KDK-23
NEANDC(OR)-151/U
INDC(SWD)-11/U

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN, DEC 76 - DEC 77

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN
APRIL 1978

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Compiled by

H Condé

National Defense Research Institute

Stockholm, Sweden

April 1978

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 relevant to the nuclear energy field are given of neutron cross section measurements and studies of the fission process. Reports are also given of nuclear structure and decay data measurements especially fission product nuclear data measurements of importance for the research on reactor safety and nuclear waste handling. Charged particle and photonuclear cross section measurements with applications in e.g. activation analysis, production of radioisotopes for medical use and in astrophysics are reported as well.

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	A	Quantity	Type	Energy Min	Max	KDK-23 Page	Lab	Comments
D		DIFF ELASTIC	EXPT-PROG	8.0+6	1.0+7	37	TLU	AMTÉN+
LI	6	(n,α)	EXPT-PROG	2.0+6	3.4+6	38	TLU	ANDERSSON+ DETECTION OF CHARGED PARTICLES IN SCATT. CHAMBER
F	19	DIFF INELASTIC	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,2n)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,np)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,d)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
AL		DIFF INELASTIC	EXPT-PROG	7.0+6	8.0+6	33	SRL	RAMSTRÖM+ TOF 35^{o} TO 150^{o}
AL	27	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
AL	27	(n,p)	EXPT-PROG	1.4+7		15	LTH	LUNDBERG+ ABS MEASUREMENT
AL	27	(n,α)	EXPT-PROG	1.4+7		15	LTH	LUNDBERG+ ABS MEASUREMENT
CA	40	(n,γ)	EXPT-PROG	2.5+6	7.0+6	39	TLU	BERGQVIST+ RESULTS COMP. TO DSD AND ON CALC.
V		DIFF INELASTIC	EXPT-PROG	7.0+6	8.0+6	33	AE	RAMSTRÖM+ TOF 35^{o} TO 150^{o}
V	51	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
MN	55	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
MN	55	(n,γ)	EXPT-PROG	1.4+7		13	LTH	MAGNUSSON+ ACT. TECHNIQUE
FE		DIFF ELASTIC	EXPT-PROG	7.0+6		34	SRL	RAMSTRÖM+ TOF 20^{o} TO 174^{o} COMP WITH OPT. MODEL CALC.
FE	56	DIFF INELASTIC	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,2n)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,np)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,d)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
CO		DIFF ELASTIC	EXPT-PROG	7.0+6	8.0+6	34	SRL	RAMSTRÖM+ TOF 20^{o} TO 174^{o} COMP WITH OPT. MODEL CALC.

Element S	A	Quantity	Type	Energy Min	Max	KDK-23 Page	Lab	Comments
CO	59	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
CO	59	DIFF INELASTIC	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,2n)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,np)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
		(n,d)	EXPT-PROG	1.6+7	2.2+7	35	SRL	CORCALCIUC+
NI	58	(n,γ)	EXPT-PROG	2.5+6	7.0+6	39	TLU	BERGQVIST+ RESULTS COMP TO DSD AND CN CALC.
NI		(n,CHARGE PART)	EXPT	PILE	2.5-2	8	CTH	SJÖSTRAND+ STUDIES ON NI 58, 59 AND 60
CU	63	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
CU	65	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
GA	79	DELAYED NEUTS	EXPT			28	SRL	ALEKLETT+
GA	80	DELAYED NEUTS	EXPT			28	SRL	ALEKLETT+
GA	81	DELAYED NEUTS	EXPT			28	SRL	ALEKLETT+
BR	87	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
BR	88	DELAYED NEUTS	EXPT			28	SRL	ALEKLETT+
BR	90	DELAYED NEUTS	EXPT			28	SRL	ALEKLETT+
BR	91	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
RB	94	DELAYED NEUTS	EXPT			28	SRL	ALEKLETT+
RB	95	DELAYED NEUTS	EXPT			28	SRL	ALEKLETT+
SR		(n,γ)	EXPT-PROG			40	TLU	BERGQVIST+ ANG.DISTR. OF GAMMAS
Y		(n,γ)	EXPT-PROG			40	TLU	BERGQVIST+ ANG. DISTR. OF GAMMAS
Y	89	(n,γ)	EXPT-PROG	6.0+6	1.6+7	39	TLU	BERGQVIST+ RESULTS COMP. TO DSD AND CN CALC.
Y	89	(n,γ)	EXPT-PROG	1.4+7		13	LTH	MAGNUSSON+ ACT TECHNIQUE
Y	89	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
ZR	101	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.
ZR	102	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.

Element S	A	Quantity	Type	Energy Min	Energy Max	KDK-23 Page	Lab	Comments
ZR	103	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.
ZR	104	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.
NB	104	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.
TC	106	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.
TC	107	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.
TC	108	FISS PROD γ	EXPT-PROG	PILE		4	CTH	BRODÉN+ ON LINE CHEM. SEP. TECH.
IN		DIFF ELASTIC	EXPT-PROG	7.0+6	8.0+6	34	AE	RAMSTRÖM+ TOF 20^{o} TO 174^{o} COMP. WITH OPT. MODEL CALC.
IN		FISS PROD γ	EXPT-PROG			29	SRL	FOGELBERG+ DECAY OF IN ISOTOPES TO EVEN MASS SN ISOTOPES
IN	115	(n,γ)	EXPT-PROG	1.4+7		13	LTH	MAGNUSSON+ ACT TECHNIQUE
IN	115	TOT INELASTIC	EXPT-PROG	1.4+7		15	LTH	LUNDBERG+ ABS. MEASUREMENT
IN	127	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
IN	129	DELAYED NEUTS	EXPT			28	RCL	ALEKLETT+
IN	130	DELAYED NEUTS	EXPT			28	RCL	ALEKLETT+
SN	122	FISS PROD γ	EXPT-PROG			29	SRL	FOGELBERG+
SN	124	FISS PROD γ	EXPT-PROG			29	SRL	FOGELBERG+
SN	126	FISS PROD γ	EXPT-PROG			29	SRL	FOGELBERG+
SN	128	FISS PROD γ	EXPT-PROG			29	SRL	FOGELBERG+
TE	136	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
I	127	(n,γ)	EXPT-PROG	1.4+7		13	LTH	MAGNUSSON+ ACT TECHNIQUE

Element S	A	Quantity	Type	Energy Min	Max	KDK-23 Page	Lab	Comments
I	137	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
I	138	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
I	139	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
I	140	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
I	141	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
XE	142	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
CS	141	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
CS	142	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
CS	144	DELAYED NEUTS	EXPT-PROG			28	SRL	ALEKLETT+
CE	140	(n,γ)	EXPT-PROG	6.0+6	1.6+7	39	TLU	BERGQVIST+ RESULTS COMP. TO DSD AND CN CALC.
PR	141	INELASTIC	EXPT-PROG	1.2+6	2.0+6	33	SRL	TROSTELL+
W	186	(n,γ)	EXPT-PROG	1.4+7		13	LTH	MAGNUSSON+ ACT TECHNIQUE
AU	197	(n,2n)	EXPT-PROG	1.4+7		15	LTH	LUNDBERG+ ABS. MEASUREMENT
AU	197	(n,γ)	EXPT-PROG	1.4+7		15	LTH	MAGNUSSON+ ACT TECHNIQUE
PB	207	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
BI		DIFF ELASTIC	EXPT-PROG	7.0+6	8.0+6	34	SRL	RAMSTRÖM+ TOF 20^{o} TO 174^{o} COMP. WITH OPT. MODEL CALC.
BI	209	DIFF INELASTIC	EXPT-PROG	2.0+6	4.5+6	32	SRL	RAMSTRÖM
TH	232	FISSION	EXPT-PROG	5.0+6	9.0+6	26	FOA	CONDÉ+
TH	232	PHOTO-FISSION	EXPT-PROG			24	LTH	ALM+
U	234	PHOTO-FISSION	EXPT-PROG			24	LTH	ALM+
U	235	FISS PROD γ	EXPT-PROG	THR		32	SRL	JOHANSSON+ DELAYED GAMMA AFTER FISSN
U	235	SPECT FISS N	EXPT-PROG	1.0+5		24	SRL	ADAMS+ SPECTR AT LOW ENERGIES STUDIED
U	236	FISSION	EXPT-PROG	5.0+6	9.0+6	26	FOA	CONDÉ+ REL TO U235 FISSION
U	236	PHOTO-FISSN	EXPT-PROG			24	LTH	ALM+
U	238	FISSION	EXPT-PROG	5.0+6	9.0+6	26	FOA	CONDÉ+ REL TO U235 FISSION
U	238	PHOTO-FISSN	EXPT-PROG			24	LTH	ALM+

1. THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

1.1 Status report, Dec 76 - Dec 77

The Swedish Nuclear Data Committee including the "Coordination Group on Measurements" have had the same members during the actual time period as reported in the Progress Report from 1977 (KDK-15) with the exception that Dr I. Malmström replaced Dr B. Svahn as a representative for the National Institute of Radiation Protection, Stockholm.

