SE8800107

KDK-97.
NEANDC(OR)-161/U
INDC(SWD)-22/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1986

Swedish Nuclear Data Committee
Stockholm, Sweden
August 1987

KDK-97

NEANDC(OR)-161/U

INDC(SWD)-22/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1986

Compiled by

H Condé

Department of Neutron Research

Uppsala University

Box 535, S-751 21 Uppsala

and

E Ramström

The Studsvik Neutron Research Laboratory

S-611 82 Nyköping

August 1987

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.

The document contains information of a preliminary or private nature and should be used with discretion. Its contents may not be quoted without the explicit permission of the originator.

1 THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

1.1 Status report, July 1986-June 1987

The Swedish Nuclear Data Committee has been equally supported for the present time period by six institutes, the National Board for Spent Nuclear Fuel, the National Defence Research Institute, the National Institute of Radiation Protection, the National Power Administration, the Studsvik Energi AB and the Swedish Nuclear Power Inspectorate, which also has coordinated the support. The members of the committee are listed under 1.3.

The Committee has discussed nuclear compilation and measurement program in progress, which are related to nuclear data. In particular, the Committee has supported a continuation of the Swedich 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). The Committee is sponsering the Spec. Meeting on Experimental Data for Decay Heat Predictions to be held at the Neutron Research Laboratory at Studsvik, September 7-10,1987. 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-75 Compilation of Actinide Neutron Nuclear Data, Part A: Experimental and Evaluated Cross Sections, Part B: Evaluated Group Cross Sections, 1986

KDK-85 Report to the Swedish Nuclear Power Inspectorate for the time period 1984-07-01--1985-06-30 (in Swedish)

KDK-86 Progress Report on Nuclear Data Activities in Sweden for 1984, September 1985

KDK-87 Report from the 25th NEANDC Meeting, Paris/Grenoble, France, November 18-20, 1985 (in Swedish)

KDK-88	Report to the Swedish Nuclear Power Inspectorate for the time period 1985-07-01--12-31 (in Swedish)
KDK-89	Report to the Swedish Nuclear Power Inspectorate for the time period 1986-01-01--03-31 (in Swedish)
KDK-90	Report from the 15th INDC-meeting, IAEA, Vienna, June 16-20, 1986 (in Swedish)
KDK-91	Swedish Nuclear Data Activities and New Facilities, May 1986
KDK-92	Report to the Swedish Nuclear Power Inspectorate for the time period 1985-07-01--1986-06-30
KDK-93	Status Report on the Evaluations of Oxygen for JEF 2 (H. Condé) October 1986
KDK-94	Report on the IAEA Advisory Group Meeting on Nuclear Data for Fusion Reactor Technology, TUD, Dresden/ Gaussig, DDR December 1-5, 1986 (in Swedish)
KDK-95	Standard Cross Sections for Fusion, Contribution to the IAEA Advisory Group Meeting on Nuclear Data for Fusion Reactor Technology, TUD, Dresden/Gaussig, DDR, December 1-5 1986 (H. Condé)
KDK-96	Report to the Swedish Nuclear Power Inspectorate for the time period 1986-07-01--12-31.

1.2 Compilation of Actinide Neutron Nuclear Data

P Andersson, Lund University, Lund
H Condé, Gustaf Werner Institute, Uppsala
C Nordborg, OECD/NEA Data Bank, Gif-Sur-Yvette, France
B Trostell, Studsvik Science Research Laboratory, Studsvik

The Swedish Nuclear Data Committee has initiated a compilation of a selected set of neutron cross section data for the most impor- tant actinide isotopes. The compilation work has been done by a working group sponsored by the Swedish Nuclear Power Inspectorate. The main part of the data information has been obtained from the OECD/NEA Data Bank at Saclay, France.

The aim of the report is to present available neutron cross section data in a comprehensible way to allow a comparison between different evaluated libraries and to judge about the reliability of these libraries from the experimental data.

The first result of the compilation was reported in 1979 (1). Since that time the compilation has been updated and further isotopes have been added (2). It now consists of 24 isotopes ranging from ^{232}Th to ^{252}Cf (KDK-75, Part A). Furthermore, in place of the resonance integrals reported in KDK-35 the compilation now includes group cross sections of the main evaluated data files for each of the 24 isotopes (KDK-75, Part B).

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)

2 P Andersson, H Condé, C Nordborg and B Trostell, Compilation of Actinide Neutron Data, KDK-75, NEANDC(OR) 159 A/U, INDC(SWD) 21/G (1986)

1.3 Members of KDK

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
Condé, Prof H	Department of Neutron Research, Uppsala University, Box 535, S-751 21 Uppsala
Elevant, Dr T	Royal Institute ofTechnology, Department of Plasma Physics, S-100 44 Stockholm
Fredin, Mr B	Asea Atom, S-721 04 Västerås
Grosshög, Dr G	Chalmers Institute of Technology, Department of Reactor Physics, S-412 96 Göteborg
Hammar, Mr L	Swedish Nuclear Power Inspectorate, Box 27106, S-102 52 Stockholm
Jirlow, Mr K	Studsvik Energiteknik AB, S-611 82 Nyköping
Lefvert, Dr T	National Power Administration, S-162 87 Vällingby
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	The T Svedberg Laboratory, Box 533 S-751 21 Uppsala
Rudstam Prof. G	The Studsvik Neutron Research Laboratory, S-611 82 Nyköping

* Ingvar Bergqvist suddenly died in a heart attack in May 87. It was a chocking message for all of us who had had the favour to work with him. Ingvar was a senior member of the Committee actively engaged in may of its acitivities through the years. He is replaced by Dr P. Ekström, head of the Swedish ENSDF activity at the Lund University.

2 LUND UNIVERSITY AND LUND INSTITUTE OF TECHNOLOGY

Sölvegatan 14
S-223 62 LUND

2.1 Division of Nuclear Physics

2.1.1 The Pelletron accelerator laboratory

R Hellborg

The research work at the laboratory is divided into a number of fields. A considerable effort has been employed in applying nuclear physics and 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 tandem accelerator, but we also have collaboration with other laboratories, e.g. the Svedberg Laboratory, Uppsala; the Studsvik Science Research Laboratory; Laboratoire National Saturne, Saclay; Technical University of Munich; Det Fysiske Institut, Aarhus; TRIUMF, 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. Atomic masses are also determined experimentally by means of nuclear decay studies.

An application of nuclear physics to solid state physics is the use of the channeling process. Epitaxially grown gallium nitride has been investigated to study the crystallographic order of the two sub-lattices.

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.

Study of gases, streaming upwards through the ground, give information about the composition of the bedrock in the ground. This method is tested in ore prospecting purposes.

The increased interest in radon measurements in 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 in collaboration with other laboratories. Low-energy nuclear structure studies using (p,γ) and (α,γ) reactions are also in progress.

2.1.2 Nuclear structure and decay data evaluation

M Bergström, L P Ekström, J Lyttkens, H M Sheppard and M Österlund

The international nuclear structure and decay data (NSDD) network is coordinated by the IAEA Nuclear Data Section. In consists of several evaluation groups and service centres. The network aims at a complete and continuous evaluation of all isobaric mass chains on a five-year cycle. The evaluated mass-chain data resulting from this effort are published in Nuclear Physics A and Nuclear Data Sheets. The data are also kept in a computer file ENSDF (Evaluated Nuclear Structure Data File), which is maintained by the National Nuclear Data Center (NNDC) at Brookhaven.

The Swedish Nuclear Power Inspectorate (SKI) has funded the activity at Lund since July, 1981. Since July 1985 part of the funding has come from other sources (FOA, NAK, SSI, Studsvik Energiteknik, Vattenfall).

The Lund group has been assigned responsibility for the mass range 59-64. The evaluation of mass 60 nuclei has been published recently, and work on A=90 (which is a temporary assignment) is in progress.

The Nuclear Structure Reference (NSR) file is a comprehensive compilation of keyworded bibliographic nuclear structure and decay data references used for the publication of Recent References in the Nuclear Data Sheets journal, for the preparation of special collections of bibliographic citations and for the preparation of responses to inquiries for specific nuclear information. References are given for papers that report experimental data on nuclear structure and nuclear reactions and on theoretical studies of specific nuclei and nuclear reactions.

A program to retrieve nuclear structure references from the NSR file (part of which is resident on disc on a VAX8200 computer (GARBO), is being written. References can be selected with a large number of criteria on, e.g., title, authors, keyword and nucleus/reaction selectors. The program is intend to complement the information in Nuclear Data Sheets, Recent References.

The retrieve facility will be available in the spring of 1987, and it can be reached from any computer in Sweden connected to the SUNET data communication network. We can also offer other services to NSDD users, e.g. MEDLIST output from decay data sets, copies of ENSDF, Wapstra's atomic masses etc. For more detailed information on the project, see ref. [1]), or contact LPE (SUNET address: GARBO::PELL PETER, BITNET: GARBOPEESELDC51).

