KDK-86
NEANDC(OR)-160/U
INDC(SWD)-20/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1984

Swedish Nuclear Data Committee
Stockholm, Sweden
September 1985

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Compiled by
H Condé
Gustaf Werner Institute
Box 531, S-751 21 Uppsala
and
E Ramström
The Studsvik Science Research Laboratory
S-611 82 Nyköping

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CONTENTS

PREFACE

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

The report also contains short information about developments of experimental techniques in applied nuclear physics as well as changes of existing or new experimental equipments.

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1 THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

1.1 Status report, July 1984-June 1985

The Swedish Nuclear Data Committee has been supported for the present time period by the Swedish Nuclear Power Inspectorate. The members of the committee are listed under 1.3.

The Committee has discussed nuclear compilation and meaurement program in progress, which are related to nuclear data. In particular, the Committee has supported a continuation of the Swedish contribution to the International Cooperation on the Evaluation of Nuclear Structure and Decay Data and to the NEA Data Bank Joint Evaluated Data File Project (JEF). A meeting was arranged at Uppsala on June 4, 1985 to inform about the content and use of JEF, version 1 and the processing program NJOY.

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 participation in international nuclear data meetings.

KDK-74 Report from the 24th NEANDC Meeting, Tokai-Mura, Japan, March 12-16, 1984 (in Swedish)

KDK-75 Compilation of Actinide Neutron Nuclear Data, Part A: Experimental and Evaluated Cross Sections, Part B: Evaluated Group Cross Sections (to be published)

KDK-76 Report to the Swedish Nuclear Power Inspectorate for the time period 1984-01-01--03-31 (in Swedish)

KDK-77 Report from the IAEA Advisory Group Meeting on Transactinium Nuclear Data, Uppsala, May 21-25, 1984 (in Swedish)

KDK-78 Report to the Swedish Nuclear Power Inspectorate for the time peiod 1983-07-01--1984-06-30 (July 1984) (in Swedish)

KDK-79 Report from 14th INDC Meeting, October 1-5, 1984 (in Swedish)

KDK-80 Report from the IAEA Advisory Group Meeting on Nuclear Standard Reference Data, CBNM, Geel, November 12-16, 1984 (in Swedish)

KDK-81 Report to the Swedish Nuclear Power Inspectorate for the time period 1984-10-01--12-31 (in Swedish)

KDK-82 Report to the Swedish Nuclear Power Inspectorate for the time period 1985-01-01--03-31 (in Swedish)

KDK-83 Report from the International Conference on Nuclear Data for Basic and Applied Sciences, Santa Fe, USA, May 13-17, 1985, (in Swedish)

KDK-84 Promemoria of the KDK Symposium on The European-Japanese "Joint Evaluated File", Uppsala, June 4, 1985

1.2 Compilation of actinide neutron nuclear data

H Condé, Gustaf Werner Institute, Uppsala
P Andersson, Lund University, Lund
B Trostell, Studsvik Science Research Laboratory, Studsvik

The KDK actinide data compilation (1) now includes total capture and fission cross section data for Th-232, U-233, -235, -238, Np-237, Pu-239-242, Am-241-244, Cm-242-248, Bk-249-250 and Cf 249-252. It is updated with new evaluations and experimental information.

The figures are drawn by a computer plotter. Calculation and compilation of group cross sections for the same nuclides are also included. A final report of the compilation is under preparation.

Reference

1 P Andersson, J-E Christiansson, H Condé, H Häggblom, C Nordborg, H Sandberg and B Trostell. Compilation Actinide Neutron Nuclear Data. KDK-35, NEANDC(OR) 153/L, INDC(SWD) 13/L, SKI B32/78 (1979)

1.3 Members of KDK

Andersson, Mr K	Swedish Nuclear Power Inspectorate, Box 27106, S-102 52 Stockholm
Bergqvist, Dr I	Lund Institute of Technology, Department of Physics, Box 725, S-220 07 Lund 7
Bonnevier, Dr B	Royal Institute of Technology, Department of Plasma Physics, S-100 44 Stockholm
Christiansson, Dr J-E	Asea-Atom, S-721 04 Västerås
Condé, Dr H (Chairman)	National Defence Research Institute, Box 27322, S-102 54 Stockholm
Grosshög, Dr G	Chalmers Institute of Technology, Department of Reactor Physics, S-412 96 Göteborg
Jirlow, Mr K	Studsvik Energiteknik AB, S-611 82 Nyköping
Lefvert, Dr T	National Power Administration, S-162 87 Väl-lingby
Linde, Mr S	Studsvik Energiteknik AB, S-611 82 Nyköping
Moberg, Dr L	National Institute of Radiation Protection, S-104 01 Stockholm

Nilsson, Dr L	Tandem Accelerator Laboratory, Box 533, S-751 21 Uppsala
Wiedling, Dr T	The Studsvik Science Research Laboratory, S-611 82 Nyköping

2 THE GUSTAF WERNER INSTITUTE, S-751 21 UPPSALA

2.1 The cyclotron laboratory

2.1.1 General

S Kullander and B Larsson

The ground breaking ceremony for the experimental laboratory buildings for the synchrocyclotron was held in December 1982. The experimental rooms are now available for installation of scientific equipment. The area is about two thousand square meters and it is located seven meters below ground.

Presently a neutron physics facility, an electron-positron pair spectrometer, a proton spectrometer and a gamma physics facility are prepared. Work on beams and equipment for biomedical work is also in progress as well as on a facility for radionuclide production.

2.1.2 Neutron experimental facilities

H Condé, O Jonsson, B Larsson, H Lundqvist, C-B Pettersson, PU Renberg and O Sundberg, L Thuresson
I Bergqvist and P Ekström, Lund University
B Holmqvist and T Wiedling, The Studsvik Science Research Laboratory
S Crona, A Håkansson, A Lindholm and L Nilsson, Tandem Accelerator Laboratory

Basic and applied neutron physics are being planned at the reconstructed GWI-accelerator. The basic research will involve studies of nuclear structure in particular by the (n,p)-reaction. Neutron scattering and reaction studies are also planned at intermediate neutron energies (see 5.1.3) from 20 to 200 MeV. In the applied field a special attention is paid to biomedical applications and radio-nuclide production.

Various neutron beams, monoenergetic, broad-spectrum and thermal, will be used for these purposes.

The semi mono-energetic neutrons source facility and the detector for the (n,p)-reaction study is shown in figure 1. The neutron are produced in thin lithium targets by the ^{7}Li(p,n)-reaction and collimated in a system of three collimators in line. The proton beam is dumped in a well shielded cavity. The proton spectrometer consists of a H-magnet with a pole-gap of 15 cm and a maximum magnetic field of 1.5 T with four driftchambers, two in front and two behind the magnet, for ray-traycing. The equipment is designed to get an overall energy resolution of better than 1 MeV at 150 MeV.

Spallation neutron sources are also being designed for research in the biomedical field and for isotope production. Preliminary studies have been made of neutron production by 72 MeV protons dumped in water. The studies have been made at the Swiss Institute for Nuclear Research (SIN) utilizing the injector beam for the 500 MeV cyclotoron.

