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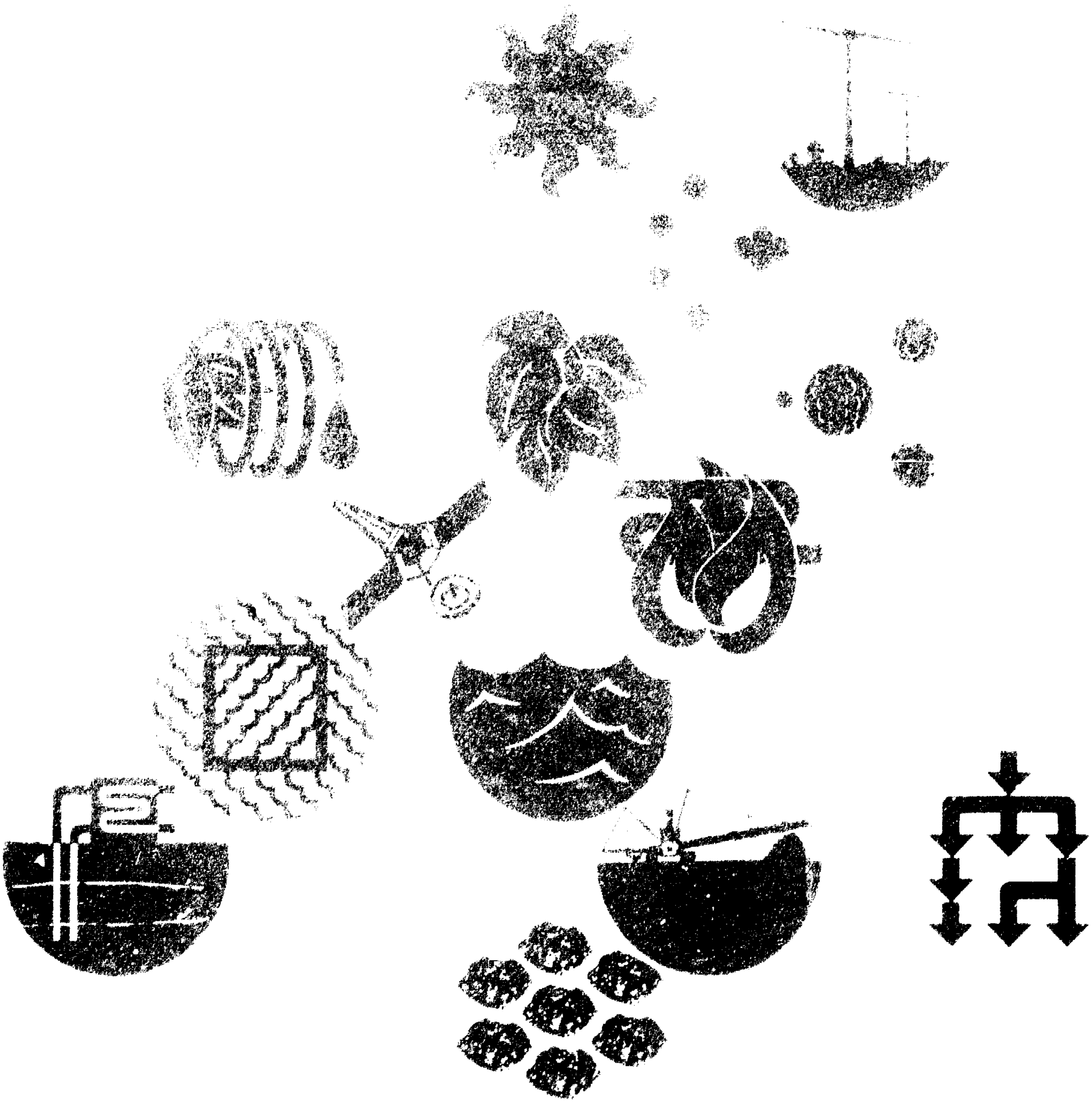

PROGRESS REPORT ON
NUCLEAR DATA ACTIVITIES
IN SWEDEN FOR 1980

NE/TEKNIK 81/4

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PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1980.

SWEDISH NUCLEAR DATA COMMITTEE
STOCKHOLM, SWEDEN

APRIL 1981

KDK-42
NEANDC(OR)-156/U
INDC(SWD)-15/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1980

Compiled by
H Condé
National Defense Research Institute
Stockholm, Sweden
April 1981

CONTENTS

PREFACE

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

Reports relevant to the nuclear energy field are given of neutron cross section measurements and studies of the fission process. Reports are also given of nuclear structure and decay data measurements especially fission product nuclear data measurements of importance for the research on reactor safety and nuclear waste handling. Charged particle and photonuclear cross section measurements with applications in e.g. activation analysis and the production of radioisotopes for medical use are reported as well.

In some cases reports are also given of measurements aiming to test nuclear models which are commonly used for the calculation of the above type of data.

In general basic nuclear physics research is not included in this report. However, the limitation between pure and applied nuclear physics is not strict why reports might be missing or added as a matter of subjective judgements.

The report also contains short information about changes of existing experimental facilities.

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

1. THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

1.1 Status report, Dec 79 - April 81

The Swedish Nuclear Data Committee has been supported for the present time period as a research project under the Board for Energy Source Development. The Committee including the "Coordination Group on Measurements" has had the same members as listed in the Progress Report from 1977 (KDK-15).

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 of the Compilation of Actinide Neutron Nuclear Data. A Swedish Nuclear Data Request List has been Compiled and sent to OECD/NEA for integration in WRENDA 80/81.

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.

The Committee arranged a seminar on "International Cooperation in Nuclear Data for Nuclear Energy and other Applications of Nuclear Physics" at Stockholm on March 23, 1981. The seminar was a part of a discussion on the future role of the Committee which has been coordinated by the Energy Research and Development Commission (DFE).

Publications

KDK-37 Progress Report on Nuclear Data Activities in Sweden for 1979 (April 1980)

KDK-38 Report from "IAEA Consultants' Meeting on Neutron Source Properties," Debrecen, Hungary, March 17-21, 1980 (April 1980) (In Swedish)

KDK-39 Report from the 11th INDC Meeting, Vienna,Austria June 16-20 1980 (July 1980) (In Swedish)

KDK-40 Swedish Nuclear Data Request List (December 1980)

KDK-41 Summary of the "Seminar on International Cooperation in Nuclear Data for Nuclear Energy and other Applications of Nuclear Physics", Stockholm, March 23 1981 (April 1981)

2. CHALMERS UNIVERSITY OF TECHNOLOGY, S-412 96 GOTHENBURG

2.1 Department of Nuclear Chemistry

2.1.1 Nuclear spectroscopic studies of short-lived radionuclides

G. Skarnemark and K. Brodén[1)]

[1)] Present address: Studsvik Energiteknik AB, Studsvik

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 1980, we have performed $\gamma\gamma t$ coincidence measurements on $^{86,87,88,89}Br$, ^{100}Zr and ^{108}Tc as well as $\gamma\gamma$ angular correlation measurements on ^{108}Tc.

2.2 Department of Reactor Physics

G.Grosshög and N.G. Sjöstrand

A 400 kV neutron generator has been installed and put into operation. The maximum ion beam current is 2 mA and the shortest pulse width is 1 ns. The generator is used for experiments on fast neutron spectrometry, for activation analysis and for irradiations in radiophysics and nuclear chemistry.

2.3 Department of Physics

2.3.1 Decay properties of exotic nuclei

G.Andersson, B. Jonson, P.O. Larsson, S. Mattson
and G. Nyman

For the first time beta-delayed three-neutron emission [1] has been observed. In an experiment performed at ISOLDE, CERN it was shown that the branching ratio for three-neutron emission amounts to P_{3n} =(1.8±0.2)% while the branching ratios for two- and one-neutron emission are (3.9±0.5)% and (82±7)% respectively.

The branching ratios for two-neutron emission [2] have been determined for the isotopes $^{30,31,32}Na$ to be (1.2±0.2)%, (0.7±0.25)% and (5.1±1.8)% respectively.

At GSI, Darmstadt the branching ratios for beta-delayed proton and alpha emission were determined for ^{114}Cs to be $(7\pm2)\times10^{-2}$ and $(1.6\pm0.6)\times10^{-3}$. The ground state alpha decay branch of ^{114}Cs (E_α=3226±30 keV) was determined to be $(1.8\pm0.6)\times10^{-4}$.

New information about ^{132}Sn has been obtained at ISOLDE by studying [4] the beta decay of ^{132}In.

