NUCLEAR PHYSICS GROUP

ANNUAL REPORT

January 1 - December 31, 1984

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1 INTRODUCTION

The experimental activities of the nuclear physics group have in 1983 as in the previous years mainly been centered around the cyclotron laboratory with the SCANDITRONIX MC-35 cyclotron. During the year the accelerator has been in extensive use for low-energy nuclear physics experiments. In addition it has been used for production of radionuclides for nuclear medicine, and for some experiments in atomic physics and in nuclear chemistry.

Most of the nuclear physics experiments have been related to the study of nuclear structure at high temperature. Experiments with the ^3He beam up to a particle energy of 45 MeV have given some interesting results which, it is hoped, will contribute to a better understanding of the cooling process in highly excited nuclei. This field of research seems to be well adapted both to the performance of the accelerator itself and to the peripheral instrumentation, including the on-line computer system. Theoretical studies have continued in the same field, and there has been a fruitful and inspiring cooperation between experimental and theoretical physicists.

The NORD-10 computer and the connected data acquisition system represents a vital part of the experimental equipment and is in extensive use for data accumulation and handling. The lack of computer capacity stresses, however, the urgent need for a new computer.

With the small experimental group attached to the cyclotron laboratory an extensive use of the equipment is difficult. Close cooperation with experimental physicists from other universities and regular visits from them, especially from the University of Bergen and the University of Jyväskylä and Helsinki, has made it possible to maintain a high activity in the laboratory. Periodically experiments have been going on continuously for days, also during nights and weekends. It has, however, also been necessary to admit longer pauses in the cyclotron running schedule, in order to get suffcient time for analyzes of the experimental data and also to make the computer available for such analyzes. Simultaneous there has been left time open for maintenance of the cyclotron.

Most of the experiments are performed as joint projects where physicists from two or three Nordic Universities take part. Some of the experiments have been supplements to or extensions of experiments performed at other Nordic laboratories, but most of them have their own merits. Occasionally the cyclotron has been disposed for experiments in nuclear chemistry for scientists from the University of Oslo and Bergen. It has also been used for a study of double ionization of helium atoms in collision with 21 MeV protons by a research group from The Institute of Physics, University of Aarhus and The Research Institute of Physics, Stockholm.

After five years of operation the cyclotron is still the newest nuclear accelerator in Scandinavia. The available beam energies (protons and alpha-particles to 35 MeV and ^{3}He-particles up to 48 MeV) make it an excellent tool for studies of highly excited low-spin states, and also for other experiments with light ions in an intermediate energy range.

To ensure the diversity of the work it has, however, also been necessary to continue our activities in some laboratories which have accelerators and instrumentation suitable for study of other problems. Thus we have maintained contact with the Niels Bohr Tandem Accelerator Laboratory at Risö and have also taken part in experiments at the Hahn-Meitner Institute in Berlin and at the Daresbury Laboratory in Cheshire, U.K. In particular we are involved with the NORD-BALL project, which consists of a complex detector arrangement build up by contributions from the part-taking Nordic laboratories. The outfit will mainly be used for experiments at the Niels Bohr Institute, but may also occasionally be moved to other laboratories.

As a part of the program for the application of the cyclotron in other fields, regular production of $^{81}Rb^{m}$-generators has continued during most of the year. However, at the end of the year the production had to be stopped due to lack of technical assistance in the laboratory.

Some of the members of the nuclear physics group have continued their participation in solar energy research. The study of solar heating system for small houses has continued. Considerable effort has been put into attempts to simplify the heat storage and distribution systems. In that connection simulating and analyzing programs for heating systems in various types of houses are developed. A close and fruitful cooperation on problems and instrumentation related to handling of data in solar energy studies and in nuclear physics experiments is established.

One of the group members has in cooperation with the State Institute of Radiation Hygiene and the University Health-Physics Service continued studies in radiation dosimetry by thermoluminescent detectors, and has also taken part in a study of resperative heat loss by divers. Although not connected to nuclear physics, the latter activity - like the solar energy project - demonstrates the near connection between various branches of physics and the value of transferring knowledge and experience from one branch of physics to another.

The value of the cyclotron laboratory for educational purposes has again been demonstrated by the activity of the students in the laboratory and also by the fact that the educated students appear to be well adapted for work in various branches of technological research.

Of eight students in progress with their graduate work at the end of 1984 five are studying nuclear instrumentation and measuring techniques, two are working in experimental and one in theoretical nuclear physics. Two Dr.Scient. students works in the field of experimental nuclear physics. In 1984 six students associated to the group completed their Cand.Scient. studies - one in experimental and two in theoretical nuclear physics, one in dosimetry, one in electronics and one in nuclear chemistry. The cyclotron and the adjoined instrumentation obviously appear as atracting features for new students at the institute.

The development sketched above would not have been possible without the continued support from the Norwegian Research Council for Science and Humanities (NAVF). Our activity at other laboratories has been funded by the Nordic Committee for Accelerator-Based Research (NOAC). Indeed, the NOAC-fund, although relatively small, has made the collective use of the various resources available in Scandinavian accelerator laboratories more efficient. Further, we are grateful to the Nordic Institute of Theoretical Atomic Physics (NORDITA) for support in terms of travel grants to guest lecturers visiting Oslo and to members of the group visiting Copenhagen. The work in solar energy research has been made possible by support from the Royal Norwegian Council for Scientific and Industrial Research (NTNF).

In 1984 the activity of Norwegian research groups in nuclear physics and chemistry, has been evaluated by an international panel appointed by the Council for Natural Science Research (RNF), a division of NAVF. In the evaluation report, submitted to RNF in november 1984, the nuclear physics group in Oslo is described as one having "an excellent standing of international comparison". The report stresses, however, the need for an increase in the research staff as well as in the technical staff. It also says that the present annual allowances for instrumentation is definitely substandard in view of the research program of the group and the accelerator available. The nuclear physics group express their thanks to the members of the evaluation panel for the interest they showed in our work when they visited our laboratory, and for the understanding they have shown for our research work and the problems we are facing. It is hoped that the evaluation will have positive impact on our research activity in the coming years.

On the personnel side we would like to thank our technical personnel E.A. Olsen and A. Kunszenti for their untiring and persistent efforts to keep the cyclotron and other equipment in operation. Further, the invaluable work of G. Midttun, B. Skaali and J. Wikne on the computer and data acquisition system is highly appreciated.

The participation of physicists from Bergen and from other Scandinavian laboratories has served as a most valuable increase of manpower at the cyclotron laboratory and has helped us to exploit the capacity of the machine far beyond the ability of our own small group. We hereby thank our colleages for their enthusiastic collaboration and for their patience and polite tolerance during all the problems which unavoidably arise with large installations.

Blindern, April 1985

Trygve Holtebekk
Leader of Nuclear Physics Group

2 PERSONNEL

2.1 Research Staff

Olav Aspelund (Government scholarship holder)
Ayse Atac (from Aug. 1)
Torgeir Engeland
Ivar Espe
Ole Kristoffer Gjøtterud
Magne Guttormsen (NAVF)*
Trygve Holtebekk (Group Leader)
Finn Ingebretsen
Svein Messelt
Mari Mehlen
Eivind Osnes
Tore Ramsøy
John Rekstad
Jon Skjæret (NTNF)**
Anders Storruste
Roald Tangen (Prof. emer.)
Per Olav Tjøm

2.2 Technical Staff

Eivind Atle Olsen
Agnes Kunszenti

2.3 Cooperators, Electronics Group Research Staff

Gisle Midttun
Bernhard Skaali
Jon Wikne

2.4 Visiting Scientists

None

2.5 Students

As of December 31, 1984, 8 graduate students (for the degree of Cand. Scient.) and 2 doctoral student (for the degree of Dr.Scient.) were associated with the group. One IAESTE summer student worked with the group in Aug./Sept.

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* NAVF: Norwegian Research Council for Science and Humanities

** NTNF: Royal Norwegian Council for Scientific and Industrial Research

3 THE CYCLOTRON

3.1 Operation and Maintenance

T. Holtebekk, S. Messelt and E. A. Olsen

The use of the cyclotron is based on a 5-day weekly operation schedule with optional night runs and week-end runs when required. Maintenance, work on new installations, developments and experimental setups are usually performed during ordinary working hours. During the year the cyclotron has been in operation 105 days with a total ion source running time of 1220 hours.

The beam has mainly been used for experiments in nuclear physics. As an average the daily running time for these experiments has been about 16 hours. In addition 28 runs on experiments related to radionuclide production, totalling 30 hours ion source running, 3 runs for atomic physics testing (36 hours) and 1 run for nuclear chemistry (3 hours) have been made.

There has been only four shorter stop periods adding to ten days, due to failures in the cyclotron equipment. Due to the lack of computer capacity and also due to lack of scientific personnel, the cyclotron has periodically not been in use. In such periodes it has been possible for the engineers to check the equipment and to keep tbe machine in a good state.

The activity in the laboratory in 1984 is distributed in the various fields as follows:

	Days	%
Nuclear physics experiments	73	46
Radionuclide production	28	2
Atomic physics	3	2
Nuclear chemistry	1	3
Unscheduled maintenance	9	3
Routine maintenance, cyclotron	50	17
Equipment maintenance*	70	23
Experimental setup, equipment tests	20	7

*Computer in use for data analyzis.

3.2 Pulse Selection System

S. Messelt

A fast external pulse selection system has been installed and tested with 13 MeV and 23 MeV protons. The deflector plates, 5 cm wide and 90 cm long separated by 3 cm, are placed inside a 20 cm i.d. beam tube between the entrance (object) slits and the 90° double focusing analyzing magnet. The vertical exit (image) slit of the magnet is used to stop the deflected beam pulses. If the vertical beam width at the object slit is D and the exit slit is set to this value, the minimum delecting voltage V_{min} to stop the beam is

$$V_{min}(kV) = \frac{1}{15} \frac{E(MeV)}{q} D(mm)$$

where q is the charge number of the beam particle.

The beam from the cyclotron is focused on the object slit by a quadrupole doublet, and for most energies and particle beams the vertical beam width is less than 5 mm with 4 mrad divergence at the object slit.

The deflection system is similar to the University of Colorado installation[1]. The deflector plates form the capacitive element in a resonant LC circuit which is driven at some integer fraction of the cyclotron frequency (fig. 3.1). The two deflector plates are diode-clamped together, with the

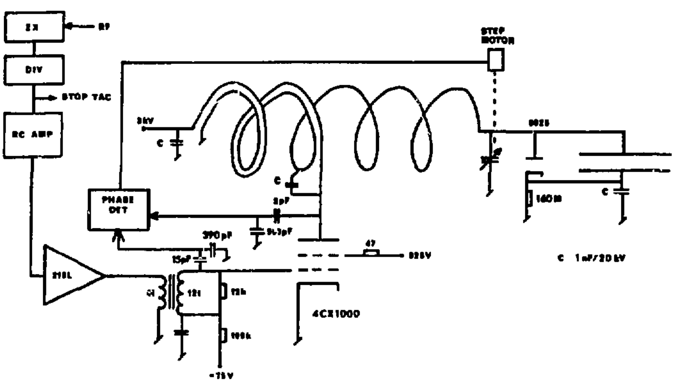

Fig. 3.1 Beam deflector system

RF grounded plate free to float to a DC voltage equal to the peak RF voltage. With this system the beam pulses will pass undeflected when the potential difference V between the plates, and also dV/dt, are zero. Precise phase control of the deflector plate RF relative to the transmitted beam burst is therefore not required, since a slight phase shift only causes a second order effect in the transmitted beam direction.