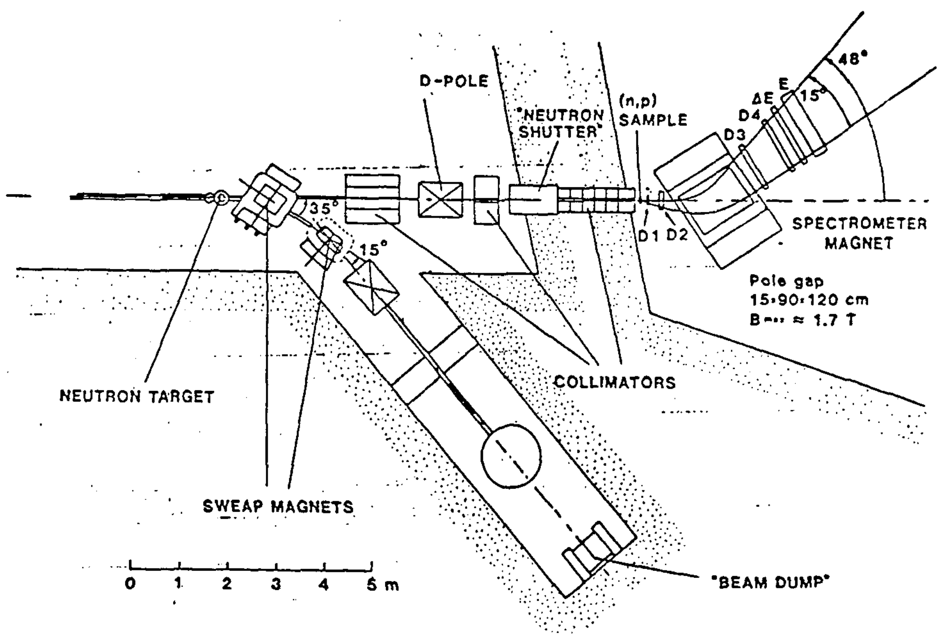

Figure. The experimental arrangement for the (n,p)-reaction study

2.1.3 Synchrocyclotron conversion

The cyclotron group, GWI

The conversion of the synchrocyclotron at the Gustaf Werner Institute to a multipurpose accelerator is in its final stage. The reconstructed cyclotron will operate with frequency modulation for protons in the energy range 110-185 MeV and at fixed frequency in the isochronous mode for protons at lower energies and for heavier particles. A three-sector magnetic field and a broad band RF system replaces the previous rotating capacitor system.

2.2 The CELSIUS project

During the autumn of 1982 the idea was considered to move the ICE ring, earlier used for beam cooling studies, from CERN to Uppsala. The quality improvements achievable in cooled circulating beams were thought to be of great interest. At that time cooling techniques were prepared for the antiproton storage ring LEAR at CERN and for an ion storage ring in an advanced planning stage at Indiana University. The technical feasibility of using the Uppsala synchrocyclotron as an injector was found to be good. The physics program outlined in the Indiana proposal was also evaluated and additional ideas were discussed.

With this background material a proposal was submitted tothe ministry of education. The project which was then approved in early 1983 is now named CELSIUS, an acronym for Cooling with Electrons and Storing of Ions from the Uppsala Synchrocyclotron. CELSIUS will open the door for new kinds of high precision scattering experiments using ultra-thin targets and beams extremely well defined in momentum. The project is a collaboration between the Tandem Accelerator Laboratory, Uppsala, the Studsvik Science Research Laboratory, the Royal Institute of Technology, Stockholm and the Gustaf Werner Institute. The experimental halls for CELSIUS is scheduled to be ready early 1985.

3 LUND UNIVERSITY AND LUND INSTITUTE OF TECHNOLOGY, S-223 62 LUND

3.1 Division of Nuclear Physics

3.1.1 The Pelletron accelerator laboratory, general

The research work at the laboratory is divided into a number of fields. A considerable effort has been employed in applying nuclear physics techniques to other fields of science and in studying practical applications. Most of the work has been done by means of the 3 MV Pelletron tandemaccelerator, but we also have collaborations with other laboratories, e.g. the Tandem Accelerator Laboratory in Uppsala, Technical University of Munich,. Det Fysiske Institut, Aarhus, Laboratoire National Saturne in Saclay, TRIUMF in Vancouver.

The most extensive program is the development of the PIXE (particle induced X-ray emission) method for trace element analysis. The method has been developed in detail at our laboratory, and is today applied to a great number of fields such as environmental sciences and water analysis, medicine, geology and biology.

Some of our work is related to astrophysical problems. In connection with studies of the r-process, we are working on a semiempirical mass formula. In order to check the formula, mass determination by means of nuclear reactions are made.

An application of nuclear physics to solid state physics is the use of the channeling process. Epitaxialy grown gallium-nitride has been investigated to study the crystalographic order of the two sublattices.

A practical application is the study of activation products distributed around some Swedish nuclear power stations. Samples of sewage sludge, fucus and lichen have been used as indicators. The activity was detected in the laboratory with a Ge(Li)-detector.

The increased interest in radon measurements i Sweden, indoors and in the ground, has stimulated the development of radon detectors at the institute. In some projects radon measurements are performed in close connection with local authorities.

Experimental studies of collective excitation modes in nuclei (giant resonances) are performed i collaboration with other laboratories. In addition work is going on in low-energy nuclear structure physics, e.g. proton and alpha capture studies and determinations of neutron capture cross sections.

3.1.2 Neutron capture measurements using the activation technique in the energy region 2.0-7.7 MeV

P Andersson, I Bergqvist and R Zorro

The study of the influence of background neutrons on (n,γ) measurements has been concluded and a report has been published (Nuclear Instruments and Methods, A234 (1985) 573).

Cross section measurements and theoretical calculations for the reactions $^{197}Au(n,\gamma)^{198}Au$ and $^{115}In(n,\gamma)^{116m}In$ have also been completed. A report describing the results has been accepted for publication in Nuclear Physics (Nuclear Physics, A443 (1985) 404).

3.1.3 Nuclear structure and decay data evaluation

P Andersson, LP Ekström and J Lyttkens

The Lund group has been assigned within the ENSDF international cooperation the mass range 59-64. The mass-chain evaluations for A=61 and A=59 have been published in Nuclear Data Sheets. The evaluation for A=60 is in progress.

Programs to retrieve data sets or specific data from an ENSDF tape (of which the evaluators are regular recipients) have also been written.

We are offering our services to Swedish NSDD users. These services include e.g. MEDLIST outputs, the latest version of A H Wapstra's atomic masses and horizontal compilations of any data contained in ENSDF. An example of the latter is a compilation of all gamma-rays from decay data sets ordered by energy.

3.1.4 Photonuclear research, general

B Forkman

During 1984 the main activity of the photonuclear research group has been preparations of experiments at the MAX accelerator. The accelerator system, presently under construction, will provide a high duty factor electron beam in the energy range 20 to 100 MeV with an average intensity of about 10 μA. This will be achieved with a combination of a 100 MeV pulsed racetrack mictrotron and a pulse stretcher ring.

In the initial phase of operation the main emphasis will be on studies of the giant resonance region with real photons. The high duty factor will permit tagging of the bremsstrahlung beam providing monoenergetic photons with an energy resolution of about 3×10^{-3} and sufficient intensity. We plan to investigate the decay properties of the giant dipole (E1) resonance and to search for E2 contributions, mainly the isovector part.

During 1984 the collaboration with American groups at the Bates linear accelerator has continued with the analysis of the data from a study of ^{9}Be, ^{12}C and ^{16}O performed with 537 and 730 MeV electrons. The main emphasis of this experiment was the Δ-resonance in nuclear media. As a next step in these studies a coincidence experiment is being prepared on ^{238}U.

