KDK-32
NEANDC(OR)-152/L
INDC(SWD)-12/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN, DEC 77 - DEC 78

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN

APRIL 1979

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Compiled by
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National Defense Research Institute
Stockholm, Sweden

April 1979

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	Energy Max	KDK-32 Page	Lab	Comments
Li	6	(n,t)	EXPT PROG	2.8+6	3.4+6	36	TLU	ANDERSSON+.
N	13	(n,p)	EXPT PROG			28	SWR	RAMSTRÖM. RESULTS FROM MEAS. ON INVERSE REACTION
F	19	DIFF INELASTIC	EXPT PROG	1.6+7	2.2+7	31	SWR	HOLMQVIST+.
		(n,2n)	EXPT PROG	1.6+7	2.2+7	31	SWR	
		(n,np)	EXPT PROG	1.6+7	2.2+7	31	SWR	
		(n,d)	EXPT PROG	1.6+7	2.2+7	31	SWR	
AL	27	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
SI	28	(n,γ)	EXPT PROG	3.2+6	1.5+7	34	TLU	BERGQVIST+. RESULTS COMP. TO DSD CALC.
S	32	(n,γ)	EXPT PROG	3.2+6	1.5+7	34	TLU	BERGQVIST+. RESULTS COMP. TO DSD AND CN CALC.
CA	40	(n,γ)	EXPT PROG	3.0+6	1.0+7	34	TLU	BERGQVIST+. RESULTS COMP. TO DSD AND ON CALC.
V	51	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
MN	55	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
MN	55	(n,γ)	EXPT PROG	1.0+6	1.5+7	12	LND	MAGNUSSON+ ACT. TECHNIQUE
FE	56	DIFF INELASTIC	EXPT PROG	1.6+7	2.2+7	31	SWR	HOLMQVIST+.
		(n,2n)	EXPT PROG	1.6+7	2.2+7	31	SWR	
		(n,np)	EXPT PROG	1.6+7	2.2+7	31	SWR	
		(n,d)	EXPT PROG	1.6+7	2.2+7	31	SWR	
CO	59	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
CO	59	DIFF INELASTIC	EXPT PROG	1.6+7	2.2+7	31	SWR	HOLMQVIST+.
		(n,2n)	EXPT PROG	1.6+7	2.2+7	31	SWR	
		(n,np)	EXPT PROG	1.6+7	2.2+7	31	SWR	
		(n,d)	EXPT PROG	1.6+7	2.2+7	31	SWR	
CU	63	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
CU	65	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
GA	80	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
GA	81	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
BR	85	FISS PROD β	EXPT PROG			22	SWR	ALEKLETT+.
BR	86	FISS PROD β	EXPT PROG			22	SWR	ALEKLETT+.

Element S	A	Quantity	Type	Energy Min	Energy Max	KDK-32 Page	Lab	Comments
BR	87	FISS PROD γ	EXPT PROG			26	SWR	FOGELBERG.
BR	87	FISS PROD β	EXPT PROG			22	SWR	ALEKLETT+.
BR	87	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
BR	88	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
BR	88	FISS PROD β	EXPT PROG			22	SWR	ALEKLETT+.
BR	89	FISS PROD β	EXPT PROG			22	SWR	ALEKLETT+.
BR	89	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
RB	93	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
RB	94	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
RB	95	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
RB	96	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
Y	89	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
Y	89	DIFF INELASTIC	EXPT PROG	2.2+6	3.5+6	30	SWR	TROSTELL.
Y	89	(n,γ)	EXPT PROG	1.0+6	1.5+7	12	LND	MAGNUSSON+. ACT. TECHNIQUE
IN	127	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
IN	128	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
IN	129	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
IN	130	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
I	127	(n,γ)	EXPT PROG	1.0+6	1.5+7	12	LND	MAGNUSSON+. ACT. TECHNIQUE
I	137	FISS PROD γ	EXPT PROG			26	SWR	FOGELBERG.
I	137	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
I	138	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
I	139	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
CS	141	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
CS	142	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
CS	143	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
CS	144	DELAYED NEUTS	EXPT PROG			22	SWR	ALEKLETT+.
BA	138	(n,γ)	EXPT PROG	1.0+6	1.5+7	12	LND	MAGNUSSON+. ACT. TECHNIQUE
PR	141	INELASTIC	EXPT PROG	1.1+6	2.5+6	30	SWR	TROSTELL.
W	186	(n,γ)	EXPT PROG	1.0+6	1.5+7	12	LND	MAGNUSSON+. ACT. TECHNIQUE
AU	197	(n,γ)	EXPT PROG	1.0+6	1.5+7	12	LND	MAGNUSSON+. ACT. TECHNIQUE
PB	206	DIFF ELASTIC	EXPT PROG	1.5+6	2.0+7	29	SWR	OLSSON+. TOF 15^{o} TO 160^{o}

Element S	A	Quantity	Type	Energy Min	Max	KDK-32 Page	Lab	Comments
PB	207	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
BI		DIFF ELASTIC	EXPT PROG	1.5+6	2.0+7	29	SWR	OLSON+. TOF 15° TO 160°
BI	209	DIFF INELASTIC	EXPT PROG	2.0+6	4.5+6	29	SWR	RAMSTRÖM.
TH	232	PHOTO-FISSION	EXPT PROG			18	LND	LINDGREN+.
TH	232	FISSION	EXPT PROG	4.0+6	9.0+6	20	FOA	CONDE+. REL TO U235 FISSION
TH	232	TOTAL FISSION (n,γ) RI $\bar{\nu}$	COMP PROG	THR	2.0+7		FOA TLU LND AE FOA	CONDE. NORDBORG. ANDERSSON. HÄGGBLOM. CONDE.
U	233	TOTAL FISSION (n,γ) RI $\bar{\nu}$	COMP PROG	THR	2.0+7	3	FOA TLU LND AE FOA	CONDE. NORDBORG. ANDERSSON. HÄGGBLOM. CONDE.
U	234	PHOTO-FISSION	EXPT PROG			18	LND	LINDGREN+.
U	235	FISS PROD	EXPT PROG	MAXW		30	SWR	JOHANSSON+. DELAYED GAMMA AFTER FISSN
U	235	FISS PROD	EXPT PROG	MAXW		30	SWR	JOHANSSON+. DELAYED β AFTER FISSN
U	235	TOTAL FISSION ELASTIC (n,γ) RI $\bar{\nu}$	COMP PROG	THR	2.0+7	3	FOA TLU SWR LND AE FOA	CONDE. NORDBORG. TROSTELL. ANDERSSON. HÄGGBLOM CONDE.
U	236	FISSION	EXPT PROG	4.0+6	9.0+6	20	FOA	CONDE+. REL TO U235 FISSION
U	236	PHOTO-FISSION	EXPT PROG			18	LND	LINDGREN+.
U	238	PHOTO-FISSION	EXPT PROG			18	LND	LINDGREN+.
U	238	TOTAL FISSION INELASTIC (n,γ) $(n,2n)$ RI $\bar{\nu}$	COMP PROG	THR	2.0+7	3	FOA TLU SWR SWR LND AE FOA	CONDE. NORDBORG. TROSTELL. TROSTELL. ANDERSSON. HÄGGBLOM. CONDE.
NP	237	TOTAL FISSION (n,γ) ν	COMP PROG	THR	2.0+7	3	FOA TLU LND FOA	CONDE. NORDBORG. ANDERSSON CONDE.

