KDK-64
NEANDC(OR)-158/U
INDC(SWD)-18/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1982

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN
MAY 1983

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Swedish Nuclear Data Committee
Stockholm, Sweden
May 1983

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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.

Reports relevant to the nuclear energy field are given on neutron cross section measurements and studies of the fission process. Reports are also given of fission product nuclear data measurements of importance for the research on reactor safety and nuclear waste handling.

The report also contains short information about changes of existing or new experimental equipments.

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1 THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

1.1 Status report, May 1982-May 1983

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 measurement 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) (KDK reports KDK-51, -56, -57 and -60).

A compilation has been made of nuclear data requests for measurements presented at recent international conferences and meetings (KDK-50).

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

KDK-50 Nuclear Data for Applied Nuclear Research and Development (May 1983) (In Swedish)

KDK-51 Intercomparison of Am-241 Evaluations for the European-Japanese Neutron Data Library (JEF) (September 1982)

KDK-52 Report to the Swedish Nuclear Power Inspectorate for the time period 1982-01-01--03-31 (March 1982) (In Swedish)

KDK-53 Progress Report on Nuclear Data Activities in Sweden for 1981 (June 1982)

KDK-54 Report to the Swedish Nuclear Power Inspectorate for the time period 1981-01-07--1982-06-30 (July 1982) (In Swedish)

KDK-55 Report from the NEANDC/NEACRP Specialist Meeting on Fast-Neutron Capture Cross Sections, Argonne Nat Lab, April 20-23, 1982 (In Swedish)

KDK-56 Intercomparison of Am-242 and Am-243 evaluations for the Joint Evaluated File (JEF) (September 1982)

KDK-57 Intercomparison of Oxygen Evaluations for the Joint Evaluated File (September 1982)

KDK-58 Report from the 23rd NEANDC Meeting, Chalk River Nuclear Laboratory, September 27-October 1, 1982 (In Swedish)

KDK-59 Report to the Swedish Nuclear Power Inspectorate for the time period 1982-07-01--09-30 (In Swedish)

KDK-60 Intercomparison of Sodium Evaluations for the Joint Evaluated File (January 1983)

KDK-61 Report to the Swedish Nuclear Power Inspectorate for the time period 1982-10-01--12-21 (In Swedish)

1.2 Compilation of actinide neutron nuclear data

H Condé, National Defence Research Institute, Stockholm
A Etemad, Chalmers University of Technology, Göteborg
P Andersson, Lund University, Lund
H Häggblom and G Olsson, Studsvik Energiteknik AB, Studsvik
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 controlled plotter. Calculation and compilation of group cross sections for the same nuclides are also in progress.

An intercomparison of Am-241, Am-242 and Am-243 evaluations for the Joint Evaluated File (JEF) has been completed (2, 3).

Reference

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

2 M A Etemad and H Condé. Intercomparison of Am-241 Evaluations for the European-Japanese Neutron Data Library. KDK-51 (1982)

3 H Condé. Intercomparison of Am-242 and Am-243 evaluations for the Joint Evaluated File. KDK-56 (1982)

1.3 Members of KDK

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2 THE GUSTAF WERNER INSTITUTE, S-751 21 UPPSALA

2.1 General

S Kullander and B Larsson

Since the synchrocyclotron was shut down, in 1977, the research has to a great extent been based on radiation sources abroad. Often the results reported arise in collaborations in which GWI is one of the participating institutes.

The research is very diversified spanning a wide range of natural science and medicin. The denominator is radiation, its production, detection and use, which often interrelates the different fields of research.

In elementary particle physics the experiment on small angle hadron-proton scattering has been terminated. It was done in collaboration with groups from Leningrad, Lyon and Clermont-Ferrand and beams up to 350 MeV from the CERN SPS were used.

A research program with the European Muon Collaboration has been initiated. High-energy muons may interact in a point-like way with the proton constituents and are therefore preferable as compared with hadron beams. The program comprises studies of the hadronic structure of virtual exchange photons and studies of the propagation of quarks in nuclei.

During 1981 physicists from Uppsala together with other European groups worked out the concepts for a detector intended to be placed in one of the eight interaction regions around the LEP ring.

Research in intermediate-energy physics has been performed in Switzerland (SIN), USA (LAMPF) and at CERN. At SIN the work on muon-induced fission continued to elucidate the mechanism of fission. At LAMPF more data on the (π,p) and (p,π) reactions were produced and at CERN interesting results were obtained with the new carbon beam. A proposal to study heavy lambda hypernuclei using the future low-energy antiproton ring at CERN was accepted.

Steadily over the years, first at the old cyclotron, now in international colaborations, the students of physical biology and their partners in various branches of science and medicine have exploited nuclear particles and radionuclides in biological experiments and clinical studies

With a view towards the exciting prospect of the new cyclotron, experiments are underway at facilities available elsewhere, e.g. the nuclear microprobe in Studsvik, proton beams in Harvard and Moscow, and a neutron beam in Grenoble. A fruitful collaboration with the medical departments in Uppsala and Stockholm, the department of organic chemistry and local industry has resulted in the recent installation of a positron emission tomograph for common use at the Academic hospital. Tests are now being made with radionuclides produced at the Uppsala Tandem Accelerator.

