KDK-53
NEANDC(OR)-157"U"
INDC(SWD)-17/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1981

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN
JUNE 1982

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CONTENTS

PREFACE

This report contains information from laboratories in Sweden about measurements and compilations which are relevant to obtain nuclear data for reserach 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 1981-May 1982

The Swedish Nuclear Data Committee has been supported for the present time period by the Swedish Nuclear Power Inspectorate. The members of the Committee is 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, the Compilation of Actinide Neutron Nuclear Data and a Swedish contribution to the Joint European-Japanese Evaluated Data File (JEF).

An investigation is in progress to specify and screen particular Swedish data requests for energy applications.

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

Publications

KDK-42 Progress Report on Nuclear Data Activities in Sweden for 1980 (April 1981)

KDK-43 Report from the 22nd NEANDC Meeting, Aix-en-Provence, France, April 6-10, 1981 (May 1981)

KDK-44 Biannual report (1979/80 and 1980/81) to the Board for Energy Source Development (June 1981) (In Swedish)

KDK-45 Intercomparison of ^{241}Pu Evaluations for the European-Japanese Data Library (November 1981)

KDK-46 Report to the Swedish Nuclear Power Inspectorate for the time period 1981-07-01--09-30 (September 1981) (In Swedish)

KDK-47 Report from the 12th INDC Meeting, Vienna, Austria, 5-9 October 1981 (In Swedish)

KDK-48 Report to the Swedish Nuclear Power Inspectorate for the time period 1981-10-01--12-31 (December 1981) (In Swedish)

KDK-49 Report from the OECD/NEA Specialists' Meeting on Fast Neutron Scattering on Actinide Nuclei, Paris, November 23-25, 1981, (January 1982)

KDK-50 Nuclear Data for Applied Nuclear Research and Development (to be published) (In Swedish)

KDK-51 Intercomparison of ^{241}Am Evaluations for the European-Japanese Neutron Data Library (JEF) (March 1982, draft)

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

1.2 Compilation of actinide neutron nuclear data

H Condé, National Defence Research Institute, Stockholm
A Etemad, Chalmers University of Technology, Göteborg
H Häggblom and G Olsson, Studsvik Energiteknik AB
B Trostell, Studsvik Science Research Laboratory

In order to simplify future updating of the KDK actinide data compilation (ref. 1), all information in the report is stored on magnetic tape. After updating with new evaluations and experimental information, each figure can be redrawn by a computer controlled plotter. Calculation and compilation of group cross sections for the resonance region is in progress.

An intercomparison of ^{241}Pu and ^{241}Am evaluations for the European-Japanese neutron data library has been completed (2, 3).

References

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 et al. Intercomparison of ^{241}Pu Evaluations for the European-Japanese Neutron Data Library. KDK-45 (1981)

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

1.3 Members of KDK

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2.1 Department of Nuclear Chemistry

2.1.1 Nuclear spectroscopic studies of short-lived radionuclides

G Skarnemark

The decay properties of short-lived radionuclides are studied by means of γ-ray, β- and delayed neutron spectroscopy. The sources are prepared using the continuous chemical separation system SISAK. The lower half-life limit of the nuclides which can be studied is 0.5-1 s.

During 1981, we have completed the evaluation of data from the 1980 measurements on very neutron-rich isotopes of Br, Zr, Nb and Tc. Chemical separation systems for Ru, Rh and Pd, to be used in nuclear spectroscopic investigations of these elements, have been developed and tested on-line.

All experiments are performed in collaboration with the Institut für Kernchemie, University of Mainz, Germany.

Publications

1 N Trautman, N Greulich, U Hickmann, N Kaffrell, E Stender, M Zendel, H Gäggeler, K Brodén, G Skarnemark, D Eriksen. Rapid Continuous Chemical Methods for Studies of Nuclei Far from Stability. Proc. 4th Int. Conf. on Nuclei Far from Stability, Helsingör 1981, CERN Report 81-09, p. 727

2 J Stachel, N Kaffrell, N Trautmann, H Emling, H Folger, E Grosse, R Kulessa, D Schwalm, K Brodén, G Skarnemark, D Eriksen. Phase Transition in Nuclear Shape in the A=100 Region?. Proc. 4th Int. Conf. on Nuclei Far from Stability, Helsingör 1981, CERN Report 81-09, p. 436

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

3.1 Division of Nuclear Physics

3.1.1 Neutron capture cross section measurements with the activation technique in the MeV region

P Andersson, I Bergqvist and R Zorro

Activation measurements for the $^{115}In(n,\gamma)^{116m}In$ reaction have been performed in the MeV region with the primary objective to investigate systematical errors in cross section measurements due to contributions of accompanying background neutrons. The background results from neutrons produced by charged particle reactions (i.e. (p,n)- and (d,n)-reactions) in the target materials and from neutrons produced in the sample and surrounding materials by reactions like (n,n') and (n,np). Another objective has been to develop methods to correct for the background neutrons. The methods are applied to determine the capture cross sections for ^{115}In and ^{197}Au in the energy region 1-8 MeV.

3.1.2 Nuclear structure and decay data evaluation

P Ekström and J Lyttkens

General

The international structure and decay data (NSDD) network, consisting of numerous evaluation groups and data service centres, aims at a complete and continuous nuclear structure data evaluation of all isobaric mass-chains on a four year cycle, the continuous publication of these evaluations and their dissemination to the scientific community. The evaluated mass-chain data resulting from this concerted international effort are published in Nuclear Physics A and the Nuclear Data Sheets, and comprise the currently recommended "best values" of all nuclear structure and decay data.