Element S	A	Quantity	Type	Energy Min	Energy Max	KDK-32 Page	Lab	Comments
PU	239	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		ELASTIC					SWR	TROSTELL.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.
		$\bar{\nu}$					FOA	CONDÉ.
PU	240	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.
PU	241	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.
PU	242	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					AE	HÄGGBLOM.
AM	241	TOTAL	COMP PROG	THR	2.0+7	3	CTH	CHRISTIANSSON.
		FISSION					CTH	-"-
		(n,γ)					CTH	-"-
		RI					AE	HÄGGBLOM.
AM	243	TOTAL	COMP PROG	THR	2.0+7	3	CTH	SANDBERG.
		FISSION					CTH	-"-
		(n,γ)					CTH	-"-
		RI					AE	HÄGGBLOM.
CM	244	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.
CM	245	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.
CM	246	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.
CM	247	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.
CM	248	TOTAL	COMP PROG	THR	2.0+7	3	FOA	CONDÉ.
		FISSION					TLU	NORDBORG.
		(n,γ)					LND	ANDERSSON.
		RI					AE	HÄGGBLOM.

1. THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

1.1 Status report, Dec 77 - Dec 78

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).

The Committee has discussed nuclear data requests in relation to measurements and compilation activities in progress. A report containing neutron cross section requests for research in the nuclear energy field has been published (KDK-29). The requests have been submitted to WRENDA. The work to compile selected neutron data for a number of actinides (see 1.2) initiated by KDK in 1978 and sponsored by the Swedish Nuclear Power Inspectorate is in progress (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-23 Progress report on Nuclear Data Activities in Sweden (Dec 76 - Dec 77) April 1978.

KDK-24 Report from "IAEA Research Coordination Meeting on the Intercomparison of Evaluations of Actinide Neutron Data", 17-19 April, 1978, Vienna (May 1978) (In Swedish).

KDK-25 Report from the 20th NEANDC Meeting, 3-7 April, 1978, Oak Ridge, USA (May 1978) (In Swedish).

KDK-26 KDK Annual Report 1977 (September 1978) (In Swedish).

KDK-27 Report from the 10th INDC Meeting, 3-7 October, 1978, Bucarest, Romania (October 1978) (In Swedish).

KDK-28 Compilation of Actinide Cross Sections, Quarterly report, July 1 Sept 30, 1978 (October 1978)

KDK-29 Swedish Request List of Neutron Nuclear Data (December 1978) (In Swedish).

KDK-30 Report from "Meeting on Nuclear Data of Higher Pu and Am Isotopes for Reactor Applications", 20-21 November, 1978, NNDC, Brookhaven, USA (December 1978) (In Swedish).

KDK-31 Report from "New-Evaluator Orientation Course for the Nuclear Data Project", 13-17 November, 1978, Oak Ridge, USA (January 1979) (In Swedish).

1.2 Compilation of neutron data for selected actinides

P Andersson, Lund Inst. of Techn.
J-E Christiansson, Univ. of Gothenburg,
H Condé, Nat. Defense Research Inst.,
H Häggblom, Studsvik Energiteknik AB,
C Nordborg*, Tandem Accelerator Lab.,
H Sandberg, Chalmers Univ. of Techn. and
B Trostell, The Studsvik Science Lab.

The Swedish Nuclear Data Committee has initiated a compilation of evaluated and experimental neutron data for 16 different isotopes from ^{232}Th to ^{248}Cm.

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

The compilation will include evaluated data from the following libraries: ENDF/B, ENDL, UKNDL, KEDAK and JENDL. A selection of experimental data is also compiled from the NEUDADA library and recent publication.

The compiled data will be presented in graphs covering for each isotope and cross section two energy regions: one from thermal energy to 0.5 eV and the other from about 10 keV to 20 MeV. The thermal values and resonance integrals (0.5 eV-50 keV) will be given in tables.

The compilation work is planned to be reported during Autumn 79.

*Present address: NEA Nuclear Data Bank, 911 90 Gif-sur-Yvette, France

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

2.1 Department of Physics

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

S E Arnell, Ö Skeppstedt and E Wallander

This year new experimental information is obtained about yrast and next to yrast states for $^{83}Sr_{45}$, $^{81}Sr_{43}$ and $^{85}Zr_{45}$. The high-spin states were studied by (α,n) and (α,3n) reactions using Kr and Sr targets. The α-particle beams were delivered by the tandem generator at Uppsala University, the cyclotron of Åbo Akademi, Finland, and the 225 cm cyclotron at the Research Institute of Physics, Stockholm.

A cc.

Our program for the investigation of neutron deficient odd Zr and Sr isotopes by (α,xn) reactions, included studies of the isotone pairs ^{85}Sr[1] - ^{87}Zr[2] (N = 47) and ^{83}Sr[3] - ^{85}Zr (N = 45), as well as ^{81}Sr (N = 43). The internal similarities within the pairs and also within the ^{79}Kr[4] - ^{81}Sr pair are drastic. For almost all high-spin yrast levels, the addition of two protons just compresses the level scheme 6 - 8 %. This rule appears to be valid also for the N = 44 and N = 46 isotones of Kr, Sr and Zr.

In ^{83}Sr very few high-spin levels were observed even in the (α,3n) reaction, and only those having positive parity (Table I). The difficulties of studying ^{85}Zr appear still greater, since only about 20 % of the total cross section proceeds via the (α,3n) channel, and so far we have only ascertained the position of the $9/2^+$ (50 keV), $13/2^+$ (872 keV) and $17/2^+$ (1884 keV) sequence of yrast levels.

Table I, ^{83}Sr levels.

E_x, keV	I^{π}
35	$9/2^+$
800	$7/2^+$, $11/2^+$
894	$11/2^+$
910	$13/2^+$
1574	$13/2^+$, $9/2^+$
1856	$15/2^+$
1988	$17/2^+$
(2107)	
3177	$21/2^+$
3645	$23/2^+$

In ^{81}Sr, by use of the (α,n) reaction, we have established not only the positive parity cascade $9/2^+ - 13/2^+ - 17/2^+$, but also K = 1/2, K = 3/2 and K = 5/2 bands up to I = $19/2^-$ (Table II). These bands show a very regular behaviour except for signature effects but only the K = 1/2 band lends itself to conventional parametrization. There are still some difficulties in this nucleus, however, especially concerning the halflives of the $5/2^-$ and $7/2^+$ isomers, which are in the range 0.5 - 2 μs. A study of the ^{80}Kr (α,3n)^{81}Sr reaction is planned.

Table II ^{81}Sr levels

E_x, keV	I^{π}	E_x, keV	I^{π}
g.s. (K = 1/2)	$1/2^-$	120 (K = 3/2)	$3/2^-$
156	$3/2^-$	221	$5/2^-$
380	$5/2^-$	337	$7/2^-$
633	$7/2^-$	559	$9/2^-$
999	$9/2^-$	798	$11/2^-$
1333	$11/2^-$	1110	$13/2^-$
1805	$13/2^-$	1473	$15/2^-$
2213	$15/2^-$	1863	$17/2^-$
2652	$(17/2^-)$	2328	$19/2^-$
3161	$19/2^-$		

Table II cont.