The inductor, which can be easily replaced, can be tuned from 4.5 MHz to 5.8 MHz, corresponding to 222 ns to 172 ns between beam bursts. With a frequency division of 3 or 4 this covers almost all particle beams and energies for our cyclotron as shown in table 1.

Table 1. Energy ranges in MeV for inductor 1
Time separation 222 ns to 172 ns

Freq. ratio	1 : 3	1 : 4
E(p)	10 - 16.5	18 - 30
E(d)	5 - 8.25	9 - 14.5
E(^{3}He) N=2	7.5 - 12	13 - 22
N=1	30 - >47	
E(^{4}He)	10 - 16	17.5 - 29.5

The pulse selection system has been tested by measuring gamma-rays from a thick target in one of the beam lines down-stream from the exit slit of the 90° magnet. The gamma-rays were detected with a NE 102 scintillator mounted on a 56 AVP photomultiplier tube. The fast anode-pulses were sent to a zero cross-over discriminator and used as start-pulses for the TAC. Pulses from the 11. dynode were used as gating pulses, the threshold corresponding to approximately 1 MeV.

The results of a test with 23 MeV protons (20.35 MHz) and a division factor of 4 are shown in fig. 3.2. The lower part of the figure shows the time-spectrum without any deflector voltage. With a low value of the deflector voltage the phase of the voltage is adjusted to make the two peaks correponding to the beam pulses just before and just after the beam pulse to be selected, decrease by the same amount (spectrum 2, fig. 3.2).

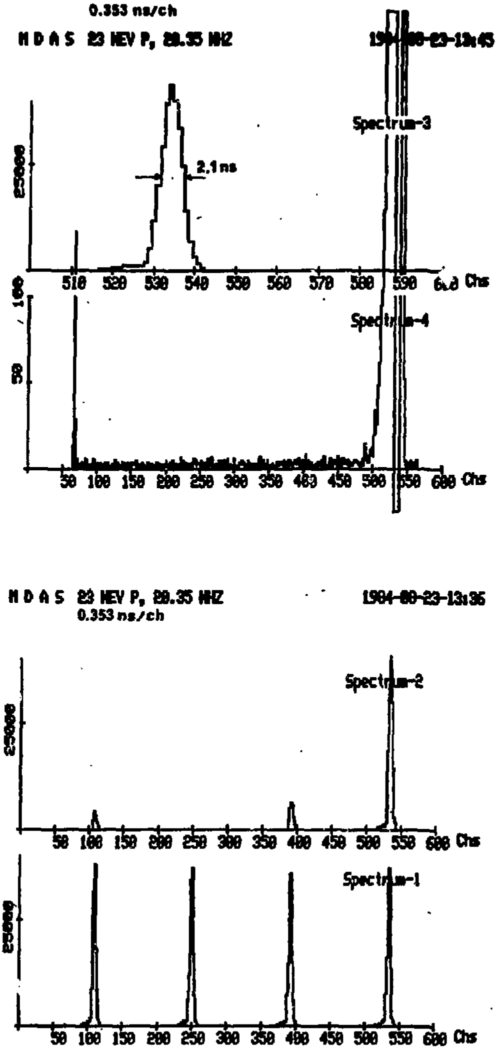

Fig. 3.2 Time spectra of the cyclotron beam with frequency ratio equal to 4. Spectrum 1 was obtained without any deflector voltage, spectrum 2 and spectrum 4 with a deflector voltage amplitude of 1 kV and 4 kV.

The deflector voltage is then increased until no trace of the two peaks is seen, as shown in spectrum 4. This spectrum was obtained with a deflector amplitude of 4 kV. The main contribution to the measured width (FWHM) 2.1 ns is the width of the beam pulse.

More details about the pulse selection system are given in a separate report[2].

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1) H.H. Wieman and L.A. Erb, Nucl. Instr. and Meth. 142 (1977) 573.

2) S. Messelt, Report 84-23, Institute of Physics, University of Oslo.

4 DATA ACQUISITION SYSTEM

4.1 Computer and Data Acquisition Hardware

4.1.1 Computer and Data Acquisition Configuration

The data acquisition system is based on a minicomputer with the CAMAC interface standard. The configuration is:

NORD-10.S computer with:
SINTRAN III operating system
448 Kb memory
2 10 Mb disk drives
1 floppy disk drive, single side/density
2 MT units, 75 IPS, 800/1600 BPI
1 CALCOMP plotter
1 Texas Instruments Omni-800 printer
2 interactive work stations, each with:
a) "DICO" video colour display, 8 colours, 384 lines each with 288 pixels, display controller and video memory in CAMAC. Another CAMAC module is used for cursor generation and colour transposition from 8 to 4096 possible colours.
b) CRT terminal
1 Tektronix 4612 video hard copy unit
1 NORDNET to ND-500 computer, 2400 baud
6 terminals
3 CAMAC crates
11 ADCs interfaced via CAMAC, controlled in multiparameter mode by an ADC scanner module.

4.1.2 The NORD-10 Computer

A. Kunszenti, B. Skaali, J. Wikne

The computer configuration has not changed during the year. As usual problems have been encountered with the magnetic tape stations. Otherwise the system has been virtually free from errors.

4.1.3 Data Acquisition Hardware

F. Ingebretsen, A. Kunszenti, G. Midttun, B. Skaali, J. Wikne

The CAMAC system has functioned well during 1984, but problems have been encountered with power supplies in aging CAMAC crates. A new version of the CAMAC ADC Scanner has been installed. Interfaces for more ADC's are currently being built. Planning has also started on a new scanner that can handle more ADC's and related modules in a more flexible way.

4.1.4 Computer Graphics Enhancements

J. Wikne and B. Skaali

Two hardware improvements in the DICO-based graphics system have been made:

1) Inclusion of a colour transposition module, giving a palette of 4096 different colours, 16 at the same.
2) Inclusion of a trackerball/function switch assembly to facilitate a cursor based operator interface to the display system.

These features are interconnected, since the trackerball to CAMAC interface is provided by the transposition module, a CTC-1 from Sension Scientific Ltd.

The trackerball is located in a desktop assembly together with three function switches and a minimum of interface electronics. The function switches communicate with the graphics software through LAMs on the CTC-1.

A NODAL written software module has been included to support the colour select possibilities and provide test facilities for the CTC-1. The cursor and function key features have been integrated into the data acquisition program SHIVA, the color palette has not yet been implemented.

4.1.5 Electronic Equipment Maintenance

J. Wikne, A. Kunszenti and E.A. Olsen

The Cyclotron Laboratory electronics now comprises a large number of instruments, computers and control systems, big and small, new and old, from several different manufacturers as well as "workshop" made. The maintenance, debugging and repair of this equipment has become a formidable task, and increasingly so as much of it, even the service intruments, gets older.

It is amazing to notice how the mean time between failures, MTBF, of both "transient" and "hard" failures of the electronics and software, varies, sometimes within an obvious pattern, sometimes without any recognizeable pattern at all. As for the former, the most important parameters are the age and the manufacturer of the complete systems, or of specific components, and the complexity of the systems.

When equipment does fail, it is also very different how easy the error is to find and correct. Some systems are poorly documented, mechanically cumbersome or difficult to obtain spare parts for. These factors often seem to be correlated with one another, and with a small MTBF. Thus the technical staff currently possesses a great knowledge as to what not to buy in the future.

All the unexplainable temporary malfunctions, mainly in the computer/data acquisition system, prompted an investigation of the laboratory mains supply, which was believed to be responsible fo. at least some of the trouble. Detailed measurements were carried out in May -June 1984 by means of a Dranetz 606-3 mains analyser. The analysis revealed that mains instabilities, especially impulse and surge/sag noise, do in fact represent a problem. Moreover, about 90 % of the noise causing problems for some equipment originates from other equipment within the laboratory. Only 10 % comes from the outside. Although some of the noise can he eliminated by special isolation transformers, the installation of a non-interruptible power supply for the data acquisition system is necessary. Such a power supply will be acquired in 1985.

4.2 Data Acquisition Software

4.2.1 The Data Acquisition Program SHIVA

B. Skaali and student F. Sørensen

SHIVA is the main data acquisition and data analysis program at the laboratory. It handles singles and mutiparameter data acquisition and off-line data sorting from magnetic tape.

Due do the limited address space of the NORD-10 computer the SHIVA system is split into a number of separate programs. Currently it consists of 18 programs with a total size of more than 600 Kbytes. These programs run as real time programs under the operating system SINTRAN III, and they communicate by means of the real time facilities of SINTRAN. Most of the programs are written in FORTRAN 77, and they are supported by libraties for command handling, graphics, I/O, etc. The general layout of the program system is shown in fig. 4.1.

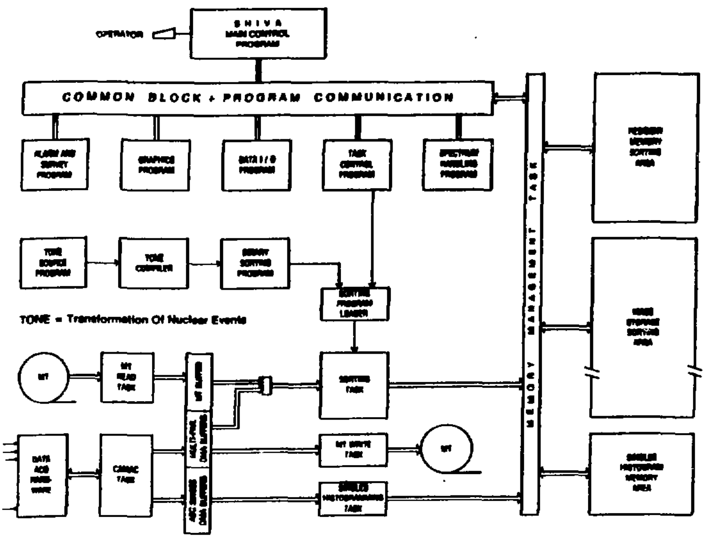

Fig. 4.1 Structure of the SHIVA data acquisition system.

The main development of the SHIVA system in 1984 has been the inclusion of a software based virtual memory system that enables storage and access of sorting spectra on disc. (F. Sørensen, thesis). This facility has greatly expanded the capacity of SHIVA, and makes possible the generation of large 2-dimensional spectra. The access of such external spectra is completely transparent for the user, excepting that the access time is slightly increased.

The virtual memory system is constructed as a set of real time programs written in PASCAL. The work was done in close collaboration with the development of the TONE compiler, (see chapter 4.2.2). External spectra as well as calls on trigonometric and mathematical functions can now be defined in a TONE program. The external spectra are stored on disc, and the function calls are translated to call of PASCAL library functions in a program of the virtual memory system.

4.2.2 Further Development of the TONE Language

L. Ihler (student), F. Ingebretsen and B. Skaali

The TONE compiler for the generation of fast data aquicition and transformation code has been described elsewhere[1]. From the extensive and very satisfactory experience with the language, further extensions and features have been implemented. The compiler code itself has been edited and changed to standard FORTRAN 77, and a large effort has been made to give the compiler source code a clear and readable structure. This has improved the transportability of the compiler considerably.

From the physicistusers point of view, the most appearent changes are the general arithmetic statements, several elementary functions and a loop structure. Since the compiler is one-pass, all statements starts with a verb. The arithmetic statement verb is "LET", and the right hand expression syntax is similar to the most common high level language syntax.

The functions implemented are SIN, COS, TAN, SQRT, EXP and LN. In addition, a system function RAND generates pseudorandom numbers.