1) Projekt kärndataevaluering (in Swedish), L P Ekström, J Lyttkens, P Andersson and HM Sheppard

2.1.3 Photonuclear research, general

B Forkman

During 1986 the main activity of the photonuclear research group has been preparations of experiments at the MAX accelerator, The accelerator system consists of a racetrack microtron used as injector to a combined storage and stretcher ring. In January 1987 the machine staff succeeded in bringing a stretched beam, with a duty cycle exceeding 50 per cent, to the nuclear physics area. The electron energy was 95 MeV and the intensity fully enough for the initial experiments with tagged, monoenergetic photons. During February 1987 the tagging system will be installed and the nuclear physics experiments can be started.

In the initial phase operation the main emphasis will be on studies with photons in the energy region above 50 MeV, e.g. in the so called quasideuteron region. Several experiments are foreseen involving groups from other places, both inside and outside Sweden.

One group of experiments using the (γ,p) reaction in some light nuclei is aimed at studies of the quasifree knockout and quasideuteron absorption contributions to the reaction cross section. These experiments will be performed with both moderate (plastic scintillators) a high (detectors of Si and Ge) energy resolution. A continuation of these studies will involve coincidence measurements, e.g. (γ,pn) and (γ,pp) studies, in light nuclei.

Experiments are also planned which involve single neutron detection. One such experiment is to look for the isovector E2 strength in ^{40}Ca employing the (γ,n_0) reaction. We will also use elastic photon scattering, (γ,γ) in connection with E2 resonances. However, in the initial period, the (γ,γ) studies will concentrate on energies above 50-60 MeV in order to determine the various amplitudes contributing to the scattering cross section in that energy region. It is also of great interest to study elastic photon scattering from the point of view of momentum transfer instead of two separate quantities, the scattering angle and the initial photon energy.

During 1986 the collaboration with American groups at the Bates linear accelerator has continued. Thus the results obtained earlier in the Δ region have been compared with theoretical calculations, such as the Δ-hole model, and a full paper was written. In the spring of 1987 the experiment at Bates, $^{238}U(e,e'fission)$, will be carried out with around 750 MeV incident electrons. The collaboration will eventually be continued as new proposals have been submitted.

3. RESEARCH INSTITUTE FOR PHYSICS, S-104 05 Stockholm

3.1 General information

I Bergström and A Nilsson

On September 30, 1985, the Knut and Alice Wallenberg Foundation made the decision to support the CRYRING-project by funding the major part of the investments for the project. CRYRING is a synchrotron and storage ring for research in atomic, molecular and nuclear structure physics using highly charged, very heavy ions. The main injector to the 35 meters ring is a cryogenic electron beam ion source (CRYSIS) which is connected to the ring via an RFQ accelerator. Also, the use of a 400 kV high voltage accelerator equipped with one or two conventional ion sources may be used for experiments with crossed beams. Atomic and molecular physics can be performed separately at the different injectors, but the main program concentrates on studies of merged and crossed beams of laser photons, electrons, atomic and molecular ions colliding with the stored ions. Also an extracted beam of particularly the heaviest ions (Xe,Hg,Pb,U) having energies of > 5 MeV/A is planned for research in atomic and nuclear physics.

The funding decision was preceeded by an investigation of a Committee appointed by the Swedish Natural Science Research Council. The analysis of the committee was based on statements of the merits of the project by a major part of the international experts. The report by the Council was made official in the beginning of 1985 and concluded that not only the scientific potential was interesting, but also that the accelerator technology involved was a challenge with its own merits. It was recommended that the project should start as soon as possible and receive full financial support. It is needless to emphasize that the Board of the Institute has given the CRYRING-project a very high priority.

Our elementary particle physics group at CERN has been hampered by the difficulties of long term planning. The group has joined the CP-violation experiment at CERN and it is hope that the new chair will strengthen the group considerably.

In neutrino physics K.E. Bergkvist has made an internationally appreciated effort to analyze the experimental evidence for massive neutrinos. In particular he has very carefully studied the methods of analyzing the end point region of the beta spectrum of tritium where the profile of the instrumental resolution function is crucial. The conclusion is that the present experimental information is compatible with the assumption that the mass of the electron antineutrino is zero.

Since no external beam of CRYRING is expected to be available before 1990, the nuclear physics group, which is still mainly involved in high spin physics, will depend very much on external facilities. The group has with great enthusiasm joined the so called NORDBALL-detector project. It is planned that the first half of this detector will be set up at the Daresbury tandem and used there until the upgrade Risotandem is in operation 1987. The equipment for in-beam measurements of g-factors and quadrupole moments including the equipment for external beam pulsing may be moved to the Uppsala synchrocyclotron. The research program of the theoretical nuclear physics group has mainly dealt with problems related to nuclei close to double magic numbers. However, the planned experimental research program at Daresbury and other external laboratories has justified efforts also in understanding the properties of high spin states of deformed nuclei.

During the last fifteen years the atomic group has been involved with problems which can be studied with beam energies up to 400 keV. The group has concentrated its efforts in studying atomic life-times by measuring natural widths as well as investigation two-electron excitations in light atoms. A few years ago some pilot experiments on electron exchange probabilities between neutral atoms and highly charged ions were started using cyclotron beams for creating these ions by the recoil technique. Experiments of this type using CRYSIS for ion production are expected to start in the spring of 1986. CRYSIS itself has during 1985 been modified since it arrived from Orsay. An ultra high vacuum ion injector for CRYSIS with a mass resolution of about 1:700 has been built and is in operation for various tests. A radio frequency quadrupole is being constructed and will be installed between CRYSIS and CRYRING. It is not excluded that beams from this RFQ can be used for atomic and molecular physics experiments. In theoretical atomic and molecular physics the efforts have been concentrated to the studies of atomic collisions with highly charged ions as well as the description of resonant states associated with scattering.

The molecular physics group is headed by Prof. P. Erman from the Royal Institute of Technology. The group has a powerful device for time resolved molecular spectroscopy using pulsed electron excitation. The equipment has recently been provided with a cool gas jet device. A high-resolution high-intensity pressurized spectrometer containing several gratings is being installed. Together with the atomic physics group a joint experiment is planned in order to study the fragmentation of molecular ions caused by laser beams. The experiment is partly a pilot set up for one of the possible standard experiments at CRYRING.

The main activity of the applied surface physics group is related to plasma wall problems. Plasma impurities in TEXTOR and JET are collected on carbon targets and then analyzed by back scattering methods in the Stockholm 2 MeV van de Graaff, which allows studies of element and time resolved plasma impurity concentrations. The group has recently in cooperation with the AB Energiteknik at Studsvik started a program of studying the improvement of metallic surface properties for components of technical interest using the 400 kV facility and the 70 kV isotope separator.

4. ROYAL INSTITUTE OF TECHNOLOGY, STOCKHOLM

4.1 Institute of Plasma Physics and Fusion Research

4.1.1 Neutron Time-of-Flight Spectrometer at JET.

T Elevant, M Olsson

A novel technique for measurements of neutron spectra (in the interval 1-20 MeV) in general and for fusion plasma ion temperatures in particular has been investigated. It is based on Time-of-Flight measurements between correlated events in two different plastic scintillators. The spectrometer has experienced a lot of development work including laboratory tests, Monte Carlo- and model calculations, design and construction work calibration, installation and comissioning. Experience during one year of operation at JET (Joint European Tours) has contributed to improvements, particularly with respect to magnetic shielding, evaluation of ion temperature and understanding of spectrometer behaviour during varying neutron emissions. Particularly, the resolution is found to be 135+/-15keV and efficiency is equal to 5*E-3 cm**2 with a flight path equal to 2 m.

Evaluations of ion temperature measurements by means of other diagnostics, and results from calculations, calibration tests and evaluation of neutron spectra agree within 20% accuracy. With enhanced statistics e.g. thousand counts, the uncertainty improves to about 12%. Stability has also been demonstrated up to 2.5kHz system countrate, which implies stable response for over two orders of magnitude.

Neutron spectra from Neutral Beam heated plasmas are analyzed with respect to beam-plasma interaction and thermonuclear contributions. Furthermore, neutron spectra measured under ICRF-heating conditions are analyzed and high energy ion tailes are evaluated.

A modified version of this technique, suitable for spectral measurements of 14-MeV neutrons during DT-operation, has been tested with a neutron point source. Instrumental resolution is equal to 280 keV, which enables measurements of ion temperatures exceeding 3 keV.

5 STUDSVIK NEUTRON RESEARCH LABORATORY AND THE DEPARTMENT OF NEUTRON RESEARCH, UPPSALA UNIVERSITY S-611 82 NYKÖPING

Since 1 July 1986 the responsibility for the operation of the Studsvik Science Research Laboratory has been taken over by the Uppsala University from the Natural Science Research Council. It has been reorganized and divided into two parts, viz. the Studsvik Neutron Research Laboratory and the Department of Neutron Research.

5.1 Neutron physics

5.1.1 <u>Precision measurements of neutron reference cross sections</u>

N Olsson and B Trostell

Accurate measurements of the secondary standard reaction C(n,n) in the energy region up to 15-17 MeV have been performed at several laboratories, e.g. Bruyères-le-Châtel, Triangle Universities Nuclear Laboratory and Lawrence Livermore National Laboratory. Ohio University has contributed with data at several energies in the range 21-26 MeV, while no precise information has been available in the range 17-21 MeV.