Most of the technical staff has worked on the improvement of the former 185 MeV synchrocyclotron. The only parts remaining are the magnet and the coils. The new accelerator expected to be ready in 1984 will be a modern 3 sector cyclotron for protons and other ions. The most important event during 1981 was the final approval of the experimental areas around the accelerator.

2.2 Synchrocyclotron conversion

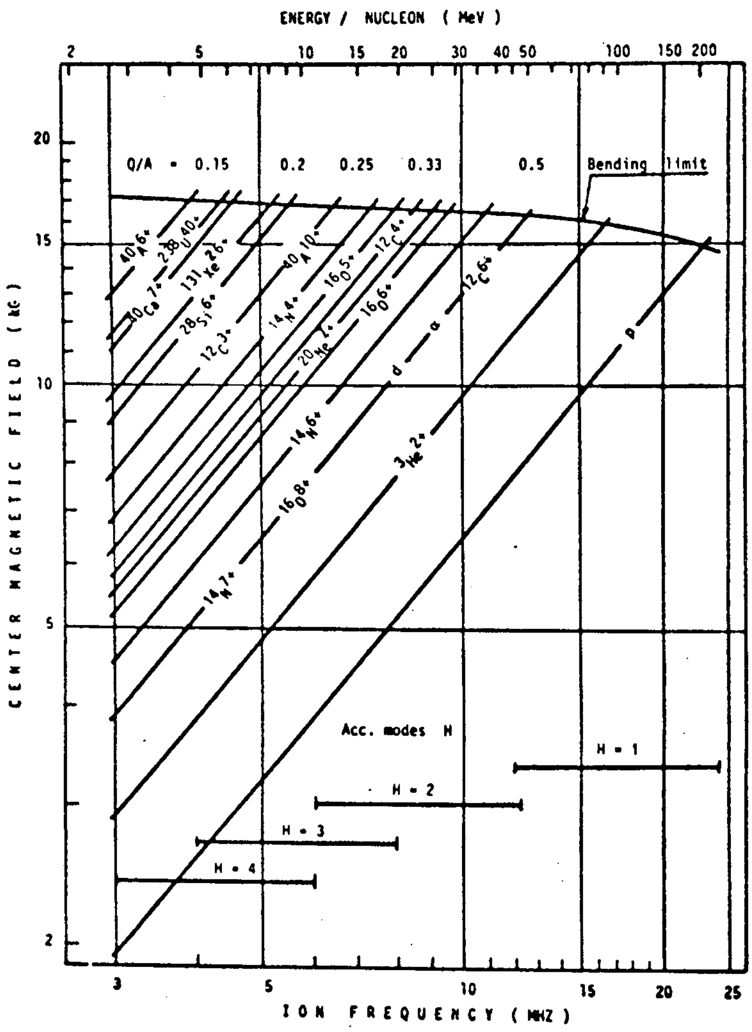

Figure 1. Centre magnetic fields vs ion frequency and energy per nucleon. Various possible acceleration harmonics H are shown for an RF-range of 12-24 MHz.

The conversion of the synchrocyclotron at the Gustaf Werner Institute is in progress. The reconstructed cyclotron will operate with frequency modulation for protons in the energy range 110-120 MeV and at fixed frequency in the isochronous mode for heavier particles with energies according to Figure 1. A three-sector magnetic-field and a broad band RF system replaces the previous rotating capacitor system. A reconstruction of other main components of the cyclotron is also undertaken.

2.2.1 The CELSIUS* project

A storage ring for the ions with electron cooling will be added to the cyclotron. The main parts of the ring is coming from the former ICE (Initial Cooling Experiment) experiment at CERN. The equipment will be upgraded to fit the performances of the Uppsala cyclotron and new target systems, diagnostic etc are being developed.

*Cooling with ELectrons and Storing of Ions from the Uppsala Synchrocyclotron (CELSIUS)

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

3.1 Divison 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 physcis 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 tandemaccelerator, but we also have collaborations with other laboratories, e.g. the Tandem accelerator laboratory in Uppsala, Max Planck Institute in Heidelberg, Technical University of Munich, Det Fysiske Institut, Aarhus.

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 and lichen have been used as indicators. The activity was detected in the laboratory with a Ge(Li)-detector.

In addition to collaborations with other laboratories in studies of giant resonances and nuclear structure, work is also going on in low-energy nuclear structure physics, e.g. proton capture studies and determinations of neutron capture cross sections.

3.1.2 Neutron capture measurements using the activation technique

P Andersson, I Bergqvist and R Zorro

A method, originally applied to measurements with 14 MeV neutrons (1), has been further developed to determine the corrections for the contribution of background neutrons to the measured cross sections in the lower MeV region. This consists of observing the dependence of the activation yield on varying sample thickness and source-to-sample distance.

Neutron capture cross sections are measured relative to the cross section of the $^{115}In(n,n')^{115m}In$ reaction and the stability of the neutron flux is checked during irradiation by means of a long counter. The induced activity is measured with the aid of a Ge(Li) detector.