3.2 Division of Mathematical Physics

3.2.1 Calculated masses and decay properties for the heaviest elements

GA Leander*, P Möller, JR Nix** and WM Howard***

We have used the model employed in 1980 by Möller and Nix in a study of nuclear ground state masses and shapes and fission barriers heights to extend the calculations to additional nuclei up to

Z=122. A table where we list calculated ground-state masses, Q_α, Q_β and Q_{EC} will be published elsewhere. However, since there were some masses missing in the 1980 calculation for Z=108 and Z=109 that are now of interest in connection with the recent discoveries of these elements we give the results for these missing elements here. Thus for $^{264}108$ and $^{265}108$ our new calculation gives the mass excesses 120.09 and 121.95 MeV respectively. For the isotopes $^{264-268}109$ the results are 128.26, 127.77, 128.52, 128.19 and 129.05 MeV respectively. Experimentally, Armbuster has obtained the masses 120.97 MeV and 128.06 MeV for $^{265}108$ and $^{266}109$ respectively.

Our results for the "super-heavy" region are quite different compared to earlier calculations. The maximum shell correction occurs at Z=114 and N=178. The most longlived nuclei in the super-heavy region are now $^{288}110$ and $^{290}110$, both with a calculated halflife of around 200 days. We feel that these new results are probably more correct than the older results. In the present version of the model the single-particle parameters have been carefully determined by comparing calculated and experimental levels in several deformed and spherical regions of the periodic system. In adition the model has been used to calculate nuclear ground-state properties from ^{16}O to the heaviest of the known elements. The agreement between calculated and experimental results were usually excellent throughout this region. When the macroscopic model parameters were determined in 1980 the last element for which we included experimental masses was ^{102}No. In the present extrapolation towards the super-heavy region we note that the difference between the experimental and calculated mass for $^{266}109$ is only 0.46 MeV. Thus the model extrapolates well 7 Z unites beyond the last element to which the model parameters were adjusted. We are at present studying other nuclear properties in the trans-fermium region to learn more about the reliability of the model for predicting the properties of the super-heavy region, but already at this stage the extrapolation properties seem quite promising.

References

1 GA Leander, P Möller, JR Nix and WM Howard, Nuclear Chemistry Annual Report 1984, LBL (1984)

2 GA Leander, P Möller, JR Nix and WM Howard, Proceedings of the 7th International Conference on Atomic Masses and Fundamental Constants (AMCO-7), September 3-7, 1984, Darmstadt-Seeheim, Federal Republic of Germany

* UNISOR, Oak Ridge Associated Universities, Oak Ridge

** Los Alamos National Laboratory

***Lawrence Livermore Laboratory, Livermore

4 RESEARCH INSTITUTE OF PHYSICS, S-104 05 STOCKHOLM

4.1 General

I Bergström

The CRYEBIS source for very highly ions, which was moved from IPN, Orsay, in the fall of 1984, will give the atomic physicists a very powerful tool in particular for investigations of atomic collisions. An improvement is being carried through so that mass-separated ions can be injected.

Next step in developing the facilities for in-beam atomic physics is to supply CRYEBIS with a post-accelerator making possible experiments at higher energies than those provided in the first phase (50 kV). An RFQ linear accelerator is being designed for this purpose.

By a decision made by the government at the end of 1982, it now seems excluded that a cyclotron entirely dedicated to heavy ions will be built in Sweden. In this situation we have tried to find both a short- and a longterm solution for the nuclear physics program. The short term programme involves our cooperation in building a rather fancy "crystal ball" detector for gamma-rays named NORDBALL, which is a joint project with participants from several Nordic laboratories. The detector consists of about 20 GeLi-detectors provided with Compton suppression as well as fast detectors for timing purposes. Some of the electronics and software needed as well as the fast detectors will be developed at the institute and part of the detector system tested at the 225 cm cyclotron. The NORDBALL will first be used at the Risø tandem which will be provided with a post-accelerator making possible the use of A=40-60 ions at energies about the Coulomb barrier.

The long term planning of atomic and nuclear physics with very heavy ions below and around the Coulomb barrier is associated with the possibility of connecting the CRYEBIS and/or a PIG source with their accelerating systems to a small synchrotron ring ($\approx$7x7 m^2). Figure 1 indicates how such a facility can be accommodated in the available laboratory space. The CRYRING (CRYebis and a synchrotron RING) may allow acceleration and storage of ions and aims first of all towards experiments with crossing and merging beams for entirely new types of investigations in atomic and molecular physics. However, the facility will also make acceleration of very heavy ions (Kr-U) possible up to energies just above the Coulomb barrier, which is of great importance for a future nuclear structure program as well as atomic physics of high energies.

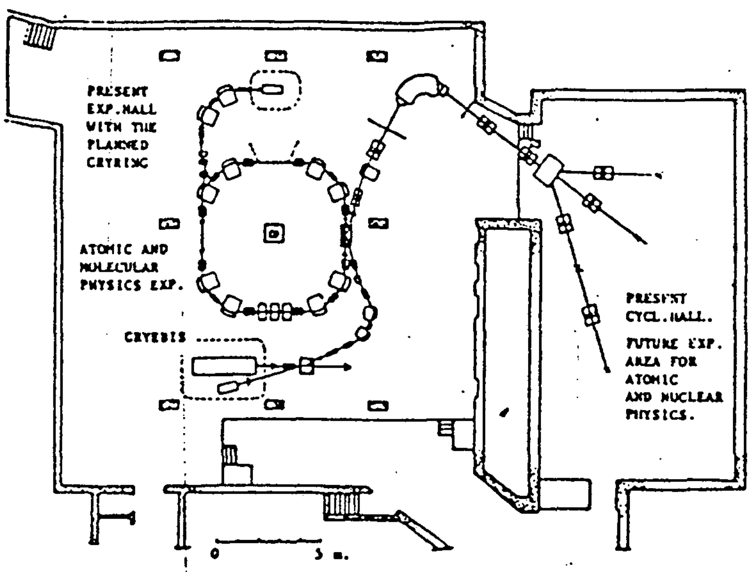

Figure. CRYRING - in a first design version - placed in the existing accelerator laboratory area.

5 THE STUDSVIK SCIENCE RESEARCH LABORATORY, S-611 82 NYKÖPING

5.1 Neutron physics

5.1.1 Precision measurements of neutron reference cross sections

N Olsson and B Trostell

The program for studies of the secondary standard reaction C(n,n) has continued during the year. The aim is to collect a very accurate data set in the energy range 17-21 MeV, a range where published results are very scarce.

The facility for neutron scattering measurements developed at the laboratory (1-3) has proven to be very well suited for studies in this energy region. The time-of-flight spectrometer has av total time resolution of less that 0.8 ns, corresponding to an energy resolution of 500 keV at 20 MeV. The efficient heavy shielding and tungsten shadow bar system, together with neutron-gamma discrimination, gives excellent background conditions. Thus the yield from elastic scattering as well as from inelastic scattering to several excited states in ^{12}C, can easily be extracted. Cross sections for excitation of the different states are then calculated by comparison with the yield from n-p-scattering, a cross section that can be considered well known within one percent. Of great importance in these calculations is also accurate knowledge of the relative efficiency of the neutron detectors, which was determined by observing the neutron yield at different angles from the T(d,n)-reaction, using cross sections of Drosg (4).

In this context attention should be paid to the importance of extracting also accurate inelastic scattering cross sections. Most of the neutron detectors used in this energy region consist of organic scintillators, and the contribution to the efficiency of these from carbon inelastic scattering is considerable. Precise knowledge of these cross sections is thus of outermost importance if reliable calculations of the neutron efficiency are to be performed.

Further measurements of angular distributions will continue until July, 1985. The data will then be theoretically treated in terms of phenomenological and microscopic optical potential models as well as direct nuclear reaction models for inelastic scattering.

