving a neutron beam of 24 keV with an intensity of 10^6 neutrons/cm^2 sec. The flux of thermal neutron is less than $6 \cdot 10^2$ neutrons/cm^2 sec. The gamma ray background is less than 320 mrem/h. More than 90% of the neutrons fall in the energy region 24.5 ± 2.5 keV. Measurements on different kinds of detectors are going on. Measurements of the neutron cross sections for 24 keV neutrons in isotopes of gadolinium are in progress. The facility will to a large extent be used for genetic and medical investigations.

3.2 Department of Reactor Physics

3.2.1 Measurements of the ^{59}Ni(n,α), ^{59}Ni(n,p) and ^{61}Ni(n,α) cross sections

J. McDonald and N.G. Sjöstrand

A thin target of ^{58}Ni and 0.85 atomic per cent of ^{59}Ni was mounted in a vacuum chamber at 45^o to a collimated beam of monochromatic neutrons with energies of 0.0290, 0.0345 and 0.0421 eV. A Si surface barrier detector was used to study the induced charged particle emission. Alpha particles with an energy of 4.75 MeV were assigned to the ^{59}Ni(n,α)^{56}Fe reaction. The cross section for this reaction was compared to that of the reaction ^{6}Li(n,α)T and found to obey the 1/v law in this neutron energy region. A value of 22.3 ± 1.6 b at 0.0253 eV was deduced. A further peak at 1.8 MeV was interpreted as being due to the ^{59}Ni(n,p)^{59}Co reaction for which a cross section of 4 ± 1 b was derived.

A thin target of nickel containing 63 per cent of ^{61}Ni was also studied. No evidence of charged particle emission was found, and an upper limit of 2 mb was placed on the cross section for the $^{61}Ni(n,\alpha)^{58}Fe$ reaction.

Preliminary results have been given in a conference report. A full report with details of the measurements is under publication.

McDonald, J. and Sjöstrand, N.G., Proc. Conf. Nuclear Cross Sections and Technology, NBS Spec. Publ. 425, p 776 (1975)

McDonald, J. and Sjöstrand, N.G., Atomkernenergie 27 (1976)

4. THE GUSTAF WERNER INSTITUTE, UNIVERSITY OF UPPSALA, BOX 531, S-751 21 UPPSALA

4.1 Accelerator Physics

H. Tyrén

With the present synchrocyclotron (in operation since 1950) only protons can be accelerated. The energy of the extracted protons is limited to a narrow energy band of 172 - 185 MeV with an energy resolution of about 0.2 MeV. The current in the internal beam is of the order of 2 μA and can be extracted with an efficiency of approx. 1%. The macroscopic and microscopic duty-cycles are 1% and 25%, respectively. A major improvement of the synchrocyclotron has been planned since 1965 and will include the following modifications:

- new pole-gap configuration to obtain sectorfocussing in a magnetic field which increases with radius
- reconstruction of the coils for the main magnet
- new central region and ion sources adapted for different ions
- new RF-system where the ranges of frequencies can be varied to be able to accelerate different particles to various energies
- new extraction system
- new vacuum tank and pump system
- new beam transport system and new experimental areas

With these modifications the present accelerator will be converted into a multi-particle variable-energy machine with high intensity and favourable time structure of the beams. The reconstruction is not yet approved by the Government.

4.2 Cyclotron-produced radionuclides for biomedical use

H. Lundqvist and P. Malmborg

High energy accelerators (proton energy > 50 MeV) have specific advantages in nuclides production. The high energy often permits the choice of production reactions, for example spallation, which give high yield and low contamination. Spallation reactions at high energy are often advantageous. One aim of the present work is therefore to look into which nuclear reaction should be used at a cyclotron of our size. Parameters of interest are yield, contamination, chemical form of activity in the target and other target characteristics. The subsequent labelling prodecure should also determine the choice of production technique. The short-lived nuclides often demand special fast and simple chemical routines. The low current in the present machine (< 1.5 μA protons in the internal beam) has limited the practical applications but has also been a stimulating factor in this work. Clinical pilot-studies on the use of some cyclotron-produced nuclides and precursors have nevertheless been started (see Table 1).

To optimize the yield and the radionuclide purity of a desired product, knowledge of production cross sections at different proton energies is essential. Literature data are often lacking, scarce or disagreeing. Therefore excitation function studies are undertaken on the reactions marked with an asterisk in table 1. Work in progress on the determination of cross sections include irradiations in the internal or external proton beam, chemical separation procedures developed at the institute and radioactivity measurements, mainly using a calibrated 70 cc Ge(Li)-detector.