Cross section measurements in the neutron energy range 2-4.5 MeV have been conducted for the reactions $^{115}In(n,\gamma)^{116m}In$ and $^{197}Au(n,\gamma)^{198}Au$ and are discussed in detail in a recent report (2). Measurements for the above nuclei are in progress in the energy range 4.5-6 MeV.

In order to improve the ratio of source neutron to those produced in the source holder we plan to use a specially built gas cell as a neutron source. To improve counting statistics we plan to measure the induced activity by means of large solid angle β-counting, measurements of (n,γ) cross sections in the MeV region will be performed in the near future for Pb-208.

References

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

2 P Andersson, R Zorro and I Bergqvist, Nuclear Physics Report LUNDFD 6/(NFFR-3043)/1-26/(1982)

3.1.3 Nuclear structure and decay data evaluation

P Andersson, L P Ekström and J Lyttkens

The Lund group has been assigned within the ENSDF international cooperation the mass range 59-64. The mass-chain evaluation for A=113 which was done in collaboration with Liverpool University has been published in Nuclear Data Sheets. The evaluation for A=61 has been submitted for publication, and work on A=59 has been started.

Programs to retrieve datasets 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 -rays from decay datasets ordered by energy.

3.1.4 Radioactivity in the environment

B Erlandsson, T Ingemansson and S Mattsson*

The presence in the environment of activation products released to the air from a nuclear power station has been studied in sewage sludge and ground level air. The measured time variation of the Co-60 concentration in sludge and ground level air was found to be in good agreement with the reported variation in release rate to the air from the power station when the prevalent wind direction is taken into account.

3.1.5 Photonuclear research, general

B Forkman

In January 1980 the funding of the MAX-accelerator, consisting of a race-track mictrotron and a pulse stretcher/storage ring, was completed and a decision made to develop the laboratory to a national laboratory for synchrotron light and energetic electrons. As a consequence of this a national board took over the responsibility for the laboratory in July 1981 and a 1 000 m^2 experimental hall was put to the disposal of the project by the university. This is presently being rebuilt and the accelerator system will be installed there during 1983.

The photonuclear group is presently studying electrofission of s-d shell nuclei using electrons from the injector to study in detail the possibilities for photon scattering experiments and giant resonance decay research with the pulse stretcher/storage ring. Equipment for a photon tagging system is under construction and detectors for a γ-spectrometer and charged-particle telescopes have been purchased.

During October 5-7, 1982, the photonuclear and electron accelerator groups at the Department of Nuclear Physics and MAX-lab organized a workshop on the use of ELECTRON RINGS FOR NUCLEAR PHYSICS RESEARCH in the intermediate energy region. The goal of the workshop was to discuss how the new generation of electron accelerator systems and rings with high current and high dutycycle can be used for nuclear structure and

*Department of Radiation Physics, Malmö General Hospital, Malmö, Sweden nuclear reaction studies. The topis were i) stretcher rings and related experiments ii) storage rings and related experiments and iii) intermediate energy physics.

Table 1. Parameter values of the racetrack microtron

Electron energy	10-100 MeV
Pulse current	25 mA
Pulse length	1-2 μs
Repetition rate	750 s^{-1} (goal)
Energy spread	10^{-3}
Rf	3 GHz
Resonant energy gain	5.3 MeV
Number of turns	19
Emittance	0.3 mm mrad

The ring may be used, either as a storage ring or as a pulse-stretcher. The latter mode will be used to transform the low dutyfactor beam ($df \approx 10^{-3}$) from the injector into an almost contineous external electron beam ($df \approx 1$).

3.2 Division of Mathematical Physics

3.2.1 Spectroscopic properties of fission isomers

W Nazarewicz
J Dudek, Institute of Physics, Warsaw

Spectroscopic properties (singels-particle states, g-factors) of fission isomers in actinide region have been studied using the optimized Woods-Saxon potential. Microscopic calculations show that the theoretical model is able to explain almost all existing experimental single particle data in the second well. Results depend strongly on used spin orbit parameters (particularly on the radius of the spin orbit potential).

3.2.2 Properties of nuclei at the third-minimum deformation

R Bengtsson, K Pomorski*, I Ragnarsson, A Sobiczewski** and S Åberg

The potential energy (with the deformation parameters $\varepsilon_{2,3,4,5,6}$) of heavy nuclei in the Ra-Th region is investigated. A rather large "island" of nucleides with a third fission barrier minimum is found.

* Institute of Physics, The Maria Sklodowska-Curie University, Lublin, Poland
**Institute of Nuclear Research, Warsaw, Poland

Such properties as moment of inertia, decoupling parameter and the energy shift between positive- and negative-parity rotational bands are studied.

3.2.3 Fission barriers and decay properties of heavy elements

W M Howard*, J Krumlinde**, P Möller and C O Wene**

We use the modified oscillator model and the Droplet model to calculate potential energy surfaces and the corresponding ground state minima and fission barriers for nuclei with $76 \leq Z \leq 110$ and $118 \leq N \leq 184$.

The work on the tabulation of approximatively 1 000 nuclei is expected to be completed during the summer of 1983.