To fill this gap and join the two regions together, we have made precision measurements of neutron scattering from carbon at 16.5, 17.6, 18.7, 19.8, 20.9, 21.6 and 22.0 MeV.

The measurements were performed using the fast neutron time-of-flight spectrometer at the Studsvik Van de Graaff laboratory described in ref. [1]. The total energy resolution of the spectrometer was between 0.5 and 1.0 MeV in the energy region considered.

The scattering yields were recorded in the angular interval 10°-160°. The 0° direction of the scattering geometry was determined by measuring the yield on both sides of this direction. Differential scattering cross sections were determined relative to the H(n,n) cross section by observing the scattering yield from a parallelepipedic polyethylene sample in the angular range 20°-35°.

The experimental data have been corrected for source anisotropy, flux attenuation and multiple scattering in the sample, and for the finite scattering geometry. Except at deep minima, where counting statistics put limits on the accuracy of the data, the total uncertainty in the differential and angle integrated elastic cross section data is less than 5%.

In addition to the elastic data, we have also been able to extract information on inelastic scattering for the 2^+(4.44 MeV), 0^+(7.65 MeV and 3^-(9.64 MeV) states in ^{12}C. Also these cross sections are of importance in the context of precise neutron measurements. 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. Accurate inelastic cross sections are thus of utmost importance if reliable calculations of the neutron detection efficiency are to be performed.

References

1. N Olsson and B Trostell, Nucl. Instr. Meth. A245 (1986) 415

5.1.2 Neutron elastic and inelastic scattering at 21.6 MeV

N Olsson, B Trostell, E Ramström, B Holmqvist and F S Dietrich*

The previously described [1] fast neutron time-of-flight spectrometer at the Studsvik Van de Graaff laboratory has been used to measure elastic and inelastic scattering from 17 elements ranging from Be to Bi at an energy of 21.6 MeV. A time resolution of better than 0.8 ns, corresponding to an energy resolution of 0.5 MeV at that energy, has been used throughout the experiments. Angular distributions have been recorded in 2.5° or 5° steps in the interval 10° - 160°. The total uncertainty in the differential and angle integrated elastic cross section data is less than 5%. The corresponding accuracy for inelastic scattering is in the range 5-50%.

----

*Present address: Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

5.1.2.1 Elastic scattering

The experimental data for the natural elements Mg, Al, Si, S, Ca, Cr, Fe, Co, Ni, Y, Ce, Pb_r (radiogenic lead) and Bi, have been analysed in terms of a standard phenomenological spherical optical model. The results of these analyses are shown in Fig. 1, where they are compared with the experimental data. As shown in the figure the agreement is in general very good.

Microscopic folding models for the optical potential according to Jeukenne, Lejeune and Mahaux (JLM) [2],Brieva and Rook [3], and Yamaguchi et al. [4] have been tested by calculating angular distributions for all the elements studied.

The results of the calculations with the different microscopic models have been intercompared by studying the normalizing constants λ_V and λ_W of the real and imaginary central potential parts, respectively. These constants were determined from least squares fits to the experimental data. Best description of the experimental data is obtained with the JLM potential, where λ_V and λ_W seem to be within 5% and 15% of unity, respectively, for all the elements studied. Angular distributions calculated with this model are shown in fig. 2 together with the experimental data. The agreement is good except at the minima in the 20°-60° range in medium to heavy nuclei, where the model seems to underpredict the cross sections. The results of the calculations with the Yamaguchi potential are slightly worse, whereas the Brieva-Rook model yields poorer agreement. For these interactions the real normalizing constants are within 10% of unity, while the imaginary potential part is underpredicted by 35% in the Brieva-Rook model and overpredicted by a similar amount in the Yamaguchi model.

Furthermore, as can be seen when comparing Figs. 1 and 2, the angular distributions calculated with the JLM model describe the data nearly as well as the individual best fits calculated with the phenomenological model.

Volume integrals of the real and imaginary potential parts calculated with the JLM model are in good agreement with those of the phenomenological analyses. The corresponding values obtained with the models of Brieva-Rook and Yamaguchi et al. show reasonable agreement.

Analyses of the elastic scattering from the lightest elements, i.e. Be, C, N and O are at present in progress.

5.1.2.2 Inelastic scattering

The favourable experimental conditions have also made it possible to observe differential inelastic scattering angular distributions. Although these states are rather weakly excited, we have hitherto been able to extract cross sections for the following levels: 2^+ (1.37 MeV) and 4^++2^+ (4.12, 4.24 MeV) in ^{24}Mg, 2^+ (1.78 MeV) and 3^- (6.88 MeV) in ^{28}Si, 2^+ (2.23 MeV) and 2^++4^++1^++3^- (4.28, 4.46, 4.70, 5.01 MeV) in ^{32}S, 2^+ (1.43 MeV) in ^{52}Cr, 2^+ (0.85 MeV) in ^{56}Fe and 2^+ +2^+ (1.45, 1.33 MeV) in ^{58}Ni and ^{60}Ni, respectively. Determination of cross section data for several levels in the lightest and heaviest nuclei is also in progress.

The inelastic angular distributions will be analysed in terms of coupled channels and distorted wave Born approximation theories.

References

1. N Olsson and B Trostell, Nucl. Instr. Meth. A245 (1986) 415.

2. J-P Jeukenne et al., Phys. Rev. C15 (1977) 10, C16 (1977) 80.

3. F A Brieva and J R Rook, Nucl. Phys. A291 (1977) 299, 317, Yukawa parameterization of interaction by H V von Geramb.

4. N Yamaguchi et al., Prog. Theor. Phys. 70 (1983) 459.

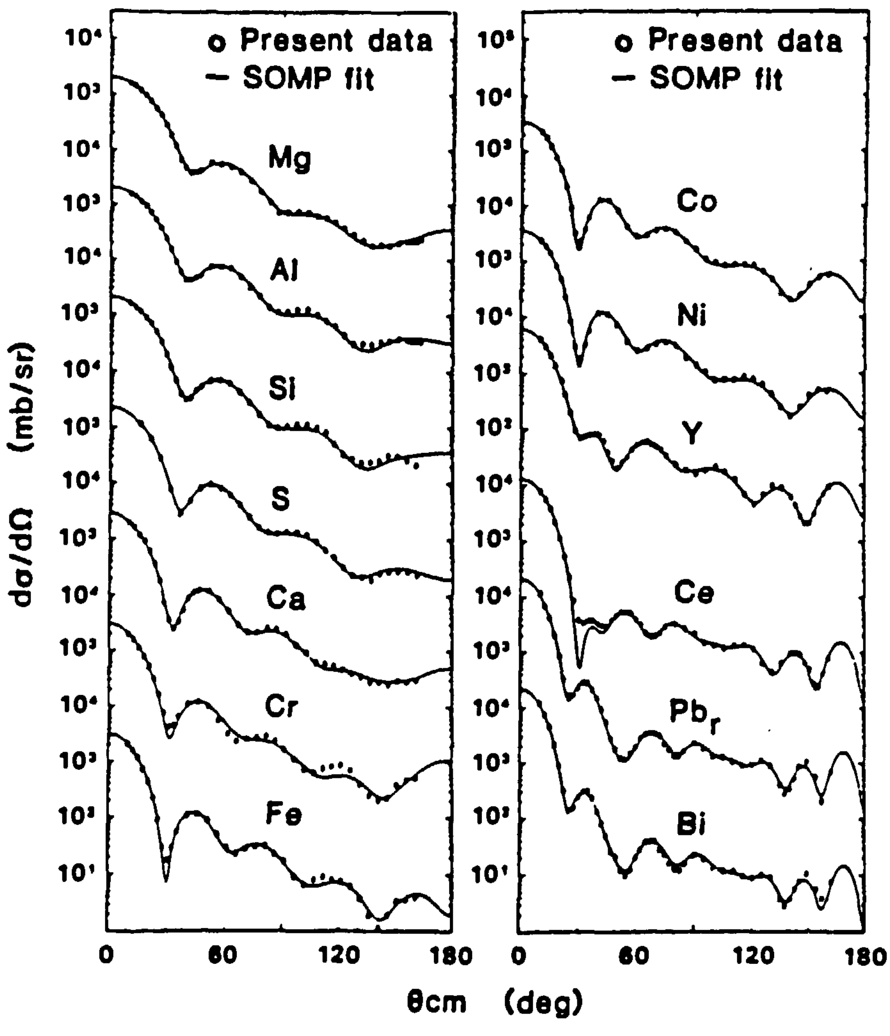

Fig. 1. Corrected differential neutron elastic scattering cross sections at 21.6 MeV for Mg to Bi in the centre of mass system plotted versus the scattering angle. The solid curves are the results of individual best fit optical model calculations.