TABLE 1.

Cyclotron-produced radionuclides for biomedical use: Production, separation from target and biomedical application.

Desired product	Target	Proton energy MeV	Primary product	Separation from target	Biomdecial application (Collaborators)
$^{11}CO_2$	B_2O_3 H_2O N_2 + + 4% O_2	20 70 12	$^{11}CO_2$ $^{11}CO_2$ $^{11}CO_2$	By boiling H_2O-target or B_2O_3-target (dissolved in dilute H_2SO_4). $^{11}CO_2$ is liberated and collected in a N_2(l)-trap.	Synthesis of organic compounds, e.g. ^{11}C-methionine for nutritional studies (B.Larsson) ^{11}C-thymidine for DNA-biosynthesis (B.Larsson and Inst.Zoophysiol., Lund). ^{11}C-glucose for metabolic studies (in progress).
^{13}NN	H_2O	70	^{13}N		Nitrogen fixation (in progress).
^{15}OO	$KClO_3$	45	^{15}OO	^{15}OO is evolved heating the target with MnO_2.	Oxygen metabolism (C-G. Stålnacke)
$H_2{}^{15}O$	H_2O	70	$H_2{}^{15}O$		Water metabolism (in progress)
*)$^{28}Mg^{+++}$	P,NaCl K_2CO_3	100	^{28}Mg	Mg^{++} precipitated as hydroxide.	Magnesium metabolism (in progress)
$^{52}Fe^{++}$	Mn	50	^{52}Fe	Ion exchange	Labelling of red cells (in progress)
*)$^{77}Br^-$	NaBr	50	^{77}Kr	Analogous to iodine below	Synthesis of halogenated precursors of protein and nucleic acids (in progress)
$^{111}In^{+++}$	Cd	45	^{111}In	Ion exchange	Protein-labelling (in progress). Particle labelling (in progress)
*)$^{122}I^-$ *)$^{123}I^-$ *)$^{125}I^-$ *)^{127}Xe	NaI NaI NaI NaI	90 68 40 20	^{122}Xe ^{122}Xe ^{125}Xe ^{127}Xe	Target dissolved in H_2SO_4 (10%) + + Zn, evolved H_2 carriers xenon to pre-evacuated bottle. Xenon decays into iodine.	Labelling of DNA-precursors (Inst. Zoophysiol., Lund), amino acids polypeptides, proteins (in progress), clinical studies of the thyroid gland (Univ.Hosp. in Lund), gastrin metabolism (Univ. Hosp. Uppsala), parathyroid gland with toluidine blue (KS, Stockholm). Labelling of starch beads
*)$^{201}Tl^+$ *)$^{203}Pb^{++}$	Tl Tl	28 28	^{201}Tl ^{203}Pb	Ion exchange, ^{201}Pb decays into ^{201}Tl. Repeated separation yields ^{201}Tl and ^{203}Pb.	^{201}Tl for heart function studies (Univ.Hosp. in Lund). ^{201}Pb for various labelling purposes (in progress) and studies in environmental hygiene (Prague, Zagreb).

*) Excitation function studies in progress.

5. LUND UNIVERSITY AND LUND INSTITUTE OF TECHNOLOGY, S-220 07 LUND 7

5.1 Department of Nuclear Physics - Pelletron group

5.1.1 The Pelletron accelerator

R. Hellborg

The new 3 UDH Pelletron tandem accelerator has been installed. The acceptance test was completed in October 1975 showing that the system can deliver an analysed proton beam above 5 μA in the energy range 0.8 to 6.0 MeV. That is in agreement with the contracted specifications. After installation, the efforts of the staff have been directed on completing the basic system in different ways. Five beam lines from the analysing/switching magnet have been set up and they will now be supplied with experimental facilities to be used in the following fields: neutron physics, beam foil spectroscopy, channeling and related effects, trace elemental analysis with proton induced X-ray emission and nuclear structure studies. We expect to begin using the accelerator for experiments in March 1976.

Work has also started on injector development. The intention is to supply the accelerator with a charge exchange cell for helium ion production and a pulser/buncher system for neutron time of flight experiments.