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**Department of Physics, University of Lund, Lund, Sweden

4 THE STUDVIK SCIENCE RESEARCH LABORATORY, S-611 82 NYKÖPING

4.1 Neutron physics

4.1.1 A facility for neutron elastic and inelastic scattering at 22 MeV

B Holmqvist, B Jonsson, L Norell, N Olsson, E Ramström and B Trostell

The aim of the present experimental program is to collect a homogeneous set of differential neutron elastic and inelastic scattering angular distributions of high accuracy. The experimental elastic scattering data should be used for studies of the spin-orbit interaction and also the isobaric spin dependence of the optical model potential without disturbing components from compound elastic scattering.

In order to perform neutron scattering experiments at 22 MeV the time resolution of the time-of-flight spectrometer has to be improved. The time resolution depends on i.e. the ion pulse width, the length of the gas target cell, the time resolution of the neutron detector as well as different geometrical factors.

A post bunching facility for production of ion pulses with a duration of down to 150 ps has been completed during the year.

The properties of the bunching system has been tested in a neutron time-of-flight experiment by using the $^{9}Be(d,n)^{10}B$-reaction and a Pilot U (Ø 25x20 mm) scintillation detector. A spectrum taken with this equipment at a flight path of 5.78 m at 0^{o} gave a time resolution of 400 ps at a neutron energy of 9.4 MeV.

A new tritium gas target, with a cell length of 1 cm has been designed. It operates at a gas pressure of 4 atm and at a high safety level. The length of the cell given corresponds to a time spread of 0.4 ns at a deuteron energy of 5 MeV.

Development of a fast, high efficiency neutron detector is in progress. It consists of a large cylindrical (Ø 12.5x30.0 cm) NE 213 liquid scintillator, and it will be aligned to detect neutrons travelling parallel to its symmetry axis, thus making use of existing collimator and shielding. The scintillator is viewed by fast photomultipliers at the front and rear flat faces allowing electronic time compensation to eliminate thickness limitations on time resolution.

Data acquisition will be made on-line by using a computer system developed to control the width of the ion beam pulse from the accelerator. With this system it is now possible to register time-of-flight spectra, monitor counts etc during pre-analyzed time intervals containing a given number of beam pulses that are accepted. Time intervals during which the ion beam pulse width is not accepted are rejected. Information is also obtained regarding the numbers of accepted and rejected time intervals.

4.1.2 The level scheme of Pr-141 from the (n,n'γ)-reaction

B Trostell and B Fogelberg

The low spin states of the nucleus Pr-141 have been investigated using the (n,n'γ)-reaction. γ-ray excitation functions have been measured at incident neutron energies from 1.1 to 2.6 MeV as well as γ-γ coincidences at an incident neutron energy of 2.5 MeV. From this information together with the determined γ-ray energies the level scheme of Pr-141 has been obtained. Spin and parity assignments, which were recognized as well established, have been taken from earlier (n,n') and charged particle works. Further assignments have been made using γ-ray selection rules. A comparison between the experimetal results and shell model calculations shows good agreement and indicates an almost complete covering of the kinematically possible states in the present experiment. A manuscript to a report on the subject is in the final stage of preparation.

4.1.3 International intercomparison of fast neutron fluence determinations

N Olsson and B Trostell
P Andersson, University of Lund, Lund

The laboratory participates in an international intercomparison of fast neutron fluence determinations at 2.5, 5.0 and 14.8 MeV neutron energy under the auspices of Bureau International des Poids et Mesures (BIPM), Paris. The work is coordinated by Dr H Liskien, Central Bureau for Nuclear Measurements (CBNM), Geel Belgium.

The comparison is based on the ^{115}In(n,n')^{115}In-reaction. After neutron irradiation of an indium sample the decay of ^{115m}In($T_{1/2}$=4.486$\pm$0.004 h) is observed by measuring the 336.23 keV γ-ray emitted in 45.9$\pm$0.1 % of the decays with a Ge(Li)-detector.

At this laboratory, which participates at the energies 2.5 and 5.0 MeV, a proton recoil telescope (PRT) was used to determine the absolute neutron flux hitting the In-sample. Since the telescope was placed in the same position as the In-sample (0^{o}, distance $\sim$15 cm), the flux measurements and In-irradiations had to be done in separate runs. Normalization was obtained by means of a relative neutron monitor, working in time-of-flight mode.

A Cr-51 source, with for us unknown absolute activity, delivered by BIPM together with the In-samples was used for normalization of the γ-ray intensities. Since the γ rays from Cr-51 have an energy of 320 keV, the photopeak efficiency ratio (336 keV)/ (320 keV) for the Ge(Li) detector had to be determined.

A preliminary analysis of the results, performed by the coordinator Dr H Liskien, CBMN, indicated a systematic significant deviation in the values reported by our laboratory.

Detailed discussions with Dr Liskien lead to the conclusion that the cause of the deviation was to look for in the absolute neutron flux measurements.

A detailed investigation of the PRT revealed a weakness in the construction of the telescope resulting in $\sim$6.5 % too high values in the calculated neutron fluxes. The FORTRAN program used for the flux calculations was also checked against a corresponding program used by CBNM. This comparison showed that the CBNM-program calculated a $\sim$2 % lower flux than the program used in Studsvik. Chemical analysis of the polyethylen foils used in the telescope showed no discrepancies, within the analysing uncertainties of $\sim$1 %, from the assumed chemical composition CH_2.