The loop structure chosen is a "WHILE <logical expression> DO <statement>" structure, similar to a "IF - THEN" structure already included.

Experience has shown that some data transformation algorithms are used in many cases. Examples are gain shift compensation and charged particle identification. This is now easily coded in a high level syntax.

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1) B. Skaali, A. Haugen, F. Ingebretsen and G. Midttun, IEEE Trans. on Nuclear Science, Vol. NS-30, 1983, 3947.

4.3 Data Analysis Software

The following programs have been developed for data analysis:

NSPECT
Ge(Li)-spectrum manipulation program. Fast peak search, peak centroid and area estimation directly from observed data. FORTRAN-77.

TSPEC
Off-line analysis of one-dimensional spectra. Fits Gaussian with optional tail functions to spectrum peaks. Automatic peak search. FORTRAN-77. Locally developed library.

SPEC-STRIP
Off-line NaI and particle detector spectrum unfolding program. Present version limited to 64 channel spectrum. Interactive, uses DICO display system. FORTRAN-77.

STACAFOLDED
Calculation of decay probabilities from Fermi gas assumptions. Outputs unfolded and folded NaI-spectra with the use of response functions in program SPEC-STRIP. FORTRAN-77. Locally developed library for graphics.

FIGEGA

Calculates first generation gamma-ray spectra from particle-gamma experiments. Input is coincident gamma spectra with NaI-detectors from different excitation intervals. FORTRAN-77. Locally developed libraries for graphics, command processing, magnetic tape handling.

TRANSMISSION

Calculates efficiency of mini-orange electron spectrometer. Graphics on Tektronix terminal. FORTRAN-77. Locally developed library for graphics.

5 NUCLEAR INSTRUMENTATION AT THE CYCLOTRON LABORATORY

5.1 Laboratory Equipment

M. Guttormsen and F. Ingebretsen

The instrumentation funds for the cyclotron laboratory in 1984 has been used mainly for gamma-ray detectors. One 20 % Ge(Li)- and three 5" × 5" NaI-detectors have been purchased together with some standard nim modules for signal processing.

The NaI-counters are to be used in a large multi-detector system formed as a ball. A frame consisting of 32 polygons (with 5 or 6 sides) is now under construction in our workshop. We plan to apply the multidetector setup in the study of heated nuclei, and we expect to obtain an acceptable particle-γ-γ coincidence rate.

Four octal logic delay line units[1] are not available. These units are extremely convenient in the often complicated fast timing part of the multi parameter coincidence setups. Furthermore, the new quad pile-up rejection module has also been used and proven very convenient and efficient.

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1) J. Wikne Report 83-39. Institute of Physics, University of Oslo.

5.2 The Quad Pile-up Rejection Module

J. Wikne and F. Ingebretsen

The prototype of the quad pile-up rejection module[1] became operative in May 1984 and was tested with very good results[2].

It was used in several experiments during the fall of 1984. In the course of these a problem related to timing constraints on part of the ADC scanner was discovered. This problem will be dealt with in the design of the new scanner version.

For the final specifications of the instrument, see ref. 2).

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1) J. Wikne and F. Ingebretsen, Annual Report 1983, Report 84-19, Institute of Physics, University of Oslo, p. 15.

2) J. Wikne and F. Ingebretsen, A NIM Module for Efficient Amplifier Pile-up Rejection, Report 84-31, Institute of Physics, University of Oslo.

6 EXPERIMENTAL NUCLEAR PHYSICS

The experimental work at the cyclotron has mainly been devoted to the study of nuclear structure at low spin and high excitation energy. The method is based on measuring the outgoing charged particle from transfer reactions in coincidence with γ-rays. In this way γ-ray spectra at various nuclear excitation energies can be produced.

Our research is of general physical interest: To what extent can a microscopical few-body system, e.g. nuclei with $A \sim 160$, be ascribed statistical properties as temperature and entropy? It is well known that the low energy part of nuclear excitations is determined by the orbitals occupied and the collective degrees of freedom. However, going a few MeV above the yrast line one is bound to use statistical concepts.

One of the most important findings is the appearence of 1 MeV to 2 MeV γ-rays in the decay of heated nuclear matter. This year the appearance of such γ-rays have been confirmed also in other systems, and a more detailed study of the origin of this favoured γ-decay has been initiated.

It is still an open question if chaotic particle motion can be produced in hot nuclear matter. This is one of the greatest challenges remaining to be investigated. However, to study such properties our experiments so far suffer from poor statistics.

An increased coincidence efficiency is mandatory for the progress in our investigations. We have under construction a frame for a many-counter system and hope for the funding of new NaI detectors to be used in future experiments. This would make us able to produce reliable first-generation γ-ray spectra. In addition an increased p-γ-γ coincidence rate will give better γ-ray resolution and open new aspects.

In subsect. 6.1 the contributions during the year to the study of nuclei at low spin and high excitation energy are given.

Also the work on high-spin states and delayed proton emission has continued in 1984 (see subsects 6.2 and 6.3). The high-spin experiments have been carried out at foreign laboratories where heavy-ion beams are available. The main topic of this research is the behaviour of nuclei exposed to rapid rotation. In particular, single-particle structures and pairing-correlations have been studied as function of rotational frequency. This field is in strong development and powerful detector-systems with Compton-suppressed Ge-detectors are now emerging. We participate in a Nordic collaboration, NORDBALL, to build a Compton-suppressed γ-ray spectrometer. In the final version the spectrometer is planned to consist of 30 Ge-counters shielded by BGO-crystals and with a γ-ray multiplicity filter. The Oslo-group has already ordered one BGO shield for this system.

6.1 Properties of Nuclei at High Temperatures

6.1.1 Characteristic Features in the Decay of Highly Excited Low-Spin States

A. Atac, M. Guttormsen, T. Ramsøy, J. Rekstad, T.F. Thorsteinsen+, G. Løvhøiden+, T. Rødland+

In recent works[1,2] we reported on some typical features in the γ-ray spectra following the (^{3}He,α) pick-up reaction on deformed rare earth targets. In the spectra from even-even nuclei a wide peak was observed at around 1 MeV. It was and interpreted as the last transition in the statistical cascade from the 2qp region into the ground band[1]. Correspondingly, a 2 MeV bump found in ^{161}Dy presumably originates from enhanced M1 single particle transitions competing with transitions of random nature[2]. In a series of investigations these phenomena have been studied further. Different reactions have been used and the bombarding energy has been varied in order to determine under which conditions these bumps in the spectra appear. The observations are summarized below.

a. Gamma-ray spectra from the ^{161,163}Dy(d,t) reactions

A detailed presentation of these experiments is given in ref. 3 and in sect. 6.1.2 in this report. The selfsupporting targets were bombarded with 15 MeV deuterons in a set up consisting of four particle-telescopes at 50° angle, two 5"×5" NaI(Tl)-detectors and a 19 % Ge(Li)-counter. The experimental conditions permit excitation of the ^{160,162}Dy nuclei up to approximately 6 MeV.

Fig. 6.1 shows NaI-spectra from these reactions with gates in the triton spectra corresponding to an excitation region from 2.7 MeV to 6.0 MeV. The upper part of the figure shows the raw spectra. The unfolded spectra are seen below. Both nuclei reveal γ-transitions with energy slightly less than 1 MeV, most likely of the same origin as the 1 MeV bump reported in ref.[1].

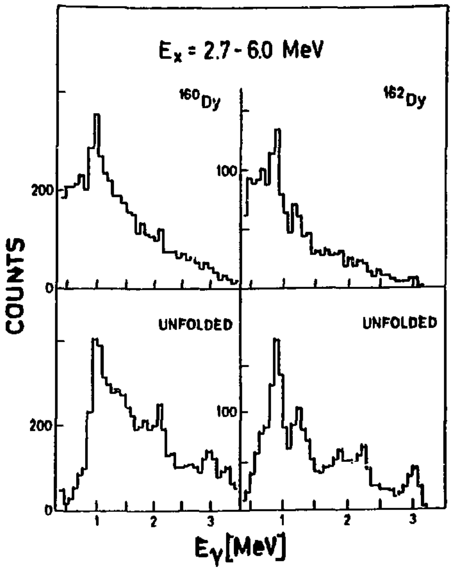

Fig. 6.1 Gamma-ray spectra from the E_x = 2.7 MeV - 6.0 MeV region in ^{160}Dy and ^{162}Dy, populated in the (d,t) reaction.

A wide peak at around 2 MeV is present in both spectra, although weak due to the low cross section to highly excited states in the (d,t) reaction. We suggest an explanaition of this peak similar to the one given in ref.[2].

b. *Gamma-ray spectra from the* $^{161,163}Dy(d,p)$ reactions

The set-up described above made it possible also to study the (d,p) reactions in the same experiment. The proton spectrum from the $^{163}Dy(d,p)$ reaction, which was shown in the annual report from last year[4], revealed an increasing cross-section with excitation energy. Thus, a gate in this spectrum over the excitation region from ground state to 8 MeV gives a corresponding γ-ray spectrum dominated by the decay of levels in the highest excitation region. A NaI-spectrum of the γ-radiation from ^{164}Dy is shown in fig. 6.2. A Ge(Li)-spectrum of the low-energy part is inserted in the figure.

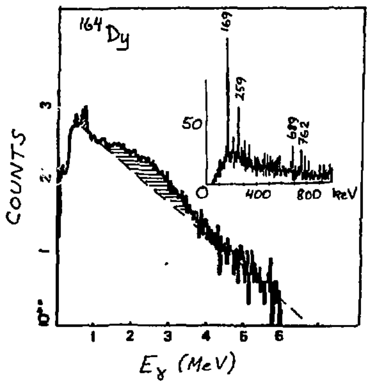

Fig. 6.2. Gamma-ray spectra from the $^{163}Dy(d,p)$ reaction. The gate in the roton spectrum corresponds to an excitation region from 4.0 MeV to 7.6 MeV. Inserted is a Ge(Li)-spectrum showing the low-energy part of the total spectrum.

Also this spectrum has an 1 MeV and a 2 MeV peak, both with considerable intensities. The Ge(Li)-spectrum indicates that a major part of the 1 MeV peak is due to specific transitions seen as resolved lines.

c. Gamma-ray spectra from the $^{162}Dy(^{3}He,^{3}He')$ reaction

The levels populated in the (d,p) and (d,t) reactions have a single particle or a single hole component in their wave functions, which determines the reaction cross section. Since γ-decay is a slow process measured in comparison with nuclear thermalization, the decay properties are not expected to depend on the creation process. In order to test this statement also the γ-radiation following inelastic excitation has been measured.

An enriched target of ^{162}Dy was bombarded with 45 MeV ^{3}He particles. Inelastically scattered ^{3}He particles were detected in four particle telescopes positioned at an angle of 40^{o} compared to the beam axis. Gamma-rays following the inelastic scattering were detected by means of two 5"×5" NaI(Tl)-counters, a 19 % Ge(Li)-counter and a 2"×3" NaI-detector equipped with a 10"×11.5" NaI anticompton shield.