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2. C. Detraz, M. Epherre, D. Guillemaud, P.G. Hansen, B. Jonson, R. Klapisch, M. Langevin, S. Mattsson, F. Naulin, G. Nyman, A.M. Poskanzer, H.L. Ravn, M. de Saint-Simon, K. Takahashi, C. Thibault, F. Touchard, Phys.Lett. 94B(1980)307. "Beta-delayed two-neutron emission from $^{30,31,32}Na$".

3. E. Roeckl, G.M. Gowdy,R. Kirchner, O. Klepper, A. Piotrowski, A, Płochocki, W. Reisdorf, P. Tidemand-Petersson, J. Żylicz, D. Schardt, G. Nyman, W. Lindenzweig, Z.Physik A294(1980)221. "The decay of 0.57 s ^{114}Cs".

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"Structure of the levels in the doubly magic nucleus $^{132}_{50}Sn_{82}$".

2.3.2 Nuclear spins and moments of short-lived nuclides determined by on-line ABMR techniques at the ISOLDE facility, CERN

C. Ekström, I. Lindgren and L. Robertsson

The atomic-beam magnetic resonance (ABMR) apparatus, connected on-line with the ISOLDE isotope separator, has been used during 1980 for continued systematic spin and moment measurements. Ground and isomeric state spins have been determined in the neutron-rich indium isotopes ^{118}In and ^{119}In, indicating a shell model structure of the states. The same interpretation holds for the nuclide ^{143}Eu (with the nuclear spin measured to be $I = 5/2$), located close to the neutron shell closure at $N = 82$.

In ^{211}Fr the nuclear as well as electronic g-factors have have been measured. Combined with previous results on the hyperfine constants, different theoretical calculations of the electronic part of the hyperfine interaction have been tested. Furthermore, the nuclear moments in $^{208-213}Fr$ have been evaluated. As evidenced by the magnetic moments, the odd-A isotopes may be described by the $h_{9/2}$ shell model proton state, while the variation in the quadrupole moments indicates a slight increase in deformation with decreasing mass number on the neutron-deficient side of the $N = 126$ shell closure.

In collaboration with a Mainz group at ISOLDE, hyperfine structure and isotope shifts have been measured in a number of barium and ytterbium isotopes using collinear beam laser techniques. The extensive set of data on barium is presently analysed and prepared for publication.

1. C. Ekström, L. Robertsson, S. Ingelman, G. Wannberg and I. Ragnarsson, Nuclear ground state spin of ^{185}Au and magnetic moments of ^{187,188}Au - further evidence for coexisting nuclear shapes in this mass region, Nucl. Phys. A348(1980)25.

2. C. Ekström and L. Robertsson, Nuclear spins of the bromine isotopes $^{74(m),75,77m,78}$Br. Physica Scripta 22(1980)344.

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C. Ekström, Application of on-line ABMR techniques to nuclides far from stability, Proc. 10th Int. Conf. on Electromagnetic Separators and Techniques related to their Applications, Zinal, Switzerland, 1980, Nucl. Instr. and Meth.

P. Buchinger, W. Klempt, A.C. Mueller, E.W. Otten, C. Ekström, J. Heinemeier and R. Neugart, Fast-beam laser spectroscopy of neutron-rich barium isotopes, Proc. Vth Int. Conf. on Hyperfine Interactions, Berlin, Germany, 1980.

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P. Buchinger, W. Klempt, A.C. Mueller, E.W. Otten, C. Ekström and R. Neugart, Isotope shift of ^{162}Yb, ^{164}Yb and ^{166}Yb determined by collinear-beam laser spectroscopy, Proc. 12th EGAS Conference, Pisa, Italy, 1980.

3. THE GUSTAF WERNER INSTITUTE, UNIVERSITY OF UPPSALA, BOX 531, S-751 21 UPPSALA

3.1 Physical biology

3.1.1 H Lundqvist, P Malmborg and C-G Stålnacke, B Långström, C Halldin and S Sjöberg, Department of Organic Chemistry, University of Uppsala

The aim of this project is to develop production techniques of short-lived positron-emitting radionuclides (^{11}C, ^{13}N, ^{15}O and ^{18}F) and to establish labelling methods of organic compounds with these. The labelled products are then used in several bio-medical projects at the Department of Physical Biology (GWI) and in collaboration with departments at the Karolinska Hospital, Stockholm, the Academic Hospital, Uppsala, and the University of Agricultural Sciences, Uppsala.

Different types of gas targets are used for the production:

a)	^{11}C :	Nitrogen gas	($^{14}N(p,\alpha)^{11}C$)
b)	^{15}O :	Nitrogen gas	($^{14}N(d,n)^{15}O$)
c)	^{18}F :	Neon gas	($^{20}Ne(d,\alpha)^{18}F$)

By adding minor components of other gases to the main target gas, the radionuclide can be obtained in different chemical forms suitable for further chemistry.

For ^{13}N a water target ($^{16}O(p,\alpha)^{13}N$) has been found to be the most convenient production route.

Beams of 10 - 20μA are regularly used giving production yields of about:

8 GBq (~200 mCi) ^{11}C

0.8 GBq (~ 20 mCi) ^{13}N

The production of ^{18}F is still under development and no regular production runs are yet made.

The radioactivities are carried to radiochemical laboratories nearby.

In the production of ^{11}C, the main labelled product is [^{11}C]-carbon dioxide. which usually has been trapped in a lead-shielded trap containing 4A molecular sieves. By heating the trap the labelled carbon dioxide is released and used in various syntheses. In most cases the [^{11}C] -carbon dioxide has been used in a routine production of [^{11}C] -methyl iodide - a synthesis now being developed to a completely automated system using microprocessor control. The labelled methyl iodide - an important precursor in the labelling of larger more interesting radiopharmaceuticals - has been used in various syntheses such as the preparation of [$^{11}CH_3$] -L-methionine or methionine containing small peptides i.e. enkephaline, of choline and other cholinergic substrates, and hydrocarbons.

Further developments of systems for routine production of important synthetic low-molecular precursors like [^{11}C]-methyllithium and [^{11}C]-hydrogencyanide are still in progress.

The development of asymmetric synthetic routes for labelling aromatic amino acids not labelled in the carboxylic position are in its beginning. Promising results fot the synthesis of [3-^{11}C]-phenylalanin have been obtained.

So far most of the bio-medical work has been done with ^{11}C-labelled radiopharmaceuticals in collaboration with medical and other groups as shown by the following examples:

a) In a project "Availability of amino acids in fodder studied by nuclide techniques", ^{11}C-labelled amino acids have been used in the search for a method to investigate feed utilization in the breeding of domestic animals (2). This work is done at the Department of Clinical Chemistry, Faculty of Veterinary Medicine, University of Agricultural Scienses, Uppsala.

b) The group around the positron camera at the Karolinska Hospital (KS) in Stockholm has shown a great interest in obtaining ^{11}C for brain studies. When not available in Stockholm, ^{11}C produced at the tandem accelerator in Uppsala has been transported 75 km on the high-way for development and use of a photosynthetic [^{11}C]-glucose production method utilizing green algae in collaboration with the Karolinska Pharmacy at KS (3).

c) A strong and growing interest in our work is now found in several departments of the Uppsala Academic Hospital (UAS). Animal experiments along the research lines of interest (nutrition, heart, brain ...) have started as an orientation to coming work with the positron emission tomographic system(s) we hope to see installed in the near future. Then it will be possible to take full advantage of our experience in radionuclide production and radiopharmaceutical chemistry and the short distance (700 m) between the TLU-GWI-Chemistry-buildings and the hospital.

References:

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3) Ehrin, E. et al., "A convenient method for production of ^{11}C-labelled glucose". J. Lab. Comp. Radiopharmaceutical 17, 453 (1980).

4. LUND UNIVERSITY AND LUND INSTITUTE OF TECHNOLOGY, S-223 62 LUND

4.1. Department of nuclear physics - Pelletron group

4.1.1. Neutron capture measurements with the activation technique

Per Andersson, Ingvar Bergqvist and Rogério Zorro

Capture cross section measurements with the activation technique in the MeV-region appear to be more difficult than expected due to background neutrons. Measurements in the neutron energy range 1-10 MeV for ^{115}In and ^{197}Au are in progress. The irradiations are performed with neutrons from the $T(p,n)^3He$-reaction. The protons are accelerated by the Pelletron accelerator and a solid target consisting of a thin tritiated Ti-layer evaporated on an Al-backing is used as a neutron source.

