KDK-110
NEANDC(OR)-162/U
INDC(SWD)-23/L

PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN SWEDEN FOR 1989

Swedish Nuclear Data Committee
Stockholm, Sweden
January 1990

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PREFACE

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

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

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1 THE SWEDISH NUCLEAR DATA COMMITTEE (KDK)

1.1 STATUS REPORT, JULY 1988-JUNE 1989

The Swedish Nuclear Data Committee has been supported for the present time period by the Swedish Nuclear Power Inspectorate. The members of the committee are listed under 1.2.

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 (ENSDF) and to the NEA Data Bank Joint Evaluated Data File project (JEF). The Committee arranged a meeting on Nuclear Data for Thermal Reactor Calculations which was held at the Department of Neutron Research, Uppsala University on April 12, 1989. International nuclear data activities at IAEA and OECD-NEA referred to national nuclear data groups for considerations have been discussed. Recommendations and support have been given concerning Swedish participation in international nuclear data meetings and participation in coordinated research activities at IAEA and OECD/NEA.

KDK-102 Report from the IAEA Meeting on the International Network of Nuclear Structure and Decay Data Evaluations, 16-20 May 1988, Gent, Belgium (in Swedish)

KDK-103 Report from the International Conference on Nuclear Data for Science and Technology, 30 May-3 June 1988, Mito, Japan (in Swedish)

KDK-104 Report to the Swedish Nuclear Power Inspectorate for the time period 1987-07-01--1988-06-30.

KDK-105 Report from the 27th NEANDC Meeting, 26-30 September 1988, LANL, USA (in Swedish)

KDK-106 PM on the KDK symposium on Nuclear Data for Thermal Reactors, April 12, 1989, Uppsala

KDK-107 Report from the OECD/NEA expert meeting on "Making Extra Gains from the Actinides" 25-26 May 1989, Paris (in Swedish)

KDK-108 Report from the 17th INDC-meeting, IAEA, Vienna, June 26-30, 1989 (in Swedish)

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2 CHALMERS UNIVERSITY OF TECHNOLOGY, S-412 96 GÖTEBORG

2.1 DEPARTMENT OF PHYSICS

2.1.1 Properties of exotic nuclei

S.E. Arnell, M. Cronqvist, B. Jonson, M. Lindroos, S. Mattsson, G. Nyman, H.A. Roth, M. Rydehell, Ö. Skeppstedt, O. Tengblad and K. Wilhelmsen

At the isotope separator on-line facility ISOLDE at CERN the decay properties of nuclei far from beta stability are investigated. Neutron deficient and neutron rich nuclides are produced in proton induced spallation and fission or fragmentation reactions respectively.

Studies of reaction mechanisms and high spin states are performed at Daresbury, Risö and The Svedberg Laboratory.

The first case of beta-delayed deuteron emission[1] has been observed. For ^{6}He the branching ratio was determined to be $(2.8 \pm 0.5)10^{-6}$.

For the neutron rich nucleus ^{9}Li the beta decay to highly excited states has been investigated[2]. Beta transitions to particle unstable, broad states at excitation energies around 11.5 MeV have been studied. The deduced log *ft*-values are found to be comparable to those characteristic of super allowed decays. This effect is also found in other light nuclei.
The quenching of the axial-vector strength[3,4] has been studied for neutron deficient isotopes of Ne and Ar.

A systematic study of the appearance of octupole deformation in nuclear ground states[5,6,7] in the mass region around A=125 is going on.

From measurements of beta spectra of more than hundred fission products the integral $\bar{\nu}$-spectrum[8] from a nuclear reactor has been determined. The average charged to neutral current cross-section ratio for the $(\bar{\nu},d)$-reaction has been calculated. It is compatible with the experimental value and thus no statistically significant evidence for neutrino oscillations is present.

The ion beams at The Svedberg Laboratory are used to investigate the competition between preequilibrium and complete fusion reactions. The emphasis has been put on the study of properties of the neutron emmission spectra. In $^{124}Sn(\alpha,xn)$ reactions at 50 and 75 MeV, the spectra at all angles could be successfully parametrized with a common set of parameters in a two-source moving source model. Inclusive and exlusive (gated with γ-rays characteristic for a specific xn channel) neutron spectra were found to be well in agreement with predictions from a preequilibrium model, the INDEX model /J.Ernst et al., Z. Phys. A281, 129 (1977) and Z. Phys. A328, 333 (1987)/.

In beam studies of the structure of nuclei far from β-stability are performed at the NORDBALL facility located at Risö, Denmark. The CTH-group has built up a "2 π neutron wall" consisting of 16 liquid scintillator detectors. The neutron wall, combined with a $\approx 4\pi$ detector system for charged particles and the highly efficient BGO-shielded Ge-detector array at NORDBALL, gives excellent opportunities to select low cross section reaction channels for γ-spectroscopy studies of exotic

nuclei. The neutron wall facility at Risoe was used for the first time in September 1989 in an experiment with 114 MeV ^{28}Si on ^{58}Ni producing residual nuclei in the mass 80-85 region. The planned experiments will primarily be devoted to studies of nuclei in this mass region. During the building-up phase of the NORDBALL facility similar studies[9,10,11] have been performed at the Daresbury recoil separator facility in collaboration with a Manchester group. Here the structure of several quasi-rotational bands in the three odd-A nuclei ^{75}Kr, ^{79}Sr and ^{79}Rb has been followed through excitation energy regions where effects of quasi-particle alignments appear.

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A.A.Chishti, W.Gelletly, C.J.Lister, B.J.Varley, D.J.G.Love and Ö.Skeppstedt.
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11. **High spin structure of ^{79}Rb.**
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3 LUND UNIVERSITY AND LUND INSTITUTE OF TECHNOLOGY

3.1 DEPARTMENT OF PHYSICS, SÖLVEGATAN 14, S-223 62 LUND

3.1.1 Applied nuclear physics at the Pelletron Acceleration Laboratory in Lund

R. Hellborg

At the University of Lund we have set up an accelerator laboratory for research in various fields of applied and basic physics. A 3UDH tandem Pelletron has been in intense use for more than 14 years. A 3UH single-stage Pelletron is at the moment under installation. The tandem accelerator has been considerably redesigned during recent years to satisfy the requirements of the experimental program [1-5]. This program consists of materials analysis with methods such as PIXE and RBS [6], beam-foil spectroscopy [7], accelerator mass spectroscopy, the study of indoor radon levels [8] and the production of short-lived isotopes for medical purposes [9]. In this report part of the experimental program is briefly presented.

The most far-reaching scientific program is the development of various methods of ion beam analysis. PIXE (Particle Induced X-ray Emission) has been extensively developed at our department for many years. In combination with other ion beam techniques, e.g. RBS, ESA, PIGE etc., it is used for applications in varoius fields of research. The most important fields are environmental sciences including atmospheric pollution, medicine, geology and biology. As a further development of ion beam analysis, a scanning nuclear microprobe has been developed. It allows elemental analysis and elemental mapping at μm

resolution. In connection with this development, a dedicated single-ended Pelletron accelerator (3MV) has been purchased and is under installation in a separate laboratory area.
Another practical application of nuclear physics is the study of the distribution of activation products around some Swedish nuclear power plants. Samples of sewage sludge, fucus and needles from coniferous trees have been used as indicators. Also direct measurements on the plume from a reactor have been made with a Ge-detector.

The determination of the activity concentration of ^{238}U in various samples has initiated a re-evaluation of the intensity of the 1001 keV gamma-ray in the decay of ^{234}Pa.

