KDK-15
NEANDC(OR)-150/U
INDC(SWD)-10/U

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN, APRIL 1977

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN

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Compiled by

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Stockholm, Sweden

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 nuclcar 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, activation analysis and astrophysics.

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 nuclcar 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.

CINDA Type Index of Neutron Cross Section Measurements

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Element S	A	Quantity	Type	Energy Min	Max	KDK-15 Page	Lab	Comments
D		DIFF ELASTIC	EXPT-PROG	1.0+7		42	TLU	AMTÉN+
LI	6	(n,α)	EXPT-PROG		<5.0+6	45	TLU	CONDÉ+ DETECTION OF CHARGED PARTICLES IN SCATT. CHAMBER
O		NONELASTIC γ	EXPT-PROG	7.0+6	1.0+7	31	FOA	NORDBORG+
AL		DIFF ELASTIC	EXPT-PROG	8.0+6		4	AE	RAMSTRÖM+ TOF DIFF-ELASTIC FROM 20^{o} TO 160^{o}
AL		DIFF INELASTIC	EXPT-PROG	7.0+6	8.0+6	4	AE	RAMSTRÖM+ TOF 35^{o} TO 150^{o}
CA	40	(n,γ)	EXPT-PROG	>3.5+6		43	TLU	BERGQVIST+ RESULTS COMP. TO DSD AND CN CALC.
V		DIFF INELASTIC	EXPT-PROG	7.0+6	8.0+6	4	AE	RAMSTRÖM+ TOF 35^{o} TO 150^{o}
FE		DIFF ELASTIC	EXPT-PROG	8.0+6		4	AE	RAMSTRÖM+ TOF DIFFELASTIC FROM 20^{o} TO 160^{o}
FE		DIFF ELASTIC	EXPT-PROG	7.0+6		5	AE	RAMSTRÖM+ TOF 20^{o} TO 174^{o} COMP WITH OPT. MODEL CALC.
CO		DIFF ELASTIC	EXPT-PROG	8.0+6		4	AE	RAMSTRÖM+ TOF DIFFELASTIC FROM 20^{o} TO 160^{o}
CO		DIFF ELASTIC	EXPT-PROG	7.0+6		5	AE	RAMSTRÖM+ TOF 20^{o} TO 174^{o} COMP WITH OPT. MODEL CALC.
NI		DIFF ELASTIC	EXPT-PROG	8.0+6		4	AE	RAMSTRÖM+ TOF DIFFELASTIC FROM 20^{o} TO 160^{o}
NI	59	(n,p)	EXPT-PROG	PILE	2.5-2	12	CTH	SJÖSTRAND+ REVISED THR VALUE 2.0±0.6 b

Element S	A	Quantity	Type	Energy Min	Max	KDK-15 Page	Lab	Comments
NI	59	(n,α)	EXPT-PROG	PILE	2.5-2	12	CTH	SJÖSTRAND+ REVISED THR VALUE 11.3±1.0 b
CU		DIFF ELASTIC	EXPT-PROG	8.0+6		4	AE	RAMSTRÖM+ TOF DIFFELASTIC FROM 20° TO 160°
GA	79	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
GA	80	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
GA	81	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
RB	85	(n,2n)	EXPT-PROG	1.4+7		23	LTH	ERLANDSSON+
RB	85	(n,p)	EXPT-PROG	1.4+7		23	LTH	ERLANDSSON+
RB	85	(n,α)	EXPT-PROG	1.4+7		23	LTH	ERLANDSSON+
RB	87	(n,2n)	EXPT-PROG	1.4+7		23	LTH	ERLANDSSON+
RB	87	(n,p)	EXPT-PROG	1.4+7		23	LTH	ERLANDSSON+
RB	87	(n,α)	EXPT-PROG	1.4+7		23	LTH	ERLANDSSON+
BR	88	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
BR	90	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
RB	94	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
RB	95	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
SR		(n,γ)	EXPT-PROG			43	TLU	BERGQVIST+ ANG. DISTR. OF GAMMAS
Y		(n,γ)	EXPT-PROG			43	TLU	BERGQVIST+ ANG. DISTR. OF GAMMAS
Y	89	(n,γ)	EXPT-PROG	6.0+6	1.6+7	43	TLU	BERGQVIST+ RESULTS COMP. TO DSD AND CN CALC.
IN		DIFF ELASTIC	EXPT-PROG	7.0+6		5	AE	RAMSTRÖM+ TOF 20° TO 174° COMP. WITH OPT. MODEL CALC.
IN		FISS PROD γ	EXPT-PROG			37	RCL	FOGELBERG+ DECAY OF IN ISOTOPES TO EVEN MASS SN ISOTOPES
IN	115	(n,γ)	EXPT-PROG	3.0+6		18	LTH	MAGNUSSON+ ACT TECHNIQUE

Element S	A	Quantity	Type	Energy Min	Max	KDK-15 Page	Lab	Comments
IN	115	(n,γ)	EXPT-PROG	3.0+6		18	LTH	MAGNUSSON+ ACT TECHNIQUE
IN	115	(n,γ)	EXPT-PROG	1.4+7		18	LTH	MAGNUSSON+ ACT TECHNIQUE
IN	129	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
IN	130	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
SN	122	SPECT (n,γ)	EXPT-PROG			34	SU	BESHAI+ ENERGY AND INT. OF GAMMA DECAY
I	127	(n,γ)	EXPT-PROG	1.4+7		18	LTH	MAGNUSSON+ ACT TECHNIQUE
I	138	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
I	140	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
XE	142	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
CS	142	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
CS	144	DELAYED NEUTS	EXPT-PROG			37	RCL	LUND+
CS	141	FISS PROD γ	EXPT-PROG			37	RCL	FOGELBERG+
BA	143	FISS PROD γ	EXPT-PROG			37	RCL	FOGELBERG+
LA	143	FISS PROD γ	EXPT-PROG			37	RCL	FOGELBERG+
LA	147	FISS PROD γ	EXPT-PROG	PILE		9	CTH	SKARNEMARK+ ON-LINE CHEM. SEP. TECH.
LA	148	FISS PROD γ	EXPT-PROG	PILE		9	CTH	SKARNEMARK+ ON-LINE CHEM. SEP. TECH.
CE	140	(n,γ)	EXPT-PROG	6.0+7		43	TLU	BERGQVIST+ RESULTS COMP. TO DSD AND CN CALC.
CE	149	FISS PROD γ	EXPT-PROG	PILE		9	CTH	SKARNEMARK+ ON-LINE CHEM. SEP. TECH.
CE	150	FISS PROD γ	EXPT-PROG	PILE		9	CTH	SKARNEMARK+ ON-LINE CHEM. SEP. TECH.
W	186	(n,γ)	EXPT-PROG	1.4+7		18	LTH	MAGNUSSON+ ACT TECHNIQUE
AU	197	(n,γ)	EXPT-PROG	3.0+6		18	LTH	MAGNUSSON+ ACT TECHNIQUE

Element S	A	Quantity	Type	Energy Min	Max	KDK-15 Page	Lab	Comments
AU	197	(n,γ)	EXPT-PROG	1.4+7		18	LTH	MAGNUSSON+ ACT TECHNIQUE
BI		DIFF ELASTIC	EXPT-PROG	7.0+6		5	AE	RAMSTRÖM+ TOF 20° TO 174° COMP. WITH OPT. MODEL CALC.
TH	232	FISSION	EXPT-PROG	5.0+6	1.0+7	30	FOA	NORDBORG+ REL TO U235 FISSION
U	234	PHOTO-FISSN	EXPT-PROG			27	LTH	ALM+
U	235	SPECT FISS N	EXPT-PROG	5.0+5		6	AE	JOHANSSON TOF SPECT FISS N
U	235	FISS PROD γ	EXPT-PROG	THR		7	AE	JOHANSSON+ DELAYED GAMMA AFTER FISSN
U	235	SPECT FISS N	EXPT-PROG	1.0+5		7	AE	ADAMS+ SPECTR AT LOW ENERGIES STUDIED
U	235	FISS PROD β	EXPT-PROG	PILE		37	RCL	ALEKLETT+ DECAY HEAT
U	236	FISSION	EXPT-PROG	5.0+6	1.0+7	30	FOA	NORDBORG+ REL TO U235 FISSION
U	236	PHOTO-FISSN	EXPT-PROG			27	LTH	ALM+
U	238	FISSION	EXPT-PROG	5.0+6	1.0+7	30	FOA	NORDBORG+ REL TO U235 FISSION
U	238	PHOTO-FISSN	EXPT-PROG			27	LTH	ALM+
U	238	(n,γ)	EXPT-PROG	3.0+6		18	LTH	MAGNUSSON+ ACT TECHNIQUE ENERGY DEP. 1-10 MeV

1. THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

Status report, Dec 75 - Dec 76

The Swedish Nuclear Data Committee has compiled and discussed nuclear data requests in relation to measurements, compilation and evaluation acitivities in progress. A special attention has been given to actinide data for use in burn-up calculations and nuclear waste problems. A subgroup with members from nuclear physics institutions at universities and national laboratories has been appointed to improve the coordination between requests and measurements. The group will screen the request lists and compile the progress reports.

International nuclear data activities at IAEA and OECD-NEA referred to national nuclear data groups for considerations have been discussed. Recommendations have been given concerning Swedish representation in international nuclear data meetings.

The Committee arranged the 19th NEANDC meeting in Stockholm on September 20-24, 1976, and in collaboration with AB Atomenergi the adherent topical discussion on Integral and Differential Afterheat Measurements.

Publications

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 Trans-actinium Isotope Nuclear Data, 3-7 November 1975, Karlsruhe (January 1976) (In Swedish)
KDK-12	Progress Report on Nuclear Data Activities in Sweden (April 1976)
KDK-13	KDK Annual Report 1975 (April 1976) (In Swedish)
KDK-14	Report from "Joint Technical Committee Meeting on Differential and Integral Nuclear Data Requirements for Shielding Calculations, 11-16 October, 1976, Vienna (November 1976) (In Swedish)
KDK-15	Peogress Report on Nuclear Data Activities in Sweden (April 1977)

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2.1 Neutron Physics Laboratory

2.1.1 Elastic Scattering of 8 MeV Neutrons

E. Ramström and B. Trostell

As a complement to earlier measurements performed at this laboratory differential cross sections for elastic neutrons scattering from Al, Co, Cu, Fe and Ni have been measured at an incident neutron energy of 8.0 MeV. All the examined elements had natural isotopic abundances.