The contribution due to accompanying background neutron sources may be considerable and must be systematically studied and corrected for. The background neutrons may be separated into primary and secondary neutrons according to their origin. The primary background neutrons are produced by (p,n)-reactions in the Ti-layer and the Al-backing whenever the proton energy is above the (p,n)-threshold. The secondary background neutrons are produced in the sample itself and in surrounding materials by reactions like (n,2n), (n,np) and (n,n'). Measurements of 14-15 MeV neutron capture cross sections indicate that these corrections may be determined by observing the dependence of sample thickness and source-to-sample distance of the activation yield (1,2). The $T(d,n)^4He$-reaction was used for the production of 14-15 MeV neutrons and the production of primary background neutrons could be neglected due to the low energy of the projectiles.

Systematical studies of the production of primary background neutrons at different neutron energies show that the solid target mentioned above can be used for neutron energies less than 4.5 MeV. The signal-to-background ratio is < 0.5 for energies > 4.5 MeV which implies serious difficulties in reproducing the (p,n)-yield corrections for different irradiations. For energies > 4.5 MeV a tritium gas cell system has to be used as a target. Since there is no such system available in Lund these measurements will be performed elsewhere.

The induced activity is measured with a Ge(Li)-spectrometer and corrections for γ-ray attenuation in the sample are made. The activation yield for the different irradiation-geometries is calculated with a computer-code which takes into consideration the geometry of the source, the neutron energy spread (3) and the variation of the neutron flux with emission angle. The integrated neutron flux is determined from the $^{115}In(n,n')^{115}In$ reaction (4). The results show good agreement with earlier activation experiments, in which no corrections due to secondary neutrons were considered, for neutron energies below about 2 MeV but diverge at higher energies. This indicates the influence of secondary neutrons from about 2 MeV. The contribution of these increases with neutron energy.

The results of the measurement of the background also show good agreement with theoretical estimations of the corrections.

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4.1.2. Studies of the gamma-ray strength function

The ^{62}Cu gamma-ray strength function between 6.6 and 8.1 MeV

B. Erlandsson, K. Nilson, A. Marcinkowski

The ^{62}Cu γ-ray strength function between 6.6-8.1 MeV is derived from an average resonance spectroscopy experiment. This strength function is found to have a steeper energy dependence in the investigated energy region than that expected from an extrapolation of the GDR. Some J^{π} assignments were made with the help of the intensities of the γ-rays to final states with known J^{π}-values tested against theoretical calculations based on the Hauser-Feshbach theory.

4.1.3. Gamma-ray strength function measurements for ^{63}Cu *

B. Erlandsson, K. Nilson, A. Marcinkowski

The $^{62}Ni(p,\gamma)^{63}Cu$ reaction has been studied in the proton energy range E_p = 1.9-2.4 MeV. Using a three-crystal pair spectrometer, γ-ray spectra of primary transitions have been measured throughout this proton energy interval in steps of about 4 keV. An average γ-ray spectrum was formed by adding all the individual spectra after proper adjustment as a result of the alterations in proton energy. From the average intensities of the primary γ-rays the γ-ray strength function for energies between 5 and 8 MeV was deduced. It was found that the values of the γ-ray strength function, in the region investigated, display a much steeper slope than the giant dipole resonance predicts.

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* This work has been published in Nucl. Phys. A348, 1 (1980)

4.1.4. A study of the Structure of the $^{64,66}Zn$ Nuclei by the Average Resonance Spectroscopy Method *

B. Erlandsson, J. Lyttkens, K. Nilson, A. Marcinkowski

The reactions $^{63}Cu(p,\gamma)^{64}Zn$ and $^{65}Cu(p,\gamma)^{66}Zn$ have been used to study the average intensities of primary gamma rays from compound nuclear states in a broad energy region just below the neutron binding energy in ^{64}Zn and ^{66}Zn. The gamma rays were detected with a three-crystal pair-spectrometer for differences in the proton energies of 16-20 keV. Spectra obtained in this way were added to get only one averaged spectrum for each of the two nuclei. Comparison of the relative intensities of the primary gamma-ray transitions were made with the predictions of the compound nucleus statistical model. The E1 gamma-ray strength functions for energies below 11 MeV have been deduced from the experimental data. From studying the secondary gamma-ray transitions between low-excited states in $^{64,66}Zn$ level schemes up to about 4 MeV have been constructed.

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* This work has been published in Nucl. Phys. A343, 197 (1980) and in Physica Scripta 22, 432 (1980).

4.1.5. Two-particle-one-hole excitations in ^{89}Zr and their lifetimes *

S.E. Arnell+, L.P. Ekström, A. Nilsson++ and E. Wallander+

High-spin levels ($J \geq 13/2$) of $^{89}_{40}Zr_{49}$ have been studied experimentally by the $^{90}Zr(\alpha,\alpha'n)$ reaction [1] and the $^{87}Sr(\alpha,2n)$ reaction [2]. Serduke et al. [3] and Gross and Frenkel [4] have performed shell-model calculations on this and some other N = 49 nuclei. In the case of $^{91}_{42}Mo_{49}$ the agreement is generally excellent between calculated and experimental [1] level positions and transition rates.

In the present investigation we have used the $^{88}Sr(\alpha,3n)$ reaction at E_α = = 40 MeV to populate levels with spins up to at least 25/2 and $23/2^-$. So far, $\gamma\gamma$-coincidences, angular distributions and lifetimes in the ns region have been studied as well as lifetimes in the ps region by means of the DSA method. The analysis of data is in progress.

Among the positive parity levels, those with spin 15/2, 17/2 (2^{nd}), 25/2 and (27/2) have not been reported earlier. Those belonging to the $\pi g^2_{9/2}\, \nu g^{-1}_{9/2}$ configuration agree very well with shell model calculations [3,4]. In addition, our measured half-life of the $21/2^+$ level, 5.9±0.1 ns, is close to the value 4.7 ns predicted by Serduke et al. [3]. The 581 and 701 keV transitions have reduced rates that are about two times smaller than those of the corresponding transitions in ^{91}Mo.

A cascade of three Doppler-shifted γ-ray transitions was observed in coincidence with the 178 keV γ-ray that deexcites the $13/2^-$ level at 2121 keV. A coincidence run with a 2 cm^3 Ge-detector proved that a 29.3 keV transition has to be placed below the cascade. Furthermore, the coincidence relations obeyed by the 68 keV and 564 keV γ-rays can get a reasonable explanation if a 9.2 keV transition is postulated above the 29.3 keV transition. (An attempt to detect this weak γ-ray ($\alpha_{total} \approx 30$) will be made, special measures being taken against the very intense beam-excited Sr KX-rays at 14 and 16 keV).

---

* Experiment performed at the Research Institute of Physics, Stockholm.

+ Chalmers University of Technology, Gothenburg.

++ Research Institute of Physics, Stockholm.

The positions of the $13/2^-$ - $19/2^-$ levels thus obtained are also in good agreement with the predictions of Serduke et al. [3]. They are closely related to the 6^+ - 9^+ levels in ^{88}Y, the $p_{1/2}$ proton essentially playing the role of a spectator.

The $21/2^-$ and $23/2^-$ levels are probably based on the 6^- and 7^- levels of ^{88}Sr and thus formed by promoting a $p_{3/2}$ and/or $f_{5/2}$ proton to the $g_{9/2}$ orbit.

A break-up of the ^{88}Sr core also appears likely in the case of the 4736 and 5378 keV levels.

---

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(2) T. Numao, T. Kobayashi and H. Nakayama, J. Phys. Soc. Japan 47 (1979) 365.

(3) F.J.D. Serduke, R.D. Lawson and D.H. Gloeckner, Nucl. Phys. A256 (1976) 45.

(4) R. Gross and A. Frenkel, Nucl. Phys. A267 (1976) 85.

4.1.6. The Mass of the Nucleus ^{148}Dy

L. Spanier, S.Z. Gui[+], H. Hick[++], E. Nolte[++]

An experiment to determine the mass of ^{148}Dy has been performed at the Munich Tandem Laboratory.

Using γ-γ-coincidences the $EC(K)/\beta^+$ ratio for the β decay $^{148}Dy \rightarrow {}^{148}Tb$ has been determined. ^{148}Dy was produced in the reaction $^{93}Ng(^{58}Ni, 3p)^{148}Dy$ and $^{93}Nb(^{58}Ni, 2pn)^{148}Ho$ $(\beta^+EC)^{148}Dy$. The ^{58}Ni beam was accelerated to 249 MeV with the Munich MP Tandem and the Munich Heavy Ion Postaccelerator. The target, which was surrounded by an aluminium positron stopper, was irraditated cyclically for 30s and γ-singles and γ-γ-coincidence spectra were measured off-beam. The β-decay scheme of ^{148}Dy is very simple.