The Committee has discussed nuclear data requests in relation to measurements and compilation activities in progress. As a result of these discussions a working group has been formed to compile selected neutron data for a number of actinides (see 1.2).

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.

Publications

KDK-16 Report from "International Specialists Symposium on Neutron Standards and Applications" 28-31 March, 1977, NBS, Gaithersburg, Maryland, USA (May 1977)(In Swedish)

KDK-17 Report from "Symposium on Neutron Cross-Sections 10-40 MeV", 3-5 May, 1977, BNL, Upton, USA (June 1977)(In Swedish)

KDK-18 Report from the 9th INDC Meeting, 16-20 May, 1977, Vienna, Austria (June 1977)(In Swedish)

KDK-19 KDK Annual Report 1976 (September 1977)(In Swedish)

KDK-20 Report from "Neutron Interlab Seminar", 14-16 September, 1977, Karlsruhe, Germany (October 1977)(In Swedish)

KDK-21 Report from "IAEA Nuclear Structure and Decay Data Meeting", 14-18 November, 1977, Oak Ridge, USA (December 1977) (In Swedish)

KDK-22 Report from NEANDC/NEACRP Specialist Meeting on Neutron Data of Structural Materials for Fast Reactors, 4-8 December, 1977, BCMN, Geel, Belgium (December 1977) (In Swedish)

KDK-23 Progress Report on Nuclear Data Activities in Sweden (April 1978)

1.2 Compilation of neutron data for selected actinides

The Swedish Nuclear Data Committee has initiated a compilation of evaluated and experimental neutron data for a number of selected actinides.

The data are primarily requested for calculations in reactor physics and of actinide build-up and for inciniration studies of nuclear waste by neutron irradiation.

The compilation work is split on five different groups according to the list below, which gives the actinides to be compiled, the types of data and the names and addresses of the compilers.

Nuclei	Data	Compiler
Th-232, U-233, U-235, U-238, Np-237, Pu-239, Pu-240, Pu-241, Pu-242, Cm-244, Cm-245, Cm-246, Cm-247, Cm-248	σ_T	H Condé National Defence Research Institute, Fack S-104 50 STOCKHOLM 80
-"-	σ_f	C Nordborg Tandem Accelerator Laboratory Box 533, S-751 21 UPPSALA
-"-	σ_γ	P Andersson Lund Institute of Technology Dept. of Nucl. Physics Box 725, S-220 07 LUND 7
-"- and Am-241, Am-243	RI, σ^{2200}	H Häggblom AB Atomenergi Fack S-611 01 NYKÖPING

Nuclei	Data	Compiler
Am-241, Am-243	σ_T, σ_f, σ_γ	J-E Christiansson University of Gothenburg Department of Nuclear Physics S-402 20 GÖTEBORG and H Sandberg Chalmers Inst. of Technology Department of Reactor Physics S-402 20 GÖTEBORG
U-235, U-238, Pu-239 U-238 U-238	(n, n) (n, n') (n, 2n)	B Trostell The Studsvik Science Lab. Studsvik, Fack S-611 01 NYKÖPING
Th-232, U-233, U-235 U-238, Pu-239	$\bar{\nu}$	H Condé address (see above σ_T)

2 CHALMERS UNIVERSITY OF TECHNOLOGY, S-402 20 GOTHENBURG

2.1 Department of Nuclear Chemistry

2.1.1 Studies of short-lived nuclides

K. Brodén, J. Rydberg and G. Skarnemark *

In our investigation of short-lived fission products around A=100, results have been obtained for $^{101-104}Zr$, ^{104}Nb and $^{106-108}Tc$ isotopes. The results include decay scheme and level life-time studies (three parameter coincidence measurements).

γ-γ angular correlation measurements are in progress for $^{106-108}Tc$, $^{144-146}La$ and ^{148}Pr.

In a near future, experiments on neutron-deficient isotopes of Zr and Nb will be performed at GSI, Darmstadt. The goal of these experiments is to isolate and study the doubly half-magic nucleus ^{80}Zr and its neighbour nuclei.

In all experiments, the rapid, on-line chemical separation system SISAK has been used. This system facilitates studies of nuclides with $T_{1/2}$>0.5 s.

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

2.2 Department of Physics

2.2.1 High spin states of neutron deficient Sr- and Zr-isotopes

S E Arnell, G Finnas, A Nilsson, S Sjöberg, Ö Skeppstedt and E Wallander

Our group is working with a systematic study of neutron deficient Sr- and Zr-isotopes. The purpose of the project is to study in what way the level structure changes when neutrons are removed from the closed neutron shell N = 50. The information is received from gamma-ray spectroscopy and (α,xn) reactions. So far results about ^{89,88,87,85}Sr have been published[1,2] and new information of high spin states of ^{83}Sr and ^{87}Zr is ready for publication. Now we are working with the nucleus ^{81}Sr and our hope is to get information of ^{79}Sr too. The experiments have been performed at the cyclotrons in Stockholm and Åbo and at the tandem accelerator in Uppsala.

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. A280 (1977) 72.

2.2.2 On line studies of neutron-deficient nuclei

G. Andersson, E. Hagberg, B. Jonson, S. Mattsson, and G. Nyman

At the Isotope Separator On-Line facility ISOLDE at CERN neutron-deficient nuclides are produced by spallation reactions in thick (~20 cm) targets bombarded with a 1 μ A beam of 600 MeV protons from the CERN synchro-cyclotron.

Far away from beta-stability, the total energy available for beta decay is high. Beta transitions to states with excitation energies higher than the separation energies for protons and alpha particles can thus be possible. Investigations of this so called beta-delayed particle emission with surface-barrier detector telescopes are, beside alpha spectroscopy, the main methods to gain information about very neutron-deficient nuclei.

Results on energies, half-lifes and, branching ratios for delayed alpha particles and/or delayed protons have been obtained for the isotopes $^{114-118}$Cs [1]. The identification of the ($T_z = -2$) to date the most neutron-deficient nucleus ^{31}Ar[2] with T 1/2 $\approx$ 75 ms has been achieved by delayed-proton spectroscopy. Detailed studies of ground state alpha emission in the regions around Yb[3], Hg[4], and Fr[5] have been performed. Accurate α-decay energies, half lifes and α-branching ratios were measured. The new isotopes ^{152}Yb, ^{157}Lu, ^{177}Hg and $^{201, 202}Fr$ have been identified. Evidence of strongly deformed bands in odd-Pt isotopes was found by α-γ coincidence measurements. By means of beta multiscaling the presently heaviest self-conjugate nucleus ^{74}Rb[6], T 1/2 = 64.9 ± 0.5 ms, has been identified.

Two years ago it was shown[7] that thermal neutron capture in a (radioactive) target of ^{84}Rb, prepared by on-line isotope separation, induced proton emission. The cross-section was determined to be 12 ± 2 b. At the high flux reactor at Grenoble additional radioactive targets have been irradiated. New results are [8] $^{37}Ar(n_{th}, \alpha)^{34}S$:
$\sigma_\alpha = 1970 \pm 330$ b, $^{37}Ar(n_{th},p)^{37}Cl$: $\sigma_p = 69 \pm 14$ b and [9]
$^{76}Br(n_{th},p)^{76}Sc$: $\sigma_p = 224 \pm 64$ b, $Q_{n,p,} = 5730 \pm 15$ keV
At the isotope separator on-line to the heavy-ion accelerator at GSI, Darmstadt, neutron-deficient nuclides formed in fusion reactions have been investigated by means of β-, γ-, x-, and particle-spectroscopy. From reactions of 290 MeV ^{58}Ni ions on enriched targets of ^{58}Ni and ^{69}Ca the new nuclei[10] $^{108-110}Te$, $^{110-114}I$, and $^{112-114}Xe$ have been identified.

References

1) J.M. D'Auria, J.W. Grüter, E. Hagberg, P.G. Hansen, J.C. Hardy, P.Hornshøj, B. Jonson, S.Mattsson, H.L. Ravn, P. Tidemand-Petersson. Submitted to Nucl. Phys.

2) E. Hagberg, P.G. Hansen, J.C. Hardy, A. Huck, B. Jonson, S. Mattsson, H.L. Ravn, P. Tidemand-Petersson, G. Walter. Phys. Rev. Letters 39(1977)792

3) E. Hagberg, P.G. Hansen, J.C. Hardy, P. Hornshøj, B. Jonson, S. Mattsson, P. Tidemand-Petersson. Nucl.Phys.A293(1977)1

4) E. Hagberg, P.G. Hansen, P. Hornshøj, B. Jonson, S. Mattsson, P. Tidemand-Petersson. In course of publication.