The measurements were carried out by the TOF-technique in the angular region 20^{o} to 160^{o} in steps of 5^{o}. The D(d,n) ^{3}He-reaction was used as neutron source (gas target) and the relative efficiency of the detector was determined by hydrogen scattering. Analysis of the results is in progress.

2.1.2 Inelastic Scattering of 7.03 and 8.00 MeV Neutrons

E. Ramström and B. Trostell

Aluminium has been proposed as a suitable material for the construction of magnet coils in fusion reactors. These coils will be exposed to high neutron fluxes produced in the thermonuclear reaction T(d,n) ^{4}He. Accordingly, a thorough knowledge of the neutron cross section data for aluminium in the energy region up to 14 MeV is important.

Differential inelastic scattering cross section between 5.5 and 9.0 MeV determined in earlier measurements show discrepancies of the order of 25 per cent. The measurements in this investigation were therefore performed at neutron energies of 7.03 and 8.00 MeV.

Vanadium is also of current interest as a construction material in fusion reactors. The investigation was therefore extended to this element and the differential cross section for inelastic neutron scattering being measured in the angular region 35^{o} to 150^{o} by the TOF-technique. The D(d,n) ^{3}He-reaction was used as neutron source (gas target) and the relative efficiency of the detector was determined by hydrogen scattering. Analysis of the results is in progress.

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(1) E. Ramström, A compilation of existing experimental cross section data for elastic and inelastic neutron Scattering from Al, AE-FN-36, 1976.

2.1.3 A study of the spin-orbit term of the spherical optical model potential by large angle fast neutron elastic scattering angular distribution measurements

E. Ramström and T. Wiedling

Polarization angular distribution measurements are considered to be useful in studying the spin-orbit term of the optical model potential. However, with regard to the study of fast neutron scattering polarization effects, the experimental technique is not trivial and the precision is usually limited. The spin-orbit term can also be studied by the observation of neutron elastic scattering angular distributions at large angles. This is obvious from optical model calculations with a spherical potential which demonstrate that the inclusion of a spin-orbit term, as well as the choice of the numerical value of its depth, can cause quite drastic changes in the neutron elastic scattering angular distributions at backward angles. Consequently, the study of differential cross section distributions at these angles is potentially a sensitive method of testing the spin-orbit concept. In the present work differential cross sections have been measured for the elements Fe, Co, In, and Bi at an incident neutron energy of 7.0 MeV for scattering angles up to 174°. Comparisons between measured and calculated data show that the experimental cross sections for the elements studied are in good agreement with calculations using a potential depth for the spin-orbit term of 6 MeV for Fe and Co and of 4 MeV for In and Bi.

E. Ramström and T. Wiedling. A study of the spin-orbit term of the spherical optical model potential by large angle fast neutron elastic scattering angular distribution measurements. Proceedings of the International Conf of the Interactions of Neutrons with Nuclei. CONF-760715-P2, p. 1460.

2.1.4 The excitation function of the $^{13}C(\alpha,n)^{16}O$ reaction and its astrophysical application.

E. Ramström and T. Wiedling

Neutron-liberating reactions as well as neutron absorbing processes play important parts in the synthesis of elements in a star and in the different phases of its life sequence. Thus the $^{13}C(\alpha,n)^{16}O$ reaction is of interest for instance in connection with processes such as hydrostatic and explosive burning, as well as in the synthesis of oxygen and other light elements. A good knowledge of the energy dependence of the cross section of the alpha-carbon reaction is evidently of importance. In the present work the neutron yield from a thick ^{13}C target was measured for α-particles in the energy range 0.60 to 1.15 MeV with a sensitive 4π neutron detector. Stellar temperatures between 3.5 and 9.2×10^{8} °K are involved in this energy region. The observed neutron yield curve was used to determine astrophysical cross section factors S(E) as well as parameters for the 1.056 MeV resonance. Starting from these quantities, an expression for the mean lifetime of ^{13}C nuclei interacting with helium was derived.

E. Ramström and T. Wiedling, The excitation function of the $^{13}C(\alpha,n)^{16}O$ reaction and its astrophysical application. Nucl. Phys. A272 (1976) 259

2.1.5 An experimental study of the prompt fission neutron spectrum induced by 0.5 MeV neutrons incident on ^{235}U.

P.I. Johansson and B. Holmqvist

For purposes of reactor calculations there is a great need for accurate information on prompt neutron fission spectra of fertile and fissile isotopes. The aim of the present work was to make a precision measurement of the prompt fission neutron spectrum of ^{235}U at an incident energy of 0.53 MeV and to observe the emitted neutrons in an energy range as large as possible, i.e. from 0.6 to 15 MeV.

An analysis of the results of previous spectrum measurements of ^{235}U made by using the time-of-flight (TOF) method shows that essential improvements must be made as regards experimental techniques and procedures, in order to increase the precision of the measurement. Thus the following important parameters have been given particular attention in the present work: a) the neutron detector efficiency, b) the energy calibration of the time-of-flight spectrometer, c) the ability of the detector system to discriminate against gamma rays originating from $(n, n'\gamma)$, (n,γ) and fission fragment processes, d) detector shielding and counting statistics.

The shape of the ^{235}U prompt fission neutron energy spectrum observed in the recent experiment have been used to find a suitable distribution function describing the data in the entire energy interval. Distributions of the Watt or Maxwellian type proposed by Terrell have been tested for that purpose. It is clear from the experimental results that the Watt distribution gives the best description of the experimental data.

P.I. Johansson and B. Holmqvist, An experimental study of the prompt fission neutron spectrum induced by 0.5 MeV neutrons incident on ^{235}U, Nuclear Science & Eng. (in press).

2.1.6 Prompt fission neutron spectrum of ^{235}U

J.M. Adams* and B. Trostell

Current reactor experiments indicate the presence of more neutrons below $\sim$ 100 KeV than can be accounted for on the basis of the evaluated experimental data currently in use. The extrapolation of fast neutron fission spectra to below the energy range of the experimental data is therefore to be treated with a certain amount of caution. The work presented here is a continuation of earlier studies performed at this laboratory and at Harwell but with the aim more specifically directed to studying the low energy region ($E_n \geq 100$ KeV) of the prompt fission neutron spectrum from ^{235}U.

The measurements were performed with time-of-flight technique. All the electronic equipment used was of commercial standard** except for the discrimination system, where a new unit, developed at Harwell, was used. Three experimental runs were made with neutron flight paths of 300, 300 and 253 cm resp. The corresponding detector biases were 50, 50 and 30 KeV of neutron energy.

The fission neutron spectrum of ^{235}U was recorded at an incident neutron energy of 100 KeV from the $^7Li(p,n)\,^7Be$-reaction, using $\sim$ 10 KeV thick Li-metal targets. The fission-sample was a hollow cylinder, height 2.95 cm and outer diameter 1.80 cm, made with a thin wall of 0.15 cm, in order to reduce the attenuation and multiple scattering corrections. At a level slightly above that of the scattered 100 KeV neutron peak a signal to background ratio of 1.2 was achieved during operation with the lowest bias setting. Analysis of the results is in progress.

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** ORTEC

2.1.7 Measurement of decay energy released in thermal fission of ^{235}U

P.I.Johansson and G. Nilsson

The energy release from fission fragments within about 10^3 s after fission is a critical parameter for the design of emergency core cooling systems in reactors. During the first few seconds after reactor shut down the major energy development is due to fission induced by delayed neutrons. After about 10 s, however, the energy of γ- and β-radiation from fission products becomes dominant.

Measurements, performed at the Neutron Physics Laboratory, Studsvik, were aimed at studying the energy distribution and the total energy of γ-radiation emitted in the interval 10 - 1 500 s after thermal fission of ^{235}U.

Thermal neutrons for inducing the fission of ^{235}U by irradiation are generated in a 6 MeV van de Graaff accelerator, which can deliver proton beams at current strengths up to 100 μA. Fast neutrons produced in the $^{9}Be(p,n)^{9}B$-reaction are thermalized using a cube-shaped moderator of paraffin.

The number of fissions in the sample is determined by two independent methods. One is based on an absolutely calibrated fission chamber and the second on the measurement of the γ-ray intensity from fission fragments whose yield is known.

The γ-radiation from the fission products is measured with a NaI-crystal with a diameter and length of 12.5 cm. The irradiated samples are placed 40 cm in front of the well shielded detector. A collimator of diameter 5 cm and length 15 cm is placed between the sample and detector.

The analysis of pulse height spectra obtained by the NaI detector was performed by the COOLC-code provided by Oak Ridge Laboratory. The code uses measured response functions to unfold measured gamma spectra and assigns realistic confidence levels to the unfolded spectra.

P.I. Johansson and G. Nilsson, Nukleära resteffektdata. Fördröjd gammastrålning från ^{235}U, AE-FN-38 (1977)

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3.1 Department of Nuclear Chemistry

3.1.1 Studies of short-lived nuclides

G Skarnemark, K Brodén and J Rydberg*

An improved system (SISAK 2) for rapid, on-line radiochemical separations has been installed at the Mainz TRIGA reactor. This new equipment facilitates measurements of nuclides with half-lives down to 0.5 s.

Results ($T_{1/2}$, γ-ray data) have been obtained for 2.2 s ^{147}La, ~1 s ^{148}La, 6 s ^{149}Ce and 4 s ^{150}Ce. Previous results for $^{143-146}La$, $^{145-148}Ce$ and $^{147-150}Pr$ (γ-ray data including partial decay schemes) have been published in refs. 1 - 5.

Preliminary results (γ-ray energies, $T_{1/2}$, decay schemes) have been obtained for the neutron-rich Zr and Nb isotopes.

γ-γ angular correlation measurements are in progress for $^{144,146}La$, ^{148}Pr and isotopes of Tc, Zr and Nb.

In a near future, experiments on neutron-deficient isotopes of Nb, Zr and Y will be performed at GSI, Darmstadt. These experiments will include γ-ray singles and coincidence measurements, γ-γ angular correlation measurements and $T_{1/2}$ determinations.