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$I(EC+\beta^+)$ was taken from the γ-singles spectra and $I(\beta^+)$ from γ-γ-coincidence spectra. After corrections the $EC(K)/\beta^+$ ratio was determined to be 14.7±2.7. Since the β-transition is allowed the decay energy can be safely deduced from this ratio to be 1.16±0.06 MeV.

Two interesting application follow immediately:

1) ^{148}Dy is the end nucleus in an α-decay chain with well determined α-energies. When we determine the mass of ^{148}Dy we also get the masses of the four other nuclei in this decay chain. These are very neutron-deficient nuclei and can be compared with mass formulae.

2) One way to estimate the possible magical properties of Z = 64 is to evaluate the B_{2p} for the N=82 isotones. The mass of ^{148}Dy indicates a step in B_{2p} not bigger than 0.5 MeV for Z = 66.

4.1.7. Beta strength function for ^{71}Ga

L. Spanier, C.-O. Wene, B. Erlandsson and K. Nilson

We have studied the isobaric-analogue states (IAS) in ^{71}Ga with the reaction $^{70}Zn(p,\gamma)^{71}Ga$ with a proton energy of about 4 MeV. The gamma rays from the IAS have been measured with a pair-spectrometer. The Gamow-Teller (GT) operator is approximately proportional to the iso-vector part of the M1 gamma transition operator. This makes it possible to deduce the GT β-strength function for ^{71}Ga which is also fed by β-transitions from the ground state and the low lying $9/2^+$ state in ^{71}Zn. We have found a tentative structure at 4 MeV in ^{71}Ga which corresponds well with the estimates given in ref. 1.

---

(1) H.V. Klapdor, C.-O. Wene
J. Phys. G: Nucl. Phys. 6 (1980) 1061-1104

4.2. Department of nuclear physics - Photonuclear group

4.2.1. Protoninduced fission of light and medium-heavy nuclei

H.-A. Gustafsson[+], E. Hagebø[++], G. Hyltén, B. Schrøder

In a series of experiments we have studied the 600 MeV protoninduced fission of U, Bi, Pb, Yb, Tb, Ce, La, Sb, Ag, Y and Se. Information has been obtained concerning fission barrier heights and mass distributions (1,2). The experiments performed at the synchrotron at CERN are completed, however, we plan to continue the investigation in collaboration with a group at the 1 GeV protonsynchrotron at Gatchina in Leningrad.

(1) G. Andersson et. al., Z. Physik A293 (1979) 241
(2) G. Andersson et. al., Proceedings of Physics and Chemistry of Fission 1979, IAEA, VIenna 1980, Vol. II, p. 329

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4.2.2. $^{28}Si(\gamma,p)^{27}Al$ and $^{28}Si(\gamma,\alpha)^{24}Mg$ reactions in the giant dipole resonance region

R. Gulbranson+, L.S. Cardman+, A. Doran+, A. Erell+, K.R. Lindgren and A. Yavin+

Using the tagged photon beam from the MUSL-II superconducting microtron, the emission of protons and alphas from the giant dipole resonance of ^{28}Si has been measured. Silicon detectors of different thickness were used as both targets and detectors. The energy range covered was 15.6--22.5 MeV and the resolution of the incident photons was 150-200 keV. Several proton decay channels up to an excitation energy of 5 MeV and α emission to the ground state and first excited state were observed.

For protons the decay to the ground state dominates but considerable strength is also observed in the p_1, p_2, p_4 and p_5 channels.

+ Department of Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois, USA

The partial cross sections for the ground state channels were compared with those obtained in p and α capture [1,2]. After averaging the data to comparable energy resolution the (p,γ_0) and (γ,p_0) cross sections were in agreement, but the (α,γ_0) and (γ,α_0) cross sections were not.

Many peaks of intermediate structure ($\Gamma \approx 300$ keV) seen in the (γ,p_0) cross section are also observed in the cross sections for the excited states.

Comparison with Hauser-Feshbach calculations indicates that proton decay is predominantly direct but the alpha decay is mainly statistical. The structural overlap between the GDR and the final states is also revealed from comparison of the integrated partial cross sections with spectroscopic factors from the $(d,^3He)$ reactions [3].

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(1) P.R. Singh et. al., Nucl. Phys. 65 (1965) 577.
(2) L. Meyer-Schützmeister et. al., Nucl. Phys. A108 (1968) 180.
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4.2.3. Cluster emission from complex nuclei irradiated by 500 MeV bremsstrahlung

J.-O. Adler, G. Andersson, H.-A. Gustafsson, K. Hansen

The investigation of light nuclei from complex targets has continued with analysis of the data from Al, C and Li. Unfortunately the change of computer system at the institute has delayed the analysis considerably. A search was made for coincidenc events from the runs made with two surface-barrier detector telescopes, but no significant yield was found. During 1980 we have published the results from the Au, Ag and Cu targets [1].

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(1) Emission of Hydrogen and Helium Nuclei from Au, Ag and Cu irradiated by 500 MeV Bremsstrahlung.
Z. Physik A295 (1980) 65
J.-O. Adler, G. Andersson, H.-A. Gustafsson, K. Hansen

5. RESEARCH INSTITUTE OF PHYSICS, S-104 05 STOCKHOLM

A. Nilsson

The intensity and reliability ot the ^{12}C-beam from the 225-cm cyclotron has been improved considerably during the year. Work is in progress to decrease the minimum frequency of the oscillator, mainly in order to extract a useful beam of $^{20}Ne^{6+}$. The PDP 11/70 computer will be replaced by a VAX 11/780 during the summer this year.

The research work in nuclear physics has been focussed on $\gamma\gamma$-correlations in the continuum, yielding information on moments of inertia in the region of very high spin, where discrete spectroscopy fails. Conventional in-beam γ-ray spectroscopy has been performed on Br, Kr, Zr, Ru, Xe, Ce and At nuclei.

During the year 72 samples of $^{11}CO_2$ with a mean strength of 75 mCi were delivered to the Karolinska Pharmacy. They were produced by bombarding a nitrogen gas target by about 4 μA of H_2^+ beam with an enrgy of 11.5-12.5 MeV per proton. After photosynthetic introduction of ^{11}C into glucose it is injected into patients for subsequent studies of brain malfunctions by means of the positron camera. Production has continued of ^{81}Rb (by the reaction $^{79}Br(\alpha,2n)^{81}Rb$ at 30 MeV), from which ^{81m}Kr is extracted at the Danderyd Hospital and used for lung ventilation studies.

The surface physics group has brought into operation an integrated ion-implantation and RBS-analyzing arrangement, in which a 10 kV accelerator and the 2 MV Van de Graaff can bombard the same specimen without breaking the ultra-high vacuum. Blistering and exfoliation of stainless steel and inconel during He bombardment have been studied, among other things. The group is also constructing a device which will collect in a time- and space-resolved way, plasma impurities expelled during the pulse ot the materials-testing fusion reactor TEXTOR in Jülich.

6. THE STUDSVIK SCIENCE RESEARCH LABORATORY

S-611 82 Nyköping, Sweden

6.1 Nuclear Chemistry Group

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

6.1.1 Development of rapid chemical separation methods to be used as a complement to mass separation

We have since a long-time worked on the development of a rapid chemical separation method based on thermochromatography and intended to be used as a complement to mass separation. Several prototypes have been built, the latest one being completed in 1979. This apparatus, which is attached to the collector end of the isotope separator, has been successfully used in a study of neutron-rich isotopes of zinc and cadmium.

A comparison between results of measurements of gamma spectra of zinc and cadmium with and without chemical separation has provided a means of unambiguously assigning gamma-rays to these elements in the presence of isobars of gallium and indium, respectively. In this way gamma-rays in the decays of $^{78-80}$Zn and $^{123-127}$Cd have been identified. These results are reported in Ref. [1].

6.1.2 Total beta-decay energies

The experimental programme to map the nuclear mass surface has continued. During 1980 new Q_β-values were determined for the nuclides ^{80,81}Ga, ^{81}Ge, ^{89,90}Br, $^{115-121}$Ag, $^{119-121}$Cd, and ^{139,140}I.

6.1.3 Delayed neutrons

An extensive programme has been carried out for measuring the branching to neutrons in the decay of the delayed-neutron precursors produced at OSIRIS. The results have now been published in two articles [2] and [3]. The former deals with precursors belonging to the elements gallium, bromine, rubidium, indium, antimony, iodine, and cesium whereas the latter contains branching ratios of the isotopes $^{89-91}Br$ and $^{139-141}I$.

6.1.4 A population of excited states in the emission of delayed neutrons

The results of a study of the branching to various excited states of the final nucleus in the neutron imission have been written up and will be published in Nuclear Physics [4]. The report contains data for the precursors ^{81}Ga, $^{88,89}Br$, $^{93-96}Rb$, ^{135}Sb, and ^{139}I.