Mass-chain evaluation

The mass-chain evaluation for A=113 which was done in collaboration with Liverpool University has been published in Nuclear Data Sheets. Work is in progress for A=61.

The results of the evaluations are included in the Evaluated Nuclear Structure Data File (ENSDF) which is the computer-based file for all nuclear structure and decay data compiled, evaluated, exchanged, published and disseminated by the international NSDD network.

Computer programs

The ENSDF-associated programs HSICC, HSMRG (for the calculation of internal conversion coefficients), GTOL (for the calculation of level energies and feeding), and LOGFT (for the calculation of log ft values) have been modified to run on our Norsk Data (ND-500) computer. Two programs, LEVELS and GAMMAS, have been written to facilitate the putting together of Adopted Levels and Gammas. The gamma-gamma correlation program DELTA and some small interactive programs (BRANCH, AVERAGE and WEISSKOPF) are also available. A preliminary version of a program to retrieve data sets from an ENSDF tape has been written.

3.2 Division of mathematical physics

3.2.1 Fission barriers and decay properties of heavy elements

W M Howard[x)], J Krumlinde[xx)], P Möller and C O Wene[xx)]

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 $118 \leq N \leq 184$. We study symmetric, mass-asymmetric and axially asymmetric shapes. Results for the

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neutron rich region below Z=101 have been published (ref. 1). The tabulation for the remaining approximately 1 000 nuclei is almost completed. One aim of the calculation is to study fission barriers in new regions, now accessible in heavy ion collisions, such as the $Z\approx 90$, N=126 region, where in some recent experiments the N=126 shell does not manifest itself.

Another aim is to study the decay from the r-process line to the line of β-stability. An important aspect of this latter study is to develop a model for the γ-strength function. At present we are studying Gamow-Teller transitions in a model where we take into account the microscopic structure of the nucleus. We are now in the final stages of developing a computer code for studying GT transitions in deformed nuclei. A GT residual interaction has been introduced. We are at this stage not considering forbidden transitions but we hope to extend the calculations to include first forbidden E1 transitions.

So far we have made one study of beta-delayed fission and the decay from the r-process line, in which we use the fission barriers of the calculation in ref. 1 but, at this stage, some simpler models for the β-strength function. In particular the calculation focuses on the production ratios of cosmochronometric pairs.

Reference

1 W M Howard and P Möller. Calculated Fission Barriers and Ground State Masses for Nuclei with $76\leq Z\leq 100$ and $140<N<184$. At. Data Nucl. Data Tables, 25 (1980) 219

3.2.2 Properties of nuclei at the third-minimum deformation

R Bengtsson, K Pomorski[x)], I Ragnarsson, A Sobiczewski[xx)] and S Åberg[xxx)].

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 nuclides with the third minimum in their potential energy is found. Main attention is paid to the isotopes of Th, for which the experimental evidence for the existence of such a minimum is found. Properties as moment of inertia, decoupling parameter and the energy shift between positive- och negative-parity rotational bands are studied.

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4.1 Neutron Physics

4.1.1 Neutron elastic scattering in the energy region of the first giant resonance for radiogenic lead and bismuth

N Olsson, B Holmqvist and E Ramström

Elastic scattering of 1.5 to 4.0 MeV neutrons from radiogenic lead, Pb_r, and ^{209}Bi has been measured by using time-of flight technique. The experimental results are plotted in fig. 1 (circles) and show the existence of a giant resonance centered at about 3 MeV neutron energy for both elements. Furthermore the giant resonance cross section peak is more pronounced for ^{209}Bi than for Pb_r. Also included are data from previous measurements (1) at the laboratory. The data were analysed in terms of an optical model potential with spherical symmetry.

The calculations of the integrated total elastic cross sections are shown i fig. 1 (solid lines). The dashed curves are the total compound elastic cross sections calculated with the well known Hauser-Feshbach-Moldauer formalism using the iterative procedure described in ref. 1. The procedure contains the normalization of the calculated compound elastic angular distribution to the experimental data according to the criterion $\sigma_{CE}=\sigma_{EL.EXP.}-\sigma_{SE}$. The dotted curves have been calculated on the basis of the formalism according to Tepel using the Hauser 5 code. In this case normalization to the experimental data was not necessary.