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2. G. Skarnemark, E. Stender, N. Trautmann, P.O. Aronsson, T. Björnstad, N. Kaffrell, E. Kvåle and M. Skarestad. Decay Properties of Some Neutron-rich Praseodymium Isotopes. Radiochim. Acta. 23 (1976) 98
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5. G. Skarnemark, A Study of Some Neutron-rich Isotopes of Lanthanum, Cerium and Praseodymium by means of the Fast, On-line Chemical Separation Technique SISAK, Thesis, Chalmers University of Technology, Göteborg 1977

* The work is performed in collaboration with T. Björnstad, Oslo, and N. Kaffrell, E. Stender and N. Trautmann, Mainz.

3.2 Department of Physics

3.2.1 High spin states of ^{85}Sr and ^{87}Zr.

S E Arnell, G Finnas[x], A Nilsson[xx], S Sjöberg,
Ö Skeppstedt and E Wallander

In a rather extensive program for investigation the structure of nuclei near ^{88}Sr, which has a closed neutron shell, N=50, and a closed proton subshell, Z=38, the structure of ^{87}Sr, ^{88}Sr and ^{89}Sr has earlier been studied[1]. New information on high spin states of the nuclei ^{85}Sr[2] and ^{87}Zr is now available from (α,xnγ)-studies. The experiments have been performed with α-beams from the cyclotrons in Stockholm and Åbo, Finland and from the tandem accelerator in Uppsala. The project is now continued with studies of still more neutron deficient nuclei.

References:

1. S.E.Arnell, A.Nilsson and O.Stankiewicz, Nucl. Phys. A241 (1975) 109.

2. S.E.Arnell, G.Finnas, A.Nilsson, S.Sjöberg, Ö.Skeppstedt and E.Wallander, Nucl. Phys., in press.

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3.2.2 Nuclear Spins and Moments

C Ekström, M Gustavsson, I Lindgren, A Rosen and
H Rubinsztein

Our program of nuclear spin and moment determinations is now concentrated mainly to the activities at CERN[x]. The experimental part concerns measurements on nuclei far from stability, using the ABMR apparatus connected on-line with the isotope separator at the ISOLDE facility. The first results were obtained with this equipment in July 1975, using conventional off-line techniques. When the on-line oven system was brought into operation in December 1975, the experimental procedure became highly facilitated and a more efficient use of the beam-time could be made.

The target system used in the production runs at ISOLDE have been concentrated to those giving the heavier alkali elements and mercury. The alkali elements rubidium, cesium and francium, and gold (daughter product of mercury) are particularly suited for atomic-beam experiments, and the atomic-beam group has performed an extensive systematic study of these elements. Altogether 31 spins and 8 magnetic moments have been determined. The new spin values are collected in Table 1. These measurements have revealed a new isomer in ^{121}Cs.

Table 1. Nuclear spin results obtained at CERN

Rb	A =	77	78	78m	79	84m						
	I =	3/2	0	4	5/2	6						
Cs	A =	120	121	121m	122	122m	123	124	126	128	130m	135m
	I =	2	3/2	9/2	1	8	1/2	1	1	1	5	19/2
Au	A =	185	186	187	188	189	189m					
	I =	5/2	3	1/2	1	1/2	11/2					
Fr	A =	208	209	210	211	212	213	220	221	222		
	I =	(7)	9/2	6	9/2	5	9/2	1	5/2	2		

In Göteborg spin measurements on radioactive isotopes of refractory elements have been performed for some time, using the ABMR technique, a project that is now essentially completed. A determination of the nuclear magnetic moment of ^{99}Mo is in progress. Spin measurements have also been performed on the radioactive lead isotopes, ^{201}Pb and ^{203}Pb, in metastable atomic states. The atomic ground state is here diamagnetic and cannot be used in an ABMR experiment[1].

Reference:

1. M.Gustavsson, I.Lindgren, J.Lindgren, A.Rosén and H. Rubinsztein, Hyperfine-structure measurements in metastable atomic states - Nuclear spins of ^{201}Pb and ^{203}Pb, in manuscript.

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x) These experiments are performed in collaboration with S.Ingelman and G.Wannberg, Uppsala and M. Skarestad, CERN.

3.2.3 Production and use of monoenergetic neutron beams in the epithermal and intermediate energy region

N Ryde, W Klamra and N Olsson

The facility erected in one of the radial beam holes of the R2-reactor at Studsvik is intended to solve a variety of problems in nuclear physics, reactor technology, astrophysics, genetics and health physics. At present the facility only contains a source of 24 keV neutrons from a beam extracted from the reactor and passed through a filter. Planned extensions of the facility to other neutron energies could as yet not be realized due to lack of funds.

During the last year the facility has been provided with a proton recoil detector, especially intended for monitoring the amount of neutrons of not desired energies in the beam. Above all for genetic research the content of high energy neutrons in the beam must be kept at a low level. During 1976 a series of measurements on detectors for reactor physical use has been performed in the 24 keV beam by the instrumental division of the Atomic Energy Company.

For next year the facility will be used mainly for research in genetics and health physics. The genetic influence of the 24 keV neutrons on barley will be studied by irradiation of grains, in cooperation with Professor L.Ehrenberg at the Wallenberg Laboratory, Stockholm, and Dr. R.Bergman, AB Atomenergi, Studsvik.

The penetrability of intermediate energy neutrons through human tissue makes them suitable for irradiation of human organs into which heavy metals are enriched. A method to measure the degree of enrichment is being developed in collaboration with Yrkeshygienska Institutionen at Karolinska Institutet, Stockholm and AB Atomenergi.

3.3 Department of Reactor Physics

N G Sjöstrand

3.3.1 Cross sections for charged particle production in Ni isotopes

To investigate the reason for the high value of the cross section for the (n, α) reaction in Ni-59 the Ni-59 sample was measured in a thermal neutron beam at the reactor of the Laue-Langevin institute in Grenoble. A considerably lower result was then obtained. Therefore, the Li sample used as a reference was also checked. It turned out that the amount of Li-6 in the sample was incorrectly determined, probably at the fabrication. In the scale of the Grenoble cross section standard the new value of the 2200 m/s (n,α) cross section of Ni-59 is now 11.3 ± 1.0 barn in good agreement with most other measurements. The (n, p) cross section is similarly reduced to 2.0 ± 0.6 b.

Reference: M. Asghar, A. Emsallem and N. G. Sjöstrand, Thermal neutron induced charged particle reactions on ^{58,59,61}Ni. (To be published)

3.3.2 Acquisition of new neutron generator

A new neutron generator is planned to be installed in the beginning of 1978. It will give 2 mA deuterium ion current at 400 kV running continuously, and pulses down to 1 ns length. Research in fast reactor physics, nuclear chemistry, nuclear physics and radiation physics is projected.

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

4.1 Accelerator Physics

H Tyrén

Subject to certain conditions the improvement program of the synchrocyclotron has now been approved by the Government. As a consequence work on the reconstruction of the accelerator has continued at a gradually increasing level of activity. A Board responsible for the project has been elected and has agreed on a plan for the rebuilding of the synchrocyclotron. It recommends that the project shall be supervised by GWI and performed in a collaboration between GWI, CERN and Instrument AB Scanditronix, Uppsala. Plans for new laboratory and office space and of a computer installation for the enlarged institute have also been worked out. The major improvement of the synchrocyclotron 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 frequences 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.

To use the full beam (e.g. 10 μA protons) it has been suggested to use a thin absorber, 1.2-1.8 MeV, with a 1-2 mm slit. The attenuated part of the beam will be separated from the transmitted beam with the aid of a bending magnet and can be used for continous isotope production.

In the new experimental area of about 500 m^2 the following beam facilities will be available:

1. Beams with an energy resolution of 0.03% FWHM for physical and biological experiments. Radiation protection sets an upper limit of 1 μA for the intensities.

2. A high intensity beam for an on-line device for isotope separation.

3. A secondary neutron beam produced in the forward direction via the reaction D(p,n)2p. The beam intensity will be 10^7-10^8 n/s with an energy spread of about 6 MeV FWHM.

4. A polarized proton beam with 10^7 p/s produced in elastic scattering of protons from ^{12}C. The energy spread of this beam will be about 0.8 MeV FWHM.

Shut-down took place at the end of 1976 and demounting of the machine is in progress.

4.2 Cyclotron-produced radionuclides for biomedical use

H Lundqvist, P Malmborg and C-G Stålnacke

High energy accelerators (proton energy 50 MeV) have specific advantages in nuclide production. The high energy often permits the choice of production reactions, for example spallation, which give high yield and low contamination. One aim of the present work is 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 procedure should also determine the choise of production technique. The short-lived nuclides often demand special fast and simple chemical routines.

The production program of 1976 is outlined in table 1. Despite the low current in the old synchrocyclotron (<1.5 μA protons in the internal beam) and several malfunctions reducing the available beam time of 1976, a routinary production of ^{11}CO, $^{11}CO_2$, ^{15}OO, $H_2{}^{15}O$, $^{28}Mg^{++}$, ^{123}I and $^{203}Pb^{++}$ has been carried on for development of synthetic procedures and for different biological and medical applications. The production of medical radionuclides (mainly ^{123}I and ^{28}Mg) was intensified to complete the different series of patient investigations performed in collaboration with clinical departments before the cyclotron shut-down (end of 1976). The work with the short-lived radionuclides will be continued at the tandem accelerator in Uppsala with a recently constructed gas target system.

To optimize the yield and the radionuclidic 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 have been undertaken on the reactions marked with an asterisk in table 1. 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. The following reports cover part of the work (1,2).

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(1) Suparb Na Chiengmai, H Lundqvist and P Malmborg, Production of Krypton Isotopes by (p,xn) reactions on Bromine. GWI-R 11/76 (1976)

(2) H Lundqvist and P Malmborg, Production of carrier-free ^{28}Mg and ^{24}Na by 50-180 MeV protons on Si, P, S, Cl, Ar and K. Excitation functions and chemical separation. To be published.

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	Biomedical application (Collaborators)
	$^{11}CO_2$	B_2O_3	20	$^{11}CO_2$	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)
		H_2O	70	$^{11}CO_2$		
		N_2 + + 4% O_2	12	$^{11}CO_2$		
	^{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.
	$H_2{}^{15}O$	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 (univ Hosp Uppsala)
	$^{52}Fe^{++}$	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)
*)	$^{122}I^-$	NaI	90	^{122}Xe	Target dissolved in H_2SO_4 (10 %) + + Zn, evolved H_2 carrier 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). Function of transplanted kidneys (Univ Hosp, Huddine) Labelling of starch beads
*)	$^{123}I^-$	NaI	68	^{123}Xe		
*)	$^{125}I^-$	NaI	40	^{125}Xe		
*)	^{127}Xe	NaI	20	^{127}Xe		
*)	$^{201}Tl^+$	Tl	28	^{201}Tl	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).
*)	$^{203}Pb^{+++}$	Tl	28	^{203}Pb		

*) Excitation function studies in progress.