Fig. 6.3 shows the ^{3}He-spectrum taken in coincidence with γ-rays in the NaI-detectors. The strong peak is partly due to random coincidences between γ-rays and elastically scattered ^{3}He-particles, partly due to

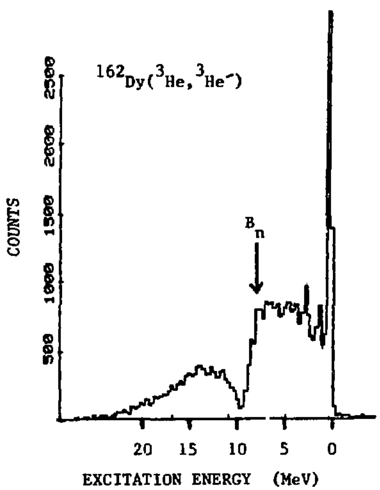

Fig. 6.3 Inelastic scattered ^{3}He-particles from ^{162}Dy, measured in coincidence with γ-rays.

inelastic excitation of the ground band in ^{162}Dy. The treshold for neutron evaporation, resulting in a considerable drop in intensity due to decreased γ-ray multiplicity, is evident. Thus, the data gives opportunity to study the γ-decay of ^{162}Dy as well as of ^{161}Dy by proper gate setting in the ^{3}He-spectrum.

The upper part of fig. 6.4 shows all γ-rays from ^{162}Dy, while the lower part shows the corresponding result for ^{161}Dy. Both an 1 MeV peak and a wide 2 MeV bump are exposed in the ^{162}Dy spectrum. Only the 2 MeV bump is seen in the spectrum from the odd nucleus. This result agrees with the earlier observations, and reveals that these peaks or bumps make a characteristic pattern in the decay of highly excited low-spin states in the rare earth mass region.

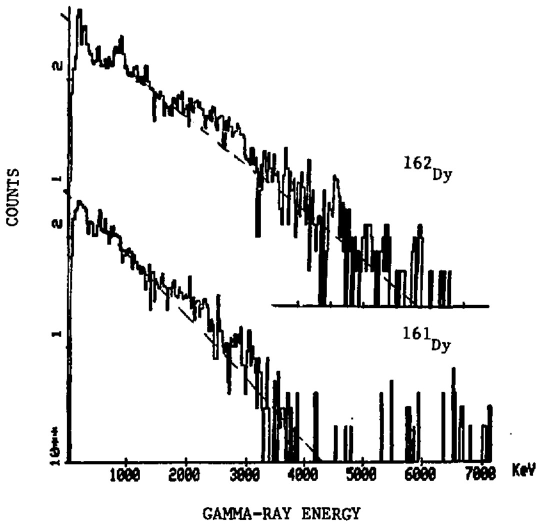

Fig. 6.4 γ-radiation from ^{162}Dy (upper part) and ^{161}Dy (lower part), as observed in the ^{162}(^{3}He,^{3}He') reaction.

d. The γ-decay following (^{3}He,α xn) reactions

The appearence of peaks or bumps with energies around 1 MeV and 2 MeV seems to be a general feature in the γ-ray spectra corresponding to decay of bighly excited low spin states. The spectra obtained in (HI,xn) reactions do not exhibit similar peaks. A satisfactory explanation of this difference in the spectra cannot be given at the present stage. The favourable Q-value (~ 14 MeV) of the (^{3}He,α) reactions permit excitation to very high energy even with the moderate beam energy obtainable with our cyclotron. Using the same setup as described in sect. 6.1.3, excitation energies above 40 MeV could be reached in the nuclei ^{161}Dy and ^{162}Dy by means of the $^{162,163}Dy(^{3}He,\alpha)$ reactions. Thus the decay properties of as much as five nuclei could be investigated in one experiment, selected by means of gates in the α-spectrum. At the lowest α-particle energies a considerable fraction of the yield is expected from compound reactions followed by evaporation of an α-particle and a number of neutrons. This process simulates to some extent the (HI,xn) reaction, although the spins are much lower. In this section we present the γ-results. Other aspects of these experiments are discussed in sect. 6.1.3.

The α-particle spectrum from the $^{162}Dy(^{3}He,\alpha)$ reaction, taken in coincidence with γ-rays in the NaI-detectors, is shown in fig. 6.5. The data

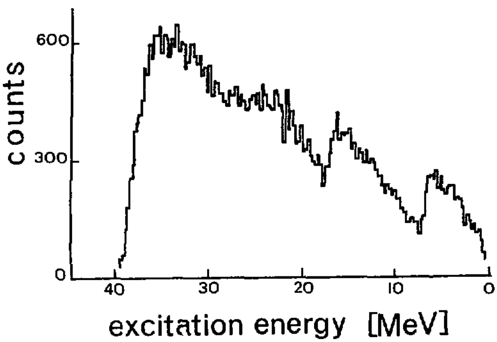

Fig. 6.5 α-particles from the $^{162}Dy(^{3}He,\alpha)$ reaction taken in coincidence with γ-rays. The beam energy was 45 MeV, the detector angle 40°. The excitation energy is relative to the ^{161}Dy isotope.

are corrected for contributions from contaminations, essentially carbon and oxygen. The tresholds for 1n, 2n and 3n emission can be recognized in this spectrum. Detailed studies of the Ge(Li)-spectra reveal that the different neutron channels can be reasonably separated by carefull selec-

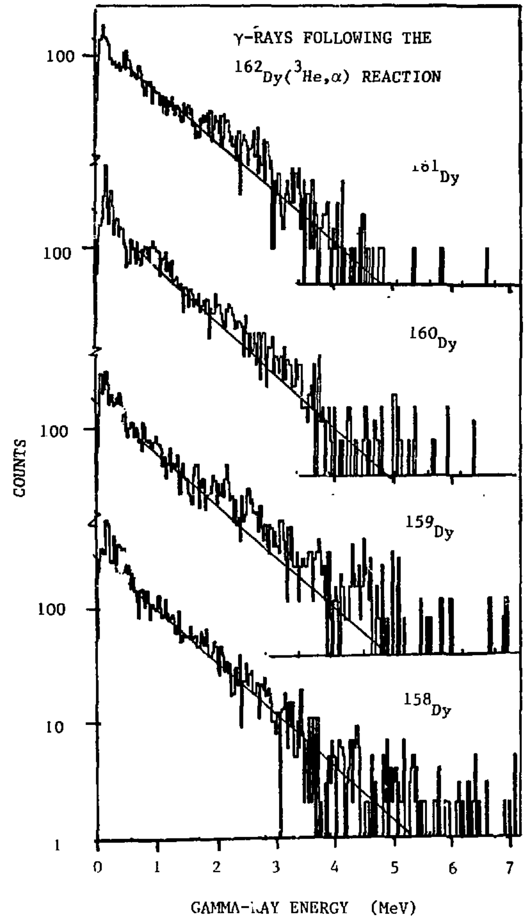

Fig. 6.6 Gamma-ray spectra from the ^{162}Dy(^{3}He,α xn) reaction. The upper spectrum corresponds to x = 0, the lowest one to x = 4. The spectra are obtained with α-particle gates as indicated in fig. 6.5.

tions of the α-particle gates.

Fig. 6.6 shows NaI-spectra for different final nuclei after the $^{162}Dy(^3He,\alpha)$ reaction. The corresponding spectra from the $^{163}Dy(^3He,\alpha)$ reaction are shown in fig. 6.7. The two characteristic features in the statistical

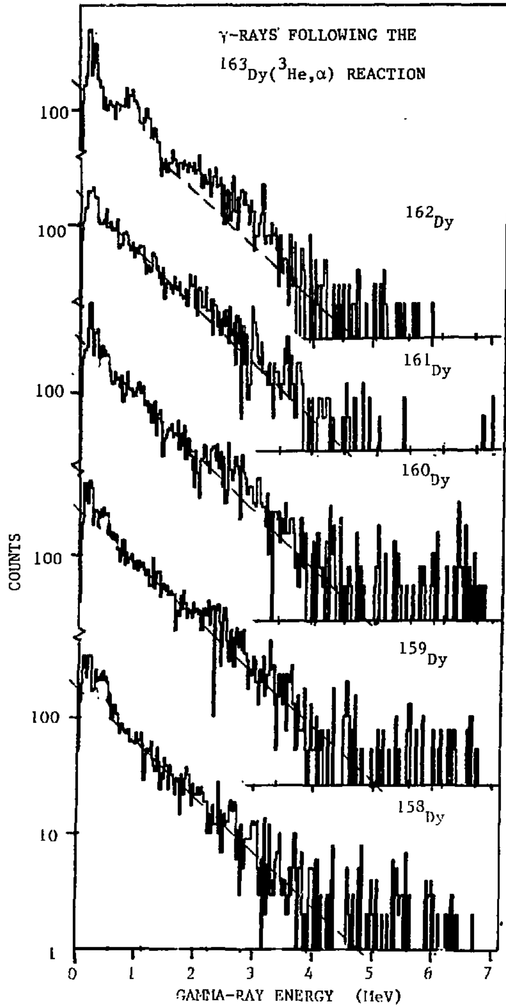

Fig. 6.7 Same as in fig. 6.6, but from the $^{163}Dy(^3He,\alpha\ xn($ reaction.

decay from highly excited low spin states, the 1 MeV bump and the 2 MeV bump, are evident in the spectra associated with the neutron channels 0n, 1n and 2n. It is striking that these patterns disappear in the spectra when more than two or three neutrons have evaporated. For these channels the spectra are similar to those seen in (HI,xn) reactions. These observations indicate that an explanation of the bump as a result of the low spin only seems less probable.

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1) A. Henriquez et al. Phys. Lett. 130B (1983) 171
2) M. Guttormsen et al. Phys. Rev. Lett. 52 (1984) 102
3) T. Ramsøy et al. Nucl. Phys. (in press)
4) Annual Report 1983, Report 84-19, Institute of Physics, University of Oslo, p. 48.

+Institute of Physics, University of Bergen

6.1.2 Cooling of Continuum States with Opposite Parities

T. Ramsøy, J. Rekstad, M. Guttormsen, A. Henriquez,
F. Ingebretsen, T. Rødland*, T.F. Thorsteinsen* and G. Løvhøiden*

The ground states of ^{161}Dy and ^{163}Dy are characterized by the Nilsson orbitals $5/2^+$[642] and $5/2^-$[523]. Therefore, with the use of single-neutron transfer reactions one expects to populate states in continuum with same spins but opposite parities. This gives a transparent situation where one can study decay structures from states coupled to configurations with certain parities.

The experiments were performed using the ^{161,163}Dy(d,t) reactions with 15 MeV deuteron beam from the cyclotron at the University of Oslo. The set-up consisted of four particle telescopes, two 5"×5" NaI-counters and one Ge counter. In the upper part of fig. 6.8 the singles triton spectra for both targets are shown. The striking similarities of the two spectra demonstrate that the neutron pick-up reaction is only minor influenced by the ground state configurations.

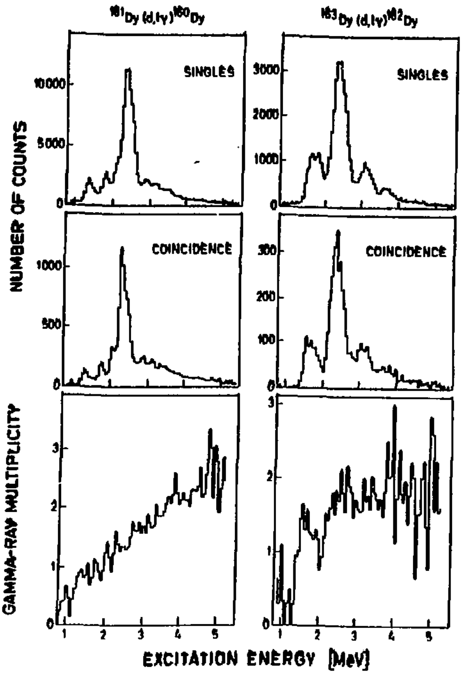

Fig. 6.8 Singles triton spectrum, tritons in coincidence with γ-rays ($E_γ$> 400 keV in the NaI-counter) and multiplicity spectrum of statistical γ-rays for ^{160}Dy and ^{162}Dy.