Reference

1 B Holmqvist, Arkiv Fysik 38 (1968) 403

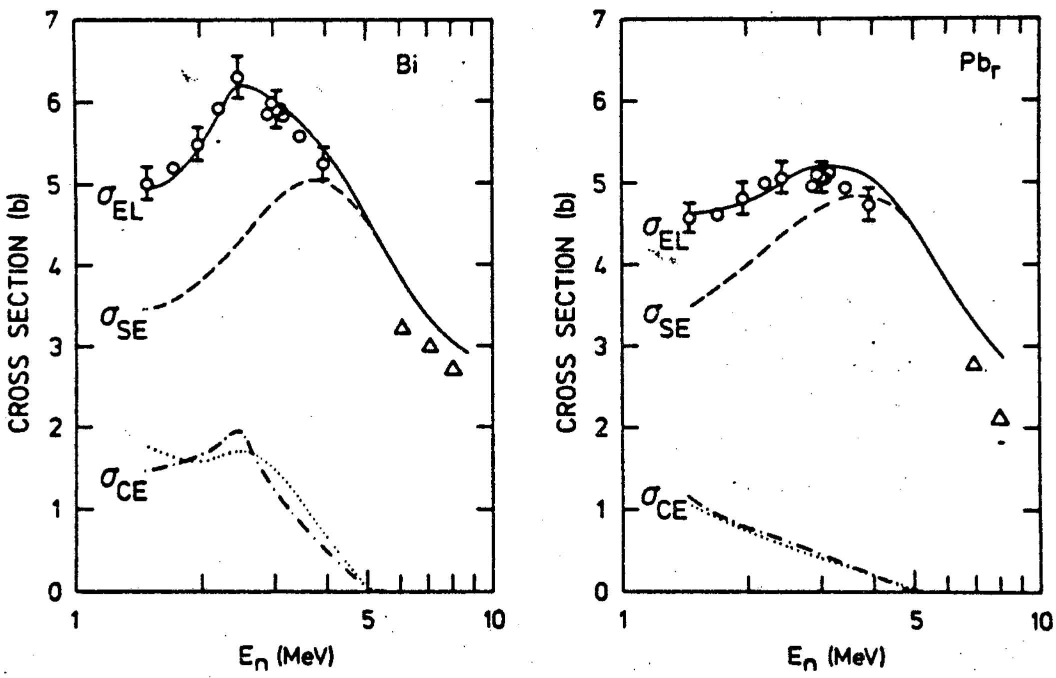

Figure 1. The experimental total elastic cross sections for Pb_r and ^{209}Bi (the circles). The triangles represent data from previous measurements at the laboratory (1). The solid lines are the total elastic cross sections from the optical model calculations. The dashed curves are the total shape elastic cross sections, the point dashed curves are the total compound elastic cross sections calculated from the iterative procedure and the dotted curves those calculated with HAUSER 5.

4.1.2 Inelastic neutron scattering

B Trostell

The analysis of experimental data obtained from neutron inelastic scattering on ^{141}Pr is now being completed and will be reported in the near future. Several new levels and gamma-ray transitions of ^{141}Pr have been observed. The level scheme is deduced from the energies of the observed gamma-rays and their intensity variation with the exciting neutron energy as well as from the observed gamma-rays in coincidence with the gamma-ray deexcitation of the 145 keV level in ^{141}Pr.

Neutron inelastic scattering excitation functions for the individual levels in ^{141}Pr will also be presented, where the cross section determination is based upon measurements relative to the excitation function of the 847 keV level in ^{56}Fe. The aim is to use this results in theoretical model calculations, using the Hauser-Feshbach and Moldauer formalisms.

4.1.3 Inelastic scattering cross sections for ^{206,207}Pb and ^{209}Bi calculated with different formalisms for level width fluctuation corrections

E Ramström

In a previous work of Almén-Ramström (1) fast neutron inelastic scattering from eighteen elements covering the atomic mass region 27 to 209 has been studied for incident neutrons in the energy range 2.0 to 4.5 MeV. The purpose of that work was to investigate the usefulness of the Hauser-Feshbach statistical model modified according to Moldauer for level width fluctuations and resonance-interference effects in describing the experimental data.

A new approach to the problem of calculating the correction factor for level width fluctuations is given in the formalism of Tepel et.al. (2) for the calculation of compound-nucleus cross sections. This formalism is included in the computer program HAUSER 5 (3).

In order to make comparisons between the cross sections obtained with the Moldauer formalism and those obtained with the Tepel formalism calculations with HAUSER 5 have been performed for ^{206,207}Pb and ^{209}Bi for incident neutron energies of 2.0 to 5.0 MeV. For these nuclei some discrepancies were found between the inelastic scattering cross sections calculated with tha Moldauer formalism and those determined experimentally (1). Thus, disagreements of the order of a factor of 2 between theory and experiment were obtained for the two first excited states in ^{209}Bi at primary neutron energies below 3.5 MeV. The same order of disagreement was also obtained for the 0.894 MeV $3/2^-$ level in ^{207}Pb at the lowest primary neutron energies studied. For the other levels in $^{206,208}Pb$ and ^{209}Bi rather good agreements (within 25 per cent) were obtained. However, the shapes of the experimental and theoretical excitation curves for all the studied levels in $^{206,207}Pb$ and ^{209}Bi differed markedly.

References

1 E Almén-Ramström, AE-503 (1975)

2 J W Tepel, H M Hofmann and H A Weidenm$ller, Phys. Lett. 49B (1974) 1

3 F M Mann, HEDL-TME 78-83 (1978)

4.1.4 The excitation function of the $^{9}Be(\alpha,n)^{12}C$ reaction

E Ramström and B Holmqvist

An accelerator drift tube arrangement, which minimizes as much as possible contamination on the target surface due to carbon from vacuum pumping stations was used together with a high efficiency 4π neutron detector described in ref. (1) for measuring the excitation function for the $^{9}Be(\alpha,n)^{12}C$ reaction in the energy region 0.51 to 0.65 MeV. Helium ions were accelerated by the Studsvik 6 MV Van de Graaff accelerator. A 2 mm thick beryllium disc was used as a target. Consequently, the incident α-particles were completely stopped in the target and the quantity measured was the integrated neutron yield within the energy interval from thermal energy up to the energy of the incident α-particles. The yield curve was then differentiated in energy intervals before the excitation function for the reaction could be determined.

A resonance was observed in the excitation function at 0.618 MeV, which corresponds to a level at 11.076 MeV in ^{13}C. This value is in good agreement with the value (11.080±0.005) MeV reported by Ajzenberg-Selove.