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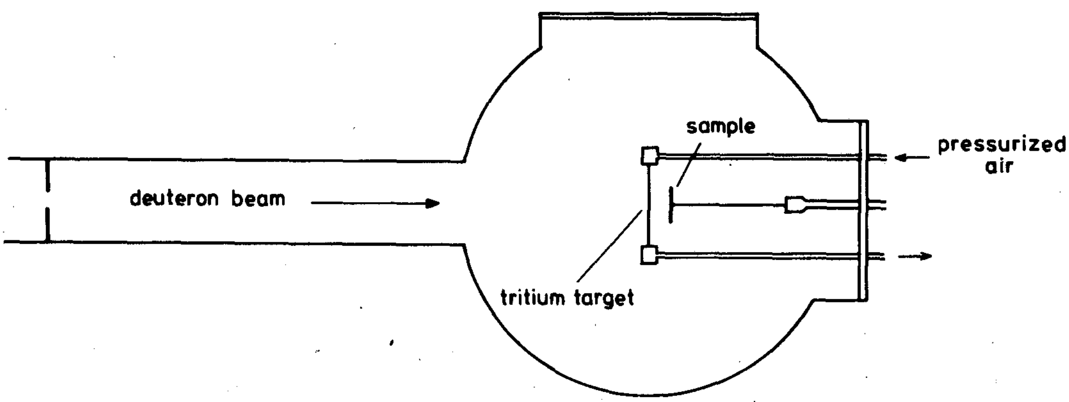
5.1 Department of Nuclear Physics - Pelletron Group

5.1.1 Neutron Capture Cross-Section Measurements with Improved Activation Technique

G Magnusson, P Andersson, I Bergqvist

A set of measurements of the radiative capture cross-section of 14.7 MeV neutrons for several nuclei from ^{55}Mn to ^{238}U with the improved activation technique (1,2) are in progress. Only the measurements for the ^{115}In(n,γ)^{116m}In reaction have been concluded.

The method involves neutron irradation for the sample in a vacuum chamber made of thin-walled aluminium. This permits a considerable reduction of material around the tritium target and a corresponding reduction of the secondary neutrons. The vacuum chamber with the target-sample arrangment is illustrated in the figure.



To determine the accuracy which can be obtained, the reaction ^{115}In(n,γ)^{116m}In has been used. The results indicate that neutron capture cross-sections at 14-15 MeV can be determined to within some 10 % and sometimes even better depending on the decay and half-live of the produced nuclei. A report on the method and its application to the ^{115}In(n,γ)^{116m}In reaction has been prepared for publication.

Preliminary results have been obtained for activation cross-sections at 14.7 MeV for ^{127}I, ^{186}W and ^{197}Au:

Reaction	Cross-section (mb)
$^{115}In(n,\gamma)^{116m}In$	0.83 ± 0.06
$^{127}I(n,\gamma)^{128}I$	0.9 ± 0.1
$^{186}W(n,\gamma)^{187}W$	0.9 ± 0.2
$^{197}Au(n,\gamma)^{198}Au$	1.2 ± 0.4

In addition neutron capture cross section measurements are in progress to investigate the influence of secondary neutrons in the neutron energy range 1-10 MeV.

The experiments have been initiated with 3 MeV neutrons for the reaction $^{115}In(n,\gamma)^{116m}In$. The energy dependence of the following reactions is also going to be studied: $^{197}Au(n,\gamma)^{198}Au$ and $^{238}U(n,\gamma)^{239}U$.

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(1) G Magnusson, I Bergqvist: Annual Report 1975

(2) G Magnusson, I Bergqvist, to be published

5.1.2 Nucleon Capture Reactions in the Giant Resonance Region

I Bergqvist and B Pålsson
A Lindholm and L Nilsson, Tandem Accelerator Laboratory, Uppsala

a) Spectrum measurements

(Partly in collaboration with Andrej Likar, Institute Jozef Stefan, Ljubljana, Yugoslavia)
(See 10.3)

b) Activation measurements

Very little data exist on the excitation functions for nucleon capture over the entire giant dipole region (GDR). Excitation functions give essential information for the understanding of the capture process.

In this experiment, the reaction $^{176}Yb(p,\gamma)^{177}Lu$ has been studied for proton of energies from 6 to 24 MeV. Measurements have been performed at the Tandem Accelerator Laboratory, Uppsala, The Niels Bohr Institute, Risø, Denmark and at Chalk River Nuclear Laboratories, Chalk River, Canada. The decay of ^{177}Lu was identified by the keV gamma transition in ^{177}Hf ($9/2^+$ to $9/2^-$) using a high-resolution gamma-ray spectrometer.

In addition to the activation measurements, we have studied the direct γ-ray spectrum following proton capture in ^{176}Yb for proton of energies from 6 to 11 MeV at the tandem in Uppsala. Since the level density in ^{177}Lu is large, only the total integrated cross-section (at 90°) has been evaluated from the spectra. Interference from background γ-rays sets a lower part limit to the cross-section evaluation of about 7 MeV proton energy.

The results from the two types of measurements are in good agreement, as can be seen from the figure. The cross-section increases with increasing proton energy, E_p, to about 0.6 mb at E_p = 13 MeV and drops off at higher energies. The peak energy E_p = 13 MeV corresponds to an excitation energy of about 19 MeV. The two components of the GDR are expected to occur at 12.4 and 15.15 MeV. The results are in good agreement with results (3) on proton capture in the spherical nucleus ^{142}Ce.

A report is being prepared.

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(1) A Lindblom, L Nilsson, I Bergqvist, B Pålsson, to be published in Nuclear Physics

(2) I Bergqvist, D M Drake, D K McDaniels, Nuclear Physics A231 (1974) 29

(3) E V Verdieck, J M Miller, Phys Rev 153 (1967) 1253

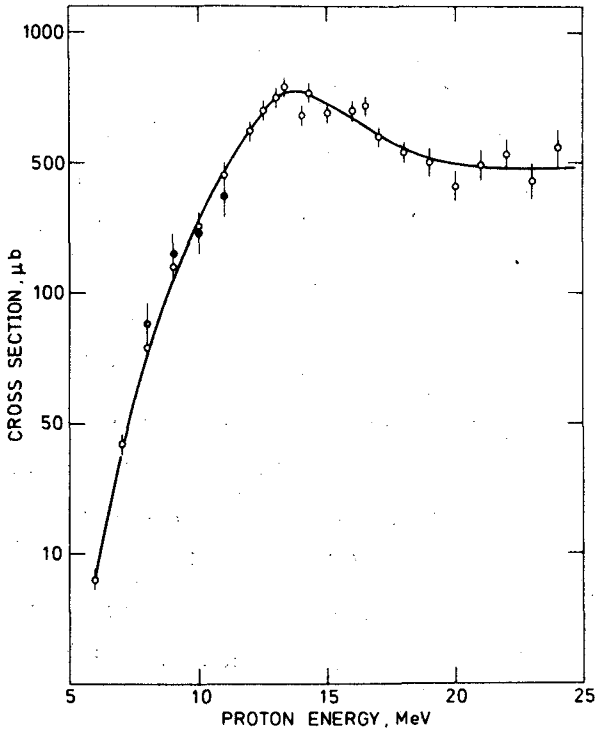

FIGURE The excitation function for the reaction $^{176}Yb(p,\gamma)^{177}Lu$. Open circles represent the activation cross-section and filled circles the cross-section deduced from γ-ray spectra

5.1.3 Coulomb Fission

D Haks[1], V Metag[1], J Schuhkraft[1], H J Specht[1], C-O Wene

In 1966, Wilets, Guth and Tenn (1) suggested that an actinide nuclide like uranium might be distorted in the Coulomb field of a heavy ion and "slowly carried over the fission barrier with little internal excitation". Several (2-3) authors have discussed this possiblitlity of "cold" direct fission, which should go much faster, 10^{-20} s, than normal "prompt" fission, 10^{-16}-10^{-17} s. According to different theoretical estimates, Coulomb fission should leave two types of "fingerprints" which could be used to identify this fission mode

1. A strong peaking in the angular distribution around 90° (CM)
2. Destructive interference between Coulomb- and Yukawa fission around the fission barrier which should show up in the excitation function.

[1] Heidelberg

The Kr-Th, Kr-U, Xe-Th and Xe-U excitation functions around 90^{o} (CM) have recently been measured at Berkeley (2) but, in this experiment, the suggested effect was not observed. The authors suggest that the observed increase in the excitation function for X-U compared to the others could be due to Coulomb fission, but this shift could also be explained by neutron transfer fission.

An experiment has been set up at UNILAC in Darmstadt in order to investigate fission below the Coulomb barrier. With the present experimental arrangement, in which a <u>thin</u> U-target is used, it is possible to measure the fission cross-section both at 0^{o} (CM) and around 90^{o} (CM), as well as the angular distribution around 90^{o} (CM). Runs have been made with ^{136}Xe at 4.5, 4.7, 4.9, 5.1, 5.5 and 5.9 MeV/nucleon (lab).

The analysis of the results is under way.

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(1) I Wilets, E Guth, J S Tenn: Phys Rev <u>156</u> (1967) 1349

(2) K Beyer, A Winther: Phys Lett <u>30B</u> (1969) 296

(3) H Hahn, W Greiner: Nucl Phys <u>A195</u> (1972) 333

(4) P Colombani, P A Buther, I Y Lee, D Cline, R M Diamond, F S Stephens: Phys Lett <u>65B</u> (1976) 39.

5.1.4 <u>A Study of the Structure of the ^{65}Cu Nucleus by the Average Resonance Spectroscopy Method</u>

B Erlandsson, A Marcinkowski, K Nilsson

The (p,γ)-reaction on ^{64}Ni was studied in the energy range 1.9 - 3.0 MeV using a Ge(Li)-detector. The energy range was equally covered with 55 spectra. The spectra were added together to get 6 average spectra. The intensities of 12 gamma-transitions to low-lying levels of the final nucleus were determined, divided by $E^{5.3}$ for each average spectrum and then added.