E_x, keV	$I^\P$	E_x, keV	$I^\P$
79 (K = 5/2)	$5/2^-$	89 (pos. par.band)	$7/2^+$
367	$7/2^-$	132	$9/2^+$
707	$9/2^-$	812	$11/2^+$
1055	$11/2^-$	905	$13/2^+$
1503	$13/2^-$	1740	$(15/2^+)$
1910	$15/2^-$	1866	$(17/2^+)$
2372	$17/2^-$		
2905	$19/2^-$		

References:

1. Arnell S E, Sjöberg S, Skeppstedt Ö, Wallander E, Nilsson A, and Finnas G. 1977, Nuclear Physics A280, 72.

2. Arnell S E, Sjöberg S, Skeppstedt Ö, Wallander E, Nilsson A, Sawa Z P, and Finnas G. 1978, Z. Physik A289, 89.

3. Arnell S E, Sjöberg S, Skeppstedt Ö, Wallander E, Nilsson A, and Finnas G. In print.

4. Sawa Z P, Forssten K, Ingebretsen F, Walus W, 1975 Fizika 7,2.

*The work is performed in collaboration with A. Nilsson, Research Institute of Physics, Stockholm.

2.1.2 On-line studies of very unstable nuclei

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

At the Isotope Separator On-Line facility ISOLDE at CERN new target techniques have made it possible to produce very neutron-rich nuclei by bombarding a UC_2 target with a 2μA beam of 600 MeV protons from the CERN syncro-cyclotron. The present limits for the production of alkalides are ^{11}Li, ^{34}Na, ^{52}K, ^{102}Rb and ^{152}Cs. So far neutron spectra have been recorded for $^{9,11}Li$, $^{27,29,30,31}Na$, $^{48,49,50,51}K$ and $^{92,97,98}Rb$. There are strong indications that a new kind of delayed-particle activity has been observed; namely beta-delayed two-neutron emission from ^{11}Li. Gamma spectroscopic investigation of ^{100}Rb give evidence for rotational 2^+ and 4^+ states in ^{100}Sr thus confirming earlier findings for ^{98}Sr.

By studying the superallowed beta decay of ^{35}K the excitation energy of the analog state in ^{35}Ar was determined to 5572.60 ± 0.17 keV. In the isobaric multiplet mass equation (IMME) for the completed mass 35 quartet the coefficient of the $T_z^{\ 3}$ term is d = −2.9 ± 3.7 keV which is consistent with 0, thus indicating the absence of charge-dependent mixing.

At the isotope separator on-line to the heavy-ion accelerator at GSI, Darmstadt, neutron-deficient nuclides formed in fusion reactions have been investigated. In the new island of alpha-emission in the trans-tin region half-lives, alpha energies, alpha-branching ratios and alpha widths for $^{107-110}Te$, $^{110-113}I$, $^{111-113}Xe$ and ^{114}Cs have been determined.

2.1.3 Nuclear spins and moments

C. Ekström, I. Lindgren, L. Robertsson, 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 resonance (ABMR) apparaturs 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 determind 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
Recent development of the ion-source at ISOLDE has made it possible to produce a high-intensity beam of negative ions.
An ABMR test run on Br showed promising results and measurements on the np^5-elements will start in a near future.

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b) E.P. Division, CERN, Geneva, Switzerland.

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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 January 1977. Research in physics this year related to the use of the synchrocyclotron therefore only concerns analysis of previously performed experiments. However, research at foreign laboratories, particularly at CERN, has continued and increased. Acc.

A major part of the activity at GWI is devoted to the reconstruction of the synchrocyclotron. The modification is now well under way. A general description of the work on the main components of the accelerator is given below:

Magnetic field: The various pieces of the pole gap have been manufactured and the assembling work has started. A field measuring program involving detailed mappings of the full scale magnet field under various coil settings is scheduled to start in the middle of 1979. A field measuring device has been designed and manufactured for this purpose. It will be possible to obtain a complete field map within 3 hours with an accuracy in each field point of better than $1:10^4$.

Extraction system: Calculations on a regenerative system show that the beam can be extracted with small losses.

RF-system: Instead of a Dee and Cee system, two identical Dee systems located at opposite sides of the magnet will be used to accomplish both frequency modulation (f.m.) and isocronous acceleration (c.w.). A full scale model of the resonator cavity has been constructed at CERN and is used to study in detail various problems in the design, such as the characteristic impendance of the cavity, the voltage distribution and the coupling of the power from amplifier to cavity at different frequencies.

In table I the expected performance of the reconstructed GWI cyclotron are summarized, assuming an internal ion source. Estimated currents for the heavy ion beams are based on results from other cyclotrons (Harwell, Oak Ridge).

Table I Expected performance of the reconstructed GWI cyclotron

Particle	Energy (MeV)	Acceleration mode	Maximum beam current (eμA)
p^+	185-200	f.m.	10 -1
p^+	110-185	f.m.	10
p^+	40-110	c.w.	40
d^+	25-100	c.w.	40
$^3He^{++}$	250-280	f.m.	2
$^3He^{++}$	75-250	c.w.	20
$^4He^{++}$	50-200	c.w.	20
$^{12}C^{4+}$	133-266	c.w.	10
$^{16}O^{5+}$	176-312	c.w.	20
$^{20}Ne^{7+}$	223-490	c.w.	0.3
$^{40}Ar^{8+}$	-320	c.w.	1
Heavier ions	-200 Q^2/M	c.w.	< 1

3.2 Physical biology

3.2.1 Production of radionuclides for biomedical use

P

H. Lundqvist, P Malmborg and C.-G. Stålnacke

During the last five 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 established production parameters and worked out methods for chemical target separation and the labelling and synthesis of biomedically useful compounds. The cyclotron radionuclide production program was summarized in last years report. The rebuilding of the synchrocyclotron will enable us to get the radionuclide production on to a rourinary basis. Expected data for the rebuilt cyclotron are given in table I (see above under 3.1).

A a.

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. When using secondary beams like ion-beams from on-line separator, fast neutrons, slow neutrons or pi-mesons the 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.

To optimize the yield and the radionuclide purity of a desired product, knowledge of production cross sections at different proton energies is essential. Literature data are often lacking, scarce or diagreeing. Therefore excitation function studies have been undertaken on some reactions. The following references cover part of this work (1,2).

ND for RI production ↓

During 1977 the work with the shortlived radionuclides, mainly ^{11}C, has been continued at the Tandem Accelerator Laboratory, Uppsala, with specially constructed gas target systems.

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(1) H. Lundqvist, P. Malmborg, B. Långström 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, IJARI Vol. 30, 39-43 (1979)

(2) H. Lundqvist and P. Malmborg, 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. IJARI Vol. 30, 33-37 (1979)

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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 Capture Cross Section Measurements with Activation Technique.

G. Magnusson, P. Andersson, I. Bergqvist

a) 14 - 15 MeV cross sections

Neutron capture cross section measurements for the nuclei ^{55}Mn, ^{89}Y, ^{115}In, ^{127}I, ^{186}W and ^{197}Au have been concluded with an activation technique developed in Lund [1]. The neutrons were produced by the $T(d,n)^4He$ reaction with a 500 keV Van de Graaff accelerator. The neutron flux was determined from the $^{27}Al(n,\alpha)^{24}Na$ reaction. The results (Table I indicate that neutron capture cross sections at 14 - 15 MeV can be determined with an accuracy of 20 % depending on decay and half life of the produced nuclei. A report is under preparation.

Acc.