The identification of the release of ^{14}C from nuclear power plants and its enrichment in living organisms as a problem of the future has been one of the main reasons for providing the Pelletron accelerator with an AMS (Atomic Mass Spectroscopy) facility. This will also be used for the dating of old artifacts.

The problem of high indoor radon levels is being studied at the institute. Radon detectors for indoor use and for use in the soil have been developed. The detectors are tested at the Pelletron accelerator. The radon problem is being studied in some research projects in cooperation with local health authorities, the Geological Survey of Sweden and the Department of Occupational Medicine, Lund.

^{18}F isotopes are produced by the Pelletron for PET purposes (Positron Emission Tomography). The $^{18}O(p,n)^{18}F$ reaction is used at a proton energy of 6-6.5 MeV. As a target water of 90% enriched $H_2{}^{18}O$ is used. The activity obtained after one hour

irradiation with a beam current of 1.5-2 μA is 10-15 mCi. The produced ^{18}F has been used in the synthesis of 2-^{18}F-FDG. Experiments with rats have been performed on several occasions and on one occasion a patient was treated.

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3.1.2 Nuclear structure and decay data evaluation

L P Ekström and J Lyttkens

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

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

The Lund group has been assigned responsibility for the mass range 59-64. Work on A=90 (which is a temporary assignment) is currently in progress.

3.1.2.1 The Nuclear Structure Reference on-line data base

M Bergström and L P Ekström

A program to retrieve nuclear structure references from the NSR file (part of which is resident on disk on a VAX8200 computer (GARBO)) has been written. References can be selected with a large number of criteria on, e.g., title, authors,

keywords and nucleus/reaction selectors. The retrieve facility can be reached from any computer connected to the SUNET/NORDUNDET data communication network.

The Nuclear Structure Reference (NSR) file is maintained by NNDC at Brookhaven. The file contains references from all major international journals (primary references) and many internal reports, conference abstracts etc. (secondary references). The purpose of NSR is twofold: (i) to provide input for the preparation of the Nuclear Data Sheets, Recent References journal and (ii) to be used for literature searches. The full file contains references from the beginning of the century. From the beginning only references containing nuclear structure data were entered, but more recently the scope has been expanded to include e.g. reaction data, intermediate energy and theoretical papers. This makes the NSR a very complete data base for all nuclear physics references.

We receive updates of the NSR three times per year. These are entered in the local data base resident on disk on GARBO. We have limited the local base to primary references from 1975 and secondary references from the last 3 years.

Advantages in using the base rather than the Nuclear Data Sheet, Recent References journal:

1) The base is more up-to-date than the journal (by as much as half a year)
2) It is possible to search on e.g. subject or author
3) In most cases it is quicker than looking through several volumes of the journal.

A more complete description of the system is given in the report "NSR-base - a program package for the on-line retrie-

val of references from the Nuclear Structure Reference file", L.P. Ekström and M. Bergström, Nuclear Physics report LUNFD6/(NFFR-3058/1-27 (1988)

3.1.2.2 The ENSDF radioactivity data base for IBM.PC and computer network access

L.P. Ekström and L. Spanier

A search facility for radioactivity γ-rays has been added as an option to the Nuclear Structure Reference data base (see above). The data base contains more than 73000 γ-rays from 2777 radioactive decays. The data have been automatically retrieved from the latest version of ENSDF.
The anticipated use of the data base is to help in the identification of unknown γ-rays in Ge(Li) detector spectra. If an energy is entered, the program will display the nineteen γ-ray energies that are closest. One can also obtain a listing of energies and intensities of all known γ-rays in a decay.

The search program and the data base are also available in a version for installation on the hard disk of an IBM-PC (640kB RAM, 1.7 MB disk space and DOS version 3.2 or later). The PC version contains all 2777 decays, but is limited to the 10 strongest transitions of any decay (approximately 15000 γ-rays).

The PC version of the data base is available for non-commercial use. Send 6 formatted 360kB floppy disks to LPE (address above) and you will obtain the search program, the data base and installation program free of charge.

A more complete description of the search program and data base is given in the report "The ENSDF Radioactivity Data Base for IBM-PC and Computer Network Access", L.P. Ekström and L. Spanier, Nuclear Physics Report LUNFD6/(NFFR-3059)/1-11 (1989)

3.1.3 The Photonuclear Research Group

B Forkman

3.1.3.1 The Tagging System at MAX

The MAXLAB ring (see 3.2) may be operated as a pulse stretcher. The 1 s long pulse from the injector racetrack microtron is stretched to around 20 ms (at E_e=75 MeV) which with a repetition rate of 50 Hz results in a duty cycle of almost 100 per cent. Under normal running conditions at 75 MeV with an average current of some 50 nA a duty cycle of 80 per cent is typical. The extracted beam is transported to the nuclear physics area and used to produce monoenergetic photons. The tagging spectrometer area is shown in fig. 1.

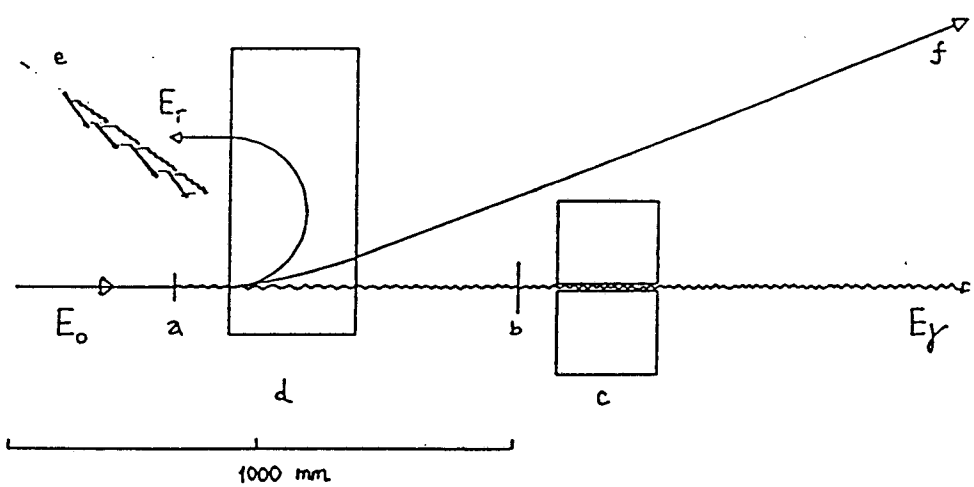

Figure 1. The lay-out around the tagging spectrometer (d). For details see the text.

The radiator (a) is a 50 μm thick Al foil in which the electrons create bremsstrahlung. The photon beam pass from vacuum to air at (b), after which they pass a lead collimator (c). The noninteracting part of the electron beam is bent out of the photon beam by the tagging magnet and dumped in a Faraday cup (f) inside a shielded area. In the photon beam a sample is placed from which nuclear reaction products are studied. A coincidence between the rest electron of energy E_r and a product determines the photon energy (tagg the photon) as $E_\gamma=E_0-E_r$ for the photon reacting in the sample. The energy of the incoming electron beam is denoted E_0. The rest electrons in the tagged range are analysed in the focal plane of the tagging spectrometer (e). The focal plane is equipped with 18 plastic scintillators grouped as 4-5-4-5 (counted from the edge of the magnet). Each group is covered by a backup detector of similar material with which coincidences can be formed either in the form of hardware or as software coincidences.
The number of photons in an energy interval corresponding to the width of a focal plane detector is obtained from the count rate in this detector $N_{r,i}$ and the tagging efficiency,

$$N_{\gamma,i} = N_{r,i} \cdot \varepsilon_{r,i}$$

The quantity $\varepsilon_{r,i}$ is measured with a lead glass detector placed directly in the beam with reduced intensity as the ratio of the number of photons in the detector in coincidence with the given focal plane detector to the singles rate in the latter. In fig. 2 the tagging efficiency measured with 75 MeV electrons is shown for the 18 focal plane detectors (number 1 disconnected). The curves show the efficiencies for 15 and 20 mm diameter collimators (o and Δ respectively) and for the natural opening angle (+ no collimator). With 75 MeV incident electrons, the tagging range is typically from 59.3 to 65.2 MeV, with an energy resolution of about 300 keV.