The results point to the existence of correlations between the intensity of high-energy gamma transitions and the spins and parities of final states populated by these transitions.

E_x	J^π	$I_\gamma/E_\nu^{5.3}$
0	$3/2^-$	305
771	$1/2^-$	185
1115	$5/2^-$	155
1482	$7/2^-$	117
1624	$5/2^-$	179
1725	$3/2^-$	308
2093	$7/2^-,5/2^-$	88
2105		238
2212	$1/2^-,3/2^-$	215
2280	$7/2^-,5/2^-$	171
2328	$3/2^-$	381
2531		205
2533		

If such a correlation exists, the 2093 and 2280 keV levels should have spins and parities $7/2^-$ and $5/2^-$.

5.1.5 The Decay of the Metastable State in ^{84}Rb and Certain (n,2n), (n,α) and (n,p) Cross-Sections

B Erlandsson, A Marcinkowski, K Nilsson

Natural rubidium consists of ^{85}Rb and ^{87}Rb and when bombarded with 14 MeV neutrons the following reactions can take place: ^{85}Rb(n,2n)^{84}Rb, ^{85}Rb(n,α)^{82}Br, ^{85}Rb(n,p)^{85}Kr, ^{87}Rb(n,2n)^{86}Rb, ^{87}Rb(n,α)^{84}Br, and ^{87}Rb(n,p)^{87}Kr. The 464 keV metastable-state in ^{84}Rb decays to the ground-state with a half-life of 20 min and the ground-state decays both to excited levels and the ground state of ^{84}Kr by β^+ and EC with a half-life of 33 days.

We have investigated the gamma-ray decay of certain excited levels in ^{84}Kr which may be fed by EC from the 464 keV level in ^{84}Rb. These levels are also fed by β^- decay from a metastable ($T_{1/2}$=6 min) state and the ground-state ($T_{1/2}$=32 min) in ^{84}Br which are formed by the ^{87}Br(n,α)^{84}Br reaction.

Since last year, we have irradiated Rb_2CO_3 samples at the 42 MeV betatron in Malmö General Hospital (adjusted to 20 MeV maximum gamma energy in order to produce ^{84}Br). We have determined an upper limit of 2×10^{-3} for the two gamma lines of energies 1464 and 1213 keV from excited states in ^{84}Kr. These spins have spins and parities which make them possible as end-states in an assumed β^+ dacay from the metastable state in ^{84}Rb.

We have also tried to determine the cross-section (reported in last year´s annual report) with a mixed powder technique, but no large difference has been observed.

5.1.6 Measurements of Atmospheric ^{85}Kr Activity

B Erlandsson, J Grintals

The strength of the radioactive isotope ^{85}Kr in the atmosphere is increasing. This is mainly due to the increasing number of nuclear power-plants.

Krypton is extracted from the atmosphere with a selective molecular sieve and ^{85}Kr measured with a spectrometer consisting of a pancake-shaped GM-tube. Coupled to this tube is a plastic scintillator working in anti-coincidence with the GM-tube.

5.1.7 Detection of ^{9}Be in Environmental and Biological Samples

Å Steen

Nuclear Techniques for the detection of trace element quantities of ^{9}Be in environmental and biological samples have been investigated. A literature search has been made for suitable nuclear reaction using p, d, α, n and photons as incoming particles. The reactions ^{9}Be(p,αγ)^{6}Li, ^{9}Be(d,nγ)^{10}Be, ^{9}Be(α,nγ)^{12}C and ^{9}Be(γ,n)^{8}Be seem to be usable for ^{9}Be concentrations in the order of ppm.

Experimentally, the possibility $^{9}Be(p,\alpha\gamma)^{6}Li$ has been tested at the resonance which occurs for E_p = 2.567 MeV with a width of 39 keV and a cross-section of 110 mb. A Ge(Li) detector was used to detect the gamma-ray of energy 3.561 MeV for ^{6}Li.

Although the detection limit does not seem to be below 1 ppm for this reaction, it might be useful to establish an upper limit for the ^{9}Be concentration in the range 1-20 ppm during conventional PIXE analyses just by monitoring the 3.561 MeV gamma-ray in a suitable detector. An internal report describing the project in detail will shortly be forthcoming (in Swedish).

5.1.8 Pelletron Accelerator

R Hellborg, K Håkansson, C Nilsson
B Pålsson (part-time)

The installation and acceptance tests of the new accelerator were completed late in 1975.

The total running-time for the first year (nine months only) has been 1605 hours. Beams of protons, deuterons and oxygen ions have been available.

A pulsed ion beam design with a 1-2 nanosec pulse-width and a duty cycle of 10% maximum repetition rate is under construction. The repetition rate will be variable up to 5 MHz.

Test bench runs are planned for early 1977.

5.2 Department of Physics - Photonuclear Group

5.2.1 The (γ,p) Reaction in ^{30}Si, ^{68}Zn and ^{130}Te at Intermediate Energies

B Bülow, B Johnsson, M Nilsson

The yields of the (γ,p) reaction on ^{30}Si, ^{68}Zn and ^{130}Te have been measured as a function of the bremsstrahlung endpoint energy, in the energy range 75 - 800 MeV, using activation analysis. The number of valence nucleons taking part in the reactions has been deduced and compared to shell model calculations and the cross-sections have been calculated and compared to results obtained using a knock-out formalism. The final complementary calculations are being carried through at present and the work will be finished during the spring.

5.2.2 The (γ,2n) Reaction in ^{12}C and ^{16}O at Intermediate Energies

B Johnsson, M Nilsson, K Lindgren

The yields of the reactions $^{12}C(\gamma,2n)^{10}C$ and $^{16}O(\gamma,2n)^{14}O$ have been measured as a function of maximum bresstrahlung energy from about 100 to 800 MeV by the activation method. The cross-sections are deduced and compared with cascade-evaporation calculations, cross-sections for the (γ,n) reaction and results from particle-induced reactions.

This work has been accepted for publication in Nuclear Physics A.

5.2.3 Calculation of the Relative Cross-Section of Light Fragments Photoproduced from Targets in the Mass Range A = 63 to 238

A Järund, B Forkman

The photoproduction of ^{24}Na from targets with $27 < A_T < 238$ has recently been studied. The mean cross-section in the energy-range 400 to 1000 MeV decreases exponentially with increasing target mass number up to 63, whereafter its rate of decrease first becomes smaller, goes through a minimum around 100 and then increases slightly above 100. During the year, calculations have been performed to reproduce the behaviour of the mean cross-section in the mass range 63 to 238, ^{24}Na being supposed to be produced through fission processes. The probability-rate of fission to neutron evaporation has been calculated and used in the Monte Carlo program of Gabriel and Alsmiller (Oak Ridge National Laboratory ORNL-TM-2481, 1969). In the same computer run, the relative probabilities of production of several light fragments were calculated. The calculations will be completed during spring-77.

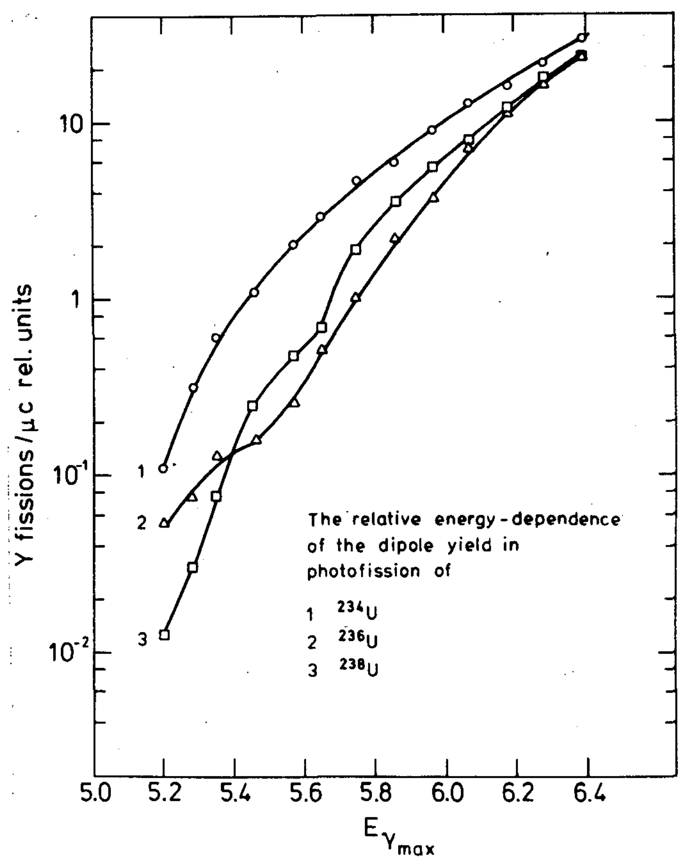
5.2.4 Photofission of ^{234}U, ^{236}U and ^{238}U in the Subbarrier Region

A Alm, L-J Lindgren, A Sandell

The experimental part of this work is now completed. Automatic track-counting has been used in the ^{238}U part of the experiment. The building and testing of the automatic counting-unit was finished during the summer. As a result we have now a method which gives us greater reliability and is time-saving, compared with manual track-counting. We are now analysing the ^{234}U and ^{238}U results by comparison with theoretical predictions from a parametrisized double-hump barrier, in the same way as in our ^{236}U work (Nucl Phys A271 (1976) 1-14). The experimental results show large differences between the yields.

In the figure the dominating dipole-channel yields are shown. During the year, we have prepared a similar experiment on Th. The aim of this experiment is particularly to investigate the quadrupole-component of the angular distribution. To make this successful, we need a refined technique since the quadrupole-component is small for Th.

The experiment will be run partly in an extracted beam and for this purpose a fission chamber is being built.



5.2.5 An Experimental Study of Binary Fission Induced by 600 MeV Protons in U, Bi, Tb, La, Ag, Y and Cu.

G Andersson, M Areskoug, H-Å Gustafsson,
E Hagebø[1], G Hyltén, B Schrøder

In this experiment, we aim to study the binary fission of some medium-heavy elements in order to obtain information about:

(i) the fission cross-section

(ii) the mass and kinetic energy distributions of the products.