5) L.C. Carraz, E. Hagberg, P.G. Hansen, B. Jonson, S. Mattsson, H.L. Ravn, M. Skarestad, P. Tidemand-Petersson. In course of publication.

6) J.M. D'Auria, L.C. Carraz, P.G. Hansen, B. Jonson, S. Mattsson, H.L. Ravn, M. Skarestad, L. Westgaard. Phys. Lett. 66B(1977)233

7) G. Andersson, M. Asghar, A. Emsallem, E. Hagberg, B. Jonson. Phys. Lett. 61B(1976)234

8) M. Asghar, A. Emsallem, E. Hagberg, B. Jonson, P. Tidemand-Petersson. Submitted to Z. Physik.

9) G. Andersson, M. Asghar, A. Emsallem, E. Hagberg, B. Jonson , P. Tidemand-Petersson. In course of publication.

10) R. Kirchner, O. Klepper, G. Nyman, W. Reisdorf, E. Roeckl, D. Schardt, N. Kaffrell, P. Peuser, K. Schneweiss. Phys. Lett. 70B(1977)150

2.2.3 Nuclear spins and moments

C Ekström, I Lindgren, T Persson, S Ingelman[a], G Wannberg[a] and J Heinemeier[b].

In order to obtain information on the nuclear structure and shapes of short-lived nuclides far from the region of beta-stability, nuclear spins and moments are being measured using an atomic-beam magnetic resonace (ABMR) apparatus connected on-line with the ISOLDE isotope separator at CERN. The systematic investigations have covered the heavier alkali elements rubidium, cesium and francium, and also the elements thulium and gold. The most complete set of data has been obtained for the cesium isotopes, in which 18 nuclear spins and 13 magnetic moments have been determined in the region $^{119-144}Cs$, a range of 26 mass units. From the measured nuclear spins and moments in cesium it is possible to follow the transition from spherical nuclei close to the N = 82 shell closure to deformed nuclei, on both sides of the beta-stability line. The main part of the cesium results has been published in Nucl. Phys. A292(1977)144.

a) Institute of Physics, University of Uppsala, Uppsala.
b) E.P. Division, CERN, Geneva, Switzerland.

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

N Ryde, R Bergman and W Klamra

The facility for production of monoenergetic neutron beams at the R2-reactor at Studsvik contains at present a source of 24 keV neutrons. During 1977 this facility has been used mainly for research in health physics. A method has been developed for indicating and measuring of heavy metals in organs of man. Neutrons of 24 keV energy can penetrate into the human body to a deep of 5-8 cms where they are thermalized. The neutron cross section for thermal neutrons being generally rather high, the gamma radiation resulting from the (n,γ)-reaction can be detected. Trials with phantoms have shown that cadmium, present in such concentrations that under certain circumstances may appear in kidney, can be detected and measured at the facility.

Reference:

N Ryde, Production and use of monoenergetic neutron beams in the epithermal and intermediate energy region, Proc. of the 1st Scient. Conf. of the Iraqi Atom. Energy Com. p. 981, 1977.

2.3 Department of Reactor Physics, Chalmers University of Technology

N G Sjöstrand and G Grosshög

2.3.1 Cross sections for charged particle production in Ni isotopes

The final results of the measurements in a thermal neutron beam at the reactor of the Laue-Langevin institute in Grenoble have now been published.

Reference: M. Asghar, A. Emsallem and N.G. Sjöstrand: Thermal neutron induced charged particle reactions on $^{58,59,61}Ni$. Zeitschr. für Physik A <u>282</u>:4, 375 - 381 (1977).

2.3.2 Installation of new neutron generator

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

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3.1 High energy physics

H Tyrén

At the end of 1976 the Swedish Government approved of the conversion of the synchrocyclotron to a sectorfocussing cyclotron. The accelerator was shut down on January 4th 1977. Research in physics this year related to the use of the synchrocyclotron therefore only concerns analysis of previously performed experiments. New data on pion production in two body nuclear reactions have been analysed in order to improve on the understanding of the reaction mechanism and to investigate to what extent one can hope to extract nuclear structure information from such reactions. Problems in the analysis of elastic and inelastic scattering of protons on nuclei have been studied, in particular the contribution of spin dependent forces to these interactions.

A major part of the activity at GWI is now devoted to the reconstruction of the synchrocyclotron. Field measurements have been made in the model magnet to study in particular conditions for isochronous acceleration of ions. In collaboration with CERN the broad band amplifier type and the ferrite type of the RF-system have been studied. Progress have been made on the design of the new experimental area. In connection with that analyses have been made of the beam transport system. Studies have been done on computer systems and the basic components for two such systems have been purchased in 1977.

3.2 Physical biology

3.2.1 Production of radionuclides for biomedical use

Hans Lundqvist, Petter Malmborg and Carl-Göran Stålnacke

During the last four years, the radionuclide production program at the institute has grown considerably. In collaboration with research groups from different parts of Sweden the chemical, biological and medical potentialities of the accelerator-produced radionuclides are being investigated. Using the relatively weak (1 μA) internal proton beam of the old synchrocyclotron we have established production parameters and worked out methods for chemical target separation and the labelling and synthesis of biomedically useful compounds. The present program is summarized in Table I.

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 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)
	^{15}OO $H_2{}^{15}O$	$KClO_3$ H_2O	45 70	^{15}OO $H_2{}^{15}O$	^{15}OO is evolved heating the target with MnO_2.	Oxygen metabolism. 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)
*) *) *) *)	$^{122}I^-$ $^{123}I^-$ $^{125}I^-$ ^{127}Xe	NaI NaI NaI NaI	90 68 40 20	^{122}Xe ^{123}Xe ^{125}Xe ^{127}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, Huddinge) 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.

The rebuilding of the synchrocyclotron will enable us to get the radionuclide production on to a routinary basis. It is still too early to present a detailed description of the planned production facilities at the rebuilt cyclotron, but some tentative parameters for the systems may already be given.

The following expected beam data are of relevance in the present context:

Expected performance of SFSC-200

Particle	Energy (MeV)	Acceleration mode	Harmonic used	Maximal beam current (μA)	Remark
p^+	120-200	f.m.	1	10	
p^+	46-120	f.f.	1	40	Technical conditions not confirmed yet
d^+	50-100	f.f.	2	40	
d^+	25- 50	f.f.	2	40	-"-
$^3He^{++}$	250-280	f.m.	1	2	-"-
$^3He^{++}$	75-150	f.f.	2	20	
$^3He^{++}$	150-250	f.f.	1	20	-"-
$^4He^{++}$	100-250	f.f.	2	20	
$^4He^{++}$	25-100	f.f.	2	20	-"-

In the production of secondary beams like

ion-beams from on-line separator
fast neutrons
slow neutrons, or
pi-mesons

full beam intensity will be used, but only the energy interval 200-100 MeV protons will be utilized. The rest of the energy should then be excellent for "parasitic" nuclide production.

In most physical and biological experiments using the primary beam one will never use more than 1 μA, leaving approximately 90% of the beam for nuclide production. By using a septum magnet, the beam could be split into two simultaneous beams. The nuclide production should thus be able to utilize most of the beam simultaneously with other experiments.

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 I. The following references cover part of this work (1,2).

To be able to continue the work during the synchrocyclotron rebuilding period we now try to utilize the possibilities, kindly put to our disposal, to use the cyclotron at the Institute for Atomic Research, Stockholm, The Tandem Van de Graaff-accelerator in Uppsala and the cyclotron at Åbo (Turku), Finland. During 1977 the work with the shortlived radionuclides, mainly ^{11}C, has been continued at the Tandem Accelerator Laboratory, Uppsala, with a specially constructed gas target system.

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1. Lundqvist, H., Malmborg, P., Långström, B. and Suparb Na Chiengmai: Simple Production of $^{77}Br^-$ and $^{123}I^-$ and their Use in the Labelling of (^{77}Br)BrUdR and (^{123}I)IUdR. Submitted for publication.

2. Lundqvist, H. and Malmborg, P.: Production of Carrier-Free ^{28}Mg and ^{24}Na by 50 - 160 MeV Protons on Si, P, Cl, Ar and K. Excitation Functions and Chemical Separation. Submitted for publication.