Reference

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

4.1.5 International intercomparison of fast neutron fluence determinations

N Olsson, B Trostell and P Andersson[x)]

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

The neutron flux comparison is based on the $^{115}In(n,n')\ ^{115m}In$ reaction. After neutron irradiation of an indium sample the decay of ^{115m}In ($T_{1/2}$ $=4.486\pm0.004$ h) is observed by measuring the 336.23 keV γ-ray emitted in 45.9 ± 0.1 % of the decays with a Ge(Li) detector. A ^{51}Cr source delivered by BIPM together with the In-samples was used for normalization of the γ-ray intensities.

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, positioned at a distance of 4 meters from the neutron producing target and at an angle of 80^{o} with respect ot the ion beam direction. The telescope efficiency for neutrons was calculated with a Monte-Carlo code, EFFINT (1). The uncertainty in the obtained neutron flux was estimated to be about 5 %.

In connection with this experiment the absolute efficiency of the Ge(Li) detector was determined by means of standard ^{113}Sn-, ^{133}Ba-, ^{152}Eu- and

x) University of Lund

^{203}Hg-sources. From this determination, absolute cross sections of the ^{115}In(n,n')^{115m}In reaction can be obtained after corrections for neutron- and γ-ray attenuation have been made. The results of the measurements will be published in the beginning of 1982.

Reference

1 P Andersson, S Lundberg and G Magnusson, Nuclear Physics Report LUNFD6/(NFFR-3021)/1-22/1978.

4.1.6 A time-of-flight spectrometer for fusion neutron diagnostics

J Lorenzen

Experimental work has been continued during 1981 for the development of neutron diagnostics in fusion at the Studsvik Van de Graaff Laboratory. The aim of this work is to determine the characteristics of a neutron spectrometer for 2.5 MeV neutrons which will be produced at the JET[x)] fusion facility in England during its so called DD-phase in the mid 1980's. The task of the diagnostics is to measure the temperature of the ion plasma.

The spectrometer is based on time-of-flight technique using conventional fast electronics together with plastic and liquid scintillators.

The spectrometer developed so far has an energy resolution good enough to resolve a plasma temperature below 5 keV. The spectrometer might also be used as a telescope providing an angular resolution of the order of 5 degrees, which allows to scan radially over the fusion plasma volume in 50 cm wide bins.

A technical description of the spectrometer has been presented at the 9th symposium on Engineering Problems in Fusion Research in Chicago (1).

[x)] JET = Joint European Torus, a tokamak facility built by EUROATOM at Culham Laboratories in England

Reference

1 9th Symposium on Engineering Problems in Fusion Research. Reports 4U-12 4V-03, Chicago 26-29 October (1981).

4.1.7 A 100-picosecond post-acceleration bunching system at the Studsvik 6 MV Van de Graaff accelerator

N Olsson, L Norell and B Johnsson

The previously described bunching facility for production of ion pulses with a duration of down to 150 ps and intended for high resolution neutron time-of-flight experiments (1, 2) has been subject to further tests. Thus, the reported direct measurements of proton pulses with a 50Ω ultrahigh-frequency Faraday cup have been completed with similar measurements of single charged hydrogen molecules (H_2^+) and deuterons, both of energy about 5 MeV, resulting in a FWHM of 250 ps.

Time-of-flight measurements of γ-rays from an Al target has been performed by means of a 2.5 cm diameter x 1.0 cm thick fast scintillation detector (NE111) coupled to a PM-tube (RCA C31024) in conjection with ORTEC fast-timing electronics. The detector system time resolution was about 200 ps and the FWHM of the γ peaks were 260 ps and 300 ps for 3.5 MeV protons and 5.0 MeV deuterons, respectively.

The stability of the bunching system was tested by measuring the target γ-ray peak for several hours without any adjustments of the system. With 3.5 MeV protons a γ peak of 280 ps FWHM, i.e. a proton pulse width of ∿200 ps FWHM were obtained, thus indicating that there is no need for any stabilizing circuits.

The system will be used in an experimental program for high resolution neutron elastic and inelastic scattering at about 22 MeV. For that purpose a fast, time compensated neutron detector with high efficiency will be constructed. The aim is to get a time resolution of about 0.5 ns.

References

1 N Olsson, A picosecond bunching system at the Studsvik 6 MV Van de Graaff accelerator, The Studsvik Science Research Laboratory Report NFL-26 (1981) 3.

2 N Olsson, Nucl. Instr. Meth. 187 (1981) 341

4.2 Nuclear chemistry

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

4.2.1 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 average beta energy, and determination of fission yields. For the progress in all parts of the research field the development of ion-sources is essential.

4.2.2 Development of the OSIRIS facility

A new target material for the OSIRIS target/ion-source system has been tested off-line during 1980. During spring 1981 an ion-source of this type was tested on-line with OSIRIS. The target consisted of uranium oxide deposited in high porosity (30-35%) aluminium oxide instead of the traditional target/ion source system. An amount of 0.7 g of $^{235}UO_2$ was impregnated on a cylinder of Al_2O_3 which was ignited to 800° C in the fabrication of the cylinder.

This special ion source turned out to be particularly efficient for selenium and tellurium, bromine and iodine. A survey measurement using

Ge(Li) detectors showed good yields of $^{85-88}Se$, $^{136-138}Te$ and a measurable but poor production of As isotopes.