6.1.5 The decay of neutron-rich gallium and germanium isotopes

The investigation of the most neutron-rich isotopes of gallium and germanium available at OSIRIS has now been completed, and decay schemes have been constructed for $^{79-82}Ga$ and $^{79-82}Ge$. The presence of low lying positive parity intruder states has been demonstrated in ^{81}Ge, but similar states could not be seen in ^{79}Ge. These states occur at low energy at relatively moderate deformation, and are found at slightly higher energy in ^{81}Ge than in ^{83}Se. This is an indication for the expected double-shell closure at ^{78}Ni. Two reports [5,6] have been written.

6.1.6 Decay of $^{89,90}Br$ and $^{139,140}I$

Using the aluminium vapour technique allowing us to separate ions like $AlBr^+$ and AlI^+, we have performed extensive investigations of $^{89,90}Br$ and $^{139,140}I$, and detailed decay schemes have now been constructed for these nuclei. For $^{89,90}Br$ they are given in the reports [7] and [8].

6.1.7 The decay of neutron-rich lanthanide isotopes

Investigations of the neutron-rich lanthanide isotopes using our fluorination technique and separating the lanthanides as di-fluoride molecular ions have started. So far, experiments have been performed for ^{147}La, $^{147,149}Pr$, and $^{147,149}Ce$.

6.1.8 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 have now been analysed and written up for publication [9].

6.1.9 Fission yields

A project aiming at the determination of the independent yield pattern for the thermal-neutron induced fission of ^{235}U started in 1979. During 1980 several series of experiments were carried out.

In order to make possible a correction for decay in the period between production and measurement the distribution of delay times must be known. This distribution is given by the delay function p(t)dt.

It turns out that the delay function is essentially governed by a single parameter, which will depend on the target - ion source conditions and the element to which the nuclide belongs. A knowledge of this delay parameter suffices for the correction of a measured yield for the decay losses unless the half-life of the nuclide under study is very short (< 1 second). In the latter case a second parameter has to be introduced into the analysis.

The delay parameter has been measured for the elements zinc, gallium, bromine, krypton, rubidium, silver, cadmium, indium, tin, antimony, tellurium, iodine, xenon, and cesium. The data will be used in the conversion of measured counting rates of isotopes of these elements into fission yields.

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6.2 Nuclear Spectroscopy Group

B Fogelberg

6.2.1 Levels and transition probabilities in ^{130}Sn

The experimental part of this study, made at the OSIRIS facility, was essentially completed last year. The data analysis and interpretation, which has been made in collaboration with K Heyde and J Sau, Gent, is also completed. A report [1] has been prepared which together with an earlier paper [2] completes the level scheme studies of heavy single closed shell even Sn nuclei, which can be reached in the decay of In isotopes.

6.2.2 Investigations of level schemes and level densities in delayed neutron emitters.

A. The decay $^{137}I \rightarrow ^{137}Xe$

The construction of the decay scheme for this complicated decay was essentially completed last year. An analysis have been made during 1980. The number of established γ-decaying excited states in ^{137}I was 106 of which 22-23 are situated above the neutron binding energy. A report describing the study has been publisehd [3].

6.2.3 B. The decay $^{87}Br \rightarrow ^{87}Kr$

A series of detailed measurements of γ-ray and γγ-coincidences for this decay have been made. The tedious construction of a level scheme from the observed 355 γ-rays and several hundred coincidence relations is made in collaboration with the nuclear chemistry group at Johannes Gutenberg Universität, Mainz.

The results will be compared with the direct measurement of the level density of ^{87}Kr described below.

6.2.4 C. A high resolution measurement of the reaction $^{86}Kr+n$ for E_n=0-400 keV.

The β-decaying ground state of ^{87}Br is from systematics believed to have $I^{\pi}=3/2^{-}$. The levels in ^{87}Kr which are populated by allowed transitions will thus have $I^{\pi}=1/2^{-}$, $3/2^{-}$ and $5/2^{-}$. Levels which are situated above the neutron binding energy (5515.4 ± 0.8 keV) and having $I^{\pi} = 1/2^{-}$ and $3/2^{-}$ can also be observed as p-wave resonances in the neutron cross section of ^{86}Kr. The reaction $^{86}Kr + n$ will therefore give very direct information on the true level density cf neutron emitting levels in ^{87}Kr. The study of $^{86}Kr + n$ was made in collaboration with physicists at ORELA. The quantities measured were both the scattering and the capture cross sections as a function of energy.

A complete analysis of the experiment is not yet done. One may, however, state with some confidence that there is almost an one-to-one correspondence between p-wave resonances and the peaks in the delayed neutron spectrum reported by Nuh et al. [4], at least up to about 250 keV where also f-wave neutron emission becomes important.

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6.3 Neutron Physics Laboratory

6.3.1 Compilation of actinide neutron nuclear data

B Trostell

The actinide Nuclear Data Working Group of the Swedish Nuclear Data Committee has completed their work during 1980, and a report on the subject has been published. A possible continuation of the work is under discussion.

6.3.2 Inelastic neutron scattering

B Trostell

The $(n,n'\gamma)$ measurements on ^{89}Y and ^{141}Pr are completed. Many γ-ray transitions in ^{141}Pr, which have not been reported earlier, have been observed.

Transitions to the ground and first excited states have been identified through a $\gamma\gamma$-coincidence study of the $(n,n'\gamma)$ reaction.

A report is being prepared, where a considerably more detailed level scheme for ^{141}Pr, than hitherto known, is presented. A report is also being prepared, where an experimental arrangement for γ-γ-coincidence spectroscopy, using the $(n,n'\gamma)$ reaction, is presented.

6.3.3 International intercomparison of fast neutron fluence determinations

B Holmqvist, N Olsson and B Trostell

The laboratory participates in an international intercomparison of fast neutron fluence determinations under the auspices of Bureau International des Poids et Mesures, Paris. The work is coordinated by Dr H Liskien, Central Bureau for Nuclear Measurements, Geel, Belgium.

The participating laboratories have to irradiate delivered indium samples with "quasi-monoenergetic" neutrons of known intensities at 2.5, 5 and 14.8 MeV incident neutron energy. The intensity determination should be made with the equipment available at each laboratory. The comparison will be based on the $^{115}In(n,n')^{115}In^{m}$ reaction. The $^{115}In^{m}$ decay ($T_{1/2}$ = 4.486 ± 0.004 h) is to be observed, by measuring the 336.23 γ-ray emitted in 45.9 ± 0.1 % of the decays, with a Ge(Li) detector.

This laboratory will use a proton recoil telescope for the neutron fluence determination and the experience, which will be gained in this field, are to be used in the construction of a new telescope for future n-p scattering measurements.

The indium samples will be received in the beginning of May 1981.

6.3.4 Neutron elastic scattering from Pb_r and ^{209}Bi

N Olsson and B Holmqvist

A comparison of the neutron elastic scattering cross sections of Pb_r (radiogenic lead; 88.2 % ^{206}Pb) and ^{209}Bi in the energy region 1 - 10 MeV shows some interesting differences.

Previous experiments indicate that there is a broad maximum (giant resonance) in the cross section of ^{209}Bi at about 3 MeV. On the other hand for ^{206}Pb the cross section seems to be constant up to about 4 MeV and then decreases. Pb (natural lead) shows a maximum similar to that of ^{209}Bi. However, there are very few data points available for Pb_r (^{206}Pb), while in the case of ^{209}Bi there is a large spread of the data points below 5 MeV.

In order to investigate the situation elastic scattering cross sections of Pb_r and ^{209}Bi have been measured with high accuracy at twelve incident energies in the range 1.5 - 4.0 MeV, with an energy spread of ± 0.025 MeV. Angular distributions have been observed in the angular region 15° - 160° and also at forward angles on the negative side in order to eliminate uncertainties in the 0°-direction determination.

The present measurements with a total error of less than 5 per cent, confirm the existence of the giant resonance for both elements. The measurements show no sign of any fine structure in this energy region within the resolution of the experiment, i.e. ± 25 keV.

6.3.5 Nuclear astrophysics

B Holmqvist and E Ramström

The aim of the astrophysical program at the laboratory is to study nuclear reaction chains being responsible for production and destruction of ^{22}Ne, ^{23}Na, ^{24}Mg, ^{26}Mg, ^{26}Al($\beta^{+}\rightarrow{}^{26}Mg$, $\tau_{1/2}=7.4\cdot 10^{5}$ years) and ^{27}Al in hydrogen and helium burning zones in stars. In particular it is interesting to find an explanation for the differences observed in certain isotopic ratios, i.e. ^{20}Ne:^{22}Ne, ^{26}Mg:^{24}Mg and ^{27}Al:^{24}Mg on earth and in meteorites.