5.1.2 14-15 MeV neutron capture cross section measurements with improved activation technique

G. Magnusson and I. Bergqvist

It has been established that most of the results from old activation measurements on radiative-capture cross sections of 14-15 MeV neutrons are in error due to the fact that corrections for secondary neutron capture in the sample have been ignored. Secondary low-energy neutrons are produced in the tritium-target backing, the sample itself and surrounding material. In the first investigation (1) on $^{115}In(n,\gamma)^{116m}In$ it was observed that the activation results strongly depend on the geometrical arrangements.

Based on these results a new method for measurements of activation cross sections was developed. The arrangement involves neutron irradiation of the sample in a vacuum chamber made of thin-walled aluminium. This implies a considerable reduction of material around the tritium-target and a corresponding reduction of secondary neutrons.

In order to determine the accuracy that can be obtained the reaction $^{115}In(n,\gamma)^{116m}In$ has been used. The results indicate that neutron capture cross sections at 14-15 MeV can be determined within about 10%.

A report on the method and the application to $^{115}In(n,\gamma)^{116m}In$ cross section is beeing prepared.

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(1) Ponnert, K., Magnusson, G. and Bergqvist, I., Physica Scripta 10, 35-41, 1974.

5.1.3 Activation capture cross sections for 14.8 MeV neutrons

G. Magnusson, P. Andersson and I. Bergqvist

A set of measurements of the radiative capture cross section of 14.8 MeV neutrons for several nuclei from ^{55}Mn to ^{238}U has been started with the improved activation technique described above (see 5.1.2).

5.1.4 Neutron capture reactions in the giant resonance region

I. Bergqvist and B. Pålsson
A. Lindholm and L. Nilsson, Tandem Accelerator Laboratory, Uppsala (see 8.3).

5.2 Department of Nuclear Physics - Photonuclear group

5.2.1 (γ,N) reactions in ^{40}Ca at intermediate energies

J-O Adler, B. Bülow, G.G. Jonsson and K. Lindgren

The study of the reactions (γ,n) and (γ,p) by detecting γ-rays from short-lived excited levels in the product nuclei has been continued. In the present experiment natural calcium is used as target. The experimental arrangement is the same as that used in the study of ^{16}O reported earlier (Nucl. Phys. A171, (1971), 560).

The first excited states in ^{39}K (2.47 MeV) and ^{40}Ca (2.53 MeV) are single hole states and may be assigned to be $(2s_{1/2})^{-1}$. From pick-up reactions, one knows that these states take the major part of the $s_{1/2}^{-1}$ strength. The aim of the present experiment is to study the yields of these two states as a function of the maximum bremsstrahlung energy. From this study we hope to get further information about the (γ,N) reaction mechanism in the pion resonance region.

5.2.2 (γ,xpyn) reactions in ^{51}V

B. Bülow, B. Johansson and M. Nilsson

The experiment is carried out with our usual activation technique using a Ge(Li)-detector. The yields for some reactions have been measured for energies in the region 75-800 MeV.

The calculations are now finished and the final results, which show good agreement with both proton and electron data, will be published in the near future.

5.2.3 Direct and semidirect reactions

B. Bülow, B. Johansson and M. Nilsson

This investigation is concentrated on reactions of direct and semidirect character. We hope to get a systematic view of these reactions. The measurements have been finished during the year and the yields for similar reactions on Si, P, Zn and Te have been obtained. Final calculations concerning these reactions are carried through at the moment and will be published in the near future.

5.2.4 The (γ,pn) and (γ,3p3n) reactions in ^{40}Ca

K. Lindgren

These reactions have earlier been studied by different authors at energies below 300 MeV and the (γ,pn) cross section has been compared to predictions based on the quasi-deuteron model. The experiments have now been extended to higher energies to investigate the importance of different reaction mechanisms.

Natural calcium was irradiated with bremsstrahlung with end-point energies between 80 and 800 MeV. The activity of the residual nuclei ^{38g}K and ^{34m}Cl was measured with a large Ge(Li)-detector and the yield curves determined. From the yield curves the cross sections were deduced.

To interpret the experimental results, calculations based on the cascade-evaporation model (T. A. Gabriel and R. G. Alsmiller, Jr, Phys. Rev. 182 (1969) 1035) were carried out. The initial interactions considered are quasi-deuteron absorption and single pion production. To take into account the population of the isomeric and ground state, the Huizenga-Vandenbosch statistical formalism was applied (Phys. Rev 120 (1960) 1305, 1313).