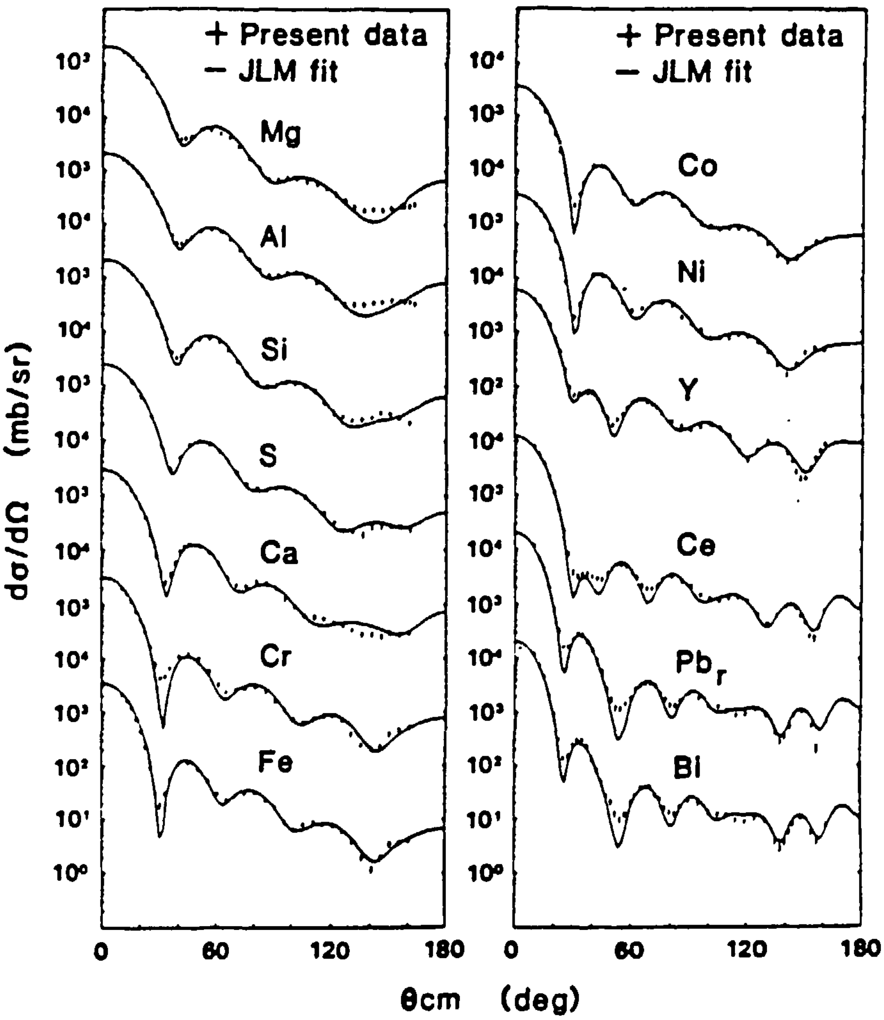

Fig. 2. Corrected differential neutron elastic scattering cross sections at 21.6 MeV for Mg to Bi in the centre of mass system plotted versus the scattering angle. The solid curves are the results of JLM microscopic model calculations.

5.1.3 The (n,p) facility at Uppsala

H Condé, B Holmqvist and N Olsson

(see 6.2.1).

5.2 Nuclear chemistry and nuclear physics

K Aleklett, B Ekström, J Eriksen, B Fogelberg, L Jacobsson, O Johansson, P-I Johansson, E Lund and G Rudstam

Introduction

The main research activity of the group is aimed at studies of the properties of short-lived neutron-rich nuclides produced at the isotope-separator-on-line facility OSIRIS. The program includes determination of total beta decay energies, nuclear spectroscopy, studies of delayed neutron, determination of fission yields including branching ratios for gamma rays of fission products, and determination of the antineutrino spectrum at a nuclear reactor. The work also includes the development of OSIRIS, especially the construction of new target-ion source systems, but also other more peripheral parts of the experimental equipment.

5.2.1 Development of the OSIRIS facility

A target+ion source system with a novel method for plasma creation [1].

A complete redesign of the ion source system has been necessary in order to reach higher temperatures and thereby shorter delay times for the released fission products. The new ion-source is unconventional in the sense that it can be used both for surface and plasma ionization of fission products released from the target. The plasma mode utilizes an intense electron beam incident through the emission orifice of the target chamber for creation of the plasma. The small size and the good insulation permit operation of the system at 2500°C with a power input of only about 450 W. The system has considerably increased the number of elements that can be studied at OSIRIS, and has increased the yields of many very short lived isotopes by factors of 10^2-10^3 compared to the previously used target and ion source.

One complete scan over most of the fission product region was obtained in an experiment aiming at the determination of fission yields. The overall efficiency for each element could then be deduced for isotopes with known fission yields. The results, shown in Fig. 1 exhibit prominent peaks for the elements with low ionization potentials which can be ionized by collisions with the Re surface at the outlet region. It can be expected that some of these peaks, if necessary for a particular application, can be strongly reduced by using Ta instead of Re at the outlet of the target chamber.

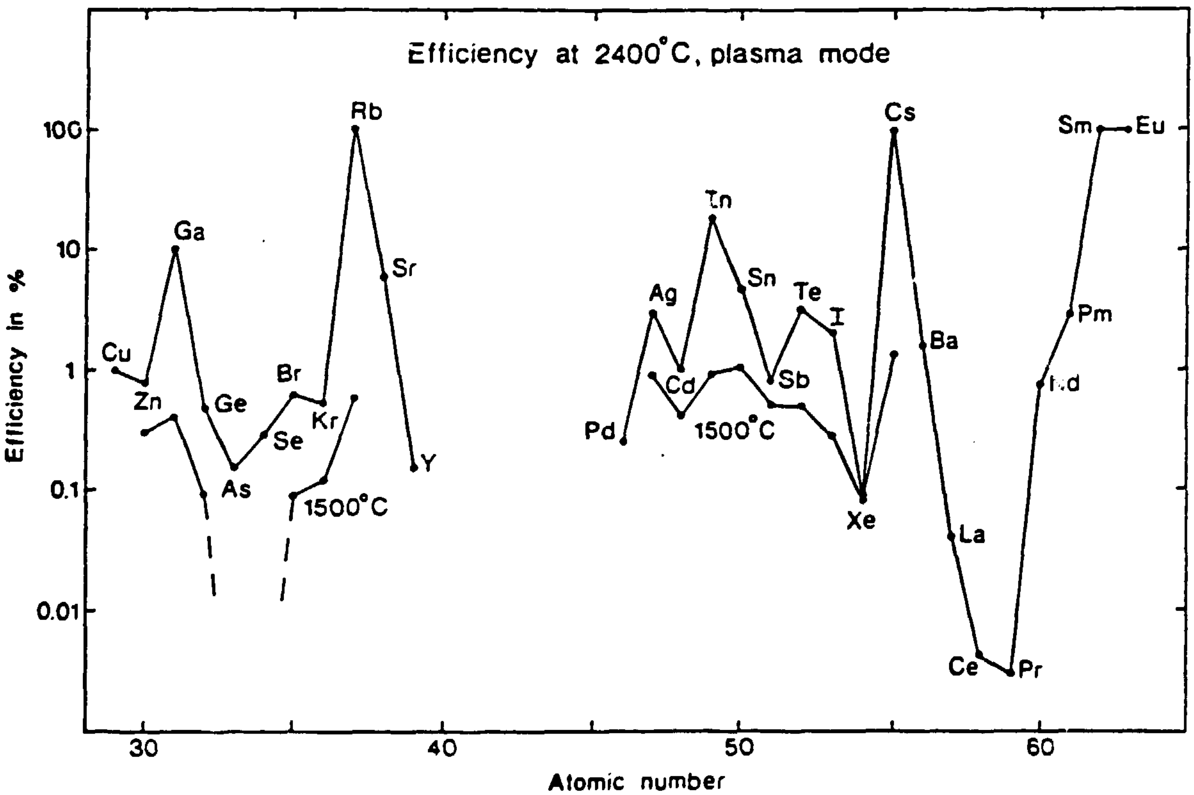

Fig. 1 The measured over-all efficiency of the ANUBIS ion source and target system as a function of the atomic number of fission product nuclei. The curve is an example from a family of curves which are obtained by varying the target temperature and the plasma density. The curves labelled "1500°C" are examples of the efficiencies obtained with the Nielsen type plasma ion source previously used at OSIRIS. The absolute scale (vertical) is uncertain to about 30%.

5.2.2 Nuclear spectroscopy and measurements of total decay energies

The possibilities for an extensive series of measurements of many previously unknown Q_β-values are now much improved due to the new target and ion-source system in use at OSIRIS. This system permits easy switching between different ionization modes and thereby also some chemical selectivity.

The status of the current experimental program can be described as follows.

A) The mass region A = 74-85

A detailed report [2] on the studies of Zn and Ga isotopes with A = 75-80 has been prepared. The data given in this report supersedes the preliminary Q_β-values reported [3] at the AMCO-7 conference (only minor adjustments have been made).