In the lower excitation part of ^{160}Dy we have put gates on the tritons and produced γ-ray Ge(Li)-spectra, as shown in fig. 6.9. Detailed γ-ray spectroscopy can then be performed and the results are displayed in the level schemes of fig. 6.10. Here we recognize groups of levels having opposite parities in the two final nuclei.

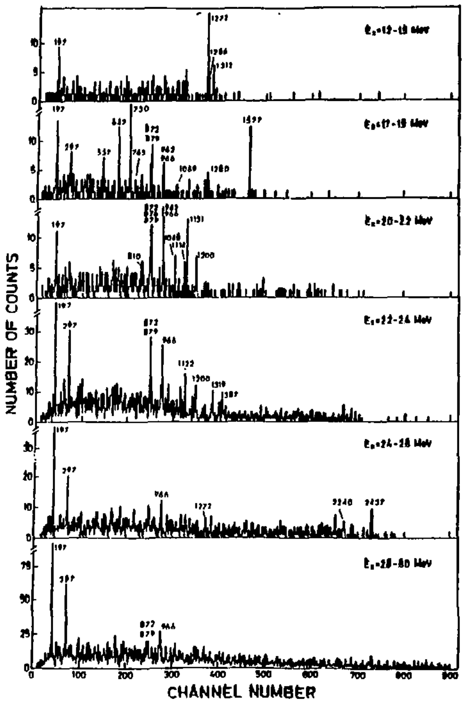

Fig. 6.9 Ge(Li)-spectra of γ-rays in coincidence with tritons leading to levels in ^{160}Dy.

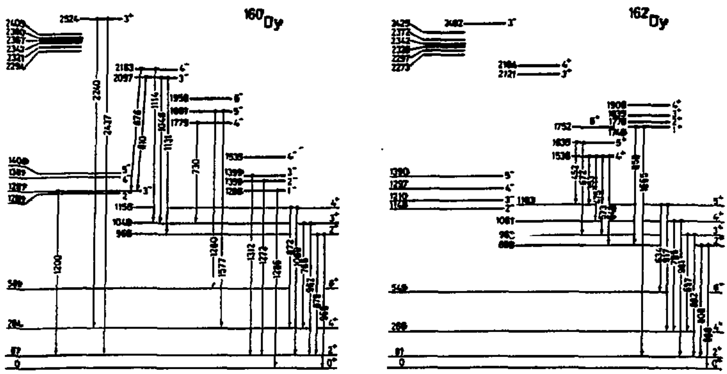

Fig. 6.10 Partial level schemes of ^{160}Dy and ^{162}Dy. The most prominent transitions from states populated in the (d,t) reaction are shown.

For the 5^- member of the $K^\pi = 4^-$ band in ^{160}Dy an enhanced direct decay branch into the ground state band was found. We estimate that only an 1 % admixture of $K = 0$ or 1 components are sufficient to explain this apparently $\Delta K = 4$ forbidden decay. These admixtures are assumed to originate from couplings to the octupole bands and/or $i_{13/2}$ alignments of the two quasiparticle state. The $K^\pi = 4^+$ band, where no such decay has been observed, has less alignment and also wrong parity for interaction with the various octupole bands.

Also states involving transfer from the $N = 4$ oscillator shell give direct γ-decay to the ground state band. The decay in ^{160}Dy should be hindered since it goes by single particle E2 transitions. Nevertheless, we observe a strong direct decay branch in the ^{160}Dy case. This can be explained by the $\Delta N = 2$ interaction which introduces the very fast $3/2^+[651] \rightarrow 5/2^+[642]$ transition.

The γ-rays from high-lying states are better studied with the NaI-counter. The effect of requiring that one NaI-counter fires in coincidence with a triton-particle is demonstrated in fig. 6.8. The γ-ray multiplicity spectrum $\langle M\rangle_\gamma^{stat}$ (lower part) is obtained from the singles N_s (upper part) and the coincidence N_c (middle part) triton-particle spectra by

$$\langle M\rangle_\gamma^{stat} = N_c/N_s \ .$$

The multiplicity spectrum of ^{162}Dy reveals large fluctuations as a consequence of higher degree of forbiddeness of the direct decay into the ground band. At the highest energies no increase in multiplicity is observed, which indicates that the parity of states in continuum puts certain limits on the number of γ-rays participating in the cooling process.

More details on this work can be found in ref[1].

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1) T. Ramsøy et al. Nucl. Phys. A (in press)

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6.1.3 Gamma-Ray Multiplicity in the ^{162,163}Dy(^{3}He,α)^{161,162}Dy Reactions

J. Rekstad. A. Atac, T. Ramsøy, M. Guttormsen, F. Ingebretsen, T.F. Thorsteinsen*, G. Løvhøiden*, and T. Rødland*

The multiplicity of γ-rays from excited states is known to increase by increasing excitation energy. However, at the neutron binding energy ($E_x \sim B_n$) the multiplicity drops off abruptly due to the evaporation of one neutron leading to low excitation energy in the neighbouring A-1 isotope. The present work adresses this variation in γ-ray multiplicity also for excitation regions were more than one neutron can be emitted in the cooling process. Fig. 6.11 shows schematically the competition between neutrons and γ-rays in the decay of heated nuclear matter. The experiment was performed at the Oslo cyclotron using the ^{162}Dy(^{3}He,α)^{161}Dy and ^{167}Dy(^{3}He,α)^{162}Dy reactions with beam energies of 45 MeV. The outgoing α-particles were detected with 4 ΔE-E telescopes. The γ-decay following the pick-up reaction was studied with 2 5"×5" NaI- and 2 Ge-detectors. The γ-ray spectra of the Ge-detectors revealed yrast-transitions in various Dy isotopes showing a maximum of 3 and 4 emitted neutrons for the ^{162}Dy and ^{163}Dy targets, respectively.

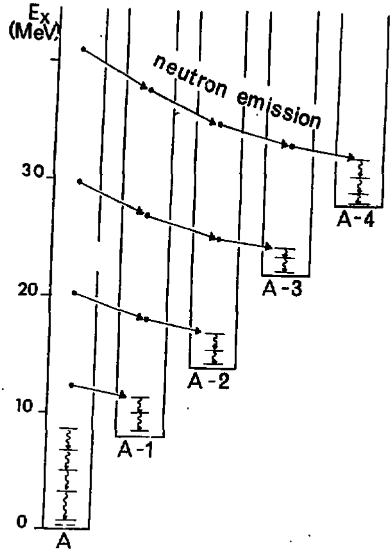

Fig. 6.11 Decay branches for a nucleus excited above the neutron binding energy.

The high-energy parts of the α-spectra are free for background from transfer on e.g. carbon and oxygen. This is because the Q-value of the reactions (~ 14 MeV) is much larger in the rare earth region than for the lighter elements. However, fig. 6.12 shows that impurities are present for α-particles corresponding to energies of ~ 12 MeV above the ground state of the nucleus produced in the reaction. In order to correct for this background, we have performed measurements with carbon foil and paper. The result after proper subtraction of the impurities is disnlayed in the lower part of fig. 6.12. There remains a peak which is probably due to silicon impurities on the target. In fig. 6.13 we show singles

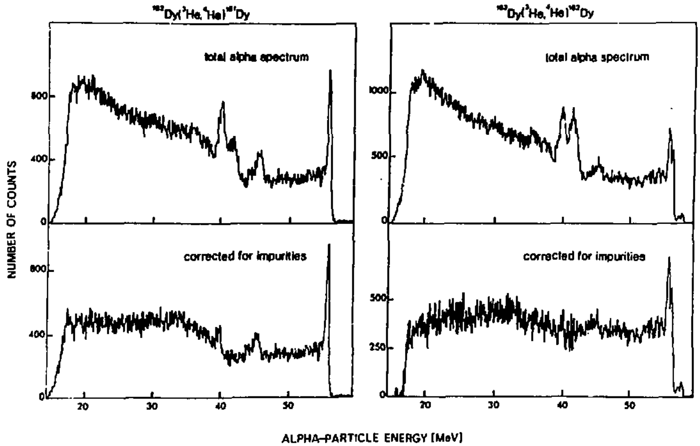

Fig. 6.12 Singles α-spectrum before and after corrections for carbon and oxygen impurities on the target.

α-spectrum (N_S), α-particles in coincidence (N_c) with γ-rays detected in the NaI counters, and the γ-ray multiplicity given by

$$\langle M_\gamma \rangle \propto N_c/N_S \ .$$

The dotted lines are drawn to indicate the spectrum if we assume also a subtraction for silicon impurities.

The multiplicity spectra show that the drop in $\langle M_\gamma \rangle$ is not so pronounced when more than one neutron evaporate. This feature is due to the energy smear-out effect caused by the neutrons. However, the xn-channels can be nicely revealed by putting gates on various γ-lines in the Ge-spectra. It is interesting to notice that the multiplicity increases for higher number of neutrons emitted, and that the multiplicity becomes highest in

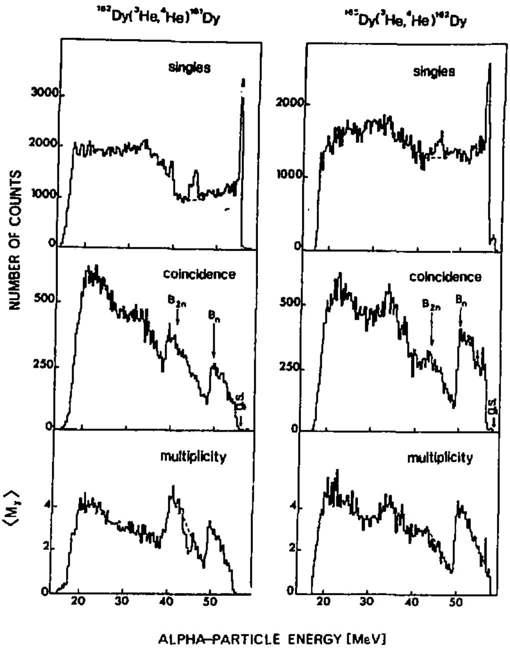

Fig. 6.13 Singles α-spectrum, α-particles in coincidence with γ-rays (E_γ > 450 keV) and multiplicity spectrum of statistical γ-rays for ^{161}Dy and ^{162}Dy.

the even-even isotopes. The fact that $\langle M_\gamma \rangle$ never falls down to ~ 0 at higher xn channels, indicates that the various isotopes are populated at high excitation energy after neutron evaporation. We probably also have contributions from evaporation of α-particles giving higher spins to the residual nucleus.

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6.1.4 Gamma-ray Transitions in ^{160}Dy following the $^{161}Dy(^{3}He,\alpha)^{160}Dy$ reaction

T. Ramsøy, M. Guttormsen, J. Rekstad, A. Atac, T.F. Thorsteinsen*, G. Løvhøiden* and T. Rødland*

The ^{160}Dy nucleus is known to show back-bending at a rotational frequency corresponding to $I \sim 12\hbar$. This back-bending is interpreted as a band-crossing between the ground-band and the S-band. It would be interesting to follow the S-band to lower spins. J. Gen-Ming et al.[1] suggested candidates for such low-spin members of the S-band. The levels were assigned spins and parities from 4^+ to 8^+.