TABLE I: RESULTS

Reaction	capture cross section (mb)
$^{55}Mn(n,\gamma)^{56}Mn$	0.58±0.08
$^{89}Y(n,\gamma)^{90m}Y$	0.39±0.04
$^{127}I(n,\gamma)^{128}I$	0.62±0.21
$^{138}Ba(n,\gamma)^{139}Ba$	1.21±0.21
$^{186}W(n,\gamma)^{187}W$	0.83±0.20
$^{197}Au(n,\gamma)^{198}Au$	1.09±0.23

b) Cross sections in the range 1 - 10 MeV

The measurements of capture cross sections in the neutron-energy range 1 - 10 MeV have been continued. The results indicate that the influence of secondary neutrons on the capture cross section is considerable even for such low neutron energies as a few MeV. The influence of these neutrons increases with energy. The experimental 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 a Pelletron accelerator. Acc.

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

4.1.2 Investigation of ^{65}Cu by means of the average resonance proton capture method

B. Erlandsson, K. Nilsson, A. Marcinkowski, J. Protrowski

The $^{64}Ni(p,\gamma)^{65}Cu$ reaction has been studied in the proton energy range E_p=2.06 - 2.55 MeV. The gamma-ray spectra were recorded with a three-crystal pair spectrometer at proton energy differences of 19 keV covering the proton range. An average gamma-ray spectrum was formed by adding all the individual spectra after proper adjustment as a result of the alterations in proton energy. The intensities of the gamma rays to final states with J^π-values were tested against theoretical calculations based on the Hauser-Feshbach theory with good results and these made it possible to deduce further J^π-values. For those states where no definite spin assignment were made the results of this experiment are as follows (all energies in keV): 2094($7/2^-$), 2107($5/2^-$), 2212($1/2^-$), 2282($7/2^-$), 2533($3/2^-$), 2753($7/2^-$), 3079($3/2^-$), 3829($7/2^-$), 3987($7/2^-$), 4009($7/2^-$). It has also been possible to extract information on the radiative strength function from the average resonance proton capture. The experimental points cover the gamma-ray energy range from 5.7 MeV to 9.7 MeV and follow well the form prescribed by the giant dipole resonance, thus providing support for the validity of giant dipole resonance concept at low gamma-ray energies as well as for the validity of the Brink hypothesis, which assumes a dipole resonance built on each excited state.

4.1.3 The average resonance spectroscopy method applied to targets of ^{50}Ti, ^{63}Cu and ^{65}Cu

B. Erlandsson, K. Nilsson, A. Marcinkowski

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

$^{50}Ti(p,\gamma)^{51}V$ for E_p = 2.1-2.5, 2.6-3.1 MeV

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

$^{65}Cu(p,\gamma)^{66}Zn$ for E_p = 1.8-2.2 MeV

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 average spectra. The intensities of high-energy gamma transitions populating the low-excited states of the final nucleus have been determined and compared with theoretical calculations based on the Hauser-Feshbach theory. For ^{51}V the following preliminary spin suggestions are made from the comparison (all energies in keV) 3083($5/2^-$), 3216($1/2^-$), 3266($3/2^{\pm}$, $5/2^-$, $7/2^+$), 3281($3/2^{\pm}$, $5/2^-$, $7/2^+$), 3455($1/2^{\pm}$, $7/2^-$), 3565($5/2^+$), 3576($3/2^-$), 3664($3/2^{\pm}$, $5/2^-$), 3681($3/2^{\pm}$, $5/2^-$), 3748($1/2^{\pm}$, 7/2), 3782($1/2^{\pm}$, $5/2^-$, $7/2^{\pm}$), 3801($7/2^+$), 3874($3/2^-$), 4030($3/2^-$, $5/2^+$), 4200($1/2^{\pm}$, $7/2^-$), 4240($1/2^-$), 4265($1/2^-$)

4.1.4 Mass formula

S.A.E. Johansson, L. Spanier, C.-O. Wene

The 1966 mass formula (S.A.E. Johansson, C.-O. Wene, Arkivfysik, 36, (1967) 353) used the experimentally determined deformation as a third variable in addition to the conventional Z and A. The formula then shows three interesting characteristics:

1. It is possible with only three free parameters to fit nuclei in the rare earth and actinide regions with a standard deviation of 0.25 MeV.

2. The deviations are correlated to fluctuations in the experimentally determined single particle level spacings, i.e. they are due to true single particle effects or "nuclear noise".

3. There are no systematic differences between calculated and experimental masses in the rare earth region, such as are shown by most of the other mass formulas using a shell correction method.

The starting point for the present extension and updating of the 1966 formula is the very strong correlation between masses and deformation shown by these results. In fact the correlation is so strong that the nuclear masses can not be successfully predicted unless the variations of the deformation within the shells are properly understood. Two applications are of special interest:

1. Masses of r-process nuclides.

2. Deformation of very heavy nuclides (A>250) for which the masses are known. The trend of deformation in this region is of interest when discussing the nuclides in the proposed "Super Heavy Island".

4.1.5 Beta delayed fission

S.A.E. Johansson, C.-O. Wene, In collaboration with H.V.Klapdor, MPI Kernphysik, Heidelberg and I.N. Isosimow, Yu.W. Naumow, University of Leningrad, Leningrad.

Although the magnitude of beta delayed fission in neutron rich very heavy nuclei can be estimated from the experimental results obtained in thermonuclear explosions (C.-O. Wene, S.A.E. Johansson, Phys, Scripta 10 A (1974) 156) much more experimental and theoretical work is needed to see all the consequences for e.g. astrophysical phenomena (C.-O. Wene, Astron. & Astrophys. 44 (1975) 233, C.-O. Wene, S.A.E. Johansson CERN 76-13, 584). Another task is to extract more detailed information from the thermonuclear explosion yield data on the neutron cross section of the target isotopes. Detailed knowledge of the beta strength function is of vital importance to all this work. The results from the work to understand S_β discussed below has to be used in future calculations of BDF branching ratios. A microscopial calculation of S_β in $^{236,\,238}U$ with a discussion of the effects on BDF in these nuclides have been published (H.V.Klapdor, C.-O. Wene, I.N. Isosimow, Yu.W. Noumow, Phys. Lett. 78B (1978) 20).

4.1.6 Beta strength function

B. Erlandsson, S.A.E. Johansson, L. Spanier, C.-O. Wene,
In collaboration with H.V. Klapdor, MPI Kernphysik, Heidelberg.

Giant resonances in the beta strength function, S_β, for different beta moments have been discussed by Fujita, Fujii, Ikeda (Phys. Rev. 133 (1964) B549) and later by other workers and used by them to explain hindrance phenomena. The existance of low-lying structures or "pygmy"-resonances was also pointed out in the early papers. The fact that these structures are not smoothed out at high level densities but exist also in heavy nuclides, has been confirmed experimentally. They are probably of less importance in determining hindrance factors for transitions between grand states or to low excited states. The picture is, however, radically different for nuclei far from stability with large Q_β-values. The appearance of "pygmy"-resonances inside the energy window seen by the decaying nucleus leads to selective population of states in a narrow energy region in the daughter (emitter) and will influence not only spectra and branching ratios for delayed particle emission and delayed fission, but also the beta decay half-lives (H.V. Klapdor, Phys. Lett. 65B (1976) 35).

Presently a survey (H.V. Klapdor, C.-O. Wene, MPI H-1978-V25) is being made over the available experimental and theoretical information important for the shape of the beta strength function. Estimates are made of the direct consequences for the prediction of beta half-lives and delayed phenomena as well as the indirect consequences for e.g. astrophysical processes. Of special interest is also what sort of experiments could be undertaken to improve our knowledge of the beta strength function. A collaboration between Heidelberg and Lund to investigate the decay of the Isobaric Analogue Resonances in medium heavy (A>70) nuclei with a big anti-Compton spectrometer has been started. A systematic investigation of the IAR MI-decay in this region would give valuable information on the "pygmy"-resonances in the Gamov-Teller strength function in medium heavy nuclides.