However, since there still remains a significant deviation in the 2.5 MeV measurement, the construction and performance of the PRT are under detailed discussions with other Swedish laboratories using this telescope.

The intercomparison work will continue during 1983.

4.2 Studies of thermonuclear reactions with applications to astrophysics

B Holmqvist and E Ramström

4.2.1 The $^{4}Be(\alpha,n)^{12}C$-reaction

Thermonuclear reactions are of interest to stellar evolution with particular attention to hydrostatic ($0.1<T_9<1.4$) ($T=T_9 \cdot 10^9$) and explosive ($1.8<T_9<2.2$) burning processes as well as to the syntheses of elements observed in the solar system and in stars. In this work the importance of the $^{9}Be(\alpha,n)^{12}C$-reaction has been studied in the temperature range of hydrostatic burning which corresponds to α-particle laboratory energies below 1 MeV. The emphasis of the experiment has been to measure the neutron yield from this reaction under very clean target (99.95 %) and vacuum ($<10^{-7}$ torr) conditions as well as by using a neutron detection system allowing measurements of cross sections in the nb- and μb-ranges. Furthermore, the measurements have been performed with a 2 mm thick beryllium disk as a target, in which all the α-particles are stopped. This technique was chosen in order to determine the total integrated cross section for the $^{9}Be(\alpha,n)^{12}C$-reaction from zero energy up to the lowest energy obtainable with the Van de Graaff accelerator, i.e. 0.4 MeV. Cross sections at such low energies are also of astrophysical interest.

The measured excitation function of the $^{9}Be(\alpha,n)^{12}C$-reaction ($0.43 \leq E_{\alpha,LAB} \leq 0.77$ MeV) has been used to calculated the astrophysical lifetime of ^{9}Be against burning in an -particle atmosphere.

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

The meteorites are the best source of information regarding the earliest history of the solar system. In some groups of meteorites, the carbonaceous chondrites, unaltered presolar grains have been found to contain a substantial excess of Mg-26 which could have arisen from **in situ** decay of $^{26}Al(7.3 \times 10^5$ years). After the crystallization process the grains are considered not to go through any high temperature stage leading to metamorphic recrystallization which would destroy their identity. Today the initial ratio $(Al\text{-}26/Al\text{-}27)_0$ can be determined from the ratios Mg-26/Mg-24 and Al-27/Mg-24 which can be measured by using the mineral grains.

The aim of the present work is to study the thermonuclear reaction $^{27}Al(\alpha,n)^{30}P$ in the α-particle energy region $3.0 \leq E_\alpha \leq 3.5$ MeV which corresponds to the temperature range $2.0 \leq T_9 \leq 2.7$ ($T_9 = T \cdot 10^9$K) of explosive carbon burning processes of interest for the syntheses of elements being observed in the solar system and in stars. As in the measurements of the $^9Be(\alpha,n)^{12}C$-reaction reported in the previous section the experiments have been performed with a very clean target (99.9999 %) and under clean vacuum conditions ($<10^{-7}$ torr) using a neutron detection system allowing measurements of cross sections in the ranges of nb and μb (1). Several resonances, not being reported earlier, have been observed.

Reference

1 E Ramström and B Holmqvist, Nucl Instr Meth 188 (1981) 153

4.3 Nuclear Chemistry

P Aagaard, K Aleklett, J Eriksen, P Hoff, L Jacobsson, O Johansson, E Lund and G Rudstam

4.3.1 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, determination of fission yields including branching ratios for gamma rays of fission products, and determination of the antineutrinospectra at a nuclear reactor. The work includes also the development of OSIRIS, especially the construction of new target-ion source systems which is essential for the whole programme.

4.3.2 Development of the OSIRIS facility

A new development of the OSIRIS facility was made in 1979 which makes possible the processing of a number of elements earlier inaccessible at OSIRIS. The method consists of adding carbon tetrafluoride to the carrier gas to be introduced into the integrated target-ion source (1). This fluorination method has been used for gammaspectroscopy of La-149, Ce-149, -150 and Pr-150 including gamma-singles and gamma-gamma-coincidence measurements. This method has also been used for gamma-branching studies of Sr isotopes as a complement to the fission yield determinations.

4.3.3 A high temperature target ion-source system

(In collaboration with M af Ugglas, AFI Stockholm)

One of the most profitable methods for increasing the yields of an ISOL-system equipped with a plasma ion-source is to run the ion-source at a higher temperature. This results in both considerably shorter delay times in the ion-source and in the production of ion beams of additional elements. It is therefore expected that also the basic research programme at OSIRIS will benefit from the special ion-source that is now being developed at the order of The Swedish Nuclear Power Inspectorate (SKI). The aim is to improve the elementary data for some of the source terms related to the fission product penetration through the "first barrier", the ceramic UO_2-matrix, in the case of nuclear fuel overheating. The preliminary task so far has involved: 1) the construction of an ISOL fuel-container for finely grained samples to operate in the temperature region 1 300-1 900 ^{o}C and 2) the analysis of the relevance of the proposed measurements to the reactor safety issue. It is expected that the container, will now make possible a systematic study of some distinct (time- and temperature-differentiated) mechanisms of the fission product transport in the fuel such as: a) diffusion in the solid state, b) desorption from the grain surfaces, c) diffusion along interconnected voids and d) the release from void openings.