One aim of this experiment has been to look for γ-ray transitions from these S-band states feeding into the g.s.b. The strongest transitions is expected to be of the type I(S-band) → $[I - 2]$ (g.s.b.). Previously a similar attempt has been undertaken by us[2], but due to poor statistics it was not possible to make any conclusions. In the present experiment however, the statistics is improved considerably.

Another aim of the present work is to continue the study of gross properties in nuclei at high intrinsic excitation energy[3,4]. Of great interest is the preference for γ-transitions of certain energies in the decay pattern from highly excited states.

The experiment was performed using the $^{161}Dy(^{3}He,\alpha)$ reaction with 32 MeV ^{3}He beam from the Oslo cyclotron. The target was self supporting dysprosium foil enriched to 90% in ^{161}Dy. The target thickness was 1.7 mg/cm^2. The experimental setup consisted of four particle telescopes, two 12.7 × 12.7 cm NaI(Tl)-counters, three Ge(Li)- and one instrinsic Ge-X-ray counter. A fast pile-up rejection circuit[5] was used to avoid energy summing of particles arriving within a period of 4 μs. The experiment was run almost continuously for a period of one month with a beam intensity of 0.5 nA. The total running time was about 500 h and the amount of data was the largest achieved in one experiment in our laboratory till now.

In fig. 6.14 the α-particle spectrum is shown together with the γ-ray multiplicity. Fig. 6.14a shows the alpha-particle spectrum corrected for impurity peaks due to reactions with oxygen and carbon. Such impurities does not affect the spectrum for α-energies beyond 34 MeV. Silicon and other heavier elements can however affect the spectrum up to ~36 MeV α-energy (first neutron emission).

The "Coriolis" peak at approx. 2 MeV excitation energy is a striking feature in the spectrum. It is known[1] to consist of several unresolved peaks. Among the corresponding levels are the suggested S-band states and also a state with large spectroscopic strength at 2.279 MeV. In ref. 1 the authors suggest the latter state to correspond to the $5/2^{+}[642]$ + $11/2^{-}[505]$ Nilsson configurations, and they assign it a spin and parity of 8^{-}. With a K-value of 8 this level could be of isomeric character.

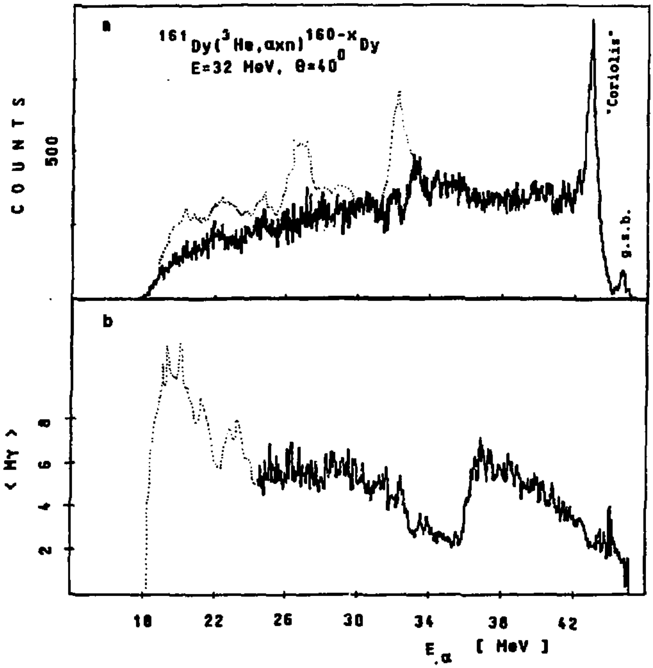

Fig. 6.14. Alpha-particle spectrum and γ-ray multiplicity from the $^{161}Dy(^{3}He,\alpha xn)$-reactions.

a) Direct α-particle spectrum. Subtracted impurity peaks are shown as dots.

b) Gamma-ray multiplisity as a function of α-particle energy. The dotted part of the curve can not be regarded as significant.

The γ-ray multiplicity shown in fig. 6.14b is derived using the procedure given in ref. 6. Due to a rather uncertain subtraction of impurities below ~25 MeV α-energy the multiplisity cannot be regarded significant here. It should be pointed out that this spectrum is generated without any restrictions on the γ-ray energy. In order to get an energy independent efficiency of the NaI counters a lower threshold of 430 keV should be applied. We observe a sudden increase in multiplicity around 600 keV which is associated with the decay of the 8^+ level in the ground band. The "Coriolis" peak decays mainly by two γ-rays.

In fig. 6.15 we show NaI-spectra from gates corresponding to population of the ^{160}Dy, ^{159}Dy and ^{158}Dy nuclei. In ^{160}Dy a bump centered around 1 MeV is apparent. A similar strongly preferred decay path is not apparent in the ^{158}Dy nucleus populated after emission of two neutrons.

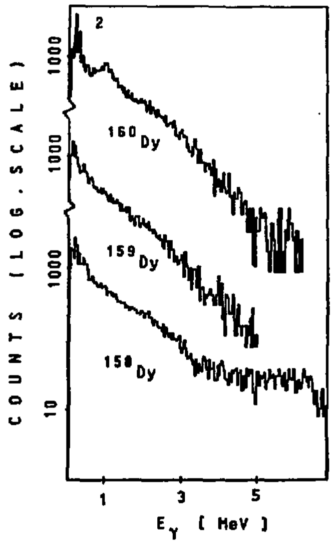

Fig. 6.15 Gamma-rays following the ^{161}Dy(^{3}He,αxn) reactions detected in two NaI-counters. The ^{160}Dy channel (upper curve) clearly displays a bump centered around 1 MeV. The high-energetic γ-transitions in the ^{158}Dy channel (lower curve) arise from excited levels in oxygen and carbon.

The feature has, however, been observed in several reactions. It is discussed in section 6.1.1 in this report.

The evaluation of the data is in progress.

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1. J. Gen-Ming et al., Phys. Rev. Lett., 46 no. 4, (1981) 222
2. R. Haugland, University of Oslo, cand.scient. thesis, (1983)
3. A. Henriques et al., Phys. Lett., 130B, no 3,4, (1983) 171
4. M. Guttormsen et al., Phys. Rev. Lett., 52, no 2, (1984) 102
5. J. Wikne et al., University of Oslo, Report 84-31, (1984)
6. J. Rekstad et al., Phys. Scripta, T5, (1983) 45

*)University of Bergen

6.1.5 First-Generation γ-rays from Regions of High Excitation Energies

T. Ramsøy, J. Rekstad, M. Guttormsen and A. Henriques

The particle-gamma coincidence technique ha sproved to be a powerful tool for investigating the decay process from spesified levels in highly excited nuclei. A photon spectrum for the decay process consists of cascades of γ-transitions from all the excited levels down to the ground state. It would be interesting to get a spectrum of only the prime transitions from the levels populated. Such first-generation spectra are expected to reveal additional information about the nuclear structure at high excitation energy. We present here a method to obtain such spectra.

In order to get a spectrum which contains only the first transitions in the cascades, the rest of the cascade must somehow be subtracted. Let F be the γ-ray spectrum corresponding to a gate in the particle spectrum at excitation energy E_x. The gate must not be made too wide, as this would allow transitions between levels within the gate. Let then G be a γ-ray spectrum from the excitation region where the first transition is expected to end up. Provided that F and G represents the same number of populated states, the first-generation spectrum (FG) is then given as:

i) $(FG) = F - G.$

The gate corresponding to spectrum G may in practise be made wide enough to cover the whole range of excitation energy from zero up to E_x. Instead of one wide gate, several narrow gates covering the same energy range may be used. Let the gate i correspond to the coincident γ-ray spectrum G_i, i running from 0 to k where gate 0 corresponds to the γ-ray spectrum $F = G_o$ (see fig. 6.16). Each of the lower gates is given a weight corresponding to the probability that the transition from 0 ends up here. The weightfunction is discussed later.

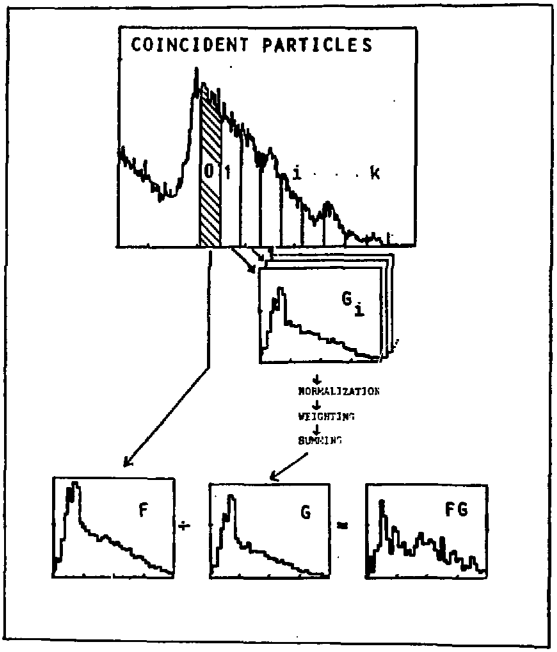

Fig. 6.16 The method for generating first-generation γ-ray spectra. The number indicated on the coincident particle spectrum is the gate number.

The spectra to be subtracted must first be normalized with respect to the number of cascades or populated levels in the corresponding gate. This information can be obtained from the direct particle spectrum, since the area of the gate in this spectrum is proportional to the number of populated states. The normalization factor needed is thus for gate i:

(ii) $$a_i = S_o - \sum_{i=1}^{k} S_i$$

where S_i is the area in the singles particle spectrum corresponding to gate i.

Another method of computing the normatization factors a_i with less uncertainty, is accomplished by using the γ-ray multiplisity. The γ-ray multiplisity as a function of excitation energy is obtained by dividing the coincident particle spectrum by the singles particle spectrum[1]. The normalization factor is now given as:

(iii) $$a_i = A_o/\langle M_O\rangle]/ \sum_{i=1}^{k} (A_i/\langle M_i\rangle)$$

where A_i is the area of the coincident γ-ray spectrum G_i and $\langle M_i\rangle$ is the average γ-ray multiplisity in gate i.

The uncertainty in normalization is now equal to the uncertainty in multiplisity normalization. A variation of 10 % in multiplisity causes rather dramatic changes in the resulting spectra. However, by taking into account the relati ns regarding the area of the first-generation spectra, it is possible to make the results stable against such variations. We have then:

(iv) $$AG = \Sigma\ a_i A_i \text{ and}$$

and

(v) $$A_o - A_G = A_o/\langle M_o\rangle$$

We introduce a correction factor, ε, in eq. (v)and write
$A_o - A_G \rightarrow A_o - \varepsilon A_G = A_o/\langle M_O\rangle$ or

(vi) $$\varepsilon = (1 - 1/\langle M_O\rangle) \cdot A_o/A_G$$

The corrected first-generation spectrum (FG)' is then:

(vii) $$(FG)' = F - \varepsilon \cdot G$$

Using this procedure the resulting first-generation spectra are fairly stable against variations in multiplisity up to 20 %.

At high excitation energies the level density is expected to be described within a statistical model. The γ-transitions are assumed to be of dipole character. The γ-width can then be expressed as:

(viii) $$\Gamma_\gamma(E_x - E_\gamma) \sim E_\gamma^3 \cdot \rho(E_x - E_\gamma)$$

where ρ(E) is the level density in a Fermi-gas model:

$$\rho(E_x - E_\gamma) \sim 1/E_x^2 \cdot \exp[2\cdot\sqrt{a(E_x - E_\gamma)}]$$

where a is the level density parameter.