The conclusion drawn from this investigation is that pion production processes are almost entirely responsible for the (γ,pn) cross section at high energies. The model employed can also explain the experimental results for the $(\gamma,3p3n)$ reaction.

5.2.5 The $(\gamma,2n)$ reaction in light nuclei

B. Johansson, K. Lindgren and M. Nilsson

Gamma one-nucleon reactions in light nuclei have been extensively studied at our laboratory. It is also of interest to study reactions where two nucleons are emitted to test different reaction models. Thus, we have begun to measure the cross section for the $(\gamma,2n)$ reaction in ^{12}C and ^{16}O in the energy region 100 - 800 MeV. These reactions have been studied earlier at energies below the pion threshold (K. Kayser et al. Z. Physic 239 (1970) 447 and P. Filss et al. Z. Physic 239 (1970) 461). Both residual nuclei are short-lived ($T_{1/2}$ = 19.4s and 71s for ^{10}C and ^{14}O respectively). To transport the irradiated targets to the measurement area quickly, we use a pneumatic system.

Up to now we have measured the yield curve for carbon between 80 and 800 MeV. The strong increase in the yield above 150 MeV is interpreted as an effect of pion production.

5.2.6 Charged photoparticles from heavy nuclei

J-O Adler, G. Andersson and H-Å Gustafsson

Measurements of angular- and energy-distribution for p, d, t, ^{3}He and ^{4}He from ^{197}Au irradiated by 500 MeV bremsstrahlung are completed. The results are compared with cascade-evaporation calculations and found reasonably good agreement except for α-particle spectra. If we calculate the directly emitted α-particles and include those in the spectra, we also find good agreement between the experiment and the calculations. We found that the contribution of directly-emitted α-particles was at about 20%.

The experiment is continued by measuring the same quantities for p, d, t, ^{3}He and ^{4}He from Ag irradiated by 500 MeV bremsstrahlung. The next step in this experiment is to run on Cu and measure angular- and energy-distribution for the same particles as above.

5.2.7 Photoproduction of ^{24}Na

A. Järund and B. Forkman

The mean recoil energies of ^{24}Na produced in Cu, Ag and Au have been measured, using the thick target-thick catcher technique. The energies are much lower than is expected from binary fission, indicating that other processes such as fragmentation are responsible for ^{24}Na-production.

The mean cross section of ^{24}Na-production as a function of A_{target} has been measured earlier. The result has been compared with theoretical calculations described by Dostrovsky et al. (Phys. Rev. 111, No 6 (1968) 1659). They start from the heavy fragments being evaporated from the excited target nucleus, and the probability of such a process is compared with the probability of neutron evaporation. The agreement with experiment is good.

5.2.8 Photoproduction of precursors of delayed neutron emitters

B. Bülow, B. Forkman, B. Johansson, A. Järund and M. Nilsson

A system to study the photoproduction of precursors of delayed neutrons has been constructed. Preparations have been made to connect the system to the IBM 1800 computer, for automatic irradiation and analysis. The first thing to be measured is the yield of $^{17}N(T_{1/2}$ = = 4.7s) at different maximum bremsstrahlung energies from targets with $19 \leq A_T \leq 209$, and later on the yield of ^{16}C ($T_{1/2}$ = 0.74s) and ^{9}Li ($T_{1/2}$ = 0.17s). The pneumatic system is developed to make it possible to measure activities with half-lives as short as 0.15s.

5.2.9 Yield distribution and recoil properties in photofission of bismuth

M. Areskoug, B. Schröder and K. Lindgren

The mass and charge distributions have been determined and for some of the products the ranges have been measured. Experimental results are compared with cascade-evaporation calculations in combination with liquid-drop model calculations for the fission process. The results have been published in Nucl. Phys. A251 (1975) 418.

5.2.10 Photofission studies using surface barrier detectors

M. Areskoug, H-Å Gustafsson, G. Hyltén and B. Schröder

Measurements have so far been restricted to the registration of the kinetic energies of two complementary fragments using surface barrier detectors. For uranium, thorium and bismuth we have collected approximately 10000, 10000 and 1000 events respectively. The analysis of the 600 MeV bremsstrahlung-induced fission data is at present being carried out and the results will be reported in 1976. We plan to extend the experiment to include also measurements of the velocities of the two complementary fragments using the time-of-flight technique.