The unusual feature of the ion-source construction is that it has been mounted in a cartridge containing no less than 20 heat shields. The cartridge surface is very smooth so that it can be shuttled into the reactor core. Both the shuttle itself and its in-core "docking unit" are now completed for test running. All units will be tested together in an isotope separator at AFI (Frescati, Stockholm). The fuel container volume is only 0.1 cm^3. It is made of tungsten and placed on a long ceramic rod to allow a remote handling as simple and as safe as possible. The goal is to facilitate a fast exchange of the fuel specimens. After fulfilment of this preliminary study the main investigation aims at describing different release mechanisms for a number of nuclides of importance. Already at present it has been foreseen in the construction that an expansion of the fuel container volume up to the size of standard LWR-pellets is necessary.

4.3.4 Total beta decay energies and corresponding nuclear spectroscopy

The experimetnal programme to map the nuclear mass surface has continued. The earlier reported Q_β-values of neutron-rich silver and cadmium isotopes have been published (2). The evaluation of the decay of I-139 and I-140 is finished, and the Q_β-value of I-139 was found to be 6.6 ± 0.2 and that of I-140 8.3 ± 0.2 MeV (3).

In these cases the total beta decay energies were determined by means of a β-γ coincidence method. The γ-rays were detected by two Ge(Li) detectors coupled in a multiplexing mode and the β-particles registered by a Si(Li) detector system. The efficiency of this system is rather low and it is not suitable for the most short-lived fission products. Therefore more efficient systems have to be developed. One possibility is to use a large volume plastic scintillator for efficient detection of β-particles. As a test case, the Q_β-value of Ag-114 was measured with a plastic scintillator in coincidence with a Ge(Li) detector for γ-rays. The efficiency and energy calibration of the system was performed using the well-known beta end-point energies of In-123, -125 produced as OSIRIS. The Q_β-value of Ag-114 was found to be 5.16 ± 0.11 MeV in agreement with a value expected from mass systematics.

Another possible way to increase the detection eficiency is to use a large area planar HPGe detector for the β-particles. This detector was initially intended for low energy photon detection but preliminary tests showed that it was applicable also to β-detection. The absorbing material between sample and detector amounts to 70 mg/cm^2, and the detector resolution is 30 keV (FWHM) for 1 MeV β-particles. The distance between sample and detector is 18 mm and the efficiency of the system roughly 30 %. An advantage with the HPGe detector is the possibility to use high energy γ-lines for the energy calibration. In this way the highest energy β-branch of In-131 was determined to 9.15 ± 0.15 MeV. Tests have shown that the linearity of the system is negligibly influenced by the presence of absorbing material between sample and detector for β-energies greater than about 2 MeV. Further tests of the response function are planned for the near future.

4.3.5 Delayed neutrons

(In collaboration with G Nyman and O Tengblad, Chalmers Institute of Technology, Gothenburg)

The delayed neutron spectra have been measured for Ga-82, Sn-134, Sb-135, -136 and Te-136 using a spectrometer consisting of two ^{3}He-filled proportional counters. Their efficiency have been determined by means of (p,n)-reactions in Fe-57 and V-51 using the proton beam from the Van de Graaff accelerator at Studsvik. The response function of the spectrometer was studied in detail using the reaction $^{7}Li(p,n)^{7}Be$ for neutron energies in the interval 0.13-3 MeV. The spectra now obtained for Ga-82, Sn-134, Sb-135 and Te-136 were much superior to those obtained previously using a single ^{3}He spectrometer with less good response function. It was also possible to separate the contributions from respectively Sn, Sb and Sb, Te for the A=134 and A=136 isobars, using different cycles for sample collections and measurements. The data analysis is not yet finished.

4.3.6 Fission yields

A series of experiments with the intention to determine the yields of fission products from thermal fission of U-235 was carried out at the end of 1980. The analysis of these data is not yet completed. The technique involves the measurement of mass separated samples during collection by means of gamma-spectroscopy and delayed-neutron counting. If the branching ratios of the gamma-rays or the delayed neutrons (i.e. the number of the gamma-rays of a given energy or the number of delayed neutrons, per disintegration) are known, the abundance of the various isobars in the samples can be deduced from the measurements. These abudances can then be converted to fission yields provided that a correction for nuclear decay during the delay between the production in the target and the collection at the detector position can be carried out. A series of measurements of the delay was reported in 1981. A complementary method to determine the delay parameters has now been developed where one determines which release mechanism is the time-controlling one, diffusion through the target material or desorption from the surfaces in the integrated target-ion source system of OSIRIS.

Determination of the delay parameters by this method usually leads to values which are less precise than the study of the delay reported last year, but a great advantage is that the measurement is done under the same ion-source conditions as the yield measurements.