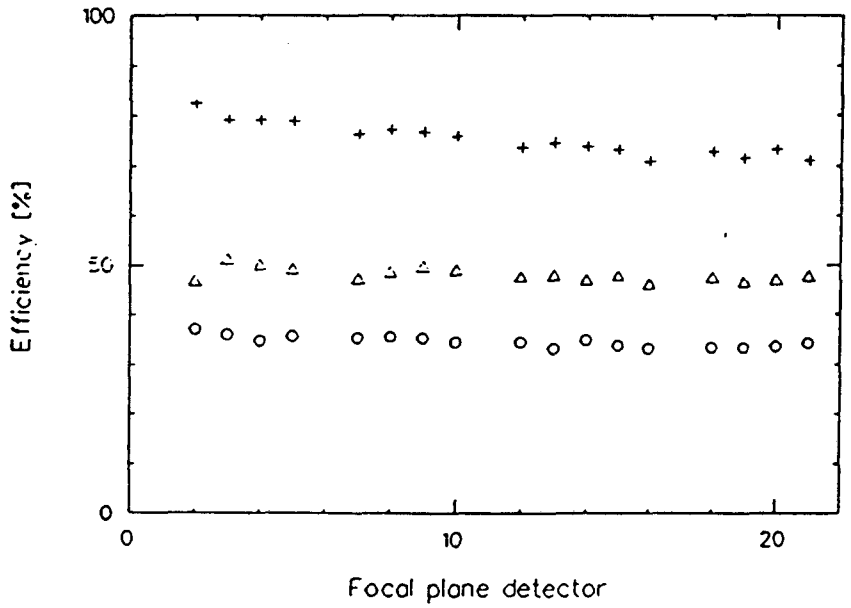

Figure 2. Measured tagging efficiencies for various collimators. The photon energy increases with increasing number of the focal plane detector.

3.1.3.2 Nuclear Physics at MAX

The nuclear physics program at the MAXLAB is based on the possibility to obtain monoenergetic photons. The tagging technique requires an electron beam with a high duty cycle, i.e. a continuous electron beam. This is achieved by stretching the short microtron pulse in the ring with the ring working in the stretcher mode. With monoenergetic photons precise photonuclear research may be performed including coincidence experiments. At present the tagging system at MAXLAB is the only source of monoenergetic photons in Europe. Also in the future the MAXLAB nuclear physics part will be able to contribute in a major way to the nuclear physics research with electromagnetic probes.

The energy region covers photon absorption on the nucleus as a whole (collective giant resonances), on clusters of nucleons and eventually on single nucleons. In particular the experiments aim at providing relevant data for the theoretical models describing the basic interaction of real photons with nuclei in the energy range from 30 to 100 MeV. The next step is then to extract information about quantities like high momentum components in the nuclear wave functions, short range correlations and cluster emissions.

3.2 THE MAX LABORATORY, S-221 00 LUND

B. FORKMAN

3.2.1 MAX I

The MAX accelerator is a combination of a 100 MeV pulsed racetrack microtron and a pulse stretcher ring.

During the last year, the accelerator system has delivered synchrotron radiation and energetic electrons as scheduled.

The accelerator system is now well adjusted for both operating modes. The control system developed takes care of ramping and different machine settings. This means that the accelerator system is running without special operators.

The reliability of the accelerator system is around 95%. Of the scheduled time, 60% of the time is used for synchrotron radiation, 25% for continuous electron beam operation and 15% for maintenance and accelerator physics. The accelerators are operated 24h/day, seven days/week, 48 weeks/year.

3.2.2 MAX II

An advanced synchrotron light source with a compact and cheap magnet lattice has been designed[1]. This ring is proposed as a successor to the present ring MAXI. The design goal is to get high performance regarding spectral distribution, flux and brilliance to a low price.

This has been achieved by using a combined function lattice where vertical focusing take place in the bending magnets and to accept a non-zero dispersion in the straight sections. Although some flexibility regarding the operation of the ring itself has been sacrified in this way, the performance of this ring as an insertion device source is quite similar to other much more complex solutions.

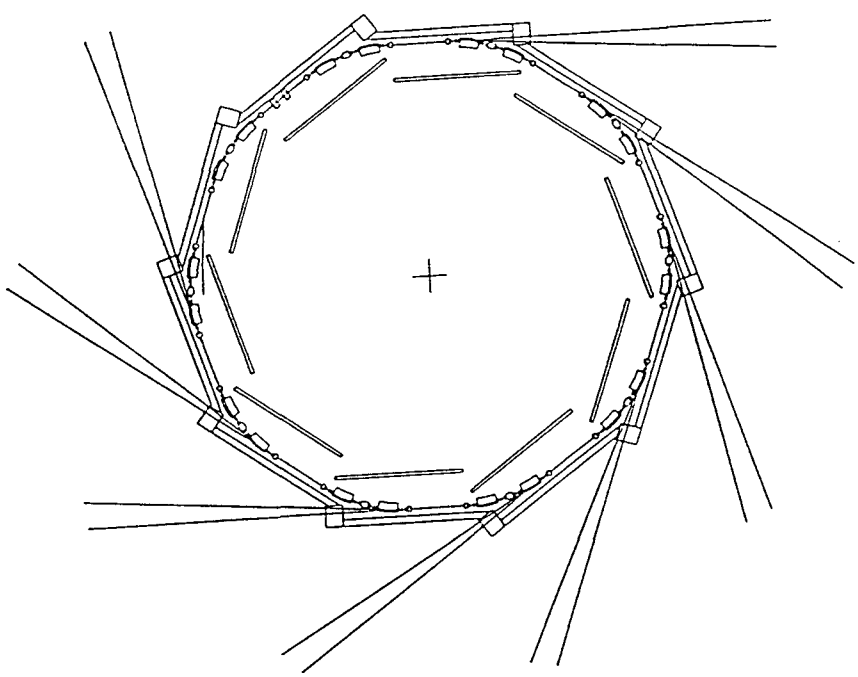

Fig 1. MAXII ring

The ring is seen in fig. 1, and the most important parameter values are given below.

MAXII

Circumference	88.2 m
Max energy	1.5 GeV
Circulating current	200mA
Hor emittance	7 10^{-9}rad m
Number of straight sections	10
Straight section length	3.2 m
Beam life-time	> 10h
Bunch length (RMS)	30 ps

The real flexibility of a machine of this kind is defined by the insertion devices. Multi-pole permanent magnet wigglers increase the flux and brilliance up to two orders of magnitude compared to conventional bending magnet light sources, undulators increase the brilliance with up to four orders of magnitude and the superconducting wiggler being constructed in Tampere will increase the spectral range to the hard X-ray region.

Reference

1. M. Eriksson and L-J Lindgren, MAXII, An Advanced VUV Synchrotron Light Source With a Simple and Compact Magnet Lattice, LUNTDX/(NTMX-7012)/1-19(1989)

4 THE MANNE SIEGBAHN INSTITUTE, FRESCATIVÄGEN 24, S-104 05 STOCKHOLM

A. Nilsson

From the 1st of July, 1988, the institute carries the name the Manne Siegbahn Institute of Physics, in commemoration of Professor Manne Siegbahn, Nobel Laureate, the institute's director 1937-1966 in place of the former name AFI-Research Institute of Atomic Physics.