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

4.1 Department of nuclear physics - pelletron group

4.1.1 MeV Neutron Cross Section Measurements With Activation Technique

G. Magnusson, P. Andersson, I Bergqvist

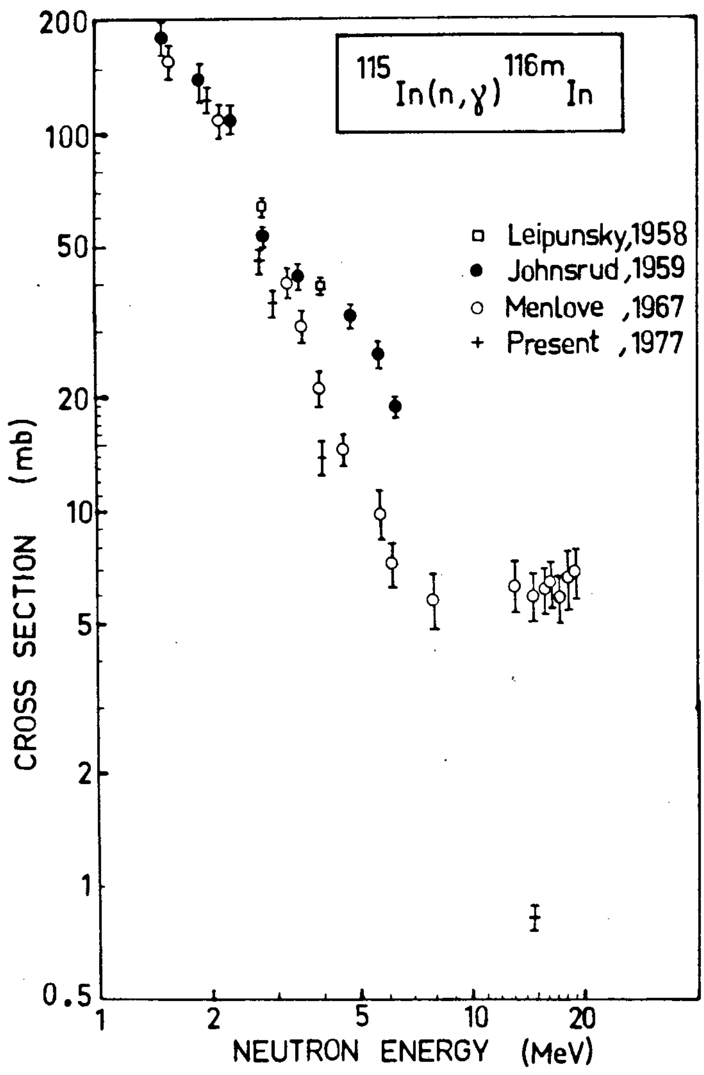
The improved activation technique earlier described (1) has been utilized in (n,γ) cross section measurements for about 10 nuclei from ^{55}Mn to ^{238}U. The neutrons have been produced from the T(d,n)^{4}He reactions and the integrated neutron flux was determined from the ^{27}Al(n,α)^{24}Na reaction. The results indicate that neutron capture cross sections at 14-15 MeV can be determined within about 10% depending on decay and half-life of the produced nuclei. Preliminary results have been obtained for activation cross sections at 14.7 MeV for ^{55}Mn, ^{89}Y, ^{115}In, ^{127}I, ^{186}W and ^{197}Au.

Reaction	cross section (mb)
^{55}Mn(n,γ)^{56}Mn	0.68±0.06
^{89}Y(n,γ)^{90m}In	0.3±0.1
^{115}In(n,γ)^{116m}In	0.83±0.06
^{127}I(n,γ)^{128}I	0.45±0.19
^{186}W(n,γ)^{187}W	0.6±0.3
^{197}Au(n,γ)^{198}Au	1.2±0.4

The measurements, which will soon be concluded, are performed at the 500 kV Van de Graaff accelerator. A report will be prepared in the beginning of 1978.

The results from the 14.7 MeV measurements indicate that previous measurements of (n,γ) cross sections at other neutron energies are also influenced by secondary neutrons. Therefore, we initiated measurements in the neutron energy range 1-10 MeV. The technique is basically the same as the one mentioned above.

The irradiations are performed with neutrons from the $T(p,n)^3He$ and $D(d,n)^3He$ reactions. The protons and the deuterons are accelerated by the Pelletron accelerator. The integrated neutron flux is determined for every irradiation form the $^{115}In(n,n')^{115m}In$ reaction.



Preliminary results of the activation cross sections for $^{115}In(n,\gamma)^{116m}In$ are given in Fig. 1 together with some earlier activation experiments. The results show good agreement for neutron energies below about 2 MeV but diverge at higher energies. This behaviour is expected. It indicates the influence of secondary neutrons from about 2 MeV. The contribution of these neutrons increases with neutron energy.

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1) G Magnusson, I. Bergqvist, Nucl. Technol. <u>34</u> (1977) 114

4.1.2 Absolute Measurement Of Neutron Reaction Cross Sections At 14.7 MeV In In, Al And Au

S. Lundberg, G. Magnusson, P. Andersson, I. Bergqvist

A recoil proton telescope has been used to determine the neutron flux for neutrons produced in the reaction $T(d,n)^{4}He$ with the deuterons accelerated by the 500 kV Van de Graaff generator. The purpose of this investigation has been to determine the cross sections for reactions often used as standard reactions at a neutron energy of 14.7 MeV.

The results show agreement with previous measurements except for the $^{115}In(n,n')^{115m}In$ reaction. Santry and Butler[1] have measured a rather low cross section for this reaction which has been found to be inconsistent with results obtained in this laboratory.

Reaction	Cross section (mb) present	previous
$^{115}In(n,n')^{115m}In$	67 5	54.5 2.2[1], 63 4[2]
$^{27}Al(n,p)^{27}Mg$	69 5	68 4[3]
$^{27}Al(n,\alpha)^{24}Na$	117 8	112 5[3]
$^{197}Au(n,2n)^{196}Au$	2259 115	2270 120[3]

An internal report describing the work in detail will shortly be published. The report will also include a computer-code, EFINT, for calculation of the telescope efficiency for arbitrary telescope geometry.

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1) D.C. Santry and J.P. Butler, Can. J. Phys., 54, 8 (1976)

2) G. Magnusson and I. Bergqvist, Nucl. Technol. 34 114 (1977)

3) M. Bormann, H. Neuert and W. Scobel, Handbook on Nuclear Activation Cross-Sections, IAEA, Vienna (1974)

4.1.3 Capture Reactions In The Giant Resonance Region

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

(see 8.2)

4.1.4 Decay γ-rays From Levels In ^{57}Fe Populated By The Reaction $^{56}Fe(d,p\gamma)^{57}Fe$

L. Carlén and I. Bergqvist
L. Nilsson, Tandem Accelerator Laboratory, Uppsala

The decay γ-rays from bound states in ^{57}Fe have been studied by the reaction $^{56}Fe(d,p\gamma)^{57}Fe$ to obtain a better understanding of the neutron capture process in nuclei near the closed neutron shell at N=28. Neutron capture experiments in this mass region show strong correlation - which indicates nonstatistical effects - between the γ-widths of the unbound capture state and the single-particle strengths of low-lying states. We have applied the $(d,p\gamma)$ reaction to investigate possible correlations between the γ-ray branchings to the same final levels from bound initial levels with large single-particle strengths. The nucleus ^{57}Fe is a suitable case to study since spins and parities have been assigned[1)] to levels strongly populated in the (d,p) stripping reaction.

We have measureed the γ-ray decay branching of levels up to E_x=5.36 MeV,. Gamma-ray spectra in coincidence with protons have been recorded with a Ge(Li) detector. An annular surface barrier detector has been used for proton detection in the backward direction. Data were stored event by event on magnetic tape for subsequent sorting and analysis.

A comparison between experimental γ-ray branchings of levels with known spin, parity and single-particle strength and calculations based on the valence capture model is in progress. The intention is to investigate whether this capture model is applicable to neutron transfer reactions to bound states in this mass region.

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1) J.A. Thomson, Nucl. Phys. A227 (1974) 485.

4.1.5 The Average Resonance Spectroscopy Method Applied To Targets Of ^{50}Ti, ^{61}Ni, ^{64}Ni, ^{63}Cu, ^{65}Cu And ^{74}Ge

B. Erlandsson, A. Marcinkowski, K. Nilsson

A three-crystal pair spectrometer has been used to study the following reactions:

$^{50}Ti(p,\gamma)^{51}V$ for E_p = 2.6 - 3.1 MeV

$^{63}Cu(p,\gamma)^{64}Zn$ for E_p = 2.1 - 3.1 MeV

$^{64}Ni(p,\gamma)^{65}Cu$ for E_p = 1.9 - 3.0 MeV

$^{65}Cu(p,\gamma)^{66}Zn$ for E_p = 2.2 - 2.8 MeV

for the $^{61}Ni(p,\gamma)^{62}Cu$ and $^{74}Ge(p,\gamma)^{75}As$ reactions only preliminary investigations have been performed.

The gamma-ray spectra were measured throughout the proton energy interval in steps of about 15-20 keV. These spectra were added to get only a few averaged spectra. The intensities of high-energy gamma transitions populating the low-excited states of the final nucleus have been determined and divided by E_γ^α, where α is between 5 and 5.8 depending on the reaction. The reduced intensities seem to gather in different groups depending on spin and parity of the final states, which is in agreement with the theoretical calculations. This makes it possible to determine spin and parity for some levels up to about 4 MeV.