4.2.3 Total beta decay energies and corresponding nuclear spectroscopy

The experimental programme to map the nuclear mass surface has continued. The earlier reported Q_β-values of $^{80,81}Ga$, $^{79,81,82}Ge$[1] and $^{89,90}Br$[2] have been published. The evaluation of the total beta-decay energies for neutron-rich silver and cadmium isotopes has been finished[3].

In one case, ^{116}Ag, the earlier reported Q_β-value 5.3 ± 0.2 MeV[4] was found to be about 1 MeV too low. A spectroscopic study of the ^{116}Ag decay resulted in a level scheme with excited states up to 2958 keV in ^{116}Cd. The levels at 2 249 and 2 026 keV were found to be mainly indirectly fed in the beta-decay. The resulting Q_β-value was 6.03 ± 0.13 MeV which fits better in the mass systematics than the earlier one.

A Q_β-measurement of ^{136}Te has been performed using the aluminium oxide ion-source. The evaluation is not completed. An earlier determination of the total β-decay energy of ^{135}Te is somewhat uncertain because of the lack of detailed knowledge of the decay structure. Recently performed spectroscopy of ^{135}Te using the type of ion-source mentioned above will probably give sufficient information for an accurate determination of the Q_β-value of ^{135}Te.

4.2.4 Delayed neutrons

There are around 70 delayed neutron precursors with known half-lives and branching ratios among the fission products. For almost half of them, including practically all the important cases, the shape of the energy spectra is also known. These precursor data when combined with the fission yield pattern, provide useful information about the effective delayed-neutron spectrum in nuclear fuel for any irradiation conditions. For reactor applications it is preferable to dump the precursors into six half-life groups (Group I: $T_{1/2} > 30$ s, Group II: $T_{1/2} = 10 - 30$ s, Group III: $T_{1/2} = 4 - 10$ s, Group IV: $T_{1/2} = 1.4 - 4$ s, Group V: $T_{1/2} = 0.4 - 1.4$ s, Group VI: $T_{1/2} < 0.4$ s). By this traditional way of treating the precursors, the 70 cases are replaced by six and a quick method of calculating the effective delayed-neutron energy spectrum for any mixture of fuel compoments at any cooling time after stopping a reactor results.

Relevant parameters (decay constant, saturation abundance) and spectra corresponding to the different groups hav been derived for the nuclides ^{232}Th, ^{233,235,236,238}U, ^{237}Np ^{239,240,241,242}Pu, and ^{252}Cf. The results are given in ref. 5.

4.2.5 Average beta energies of fission products

The knowledge of the average beta and gamma energies emitted in the decay of the fission products are important quantities for the evaluation of the heating of nuclear fuel by the decaying fission products. Measurements of the average beta energy of about 30 of the most important fission products were carried out at OSIRIS a couple of years ago. The results are accepted for publication in Nucl. Sci. Eng. (6).

4.2.6 Fission yields

An extensive series of fission experiments was carried out in November and December 1980, including studies of isotopes of the elements zinc, gallium, bromine, krypton rubidium, silver, cadmium, indium, tin, antimony, tellurium, iodine, xenon, and cesium. The delay properties of all these elements were studied. Some typical results are given in Table 1 in the form of "delay half-lives", defined as the time necessary to decrease the target content of a given element to half its original value when no further production takes place.

Table 1

Element	Delay half-life s	Element	Delay half-life s
zinc	7.7 + 3.1	indium	3.2 + 0.3
gallium	6.9 ± 1.9	tin	210 ± 10
bromine	190 ± 20	antimony	190 ± 20
krypton	120 ± 10	tellurium	900 ± 50
rubidium	390 ± 10	iodine	53 ± 7
silver	21 ± 2	xenon	58 ± 3
cadmium	140 ± 20	cesium	470 ± 40

The results tabulated above are valid for the experimental conditions prevailing during the runs (target UO_2/UC on a support of carbon cloth, temperature around 1 500^o C), and they can be used to correct measured counting rates for decay during the delay between production and measurement using the methods described in ref. 7.

In the main series of experiments samples are measured during collection for a predetermined period of time by means of either a γ-spectrometer or a neutron counter. After correction for delay, counting efficiency, branching ratio, and reactor power one arrives at a figure which is the product of the fission yield and the overall separator efficiency. The latter factor is nearly the same for all isotopes of a given element but varies from element to element. This means that relative yields are directly obtainable and that they have to be normalized against the yield of one of the isotopes determined absolutely by radiochemical or other techniques.

The yields are also corrected to correspond to cumulative yields. The correction to be applied depends on the delay properties, the timing of the experiment and the ratio between parent and daughter yields. It is usually small, and it can be determined in an iterative way.

Preliminary yields (independent for cases with no feeding from the parent, otherwise cumulative) have been obtained for the nuclides listed below (isotope used for normalization underlined):

^{84m}Br, ^{84}Br, ^{85}Br, ^{86}Br, ^{86}Br, ^{87}Br, $\underline{^{88}Br}$, ^{89}Br, ^{90}Br;

^{85m}Kr, ^{87}Kr, $\underline{^{89}Kr}$, ^{90}Kr, ^{91}Kr, ^{92}Kr, ^{93}Kr;

^{90}Rb, ^{90m}Rb, ^{91}Rb, ^{92}Rb, $\underline{^{93}Rb}$, ^{94}Rb, ^{95}Rb, ^{96}Rb, ^{97}Rb, ^{98}Rb;

$\underline{^{130}Sn}$, ^{131}Sn, ^{131m}Sn, ^{132}Sn;

$\underline{^{131}Sb}$, ^{132}Sb, ^{132m}Sb, ^{133}Sb, ^{134}Sb;

^{133}Te, ^{133m}Te, $\underline{^{134}Te}$, ^{135}Te;

^{134m}I, ^{134}I, ^{135}I, ^{136L}I, ^{136H}I, ^{137}I, $\underline{^{138}I}$, ^{139}I, ^{140}I, ^{141}I;

^{134m}Xe, ^{137}Xe, $\underline{^{139}Xe}$, ^{140}Xe, ^{141}Xe;

^{138m}Cs, ^{139}Cs, $\underline{^{140}Cs}$, ^{141}Cs, ^{142}Cs, ^{143}Cs, ^{144}Cs, ^{145}Cs, ^{146}Cs.