During 1986 and 1987 the design of CRYRING (see 4.1) was finalized and the funding was secured by grants from the Wallenberg foundation. The CRYRING project will involve a majority of the institute's engineers and physicists for a long time period.

4.1 THE CRYRING PROJECT

The CRYRING project consists of an electron beam ion source CRYSIS, with an isotope separator, INIS, as injector, an RFQ, and a synchrotron and storage ring. In september 1985 the major part of the ring was funded by the Wallenberg foundation. A detailed study of the project and the different technical uncertainties was then initiated. In late 1986 a design of all major parts was proposed. In January 1987 the project was reviewed by an international advisory committee established on demand of the foundation. The review resulted in that a first phase was defined and financed. This phase consisted of CRYSIS with ion injector (INIS), the RFQ, and the synchrotron

and storage ring with electron cooler. The plans for an extracted beam and a second injector were delayed to a second phase. The second injector will be used in the crossed and merged beam experiments. A layout of phase one is shown in Figure 1. After completion of the building programme INIS and CRYSIS were moved to their positions in summer 1988.

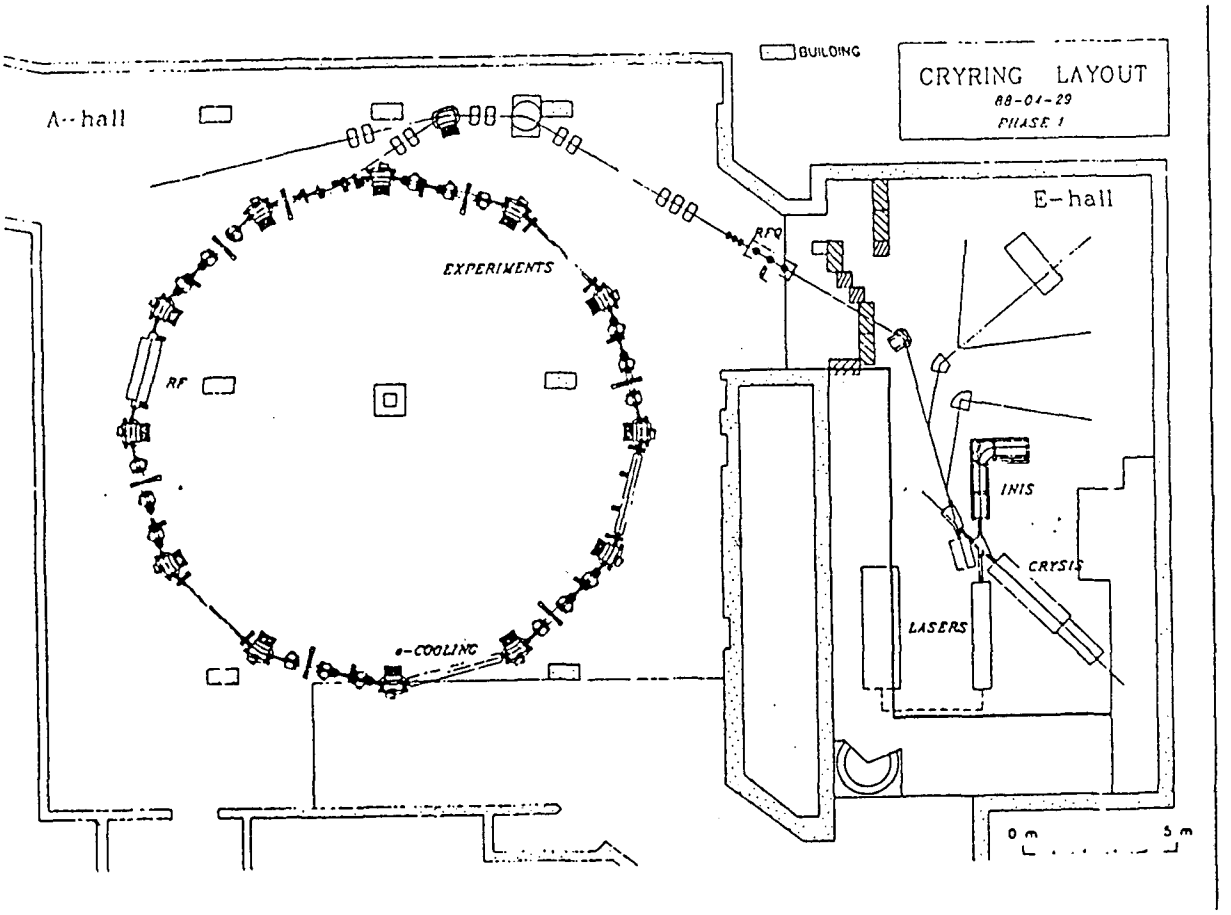

Fig 1. Layout of CRYRING, phase 1

CRYSIS has been operated with gas injection at moderate electron energies (6-10 keV) and currents (40-100 mA). Ions with

charge states up to 18 for Argon and 40 for Xenon have been produced with around $3x10^9$ charges/pulse at pulse frequencies around 1 Hz.

4 keVxq Xenon beams have been delivered to the first generation of atomic physics experiments.

The main limiting factor for the performance of the source is the injection of electrons into the magnetic field. A new improved gun from Orsay has recently been mounted at CRYSIS and the first tests indicate a substantial improvement.

The ion injector has been completed and tested. Injection of isotopically pure ion beams into CRYSIS have been performed.

The RFQ accelerator is built by the Institute of Applied Physics at the University of Frankfurt and the rf amplifier belonging to it is built in cooperation with the Swedish Telecommunication Administration. Both were installed by the autumn of 1989.

The main data of the RFQ are the following:

Type	4 rod, O-mode-$\lambda/2$		aperture	3.0 mm
E_{in}	10	keV/u	f	108.48 MHz
E_{out}	300	keV/u	$V_{RF,max}$	70 kV

The ring has six superperiods, each with two straight sections, one with all beam forming-elements and the other free for other equipment, injection, acceleration, cooling, diagnostics, extraction and experiments. In the studies it was found that resonant excitation of the magnets combined with flat top for storage or slow extraction needed development work to be realized. Using existing technique meant a reduc-

tion in repetition rate and significantly increased demands on the main power system. A new high voltage distribution system with harmonic filter will therefore be installed in a new building on top of the storage ring building. The power supplies were in operation in November 1989. The magnet cycle decided on will give a minimum rise time of 150 ms and a flat top of more than 150 ms. The maximum cycling frequency will be 2 Hz. The length of the beam pulse from CRYSIS will be about 60 μs. The acceleration system chosen is of the driven drift-tube type.

The electron cooler is being designed for a maximum electron energy of 20 keV and a solenoidal field of 0.2 T. The low ion energy at injection, 0.3 MeV/u, makes the correction of the orbit very important. To keep this correction at a reasonable level the magnetic fields of the cooler have to follow the energy of the ions. The extraction of the beam is planned to be done with a third order resonance technique. With the fastest ramping this will give approximately 30% duty factor.

The present time plan aims at first injection tests during 1990.

4.2 NUCLEAR PHYSICS, NUCLEAR SPECTROSCOPY AND NUCLEAR MOMENTS

A. NILSSON

4.2.1 General

After the shutdown of the 225-cm cyclotron at the institute in March, 1986, the activities in nuclear spectroscopy and nuclear moments have mainly proceeded along two lines:

i) Nuclear physisists from our institute have increased the collaborations with other laboratories and moved all experimental investigations to external laboratories, especially Daresbury, Stony Brook, Risö, Orsay and Studsvik.
ii) Our institute is also heavily involved in building up new experimental equipments for future investigations. The main effort goes into the NORDBALL project where MSI is responsible for electronics, some detectors (gamma- and particle detectors) as well as programs for data analysis and data taking. Investigations of nuclear momets will mainly take place in Uppsala where a group from MSI has installed pulsing systems on the main beamline as well as a full experimental station for g-factor measurements.