The program is dividen in two parts: 1. observation of excitation functions for production and burning of nuclei in the ratios entioned above, and 2. calculations of yields for reactions which can not be measured experimentally because the initial nucleus is radioactive or the energy range of interest is difficult to cover. In order to perform experimental observations a beam handling system and a highly sensitive neutron have been constructed. The measured excitation functions will be interpreted using existing nuclear models. The results from these investigations will be used in the calculations of yields for the reactions.

6.3.6 Integral measurement of energy release due to beta radiation following thermal-neutron fission of ^{235}U and ^{239}Pu

P-I Johansson

The energy release form fission fragments within about 10^3 s after fission is a critical parameter for the design of emergency core cooling systems in reactors. During the first few seconds after the shut down of a reactor the major energy development in the fuel is due to fissions induced by delayed neutrons. After about 10 s, however, the fission-product energy release is dominating.

Measurements have been performed at the laboratory with the aim of studying the energy distribution and the total energy of γ- and β-radiation emitted 10 - 1500 s after thermal fission of ^{235}U and ^{239}Pu. Final data for gamma radiation from ^{235}U have been reported [1].

Thermal neutrons for inducing fissions in ^{235}U and ^{239}Pu were produced by means of a 6 MeV Van de Graaff accelerator together with the $^9Be(p,n)^9B$-reaction using a thick target and a moderator of paraffin. The neutron flux available was about 10^8 n/(s.cm^2).

The beta radiation from the fission products was measured with a spectrometer consisting of three Si(Li)-crystals. The efficiency is 100 % for beta energies up to about 1.5 MeV and 30 % at 6 MeV. One crystal was placed between the other two. The center crystal was operated in anticoincidence mode with the side crystals in order to suppress events from beta particles which lost only part of their energy in the main crystal.

Measurements have been carried out with irradiation times of 4, 10 and 120 s and with cooling times from 10 s to 1500 s.

The result so far indicate a beta decay energy from ^{235}U which is about 10 % higher than the beta energy from ^{239}Pu for cooling times of 200 s to 1500 s. The effect on the result caused by backscattering in the sample itself and the backing material need to be studied in more detail before a final result.

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

7.1 The high-energy gamma-ray spectrometer

A Lindholm, L Nilsson, A Waheed, A Andersson, O Blockson,
J Blomberg, I Carlsson, F Dahlén, O Johansson and A Karlsson

The program to improve the timing and energy resolution of the large, 22.6 cm in diameter and 20.8 cm long, NaI(Tl) detector has been completed. The timing resolution was improved from about 12 ns to 3 ns (FWHM) by the exchange of the seven original photomultiplier tubes against six faster ones, RCA 8575. The seventh windows at the back surface ot the detector is used for a light emitting diode. The pulses from this diode will be used to control the dead time of the whole detection system and to check the pulse-height shifts versus count rate and other parameters.

The energy resolution of the detector is improved by an anticoincidence shield consisting of two NE 102A plastic scintillators, one front cylinder, 40 cm in diameter and 8 cm thick, and one annualar cylinder 35 cm long with inner and outer diameters of 29 and 48 cm, respectively, The normal mode of operation of this system is the anticoincidence mode, i e events in the central detector are accepted only if there is no simultaneous event ($E_\gamma > 100$ keV) in any of the two plastic detectors.

The detector assembly has been tested at a number of gamma-ray energies in the range 2-30 MeV. Gamma rays were obtained from radioactive sources and from (p,γ) reactions on ^{13}C, ^{89}Y and ^{3}H. Fig. 1 shows a spectrum from ^{13}C(p,γ)^{14}N at the E_p = 3.11 MeV resonance (E_γ = 10.4 MeV). The "accepted" as well as the

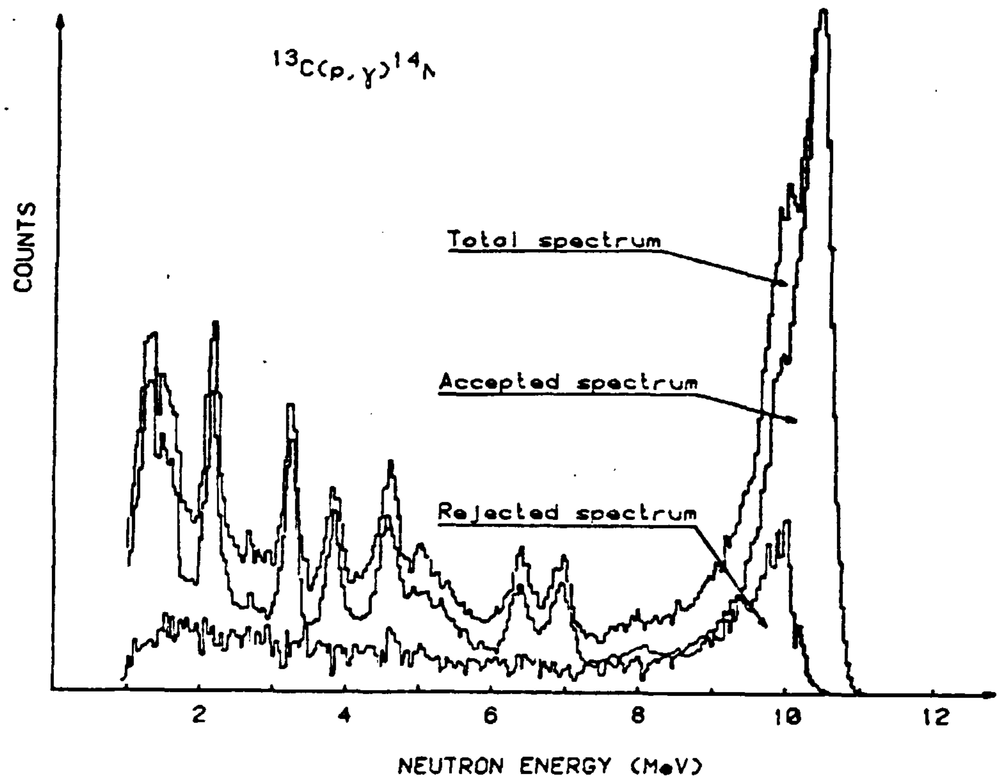

Figure 1

"rejected" spectrum is shown and it can be argued that the "efficiency" of the anti-coincidence shield is about 50 % at this gamma-ray energy. From the figure it can be seen that a very clean response function results if the 'rejected' spectrum is subtracted from the 'accepted' spectrum. Such a procedure would in principle imply that a correction for the lower-than-100-% efficiency of the anti-coincidence shield is applied. Before this procedure can be adopted in practice the efficiency of the anti-coincidence shield must be studied in detail at various incident gamma-ray energies.

7.2 Nucleon capture reactions in the giant multipole resonance region

7.2.1 Introduction

This report concerns studies of reaction mechanisms for nucleon capture in the giant resonance region and giant resonance properties. Most of the research work described here has been performed at the Tandem Accelerator Laboratory (TLU), but we give also short accounts for work performed in collaboration with research groups at Los Alamos Scientific Laboratory (LASL), USA and Centre d'Etudes de Bruyeres-le-Chatel (CEBC), France. During 1980 a considerable amount of effort has been devoted to a major reconstruction of the TLU high-energy gamma-ray detector. The big NaI(Tl) scintillator has been equipped with new photomultiplier tubes and with a plastic anticoincidence shield. This modification has given significantly improved timing and energy resolution. See (7.1)

7.2.2 Neutron capture in spherical nuclei

I Bergqvist, N Olsson and R. Zorro, Department of Physics, University of Lund
A Lindholm, L Nilsson and M Saleem

Neutron capture has in recent years been studied for a number of target nuclei covering the mass region $28 \leqslant A \leqslant 208$ in the giant dipole resonance region. The experimental data have been analyzed in terms of the direct-semidirect (DSD) model. The model considers two capture amplitudes, the direct and the semidirect. According to the semidirect description the interaction between the incident nucleon and the target nucleus excites a collective oscillation of the target nucleus while the nucleon itself is simultaneously captured into a single-particle orbit. The decay of the collective state completes the capture process and accounts for the enhancement of the cross section in the region of the giant dipole resonance. Satisfactory decriptions of the cross sections and gamma-ray spectra have been obtained by the use of a complex particle-vibration coupling in the model calculations. The coupling strength is related to the isospin-dependent part of the optical potential. In the light nuclei ^{28}Si, ^{32}S and ^{40}Ca the coupling strengths v_1 and w_1, 75 and 35 MeV respectively, are about equal to the strengths of the symmetry potential obtained from studies of quasi-elastic (p,n) transitions. In the heavy nuclei considerably larger w_1 values are needed to reproduce the observed cross sections. The reason for this is not understood at present.