4.1.6 Beta Delayed Fission

S.A.E. Johansson and C.-O. Wene

The theoretical study of beta-dalayed fission (BDF) was started at the institute at the end of 1971 (1). Several works have been published where the effect of β-delayed fission is discussed (2,3,4,5). The focus has been on BDF in the very neutron-rich nuclides produced e.g. in the astrophysical r-process and in thermonuclear explosions. This work is now of immediate importance in view of the present increasing interest in using BDF to investigate the beta strength function, S , in very heavy nuclei and the fission barrier for nuclei far off stability.

These possibilities were pointed out in ref (3). Also the effect of BDF in the astrophysical r-process is being acknowledged. A special problem is the production ratios of the chronometric pairs $^{244}Pu/^{232}Th$, $^{235}U/^{238}U$ and $^{232}Th/^{238}U$ (4,6,7).

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1) S.A.E. Johansson, C.-O. Wene; Delayed fission: superheavy elements and the abundance of the very heavy elements, Annual Report 1972, Department of Nuclear Physics, University of Lund, January 1973, p. 5.40.

2) S.A.E. Johansson, C.-O. Wene; The Importance of Delayed Fission in the Production of Very Heavy and Superheavy Elements in Proceedings of Int. Conf. Nucl. Phys., Munich, August 27 - Sept 1, 1973 (Ed. J. de Boer, H.J. Mang) Vol I, p. 599, North Holland, American Elsevier; Amsterdam-London-New York, 1973.

3) C.-O. Wene, S.A.E. Johansson, Phys. Scripta 10A (1974) 156

4) C.-O. Wene, Astron Astrophys 44 (1975) 233

5) C.-O. Wene, S.A.E. Johansson, CERN 76-13, 584

6) K.L. Hainebach, D.N. Schramm, Astrophys. Journal 212 (1977) 347

7) T. Kirsten, Time and the solar system, MPI Kernphysik Heidelberg, November 1976 (to be published in: "The origin of the solar system", S.F. Dermott, Editor; Johan Wiley and Sons, Publ).

4.1.7 Fission Of ^{238}U Induced By ^{136}Xe For Energies Close To The Coulomb Barrier

C.-O. Wene
D. Habs, V. Metag, J. Schukraft and H.J. Specht, MPI, Kernphysik, Heidelberg and Universität, Heidelberg
K.D. Hildebrand, GSI, Darmstadt

The present development of heavy ion accelerators has made it possible to test different predictions of Coulomb fission (1-4) or other possible mechanisms for "fast" or "direct" fission (5). At the UNILAC in Darmstadt the $^{136}Xe + ^{238}U$ system has been studied at ^{136}Xe bombarding energies corresponding to 80-110% of the Coulomb barrier (6). The energies of the fission fragments and of the back-scattered projectile-like particles were measured by semi-conductor detectors. Exploiting the small difference in stopping power between ^{136}Xe and the light fission fragment, it is possible to measure the intensity of fragments close to the beam by putting a foil in front of an annular detector that is thick enough to stop the elastically scattered Xe-projectiles but still permits the light fragments to go through and be detected in coincidence with the backscattered projectiles. Through this technique it was possible to measure the fission intensity close to 0^{o} in the fissioning system. For fission angles $60^{o}<\theta_F<120^{o}$ both fission fragments were detected in coincidence with the backscattered projectiles. The correlated fragment energies give θ_F for each event assuming the mass division to be known. The two cases possible in asymmetric fission (light or heavy fragment at $\theta_F<90^{o}$) were distinguished by placing a 5.6 mg/cm^2 thick Ni-foil in front of one of the detectors.

Thus using a foil technique and exploiting the detailed kinematics involved in a heavy ion reaction, it is possible, by the fairly simple set-up used, to measure not only the excitation function but also the angular distribution. The result shows none of the fingerprints predicted for Coulomb fission, i.e. no pronounced peaking around 90^{o} (F) (1,2) or strong interference effects around the Coulomb barrier (4). The angular distribution at low bombarding energies shows a $1/\sin\langle\theta\rangle$ distribution while at higher Xe-energies the distribution becomes uniform.

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1) E. Guth, L. Wilets: Phys. Rev. Lett. 16 (1966) 30
2) L. Wilets, E. Guth, J.S. Tenn: Phys. Rev. 156 (1967) 1349
3) K. Beyer, A. Winther: Phys. Lett. B30 (1969) 296
4) H. Holm, W. Greiner: Nucl. Phys. A211 (1974) 333
5) H.H. Duebler, K. Dietrich: Phys. Lett. B62 (1976) 369
6) S. Habs, V. Metag, J. Schukraft, H.J. Specht, C.-O. Wene, K.D. Hildebrand: Z. Physik A283 (1977) 261

4.1.8 The Pelletron Accelerator

Staff: R. Hellborg, K. Håkansson. C. Nilsson

The pelletron accelerator has been used for experiments the whole year 1977 with stops only for a few weeks of summer- and winter-service. It has been run by three shifts for 7 days a week, with only the day-shift being managed by an operator from the machine staff. 31 persons have been attached full- or part-time to the accelerator group, 6 technical and mechanical staff members and 25 scientists.

4.2 Department of Physics - Photonuclear Group

4.2.1 The $(\gamma,2p)$ Reaction On ^{30}Si And The $(\gamma,2p)$, $(\gamma,2pn)$, $(\gamma,3p)$ And $(\gamma,3pn)$ Reactions On ^{31}P At Intermediate Energies

B. Bülow, B. Johnsson, M. Nilsson

The yields of the $(\gamma,2p)$ reaction on ^{30}Si and of the $(\gamma,2p)$, $(\gamma,2pn)$, $(\gamma,3p)$ and the $(\gamma,3pn)$ reactions on ^{31}P have been measured as a function of the maximum bremsstrahlung energy in the range 75-640 MeV. The cross sections have been deduced and are compared to Monte-Carlo calculation. The magnitude of the cross sections in the energy range above the threshold for photoproduction of mesons is also discussed using a simple analytical approach.

This work has been accepted for publication in Z. Physik.

4.2.2 Photoproduction Of ^{17}N

G Andersson, B. Bülow, B. Forkman, J. Grintals, B Johnsson, A. Järund, M. Nilsson

The yields for photoproduction of ^{17}N have been measured from ^{197}Au, ^{nat}Cu, ^{27}Al and ^{19}F. The measurements will be extended to include some more target nuclei in the mass range $19 \leq A_t \leq 197$. The detection of ^{17}N is carried out by counting the neutrons following the β^--decay of ^{17}N. Mean cross sections will be derived and compared to those obtained by Järund and Forkman (1) in a similar investigation on photoproduction of ^{24}Na from different target nuclei. The measurements will be finished during the late spring 1978.

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1) A. Järund, B. Forkman: Z. Physik A281 (1977) 39

4.2.3 Photoproduction Of ^{24}Na In ^{159}Tb

A. Järund, K. Lindgren

Photoproduction of ^{24}Na from a large number of nuclei in the mass region $27 \leq A_t \leq 239$ has been studied earlier by A. Järund, B. Friberg and B. Forkman (Z. Physik 262, (1973); Z. Physik A281 (1977) 39).

The mean cross sections deduced in the energy range 400 to 1000 MeV were found to vary with the target mass number in a manner similar to that for proton induced reactions. However, in the mass region 140 to 181 no measurements have been reported neither for photon nor for proton induced reactions.

In present experiment a sample of Tb_2O_3 was irradiated, and from the measured yield the mean cross section in the energy range 400 to 800 MeV was calculated to 2.6 μb. This value is considerably higher than for neighbouring target nuclei. The relative variation of experimental mean cross sections is fairly well reproduced by Monte Carlo-calculations, in which it is assumed that ^{24}Na is formed in a binary fission.

4.2.4 Charged Photoparticles From Complex Nuclei

J.-O. Adler, G. Andersson, H.-Å. Gustafsson, K. Hansen

The studies of photoemission of hydrogen and helium isotopes from complex target nuclei at intermediate energies which started with measurements on Au, Ag and Cu have continued during 1977 with measurements on Al and C.

As for heavy nuclei we have irradiated Al and C with 500 MeV bremsstrahlung and measured energy and angular distributions.

Data analysis is in progress and the results will be published during spring-78.

4.2.5 Binary Fission Induced By 600 MeV Protons In U, Bi, Tb, La And Ag

G. Andersson, M. Areskoug, H.-Å. Gustafsson, E. Hagebø, G. Hyltén, B. Schrøder

The experiment was performed at the 600 MeV synchro-cyclotron at CERN, Geneva, and the data-taking was completed in May 1977. The complementary fission products were detected in coincidence with two surface barrier detectors and a transmission detector, the latter included to allow time-of-flight measurements. From the coincidence count-rates the fission cross sections were obtained. At present these are anlysed to yield the fission barrier heights of Tb, La and Ag. In current theoretical predictions, these barrier heights differ considerably.