References

1 N Olsson, Nuclear Instrument Methods, 187 (1981) 341

2 N Olsson and B Trostell, Nuclear Instrument Methods, 224 (1984) 142

3 N Olsson and B Trostell, Proceedings of the Neutron-Nucleus Collision Conference, Ohio, USA, September 5-8, 1984 (to be published)

4 M Drosg, LA-8532, Los Alamos Scientific Laboratory (1980)

5.1.2 Neutron elastic and inelastic scattering at 21.6 MeV

N Olsson, E Ramström, B Trostell and B Holmqvist

The previously described (1, 2) fast neutron time-of-flight spectrometer at the Van de Graaff laboratory at Studsvik has been used to measure elastic and inelastic scattering from seventeen elements ranging from Be to Bi at an energy of 21.6 MeV. A time resolution of better that 0.8 ns corresponding to an energy resolution of 500 keV at that energy has been used throughout the experiments. The favourable experimental conditions have also made it possible to observe differential inelastic angular distributions for, among other things, 2^+ and 3^- state in a number of nuclei. Since the angular distributions, in particular for elastic scattering, are heavily peaked at forward angles the cross sections were measured on both sides of the 0^o direction and in small angular intervals, i.e. 2.5^o in the critical angular range. This precaution was found necessary in order to avoid large uncertainties in the angle integrated cross sections. At larger scattering angles where the variation of the differential cross sections is not pronounced the measurements were made at 5° intervals.

The observed neutron elastic angular distributions are at present being corrected for neutron attenuation in the sample, for anisotropy of the source neutrons and for neutron multiple scattering by using a Monte Carlo computer code (3).

The results of the homogenous set of neutron elastic and inelastic angular distributions of high accuracy will be used to study phenomenological and microscopic optical potential models (OPM) as well as models describing direct nuclear processes for the neutron inelastic scattering.

References

1 N Olsson, Nuclear Instrument Methods, 197 (1981) 341

2 N Olsson and B Trostell, Contribution to the Neutron-Nucleus Collissions Conference, hels at Burr Oak, Ohio, USA, September 5-8, 1984 (to be published)

3 B Holmqvist, B Gustavsson and T Wiedling, Arkiv Fysik 34 (1967) 481

4 B Holmqvist, Arkiv Fysik 38 (1968) 403

5.1.3 Experimental determination of total and non-elastic cross sections for neutrons in the energy region 20-200 MeV

B Holmqvist and T Wiedling, The Studsvik Science Research Laboratory
H Condé, P-U Renberg and O Sundberg, The Gustaf Werner's Institute

The total neutron cross section is one of the very few nuclear reaction parameters which can be determined by a straight-forward absolute measurement. For that reason the total cross section is a quantity of fundamental importance in connection to studies of partial neutron cross sections as for instance (n,n), (n,n'), (n,p), (n,α) etc. Previous total neutron cross section work has essentially been performed at energies up to about 20 MeV, but the present state of the art allows high precision measurements to be made even above that energy.

At present, possibilities are investigated to make total neutron cross section measurements by using a white neutron source together with high resolution time-of-flight technique at the reconstructed Gustaf Werner Institute cyclotron (see 2.1.2)

5.2 Nuclear astrophysics

5.2.1 The $^{27}Al(\alpha,n)^{30}P$-reaction

B Holmqvist and E Ramström

The $^{27}Al(\alpha,n)^{30}P$-reaction is of importance in connection with the ^{26}Al problem where it may influence the isotopic ratio $^{27}Al/^{24}Mg$ which is used to calculated the initial ratio of $(^{26}Al/^{27}Al)_0$ in the solar nebula. The aim of the present work has been to measure the $^{27}Al(\alpha,n)^{30}P$-reaction for -particle energies from threshold up to 3.66 MeV corresponding to stellar temperatures between 2.08 and 2.75×10^9 K. The measurements have been performed using the thick target technique and very clean vacuum conditions.

The reaction rates of the $^{27}Al(\alpha,n)^{30}P$-reaction in a plasma at six different plasma temperatures have been calculated based on the present data. The results are in fair agreement (±20-40 %) with other recent measurements.

5.3 Nuclear chemistry and nuclear physics

K Aleklett, B Ekström, J Eriksen, B Fogelberg, L Jacobsson, O Johansson and G Rudstam

5.3.1 Introduction

The main research activity of the group has been connected to studies of the properties of short-lived neutron-rich nuclides produced at the isotope-separator-on-line facility OSIRIS. The programme includes determination of total beta decay energies, nuclear spectroscopy, studies of delayed neutrons and determination of fission yields including branching ratios for gamma-rays of fission products. The work also includes the development of OSIRIS, especially the construction of new target-ion source systems, which is important for extensions of the research activities.

5.3.2 Development of the OSIRIS facility

During 1984 the isotopic separator was used with CF_4 added to the carrier gas for separation of yttrium and lanthanides.

Further development of a high temperature ion source has been made during 1984. A prototype is nearly completed and all necessary voltage and current supplies have been acquired. A test run (off-line) is planned for early 1985 and production runs on-line before summer.

5.3.3 Studies of nuclear properties at low energies

5.3.3.1 Single hole and three quasi particle levels in ^{131}Sn

This rather comprehensive study of levels in ^{131}Sn populated in the decay of three different isomers of ^{131}In was described in last year's progress report. Two reports (1, 2) on different aspects of the level scheme of ^{131}Sn have been published during 1984.

5.3.3.2 The total decay energy of ^{130}In

The ground state mass of ^{130}In has never been measured accurately, despite that the decays of three isomers of ^{130}In are otherwise well studied. The current study of ^{130}In, performed at the TRISTAN facility, aimed both at a measurement of the total decay energy and at a search for a possible ground state beta-transition from the low spin isomer. Such a transition was found and restricts the J^{π} of the low spin isomer to 1^-. The Q_{β}-value was obtained as 10.12 ± 0.18 MeV. A report (3) on these measurements has been written. The work was made in collaboration with physicists at the TRISTAN facility in Brookhaven.

5.3.3.3 A measurement of the g-factor of the 6^+ level in ^{132}Te

The first 6^+ level in the closed shell nucleus ^{134}Te is thought to be a rather pure $\pi(g_{7/2})^2$ state. The magnetic moment of this level was measured (4) several years ago by Wolf and Cheifetz. The current investigation of the 6^+ level in ^{132}Te had the purpose of seeking the possible influence of two neutron holes in the N=82 shell on the purity of the proton $(g_{7/2})^2$ configuration. The experiment was made using isotope separated activities at the TRISTAN facility and superconducting magnet (5) for the perturbed angular correlation (PAC) measurements. The derived value for the g-factor of the 6^+ level turned out to be significantly larger than expected for a nuclear level mainly having a $\pi(g_{7/2})^2$ configuration. Possible theoretical or experimental reasons for the unusual magnitude of the g-factor is now being investigated. The work is made in collaboration with physicists at the TRISTAN facility i Brookhaven.

5.3.3.4 Studies of levels in ^{96}Mo and ^{106}Pd with the (n,γ)-reaction (En=2 and 24 keV

Nuclei with even numbers of protons and neutrons near A=100 are generally poorly described by conventional nuclear models due to e.g. the occurence of unexpected "intruder states". There are, however, good reasons to expect that the IBA model may offer a means to understand the structure of nuclei in this region. The current experiments were undertaken to give a basis for comparisons with this model, and also to give reliable information on spins and parities of low lying levels in ^{96}Mo and ^{106}Pd. The experiments consisted of neutron capture gamma-ray measurements at neutron energies of 2 and 24.3 keV for both nuclei. The gamma-ray data is now being compared to Monte Carlo calculations (6) of the capture process for extraction of J^{π}-values for the low lying levels. The work was made at Brookhaven National Laboratory in collaboration with DD Warner, RF Casten and A Bruce.