As a first approximation we have used this distribution for weigthing of the spectra. One could think of introducing an iterative procedure where the obtained first-generation spectrum is used in the next step. The procedure has, however, shown to be remarkably insensitive to the choise of weight function, at least for the higher excitation energies (E_x > 3 MeV).

Some of the resulting first-generation γ-ray distributions

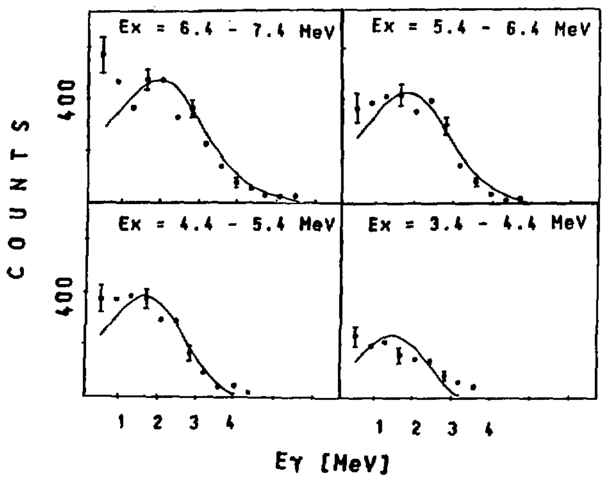

Fig. 6.17 First-generation γ-ray spectra from the ^{164}Dy nucleus populated in the ^{163}Dy(d,p)^{164}Dy reaction.

from selected gates in a proton spectrum are shown in fig. 6.17. The spectra were obtained using the $^{163}Dy(d,p)^{164}Dy$ reaction with a deuteron energy of 15 MeV. The γ-rays were detected in a 12.7 cm × 12.7 cm NaI(Tl) detector. The experimentally obtained distributions are shown as open dots in the figure. Statistical errors are indicated for some points.

The statistics in the first-generation raw spectra is rather poor so we have added several gates together to make a broad window of approximately 1 MeV.

The drawn lines in fig. 6.17 are theoretical distributions computed with eq. (viii) and (ix). As a general tendency the experimental results show quite good resemblance with theory. The mean value of the γ-ray energy is in excellent agreement with theory.

One should however take into account that the broadness of the windows used could smear out structures and real differences between the curves. An improvement in the statistics in the coincident γ-ray spectra is needed to draw more conclusions about level-structure.

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1. J. Rekstad et al., Phys. Scripta, T5, (1983) 45

6.2 High-Spin Properties of Nuclei

6.2.1. High-Spin States in $^{163-166}Hf$

H. Hübel*, K.P. Blume*, K.H. Maier**, A. Maj**, H. Kluge**, A. Kuhnert**, J. Recht** and M. Guttormsen

The neutron deficient even-even mass Hf isotopes ($163 \leq A \leq 166$) show all sharp back-bendings with high angular momentum alignments at the first band-crossing frequency ($\hbar\omega \sim 0.25$ MeV). This behaviour is due to the small deformations and low moment of inertias for these nuclei. Thus, the Coriolis force couples the single particle motion strongly to the collective motion.

High-spin states in $^{163-166}Hf$ were populated by bombarding ^{148}Sm with $^{20,22}Ne$ beams from the VICKSI accelerator facility of the HMI, Berlin. Four, and in later experiments six n-type Ge-detectors with BGO-shields for Compton-suppression were used. The spectrometers belong to the German OSIRIS collaboration. As an example fig. 6.18 shows the γ-γ coincidence spectrum of yrast transitions in ^{166}Hf. Preliminary level schemes of ^{164}Hf and ^{166}Hf are shown in figs. 6.19 and 6.20, respectively.

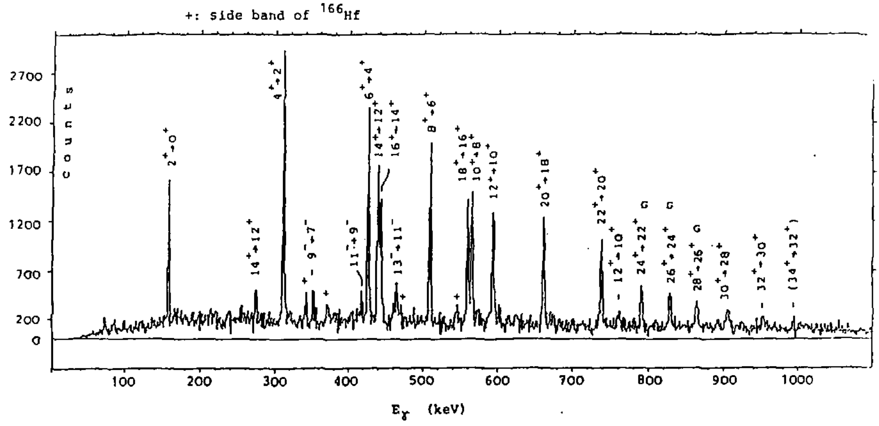

Fig. 6.18 Sum of γ-γ coincidence spectra showing transitions in the yrast sequence of ^{166}Hf. Gate energies are marked with "G".

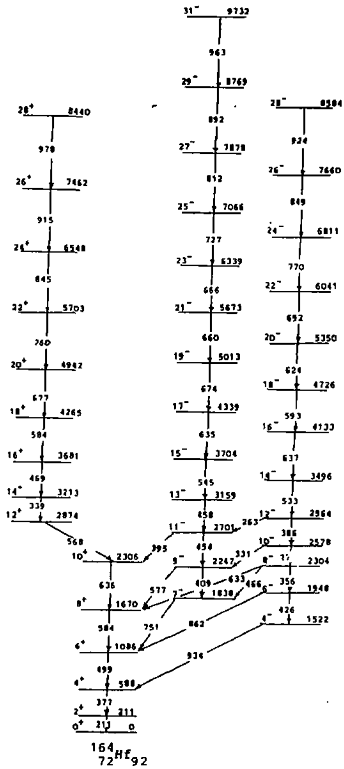

Fig. 6.19 Level scheme of ^{164}Hf.

Our data on ^{164,166}Hf indicate that a change in structure takes place around $\hbar\omega$ = 0.49 MeV. Here, the last experimental γ-transitions in the yrast band are observed with appriciated intensity, but the next transitions are not seen. This could mean an abrupt band-termination as a

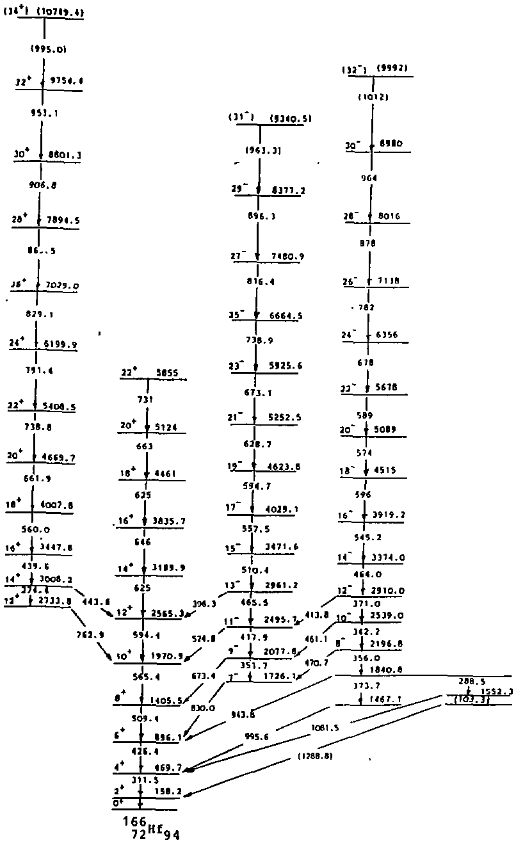

Fig. 6.20 Level Scheme of ^{166}Hf.

consequence of change in the nuclear shape. We now plan to investigate this feature also in the lighter isotopes where the transition should appear at lower spins.

Fig. 6.21 gives a review of the data on yrast transitions in $^{162-168}$Hf, where the angular momenta are plotted as a function of $E_\gamma = 2\hbar\omega$.

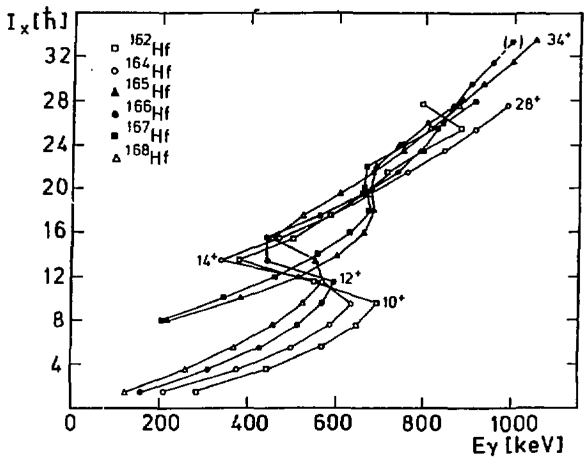

Fig. 6.21 Aligned angular momentum I_x as a function of rotational frequency for the yrast sequence in ^{162}Hf to ^{168}Hf. The data for ^{162}Hf, ^{167}Hf and ^{168}Hf were taken from refs. 1, 2 and 3, respectively.

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1) L.L. Riedinger et al., Oliver Lodge Laboratory, Liverpool, Annual Report 1983/84
2) E.S. Paul et al., Shuster Laboratory, Manchester, Annual Report 1983
3) R. Chapman et al., Phys. Rev. Lett. 51 (1983) 2265

*Institut für Strahlen- und Kernphysik, Universität Bonn
**Hahn-Meitner-Institut, Berlin

6.2.2 High-Spin Structure in ^{169}W and ^{170}W

J. Recht[*], Y.K. Agarwal[*], K.P. Blume[*], M. Guttormsen, H. Hübel[*], H. Kluge[**], K.H. Maier[**], A. Maj[**], N. Roy[**], D.J. Decman[**], J. Dudek[***] and W. Nazarewicz[***]

The investigations presented here was triggered by our interest in pairing reduction and shape-changes as a function of rotational frequency. High-spin states in ^{169,170}W were populated in the ^{154}Gd(^{20}Ne,xn) reactions at VICKSI, Berlin. States with spins up to 36 and 61/2 were identified in ^{170}W and ^{169}W, respectively. The level schemes are shown in figs. 6.22 and 6.23.

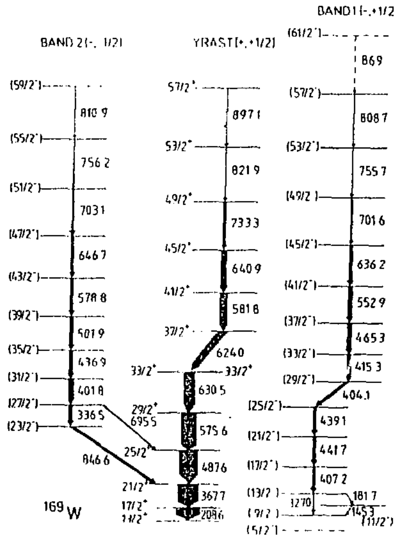

Fig. 6.22 Level scheme of ^{169}W.

The data are interpreted within the framework of a pairing-selfconsistent cranking model. Our calculations for the yrast states in ^{170}W (see fig. 6.24) reveal that the data of the second backbending are well explained by an $\nu i^2_{13/2}\pi h^2_{11/2}$ alignment. The calculations also predict a shape-change from $\gamma \sim -6^o$ at $I^\pi \sim 30^+$ to $\gamma \sim -20^o$ at $I^\pi \sim 36^+$ (see the broken line of fig. 6.25) as a consequence of the $\pi h^2_{11/2}$ alignment.