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4.1.7 The Pelletron Accelerator

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

The Pelletron accelerator has been used for experiments the whole year 1978 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 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 has continued during the year with measurements on Al. A new detector holder has also been designed and constructed as a preparation of measurements on Li. The results of earlier measurements on Au, Ag and Cu has been published (Internal Report, LUNFD6/(NFFR-3018)/1-32(1978).

4.2.2 Binary Fission Induced by 600 MeV Protons in U, Pb, Tb, La, Sb, Ag and Y.

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

The experiment is performed at the 600 MeV synchro-cyclotron at CERN, Geneva. Complementary fission products are detected in Coincidence with two detector arms, one containing a start transmission detector and a Si surface barrier detector, the other a gasionization chamber including a Si detector. From the measured kinetic energies and times-of-flight the masses of complementary fission products may be determined. The energy loss measurements with the ionization chamber yield a rough estimate of the charges of particles in this detector arm. At present we have studied in particular Tb, La, Sb, Ag and Y to look for the Busmaro-Gallone point below which the fission process is expected to be negligible. The current macroscopic theories predict the location to be around Ag. For Y with mass 89 we still find symmetric fission in contradiction to the theoretical estimates. An analysis of the fission probabilities also show contradictions between experimental data and theoretical predictions of the fission barrier heights. The results of the analyses of the mass distributions are published in Phys. Lett. 71B (1977) 279.

4.2.3 Photoproduction of ^{17}N

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

The yields for photoproduction of ^{17}N from target nuclei in the mass region $19 \leq A_{+} \leq 197$ has been measured by use of activation analysis. BF_3-counters were used to detect the neutrons following the β^--decay of ^{17}N. Multiscaling was performed in order to check the half-life.
The measurements were finished during 1978 and now include the target nuclei ^{19}F, ^{27}Al, ^{32}S, ^{51}V, ^{nat}Cu, ^{nat}Ag, ^{127}I and ^{197}Au. Mean cross sections in the energy range 400 - 800 MeV has been deduced. The analysis is in progress and we hope to get the results published during 1979.

4.2.4 Near barrier photofission

L.J. Lindgren and A. Sandell

During the year our work on subbarrier photofission of $^{234,236,238}U$ have been published (Nucl. Phys. A298(1978)43) and a special report on ^{238}U (γ, f) in Z.Phys. A285, 415. Measurements and analysis of $^{232}Th(\gamma, f)$ have have been completed and reported in Nucl. Phys. Rep. LUNFD6/NFFR-3027. Mutual experiments on subbarrier photofission have started together with a group in Moscow (Institute of Physical Problems). Work on construction and test of PPAC detectors for use in fission experiments have been reported in Nucl. Phys. Rep. LUTFD2/(TFKF-5004).
Photofission experiments on nuclei in the A=200 mass region are planned to start during 1979 using the 100 MeV Race track facility.

4.2.5 $^{28}Si(\gamma,p)^{27}Al$ and $^{28}Si(\gamma,\alpha)^{24}Mg$ Reactions in the Giant Resonance Region

L. Cardman, University of Illinois, at Urbana-Champaign,
A. Doran, Tel-Aviv University, A. Erell, Tel-Aviv University,
R. Gulbranson, University of Illinois, at Urbana-Champaign,
K. Lindgren, A. Yavin, Tel-Aviv University.

The emission of protons and alphas after excitation of silicon with monoenergetic photons from the tagged photon facility at University of Illinois has been studied. A Si(Li) detector was used as both target and detector. The total cross sections for several decay channels (up to p17) are measured. So far data have been taken in the energy region 13.5-25 MeV with an overall energy resolution of about 150 keV. The same technique as outlined above is being used for study Ge(γ,p) reactions.

4.2.6 Race-track Microtron/pulse-stretcher/storage ring system (MAX)

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

Test runs with the 100 MeV race-track microtron have started in the beginning of 1979. Design and construction of the pulse-stretcher/storage ring have started.

5. NATIONAL DEFENCE RESEARCH INSTITUTE

S-104 50 Stockholm, Sweden

5.1 Fission cross section ratio measurements

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

Fission cross section ratios for $^{232}Th/^{235}U$ and $^{236}U/^{235}U$ have been measured as a function of neutron energy from 4 to 9 MeV at the tandem accelerator at Uppsala. The measurements were made with back-to-back fission chambers utilizing time-of-flight techniques. The fission cross section ratios obtained for $^{232}Th/^{235}U$ and $^{236}U/^{235}U$ were in fair agreement with other recent measurements within the experimental accuracies of 5 and 3 percent, respectively. However, in the neutron energy region from 3 to 5 MeV deviations of about 10 percent was observed between the present and previous $^{236}U/^{235}U$ data.

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1. C Nordborg, H Condé and L G Strömberg, Proc. Int. Conf. on Neutron Physics and Nuclear Data, Harwell, Sept 1978, p 910, OECD/NEA (1978)

5.2 Studies of the $^{6}Li(n,t)^{4}He$ reaction

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

(see 8.2)

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*Present address: NEA Nuclear Data Bank, F-911 90 Gif-sur-Yvette, France

6. RESEARCH INSTITUTE OF PHYSICS

S-104 05 Stockholm, Sweden

A Nilsson

The 225-cm cyclotron is in operation again after the shut-down necessary for building the new experimental hall. So far one beam line for nuclear physics work has been completed, the other three being under construction. The new PDP 11/55 system for data collection (particularly multi-dimensional coincidence work) is also operative, as well as the PDP 11/70 computer for data analysis and general calculations. Acc

A short beam-line has been installed for piping the beam to a gas target for production of short-lived gaseous activities.

Successful test runs have been made on the $^{14}N(p,\alpha)^{11}C$ reaction, using a 12.5 MeV proton beam.

The target technique for production of ^{81m}Rb has been improved and deliveries on a routine basis to the Danderyd Hospital will soon begin of this nucleus.

The surface physics group at the institute has established a cooperation with the Institute of Plasma Physics at Jülich on the problems of plasma-wall interactions. In particular the properties of stainless steel and inconel as walls for fusion devices will be studied. Angular distributions of particles sputtered during He^+ and Ar^+ bombardment have been investigated for a number of targets, bombarding energies, and temperatures.

A+n
PWI

7. THE STUDSVIK SCIENCE RESEARCH LABORATORY

S-61182 Nyköping, Sweden

7.1 Nuclear chemistry group

K Aleklett, P Hoff, L Jacobsson, B Johansson, O Johansson, E Lund, G Rudstam and M af Ugglas

7.1.1 Total beta decay energies

Measurements of total beta decay energies have been one of the main lines of research in the group for a long period of time. By now, a large amount of data have been obtained with a considerable extension of our knowledge about the mass surface far out on the neutron-rich side of stability as a result.

The work has been completed for isotopes of bromine, and a report giving total desintegration energies of ^{85}Br, ^{86}Br, ^{87}Br, ^{88}Br and ^{89}Br has been accepted for publication in Z. Physik (ref. [1]). For ^{85}Br and ^{86}Br our results are in agreement with earlier published data. The accuracy is improved by a factor of 5 - 10, however. For ^{87}Br and ^{89}Br no values have been given earlier. For ^{88}Br, finally, our result is at variance with another determination made at the Laue-Langavin Institute in Grenoble[2] We belive that our result is the correct one, explaining a mistake in the level fed by the beta particles, as the cause of the discrepancy.