The remaining elements - zinc, gallium, silver, cadmium, and indium - are not yet analyzed.

During the course of the work it became evident that in many cases, the main contribution to the uncertainty of the measurements comes from badly known branching ratios for the gamma-rays used for abundance measurements. Sometimes, no absolute measurement of the branching ratio exists at all. This has forced us to start a special project with the goal to determine the relevant branching ratios with an accuracy which is acceptable. The method chosen was concurrent measurements of the beta-decay and the intensity of the gamma-peaks. Well calibrated beta- and gamma-detectors are essential. The efficiency of the Ge(Li)-detector for gamma-registration is determined with a set of standard sources,

^{152}Eu, ^{133}Ba and ^{57}Co. 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. A computer programme BRANCH is used for the calculation of the experimental results. Experimental data have been obtained for about 150 nuclides, although no final results have been obtained yet.

References

1 K Aleklett, P Hoff, E Lund and G Rudstam, Total beta-decay energies and masses of $^{80,81}Ga$ and $^{79,81,82}Ge$, Z, Phys, 302 (1981).

2 P Hoff, K Aleklett, E Lund and G Rudstam, Decay schemes and total decay energies of ^{89}Br and ^{90}Br, Z. Phys, A300 (1981) 289.

3 K Aleklett, P Hoff, E Lund and G Rudstam, Total beta-decay energies, masses and mass systematics of neutronrich silver and cadmium isotopes (submitted to Phys. Rev. C.).

4 K Aleklett, E Lund, G Nyman and G Rudstam, Q_β-values of fisson products far from β-stability, Proc. of 3rd Int. Conf. on Nuclei far from Stability, Cargese 1976, CERN Report 76-13 p. 113.

5 G Rudstam, Six group representation of delayed-neutron energy spectra (accepted for publication in Nucl. Sci. Eng.)

6 K Aleklett and G Rudstam, Average beta-decay energies for short lived fission products, (accepted for publication in Nucl. Sci. Eng.).

7 G Rudstam, Analysis of Results from Delay Studies in ISOL-systems, The Studsvik Science Research Report NFL-20 (1981); Dead Time Corrections in Delay Studies, NFL-20 Complement (1980).

4.2.7 Measurement of delayed gamma rays from thermal fission of ^{239}Pu

P-I Johansson

Measurements are being made of the energy distribution and the total energy of γ-radiation emitted in the interval 10-1 500 s after thermal fission of ^{239}Pu.

Fast neutrons produced in the $^{9}Be(p,n)^{9}B$-reaction at the 6 MeV Van de Graaff were thermalized using a cube-shaped moderator of paraffin. The thermal neutron flux was about 10^8 n/(s cm^2).

The 99 % enriched plutonium samples (10 mm in diameter, 4 mg/cm^2) were capsuled with 4 mg/cm^2 of titanium. The disks were enclosed in cylinders of polyethylene and transported by a pneumatic system.

The number of fissions in the sample was determined by two independent methods. One was based on an absolutely calibrated fission chamber 100 μg ^{239}Pu) and the second on the measurement of the γ-ray intensity from fission fragments whose yield is known.

The γ-radiation from the fission products was measured with a NaI-crystal with a diameter and length of 12.5 cm.

The photopeak efficiency and the detector response have been measured utilizing sources of known strength in the energy range 60 keV to 4 MeV and charged particle reactions for higher energies.

Measurements have so far been carried out with irradiation time of 120 s in the time range 300 to 1 500 s. In progress are measurements after neutron irradiation of 4 and 10 s to obtain data for the shortest cooling time.

4.2.8 Measurements of delayed gamma rays from fast fission of ^{238}U

P-I Johansson

Measurements are being made of the energy distribution and the total energy of γ-radiation emitted in the interval 10-1 500 s after fast fission of ^{238}U.

Neutrons of the energy 2.3 MeV were obtained by the $T(p,n)^3He$ reaction at the 6 MeV Van de Graaff accelerator. The energy and the energy spread of the neutron beam were determined by time-of-flight technique. The time-of-flight technique was also used to monitor the neutron flux during the sample irradiation.

The uranium samples (13 mm in diameter, 110 mg/cm^2) were depleted to about 0.04 % ^{235}U. The disks were enclosed in cylinders of polyethylene and transported by a pneumatic system.

The method for determining the number of fissions utilized a high resolution Ge(Li)-detector with known efficiency. The γ-ray intensity emitted from fission products of known independent yield, half-life and branching ratio is measured at various time invervals after irradiation.

The γ-radiation from the fission products was measured with a calibrated NaI-crystal (see 4.2.7) with a diameter and length of 12.5 cm.

Measurements have been carried out with irradiation time of 120 s in time range 300 to 1 500 s. Measurements are in progress to obtain decay data in the the time range 10 to 300 s after irradiation.