5.2.11 An experimental study of binary fission induced by 600 MeV protons in U, Bi, Pr, Ag, Sr and Cu

G. Andersson, M. Areskoug, H-Å Gustafsson, E. Hageby[1],
G. Hyltén and B. Schröder

The aim of this experiment is to study binary fission induced by 600 MeV protons in targets with varying mass numbers. The two main problems of theoretical interest in this connection are:

i) the variation of the fission barrier height with mass number and

ii) the possible existence of the Businaro-Gallone point and its location.

The experiment consists of measurements of kinetic energies with surface barrier detectors and velocities, with time-of-flight techniques, of two complementary fragments. So far, only one irradiation period of some 5 shifts has been used to check the response of our equipment to the high-energy protons. It turned out that the techniques used are well suited for high-energy fission studies and some preliminary data were obtained for U and Bi. The experiment is being carried out at the synchrocyclotron at CERN, Genéva.

5.2.12 Angular distributions of fission fragments in subbarrier photofission of ^{234}U, ^{236}U and ^{238}U

A. Alm[2], L-J Lindgren and A. Sandell

The experimental work on ^{236}U has been completed and the results have been analysed in the framework of the two-humped barrier model.

The barrier for channel $(I, \pi, K) = (2, +, 0)$ was found to be in agreement with the ground-state barrier determined in particle induced fission.

In our work we find the $(1, -, 0)$ barrier to be almost degenerated with the $(2, +, 0)$ barrier at the position of the outer hump and approximately one MeV higher at the inner hump: this is in agreement with theoretical predictions.

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1) NP division, CERN, Genéva, Switzerland

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Experimental work on ^{234}U and ^{238}U are in progress. The hitherto used manual track-counting method will be replaced with an automatic method which is under development.

5.2.13 100 MeV microtron/pulse-stretcher (MAX) project

R. Alvinsson, O. Cederholm, M. Eriksson, L. Hansson, L-G Johansson, B. Norrs, L. Persson and L. Thånell

For the past three years, the synchrotron staff has been studying a proposed high-duty-factor accelerator system named MAX, composed of a 100 MeV race-track microtron and a pulse-stretching storage ring. This is intended for use mainly in nuclear physics experiments at well-defined energies. The project has not yet been authorized. Besides theoretical design studies, some experimental and practical work within the limits of existing economic and technical resources has been done. Thus, a 6 MeV pre-accelerator has been built and tested as regards beam quality, an accelerating linac to be used in the microtron has been completed and is due to be tested, an injection transport system is being manufactured and machining of the two large 180^{o} magnets has proceeded well.

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

6.1 Fission cross section ratio measurements

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

Measurements of neutron-induced fission cross section ratios for ^{236}U, ^{238}U and ^{232}Th relative to ^{235}U have been made in the neutron energy range from 5 to 10 MeV. The measurements were made at the tandem accelerator at Uppsala using a back-to-back fission chamber and time-of-flight techniques. The amount of fissionable material for ^{236}U and ^{238}U relative to ^{235}U were estimated from a measurement of the relative number of fissions for $^{236}U/^{235}U$ or $^{238}U/^{235}U$ in a thermal beam knowing the isotopic abundances of ^{235}U in the ^{236}U and ^{238}U-samples. The amount of ^{232}Th was determined by a weighing procedure at the fabrication. Futher measurements are planned in the energy region of the "second fission threshold" using a new set of foils ordered from the CBNM, Geel.

Nordborg, C., Condé, H. and Strömberg, L-G, Conf. in Physics, Gothenburg, Sweden, June 10-12, 1975, p 154

6.2 Fission fragment angular distributions

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

The fission-fragment angular distributions have been measured at four neutrons energies in the range 5 to 10 MeV for $^{235,\ 236,\ 238}U$ and ^{232}Th at the tandem accelerator at Uppsala. The fragments were detected in a scattering chamber containing "macrofol" plastic detectors. The angular dependence of the fission fragment attenuation in the foils was studied, using photofission induced by 100 MeV bremsstrahlung at the 1.2 GeV electron synchrotron at Lund. At these energies the fission fragment angular distributions are known to be isotropic.

Preliminary results give a relatively large anisotropy close to the threshold for second chance fission in accordance with previous measurements.