4.2.2 Measurements of nuclear moments in shell model nuclei.

The last experiments at the old 225-cm cyclotron were devoted to studies of high spin structure of medium light Pb nuclei. The results have been reported in a number of recent publications. A summary of new or improved g-factor measurements in $^{198-203}$Pb is given below (table 1).

Table 1

Nucleus	Level	*g*-factor	Nucleus	Level	*g*-factor
^{198}Pb	(8^-)	-0.0471 (8)	^{201}Pb	$29/2^-$	-0.0697 (4)
^{199}Pb	$29/2^-$	-0.0742 (9)	^{201}Pb	$41/2^+$	-0.18 (4)
^{199}Pb	$33/2^+$	-0.145 (9)	^{202}Pb	16^+	-0.042 (10)
^{200}Pb	12^+	-0.1541 (10)	^{202}Pb	19^-	-0.099 (3)
^{200}Pb	19^-	-0.094 (7)	^{203}Pb	$21/2^+$	-0.063 (2)
^{201}Pb	$25/2^-$	-0.063 (3)	^{203}Pb	$25/2^-$	-0.059 (3)

An attempt to measure g(11^-) in ^{194,196}Pb was made together with E.Dafni at the Weizmann Institute at Rehovot. Gamma spectroscopy and g-factor measurements on N=82 nuclei has continued in collaboration with physicists at ZfK, Rossendorf. Work on ^{140}Ce was completed recently. Our interest is now focused on ^{145}Eu. We have also started nuclear moment measurements of isomers in nuclei in the ^{132}Sn region at the on line isotope separator (OSIRIS) at the Swedish research reactor at Studsvik.

At the The Svedberg Laboratory (TSL) in Uppsala we are installing equipment to be used for nuclear moment determinations. Here the focus will be on nuclei in the lead region.

4.2.3 High Spin Structure Studies

In a collaboration project at Oak Ridge with participants from Stockholm, high spin structures have been studied in ^{183,184}Pt and ^{183}Au. Furthermore, at the Tandem accelerator in Daresbury, England, we have taken part in experiments aiming at high spin studies of nuclei around ^{122}Ba, ^{159}Tb, ^{161}Lu, as well as light Os and Pt isotopes. The latter experiments which focussed at nuclei around ^{122}Ba have revealed a lot of new features in this almost unknown region. The level structures of $^{119-123}$Cs and $^{120,122-124}$Ba have been strongly extended, and for the first time also a level structure has been deduced for ^{123}La.

The neutron deficient Hg isotopes in the transitional region between the spherical Pb isotopes and the well deformed rare earth nuclei, are known at low spin to show the coexistence of shapes of well deformed prolate and less deformed oblate structures. In a collaboration with IPN, Orsay, the high spin

level structure of the $^{185,187,188}Hg$ isotopes have been investigated. The experiments have been performed at the Chateau de Cristal detector facility at CRN, Strasbourg.

5. UPPSALA UNIVERSITY

5.1 THE NEUTRON RESEARCH LABORATORY AND THE DEPARTMENT OF NEUTRON RESEARCH, STUDSVIK, S-611 82 NYKÖPING

5.1.1 Neutron physics

5.1.1.1 Cross sections and partial kerma factors for elastic and inelastic neutron scattering from carbon in the energy range 16.5 - 22.0 MeV

N Olsson, B Trostell and E Ramström

In many applications precise knowledge of neutron scattering cross sections for carbon is very important. Below 15 MeV several data sets exist from different laboratories, e g Bruyères-le-Châtel, Triangle Universities Nuclear Laboratory and Lawrence Livermore National Laboratory. Data in the energy range 21 - 26 MeV have been reported from the Ohio University. In order to fill the gap between these two energy regions the Studsvik high resolution, low background time-of-flight facility (1) has been used to obtain a comprehensive set of differential neutron scattering cross sections for carbon at the neutron energies 16.5, 17.6, 18.7, 19.8, 20.9, 21.6 and 22.0 MeV. Angular distributions in the range 10° - 160° have been measured for the 0^+ ground state as well as for the 2^+ (4.44 MeV), 0^+ (7.65 MeV) and the 3^- (9.64 MeV) excited states. Angle-integrated cross sections have been determined by fitting Legendre polynomial expansions to the differential data. Partial kerma factors for elastic and inelastic (4.44 MeV level) scattering have been deduced from these fits.

The results have been treated in terms of a phenomenological spherical optical model. Potential depths and geometrical parameters were determined from fits to the elastic scattering data, while deformation parameters were obtained from inelastic scattering using the distorted-wave Born approximation. Since it can be argued that the carbon nucleus is much too deformed to be treated without taking coupling effects between different reaction channels into consideration, the data were also analysed in the framework of the coupled-channels formalism with a deformed optical model potential. By intercomparing the results of these two approaches, we have concluded to what extent the spherical optical model can be used and if the description of the experimental data is significantly improved by the introduction of the more complicated coupled-channels calculations.

The analyses in terms of the spherical optical model as well as in terms of the coupled-channels formalism have provided information for cross section and partial kerma factor calculations also outside the measured energy range.

The results of this work have recently been published (2, 3).

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1. N Olsson and B Trostell, Nucl Instr Meth A245 (1986) 415
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5.1.1.2 Neutron elastic and inelastic scattering at 21.6 MeV for 16 elements covering the mass range 9 to 209.

N Olsson, E Ramström and B Trostell

The Studsvik high resolution, low background time-of-flight facility described in ref 1 has been used to measure elastic and inelastic scattering from 16 elements ranging from Be to Bi at an energy of 21.6 MeV. A time resolution of better than 1 ns corresponding to an energy resolution of 0.7 MeV at that energy has been used throughout the experiments. The spectra of scattered neutrons were measured in steps of 2.5° or 5° in the angular interval 10° - 160°. For 13 of the elements ranging from Mg to Bi the experimental data for elastic scattering have been published together with the analysis in terms of a standard phenomenological spherical optical model (2). Potential depths and geometrical parameters were determined from individual best fits to the data. Volume integrals of the real and imaginary parts of the potential were calculated using these parameters. A similar technique was utilized to calculate root mean square radii of the real potential. In the same reference microscopic folding models for the optical potential according to Jeukenne, Lejeune and Mahaux, Brieva and Rook and Yamaguchi et al. have been tested by calculating angular distributions, volume integrals and root mean square radii for the real and imaginary potential parts. The results of these calculations are compared with those of the phenomenological analyses.

For the lighter elements Be, N and O the results for elastic scattering have as well been treated in terms of a phenomenological spherical optical model, while inelastic scattering cross sections for ^{14}N and ^{16}O were calculated using the distorted-wave Born approximation. The coupled-channels

formalism for rotational and vibrational nuclei was also used in the analysis of scattering from ^{9}Be and ^{16}O and potential parameters and deformations were derived. A report on this work has been accepted for publication in Nucl Phys (3).

For a few of the even-even nuclei studied, i e ^{24}Mg, ^{28}Si, ^{32}S, ^{40}Ca, ^{52}Cr, ^{56}Fe and ^{58,60} Ni also angular distributions for inelastic scattering from some low-lying strongly excited states have been determined. The results have been analysed in terms of rotational, vibrational or rotation-vibrational models using the coupled-channels formalism. Potential depths and geometrical parameters as well as deformation or deformability parameters have been determined from fits to the measured data. The results of this work will be reported in a paper which is under preparation for submission to Nucl. Phys.