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

5.1 The high-energy gamma-ray detector

L Nilsson, A Lindholm. B Stridh and M S Saleem

The high-energy gamma-ray detector system, constructed in 1980, has been further investigated (1).

The system consists of a large 22.6 cm in diameter and 20.8 cm long NaI(Tl) detector surrounded by a plastic annulus scintillator and a cylindrical plastic scintillator placed in front of the NaI.

By excluding from the spectrum of the center detector pulses which are accompanied by a pulse larger than $\sim$100 keV in the outer detectors, a better energy resolution is accomplished. The FWHM of monoenergetic gamma peaks is lowered from 11 % to 8.5 % at 10 MeV and from 9.6 % to 6.6 % at 25 MeV. The time resolution is improved from about 12 ns to 3 ns (FWHM) by replacing the old photomultiplier tubes by faster ones, RCA 8575.

Reference

1 B Stridh. Characteristics of a NaI-detectorsystem for high energy gamma radiation. TLU 86/81, Tandem Laboratory Report, Uppsala 1981 (in Swedish)

5.2 Nucleon capture reactions in the giant multipole resonance region

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N Olsson, Studsvik Science Research Laboratory
A Lindholm, L Nilsson and M S Saleem

Parts of this work are performed in collaboration with scientists from Centre d'Etudes de Bruyeres-le-Chatel (CEBC), France, Los Alamos National Laboratory (LANL), USA and University of Oregon (UO), USA.

The reaction $^{208}Pb(n,\gamma_0)^{209}Pb$ has been investigated in a collaboration between TLU, UO, LANL and CBC (1). Cross sections were measured for neutron energies between 0.8-6.0 MeV at CEBC, 5.5-8.0 MeV at TLU and for energies larger than 7.0 MeV at LANL. Data are compared with calculations based on the compound nucleus (CN) model and the direct-semidirect (DSD) model. As was found in earlier capture experiments (2) the CN model accounts for observed cross sections for energies less than 4 MeV and the DSD model nicely describes experimental data above 6 MeV, i.e. in the giant resonance region.

Neutron radiative capture is a promising tool to localize giant resonances in nuclei. The presence of giant resonances with multipolarities other than E1 would show up as a forward-to-backward asymmetry in the angular distributions of the capture gamma rays. At TLU the for-aft asymmetry was measured at 6.2 and 6.7 MeV. The result is in rough agreement with previous calculations (3). The measurements of forward to backward asymmetries performed at LANL cover the neutron energy region from 7 to 20 MeV and show strong forward-peaked asymmetries in the region of the isovector E2 resonance (4).

The experiments on neutron capture in silicon and sulphur has been finished and a report on the results from $^{28}Si(n,\gamma_0)^{29}Si$ and $^{29}Si(n,\gamma_1)^{29}Si$ is under preparation. Part of the results has been published previously (5). Cross sections for these reactions show very rapid fluctuations and the results will be compared with calculations based on a model (6) describing the structure in the excitation function in terms of capture via single-particle type resonances.

Total (n,γ) cross sections for ^{165}Ho and ^{238}U have been measured in a collaboration with LANL and UO. Also for these deformed nuclei the DSD model gives a good description of the observed data. A report (7) on these measurements has been submitted to Nuclear Physics.

During 1981 efforts have been spent to extend the neutron capture experiments to energies between 20 and 30 MeV using the $^{3}H(d,n)^{3}He$ reaction for neutron production. The main interest is to look for isovector E2 strength in ^{41}Ca and ^{90}Y which as mentioned above should show up as for-aft asymmetry in the angular distribution of capture gamma rays. Some preliminary experiments on calcium have been made indicating an asymmetry of about +0.5 at 31 MeV excitation energy in ^{41}Ca.

References

1 S Joly, G Grenier, D M Drake, F Rigaud, I Bergqvist, D K McDaniels, A Lindholm, L Nilsson, N Olsson, A Waheed and R Zorro. To be published

2 A Lindholm, L Nilsson, M Ahmad, M Anwar, I Bergqvist and S Joly. Nucl. Phys. A339 (1980) 205

3 F Saporetti and R Guidotti. Lett. Nuovo Cim. 22 (1978) 202

4 D M Drake, S Joly, L Nilsson. S Wender, K Aniol, I Halpern and D Strom. Pys. Rev. Letters 47 (1981) 1581

5 A Lindholm, L Nilsson, I Bergqvist and N Olsson. Z Physik, A289 (1979) 229

6 M Micklinghoff and B Castell. Z Phys. A282 (1977) 117. M Micklinghoff and B Castel. Ann. of Phys. 114 (1976) 452

7 D K McDaniels, V Vargese, D M Drake, E Arthur, A Lindholm, I Bergqvist and J Krumlinde. Submitted for publication in Nucl. Phys.

5.3 The n-d reaction

L Glantz, G Jansson, A Johansson, I Koersner and B Sundqvist

Previous experiments at TLU on the D(n,d)n reaction have shown that it is possible to measure the elastic n-d cross section with an accuracy down to a level of 1 %. The results were analysed with the code by P Doleschall, based on the Faddeev equations. At 10 MeV neutron bombarding energy discrepancies of the order of 10 % between the experimental and the theoretical cross sections could be noticed. The reason for these deviations has not yet been found. It is therefore of great interest to measure the n-d cross section with good accuracy (1 %) at other neutron bombarding energies.