6.3 Gamma ray production cross section of oxygen

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

The gamma ray production cross section of oxygen has been measured at incident neutron energies between 7 and 10.5 MeV. The 6.13, 6.92 and 7.12 MeV gamma rays produced in the (n,n'γ) reaction on ^{16}O and the 3.09, 3.68 and 3.85 MeV gamma rays from the (n,α γ) reaction were observed. The measurements were made at the tandem accelerator at Uppsala using the $^2H(d,n)$ and $^3H(p,n)$ reactions. The gamma rays were detected with a large NaI crystal using time-of-flight techniques. The differential cross sections at 90^o and the angular distribution at one neutron energy were measured. The cross sections were normalized to the (n-p) scattering cross section by the use of a proton recoil telescope. The results which show a marked structure of the cross section over the whole energy region are compared with previous measurements.

The production cross section of the 4.44 MeV gamma ray in inelastic neutron scattering on carbon was also measured at some neutron energies for comparison with earlier measurements normalized to the carbon cross section.

7. THE SWEDISH RESEARCH COUNCILS' LABORATORY, STUDSVIK S-611 01 NYKÖPING 1

7.1 Total decay energies of neutron-rich nuclides

K. Aleklett, E. Lund and G. Rudstam

The total decay energy of fission products is of great interest because of the possibility of using this quantity for mapping the nuclear mass surface far out on the neutron-rich side of stability. By measuring samples from the isotope-separator-on-line arrangement "OSIRIS" the decay energy has been obtained for the nuclides ^{129}Sn, ^{130}Sn, ^{130}Sb, ^{131}Sn, ^{132}Sn, ^{134}Sb, ^{135}I, ^{136}I, ^{140}Cs and ^{143}Cs. The method used for these cases required a half-life of about 5 s or longer. It is described in an article accepted for publication in Nucl. Instr. Methods (1).

The spectrometer for measuring decay energies has now been rebuilt with the aim of lowering the half-life limit to less than 1 s. The new spectrometer has been used for studying $^{76-78}Zn$, $^{76-81}Ga$, $^{79,81}Ge$, ^{83}As, ^{88}Br, $^{126-129}In$ and ^{139}I, but the analysis of the results remains to be done.

7.2 Delayed-neutron emission from fission products

E. Lund and G. Rudstam

A sensitive neutron counter containing 30 ^{3}He-detectors has been used for a survey of delayed-neutron precursors in fission. Accurate half-life determinations have been obtained for 44 precursors, among them 18 new ones. The results have been accepted for publication in Phys. Rev. (2, 3).

The delayed-neutron energy spectra of the precursors ^{94}Rb and ^{95}Rb have been remeasured because of a possible contamination in earlier measurements. The results are presently being analyzed.

The energy spectra of the delayed neutrons can be described in terms of a fine structure superimposed on a gross structure consisting of 1 - 3 components of different wave-numbers. Such a characterization has been carried out for the 24 precursors whose spectra have been measured in this laboratory. These precursors are responsible for about 85% of the delayed-neutron effect in ^{235}U or ^{239}Pu. Thus, the weighted sum of the spectra represents well the effective delayed-neutron energy distribution in nuclear fuel.

7.3 Decay heat in nuclear fuel

K. Aleklett and G. Rudstam

An important part of the power developed in nuclear fuel by the decay of fission products originates from the emission of beta particles. The contribution of individual fission products to this part of the decay heat is obtained by measuring their average beta energy. The method for doing this has been developed, and isobars of the mass numbers 77, 78, 86, 87, 88, 89, 90 and 91 (altogether 17 nuclides) have been measured. The analysis of these measurements is under way. It seems that the average beta energy can be determined with a standard deviation of 2-4%

7.4 Nuclear spectroscopic studies of fission products

B. Fogelberg and H. Tovedal

The decay properties of shortlived fission products are studied by means of γ-ray and conversion electron spectroscopy, and by measurements of level half-lives. During the year, studies have been made of the level structures of the odd-mass isotopes of Sn with A = 119 - 125, of Cd with A = 113 - 117 and of ^{95}Sr, ^{96}Zr and 144, ^{145}Ba.

Another line of investigations concerns studies of γ-rays emitted in competition with delayed neutrons. Pronounced γ-ray emission from unbound levels in ^{87}Kr, ^{137}Xe and ^{134}Te have been observed so far.

Reports have been written on the studies of $^{119-125}Sn$ (4), ^{117}Cd (5), ^{119}Cd (6), ^{87}Kr (7) and ^{96}Zr (8).