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5.1.2 Nuclear chemistry and nuclear physics

K Aleklett, J Eriksen, B Fogelberg, M Hellström, L Jacobsson, O Johansson, P-I Johansson, G Rudstram, L Siehver and L Spanier

Introduction

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

5.1.2.1 Development of the OSIRIS facility

The installation of a new type of target and ion source system was described in the previous contribution. This system has now been used for a number of investigations of various fission products over the mass range A=74-162. The performance of the system, as regards the production of very short lived nuclear species, is governed by mainly two parameters, namely the ionization efficiency and the delay time for the release of products from the target. These parameters have been investigated carefully as part of the extensive studies of absolute fission yields described later. Both parameters are temperature dependent and also depend on the structure of the target

in terms of U/C ratio, porosity, etc. Studies of different methods for manufacture of targets are in progress.

5.1.2.2 Nuclear spectroscopy and measurements of total decay energies

A) The mass region 74-86

The ß-decay half-lives of $^{74, 75, 76, 78}$Cu have been determined by following the decays of the strongest γ-rays in these decays. The reported results [1] unfortunately contains an erroneous value for the half-life of ^{76}Cu which should read 0.9 ± 0.08 s.

The decays of neutron-rich isotopes of As with mass 83-86 have been studied in collaboration with scientists from Oslo University. Decay scheme information has been obtained for $^{83, 84, 85}$As.

B) The mass region 113-126

The decays of Pd and Ag nuclei in the mass range A=113-117 have been studied both to elucidate the level structure, transition probabilities etc, of the daughter nuclei and to clarify the complex isomeric decay chains for the odd mass numbers. A preliminary account [2] has been given of the structure, including "intruder states", of $^{113, 115}$Ag. Other reports describe [3, 4] the level systematics and transition probabilities of odd-mass Ag and Cd nuclei up to A=123. Measurements of total decay energies for the Pd and Ag nuclei are being evaluated. A spectroscopic study of the decays of heavy even-mass isotopes of Cd has been briefly described in a conference report [5].

C) The region near the closed shells at ^{132}Sn

The half lives of the 4^+, 6^+, and 8^+ levels of ^{132}Sn have been studied in collaboration with scientists from MSI and Rossen dorf. Considerable improvements in accuracy were obtained as compared with previous works.

The decay $^{134}Sn \rightarrow {}^{134}Sb$ has been studied for the first time. Several levels having simple p-n configurations were identified in ^{134}Sb. These measurements also provided information on previously unobserved low spin two-proton levels in ^{134}Te. The results include data on absolute γ-ray intensities for ^{134}Sn and ^{134}Sb.

The decay of ^{135}Sb has been studied in collaboration with scientists from the Oslo university. The results regarding the excited states of ^{135}Sb have been published [6, 7]. An analysis of the total decay energy is in progress. A special, precise determination of total decay energies in an other measurement was used to extract the lowest lying proton hole energies of ^{131}In, [8].

D) The Lanthanide region

An experimental program to characterize the decays of fission product nuclei with $A \geq 150$ has been initiated during the last year. Rather comprehensive data on γ-ray decay properties, transition multipolarities and total decay energies have been obtained for ^{156}Pm and ^{159}Sm.

5.1.2.3 Measurements of fission yields

The experimental study of yields in the thermal-neutron induced fission of ^{235}U has now been completed. Briefly, the activity of a fission product is determined by means of gamma spectroscopy and neutron counting of mass-separated samples. After correction for delay, counting efficiency, branching ratio and reactor power the result will be a product of the fission yield and the overall separation efficiency. The latter factor is nearly the same for all isotopes of a given element. Thus relative yields are directly obtainable and have to be normalized against the yield of one of the isotopes determined absolutely by any other technique. The new target and ion source system has had a considerable impact on the fission yield determinations and a rather comprehensive set of measurements had been made for the mass region A=75-158, providing improved data for a large number of short-lived fission products, see refs. [9, 10].

In the case of fast fission of ^{238}U, the Van de Graaff accelerator at Studsvik was used for the experiments which involve irradiation of ^{238}U samples by fast neutrons and subsequent gamma-ray spectroscopy. Fast monoenergetic neutrons (2.3$\pm$0.1 MeV) were obtained by bombardment of a tritium target with protons.

Cumulative fission yields have so far been measured for 44 nuclides representing 24 mass chains in the mass regions 89-105 and 129-151. The next phase of the experiment will consist of the determination of independent yields using the OSIRIS isotope separator.

5.1.2.4 The antineutrino spectrum at a nuclear reactor

The aim of this investigation is to provide an experimental basis for the evaluation of the high-energy part of the antineutrino spectrum. The procedure is to choose those fission products which give the largest contributions to the antineutrino spectra in the range above 5 MeV for a measurement of the continuous beta spectrum from as low energy as possible up to the end-point. The beta spectra are then converted to antineutrino spectra.

The technique is to measure an isotope separated sample with a telescope consisting of a thin plastic detector and a planar HPGe detector. The beta spectrum is recorded when the telescope components are in coincidence mode and the gamma spectrum when they are in anticoincidence mode. Peaks in the gamma spectrum are used to evaluate the sample composition at any time.

The first experimental phase of this project has been carried out at the isotope-separator-on-line facility ISOLDE at CERN. The second phase has been carried out at OSIRIS using the conventional plasma ion-source and the third phase using the new high-temperature ion-source. As a byproduct of the antineutrino project the average beta energy is obtained for individual nuclides. These data are extremely important for evaluation of the decay heat in nuclear fuel, and also useful for a systematic study of the behaviour of the beta strength function far away from stability. A report [11] has been submitted for publication.

5.1.2.5 Delayed neutron branching ratios

An evaluation of the delayed neutron branching ratios have been made to provide updated values for the JEF-II file. The evaluation is also available as a laboratory report [12].

5.1.2.6 Determination of gamma spectra and average gamma energies for fission products

Gamma spectra have been measured for short-lived fission products using a large NaI(Tl)-spectrometer. The samples were produced with the OSIRIS isotope separator. The abundances of the various isobars in the sample were determined by means of gamma peaks recorded with a Ge(Li)-spectrometer. Average gamma energies were deduced from the spectra. The data have been presented at two conferences [13, 14].

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5.2 THE T SVEDBERG LABORATORY, DEPARTMENT OF RADIATION SCIENCES AND DEPARTMENT OF NEUTRON RESEARCH, BOX 535, S-751 21 UPPSALA.

General

The main facilities at the T Svedberg Laboratory (TSL) are the rebuilt 200 MeV Gustaf Werner synchrocyclotron, CELSIUS a storage ring with acceleration and electron cooling capacity and a 12 MeV tandem van de Graaff accelerator.

5.2.1 The Gustaf Werner Cyclotron

A Johansson

The Gustaf Werner synchrocyclotron has been reconstructed from a classical synchrocyclotron with cylindrical poles to a sector focussed cyclotron presently operating in a constant frequency, isochronous mode and in the near future also in a frequency modulated, synchrocyclotron mode.

The cyclotron is initially equipped with an internal ion source of the penning ionization (PIG) type. In the isochronous mode of operation both first and second harmonic acceleration (h=1 and h=2) can be performed using the same source. Five different gases can be remotely selected for the ion source.