5.3.3.5 Observation of extremely low s-wave strength in the reaction ^{136}Xe + n

The neutron cross section of ^{136}Xe has been investigated using transmission measurements at the Oak Ridge Electron Linear Accelerator. A sample of xenon gas, enriched to 93.6 % in ^{136}Xe, was used as target. Measurements were made at a flight path of 80 m with an energy resolution 0.1 %. Thirty-five resonances were found in the 0-500 keV region. Considerations of the experimental sensitivity suggest that another 3-6 resonances may have escaped detection. All strong resonance could be assigned as p-wave from the absence of interference between potential and resonance scattering. Only four very weak resonances can possibly originate from s-wave neutron interactions, but other ℓ-values are not excluded for these resonances. It is thus quite possible that ^{137}Xe is completely lacking s-wave strength in the first 500 keV of unbound levels. In any event, a conservative upper limit of the s-wave strength function in this region can be derived as $S_0 < 1.0 \times 10^{-6}$. Such a low value of s-wave strength is highly unusual in a heavy nucleus, and is matched only by the reaction ^{208}Pb+n.

In contrast, the p-wave strength function was found to be similar to what is observed for other nuclei in the mass region near ^{137}Xe. We derived a value of $S_1 = (8.7 + 2.4) \times 10^{-5}$ for a radius of 6.96 fm from the reduced widths of resonances with definite =1 assignment. This value would not be significantly altered by inclusion of strength from the few weak unassigned resonances.

The work has been made in collaboration with J Harvey and S Raman at Oak Ridge National Laboratory and with M Mizumoto at JAERI, Japan.

5.3.3.6 Q_β-values near the N=50 and N=82 shells and close to the r-process path

Earlier Q_β measurements at OSIRIS were made using an array of Si(Li) detectors with a well known response function for recording beta-spectra in coincidence with selected gamma-transitions. The system had a relatively good resolution and precision but had the disadvantage of accepting beta-particles only within a very narrow solid angle. We have therefore investigated the possibility of using a standard HPGe-detector as the main detector for beta-particles. The efficiency of the HPGe-detector is about one order of magnitude higher than for the Si(Li) detector array. The test measurements with this detector were satisfactory, and showed that Q_β measurements are feasible for most fission products having a thermal fission yield of more than about 10^{-4} %/f. A rather large program for Q_β measurements has been initiated, primarily to study Cu, Zn and Ga with A=74-82 and also Cd, In and Sn with A=125-134. The program has so far resulted in improved Q_β determinations f or $^{75-78}$Zn and new experimental values for ^{79,80}Zn. A survey study of Cu isotopes showed good activities for $^{74-76}$Cu and also 0.2 s ^{78}Cu was detected.

5.3.3.7 Gamma Branching Ratios

In connection with the determination of the yield pattern in thermal neutron induced fission of ^{235}U, gamma branching ratios are determined for the fission products. Branching ratios have been measured for about 100 nuclides, and the final analysis has been made for the following nuclides: $^{75-78}$Zn, $^{75-81}$Ga, ^{77,79,81}Ge, $^{84-88}$Br, $^{87-94}$Kr, $^{88-94}$Rb, ^{131m,114,115,115m,116,116m,117,117m,118,121}Ag, ^{125,125m,126m,127,127m,128}In, ^{125m,127,127m,129,129m}Sn, ^{134}Sb, ^{135,136}Te, ^{134,136,136m,137,138,139}I, $^{137-141}$Xe, ^{139,140,141,143,144,145}Cs.

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6 TANDEM ACCELERATOR LABORATORY, BOX 533, S-751 21 UPPSALA

6.1 General

A Johansson and A Lindholm

During the last few years the trend has been to devote more beamtime to applied and basic research outside nuclear physics. Thus, in 1984 about 60 % of the effective beamtime was used for nuclear solid state physics, desorption of biomolecules, production of radioactive isotopes for biological and medical applications, accelerator mass spectroscopy, studies of hydrogen profiles of metal hydrides, RBS-analysis and student laboratory exercises. The rest of the beamtime, about 40 %, has been for neutron capture reactions, few-particle reactions, Coulomb excitation and gamma-ray spectroscopy.

During the last two years the prestanda of the tandem accelerator have been further improved. In particular the work on the sputter ion source injector has been completed. Parts of the beam control system for the ion source, the accelerator, the analyzing and the steering magnets are now coupled to and can be manupulated via a computer. New high energy accelerator tubes have been installed. Furthermore the new charging belts reported on in the former biennial report (TLU 1982) have been successfully run for an extended time.

6.2 Accelerator improvements

6.2.1 The computer controlled beam transport system

O Johansson, G Possnert and J Åström

A microcomputer based system for controlling ion optical elements along the accelerator beamline has been installed.

The advantage of the system is that optical parameters for different ions can be changed quickly and repeatedly.

The elements included in the control system so far are: the injector, analysing and switching dipole magnets, the three magnetic quadropole doublet lenses (HE, SW and BL), the faraday cups (LE, HE and AM) and the stepping motor for sample change in the sputter ion source (see figure).

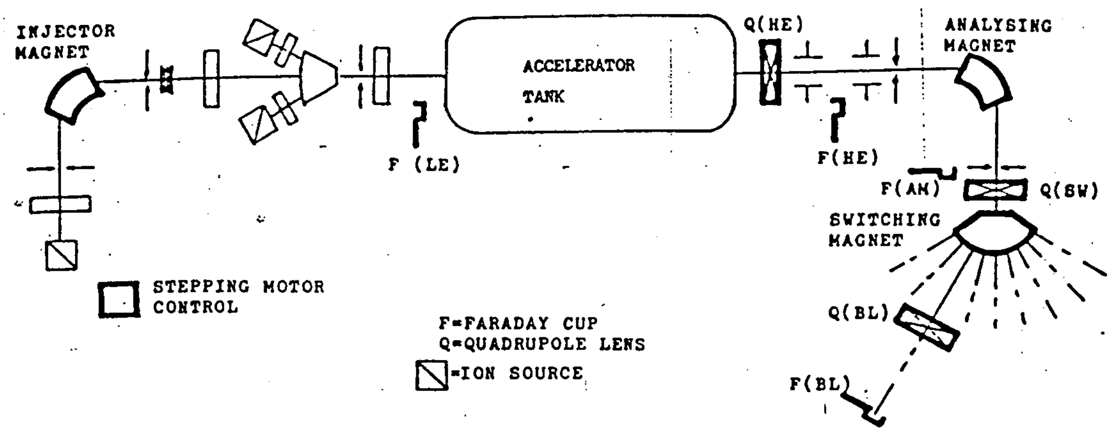

Figure. Schematic drawing of the accelerator. The elements included in the control system are drawn with heavy lines

6.2.2 The Uppsala system for mass spectrometry

G Possnert, T Kronberg, B Sundqvist and J Åström

The work to improve the Uppsala accelerator system for use in ultra sensitive mass spectrometry has been in progress for three and a half years. The early test showed that several improvements on the original installation have to be undertaken in order to fulfil the special requirements of this application. The most important modifications and new installations completed at present are:

1 Construction and installation of a new versatile cesium sputter ion source and injector system with 90° analysing magnet, making reproducable production of well defined (mass and emittance) heavy ion beams feasible.

2 Computer control of different ion optical elements in the beam transport system as well as data taking, allowing rapid and reproducable measurements of different isotopes either by single ion counting or by current integration.

3 Devote a separate beamline (+30^{o}) after the switching magnet with a 10^{o}-electrostatic (1 m long) deflector and a ΔT-T-time-of-flight detector telescope for heavy ion identification.