Ref (1) reports on experiments to investigate the importance of compound-nucleus (CN) processes in neutron capture. Measurements were performed with four target nuclei covering a wide mass range: ^{40}Ca, ^{58}Ni, ^{89}Y and ^{206}Pb.

In a previous paper (2) we reported rather strong variations in the neutron capture cross sections for ^{28}Si and ^{32}S. This structure was later discussed theoretically (3) in terms of capture via single-particle type resonances. This theoretical work prompted us to study ^{28}Si(n,γ) and ^{32}S(n,γ) excitation functions in more detail.

A strong resonance in the yield is observed around 4.6 MeV where the model predicts a resonance with the same integrated cross section. In general, however, the agreement between experiment and model prediction is poor. This is true, in particular for the $^{28}Si(n,\gamma_1)$ cross section, where two strong resonances are predicted around 5 MeV whereas the observed structure in this region is very much weaker.

7.2.3 Proton capture in ^{176}Yb

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E D Earle and D Santry, Chalk River Nuclear Laboratories, Canada
A Lindholm and L Nilsson

The proton capture cross section for the reaction $^{176}Yb(p,\gamma)^{177}Lu$ has been measured for incident proton energies between 6 and 24 MeV, (4). Activation techniques were used and irradiations were performed at the Tandem Accelerator Laboratory (TLU), Uppsala, at the Niels Bohr Institute (NBI), Risø, Denmark and at Chalk River Nuclear Laboratories (CRNL), Chalk River, Canada. In addition, spectrum measurements were performed between 8 and 11 MeV at TLU. The results obtained with the two methods are in agreement within the experimental uncertainties indicating that cascading via unbound states is negligible.

The excitation function for this deformed target nucleus agrees remarkably well with the results of previous studies on spherical nuclei, e g $^{142}Ce(p,\gamma)^{143}Pr$. The results indicate that the giant dipole resonance (GDR) is strongly excited as predicted by the direct-semidirect (DSD) model. It is found that the model describes reasonably well the excitation function. In the low-energy proton range, where the excitation function increases rapidly with proton energy, the observed cross section is significantly higher than the DSD predictions. The difference can only partly be explained by compound nucleus contributions. In the high-energy end, the predicted cross section tends to be too high primarily due to an increasing contribution of direct capture to orbitals with large angular momenta.

7.2.4 Measurements of neutron-capture cross sections and studies of gamma-ray strength functions

S Joly, G Grenier and J Voignier, Centre d'Etudes de Bruyeres-le-Chatel, France
D M Drake, Los Alamos Scientific Laboratory, USA
L Nilsson

This result of this collaboration has been published (5) with the following abstract:

"Gamma-ray spectra following neutron capture in rhodium, thulium and gold for neutron energies between 0.5 and 3.0 MeV have been measured with a NaI scintillator surrounded by an annular NaI crystal. The γ-ray strength functions were deduced from the capture γ-ray spectra by the spectrum fitting method. A bump around 6 MeV is observed for gold as well as a smaller one around 3.5 MeV for thulium. The present results are compared with extrapolations of giant dipole resonance data and measured average total radiative widths."

7.2.5 The isospin structure of the giant dipole resonance in ^{41}Ca

D M Drake and M Drosg, Los Alamos Scientific Laboratory, USA
A Lindholm and L Nilsson

The results of this work have been summarized in a paper published in Physical Review C (6) with the following abstract:

"Differential 90° cross sections for $^{40}K(p,\gamma_0)^{41}Ca$ were measured over the entire giant dipole resonance region. The data are compared with similar results for the $^{40}Ca(n,\gamma_0)^{41}Ca$ reaction and with calculations based on the direct-semidirect capture model. An observed energy difference of about 1.5 MeV between the centroids of the (p,γ_0) and (n,γ_0) cross section curves is interpreted as the result of isospin selection rules."

7.2.6 The angular distribution of gamma rays from the $^{208}Pb(n,\gamma)$ reaction

The angular distribution of the gamma radiation from capture reactions can be used to obtain information on the properties of giant multipole resonances other than the giant dipole, e g the isoscalar quadrupole resonance. Other multipole amplitudes are generally small compared with the dipole amplitude but they manifest their presence through non-vanishing odd terms in the Legendre expansions of the angular distributions. In parallel with the experimental activities to study multipole mixing the DSD model has been extended to include capture via other multipole resonances, e g the isoscalar and isovector quadrupole resonances. A convenient measure of the multipole mixing is the intensity ratio $R = (I(55^\circ) - I(125^\circ))/(I(55^\circ) + I(125^\circ))$.

7.2.6.1 The region of the isoscalar quadrupole resonance

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D K McDaniels, University of Oregon, USA
D M Drake, Los Alamos Scientific Laboratory, USA
S Joly, Centre d'Etudes de Bruyeres-le-Chatel, France

The isoscalar quadrupole resonance in ^{208}Pb is located at 10.5 MeV corresponding to capture of 6.6 MeV neutrons. Measurements of the intensity ratio R have been performed at 6.2 and 6.7 MeV. The results are in reasonable agreement with the predictions from the DSD model (Fig 2). Care must be exercised,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.

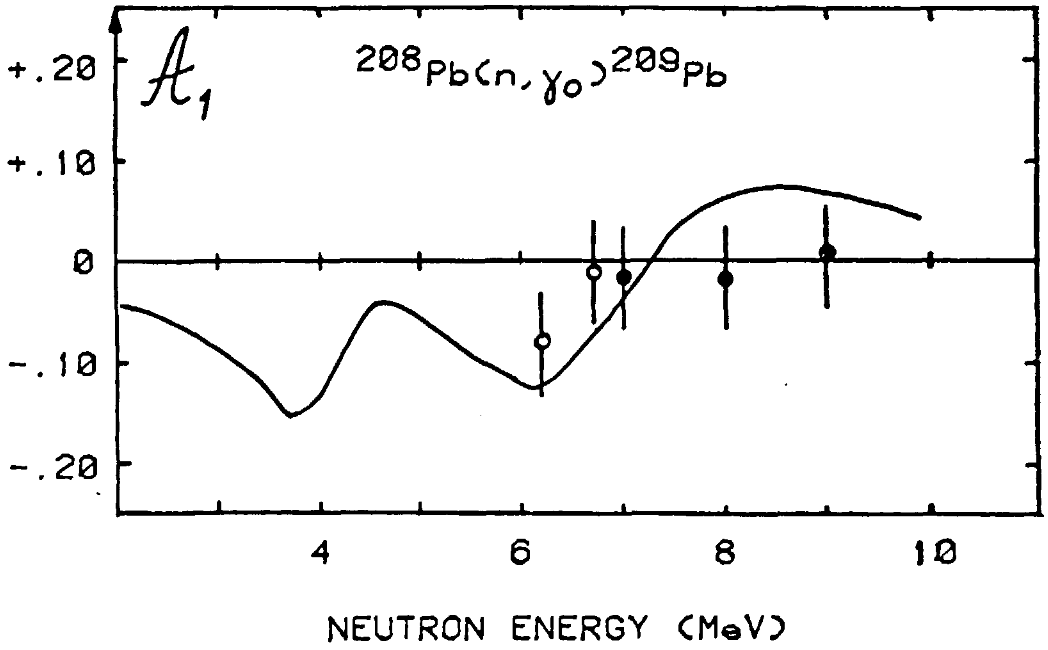

Figure 2

In addition to the angular distribution measurements, differential 90^{o} cross sections have been measured between 0.8 and 7.7 MeV. The experiments are performed partly at CEBC (E_n=0.8 - 5.9 MeV) and partly at Uppsala (E_n=5.7-7.7 MeV). The data from the two laboratories are in agreement and also agree with previous data from LASL.

7.2.6.2 The region of the isovector quadrupole resonance

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K Aniol, I Halpern and D Storm, University of Washington, USA
J Faucett, University of Oregon, USA
S Joly, Centre d'Etudes de Bruyeres-le-Chatel, France
S Wender, Triangle Universities Nuclear Laboratory, USA
L Nilsson

The theoretical calculations of the front-to-back asymmetry, R, show a rather weak influence from the isoscalar E2 resonance, whereas in the region of the isovector E2 resonance ($E_n \approx 20$ MeV) the R value increases steeply from about zero to more than +0.5. A couple of attempts have been made at LASL during the last few years to observe this steep increase of R. Several technical difficulties associated with capture of neutrons of about 20 MeV have occured, however, and not until recently have reliable data been taken. The preliminary analysis of the data indicate large R values in qualitative agreement with the DSD model predictions. Detailed analysis of the new data is under way.