Fig 1 shows the range of energies that can be reached for various ions. The presently installed central region is optimized for CW acceleration in the harmonic modes 1 and 2, which means that protons are available in the energy range 12 to 110 MeV and heavy ions between 12 and 200 Q^2/A MeV/nucleon, where Q is the charge and A the mass number of the ion. In the future also the harmonoic modes 3 and 4 will be used and thereby the lowest energy will be reduced to below 3 MeV/A.

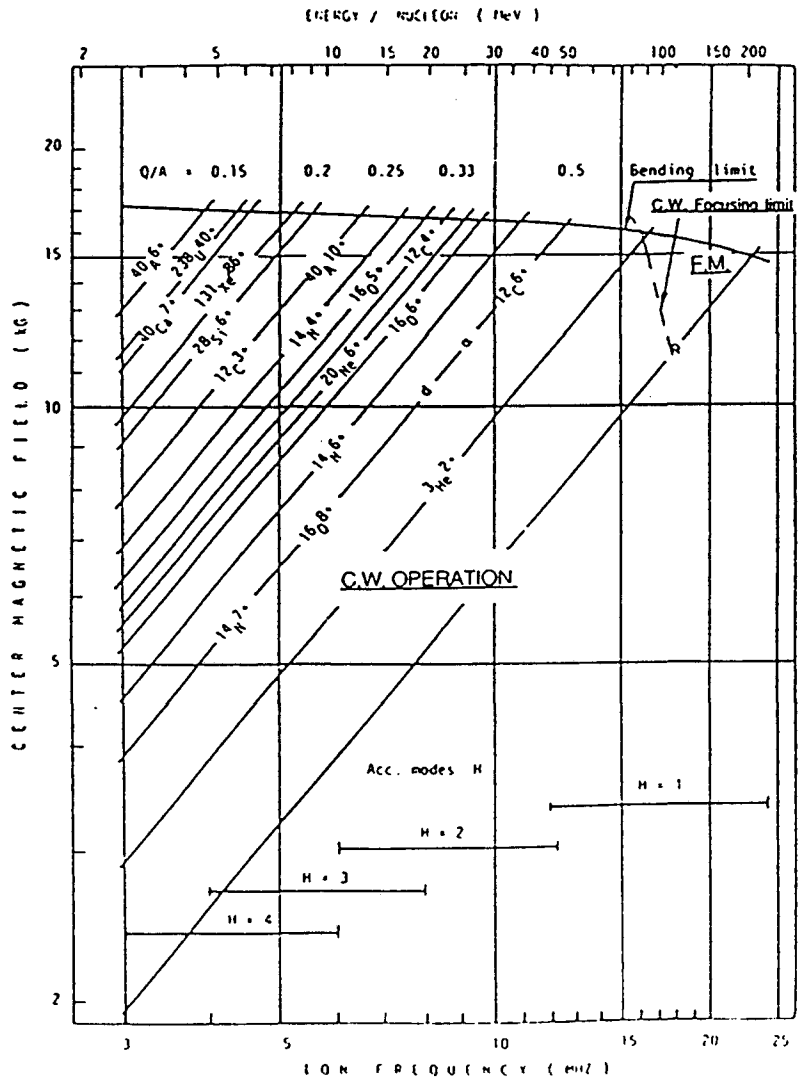

Fig 1. Energy per nucleon, centre magnet fields and ion frequencies for some ions.

An external heavy-ion source of the ECR type is under construction for the cyclotron. The construction of the building for the source was completed by the end of 1988. The injection line is planned to be installed by 1990. The construction of the source has been to the largest part carried out at the Physics Department at the University of Jyväskylä, Finland.

In addition to the existing internal PIG ion source and the external ECR ion source, an external ion source for polarized

protons and deuterons has been funded and is being purchased commercially through the Equipment Board for the Swedish Universities.

The polarized ion source will be based on the atomic-beam method, with state selection accomplished by multipole magnets and rf-transitions. Following ionization and extraction, polarized protons or deuterons of 20 keV maximum energy will be deflected into a beam transport system, common with the ECR ion source, and injected vertically into the central region of the cyclotron.

The ion source is specified to deliver polarized protons and deuterons with an intensity of 50 μA within an emittance of 55 mm mrad $(MeV)^{1/2}$, and with polarizations higher than 75 % of the theoretical values. The delivery and installation of the polarized ions source are expected during 1990.

A neutron physics facility (see 5.2.2) with a light ion spectrometer and an electron-positron pair-spectrometer are in operation at the cyclotron for (n,p)-and (p,γ)-reaction studies, respectively. Futhermore, a high resolution spectrometer for charged particle induced reaction studies is in preparation and also a multiparameter detector system for heavy ion reaction studies.

Work on beams and equipment for biomedical experiments are also in progress as well as on a facility for radionuclide production.

The first clinical cancer treatments have been made using the proton beam.

5.2.2 A Facility for Studies of Neutron Induced Reactions in the 50 - 200 MeV Range

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The upgraded Gustaf Werner cyclotron of the The Svedberg Laboratory, Uppsala, Sweden has been equipped with a facility designed to produce well collimated and energetically well defined neutron beams in the energy region from about 50 to 200 MeV. This arrangement will initially be used in studies of light-particle emission from neutron-induced reactions with the emphasis on the (n,p)-reaction to investigate isovector excitations. To that end a magnetic spectrometer with large angular and momentum acceptances has been constructed. At a later stage, the spectrometer, slightly modified, might be used in studies of (p,n) and (n,n′) reactions. Further developments might include (n,d) and (n,α) reactions and polarized protons and neutrons.

Studies of charged-particle emission from fast-neutron-induced reactions involve several experimental problems. The competing requirements are high signal counting rate, good energy and angular resolution and low background. In addition, the setup should allow particle identification and observation of particles emitted in the zero degree direction.

The Uppsala facility uses the $^{7}Li(p,n)\ ^{7}Be$ reaction in a thin isotopically enriched lithium foil as neutron source. After passage through the lithium foil the proton beam is deflected to a Faraday cup in a well shielded beam dump. A collimator system in the 0° direction produces a well defined neutron beam at the (n,p) sample position. The long flight path allows TOF techniques to be utilized to discriminate against the low-energy tail in the neutron spectrum.

The neutron-induced reactions take place in several thin tagets, sand-wiched between multiwire chambers, introduced to allow identification of the target, in which a particular reaction event occurs. Thus the amount of target material can be increased considerably without any severe deterioration of the energy resolution. Futhermore this arrangement allows cross sections for various nuclides to be measured simultaneously. For example, cross sections can be measured relative to the n-p scattering cross section, which is better known than any (n,p) cross section.

Energies and angles of emitted charged particles are determined by ray-tracing in a constant-field magnetic dipole equipped with two front and two rear multi-wire drift chambers, giving horizontal and vertical position information. Particle identification is performed with two plastic scintil-

lators placed after the rear drift chambers. These scintillators also form part of the trigger for the spectrometer. The intensity of the neutron beam is monitored by n-p scattering in a thin polyethylene foil placed in the multi-target holder. A separate neutron flux monitor, also based on n-p scattering is positioned in the neutron beam after the charged-particle spectrometer. This monitor records the neutron flux independent of the position of the spectrometer. The neutron beam is dumped about 10 m from the spectrometer in a well shielded cave in the wall of the experimental area.

Measurements are in progress of the ^{12}C, $^{54,56}Fe$ and ^{90}Zr (n,p) double differential cross sections at 100 MeV.

5.2.3 CELSIUS

S Kullander, C Ekström, A Johansson, D Reistad and L Westerberg

The CELSIUS ring at the The Svedberg Laboratory, Uppsala, is now being commissioned. The Gustaf Werner cyclotron injects into the ring particles, ranging from protons to krypton ions, which are accelerated and made to interact with a variety of internal targets.