B) The mass region 123-135

The measurements and evaluations are essentially completed for isotopes of Cd with A = 123-128 and for In isotopes up to A = 130. A report [4] on the decay scheme studies of the off mass Cd isotopes has been published, and another report [5] on the total decay energies is near completion. The decay scheme studies of the even mass Cd nuclei are also near completion, but some additional information on conversion coefficients is needed here.

The set of data obtained in the studies of total decay energies includes the Sn isotopes with A = 129-134 and Sb isotopes having A = 131-135. The analysis of the Sn and Sb data is not yet completed.

C) Other spectroscopic studies

Some studies which were initiated several years ago have been completed during the last year. One of these concerns the γ-ray decay of unbound levels in the neutron emitter ^{137}Xe, and another describes a study of the level properties of ^{150}Nd using sources from OSIRIS obtained with the fluorination technique. Both these works have been published during the year. The investigation of ^{150}Nd showed quite clearly that this nucleus has a β-band with much smaller deformation than the ground band, which is contrary to the predictions of current nuclear models, including the IBA.

5.2.3 Measurements of fission yields and absolute γ-ray branching ratios at OSIRIS

Information on the absolute intensities of γ-rays is an essential prerequisite for the OSIRIS program of fission yield measurements. The large amount of data which has been collected at OSIRIS is now being evaluated together with available data from the literature. It is expected that a comprehensive table of absolute γ-ray intensities for nuclei in the fission product region will be published next year.

Some additional experiments have also been performed, primarily the study the previously practically unknown Cd isotopes with A = 123-128. A separate report [6] on the half-lives and γ-ray branching data for these isotopes has been published.

The experimental study of yields in the thermal-neutron induced fission of ^{235}U has now been completed. The methods used for the experiment and the analysis are described , and the results are given in terms of cumulative yields in two laboratory reports [7][8]. Some results are shown in Fig. 2.

The new target and ion source system has had a considerable impact on the fission yield determinations, both because many more fission products of several additional elements now are available, and because the much shorter delay between the fission event and the mass separation strongly reduces the uncertainties due to delay losses. A rather comprehensive set of measurements has therefore been made for the mass region A = 75-158, providing improved data for practically all important short-lived fission products.

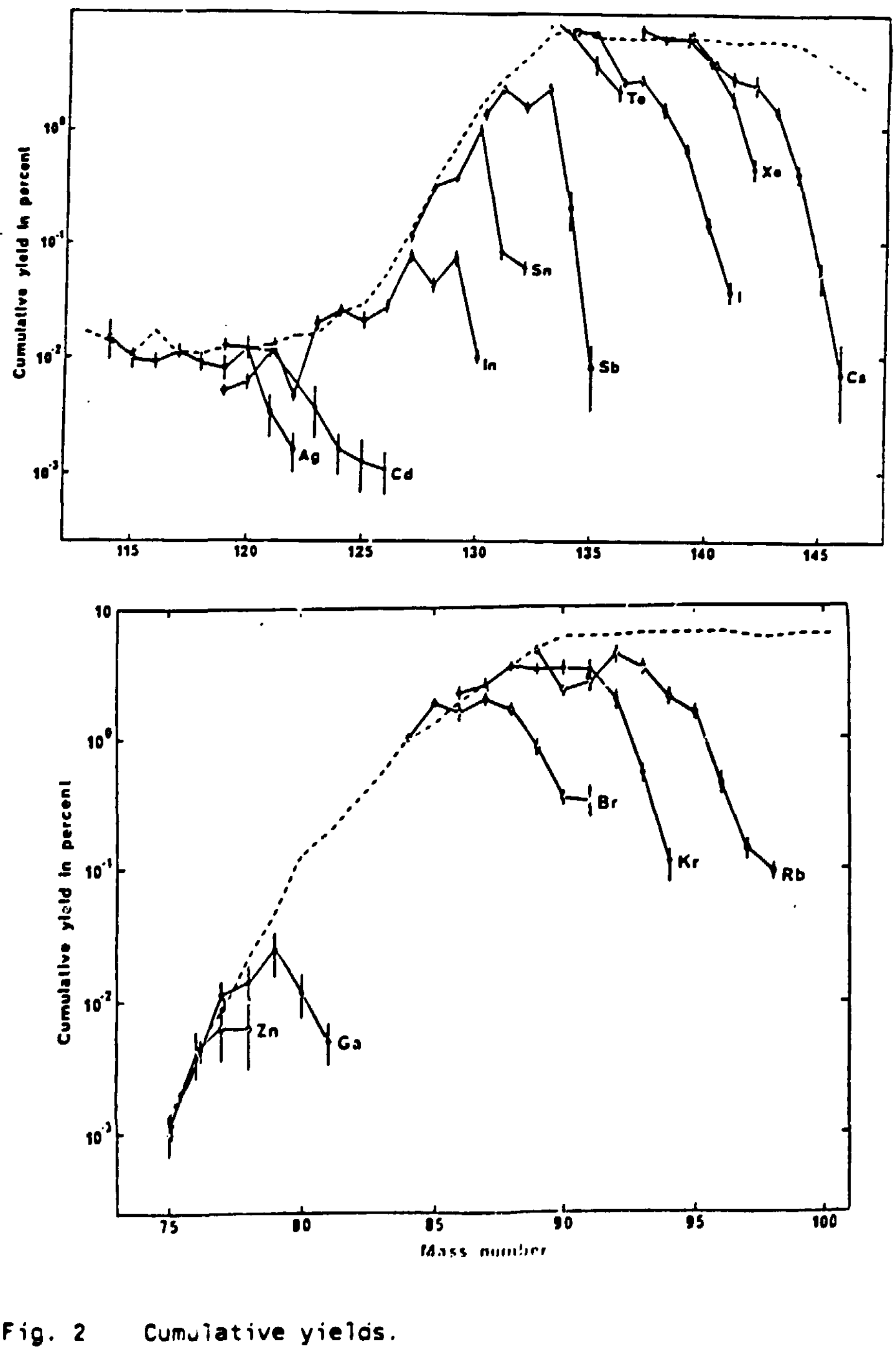

Fig. 2 Cumulative yields.
The experimental points have been joined by straight lines.
Dotted curve: ENDF/B-V chain yields.

The new target and ion source system has had a considerable impact on the fission yield determinations, both because many more fission products of several additional elements now are available, and because the much shorter delay between the fission event and the mass separation strongly reduces the uncertainties due to delay losses. A rather comprehensive set of measurements has therefore been made for the mass region A = 75-158, providing improved data for practically all important short-lived fission products.

Fission yields from ^{238}U.

An experiment with the intention to determine the yields of fission products from fast fission of ^{238}U was carried out at the Van de Graaff accelerator last year. The measurements were performed when the accelerator was a NFL-facility. The result of this measurement will mainly be cumulative yields for fission products with half-life longer than a few seconds and yield greater than about 0.1%. With the new ion source ANUBIS at OSIRIS we have a unique possibility to make accurate yield measurements of more shortlived nuclides and those with lower cumulative yield. The result from the present experiment can then be used to normalize yield data from OSIRIS.

Cumulative fission yields have been obtained for 44 nuclides, representing 24 mass chains (Table 1). So far, the results are only preliminary because only half of the data have been analyzed.

Table 1. Cumulative fission yields have been obtained for the following nuclides.

^{89}Kr	^{89}Rb	^{91}Sr	^{92}Sr	^{93}Sr	^{93}Y	^{94}Sr	^{94}Y
^{95}Y	^{97}Zr	^{97}Nb	^{99}Mo	^{99m}Tc	^{101}Mo	^{105}Ru	^{105}Ru
^{105}Rh	^{129m}Sn	^{129}Sb	^{131}Sb	^{131}I	^{132}Sn	^{132}Sb	^{132}Te
^{132}I	^{133}Sb	^{133}Te	^{133}I	^{134}Te	^{134}I	^{135}I	^{135}Xe
^{138}Xe	^{138}Cs	^{139}Cs	^{140}Ba	^{140}La	^{141}Ce	^{142}Ba	^{143}Ce
^{146}Ce	^{146}Pr	^{147}Nd	^{151}Pm				

5.2.4 The antineutrino spectrum at a nuclear reactor

This is a project where part of the measurements have been carried out at ISOLDE. A new set of measurements has been carried out at OSIRIS, and the analysis is under way. A final experimental period at OSIRIS is foreseen for the Spring of 1987.

5.2.5 Decay heat measurement

The energy release due to beta radiation following thermal-neutron fission of ^{239}Pu has been studied at the Van de Graaff-accelerator. The analysis is now completed, and the results are given in a laboratory report [9] (cf. also Fig. 3).

5.2.6 Summation calculation of the decay heat in nuclear fuel

As a byproduct of the antineutrino project one obtains the average energy of the beta particles emitted in the decay of individual nuclides. The average beta energies are important input data for the evaluation of the decay heat in nuclear fuel. An analysis of the decay heat using the new data has been carried out [10]. The results are shown for thermal-neutron induced fission of ^{235}U and ^{239}Pu in Fig. 3 where they can be compared to integral determinations from this laboratory.