A number of measurements at 10 MeV have recently been carried out. The data analysis is in progress.

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

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T Andersson[x)], L Nilsson and C Nordborg[xx)], Tandem Accelerator Laboratory, Uppsala

Measurements have been made on the $^{6}Li(n,t)^{4}He$ reaction and on its inverse the $T(\alpha,{}^{6}Li)n$ reaction to improve the knowledge of the $^{6}Li(n,t)$ cross section in the neutron energy region above 200 keV up to about 3 MeV.

Angular distributions of the tritons and the ^{6}Li-ions have been measured at six different energies for the $^{6}Li(n,t)^{4}He$ and the $T(\alpha,{}^{6}Li)n$ reactions, respectively. The results show a significant change in the angular distributions between 2.8 and 3.5 MeV of neutron energy.

The $^{6}Li(n,t)$ cross section has been calculated from a measurement of the excitation function for the $T(\alpha,{}^{6}Li)n$ reaction. The measurement was made at an angle of 3^{o} in the laboratory system and at alpha energies from 11.5 to 16.7 MeV, corresponding to neutron energies from about 200 keV to 2.8 MeV. The ^{6}Li yield was measured relative to the elastic α-t scattering to allow cross section determination.

Present adresses:

x) Swedish Steel AB, Luleå, Sweden

xx) NEA Data Bank, Gif-sur Yvette, France

In a separate measurement the α-t differential scattering cross sections were measured at alpha energies beween 11.5 and 17 MeV. The results show two resonances at alpha energies of about 11.5 and 16.5 MeV.

CINDA Type Index of Neutron Cross Section Measurements

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Element S	A	Quantity	Type	Energy Min	Energy Max	KDK-53 Page	Lab	Comments
D		ELASTIC	EXPT PROG		1.0+7	29	TLU	GLANTZ+.
LI	6	(n,t)	EXPT PROG	2.0+5	2.8+6	30	TLU	ANDERSSON+. MEAS. ON IN-VERSE REACTION
SI	28	(n,γ)	EXPT PROG	3.2+6	1.5+7	27	TLU	BERGQVIST+. RESULT COMP. TO DSD AND CN CALC.
ZN		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR MANY ZN ISOTOPES
GA		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR MANY GA ISOTOPES
BR		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 8 BR ISOTOPES
KR		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 7 KR ISOTOPES
RB		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 9 RB ISOTOPES
AG		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR MANY AG ISOTOPES
AG	116	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
CD		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR MANY CD ISOTOPES
IN		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR MANY IN ISOTOPES
IN	115	(n,γ)	EXPT PROG	1.0+6	8.0+6	8	LND	ANDERSSON+. ACT. TECHNIQUE

Element S	A	Quantity	Type	Energy Min	Energy Max	KDK-53 Page	Lab	Comments
IN	115	DIFF INELASTIC	EXPT PROG	2.5+6	5.0+6	16	SWR	OLSSON+. ACT. MEAS. AT 2.5 AND 5.0 MEV
SN		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 3 SN ISOTOPES
SB		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 4 SB ISOTOPES
TE		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 3 TE ISOTOPES
TE	135	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
TE	136	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
I		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 8 I ISOTOPES
XE		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 5 XE ISOTOPES
CS		FISS YIELD	EXPT PROG			21	SWR	RUDSTAM+. YIELDS DETERMINED FOR 9 CS ISOTOPES
PR	141	INELASTIC γ	EXPT PROG	1.1+6	2.5+6	11	SWR	TROSTELL.
HO	165	(n,γ)	EXPT PROG			27	TLU	BERGQVIST+. RESULTS COMP. TO DSD CALC.
AU	197	(n,γ)	EXPT PROG	1.0+6	8.0+6	8	LND	ANDERSSON+. ACT. TECHNIQUE
PB	206	ELASTIC	EXPT PROG	1.5+6	4.0+6	12	SWR	OLSSON+. RADIOGENIC LEAD
PB	206	DIFF INELASTIC	ExTh PROG	2.0+6	5.0+6	14	SWR	RAMSTRÖM. COMP. EXP. AND MODEL CALC.
PB	207	DIFF INELASTIC	ExTh PROG	2.0+6	5.0+6	14	SWR	RAMSTRÖM. COMP. EXP. AND MODEL CALC.
PB	208	(n,γ)	EXPT PROG	5.5+6	8.0+6	27	TLU	BERGQVIST+. RESULTS COMP. TO DSD AND CN CALC.
BI	209	ELASTIC	EXPT PROG	1.5+6	4.0+6	12	SWR	OLSSON+.

Element S	A	Quantity	Type	Energy Min	Energy Max	KDK-53 Page	Lab	Comments
BI	209	DIFF INELASTIC	ExTh PROG	2.0+6	5.0+6	14	SWR	RAMSTRÖM. COMP. EXP. AND MODEL CALC.
TH	232	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
U	233	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
U	235	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
U	236	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
U	238	(n,γ)	EXPT PROG			27	TLU	BERGQVIST+. RESULTS COMP. TO DSD CALC.
U	238	FISS PROD γ	EXPT PROG	2.3+6		26	SWR	JOHANSSON. DELAYED GAMMA
U	238	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
NP	237	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
PU	239	FISS PROD γ	EXPT PROG	MAXW		25	SWR	JOHANSSON. DELAYED GAMMA
PU	239	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
PU	240	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
PU	241	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
PU	242	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.
CF	252	DELAYED NEUTS	EVAL PROG			21	SWR	RUDSTAM+.