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8.3 STUDIES OF THE $^{6}Li(n,t)^{4}He$ REACTION

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The present study aims at giving information on the ^{7}Li system of relevance for R-matrix calculations. In particular the neutron energy region from 2 to 4 MeV is of interest for extensions of these calculations to higher energies.

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

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

The $^{6}Li(n,t)$ measurement was described in a report to the Neutron Physics Conference at Harwell, September 1978.

The outgoing tritons and alpha particles were recorded with solid state detectors at four angles simultaneously by the use of a thin-walled scattering chamber.

Angular distributions of the tritons formed in the $^{6}Li(n,t)^{4}He$ reaction have been recorded at three incident neutron energies, 2.0, 2.7 and 3.5 MeV. The preliminary results indicate a significant change in the angular distribution over this energy region in qualitative agreement with preliminary R-matrix calculations.

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

The differential cross sections for the $T(\alpha,{}^{6}Li)n$ reaction are being measured with good energy and statistical accuracy over a wide excitation energy of ^{7}Li.

The target in the $T(\alpha,{}^{6}Li)n$ reaction experiment consists of tritium absorbed in a thin titanium layer evaporated onto a nickel backing. The alpha beam enters the target through the nickel backing and the outgoing ^{6}Li ions, emitted at angles near 0^{o} in the laboratory sytem, are recorded by a combined magnetic spectrometer - surface barrier detector system.

Because the ^{6}Li ions are emitted in a narrow forward cone ($<15^{o}$) the experiment must be done with good angular resolution. Furthermore two different energy groups of ^{6}Li ions are produced in the $T(\alpha,{}^{6}Li)n$ reaction corresponding to forward and backward emission in the center-of-mass system.

The emitted ^{6}Li ions have a charge distribution dominated by Li^{3+}. The Li^{3+}/Li^{2+} ratio is about 10 and ions with unit charge are negligible.

The ^{6}Li yield was measured relative to the elastic α-t scattering to allow cross section determination. The recoiling tritons were detected at one fixed angle relative to the incoming alpha beam by the use of a solid state detector. This angle was estimated in a separate measurement using the H(p,p)H reaction. The target was CH_2 evaporated on a thin carbon foil. The angle ($\sim 24^o$) was calculated from the energy shift of the scattered protons relative to that of the incident proton beam.

The α-t differential scattering cross sections were measured separately at alpha energies between 11.5 and 17 MeV. The same tritium target as in the T(α,^{6}Li)n reaction experiment was placed in a scattering chamber. The recoiling tritons were counted at three different angles (22, 24 and 26^o) by solid state detectors relative to the integrated proton beam. The preliminary results show two resonances at alpha energies of about 11.5 and 16.5 MeV but no significant changes in the relative energy dependence of the differential cross sections over the studied angular interval.

The differential cross section at 3^o in the laboratory system of the T(α,^{6}Li)n reaction have been measured at alpha energies from 11.5 to 16.7 MeV corresponding to neutron energies from about 200 keV to 2.8 MeV for the ^{6}Li(n,t)^{4}He reaction. Measurements of the angular distribution of the ^{6}Li ions are in progress at a number of alpha bombarding energies between 13 and 18 MeV.

The outcome of the combined results from the ^{6}Li(n,t) and T(α,^{6}Li) cross section measurements will hopefully improve the knowledge of the ^{6}Li(n,α) standard cross section up to about 3-4 MeV of neutron energy.

CINDA Type Index of Neutron Cross Section Measurements

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Element S	A	Quantity	Type	Energy Min	Energy Max	KDK Page	Lab	Comments
Li	6	(n,t)	EXPT PROG	2.0+5	2.8+6	39	TLU	ANDERSSON+. MEAS. ON IN-VERSE REACTION
SI	28	(n,γ)	EXPT PROG	3.2+6	1.5+7	32	TLU	BERGQVIST+. RESULTS COMP. TO DSD CALC.
S	32	(n,γ)	EXPT PROG	3.2+6	1.5+7	32	TLU	BERGQVIST+. RESULTS COMP. TO DSD AND CN CALC.
GA		DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
GA	79	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
GA	80	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
GA	80	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
GA	81	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
GA	81	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
GA	81	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
GA	82	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
GE	79	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
GE	80	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
GE	81	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
GE	81	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
GE	82	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
BR		DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
BR	86	FISS PROD γ	EXPT PROG			4	CTH	SKARNEMARK+.
BR	87	FISS PROD γ	EXPT PROG			4	CTH	SKARNEMARK+.
BR	87	FISS PROD γ	EXPT PROG			24	SWR	FOGELBERG.
BR	88	FISS PROD γ	EXPT PROG			4	CTH	SKARNEMARK+.
BR	88	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
BR	89	FISS PROD γ	EXPT PROG			4	CTH	SKARNEMARK+.
BR	89	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
BR	89	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.

Element S	A	Quantity	Type	Energy Min	Max	KDK Page	Lab	Comments
BR	89	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
BR	90	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
BR	90	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
BR	90	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
BR	91	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
KR	86	SCATTERING	EXPT PROG	THR	4.0+5	24	SWR	FOGELBERG.
KR	86	(n,γ)	EXPT PROG	THR	4.0+5	24	SWR	FOGELBERG.
RB		DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
RB	93	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
RB	94	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
RB	95	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
RB	96	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
Y	89	INELASTIC γ	EXPT PROG	2.2+6	3.5+6	25	SWR	TROSTELL.
ZR	100	FISS PROD γ	EXPT PROG			4	CTH	SKARNEMARK+.
TC	108	FISS PROD γ	EXPT PROG			4	CTH	SKARNEMARK+.
AG	115	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
AG	116	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
AG	117	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
AG	118	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
AG	119	FISS PROD β	EXPT PTOG			20	SWR	ALEKLETT+.
AG	120	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
AG	121	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
CD	119	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
CD	120	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
CD	121	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
IN	115	(n,γ)	EXPT PROG	1.0+6	1.0+7	11	LND	ANDERSSON+. ACT. TECHNIQUE
IN		DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
SN	130	FISS PROD γ	EXPT PROG			23	SWR	FOGELBERG+.
SB		DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
SB	135	DELAYED NEUTS	EXPT PROG			21	SWR	ALEKLETT+.
I		DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
I	137	FISS PROD γ	EXPT PROG			24	SWR	FOGELBERG.

Element S	A	Quantity	Type	Energy Min	Energy Max	KDK Page	Lab	Comments
I	139	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
I	139	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
I	139	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
I	140	FISS PROD γ	EXPT PROG			21	SWR	ALEKLETT+.
I	140	FISS PROD β	EXPT PROG			20	SWR	ALEKLETT+.
I	140	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
I	141	DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
CS		DELAYED NEUTS	EXPT PROG			20	SWR	ALEKLETT+.
LA	147	FISS PROD γ	EXPT PROG			22	SWR	ALEKLETT+.
CE	147	FISS PROD γ	EXPT PROG			22	SWR	ALEKLETT+.
CE	149	FISS PROD γ	EXPT PROG			22	SWR	ALEKLETT+.
PR	141	INELASTIC γ	EXPT PROG	1.1+6	2.5+6	25	SWR	TROSTELL.
PR	147	FISS PROD γ	EXPT PROG			22	SWR	ALEKLETT+.
PR	149	FISS PROD γ	EXPT PROG			22	SWR	ALEKLETT+.
AU	197	(n,γ)	EXPT PROG	1.0+6	1.0+7	11	LND	ANDERSSON+. ACT. TECHNIQUE
PB	206	DIFF ELASTIC	EXPT PROG	1.0+6	1.0+7	26	SWR	OLSSON+. TOF 15° TO 160°
PB	208	(n,γ)	EXPT PROG	5.7+6	7.7+6	37	TLU	LINDHOLM. ANG. DISTR.
BI	209	DIFF ELASTIC	EXPT PROG	1.0+6	1.0+7	27	SWR	OLSSON+. TOF 15° TO 160°
U	235	FISS YIELD	EXPT PROG		THR	22	SWR	ALEKLETT+.
U	235	FISS PROD γ	EXPT PROG	MAXW		28	SWR	JOHANSSON. DELAYED GAMMA
U	235	FISS PROD β	EXPT PROG	MAXW		28	SWR	JOHANSSON. DELAYED BETA
PU	239	FISS PROD γ	EXPT PROG	MAXW		28	SWR	JOHANSSON. DELAYED GAMMA
PU	239	FISS PROD β	EXPT PROG	MAXW		28	SWR	JOHANSSON. DELAYED BETA