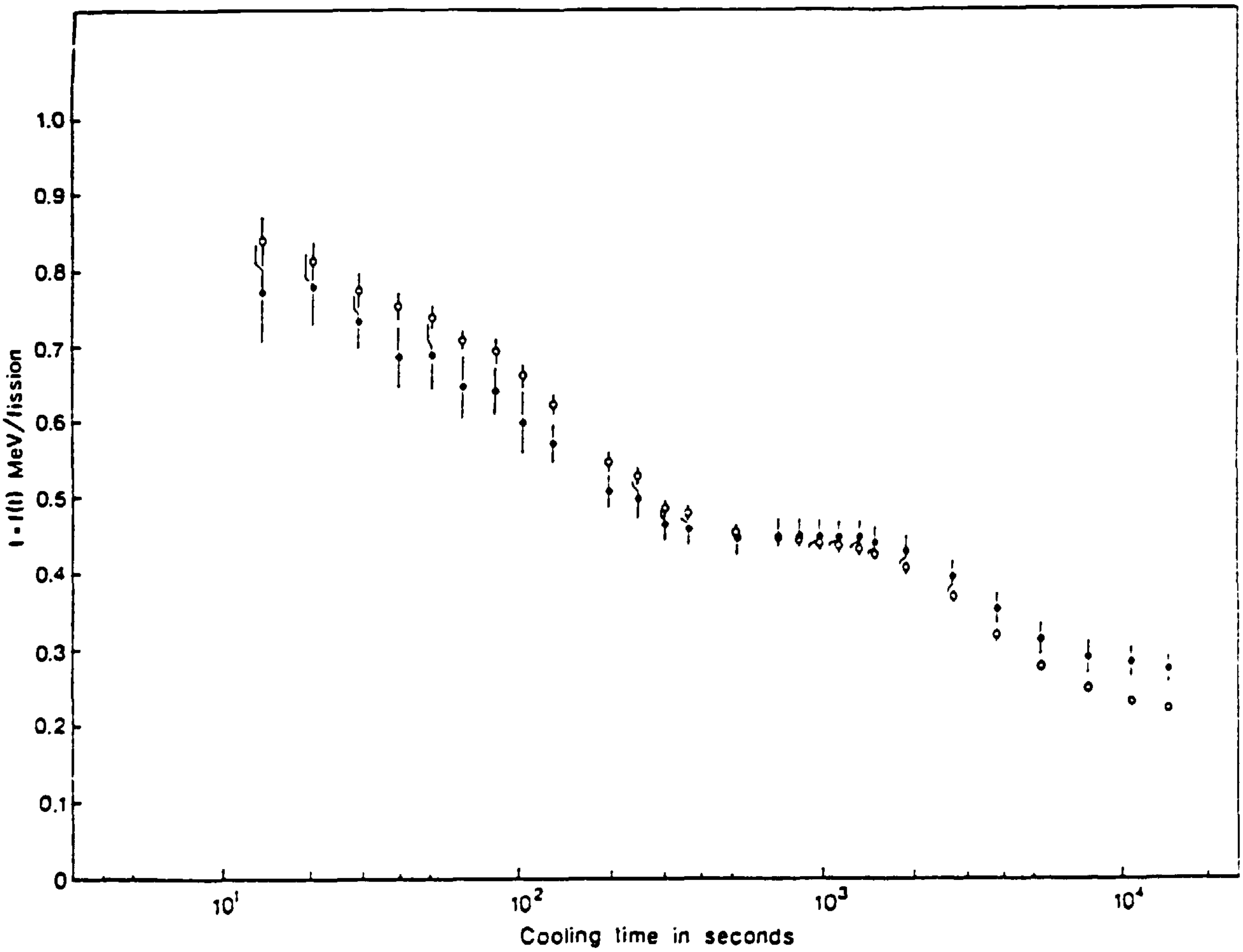

Fig. 3a Beta heat multiplied by cooling time for thermal fission of ^{235}U.
Filled circles = integral measurement [20].
Open circles = summation calculation using FPLIB6C library.
Irridation time 4-120 s.

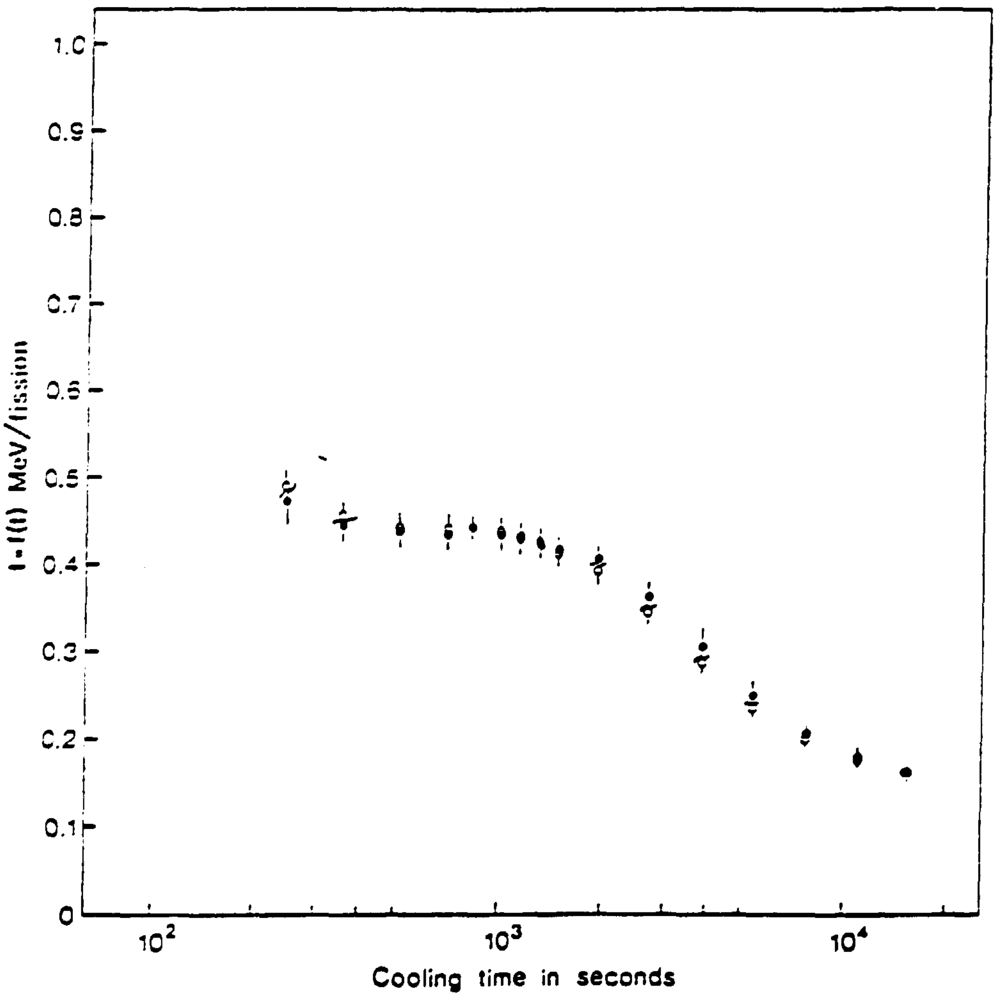

Fig. 3b Beta heat multiplied by cooling time for thermal fission of ^{239}Pu.

Filled circles = integral measurement [9].

Open circles = summation calculation using FPLIB6C library.

Irradiation time 120 s.

References

1. L Jacobsson and B Fogelberg, Contribution to EMIS-11, Los Alamos, Aug. 18-23, 1986.

2. B Ekström, B Fogelberg, P Hoff, E Lund and A Sangariyavanish, Physica Scripta.

3. E Lund, K Aleklett, B Fogelberg and A Sangariyavanish, Proc. of the 7th International Conference on Atomic Masses and Fundamental Constants, Ed. by O Klepper, Technische Hochschule Darmstadt, THD 26 p. 102 (1984).

4. P Hoff, B Ekström, H Göktürk and B Fogelberg, Nucl. Phys. A459 (1986) 35.

5. L Spanier et al., to be published.

6. H Göktürk, B Ekström, E Lund and B Fogelberg, Z. Phys. A324 (1096) 117.

7. G Rudstam, P Aagaard and H-U Zwicky, Report NFL-42, The Studsvik Science Research Laboratory (1985).

8. G Rudstam, Report NFL-43, The Studsvik Science Research Laboratory (1985).

9. P-I Johansson, Report NFL-53, The Studsvik Neutron Research Laboratory (1986).

10. G Rudstam, Report NFL-51, The Studsvik Neutron Research Laborarory (1986).

6 THE T SVEDBERG LABORATORY, BOX 533, 751 21 UPPSALA

6.1 General

The T(he) Svedberg Laboratory (TSL) is a new laboratory effective from July 1, 1986, consisting of the former Gustaf Werner Institute (GWI) and the Tandem Accelerator Laboratory (TLU). The sections of GWI and TLU have reappeared as parts of two units, namely

1) The TSL housing the Gustaf Werner Cyclotron, the tandem accelerator and the CELSIUS ring.