A schematic drawing of the accelerator system is shown in figure where just more pertinant part relevant to the AMS application are included.

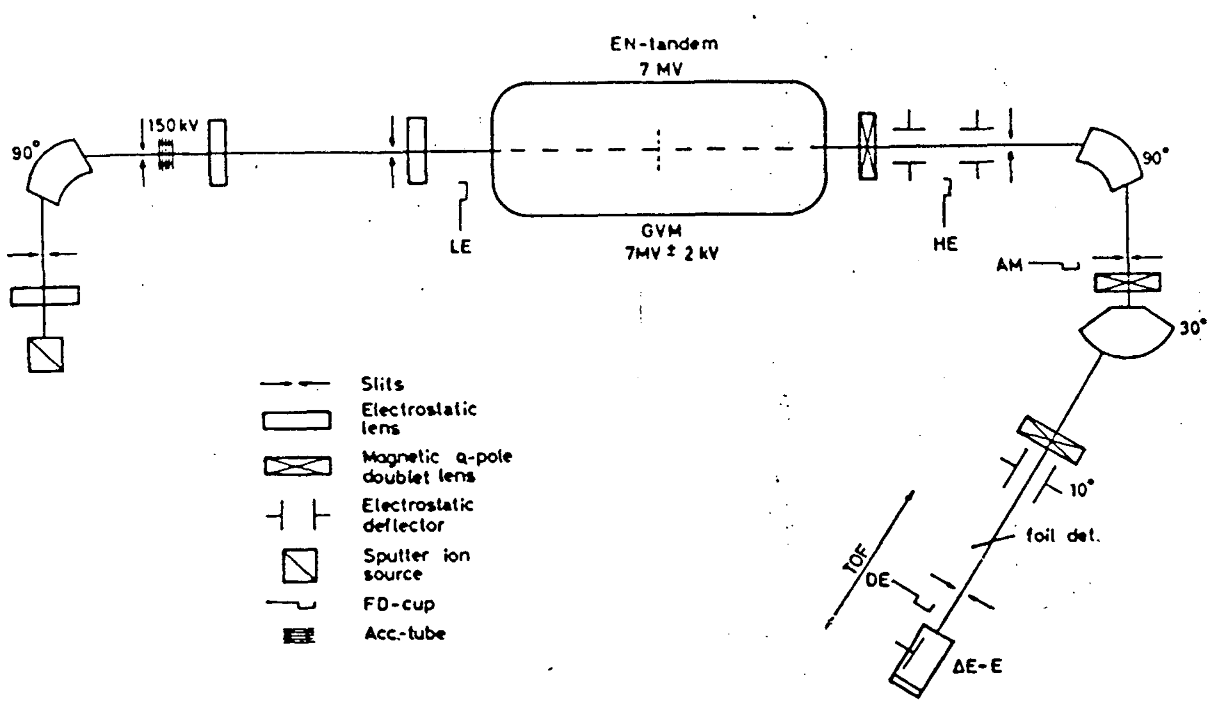

Figure. Schematic drawing of the Uppsala AMS-system

6.3 Nuclear fewbody systems

K-H Flodqvist, L Glantz, G Janson, A Johansson, I Koersner and B Karlsson, Tandem Accelerator Laboratory

6.3.1 Introduction

The experimental investigation of fewbody systems has continued with measurements on the D(^{3}He,^{3}Hep)n, D(^{3}He,Tp)p and D(^{3}He,pp)T-reactions. The spectra obtained has a rather complicated structure with peaks interpreted as due to nucleon-nucleon final state interaction and to resonances in ^{4}He. The analysis of data from elastic nd scattering has been pursued in collaboration with the Karlruhe group.

6.3.2 The D(n,d)N-reaction

The analysis of our latest experiments on elastic n-d scattering in the energy range from 6 to 12 MeV reported on earlier, has now been completed. The data were analyzed in terms of dynamically exact three-body calculations based on the Faddeev equations and separable potentials. Comparisons were made with the results from two advanced calculations, one performed by Y Koike (YK) (1) and the other by P Doleschall (PD) (2). Some preliminary results were presented at the few body conference in Karlsruhe in August 1983.

In comparison, discrepancies of our experimental cross sections from the theoretical predictions can be observed, as well as differences to experimental values recently obtained in measurement at Karlsruhe (3). The situation is shown in the figure where the cross section ratio between experiment and theory (YK) at 170° is plotted as a function of the neutron energy. While for our data this ratio is only slightly increasing the structure is more drastic for the Karlsruhe data. It is not clear what the reason for this difference could be. Both experiments indicate a different energy dependence than that predicted by theory. Since the nd-system is of fundamental significance due to the absence of the Coulomb interaction, it is essential that any discrepancy is resolved.

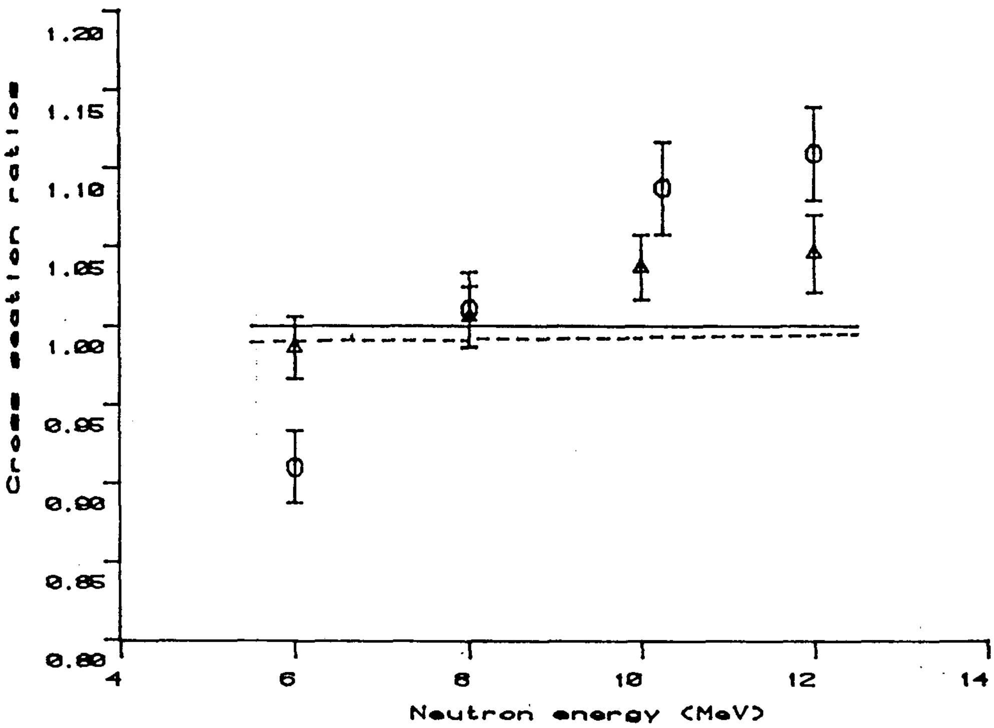

Figure. Experimental cross sections of the neutron deuteron elastic scattering around 170° divided by the calculated cross sections are shown as a function of the incident energy. Experimental data from present experiment and from ref 3 are shown by open triangles and circles respectively. The dashed line shows the ratio between the PD and YK results.

References

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6.4 Studies of giant multipole resonances

S Crona, A Håkansson, A Lindholm and L Nilsson, Tandem Accelerator Laboratory, Uppsala, I Bergqvist and R Zorro, Department of Physics, University of Lund, N Olsson, Studsvik Science Research Laboratory

6.4.1 Introduction

The mechanism for fast nucleon capture has been studied for a number of years. The studies have often been performed in collaboration with research groups at Institut Jozef Stefan, Ljubljana, Yugoslavia. Los Alamos National Laboratory (LANL), USA, and Centre d'Etudes de Bruyeres-le-Chatel (CEBC), France.