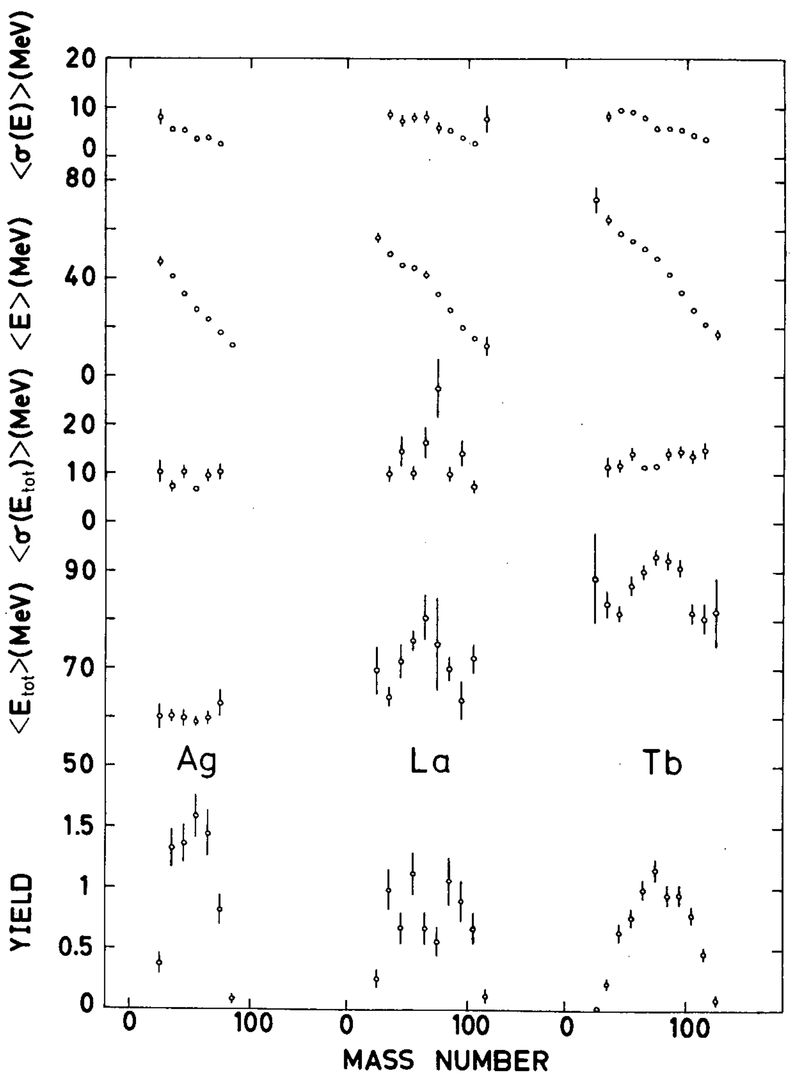

Figure 1

The mass distribution for these three elements are shown in fig. 1, which also gives mean values and standard deviations of the total- and single kinetic energies as a function of mass. The most interesting feature of fig. 1 is the indication of an asymmetric mass distribution in the case of La. A comparison of the mass widths with the predictions of the liquid drop model (L.R. Nix, Nucl. Phys. A130 (1969) 241) shows that the widths of Tb and La are in good agreement with the predictions, however, Ag has a width about three times smaller than expected. The predicted sharp increase in the mass width around Ag is connected with the location of the Businaro-Gallone point at Ag in the quoted version of the liquid drop model. Below this limit the saddle-point is expected to lose its stability against asymmetric deformations. Our experimental results on the mass widths indicate that the Businaro-Gallone point is to be found, if it exists, in a mass range much lower than Ag.

The results of the analyses of the mass distributions are published in Phys. Lett. 71B (1977) 279.

4.2.6 Subbarrier photofission of ^{234}U, ^{236}U, ^{238}U And ^{232}Th

A. Alm[1], L.-J. Lindgren, A. Sandell, T. Åkesson

During the year the works on ^{238}U and ^{234}U have been completed (Nuclear Physics Report LUNFD6/NFFR-3009 and Nuclear Physics Report LUNFD6/NFFR-3017). The experimental results were analysed within the framework of the double hump fission barrier model. In the cas of ^{238}U, the outcome of the analysis were, that the resulting barrier parameters are in agreement to those obtained in particle induced fission, except for the resonance parameters, where our values are changed due to an additional resonance found in the 1^-0 channel. As was the case with ^{236}U (Nuclear Physics A271 1976), the theoretical prediction of degenerated outer saddle points 2^+0 and 1^-0 barriers were found. In the case of ^{234}U, our data were not consistent to those barrier parameters obtained in particle induced fission. In order to reduce the number of freee parameters, the degeneracy of the outer 2^+0 and 1^-0 saddle points was assumed. However, the main difference between the barrier parameters obtained in our analysis, and those obtained in particle induced fission, is a thinner barrier at the first saddle point of ^{234}U, possibly effected by the N=125 shell. The experimental part of the $^{232}Th(\gamma,f)$ work is almost completed, and the interpretation of the results will begin in the first half of 1978.

[1] present address: ASEA, Västerås

4.3 Electron Accelerator Laboratory

Staff: O. Cederholm, M. Eriksson, J. Grintals, L. Hansson, L.-E. Johansson, L. Persson, W. Stiefler, B.-E. Wingren

4.3.1 1.2 GeV Electron Synchrotron

The running-for-experiments time was 800 hours this year. Almost all the time has been spent for photo-nuclear reaction experiments.

Because of the work on the new accelerator system only minor maintenance has been spent on the synchrotron and then mainly on the vacuum system.

4.3.2 100 MeV Race-track Microtron/Pulse-stretcher System (MAX)

In June 1977 this project was funded by the Swedish Atomic Research Council, the University of Lund, the Wallenberg Foundation and the Bank of Sweden Tercentenary Foundation.

Most parts to the race-track microtron have been manufactured. During this year, the vacuum chambers and two new pulse-modulators have been constructed.

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

5.1 Fission cross section ratio measurements

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

Fission cross section ratios of $^{238}U/^{235}U$ and $^{236}U/^{235}U$ in the neutron energy region from 5 to 9 MeV have been measured, calculated and corrected. The data are in fair agreement with other recent measurements above 5.5 MeV neutron energy while systematically lower values have been obtained below this energy. Additional measurements for the $^{232}Th/^{235}U$ fission cross section ratio are in progress.

5.2 Studies of the $^{6}Li(n,\alpha)T$ reaction

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

(see 8.3)

6. RESEARCH INSTITUTE OF PHYSICS, S-104 05 STOCKHOLM 50

A Nilsson

The work in nuclear physics is concentrated on high-spin states populated by bombardment with α-particles and heavy ions in the 225-cm cyclotron. The building of concrete walls separating four caves for physics experiments and one cave for isotope production in an external beam is near completion in the new experimental area. A new data collection and handling system, comprising one PDP 11/45 and one PDP 11/70, is being installed to meet the demands for faster data acquisition.

The research aiming at the production of ^{15}O-labelled deoxyglucose was continued until the ultimate shut-down of the 80-cm cyclotron (the magnet of which will be used for beam switching in the above-mentioned area). Other activities of bio-medical interest included proton-induced X-ray analysis of Cd and Pb in human blood and sperm, performed at the 2 MV Van de Graaff in cooperation with researchers at the Caroline Hospital in Stockholm.

The surface physics group at the institute has continued their studies relevant for first-wall deterioration in fusion reactors. A new method to determine the time when blistering of a He-ion-irradiated surface starts has been developed, using a laser beam to monitor the accompanying change of reflectivity. The thickness of the resulting flakes has been measured (by direct observation in a scanning electron microscope) as a function of ion energy in the range 10-80 keV.

7. THE STUDSVIK SCIENCE RESEARCH LABORATORY,

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7.1 Nuclear Chemistry Group

(K Aleklett, P Hoff, L Jacobsson, B Johansson, O Johansson, E Lund and G Rudstam)

7.1.1 Total beta decay energies

Most of our results have now been published, namely those for the nuclides $^{75-78}$Zn, $^{76-79}$Ga, ^{79,80}Ge, and ^{80,81,83}As (ref.[1]) for the nuclides ^{128,130,131,134}Sb, ^{134,135}Te (ref.[2]), and finally, for the doubly closed shell nuclide ^{132}Sn and its daughter ^{132}Sb (ref.[3]). In the case of the element indium a new series of experiments have been carried out to complement earlier measurements. A report containing the new data has been prepared for publication (ref.[4]). This includes decay energies for ground states and isomeric states of $^{120-129}$In.

The total decay energies, and their implications are also discussed in two thesises publicly defended during 1977 (refs.[5] and[6]).

7.1.2 Delayed neutrons

During 1977 two articles based on earlier work have been prepared and published. These contain spectra of $^{79-81}$Ga, ^{94,95}Rb, and ^{129,130}In (ref.[7]), and spectra of ^{88,89}Br, ^{138,140}I, ^{142}(Xe,Cs), and ^{144}Cs (ref.[8]).