2. A Department for Radiation Science, consisting of the previous sections of high energy physics, nuclear physics, ion physics and physical biology.

Both of these will depend on Uppsala university: one direct under the University Board (Laboratory) and the other as part of the Faculty of Mathematics and Natural Sciences (Department).

The main facilities at the TSL are the rebuilt 200 MeV Gustaf Werner synchrocyclotron, CELSIUS a storage ring with acceleration and electron cooling capacity and a 12 MeV tandem accelerator.

The Gustaf Werner cyclotron will operate in two modes, i.e. as an isochronous, variable-energy cyclotron up to 110 MeV proton energy and as a synchrocyclotron for higher proton energies, up to 200 MeV. Heavier ions are accelerated to corresponding energies in the isochronous mode. The expected maximum average proton beam currents are 40 μA for the isochronous mode and 10 μA for the synchrocyclotron mode (Table 1).

The pulse width in the isochronous mode is about 5 ns at a frequency of 20 MHz. As a further development a pulsing system is planned with the aim to reduce the pulse width to about 1 ns and to decrease the frequency in steps down to 5 MHz. In the synchrocyclotron mode the pulses are delivered in macro-pulse structure with a pulse length of 25-50 μs and a frequency of 1 kHz with fast extraction. With slow extraction the pulse can be stretched to a length of 1 ms at a frequency of 500 Hz. The micro-pulse structure is the same as for the isochronous mode.

Table 1. Expected performance of the SFSC-200 cyclotron

Ion	Final energy	Acc. mode	Extr. meth.	Energy resolution	Horiz. emittance (π mm.mrad)	Estimated intensity (eμA)
p	110-200	1-f.m.	Reg	0.22	2-3	10-1
p	45-110	1-c.w.	Reg	0.5	2	40
p	45-110	1-c.w.	Prec	0.17	7	40
$^{3}He^{2+}$	250-267	1-f.m.	Reg	0.22	2-3	2
$^{3}He^{2+}$	137-250	1-c.w.	Reg	0.5	2	20
$^{3}He^{2+}$	35-137	2-c.w.	Prec	0.17	7	20
d	25-100	2-c.w.	Prec	0.17	7	40
$^{12}C^{4+}$	133-267	2-c.w.	Prec	0.17	7	5
$^{16}O^{5+}$	167-312	2-c.w.	Prec	0.17	7	10
$^{20}Ne^{7+}$	223-490	2-c.w.	Prec	0.17	7	0.1

The on-line storage ring, named CELSIUS, will be provided with an acceleration system working up to about 1 GeV and an electron cooling capability. Special target arrangements utilizing jet gas, micro pellets and thin fibres are being developed. The calculated energy resolution of the cooled ion beam is 10^{-4} for 10^{10} particles stored in the ring.

Presently a neutron physics facility for (n,p)-reaction studies, an electron-positron pair spectrometer, a proton spectrometer and a modular detector called the NORDBALL for multiparameter nuclear reaction studies are prepared. The NORDBALL consists of gamma-ray, charged particle, beta and neutron detectors mounted in a spherical matrix. The detector is built as a Nordic enterprise with participating laboratories from Denmark, Finland, Norway and Sweden.

Work on beams and equipment for biomedical experiments is also in progress as well as on a facility for radionuclide production. A spallation source for epithermal neutrons is also being designed for research on neutron capture therapy.

A first beam for the experiments are planned in the fall of 1987 from the cyclotron. The first beam for CELSIUS has been asked for during the same time period. The cooling system is scheduled for installation in late 87 - early 88.

6.2 Research at the Gustaf Werner Cyclotron

6.2.1 The (n,p) facility

H Condé, B Holmqvist and N Olsson, Department of Neutron Research, Uppsala University
O Jonsson, L Nilsson and P-U Renberg, The Svedberg Laboratory
J Blomgren, A Håkansson, A Lindholm and G Tibell, Department of Radiation Sciences, Uppsala University
P Ekström and R Zorro, Lund University

The upgraded Gustaf Werner cyclotron of the The Svedberg Laboratory, Uppsala, Sweden will be equipped with a facility to produce well collimated and energetically well defined neutron beams in the energy region from about 20 to 185 MeV.

The neutron facility will initially be used with the (n,p) reaction to study isovector excitations. To that end a magnetic spectrometer with large angle and momentum acceptance has been constructed. At a later stage the spectrometer, slightly modified, might be used in studies of (p,n) and (n,n') reactions. Further developments might include polarized protons and/or neutrons.

The neutron production facility

The neutrons are produced in a thin ^{7}Li metal target ($\approx$ 150 mg/cm^2), mounted in a water-cooled rig. The rig contains four separate targets which can remotely be put in beam position. To avoid overheating the targets can be wobbled.

After passage through the target the proton beam is deflected by means of two dipole magnets and focused on a graphite block at the end of a well shielded beam dump. The neutron beam at 0° is defined by a system of three collimators (Fig. 1). The diameter of the beam is about 8 cm at the position of the (n,p) target located about 8 m downstream from the neutron production target.

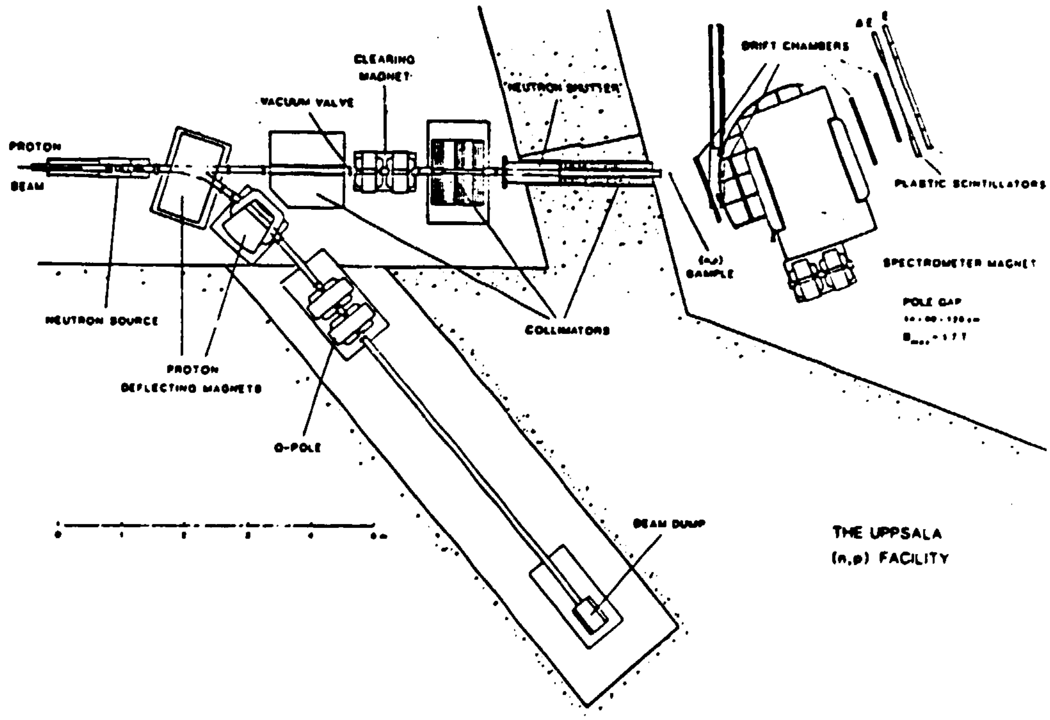

Figure 1

The (n,p) spectrometer

The (n,p) spectrometer consists of a large uniform-field magnet with two drift chambers before the magnet and two after for ray-tracing (Fig. 1). The spectrometer magnet is an H-magnet with a pole gap of 14 cm and a pole face area of 90 x 120 cm². The maximum magnetic field is of the order of 1.7 T. The spectrometer can be positioned to cover all relavant proton emission angles. The spectrometer magnet will be equipped with a chamber containing helium gas to reduce the energy spread caused by air scattering. The trigger for the drift chambers is obtained from a telescope consisting of two plastic scintillators with dimensions 90 x 30 x 1 cm³, each viewed by photomultiplier tubes at both ends.

The expected total energy spread of the (n,p) facility is about 1 MeV and a typical counting rate 0.1-0.2 counts/s/mb/sr.

6.2.2 Development of a neutron spallation source for neutron capture therapy

E Grusell, B Larsson, C-B Pettersson and Ormanong Sornsunsitook, Section for Physical Biology, Uppsala University
H Condé, Department of Neutron Research, Uppsala University
B Dahl and N G Sjöstrand, Chalmers University of Technology, Göteborg
J Crawford and H Reist, Swiss Institute of Nuclear Research, Villigen

Neutron capture therapy (NCT) of cancer is based on the possibility to tag ^{10}B antibodies to selected (normal or malignant) cell populations. The large thermal capture cross section for ^{10}B coupled with the "damage efficient" reaction $^{10}B(n,alpha)^{7}Li$ gives a greatly enhanced and localized dose.