A publication reporting total disintegration energies of isotopes and isomers of indium in the mass range 120 - 129 (altogether 18 cases) has been published during 1978 (ref. [3]).

The decay scheme of ^{88}Br has been studied, partly to back up the determination of the beta disintegration energy.

7.1.2 Delayed neutrons

The main effort in the field of delayed neutrons has been devoted to measuring neutron branching ratios. The method consists of counting the number of beta particles and delayed neutrons from the same sample by means of calibrated detectors. Measurements have been carried out on the decays ^{80}Ga, $^{87-89}$Br, $^{93-95}$Rb, $^{127-130}$In, $^{137-139}$I and $^{141-144}$Cs.

It should be noted that our measurements for ^{80}Ga and $^{127-130}$In are the first ones ever obtained for these nuclides, and that our measurements for the other cases are generally more accurate than values published before.

The problem of the feeding of excited states in the final nucleus by the emission of neutrons has been treated both theoretically (refs. [4,5]) and experimentally. Measurements have been carried out for $^{80,\,81}Ga$, ^{88}Br, $^{93-96}Rb$, ^{138}I and $^{143,\,144}Cs$. Reports dealing with the decay of ^{88}Br and ^{138}I have been written (refs. [6,7]) The experimental results are well reproduced by theories on gross beta decay and, so far, the experiments have given no indications for non-ststistical effects in the beta decay to regions above the neutron binding energy.

A report on the status of delayed neutron data has been published [8].

7.1.3 Decay heat in nuclear fuel

The decay heat in nuclear fuel is the weighted sum of average beta and gamma energies of the individual fission products. The group has been engaged in determing these average energies for the individual fission products available at OSIRIS. Based on the presently obtained average beta energies and additional ones calculated from published decay schemes and from beta strength data (the latter obtained a few years ago at OSIRIS) a fairly complete set of average beta energies has been obtained. A preliminary report containing these energies has been written [9] They have also been included in the data library FPLIB of the inventory code INVENT [10] for a calculation of the beta part of the decay heat in nuclear fuel. The results demonstrate an excellent agreement between the calculated values and results from an integral experiment from Oak Ridge [11] In fact, the new average values agree much better with experiments than the currently used American data base ENDF/BIV [12].

A detailed comparison between decay heat values in ^{235}U and ^{239}Pu obtained using the FPLIB library in conjunction with the INVENT code and experimental integral results from Oak Ridge and Los Alamos is under way. Experimental integral determinations are also being carried out at this laboratory, and a comparison will be made with the results from this project as soon as they are in their final state.

7.1.4 Energy spectrum of antineutrinos

With the new decay data of fission products at hand it has been natural to evaluate the energy distribution to be expected for antineutrinos around a nuclear reactor. Such spectra are required for the interpretation of experimental results in the antineutrino field carried out using a reactor as the source of the antineutrinos. The energy spectrum obtained in the present analysis is weaker at energies above about 8 MeV than antineutrino spectra earlier published. The reason for this is connected to the strong feeding of high-lying daughter states in the beta decay of fission products with high disintegration energies, which has been demonstrated at this laboratory [13].

A report describing the work on the antineutrino spectrum has been written [14]

7.1.5. Theoretical study of the evaporation step in nuclear reactions

As has been shown earlier [15] it is possible to treat the evaporation step in nuclear reactions induced by high-energy particles analytically by keeping track of the evolution of the spin along the evaporation chains. Experimental work at ISOLDE, CERN, has now made available spallation distributions covering an unusually wide yield range - about a factor of 10^{11} in the case of isotopes of cesium formed in the interaction of 600 MeV protons with a lanthanum target, for example [16]. With this experimental material at hand it now becomes possible to subject the two-step nuclear reaction model (cascade + evaporation) to a severe test.

So far, a preliminary calculation of the yields of cesium isotopes from lanthanum has been carried out. The experimental data were obtained using a thick target. Consequently, there will also be contributions from secondary reactions. The calculation therefore starts with an analysis of this effect. Next, the set of residual nuclei to be used as starting points for the evaporation chains is established by means of an analysis of the cascade process using the Monte Carlo technique. The results of this analysis combined with the results of the analysis of the secondary effect, are used as input data for the evaporation calculation. This latter calculation is described in a laboratory report [17]

The study of nuclear reactions outlined above is only in its initial stage. The results obtained so far are very important, however, because they show that the cascade-evaporation model forms a useful description of the spallation reactions.

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1) K Aleklett, E Lund and G Rudstam, to be published in Z Physik (1979)

2) R Stippler, F Munnich, H Schrader, J P Boucquet, M Asghar, G Siegert, R Decker, B Pfeiffer, H Wollnik, E Monnand and F Schussler, Z Physik A284 (1978)95.

3) K Aleklett, E Lund and G Rudstam, Phys Rev C18(1978)462.

4) O K Gjötterud, P Hoff and A C Pappas, Nucl Phys A303 (1978)281

5) O K Gjötterud, P Hoff and A C Pappas, Nucl Phys A303 (1978)295

6) P Hoff, to be published.

7) P Hoff, To be published.

8) G Rudstam, Proceedings of the Second Advisory Group Meeting on Fission Product Nuclear Data, Petten, Netherlands, 5 - 9 September 1977 p.567 (IAEA Vienna, 1978).

9) G Rudstam and K Aleklett, The Studsvik Science Research Laboratory Report NFL-7 (1979).

10) G Rudstam, Internal Report from the Studsvik Science Research Laboratory LFK-76 (1977).

11) J K Dickens et.al. ORNL/NUREG-14(1978).

12) P F Rose and T W Burrows, US Report BNL-NCS-50545(ENDF-243) (1976).

13) K Aleklett, G Nyman and G Rudstam, Nucl Phys A246 (1975)425.

14) G Rudstam and K Aleklett, The Studsvik Science Research Laboratory Report NFL-2 (1978).

15) G Rudstam, Nucl Phys A126 (1969)401.

16) H L Ravn, L C Carraz, J Denimal, E Kugler, M Skarestad, S Sundell and L Westgaard, Nucl, Instr. Methods 139(1976)267.

17) G Rudstam and E Hagebö, in manuscript (1978).

7.2 Nuclear Spectroscopy

(B Fogelberg)

7.2.1 Studies of the heavy even mass isotopes of Sn

(Work performed in collaboration with P. Carlé, Research institute for Physics, Stockholm)

During the last three years, a large fraction of the time has been devoted to a study of the level structure of even Sn isotopes as observed in the decays of In Nuclei with A=120-128. The experimental work has consisted of measurements of γ-rays, $\gamma\gamma$-coincidences, conversion electrons and level half-lives in the ns and μs regions. Two isomers with suggested $I^{\pi}=3^{+}$ and $(8)^{-}$ were observed in each of the nuclei $^{124,\,126,\,128}In$ and three isomers with suggested I^{π} of 1^{+} and 4^{+} or 5^{+} and $(8)^{-}$ were found in $^{120,\,122}In$.

Several two-quasiparticle states could be unambigously identified in the Sn nuclei on the grounds of log ft values, γ-ray transition probabilities and energy level systematics. A comprehensive report on the study have been written [1].

7.2.2 Gamma-ray studies of the delayed neutron emitters ^{87}Br and ^{137}I.

The data analysis of the study of the decay $^{137}I \rightarrow {}^{137}Xe$ is now essentially completed. A level scheme showing approximately 60 excited states have been constructed. About one third of the levels are situated above the neutron binding energy.