The description of delayed-neutron spectra in terms of a fine-structure component and a few continuous components corresponding to different neutron wave numbers was reported last year. The aim is to facilitate the calculation of gross properties of interest to nuclear technology. The earlier report has now been revised and has been widely distributed by IAEA (ref.[9]). A shortened version, which does not contain figures of the spectra of all the precursors included in the analysis, has been published (ref.[10]).

An extensive project has started in which the branching ratio of all delayed-neutron precursors produced at OSIRIS will be determined. Both the neutron and the beta activity will be measured yielding a direct determination of the branching ratio. The samples are positioned inside a neutron counter containing 29 ^{3}He-tubes and viewed by a plastic beta detector. Both neutrons and beta particles are measured from the same sample. A number of precursors have already been measured, but the analyses of the measurements are not yet finished, and no final results can be given at this point. The list of cases studies includes: $^{87-91}$Br, ^{127}In, ^{136}Te, $^{137-141}$I, and ^{141}Cs.

A report on the status of delayed neutron data has been given at the Second Advisory Group Meeing on Fission Product Nuclear Data in Petten, Netherlands, 5 - 9 September 1977 (ref.[11]). It will later be publised in the proceedings of the meeting.

7.1.3 Average beta energies

The project aiming at measuring the average beta energy of individual fission products has progressed with the analysis of earlier measurements and with a number of new experiments. The analysis is not yet in its final state. It is necessary to know the efficiency and the response functions of the beta spectrometer very well in order to be able to convert the measured pulse spectrum into an electron spectrum from which the average beta energy is deduced. These functions have been carefully studied, but there may still be a systematic uncertainty in the efficiency values at high electron energies. Such an error will cause all results to be either systematically too low or too high. This uncertainty will be sorted out by comparisons with measurements done at a large electromagnetic beta spectrometer which has now been attached to OSIRIS.

7.1.4 Nuclear Spectroscopy Group

(B Fogelberg and H Tovedal)

The work aims at determining the decay schemes of shortlived fission product nuclei at the OSIRIS facility. During 1977 the decays of the even mass isotopes of In have been investigated. Two or three isomers of In were observed in each isotope up to A = 128. The experimental part of this comprehensive study is now essentially completed. Energy level schemes, based on $\gamma\gamma$-coincidence measurements, have been constructed for $^{122,124,126,128}Sn$. Measurements of level half-lives in the ns and μs regions have permitted determinations of transition probabilities from low lying negative parity states (ref.[12]).

Last year we reported on the measurement of the neutron binding energy of the neutron emitter ^{137}Xe (ref.[13]). Knowledge of this quantity is necessary in order to make meaningful comparisons between γ-ray decay schemes of the unbound levels in ^{137}Xe, and the delayed neutron spectrum following the decay of ^{137}I. During 1977, much effort have been put into the construction of a γ-ray decay scheme for transitions in ^{137}Xe following the decay of ^{137}I. A total of 57 levels have been firmly establised, through extensive $\gamma\gamma$-coincidence measurements. One of these levels is situated at the neutron binding energy (within 0.5 keV) and 18 more γ-decaying levels were found up to some 800 keV above the binding energy. At present, we are undertaking a detailed comparison between our results and the published data on the delayed neutron spectrum.

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7.2 Neutron Physics Laboratory

7.2.2 Neutron inelastic scattering from some odd-mass nuclei in the energy range 2.0 to 4.5 MeV

E Ramström

Fast neutron inelastic scattering from nine odd-mass nuclei, i.e. ^{27}Al, ^{51}V, ^{55}Mn, ^{59}Co, ^{63}Cu, ^{65}Cu, ^{89}Y, ^{207}Pb and ^{209}Bi, has been measured with a time-of-flight technique for incident neutrons in the energy range 2.0 to 4.5 MeV. Excitation functions for the population of the individual levels in the nuclei have been derived. The experimental data have been used to investigate the usefulness of the Hauser-Feshbach statistical model modified according to Moldauer in describing the scattering process. It was found that the inelastic scattering cross sections calculated with the Hauser-Feshbach-Moldauer model in most cases describe the experimental data well within 20 per cent, with the exception of a few levels in the heavier nuclei with collective excited states.

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

P-I Johansson and G Nilsson

The energy release from fission fragments is a critical parameter for design of emergency core cooling systems in reactors.

Measurements have been performed at the laboratory with the aim of studying the energy distribution and the total energy of β- and γ-radiation emitted 10-1500 s after thermal fission of ^{235}U. Measurements of gamma-ray emission are completed and reported[1)]. Thermal neutrons for inducing fissions are produced by a van de Graaff accelerator. The samples of ^{235}U are of the thickness 5 ng/cm^2 and enclosed in cylinders of polyethylen for pneumatic transportation between the neutron source and detector.

The beta-ray energy released was detected by a flat Si(Li) detector in anticoincidence mode with two side detectors. The response matrix is determined by beta-ray decay sources and by a beta-spectrometer.

The data analysis, now in progress, is very similar to that for the gamma-ray energy[1)].

7.2.4 The excitation function of the ^{13}C(α,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 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 x 10^8K 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.

7.2.5 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) ^4He. Accordingly, a thorough knowledge of the neutron cross section data for aluminium in the energy region up to 14 MeV is important.

Earlier measurements of differential inelastic scattering cross section between 5.5 and 9.0 MeV show discrepancies of the order of 25 per cent[2]. 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, 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.

7.2.6 Measurement of the energy levels and inelastic neutron scattering cross sections of ^{141}Pr from the (n,n′γ)-reaction

B Trostell and T Wiedling

As an extension of earlier measurements performed at this laboratory[3] the excitation functions of the levels in ^{141}Pr have been studied with the (n,n′γ)-reaction from E_n = 1.2 to 2.0 MeV.

A pulsed proton beam from the 6.0 MeV Van de Graaff accelerator incident upon a tritium gas target produced neutrons with a total energy resolution of 40-50 keV.

In order to resolve close lying levels a Ge(Li) detector was used to detect the γ-rays. The detector, placed in 125^{o} relative to the ion beam, had a well collimated heavy shield and togheter with TOF-gating an excellent signal to noise ratio was achieved.

The relative target neutron flux was monitored with a directionally sensitive, collimated and shielded standard long counter and the cross sections measured relative to the 847 keV γ-ray production cross section of ^{56}Fe.

The C(n,n)-reaction was used as a background check.

Analysis of the results is in progress.

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

E Ramström and B Trostell

The study of differential cross section angular distributions for neutron elastic scattering at large angles is a sensitive method for testing the effect of the choice of the numerical value of the spin-orbit term of the optical model potential. This is obvious from calculations which demonstrate that changes in the depth of the spin-orbit term cause quite drastic changes in the neutron elastic scattering angular distributions at backward angles. Thus differential cross sections for neutron elastic scattering have been studied in the angular region 20^{o} to 174^{o} for Fe, Co, In and Bi at a primary neutron energy of 7.0 MeV and for Co, In and Bi at 8.0 MeV. Comparisons between measured and calculated data show that the experimental cross sections for all the studied elements and energies are in good agreement with calculations using a potential depth for the spin-orbit term of 6 MeV.

7.2.8 Prompt fission neutron spectrum of ^{235}U

J M Adams* and B Trostell

Reactor experiments indicate the presence of more fission neutrons below ~100 keV than can be accounted for on the basis of the evaluated experimental data currently in use[4)]. The prompt fission neutron spectrum of ^{235}U have therefore been measured at an incident neutron energy of 100 keV by the TOF-technique.

* AERE, Harwell, England

A ~10 keV thick Li-metal target bombarded with a pulsed proton beam from the Studsvik 6 MeV Van de Graaff accelerator served a neutron source. Two heavy shielded NE 213 scintillators placed in 87.5 resp. 92.5 degrees relative to the ion beam viewed the ^{235}U-enriched sample, which was a hollow thin walled cylinder. The detector biases were set to ~30 keV neutron energy.

The detector efficiences were determined from the angular distributions from the ^{7}Li(p,n)^{7}Be-, ^{3}H(p,n)^{3}He- and ^{2}H(d,n)^{3}He-reactions at different incident ion energies. The energy calibration of the detectors was performed with the ^{9}Be(d,n)^{10}B-reaction and the thick target neutrons from the ^{65}Cu(p,n)^{65}Zn-reaction seen through an iron absorberer.

The relative neutron flux was monitored with a directionally sensitive standard long counter.

Analysis of the results is in progress.

7.2.9 Neutron elastic scattering

S Lundberg and N Olsson

Extensive studies of the neutron elastic scattering process have been in progress for several years. A summary of results of these studies has recently been presented[5]. The immediate goals of the scattering program are to perform precision measurements on some heavy elements, particularly lead and bismuth, in the energy range 3 to 3.5 MeV and close to 8 MeV. The observed data are to be subject to optical model analysis in a study of the details of its potential.