The high water content of cells means that tissue will act as a good moderator for neutrons. To obtain a satisfactory thermal neutron distribution deep in tissue epithermal neutrons in the keV-region are required. Higher energy neutrons in the MeV-region cause an unwanted damage to the tissue by recoiling atoms and neutron reactions producing charged particles.

The dose rate delivered to the tumour should be of the order of 300 rad/h, corresponding to an epithermal neutron flux of about 10^9 n/cm², s in order to obtain a killing dose to the tumour within a reasonable time.

Different means to produce epithermal neutrons for NCT of correct energy and intensity are envisaged. One possibility of great interest is the neutron spallation source. The optimum design for an epithermal neutron spallation source will largely depend on the proper choice of materials and geometric arrangement for the moderator and beam tube.

An investigation is underway of a neutron spallation source for NCT in which the Monte Carlo calculations are made at the Department of Reactor Physics of the Chalmers University of Technology and the experimental tests at the Injector I, 72 MeV cyclotron, at the Swiss Institute of Nuclear Research.

6.3 Research at the Tandem Accelerator

6.3.1 General

During the last years the trend has been to devote more beamtime to applied and basic research outside nuclear physics. Thus 1986 about 70% of the effective beamtime was used for nuclear solid state physics, desorbtion 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 30%, has been for nuclear physics, mainly radiative-neutron-capture studies.

6.3.2 Studies of giant multipole resonances

A Håkansson, A Lindholm and L Nilsson, The Svedberg Laboratory, Uppsala
I Bergqvist and R Zorro, Department of Physics, University of Lund
N Olsson, Department of Neutron Research, Studsvik

6.3.2.1 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 studies have been made for nuclei in the mass region 40-208 and for neutron energies in the region 2-14 MeV, i.e. covering the region of the giant dipole resonance (GDR). The best quantitative description of the capture process is obtained using a complex particle-vibration coupling in the DSD-model calculations. The coupling strength is related to the isospin-dependent part V_1 and W_1 of the optical potential. In light nuclei like ^{40}Ca the used coupling strengths V_1 and W_1 are about equal to the strenghts 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 valuable tool to investigate giant quadrupole resonances. The E2 resonance will manifest itself as a for-aft asymmetry in the angular distribution of the capture gamma-rays through interference with the E1 resonance.

6.3.2.2 Neutron capture in yttrium

Neutron capture has previously (1,2) been used to investigate properties of the isovector quadrupole resonance (IVQR) in light and heavy nuclei (^{40}Ca and ^{208}Pb, respectively). In a recent experiment ^{89}Y was chosen as medium mass nuclei for the same kind of investigation. The angular distribution of gamma rays from capture to the ground state in ^{90}Y was measured at 3 angles, 55°, 90° and 125°, and at 7 neturon energies between 12 and 27 MeV. The for-aft assymetry defined by

$$A_1 = (I(55°) - I(125°)) / (I(55°) + I(125°))$$

is shown in the figure. The solid curves are results of DSD calculations for different isovector strengths (in % of the $T_<$-part of the estimated energy-weighted sum rule strength for the IVQR). The data are consistent with an energy of the IVQR of 26+-1 MeV and a resonance width of 10+-2 MeV. The results are presenteed in ref 3.

6.3.2.3 Study of the $^{209}Bi(n,\gamma)^{210}Bi$ reaction

According to Speth et.[4] al the transition from the IVQR state to the low-lying octopole state in heavier nuclei is as strong as the transition to the ground state. This transition should also show assymetry (interference between E1 and E2 amplitudes) like the transition to the ground state.

A study of the decay of the IVQR by means of the $^{209}Bi(n,\gamma)^{210}Bi$ reaction is in progress.

References

1. I Bergqvist, R Zorro, A Håkansson, A Lindholm, L Nilsson, N Olsson and A Likar, Nucl. Phys. A419 (1984) 509

2. D M Drake, S Joly, L Nilsson, S A Wender, K Aniol, I Halpern and D Storm, Phys. Rev. Lett. 47 (1981) 1381

3. R Zorro, I Bergqvist, S Crona, A Håkansson, A Likar, A Lindholm, L Nilsson and N Olsson, Nuclear Physics Report, LUNFD6/(NFFR-3056) (1986)

4. J Speth, D Cha, V Klemt and J Wambach, Phys. Rev. C31 (1985) 2310

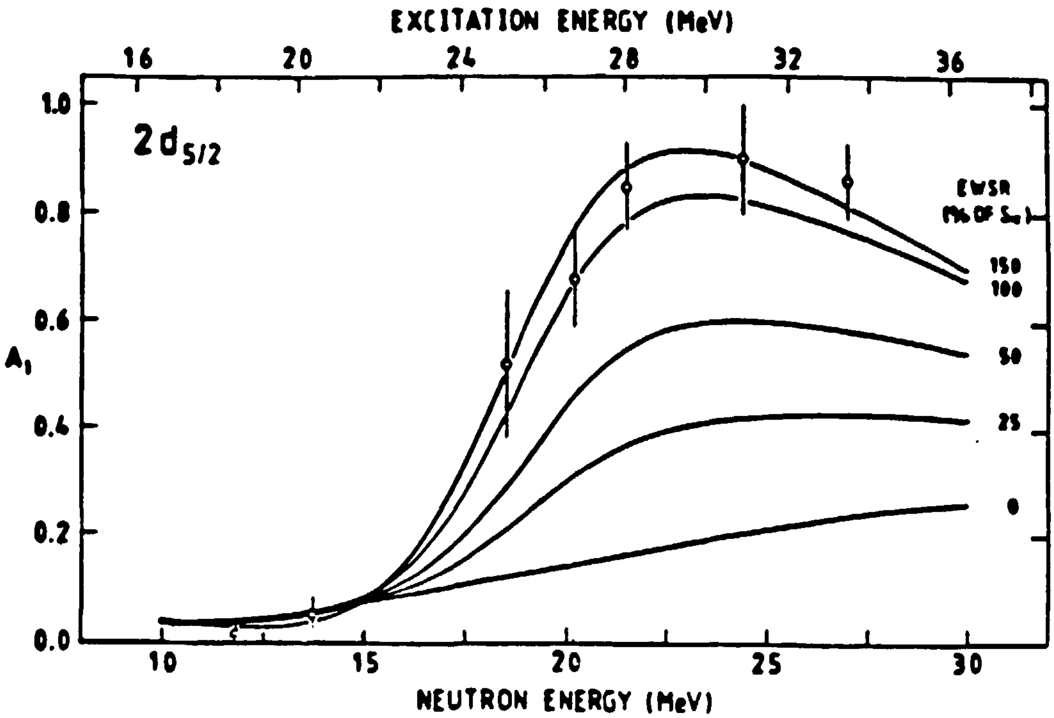

Figure caption

Figure. Measured forward-to-backward anisotropies A_1 for the $^{89}Y(n,\gamma_0+\gamma_1)^{90}Y$ reaction. For further information see text

CINDA index

Element S	A	Quantity	Type	Energy min	Energy max	KDK-97 page	Lab	Comments
C		Diff elastic	Expt prog	1.7+7	2.2+7	18	SWR	Olsson+
C		Diff inelast	-"-	1.7+7	2.2+7	18	"	-"-
MG		Diff elastic	-"-	2.2+7		19	"	-"-
MG		Diff inelast	-"-	2.2+7		19	"	-"-
AL		Diff elastic	-"-	2.2+7		19	"	-"-
SI		Diff elastic	-"-	2.2+7		19	"	-"-
SI		Diff inelast	-"-	2.2+7		19	"	-"-
S		Diff elastic	-"-	2.2+7		19	"	-"-
S		Diff inelast	-"-	2.2+7		19	"	-"-
CA		Diff elastic	-"-	2.2+7		19	"	-"-
CR		Diff elastic	-"-	2.2+7		19	"	-"-
CR		Diff elastic	-"-	2.2+7		19	"	-"-
FE		Diff elastic	-"-	2.2+7		19	"	-"-
FE		Diff inelast	-"-	2.2+7		19	"	-"-
CO		Diff elastic	-"-	2.2+7		19	"	-"-
NI		Diff elastic	-"-	2.2+7		19	"	-"-
NI		Diff inelast	-"-	2.2+7		19	"	-"-
Y		Diff elastic	-"-	2.2+7		19	"	-"-
Y	89	(n,γ)	-"-	1.2+7	2.7+7	40	TLU	Håkansson+
CE		Diff elastic	-"-	2.2+7		19	"	-"-
PB		Diff elastic	-"-	2.2+7		19	"	-"-
BI		Diff elastic	-"-	2.2+7		19	"	-"-
U	235	Fiss prod β	-"-	Maxwl		26	"	Aleklett+
U	235	Fiss prod γ	-"-	Maxwl		27	"	-"-
U	235	Fiss yield	-"-	Maxwl		27	"	-"-
U	235	Fiss prod β	-"-	2.5-2		30	"	Johansson
U	238	Fiss yield	-"-	2.5+6		29	"	Johansson
PU	239	Fiss prod β	-"-	2.5-2		30	SWR	Johansson