An extensive literature search for gamma-ray branching ratios revealed that many published values are doubtful. In addition, there are many cases where no branching ratios are known. This has prompted us to carry out a complementary project consisting of the determination of the branching ratios for most of the gamma-rays used in the evaluation of the fission yields (cf. Section 4.3.7). As this study is not yet completed, we have not been able to make a final analysis of the fission yields although a preliminary analysis has been carried out using available data. It is likely that many of the resulting yields will have to be adjusted as soon as the branching ratio experiment comes to an end. In the meantime a preliminary "progress report" has been worked out in the form of an internal report consisting of two parts, one describing the experimental methods and the treatment of data and the other presenting the preliminary yields (4).

The fission experiment is very extensive with a total of 40 fission yields (including 3 yields of isomeric states) in the light mass region and 93 fission yields (including yields of 33 isomeric states) in the heavy mass region. Among all these yields 61 have not been reported before. Especially interesting is the great number of isomeric yields. Until now, the partition of the isotopic yield on isomeric states is known for very few cases only. The present work considerably extends this knowledge. A systematic study of the spin dependence of the isomeric yields is outlined in the above-mentioned report.

4.3.7 Gamma-ray branching ratios

Since it became evident that many branching ratios were only known with an unsatisfactory precision, a special project was started to determine the relevant branching ratios with an acceptable accuracy.

The standard method for determining the branching ratios is concurrent measurements of the beta-decay and the intensity of the γ-peaks. The efficiency of the Ge(Li)-detector for γ-registration is determied with a set of standard sources (Eu-152, Ba-133 and Co-57). The efficiency of the plastic scintillator for beta-detection is determined using the $\beta\gamma$-coincidence method with OSIRIS-produced neutron-rich indium and tin isotopes. The accuracy of the efficiency calibration of the γ-detector is better than 5 % while the β-efficiency is about 5 % for mean beta energies above 1 MeV. For mean beta energies below that value the efficiency curve of the detector is not sufficiantly accurate, and the β-efficiency has to be determined for each nuclide using the $\beta\gamma$-coincidence method.

The determination of the beta activity for each nuclide is based on resolving the composite beta decay curves of the isobars. In some cases the half-lives of the members of the mass chain differ too little to make such a decomposition possible. Complicated isomerism also makes the standard procedure less accurate. Therefore a new approach for the determination of gamma branching ratios is being tested. It is a combination of the $\beta\gamma$-coincidence method and beta and gamma activity determinations for each nuclide in the mass chain. For this method an automatization of the collection, counting and transportation of the samples is needed.

Until now the gamma branching ratios for about 60 nuclides have been determined using the standard procedure. Another 10 nuclides involved in the fission yield determinations are delayed neutron precursors, and the neutron branching ratios (5, 6) are used in the calculations. Still about 60 gamma branching ratios remain to be determined using more sophisticated methods. With the extension mentioned above we hope to be able to determine most of them.

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5.1 Accelerator improvements

5.1.1 The new injector system

G Possnert, Å Andersson , J Blomberg, I Carlsson, B Hemryd, A Karlsson, G Widman and J Åström

A new injector system with high mass resolution is installed at the tandem accelerator low energy side before the duoplasmatron ion-source station. The beams from the new sputter ion-source will be analysed in a 90° double focusing dipole magnet. A mass resolution in the order of M/ M 200 depending of the mass-defining slitsettings, will be obtained.

The ion optics of the injector system from the new ion-source up to the accelerator terminal has been studied and optimized by a beam transport code.

5.1.2 The new ion-source

(G Possnert, J Åström, J Blomberg, F Dahlen and A Karlsson)

Up to day a HICONEX 834 sputter ion-source has been used to produce beams of heavier elements for the accelerator. The performance of this ion-source has so far been sufficient when the experimentalists just wanted to have beams of a certain ion without any requirements of controlling the sputtering process. New research programs at the laboratory have, however, changed this situation. Especially the high energy mass spectroscopy project but also the program dealing with desorption of biomolecules need more stable, reproducable and well controlled production and tested a new sputter ion-source filling the demands of these special applications.

The advantages of the new sputter ion-source in comparison with HICONEX 834 will be summarized below.

1 A low emittance will be achieved since the cesium sputter beam spot diameter is $\sim 300\,\mu$m.

2 Visual control of the sputtering position when steering and focusing the cesium beam on the sample.

3 Good stability in the extracted negative beam current will be obtained as consequence of different power supplies for the cesium beam and the negative ion beam.

4 Up to 60 samples can be loaded simultaneously. The samples are changed by a computer controlled stepping motor.

5 The vacuum system is constructed in such a way that minimum exposure to atmosphere will occure when changing sample. This together with a powerful pumping (700 l/s) permit short shut down times.

5.2 Nucleon capture reactions in the giant multipole resonance region

5.2.1 Neutron capture in spherical nuclei

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In a previous paper (1) we reported rather strong variations in the neutron capture cross sections for Si-28 and S-32. This structure was later discussed theoretically (2) in terms of capture via single-particle type resonance. This theoretical work prompted us to study $^{28}Si(n,\gamma)$ and $^{32}S(n,\gamma)$ excitation functions in more detail. The results for $^{28}Si(n,\gamma_0)$ were compared with results of continuum shell model calculations. The 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 in the neutron 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 isoscalar quadropole resonance is week. A report on these results is under preparation (3).