The best quantitative description is obtained using a complex particle-vibration coupling in the DSD-model calculations. The coupling strength is related to the isospin-dependent part of the optical potential. In light nuclei like ^{40}Ca the used coupling strengths V_1 and W_1 are about equal to the strengths of the symmetry potential obtained from studies of quasi-elastic (p,n)-transitions. In heavy nuclei considerably larger W_1 values are needed to reproduce the observed cross sections. The reason for this is not understood at present.

Theoretical estimates indicate that neutron radiative capture should be a valuable tool to investigate giant quadrupole resonances. The E2 resonance will manifest itself in the angular distributions of the capture gamma-rays through interference with the E1 resonance.

6.4.2 Neutron capture in silicon and sulphur

For light nuclei ^{28}Si and ^{32}S rather strong variations in the neutron capture cross sections are observed. In ref 1 we report on $^{28}Si(n,\gamma)^{29}Si$. 90^{o} cross sections are measured in energy steps <150 keV. The structure in the excitation functions has been discussed theoretically (2) in terms of capture via single-particle type resonance. This microscopic model seems to provide a very promising means towards a better understanding of the capture process in and below the giant resonance region in light nuclei.

Angular distribution studies reported in the same paper in the energy range 8-14 MeV indicate that the capture process is essentially of direct character and that the effect of interference between the electric dipole and the isoscalar quadropole resonance is weak.

6.4.3 Neutron capture in calcium

In ref 3 we report on measurements on $^{40}Ca(n,\gamma_0)^{41}Ca$. The 90^o cross sections for this reaction, have previously been measured in the energy range 3.5-17 MeV. We extend these measurements to 27.5 MeV. The experimental cross sections are compared with theoretical estimates by the DSD model. With isospin conservation, neutron capture should excite only the $T_<$ part of the GDR, but in order to get a good fit to experimental data another resonance at the energy of the $T_>$ resonance was included. The origin of this apparent violation of isospin conservation is not presently understood.

The main purpose of the $^{40}Ca(n,\gamma_0)^{41}Ca$ experiments was to examine the influence of a possible giant isovector E2 resonance in Ca. Calculations of angular distributions show that interference between resonant E2 capture and direct and semidirect E1 capture gives a strong fore-aft assymmetry in the capture gamma-ray emission. The fore-aft asymmetry defined by

$$A_1 = (I(55^o) - I(125^o))/(I(55^o) - I(125^o))$$

is shown in the figure. The solid curve is the result of a DSD calculation where the energy and width of the giant E2 resonance were taken to be 32 MeV and 5 MeV, respectively. The fraction of the isovector EWSR exhausted by this resonance was taken to be 35 %, i.e. 100 % of the $T_<$ art of the resonance.

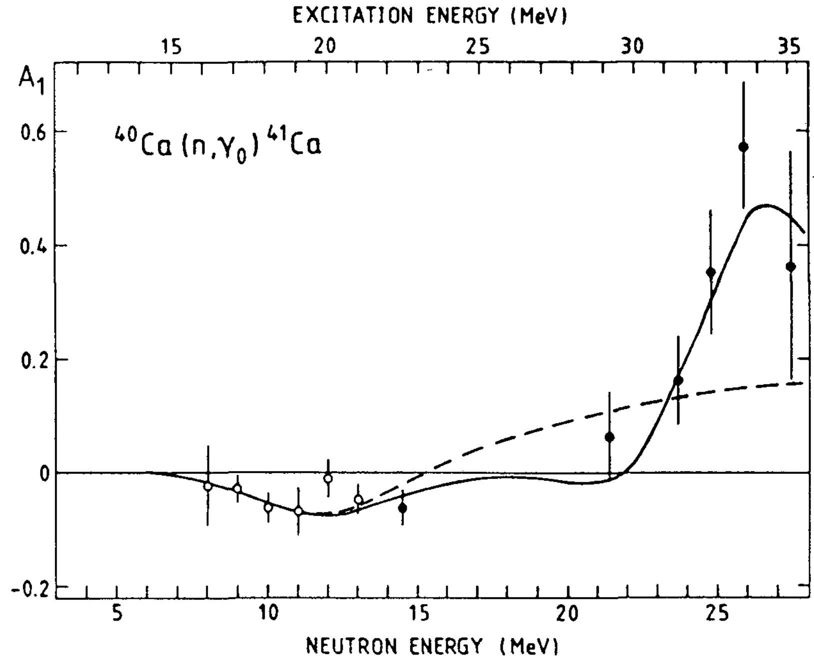

Figure. Measured forward-tobackward anisotropies A_1 for the $^{40}Ca(n,\gamma_0)^{41}Ca$ reaction. Open circles represent measurements at Triangle Universities Nuclear Laboratories, USA (4). The solid curve is obtained from a calculation based on the DSD model including capture via the isoscalar E2 and the isovector E1 and E2 resonances. The dashed curve is obtained when no isovector E2 resonances is included.

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6.4.4 The high-energy gamma-ray detector

The high-energy gamma-ray detector system consists of a large NaI(Tl) detector placed inside an annular plastic scintillator.

In August 1984 a new NaI(Tl) crystal (25 cm in diameter and 36 cm long) was installed. The bare crystal has a resolution of 2.6 % (FWHM) at E_γ=6.31 MeV. For the whole spectrometer a resolution of 1.5 % was obtained at E_γ=22.6 MeV. During the tests the low-energy discriminator of the anticoincidence shield was set at 40 keV. Our preliminary tests, in which no further gain stabilization was used, show that the long-term gain stability is within 1 % for count rates up to 100 kHz above 0.5 MeV.

6.4.5 Neutron detectors for experiments at the Gustaf Werner Institute synchrocyclotron

F Dahlén, A Håkansson, O Johansson, A Lindholm and L Nilsson, Tandem Accelerator Laboratory, Uppsala

As a continuation of our research on giant multipole resonance, we intend to study their decay properties at the Gustaf Werner Institute (GWI) as soon as the reconstruction of the synchrocyclotron is finished. The decay of giant resonances in heavy nuclei can be expected to proceed mainly through neutron emission.

Therefore we have initiated a study of detectors for neutrons in the 1-10 MeV region. We have available at TLU a liquid (NE 213) scintillator detector, 30 cm in diameter and 5 cm thick, and have constructed two rectangular plastic (NE 102A) scintillation detectors (50 cm long, 20 cm wide and 2.5 and 5 cm thick, respectively). The scintillators are supplied with PM tubes (XP 2230B) in both ends and time derivation is performed by a mean timer. The mean timer and the PM bases are constructed at TLU according to a scheme outlined at the Swiss Institute for Nuclear Research (SIN).

In order to improve the timing output from the NE 213 detector a reconstruction of the NE 213-detector has been made, implying conversion from positive to negative high voltage. This detector has also been tested with a 'tripple' mean timer to improve the time resolution.

Tests performed at NFL in Studsvik, have given a time resolution for the 2.5 cm NE 102A-detector of 800 ps at a neutron energy of 9.5 MeV. The detectors are also suited for position measurements, and here a spatial resolution of 10 cm has been obtained. The efficiencies are under investigation at present.

The result from the tests implies also that plastic detectors are not suited for our purpose because of the high gamma background, but they are useful as trigger detectors for the multiwire proportional counters in the planned (n,p) experiments at GWI.

During 1985 we intend to construct two more detectors similar to the NE 213-detector.