For control purposes, two heavy elements are included in the study. The problems of physical interest are:

(a) the fission barrier heights for medium heavy elements

(b) the possible existence and location of the Businaro-Gallone limit, below which the saddle point loses its stability against asymmetric deformations.

In current theoretical predictions, these quantities differ considerably.

The investigation is being performed at the 600 MeV proton synchro-cyclotron at CERN, Geneva.

Measurements have resulted in fission cross-sections of (1.9±0.2) mb and (1.0±0.3) mb for Tb and Ag respectively, measured relative to uranium (σ_F = 1.3±0.13 b).

The mass distributions were found to be symmetric but rather wide. Thus, the FWHM is about 70 amu for Tb and 50 amu for Ag. So far, we have seen no indication of the Businaro-Gallone point.

Preliminary results for Tb and Ag have been published in Physics Letters 64B (1976) 421.

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[1] Department of Chemistry, University of Oslo, Blindern, Oslo 3, Norway

5.2.6 100 MeV microtron/pulse stretcher system (MAX)

O Cederholm, M Eriksson, J Grintals, L Hansson,
L-G Johansson, L Persson, W Stiefler and L Thånell

The construction work on the high-duty-factor electron accelerator system MAX, composed of a 100 MeV race-track microtron and pulse-stretching storage ring, has continued.

During the year, the following work on the microtron has been carried out:

(1) The acceleration linac has been tested and adjusted. The linac can easily give the required energy gain.

(2) A new beam-position monitor has been constructed.

(3) The 180^{o}-bending magnets and their power-supply have been constructed. The magnet fields are of the desired quality and no major corrections need to be carried out.

(4) New pulse-modulators, to give a high repetition rate, and parts of the vacuum system are being constructed.

For the stretcher, calculations have been made of the effect of inserting a Wiggler magnet system into one of the straight sections. The Wiggler consists of three wedge-shaped magnets. The bending radius in the centre-magnet would be 16 cm. For 100 MeV electrons, this is sufficient to give synchrotron radiation down to about 200 Angstrom.

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.

The corrections which are necessary to apply to the measured data have been studied very carefully, being of the order of 3%. Corrections have been made for incident neutron spectrum, anisotropy of the fission fragment angular distributions, detector efficiency and bias losses, deposited material and isotopic composition and scattering effects.

Final data have been produced for the ratio of $^{238}U/^{235}U$ fission cross sections (1). Additional measurements for ^{236}U and ^{232}Th are in progress as a complement to the earlier obtained data.

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(1) C Nordborg, H Condé and L G Strömberg, Proceedings of the NEANDC/NEACRP Specialist meeting on Fast Neutron Fission Cross Sections of ^{233}U, ^{235}U, ^{238}U and ^{239}Pu, p 128, NEANDC(US)-199/L (1976)

6.2 Fission fragment angular distributions

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H Condé and L G Strömberg

The fission-fragment angular distributions have been measured at four neutron energies in the range 5 to 10 MeV for $^{235,236,238}U$ and ^{232}Th at the tandem accelerator at Uppsala with the two-fold purpose to be able to correct the observed fission cross section data and to obtain more information about the reaction mechanism.

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 anistropy 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 production cross section of oxygen has been measured at incident neutron energies between 7 and 10.5 MeV. The production of the 6.13, 6.92 and 7.12 MeV gamma rays by the $(n,n'\gamma)$ reaction in ^{16}O and of the 3.09, 3.68 and 3.85 MeV gamma rays by the $(n,\alpha\gamma)$ reaction has been studied. In addition, the production cross section of the 4.44 MeV gamma ray from inelastic neutron scattering on carbon has been measured at one neutron energy, since many earlier measurements of gamma ray production cross sections have been performed relative to this cross section.

Monoenergetic neutrons were produced by the $^{2}H(d,n)^{3}He$ and $^{3}H(p,n)^{3}He$ reactions. The gamma radiation was detected by a large NaI(Tl) scintillator using time-of-flight techniques. The neutron flux was mesured by means of a proton-recoil telescope using the n-p scattering cross section. The differential gamma ray production cross sections at 90^{o} and angular distribution at one neutron energy were measured.

The results for oxygen, which show pronounced structure of the cross section over the whole energy region, are in disagreement with current data files, whereas the results for carbon are in agreement with a number of recent investigations of the $^{12}C(n,n'\gamma)^{12}C$ and $^{12}C(n,n')^{12}C$ reactions. The absolute errors of the results were estimated to be about 10% and the neutron energy resolution about ±50keV. As a consistency check of the neutron flux measurement, a separate measurement was made of the $^{27}Al(n,\alpha)^{24}Na$ cross section was calculated to be 55± 6 mb in agreement with previous measurements.

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A Nilsson

Most of the work in nuclear physics has been concentrated on investigations on states of very high angular momentum which have been populated in heavy ion reactions. To meet the need of these investigations the 225-cm cyclotron at the institute has been improved and is now capable of delivering α-particles with energies in the range 40-60 MeV and 120 MeV ^{12}C ions (accelerated in the 4^+ state). A new experimental hall to the 225-cm cyclytron is being built. The installation of beam-handling and experimental equipment is scheduled to commence in August 77. The first beam to the new experimental area is expected to be delivered during the first quarter of 1978. The operation of the 80-cm cyclotron is scheduled to be discontinued in March 1977.

In applied nuclear physics studies have been made on the production of short-lived radionuclieds for medical applications (^{15}O, ^{123}I and ^{81m}Kr) and on proton induced X-ray analysis of archeologic findings and paintings.

In connection with the atomic and molecular physics program at the institute a program has been initiated to study first-wall ion irradiation in fusion reactors, Thus, sputtering yields for He^+ and Ar^+ bombarding different materials in the energy range 10-120 keV, depth distributions of elemental species in various materials and heavy surface rupture effects in Al induced by 40 keV He^+ bombardment have been studied.

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8.1 Institute of Physics

8.1.1 The decay of ^{123}Sn

S Beshai, L-E Fröberg, L Gidefeldt and B Sundström

The ^{123}Sn decay has been investigated by use of high-resolution solid state detectors in single and coincidence measurements. The activity was produced by the irradiation of enriched ^{122}Sn (92 %) by thermal neutrons. The following gamma energies and intensities were obtained

energy keV	intensity
58.5 (2)	0.45 (5)
160.5 (2)	3.02 (16)
1021.01 (5)	3.16 (11)
1030.26 (5)	51.9 (16)
1088.67 (5)	1000.
1100.3 (4)	0.077 (21)
1177.1 (2)	0.39 (3)
1181.4 (3)	0.51 (9)
1260.8 (4)	< 0.1
1337.44 (7)	1.22 (6)

8.1.2 Angular correlation measurements in ^{131}Xe

Chr Bargholtz, S Beshai and L Gidefeldt

A 12-channel goniometer has been used to measure five γ-γ cascades in ^{131}Xe appearing in the decay of ^{131}I. The following results were obtained: 325.8-177.2 keV, $A_2 = 0.018(11)$, $A_4 = -0.003(10)$; 318.1-404.8 keV, $A_2 = -0.18(4)$, $A_4 = -0.05(3)$; 272.5-364.5 keV, $A_2 = 0.15(4)$, $A_4 = -0.03(3)$; 284.3-80.2 keV, $A_2 = -0.005(7)$, $A_4 = 0.005(15)$; 318.1-324.6 keV, $A_2 = 0.24(5)$ $A_4 = -0.01(5)$. The result for the 318.1-324.6 keV cascade has not been corrected for a small influence from the 318.1-404.8 keV cascade. Four E2/M1 mixing ratios are deduced from the angular correlation coefficients (energies in keV): $-0.28 \leqq \delta(325.8) \leqq -0.20$, $-0.19 \leqq \delta(318.1) \leqq -0.035$, $-1.5 \leqq \delta(324.6) \leqq -0.05$, $\delta(272.5) = -0.38(17)$.

8.1.3 Halflife of the 364 keV state in ^{131}Xe

J Becker, K Fransson, B Sundström

As a complement to measurements made on the MCG (described elsewhere) the halflife of the 364 keV state in ^{131}Xe has been determined by the delayed coincidence method, using a TPHC. A preliminary result is 60 ± 3 ps.

8.1.4 Gamma-gamma angular correlation studies in ^{97}Tc

S Beshai, M El-Khosht, L-E Fröberg and L Gidefeldt

By use of a multichannel goniometer gamma-gamma angular correlations have been measured in ^{97}Tc. The obtained angular correlation coefficients are (energies in keV):

108.8 - 215.7	$A_2 = 0.38(3)$	$A_4 = -0.06(5)$
754.0 - 215.7	$A_2 = 0.01(2)$	$A_4 = -0.01(2)$
569.3 - 215.7	$A_2 = 0.25(1)$	$A_4 = 0.00(2)$
460.6 - 324.6	$A_2 = 0.08(2)$	$A_4 = -0.02(2)$
645.2 - 324.6	$A_2 = 0.09(4)$	$A_4 = 0.03(3)$

These data are used to deduce the E2/M1 mixing-ratios of several transitions:

108.8	$\delta = 1.6(4)$		
215.7	$\delta = 0.21(5)$		
569.3	$\delta = 2.8(5)$	or	0.13(5)
460.0	$\delta = 1.6(4)$	or	-0.01(10)

The spin of the 785.0 keV level is found to be 5/2.

8.1.5 Directional correlation studies in ^{90}Zr

S Beshai, K Fransson, L-E Fröberg and B Sundström

Gamma-gamma directional correlation is measured with the MCG in the decay of ^{90}Nb (14.6 h). The ^{90}Nb sources is produced by irradiations with the newly constructed irradiation facility BLENDA at the 225-cm cyclotron in Stockholm. The reaction used is $^{89}Y(\alpha, 3n)^{90}Nb$. The following preliminary results for the directional correlation coefficients has been found.

Cascade (keV)	A_2	A_4
1129-141	-0.094 ± 0.022	0.031 ± 0.016
1129-1611	-0.084 ± 0.019	0.011 ± 0.015
1129-1715	-0.01 ± 0.07	0.035 ± 0.051
1129-1984	-0.006 ± 0.051	-0.03 ± 0.043
1913-827	0.138 ± 0.036	0.053 ± 0.028
2186-142	0.155 ± 0.075	0.000 ± 0.055
2186-132	0.133 ± 0.057	-0.017 ± 0.04
2186-890	0.125 ± 0.066	-0.040 ± 0.057

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9.1 Total decay energies of neutron-rich nuclides

K. Aleklett, E. Lund and G. Rudstam

A large part of the programme aiming at mapping the nuclear mass surface by measuring total beta decay energies has now been completed. Results for some 50 nuclides are summarized in Table 1. Details of the experiments are given in a series of publications and reports [1-6].