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(1) E. Lund and G. Rudstam, accepted for publ. in Nucl. Instr. Methods
(2) G. Rudstam and E. Lund, accepted for publ. in Phys. Rev.
(3) E. Lund and G. Rudstam, accepted for publ. in Phys. Rev.
(4) B. Fogelberg, K. Fransson, M. af Ugglas and L-E de Geer, Z. Phys. (in press)
(5) B. Fogelberg, Y. Kawase, J. McDonald and A. Bäcklin, accepted for publ. in Nucl. Phys.
(6) Y. Kawase, B. Fogelberg, J. McDonald and A. Bäcklin, Nucl. Phys. A241, (1975), 237.
(7) H. Tovedal and B. Fogelberg, Nucl. Phys. A252, (1975), 253
(8) G. Sadler et al., Nucl. Phys. A252, (1975), 365.

8. TANDEM ACCELERATOR LABORATORY, BOX 533, S-752 21 UPPSALA

8.1 The tandem accelerator

Within the near future the accelerator will be furnished with a new ion source of the sputtering type. The ion source (HICONEX 834) has been ordered from General Ionex Corporation and is designed to deliver negative ion beams in the 1-20 μA range of a variety of species covering the entire periodic table of atoms.

8.2 Precise measurements of the elastic n-d differential cross sections at low energies

L. Amtén, L. Gönczi, A. Johansson and B. Sundqvist

Scattering phenomena in three-nucleon systems have been studied extensively in recent years both experimentally and theoretically. The uncertainties of the experimental neutron data are often of the order of 10%. Faddeev type calculations may be capable of revealing new facts about two-nucleon forces used as data, but to achieve this it appears necessary that both calculations and measurements are improved to the 1% level.

The method consists of using a foil of a known mixture of $(CH_2)_n$ and $(CD_2)_n$ and measuring the ratio between the number of recoiling deuterons and protons into a Si(Sb) ΔE-E telescope. The n-d elastic cross sections are then calculated making use of the n-p elastic cross sections which are known to 0.3-0.8% for $E_n^{lab} < 10$ MeV (1). In this way most of the difficulties with neutron beam normalization and neutron detection are avoided.

The method has been used with the telescope at 0^o, i.e. 180^o n-d scattering, and $E_n^{lab} = 8.1$ MeV (2), resulting in cross sections which are somewhat larger than those previously reported. Measurements with a Si(Sb) position sensitive detector placed at the angle where the cross section has a minimum are in progress.

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(1) E. Lomon and R. Wilson, Phys. Rev. C9 (1975) 1329

(2) L. Amtén, L. Gönczi, A. Johansson, L. Nilsson and B. Sundqvist, TLU 26/74, Tandem Laboratory Report 1974

8.3 Neutron capture reactions in the giant resonance region

A. Lindholm and L. Nilsson
I. Bergqvist and B. Pålsson, Department of Physics, University of Lund
(Partly in collaboration with A. Likar, Institute Jozef Stefan, Ljubljana, Yugoslavia)

Our experimental efforts in the neutron capture field are at present being devoted to two types of activities; studies of the importance of compound-nucleus capture processes in the energy region below the giant dipole resonance and investigations of the role of semi-direct capture through the giant isoscalar quadrupole resonance.

Regarding the first activity, experiments for Si and S have been completed (1). The results are compared with calculations based on the semi-direct and compound-nucleus models. It is evident that the compound-nucleus process plays an important role in the energy region just below the giant dipole resonance, in some cases it is even dominant. Similar studies are being performed in Y and Ce.

The effect of semi-direct quadrupole capture is being investigated for nuclei near the closed neutron shell N=50, i.e. Sr and Y. Angular distributions of transitions to individual final levels show definite non-zero fore-aft anisotropies, which might be interpreted in terms of interference between multipole transitions of different parity, e.g. E1 and E2. The experimental data are compared with calculations based on the generalized semi-direct model (2), which includes capture wia the isoscalar quadrupole resonance.

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(1) A. Lindholm, L. Nilsson and I Bergqvist, TLU 35/75, Tandem Laboratory Report 1975

(2) M. Potokar, to be published

8.4 Fission cross section ratio measurements

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

(See 6.1)

8.5 Fission fragment angular distributions

C. Nordborg

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

(See 6.2)

8.6 Gamma ray production cross section of oxygen

C. Nordborg and L. Nilsson

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

(See 6.3)