CELSIUS is an acronym for Cooling with ELectrons and Storing of Ions from the Uppsala Synchrocyclotron. The circumference of CELSIUS is 82 metres corresponding to a frequency of 3 MHz at a proton energy of 1.8 GeV. No experimental area except for the area outside the first quadrant for external beam experiments is planned.

In CELSIUS, protons can be accelerated up to a maximum energy of 1.36 GeV. After power-supply upgrading, protons of 1.8 GeV would be available. Both η, ω and η' mesons will be produced and studied at CELSIUS. In the autumn of 1989, the electron cooler will be installed. The present maximum energy for the electrons is 300 keV corresponding to 550 MeV protons and 550 MeV per nucleon for heavier ions. For higher proton energies the experiments will be made without cooling at the final energy. For proton-hydrogen interactions, beam life times in this case are expected to be of the order of one minute for a design luminosity of 10^{32} $cm^{-2}s^{-1}$. Since the beam from the synchrocyclotron is pulsed, more than 10^9 protons can probably be injected with multi-turn injection into CELSIUS. With charge exchange (stripping) injection, which is being tested, more intense beams could be stored.

Ion storage rings will be important tools for many types of experiments. In particular, they will open up some new avenues to high-precision physics. It will become possible to use extremely thin targets (10^{-9} g/cm^2) and still have a high luminosity since the coasting particles recirculate through a target typically a few million times per second. Better definition of the beam energy, less background of target non-associated particles and smaller target perturbation on reacting particles are expected features as compared with experiments where an external beam passes once through the target. In cases where more modest resolution is required, the maximum luminosity may be reached with thicker targets and, consequently, shorter beam lifetimes.

The proposed physics programme may be divided schematically into intermediate energy nuclear physics, using both light and heavy ions, and elementary-particle physics in the field of

rare reactions and decays. Fourteen letters of intent and proposals have been submitted to the programme advisory com mittee of The Svedberg Laboratory and so far seven have been approved.

5.2.4 Research at the Tandem Accelerator
G Possnert

During the last years the trend has been to devote more beam-time to applied and basic research outside nuclear physics. Thus 1989 almost 100 % of the effective beamtime was used for nuclear solid state physics, desorbtion of biomolecules, production of radioactive isotopes for biological and medical applications, accelerator mass spectroscopy, studies of hydrogen profiles of metal hydrides, RBS-analysis and student laboratory exercises.

5.2.5 A spallation neutron source for neutron capture therapy with epithermal neutrons

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The aim of the present joint Swedish-Swiss project is to construct an accelerator-based intermediate energy neutron source that would permit irradiation of neoplasms in the central nervous system by an intermediate energy neutron fluence rate of at least $10^9 ncm^{-2}s^{-1}$. The accelerator should be of a moderate size to permit accomodation in a hospital environment. Therefore the rather low proton energy of 72 MeV was chosen.

The clinical interests beyond this collaboration are primarily focused on the treatment of vascular malformations in the central nervous system. In a longer perspective, the treatment of malignant brain tumours is given priority over other malignancies considered, such as melanomas and colorectal carcinomas.

The work on the project has so far been devoted to studies of different moderator materials and configurations useful for combination with neutron production by 72 MeV protons stopped in heavy materials. The aim is to optimize the performance of a neutron source for NCT. The required characteristics are firstly that the bulk of the neutrons should have an energy between 1 and 100 keV, and secondly that the useful intensity of thermal neutrons should be at least $10^{12} ncm^{-2}h^{-1}$.

Iron and graphite moderator option was studied experimentally at the 72 MeV injector I cyclotron at PSI. The neutrons were produced by stopping the 72 MeV protons in a tungsten block. The moderator consisted of an iron block, approximately 50 cm by 60 cm by 60 cm. On one side it was covered with 13 cm of graphite.

The neutron field in two plastic phantoms (20 cm by 20 cm by 20 cm) was probed with different foil detectors: gold activation with and without Cd-shielding to measure the thermal neutron flux, and by plastic proton recoil track detectors to measure neutrons with energies above about 150 keV.

The results from the gold activation foils were compared with Monte Carlo calculated values. A fair agreement was obtained.

Further neutron transport calculations by the code MCNP were made for spherical iron moderators of three diameters: 50 cm, 100 cm and 150 cm covered with 15 cm of graphite. Both the iron and the carbon contained one percent boron-10 to suppress the thermal neutron flux at the phantom surface.

It was seen that useful intensities of thermal neutrons can be obtained in the depth of the phantom at proton currents of less than 0.5 mA and that the fast neutron contribution is small if the iron moderator is thick enough. It is also clear that the useful depth is increasing with moderator thickness. Work is in progress on designing a spallation neutron source for preclinical tests.

CINDA index

S	A	Quantity	Type	Energy min	Energy max	KDK-110 page	Lab	Comments
BE		Diff elastic	Expt prog	2.2+7		32	SWR	Olsson+
BE		Diff inelastic	-"-	2.2+7		32	-"-	-"-
C		Diff elastic	-"-	1.7+7	2.2+7	30	-"-	-"-
C		Diff inelastic	-"-	1.7+7	2.2+7	30	-"-	-"-
C	12	(n,p)	-"-	1.0+8		45	TSL	Condé+
N		Diff elastic	-"-	2.2+7		32	SWR	Olsson+
N		Diff inelastic	-"-	2.2+7		32	-"-	-"-
O		Diff elastic	-"-	2.2+7		32	-"-	-"-
O		Diff inelastic	-"-	2.2+7		32	-"-	-"-
MG		Diff elastic	-"-	2.2+7		32	-"-	-"-
MG		Diff inelastic	-"-	2.2+7		32	-"-	-"-
AL		Diff elastic	-"-	2.2+7		32	-"-	-"-
SI		Diff elastic	-"-	2.2+7		32	-"-	-"-
SI		Diff inelastic	-"-	2.2+7		32	-"-	-"-
S		Diff elastic	-"-	2.2+7		32	-"-	-"-
S		Diff inelastic	-"-	2.2+7		32	-"-	-"-
CA		Diff elastic	-"-	2.2+7		32	-"-	-"-
CA		Diff inelastic	-"-	2.2+7		32	-"-	-"-
CR		Diff elastic	-"-	2.2+7		32	-"-	-"-
CR		Diff inelastic	-"-	2.2+7		32	-"-	-"-
FE		Diff elastic	-"-	2.2+7		32	-"-	-"-
FE		Diff inelastic	-"-	2.2+7		32	-"-	-"-
FE	54	(n,p)	-"-	1.0+8		45	TSL	Condé+
FE	56	(n,p)	-"-	1.0+8		45	TSL	Condé+
CO		Diff elastic	-"-	2.2+7		32	SWR	Olsson+
NI		Diff elastic	-"-	2.2+7		32	-"-	-"-
NI		Diff inelastic	-"-	2.2+7		32	-"-	-"-
Y		Diff elastic	-"-	2.2+7		32	-"-	-"-
ZR	90	(n,p)	-"-	1.0+8		45	TSL	Condé+
PB		Diff elastic	-"-	2.2+7		32	SWR	Olsson+
BI		Diff elastic	-"-	2.2+7		32	-"-	-"-

S	A	Quantity	Type	Energy min	Energy max	KDK-110 page	Lab	Comments
U	235	Fiss prod β	Expt prog	Maxwl		35	SWR	Aleklett+
U	235	Fiss prod γ	-"-	Maxwl		35	-"-	-"-
U	235	Fiss yield	-"-	Maxwl		37	-"-	-"-
U	238	Fiss yield	-"-	2.3+6		37	-"-	-"-