5.2.2 The $^{208}Pb(n,\gamma)^{209}$-reaction in the region of the isoscalar quadropole resonance

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The angular distribution of the gamma radiation from capture reactions can be used to obtain information on the properties of giant multipole resonances other than the giant dipole, e.g. the isoscalar and the isovector quadropole resonances. A convinient measure of the multipole mixing is the intensity ratio

$$A_1=(Y(55^o)-Y(125^o)/(Y(55^o)+Y(125^o))$$

The isoscalar quadropole resonance in Pb-209 is located at 10.5 MeV corresponding to capture of 6.6 MeV neutrons. Measurements of the intensity ratio A_1 have been performed at 6.2 and 6.7 MeV. The results are in reasonable agreement with the predictions from the DSD model. Care must be excercised, however, in the comparison of the experimental data with the model predictions because of the relatively strong importance of compound-nucleus processes at these neutron energies.

5.2.3 The $^{208}Pb(n,\gamma)^{209}Pb$-reaction in the region of the isovector quadropole resonance

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Ref (4) reports results from measurements of the forward-to-backward anisotropies, A_1, for the $^{208}Pb(n,\gamma)^{209}Pb$-reaction at neutron energies 10-20 MeV. Theoretical calculations of A_1 indicate a steep increase in the region of the isovector E2 - resonance

(E_n 20 MeV) because of interference between giant E1 and E2 capture amplitudes. It was found that $A_1=0$ within errorbars for 10 MeV<E_n<18 MeV but increases from 0 to 0.8 between E_n=18 MeV and E_n=20 MeV. The results thus show a qualitative agreement with theoretical calculations. From these experimental results it is concluded that the isovector giant E2 resonance lies within 1 MeV of 22.5 MeV. The data are not precise enough to provide useful information for the strength and width of the resonance.

5.2.4 The $^{40}Ca(n,\gamma)^{41}Ca$-reaction in the region of the isovector quadrupole resonance

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The $^{40}Ca(n,\gamma)^{41}Ca$-reaction has before this experiment been investigated at TLU, LANL and Triangle Universities Nuclear Laboratory, USA. Below E_n=15 MeV 90° - cross sections as well as forward-to-backward asymmetries have been measured. Using the $^3H(d,n)^4He$-reaction we extended the experiments to the neutron energy region 20-28 MeV ($28 \leq E_{exc} < 36$ MeV). Cross sections at 90° as well as A_1 values were measured.

The isovector E2 resonance in Ca-41 is expected at an energy of 32-25 MeV. No sign of the E2 resonance is observed in the 90° cross sections as expected. The A_1-values show, however, a steep increase in the energy interval 30 MeV<E_{exc}<34 MeV. The DSD model gives good agreement with experimental data assuming an isovector E2 resonance at an excitation energy of 32.0 MeV exhausting the sum rule strength of the T<part, i.e. 35 % of the total T=1 strength.

5.2.5 Neutron detectors for experiments at the Gustaf Werner Instititute synchrocyclotron

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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 resonance 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, as are now constructing two rectangular plastic (NE 102A) scintillator detectors (50 cm long, 20 cm wide and 2.5 and 5 cm thick). The scintillators will be supplied with PM tubes (XP 2230B) in both ends and time derivation will be 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).

The components of the detectors are just now being assembled and we plan several test at TLU during the spring of 1983. A comparison between the liquid and plastic scintillators in an environment similar to that around the GWI machine is planned to take place at the Orsay cyclotron laboratory in Paris in the autumn of 1983.

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CINDA Type Index of Neutron Cross Section Measurements

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Element Z	A	Quantity	Type	Energy Min	Max	KDK-64 Page	Lab	Comments
SI	28	(n,γ)	EXPT PROG	8.0+6	1.4+7	25	TLU	BERGQVIST+. ANG DISTR
S	32	(n,γ)	EXPT PROG	8.0+6	1.4+7	25	TLU	BERGQVIST+. ANG DISTR
CA	40	(n,γ)	EXPT PROG	2.0+7	2.8+7	27	TLU	NILSSON+. RESULTS COMP TO DSD CALC
GA	82	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
AG	114	FISS PROD	EXPT PROG			19	SWR	ALEKLETT+.
IN	115	(n,γ)	EXPT PROG	4.5+6	6.0+6	10	LND	ANDERSSON+. ACT TECHNIQUE
IN	131	FISS PROD	EXPT PROG			19	SWR	ALEKLETT+.
SN	134	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
SB	135	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
SB	136	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
TE	136	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
I	139	FISS PROD	EXPT PROG			19	SWR	ALEKLETT+.
I	140	FISS PROD	EXPT PROG			19	SWR	ALEKLETT+.
PR	141	INELASTIC	EXPT PROG	1.1+6	2.6+6	15	SWR	TROSTELL+.
AU	197	(n,γ)	EXPT PROG	4.5+6	6.0+6	10	LND	ANDERSSON+. ACT TECHNIQUE
PB	208	(n,γ)	EXPT PROG	6.2+6	6.7+6	26	TLU	LINDHOLM+. RESULTS COMP TO DSD CALC