A study of the decay $^{87}Br \rightarrow {}^{87}Kr$ by means of γ-ray and γγ-coincidence measurements was started in 1978. The work is aiming at obtaining rather exhaustive information on the level structure in ^{87}Kr, especially for the high lying levels. The counting times were therefore rather long, of the order of 80 h, at the maximum possible counting rates which did not cause deterioration of the detector resolution. The analysis of the experimental results are still in an early stage.

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1) Levels and transition probabilities in 120, 122, 124, 126, 128 Sn studied in the decay of In isotopes, B. Fogelberg and P. Carlé, Nucl Phys (in press)

7.3 Neutron Physics Laboratory

7.3.1 Compilation of neutron data for selected actinides

B. Trostell

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 incineration studies of nuclear waste by neutron irradiation.

The compilation work is split on five different groups. Our laboratory studies the (n,n)-cross sections of ^{239}Pu, ^{235}U and ^{238}U from thermal energies up to 20 MeV and the (n,n')-and (n,2n)-cross sections of ^{238}U from threshold up to 20 MeV. Five libraries are considered, i.e. ENDF/B, KEDAK, LLL ENDL, UKNDL and JENDL. The data of the latest version (V) of ENDF/B, which is to be released in spring -79 will be included before the final report is published (autumn -79).

7.3.2 Fission cross section measurements on highly α-active Actinides

B. Trostell

A fission fragment detector has been constructed for fission cross section measurements on highly α-active actinides.

This type of detector should meet the following requirements:

- sufficient discrimination between α-particles and fission fragments
- resistance against radiation damage
- high efficiency
- good time resolution for suppression of spontaneous fission events in time-of-flight experiments
- insensitivity against neutrons and γ-rays

A detector with the characteristics of above is a spherical avalanche detector of the Karlsruhe type, where two halfspherical insulated shells enclose a quenching gas at low pressure.

The sample is applied on the inner shell and the spherical geometry ensures small flight path differences. By properly adjusting the pressure and high tension extremely good α-discrimination and time resolution can be achieved. The detector is not sensitive to neutrons or γ-rays, and with a small steady gas flow through the detector no radiaiton damage effects are to be expected.

Because of a fission fragment detection efficiency of about 100 %, only μg-amounts of sample material will be necessary, thereby reducing the α-particle intensity as well as sample attenuation effects.

Measurements of the ^{241}Am and ^{244}Cm fission cross sections relative to that of ^{235}U will take place as soon as the sample preparation of the detectors has been arranged.

7.3.3 Excitation functions of the ^{9}Be(α,n)^{12}C, the ^{13}C(p,n)^{13}N and the ^{13}N(n,p)^{13}C reactions

E. Ramström

In stars the build-up of elements takes place during various burning phases in the stellar evolution. During these phases different nuclear reactions are of special interest. In the present work two reactions, which are possible to take place in stars, viz. ^{9}Be(α,n)^{12}C and ^{13}C(p,n)^{13}N, have been studied. The protons and helium ions were accelerated by the Studsvik 6 MV Van de Graaff accelerator.

Acc

Since the ^{9}Be(α,n)^{12}C reaction has a positive Q-value of 5.708 MeV, it can take place in astronomic objects at low energies from nuclear physics point of view. Consequently, it is important to know the cross section for the reaction down to as low an α-particle energy as possible.

The integrated neutron yield was measured at α-particle energies in the interval 0.44 to 0.80 MeV. Outgoing from these measurements the differential yields were calculated as well as the absolute cross sections. It was also found that the measured yield of neutrons in the energy interval 0-0.44 MeV was less than one per cent of that obtained in the region 0-0.60 MeV. Thus this investigation shows that there are obviously no significant resonance effects at 0.152 and 0.246 MeV.

The cross sections for some (n,p) and (n,α) reactions, which are important parameters in the calculations of the build-up of elements in stars as well as in the calculations of neutron production in supernovae, can only be obtained by studying the inverse reaction and then computing the cross sections for the direct reaction by means of the reciprocity theorem. This is the case for the ^{13}N(n,p)^{13}C reaction. Thus the ^{13}C(p,n)^{13}N reaction has been studied. Two different targets were used with thicknesses of 41.2 and 60.4 μg/cm^2 corresponding to 3.5 and 5.1 keV, respectively, at a proton energy of 4.0 MeV. The neutron yield from the reaction was measured from threshold (3.237 MeV) up to 4.25 MeV. The excitation function for the $^{13}N(n,p)^{13}C$ reaction was then calculated with the reciprocity theorem.

7.3.4 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 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.

7.3.5 Neutron elastic scattering from Pb_r and Bi

N. Olsson and E. Ramström

Comprehensive studies of neutron elastic scattering have been in progress for several years at our laboratory. As a component part of these studies the cross sections for elastic scattering from Pb_r (radiogenic lead) and Bi is planned to be measured in the energy range 1.5 MeV to about 20 MeV. In this region only a few data points have been published hitherto.

As a part of this project the differential cross sections for Bi and Pb_r have been measured in the angular range 15^o to 160^o at five incident neutron energies around 3.0 MeV, viz. 2.93, 3.00, 3.07, 3.14 and 3.21 MeV, with an energy spread of ± 0.025 MeV. These measurements were performed in order to find out if there is any structure in the total elastic scattering cross section curves for these two elements in this energy range. However, no such structure was found with the energy resolution of the incident neutrons used in this investigation.

7.3.6 Measurements of the (n,n'γ)cross sections of ^{141}Pr and ^{89}Y

B. Trostell

Measurements of the inelastic neutron scattering cross sections have been performed on two magic neutron number isotopes i.e. ^{141}Pr and ^{89}Y, for the purpose of investigating the usefulness of the Hauser-Feshbach and Moldauer formalisms in describing neutron inelastic scattering for such nuclei.

In order to determine the exitation functions for separate energy levels from threshold and upwards, a coaxial Ge(Li)-detector was used to observe the prompt γ-rays from the (n,n'γ)-process. The measurements were performed at a detecting angle of 125° in the neutron energy ranges 1.1 to 2.5 MeV (^{141}Pr) and 2.2 to 3.5 MeV (^{89}Y) in steps of 0.1 MeV with a neutron energy spread of ± 50 keV. At some neutron energies the angular distributions were also recorded.

The cross sections were measured relative to the 847 keV γ-ray production cross section of ^{56}Fe. At 2500 keV one hundred different γ-rays were observed from the Pr-scatterer and these are indications of several previously not reported transitions. The analysis of the results is in progress.

7.3.7 Integral measurement of beta radiation energy released from fission products created in thermal fission of ^{235}U

P-I Johansson and G. Nilsson

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

Measurements have been performed at the Studsvik Science Research Laboratory, with the aim of studying the energy distribution and the total energy of γ- and β-radiation emitted 10 - 1500 s after thermal fission of ^{235}U. Data for the gamma measurement have been completed and beta measurements are near completion.

Thermal neutrons for inducing fissions in ^{235}U were produced by the 6 MeV van de Graaff accelerator using the $^{9}Be(p,n)^{9}B$-reaction and a cubic-shaped moderator of paraffin. The neutron flux available was about 10^8 n/(s·cm^2).

Acc

The uranium samples were 10 mm in diameter and their thickness was about 4 mg/cm^2 They were enriched to 99.3 % ^{235}U and capsuled with 4 mg/cm^2 of titanium to ensure that no fission fragments were lost. The disks were enclosed in cylinders of polyethylene and transported by a pneumatic system to the position for irradiation and measurements, respectively.

Measurements have been carried out with irradiation time of 4, 10 and 120 s to reveal the time dependence of the decay energy.