7.2.10 A study of the neutron induced reactions for ^{19}F, ^{56}Fe and ^{59}Co in the energy interval 16 to 22 MeV

V Corcalciuc*, B Holmqvist, A Marcinkowski** and G A Prokopets***

The analysis of the experimental data of this work were completed about one year ago. A paper regarding the results of the measurements has been written, the abstract of which is given below.

Abstract

Cross section have been measured for the production of prompt γ-rays following the interaction between the nuclei ^{19}F, ^{56}Fe and ^{59}Co and neutrons at the energies 16.2, 18.1, 19.3, 20.5 and 21.8 MeV. The γ-ray spectra were observed with a Ge(Li)

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spectrometer and time-of-flight technique. Analysis of the experimental data revealed that only (n,n') (n,2n) and (n,np) or (n,d) reactions takes place with a noticeable probability. The experimental cross sections have been used for comparisons with compound statistical model calculations of the cross sections for the population of low-lying states of the reaction products. These investigations showed that the statistical model approach is not sufficient to describe the experimental excitation functions. The results indicate that direct and pre-compound processes must be included in the analysis of γ-ray yields from neutron induced reactions at bombarding energies above 14 MeV.

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

8.1 The tandem accelerator

During 1977 a new gas transport system has been installed which will considerably speed up the openings of the pressure vessel and allow for the use of SF_6 as insulation gas. The sputter ion source (Hiconex 834) is now running very well and a number of negative ion beams have been produced.

8.2 Precise measurements of the differential cross section for n-d elastic scattering

L Amtén, A. Johansson and B Sundqvist

In Uppsala the nuclear few body problem has been studied by comparing our high accuracy (~ 1 %) experimental data with sophisticated dynamically exact three body calculations (Faddeev calculations). As one part of this project the differential cross section for n-d elastic scattering has been measured at 8 and 10 MeV (neutron lab energy). Earlier only two measurements between 6 and 13 MeV (1,2) have been reported both suffering from large relative and absolute errors.

During the last year no experimental work on this reaction has been performed at Uppsala but instead the existing data have been thoroughly examined (3,4). The experimental method was described in the last "Progress Report".

Significant discrepancies have been established between the measured cross section and the results from a large number of Faddeev calculations. At the cross section minimum the measurements give a lower cross section than all calculations. In this region the cross section depends on different two body terms (^3S, ^1P, $^3P_0$, $^3P_2$, $^3D_1$) but there is also a relatively high sensitivity of the deuteron tensor force. Approximately 10 % of the cross section emanates from this force and thus there is a possibility to extract knowledge about this parameter.

The present n-d data give an opportunity to test to what extent the principle of charge symmetry is valid in this type of scattering since the corresponding p-d cross sections are well known (5). It is found that the n-d cross section at the minimum is 12 % smaller than the p-d, which is in good agreement with recent calculations, which include the Coulomb forces in an exact way.

More measurements on the 10 MeV angular distribution are in progress.

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8.3 Studies of the $^{6}Li(n,\alpha)T$ reaction

T Andersson, L Nilsson and C Nordborg
H Condé and L G Strömberg, National Defense Research Institute, Stockholm

Angular distributions of the t and α:s have been measured at incident neutron energies E_n = 2.0, 2.8 and 3.4 MeV. The measurements have been made by recording the outgoing α- and t-particles with solid state detectors at 8 different angles using a thin (300 μg/cm^2) ^{6}Li metal target. A measurement of the differential $^{6}Li(n,\alpha)$ cross section at about 30^{o} relative to the 180^{o} n-p scattering cross section is in progress. A ^{6}LiH samle is used in this experiment which has been analyzed by means of Coulomb scattering of ^{32}S-ions.

Measurements of the differential cross section for the inverse reaction $T(\alpha,{}^{6}Li)n$ by recording the outgoing ^{6}Li ions with a magnetic spectrograph are also in progress.

8.4 Neutron capture reactions in the giant resonance region

I Bergqvist, N Olsson and S Lundberg, Department of Physics,
University of Lund
A Lindholm and L Nilsson

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).

The reactions $^{89}Y(n,\gamma)^{90}Y$ and $^{140}Ce(n,\gamma)^{141}Ce$ have been studied in a joint project with a research group at Los Alamos (2). Experiments in Uppsala and Los Alamos cover the entire giant resonance region with neutron energies between 6 and 16 MeV. In this energy 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 other capture processes than DSD at neutron energies below 7 MeV capture experiments on ^{40}Ca, ^{58}Ni and ^{89}Y are performed. Neutrons with energies between 2.5 and 7 MeV are produced using the $^{3}H(p,n)^{3}He$ reaction. In this energy region calculations based on the CN model in addition to the DSD model give the same energy dependence of the capture cross sections as observed in the experiments.

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 $4\pi \cdot (\frac{d\sigma}{d\Omega})_{90^{\circ}}$, 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 asymmetries 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 (3).

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9.1 Institute of Physics

9.1.1 Gamma-gamma directional correlations in ^{90}Zr

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

Directional correlations of $\gamma\gamma$-cascades in ^{90}Zr have been measured employing a twelve-channel goniometer. The obtained correlation coefficients are:

141.2-1129.1 keV, A_2=-0.070(12), A_4=-0.003(10); 1611.8-1129.1 keV, A_2=-0.088(20), A_4=0.013(18); 1716.4-1129.1 keV, A_2=-0.011(75), A_4=0.041(60); 1984.7-1129.1 keV, A_2=-0.006(54), A_4=-0.036(50); 827.7-1913.3 keV, A_2=0.164(40), A_4=0.062(35); 132.7-2186.4 keV, A_2=0.187(38), A_4=-0.063(36); 890.6-2186.4 keV, A_2=0.132(51), A_4=-0.023(48).

The spin and parity 7^+ is assigned to the 5060.0 keV level. The multipole mixing ratios of the involved γ-ray transitions have been determined.

Transition keV	Mixing ratio	Multipoles and spins
132.7	$-0.05 \leq \delta \leq 0.13$	M4/E3 ; $5^- - 2^+$
141.2	$-0.10 \leq \delta \leq 0.10$	M3/E2 ; $8^+ - 6^+$
827.7	$-0.17 \leq \delta \leq 0.05$	M2/E1 ; $7^+ - 6^-$
	$-0.17 \leq \delta \leq 0.17$	M2/E1 ; $7^+ - 7^-$
890.6	$-0.05 \leq \delta \leq 0.08$	M3/E2 ; $4^+ - 2^+$
1129.1	$-0.18 \leq \delta \leq 0.06$	M2/E1 ; $6^+ - 5^-$
1611.8	$0.19 \leq \delta \leq 4.2$	E2/M1 ; $7^+ - 6^+$
1716.4	$-0.11 \leq \delta \leq 0.55$ (or $\delta \geq 1.70$)	E2/M1 ; $7^+ - 6^+$
	$-0.19 \leq \delta \leq 0.19$	M3/E2 ; $8^+ - 6^+$
1913.3	$-7.3 \leq \delta \leq 0.01$	E2/M1 ; $6^- - 5^-$
	$-0.13 \leq \delta \leq 0.17$	M3/E2 ; $7^- - 5^-$
1984.7	$-0.07 \leq \delta \leq 0.37$ (or $\delta \geq 2.4$)	E2/M1 ; $7^+ - 6^+$
	$-0.5 \leq \delta \leq 0.2$	M3/E2 ; $8^+ - 6^+$
2186.4	$-0.10 \leq \delta \leq 0.10$	M3/E2 ; $2^+ - 0^+$

9.1.2 Gamma-gamma directional correlations studies in ^{206}Pb

Chr. Bargholtz, S. Beshai, M. El-Khosht, L. Gidefeldt,
B. Sundström och K. Viktorsson (i samarbete med Åbo Akademi)

By use of a multichannel goniometer gamma-gamma directional correlations have been measured in ^{206}Pb. The obtained directional coefficients are (energies in keV) :

	A_2	A_4
632 - 184	0.014(19)	0.003(12)
895 - 184	0.046(12)	-0.020(10)
1019 - 184	0.026(14)	0.003(12)
262 - 632	0.009(17)	0.015(18)
386 - 632	-0.023(71)	0.032(49)
620 - 398	-0.120(30)	-0.002(27)
516 - 881	0.180(11)	-0.0095(57)
1098 - 881	-0.072(27)	0.009(21)
497 - 1098	-0.136(16)	0.0120(61)
620 - 1098	-0.173(24)	0.001(20)
1719 - 343	0.025(19)	0.006(19)
1719 - 881	-0.079(17)	-0.006(15)
1719-(343)-537	0.063(27)	-0.004(23)
$1719-\left(\substack{881\\343-537}\right)-803$	-0.0641(81)	-0.0128(71)