6.5 Experiments connected to fusion research

B Emmoth, Research Institute for Physics, Stockholm, LE Svensson and L Westerberg, Tandem Accelerator Laboratory and E Karlsson, Department of Physics, University of Uppsala

Several samples from plasma physics experiments have been investigated. Figures 1 and 2 shows the results from some preliminary experiments on samples exposed to a plasma in the TEXTOR-tokamak at KFA, Jülich compared to the profile for a foil of the same material which has been implanted with 5 keV protons. From a comparison of such spectra it is possible to derive the temperature at the egde of the plasma. Such data are also important for the understanding of the plasma-wall interaction. The work at the tandemaccelerator allows a better depth resolution and a larger depth range than the methods used earlier for this purpose.

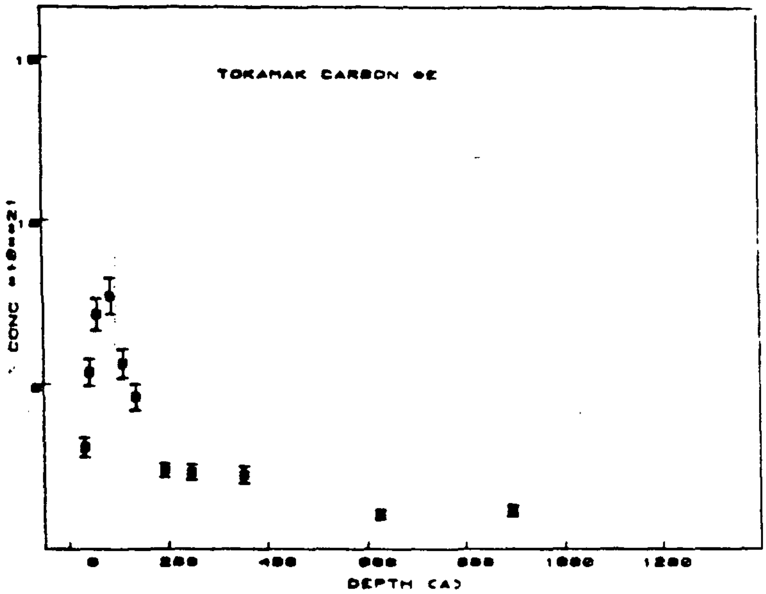

Figure 1. H-profile of a TEXTOR-exposed sample

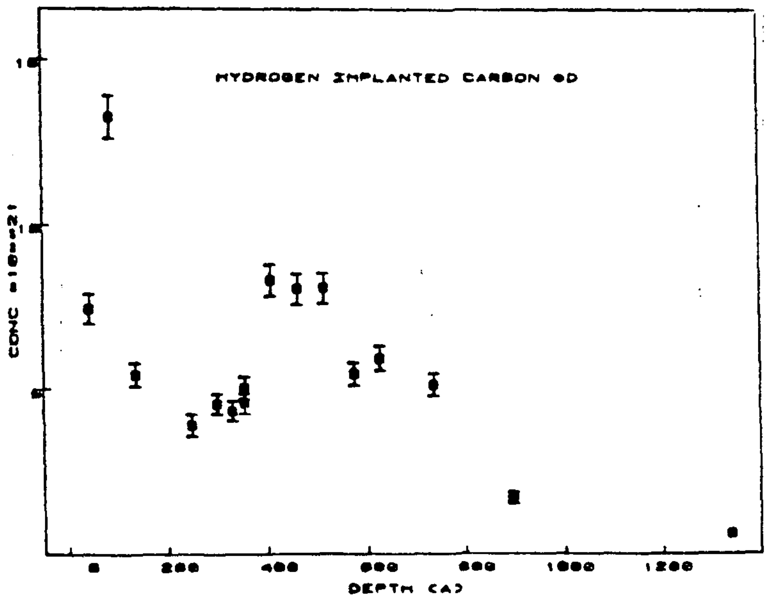

Figure 2. H-profile for the TEXTOR-exposed sample with H-implantation

CINDA index

Element				**Energy**		**KDK-86**		
S	**A**	**Quantity**	**Type**	**Min**	**Max**	**page**	**Lab**	**Comments**
D		Elastic	Expt prog	6.0+6	1.2+7	29	TLU	Flodqvist+
BE		Elastic	" "	2.2+7		18	SWR	Olsson+
BE		Diff inelastic	" "	2.2+7		18	"	"
C		Elastic	" "	1.7+7	2.2+7	17	"	"
C		Diff elastic	" "	1.7+7	2.2+7	17	"	"
C		Diff inelastic	" "	1.7+7	2.2+7	17	"	"
N		Elastic	" "	2.2+7		18	"	"
N		Diff elastic	" "	2.2+7		18	"	"
Q		Elastic	" "	2.2+7		18	"	"
Q		Diff elastic	" "	2.2+7		18	"	"
MG		Elastic	" "	2.2+7		18	"	"
MG		Diff elastic	" "	2.2+7		18	"	"
AL		Elastic	" "	2.2+7		18	"	"
AL		Diff elastic	" "	2.2+7		18	"	"
SI	28	(n,γ)	" "	8.0+6	1.4+7	31	TLU	Lindholm+
SI		Elastic	" "	2.2+7		18	SWR	Olsson+
SI		Diff elastic	" "	2.2+7		18	"	"
SI	28	(n,γ)	" "	8.0+6	1.4+7	31	TLU	Lindholm+
S		Elastic	" "	2.2+7		18	SWR	Olsson+
S		Diff elastic	" "	2.2+7		18	"	"
CA	40	(n,γ)	" "	3.5+6	2.8+7	32	TLU	Lindholm+

Element		Quantity	Type		Energy		KDK-86	Lab	Comments
S	A				Min	Max	page		
CA		Elastic	Expt	prog	2.2+7		18	SWR	Olsson+
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CR		Diff elastic	"	"	2.2+7		18	"	"
FE		Elastic	"	"	2.2+7		18	"	"
FE		Diff elastic	"	"	2.2+7		18	"	"
CO		Elastic	"	"	2.2+7		18	"	"
CO		Diff elastic	"	"	2.2+7		18	"	"
NI		Elastic	"	"	2.2+7		18	"	"
NI		Diff elastic	"	"	2.2+7		18	"	"
CU	74	Fiss prod β	"	"			23	SWR	Aleklett+
CU	75	" " "	"	"			23	"	"
CU	76	" " "	"	"			23	"	"
CU	78	" " "	"	"			23	"	"
ZN	75	" " "	"	"			23	"	"
ZN	76	" " "	"	"			23	"	"
ZN	77	" " "	"	"			23	"	"
ZN	78	" " "	"	"			23	"	"
ZN	79	" " "	"	"			23	"	"
ZN	80	" " "	"	"			23	"	"
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Y		Diff elastic	"	"	2.2+7		18	"	"
IN	115	(n,γ)	"	"	2.0+6	7.7+6	11	LND	Andersson+
IN	130	Fiss prod β	"	"			21	SWR	Aleklett+
XE	136	Strnth fnctn	"	"	0	5.0+5	23	SWR	Eleklett+

Element S	A	Quantity	Type		Energy Min	Max	KDK-86 page	Lab	Comments
CE		Elastic	Expt	prog	2.2+7		18	SWR	Olsson+
CE		Diff elastic	"	"	2.2+7		18	"	"
AU	197	(n,γ)	"	"	2.0+6	7.7+6	11	LND	Andersson+
PB	206	Elastic	"	"	2.2+7		18	SWR	Olsson+
PB	206	Diff elastic	"	"	2.2+7		18	"	"
BI		Elastic	"	"	2.2+7		18	"	"
BI		Diff elastic	"	"	2.2+7		18	"	"