The analysis of pulse height spectra obtained by the detector was performed by a code developed at the laboratory. The code used measured response functions to unfold the spectra.

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

(B Holmqvist, V Corcalcine, Inst of Atomic Physics, Bucarest, Romania, A Marcinkowski, Inst of Nuclear Research, Warsaw, Poland, and G A Prokopets, Kiev State University, Kiev, USSR).

The analysis of the experimental data has been finished and the work has been published in Nuclear Physics. The abstract is given below.

Abstract

Cross sections 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) spectrometer and a time-of-flight technique. Analysis of the experimental data revealed that only (n,n'), (n,2n) and (n,np) or (n,d) reactions take 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 when bombarding energies exceed 14 MeV.

7.3.9 Radiation damage studies

B Holmqvist

Introduction

The main activity of the group has been to study radiation induced void swelling in high purity aluminium and stainless steel. Radiation damage was introduced in the specimens by irradiation with self-ions in order not to disturb the chemical composition. These

Acc. irradiations have been made by using the 6 MV Van de Graaff accelerator and its efficient heavy ion source. The research program has been devoted to studies of the influence of various metallurgical parameters on the swelling. In particular differences in chemical composition and thermomechanical treatment has been investigated. Furthermore the stability of voids in aluminium has been studied during isochronous annealing.

The specific studies are briefly described in the laboratory's progress report, 1978.

7.3.10 A post buncher sytem

N Olsson

The development of a post acceleration klystron buncher has been initiated, in order to improve the time resolution in time-of-flight experiments at the 6 MV Van de Graaff accelerator. The buncher is designed as a resonator with high Q-value.

At present time the project has progressed so far that the resonator is built and tuned to its resonance frequency (90 MHz). The resonator Q-value is about 2000. The frequency multiplier and a 15 W amplifier have been built. A new ion beam line is being built and a vacuum of about 10^{-7} torr is expected.

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

8.1 The EN-tandem accelerator

A new gas handling system was taken into use last year. This step was taken as a part of an upgrading program for the accelerator. The aim is to reach 7 MV at the end of 1979.

Au

8.2 Studies of fast neutron capture

I. Bergqvist, N. Olsson and B. Pålsson, Department of Physics, University of Lund

M. Ahmad, A. Lindholm and L. Nilsson

Neutron capture has been studied for a number of target nuclei covering the mass region $28 \leqslant A \leqslant 208$ in the giant dipole resonance region. The experimental data have been analyzed in terms of the direct-semidirect (DSD) model Results for yttrium and cerium have been published recently (1). Satisfactory descriptions of the cross sections and gamma-ray spectra have been obtained by the use of a complex particle-vibration coupling in the model calculations. The coupling strength is related to the isospin-dependent part of the optical potential In the light nuclei ^{28}Si, ^{32}S and ^{40}Ca the coupling strengths v_1 and w_1, 75 and 35 MeV respectively, are about equal to the strengths of the symmetry potential obtained from studies of quasi-elastic (p,n) transitions. In the heavy nuclei considerably larger w_1 values are needed to reproduce the observed cross sections. The reason for this is not understood at present.

In the lighter nuclei compound-nucleus capture processes play an important role below and in the lower part of the GDR region. The importance of these processes has been further studied in a number of light and medium-weight nuclei A report on these studies is presently under preparation.

Recently it has been shown that the angular distribution of the gamma radiation from capture reactions can be used to obtain information on the properties of giant multipole resonances other than the giant dipole, e g the isoscalar quadrupole resonance. Other multipole amplitudes are generally small compared with the dipole amplitude but they manifest their presence through non-vanishing odd terms in the Legendre expansions of the angular distributions. In parallel with the experimental activities to study multipole mixing the DSD model has been extended to include capture via the isoscalar and isovector quadrupole resonances. A comparison between experimentally obtained angular distribution coefficients and model predictions for (n,γ) transitions to the $2d_{5/2}$ and $3s_{1/2}$ states in ^{89}Sr and ^{90}Y has recently been published (2). A similar investigation concerning the (n,γ) transition to the $2s_{1/2}$ ground state in ^{29}Si is being performed at present.

In a previous work (3) rather strong variations in the ^{28}Si(n,γ_0) cross section were observed. This structure was recently discussed theoretically (4) in terms of capture via single-particle type resonances. This theoretical work prompted us to study ^{28}Si(n,γ) excitation functions in more detail. A strong resonance in the (n,γ_0) yield is observed around 4.6 MeV where the model predicts a resonance with the same integrated cross section. In general, however, the agreement between experiment and theory is poor. This is true in particular, for the ^{28}Si(n,γ_1) cross section, where two strong resonances are predicted around 5 MeV whereas the observed structure is very much weaker.

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8.2 Studies of the $^6Li(n,t)^4He$ reaction

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The study includes measurements on the $^6Li(n,t)^4He$ reaction as well as on the inverse reaction $T(\alpha,{}^6Li)n$.

The $^6Li(n,t)^4He$ reaction

The $^6Li(n,t)$ measurements are utilizing the $^7Li(p,n)$ reaction as a neutron source. Evaporated ^6Li metal samples about 300 μg/cm^2 in thickness are mounted in the center of a thin-walled scattering chamber, 30 cm in diameter. The outgoing tritons and alpha particles are recorded with solid state detectors at four angles simultaneously. Angular distributions of the tritons formed in the $^6Li(n,t)^4He$ reaction have been recorded at two incident neutron energies, 2.8 and 3.4 MeV. The preliminary results indicate a significant change in the angular distribution over this energy region in qualitative agreement with preliminary R-matrix calculations. Measurements at a few more neutron energies are planned.

The $T(\alpha,{}^6Li)n$ reaction

In parallell with the $^6Li(n,t)$ experiment a study of the inverse reaction $T(\alpha,{}^6Li)n$ is in progress. The cross section for this reaction is being measured with good energy and statistical accuracy over a wide excitation energy range of ^7Li. The maximum alpha particle energy that can be obtained with the tandem accelerator is 18 MeV corresponding to 3.4 MeV neutron energy of the inverse reaction.

Acc

The target in the $T(\alpha,{}^6Li)n$ reaction experiment consists of tritium adsorbed in a thin titanium layer evaporated onto a nickel backing. The alpha beam enters the target through the nickel backing and the outgoing ^6Li ions, emitted at angles near 0^o in the laboratory system, are recorded by a combined magnetic spectrometer - surface barrier detector system The ^6Li yield is being measured relative to the elastic α-t scattering to allow cross section determination.

Because the ^{6}Li ions are emitted in a narrow forward cone (<15°) the experiment must be done with good angular resolution. Furthermore two different energy groups of ^{6}Li ions are produced in the T(α,^{6}Li)n reaction corresponding to forward and backward emission in the center-of-mass system. The emitted ^{6}Li ions have a charge distribution dominated by Li^{3+} The Li^{3+}/Li^{2+} ratio is about 10 and ions with unit charge are negligible.

Preliminary runs have shown that the differential cross section for the T(α,^{6}Li)n reaction can be measured with good accuracy relative to the alpha-triton scattering cross section.

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9. UNIVERSITY OF STOCKHOLM

9.1 Institute of Physics

9.1.1 The absolute transition probabilities in the decay of 53.2 keV level in ^{105}Ag

K Fransson, B Sundström and S Beshai

The halflife of the $9/2_1^+$, 53.2 keV state in ^{105}Ag has been measured by the delayed-coincidences technique with the result $T_{1/2}$=2.33±0.08 ns.