9.2 Delayed-neutron emission from fission products

E. Lund and G. Rudstam

A survey of delayed-neutron activities comprising half-life determinations for 44 cases, among them 18 new ones, has been published [7-8]. Spectra of delayed neutrons from the precursors $^{79-81}$Ga, ^{94,95}Rb and ^{129,130}In have been analyzed and described in a laboratory report [9]. Another publication [10] gives spectra of the delayed neutrons from the precursors ^{88,90}Br, ^{138,140}I, ^{142}(Xe,Cs), and ^{144}Cs. The delayed neutron spectra may be characterized in terms of a fine structure superimposed on a gross structure consisting of 1 - 4 components of different wave-numbers as shown in ref. [11]. By combining the spectra from the various precursors it is possible to evaluate the effective delayed-neutron spectrum in nuclear fuel for any irradiation conditions.

9.3 Decay heat in nuclear fuel

K. Aleklett and G. Rudstam

A study of average beta energies of individual fission products is being carried out in order to provide data for an evaluation of the decay heat in nuclear power. The main emphasis during the year has been to refine the experimental method to be used. A number of measurements have also been done, especially for nuclides at the light mass peak, but the results have not been finally analyzed yet.

9.4 Nuclear spectroscopic studies of fission products

B. Fogelberg and H. Tovedal

The decay properties of short lived fission product nuclei are studied by means of γ-ray and conversion electron spectroscopy, and by measurements of level half-lives. During 1976, studies have been made on the decays of In isotopes to the even mass Sn isotopes with $120 \leq A \leq 128$ and of ^{141}Cs, ^{143}Ba and ^{143}La.

The studies also include measurements of γ-rays emitted in competition with delayed neutrons from unbound levels. Extensive $\gamma\gamma$-coincidence measurements for the decays of $^{137}I \longrightarrow {}^{137}Xe$ and $^{87}Br \longrightarrow {}^{87}Kr$ have been performed. As a complement to these measurements, the neutron binding energy of ^{137}Xe have been determined to 4025.2 ± 0.6 keV using the ^{136}Xe (n, γ) reaction. This latter measurement was made in collaboration with W. Mampe, ILL, Grenoble.

Published works during 1976 are listed as references 12-15 below.

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1) E. Lund and G. Rudstam, Spectrometer for measuring total beta decay energies, Nucl Instr Methods 134 (1976) 173

2) K. Aleklett, E. Lund, and G. Rudstam, The total binding energy of the doubly closed shell nuclide $^{132}_{50}Sn_{82}$, The Swedish Research Councils' Laboratory Report LF-73 (1976).

3) K. Aleklett, E. Lund, G. Nyman, and G. Rudstam, Total beta-decay energies and masses of short-lived isotopes of zinc, gallium, germanium, and arsenic. The Swedish Research Councils' Laboratory Report LF-74 (1977).

4) K. Aleklett, E. Lund, and G. Rudstam, Total beta decay energies and masses of strongly neutron-rich indium isotopes ranging from A=120 to 129, The Swedish Research Councils' Laboratory Report LF-76 (1977).

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9) G. Rudstam and E. Lund, Energy spectra of delayed neutrons from the precursors ^{79}(Zn,Ga), ^{80}Ga, ^{94}Rb, ^{95}Rb, ^{129}In, and ^{130}In, The Swedish Research Councils' Laboartory Report LF-77 (1976).

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14) J. Blachot, S. Dousson, E. Monnand, F. Schussler, and B. Fogelberg, Désintégration de ^{143}La, Journal de Physique-Lettres 37 (1976) L-275.

15) E. Monnand and B. Fogelberg, Beta- and gamma-ray studies of ^{144}Cs, ^{144}Ba, and ^{144}La, CERN 76-13 (1976) 503.

TABLE 1

Summary of the experiment Q_β-values and deduced atomic mass excesses reported in refs.[1-5] and [12]

Nuclide	Half-Life	$Q_{\beta}-$ value (MeV)	Mass excess (MeV)	Comment
^{75}Zn	10.1 s	≥5.62 ± 0.20	≥-62.94 ± 0.28	← Equality sign is valid if the measured β-group feeds the ground state
^{76}Zn	5.7 s	3.98 ± 0.12	-62.46 ± 0.19	
^{77}Zn	1.4 s	6.91 ± 0.22	-58.96 ± 0.23	
^{78}Zn	1.6 s	6.01 ± 0.18	-57.63 ± 0.25	
^{76}Ga	27.6 s	6.77 ± 0.15	-66.44 ± 0.15	
^{77}Ga	13.2 s	5.34 ± 0.06	-65.87 ± 0.06	
^{78}Ga	5.09 s	8.14 ± 0.16	-63.64 ± 0.16	
^{79}Ga	2.9 s	6.77 ± 0.08	$-62.86\ ^{+0.21}_{-0.12}$	
^{79}Ge	40 s			
^{79}Ge	18.5 s	$4.09\ ^{+0.18}_{-0.07}$	$-69.63\ ^{+0.19}_{-0.09}$	
^{80}Ge	29.5 s	2.64 ± 0.07	-69.75 ± 0.15	
^{80}As	15.2 s	5.37 ± 0.12	-72.39 ± 0.13	
^{81}As	34 s	3.76 ± 0.08	-72.63 ± 0.08	
^{83}As	13.3 s	5.46 ± 0.22	-69.98 ± 0.22	
^{85}Br	2.87 min	2.870±0.019	-78.60 ± 0.02	
^{86}Br	55.7 s	7.61 ± 0.06	-75.65 ± 0.06	
^{87}Br	55.5 s	6.84 ± 0.12	-73.87 ± 0.12	
^{120}In	3.08 s	5.43 ± 0.29	-85.67 ± 0.29	low spin isomer
^{120}In	50.08 s	5.30 ± 0.20	-85.80 ± 0.20	high spin isomer
^{121}In	23.1 s	3.40 ± 0.05	-85.80 ± 0.05	ground state
^{122}In	1.5 s	6.3 ± 0.5	-83.6 ± 0.5	low spin isomer
^{122}In	9.2 s	6.25 ± 0.19	-83.69 ± 0.19	high spin isomer
^{123}In	5.98 s	4.44 ± 0.06	-83.38 ± 0.06	ground state
^{123}In	47.8 s	4.69 ± 0.21	-83.13 ± 0.21	isomeric state
^{124}In	3.2 s	7.18 ± 0.05	-81.06 ± 0.05	low spin isomer
^{124}In	2.4 s	7.37 ± 0.21	-79.87 ± 0.21	high spin isomer

Nuclide	Half-Life		Q_{β^-} value (MeV)	Mass excess (MeV)	Comment
^{125}In	2.33	s	5.48 ± 0.08	-80.42 ± 0.08	ground state
^{125}In	12.2	s	5.66 ± 0.12	-80.24 ± 0.12	isomeric state
^{126}In	2.1	s	8.17 ± 0.08	-77.85 ± 0.08	low spin isomer
^{126}In	1.55	s	8.06 ± 0.17	-77.96 ± 0.17	high spin isomer
^{127}In	1.3	s	6.46 ± 0.07	-77.05 ± 0.07	ground state
^{127}In	3.7	s	6.65 ± 0.18	-76.84 ± 0.18	isomeric state
^{128}In	6.5	s	9.31 ± 0.16	-74.00 ± 0.17	low spin isomer
^{128}In	0.95	s	9.39 ± 0.22	-73.92 ± 0.23	high spin isomer
^{129}In	0.9	s	7.60 ± 0.12	-73.03 ± 0.17	ground state
^{129}In	1.2	s	7.8 ± 0.6	-72.8 ± 0.6	isomeric state
^{127}Sn	4.13	min	3.206 ± 0.024	-83.498 ± 0.25	isomeric state
^{127}Sn	2.2	h	3.201 ± 0.024	-83.503 ± 0.025	ground state
^{128}Sn	59	min	1.29 ± 0.04	-83.31 ± 0.06	
^{129}Sn	2.23	min	4.00 ± 0.12	-80.63 ± 0.12	
^{130}Sn	3.8	min	2.19 ± 0.03	-80.14 ± 0.09	ground state
^{130}Sn	1.7	min	4.00 ± 0.31	-78.33 ± 0.32 [a)]	7^- isomeric state
^{131}Sn	55.4	s	4.59 ± 0.20	-77.43 ± 0.22	
^{132}Sn	40	s	3.08 ± 0.04	-76.59 ± 0.08	doubly closed
^{128}Sb	10.0	min	4.39 ± 0.04	-84.60 ± 0.04	
^{130}Sb	6.5	min	5.02 ± 0.08	-82.33 ± 0.08	
^{131}Sb	23	min	3.18 ± 0.09	-82.02 ± 0.09	
^{132}Sb	2.8	min	5.53 ± 0.07	-79.67 ± 0.07	
^{134}Sb	10.7	s	8.24 ± 0.21	-74.17 ± 0.26	
^{134}Te	41.8	min	1.56 ± 0.09	-82.41 ± 0.11	
^{135}Te	19.2	s	5.95 ± 0.24	-77.85 ± 0.24	

a) Based on the mass excess of 6.5 min ^{130}Sb

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

10.1 The tandem accelerator

During 1975 a sputtering ion source (HIONEX 83) was installed. It is already in use for experiments with ^{32}S beams and is at present tested for other ions like ^{12}C and ^{56}Fe.

10.2 Precise measurements of n-d elastic scattering cross sections

L Amtén, A Johansson and B Sundqvist

Very few measurements of n-d elastic scattering data have been reported in the region 6-13 MeV (1,2) and the reported data have large relative and absolute errors. As part of a larger project to measure three nucleon scattering observables with high relative and absolute accuracy (~ 1 percent) for comparison with dynamically exact threebody calculations we reported last year on n-d elastic scattering measurements at 8 MeV (3). These measurements have been extended to include an angular distribution at 10 MeV neutron energy.

The experimental method consists of using a polyethylene foil of well known ratio of hydrogen to deuterium atoms as target. The recoiling protons and deuterons are detected and the n-p differential cross section, which is known to .8 % at 10 MeV, is used as reference. Cross sections have been measured at 180° and around the cross section minimum at 105°-140° (CM angles) using two ΔE-E telescopes, the latter having a position sensitive detector as E detector. Adding six of the eight data points around the minimum gives a statistical precision of 2.7 %, while at 180° the corresponding figure is better than 1 %.

The results have been compared with three different exact threebody calculations and with a calculation in a more simple model. None of the theoretical curves gives a completely satisfactory description of the experimental results. In the region of the cross section minimum all four theories predict

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(1) B E Bonner, E B Paul and G C Phillips, Nucl Phys A128 (1969) 183

(2) J D Seagraves, J C Hopkins, D R Dixon, P W Keaton Jr, E C Kerr, A Nüler, R H Sherman and R K Walter, Annals of Phys 74 (1972) 250

(3) L Amtén, L Gönczi, A Johansson, L Nilsson and B Sundqvist, TLU 26/74 Revised version, Tandem Laboratory Report, Uppsala 1977

values larger than the experimental data while at 180° some theoretical values are larger and some smaller than the experimental one.

A report describing the experiment and analysis is in progress (4).

10.3 Neutron capture reactions in the giant resonance region

I Bergqvist and B Pålsson, Department of Physics, University of Lund, and A Lindholm and L Nilsson, Tandem Accelerator Laboratory, Uppsala

The neutron capture process has been studied for many years through the recording of capture γ-ray spectra. This method makes possible the determination of total capture cross sections as well as cross sections for capture into individual levels in the final nucleus. Calculations based on the direct and the semi-direct (DSD) models show that for neutron capture in heavy elements observed excitation functions and the main features of the gamma-ray spectra can be accounted for. Recent studies have been concentrated on neutron capture in the light elements silicon and sulphur. The results of these experiment are reported in Ref 1 together with calculations based on the DSD and compound nucleus (CN) models. It was found that excitation functions for these nuclei do not show the resonance form found for heavy nuclei and that the DSD model could not account for observed cross sections. The introduction of the compound nucleus model implies a conclusive improvement in reproducing observed data, in particular for neutron energies below and in the lower part of the giant dipole resonance (GDR).

To verify the importance of compound nucleus processes in light nuclei the measurement on neutron capture in ^{40}Ca reported in ref 2 has been extended down to neutron energies of 3.5 MeV. A comparison between observed partial cross sections and calculations based on the DSD and CN models clearly illustrates the importance of CN processes in Ca (n,γ) similar to that observed for silicon and sulphur.

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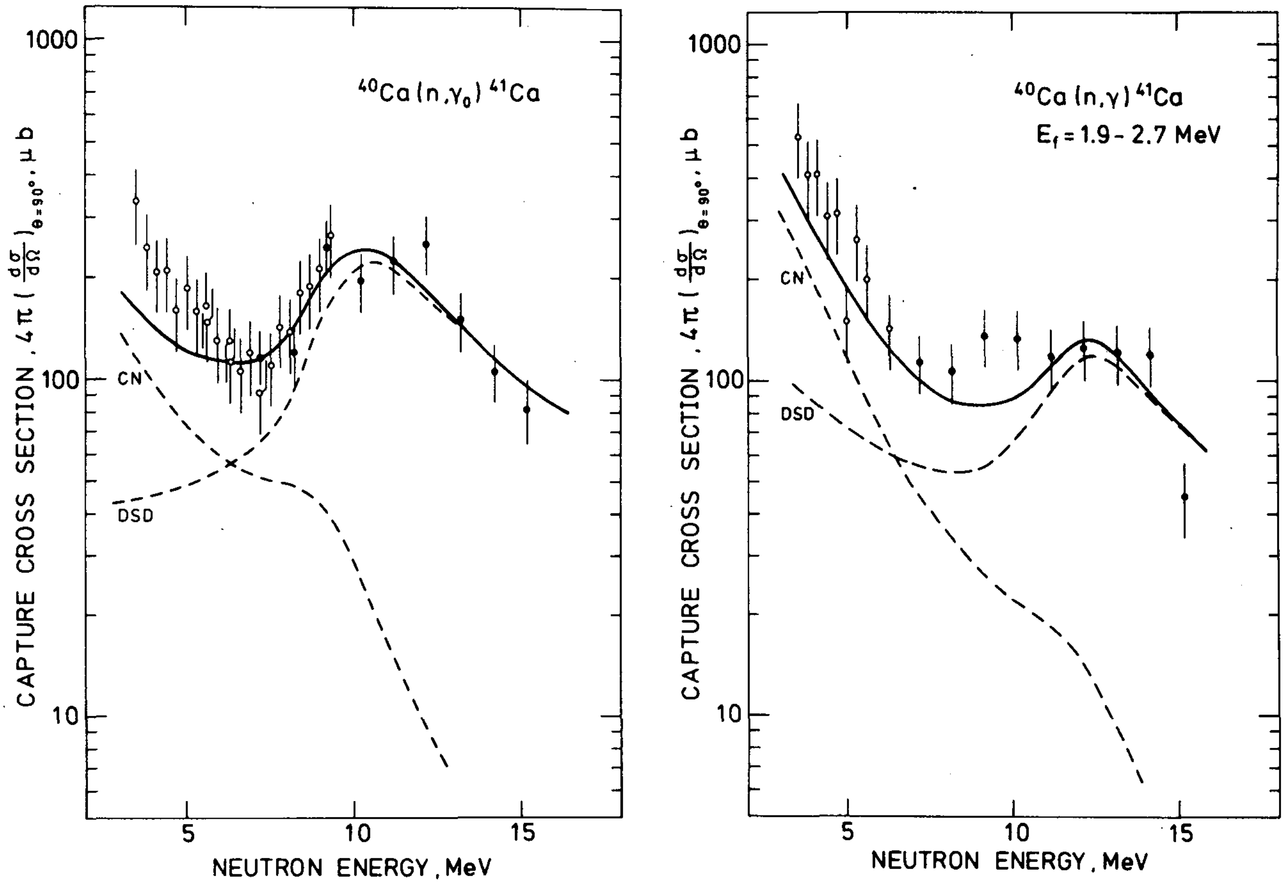
(4) L Amtén, A Johansson and B Sundqvist, TLU 52/77, Tandem Laboratory Report, Uppsala 1977



Cross-sections for the ^{40}Ca(n,)^{41}Ca reaction, the left figure for capture of the neutron into the $1f_{7/2}$ ground state, the right for capture into a group of levels between 1.9 and 2.7 MeV above the ground state, mainly $2p_{3/2}$ states. The experimental results are from ref (2) (filled circles) and the present work (open circles). The dashed curves show the compound nucleus (CN) and direct-semidirect (DSD) cross sections. The solid curve is the sum of the two.

The reactions ^{89}Y(n,γ)^{90}Y and ^{140}Ce(n,γ)^{141}Ce have been studied in a joint project with a research group at Los Alamos. Experiments in Uppsala and Los Alamos cover the entire giant resonance region with neutron energies between 6 and 16 MeV. In this energy region the DSD model accounts for the main features of the observed data but there is a slight disagreement in the low energy part of the GDR, which may imply that compound nucleus processes are involved. To clarify the importance of these processes an extension of this experiment to lower neutron energies is planned for the near future. Beams of neutrons with energies between 3 and 6 MeV will be produced using the ^{3}H(p,n)^{3}He reaction. A new tritium gas handling system has been constructed and is now ready to be installed.

In cooperation with a group from Institute Jozef Stefan, Ljubljana, investigations have been made on the angular distributions of the gamma radiation from neutron capture in Sr and Y. There are two purposes for these experiments:

1. Previous capture cross section measurements were mostly performed with a detection angle of 90°. The integrated cross sections were estimated by $4\pi \cdot (\frac{d\sigma}{d\Omega})_{90^o}$, i e assuming isotropy, for comparison with the calculated cross sections $\int_{4\pi} \frac{d\sigma}{d\Omega} d\Omega$. Calculations of angular distributions performed by the Ljubljana group show that large deviations from isotropy might exist.

2. Fore-aft anisotropies in the angular distribution might be explained in terms of interference between multipole transitions of different parity, e g between E1 and E2 transitions. Angular distribution measurements thus offer a possibility to determine the quadrupole contribution to the capture cross section. Subsequently, this information might be used to derive properties of the giant quadrupole resonance.

The results from the experiments on Y and Sr are in qualitative agreement with preliminary calculations by the Ljubljana group based on the DSD model.

10.4 Studies of the $^6Li(n,\alpha)T$ reaction

H Condé, National Defense Research Institute, Stockholm
T Andersson, M Anwar, C Nordborg and L Nilsson

The present investigation aims at measuring the $^6Li(n,\alpha)T$ cross section relative to the 180° n-p (or n-d) cross section for neutron energies up to about 5 MeV by recording the outgoing tritons and (or) alpha particles in semi-conductor counter telescopes. A special scattering chamber is being constructed for this purpose. It will be equipped with an air lock system allowing targets to be transferred under vacuum from the evaporation chamber to the scattering chamber. The relative

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(1) A Lindholm, L Nilsson, I Bergqvist and B Pålsson, to be published in Nuclear Physics

(2) I Bergqvist, D M Drake and D K Mc Daniels, Nucl Phys A231 (1974)29

numbers of hydrogen and lithium-6 atoms in the target will be measured by proton elastic scattering. This can be done provided the ^{6}Li-p scattering cross section is known. A separate experiment is planned to perform a precision measurement of this cross section.

It is also intended to study the inverse reaction $T(\alpha, {}^{6}Li)n$ in the present investigation. In this experiment the outgoing ^{6}Li ions are emitted in a narrow cone in the forward direction and must be detected in a heavy flux of transmitted and scattered alpha particles and recoiling tritons. For this reason the outgoing particles will be analyzed by means of the magnetic spectrograph. In the focal plane of the spectrograph, ^{6}Li ions will be identified by a ΔE-E telescope. The $T(\alpha, {}^{6}Li)n$ cross section will be measured relative to the T-α scattering cross section by relating the number of detected ^{6}Li ions to that of recoiling tritons. A separate ΔE-E telescope placed at about 20° to the incident beam will be used for tritium detection.

Some preparatory experiments are being performed at present and the first production runs are planned for the first half of 1977.