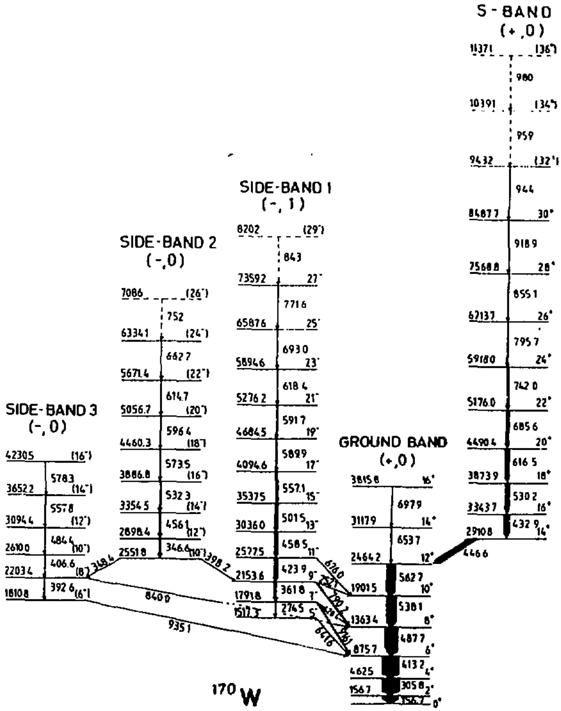

Fig. 6.23. Level scheme of ^{170}W.

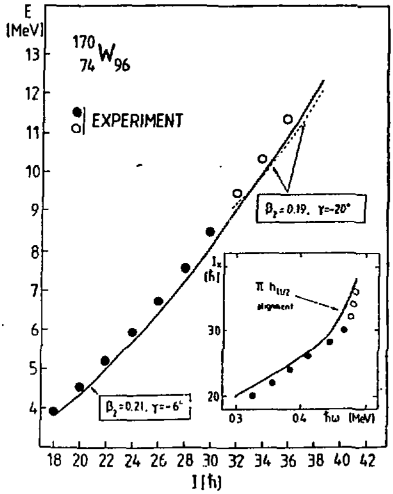

Fig. 6.24 Excitation energy for ^{170}W and angular projection along the axis of rotationm I_x, as a function of rotational frequency.

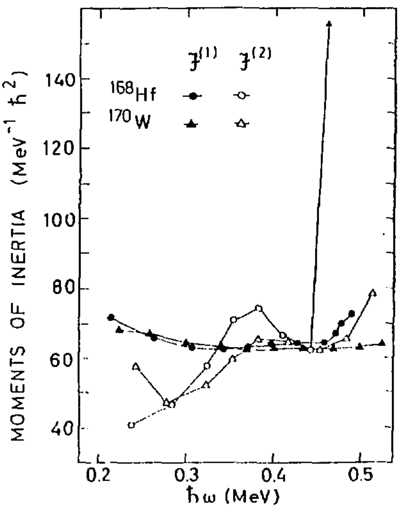

Fig. 6.25 Experimental $J^{(1)}$ and $J^{(2)}$ moments of inertia for neutron s-bands in ^{168}Hf and ^{170}W.

In fig. 6.25 we have plotted the moment of inertia parameter $J^{(2)}$ as a function of rotational frequency. Both ^{168}Hf and ^{170}W show a bump around $\hbar\omega \sim 0.38$ MeV. In this region of frequency we expect no band-crossings. Thus, it is tempting to interprete these irregularities as a sudden change in the pairing correlations in the s-band.

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*** Niels Bohr Institute, Blegdamsvej 17, Copenhagen, Danmark

6.2.3 Decay of the Ground State and the $29/2^+$ Isomer in ^{217}Ac

D.J. Decman*, H. Grawe*, H. Kluge*, K.H. Maier*, A. Maj*, N. Roy*, Y.K. Agarwal**, K.P. Blume**, M. Guttormsen, H. Hübel** and J. Recht**

This study extends the knowledge about $N = 128$ isotopes with odd Z beyond previously studied ^{211}Bi, ^{213}At and ^{215}Fr. Of particular interest in this region is the rapid transition from shell model structure at $N = 126$ to well deformed shapes at $N = 132$ as known from the radium isotopes.

The nucleus ^{217}Ac was studied at VICKSI using the ^{205}Tl(^{16}O,4n), ^{206}Pb(^{15}N,4n) and ^{209}Bi(^{12}C,4n) reactions. The comprehensive studies included α-γ, γ-γ, α-e and e-e coincidence experiments as well as γ-ray and α-particle pertubed angular distribution measurements. Here we found the shortest known α-decay of a ground state with $T_{\frac{1}{2}}(^{217}Ac^{gs})$ = 69±4 ns. The g-factors were measured with the DPAD method both by observing γ-rays as well as α-particles, and gave $g(^{217}Ac^{gs}) = +0.85\pm1$ and $g(^{217}Ac^{m}) = +0.347\pm5$.

As shown in fig. 6.26 the $29/2^+$ isomer with $T_{\frac{1}{2}}$ = 740±40 ns decays mainly by γ-cascades, but also by α-emission to the single particle states $\pi h_{9/2}$, $f_{7/2}$, $i_{13/2}$ of ^{213}Fr. In fig. 6.27 is shown γ-ray transitions in coincidence with the E_α = 9.65 MeV α-decay of the ground state.

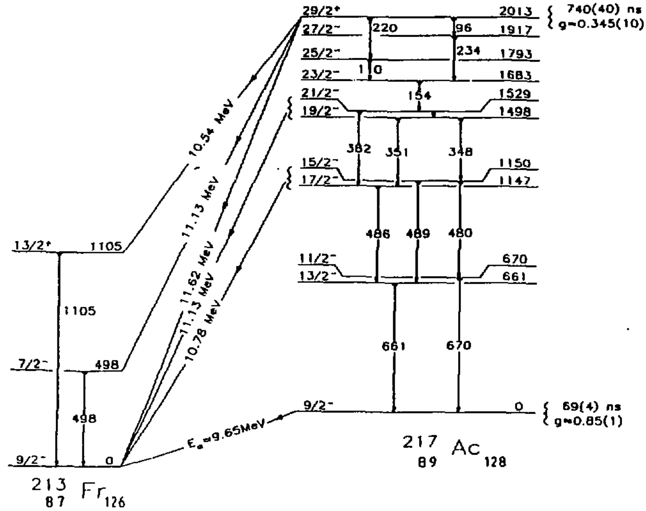

Fig. 6.26 The decay scheme of $^{217}Ac^{m}$.

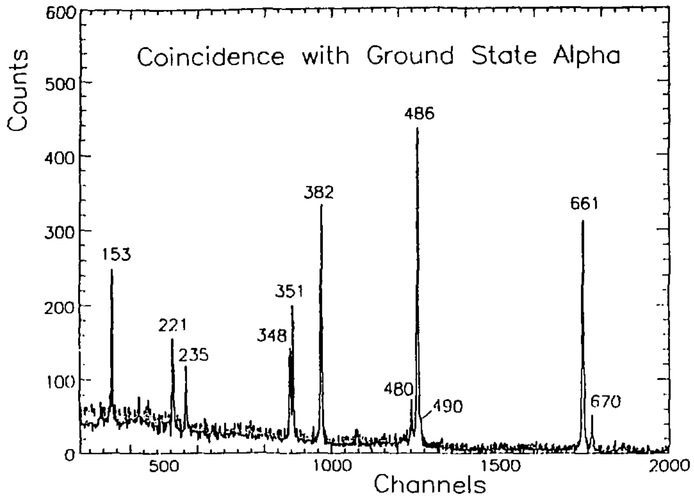

Fig. 6.27 Higher γ-ray energy part of γ-rays delayed to the beam burst and in coincidence with the subsequent α-decay of $^{217}Ac^{gs}$.

The results reveal that ^{217}Ac has a close similarity with the ^{215}Fr nucleus. The known levels in both nuclei can be fairly well explained by the shell model. No evidence is seen for a transition to deformed shapes, as found for nuclei with slightly higher neutron numbers.

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6.2.4 Gamma-Ray Spectroscopy of ^{89}Y

J. Kownacki*, T. Batsch*, Z. Zelazny*, M. Guttormsen, T. Ramsøy, and J. Rekstad

The almost spherical ^{89}Y nucleus has a neutron magic number of N = 50. The high spin states are assumed to be built on the $\pi g_{9/2}$ structure coupled to the $\nu g_{9/2}^{-2}$ configuration. These orbitals are deformation driving and one aim of our study is to investigate the excistence of shape-changes as a function of spin in this mass region.

The first tentative experiments have been performed using the $^{87}Rb(\alpha,2n)^{89}Y$ reaction with 28 MeV α-particles delivered from the Oslo cyclotron. In all 4 Ge(Li)- and 2 NaI-counters were used in the γ-ray coincidence experiment. Also the angular γ-ray distributions were measured at this beam energy. In order to obtain information on the various reaction channels and the spin of certain transitions, γ-ray excitation functions were measured at 24, 26, 28 and 30 MeV of beam energy.

Fig. 6.28 shows a Compton-suppressed Ge(Li) spectrum taken at 90° with E_α = 28 MeV. The far strongest transition is due to the deexcitation of the $9/2^+$ isomer ($T_{1/2}$ = 16.1 s) down to the $1/2^-$ ground state with a γ-ray energy of 909.7 keV. This isomeric state corresponds to the $\pi g_{9/2}$ configuration. The data analyses are in the very beginning.

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* Institute of Experimental Physics, Warsaw University, Poland

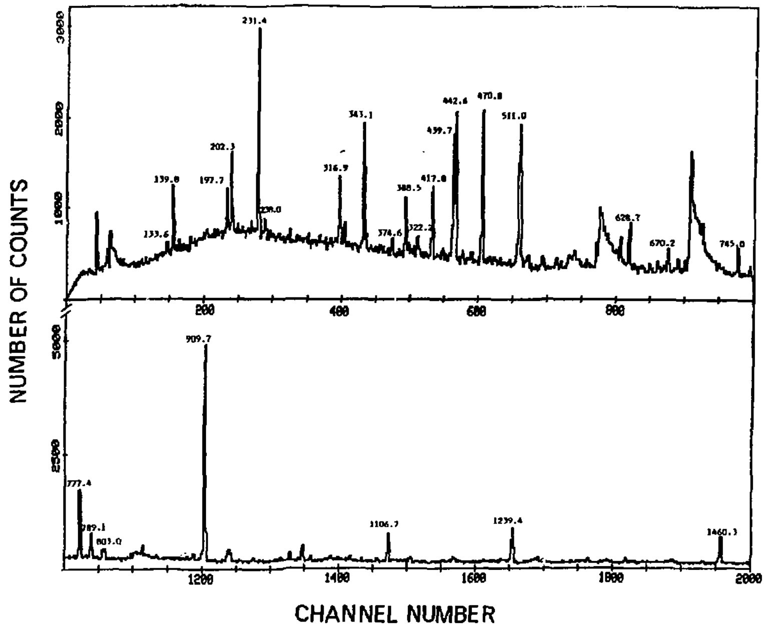

Fig. 6.28 Compton-suppressed γ-ray singles spectrum obtained with 28 MeV α-particles on ^{87}Rb.

6.3 Delayed Particle Emission

6.3.1 Beta-delayed Proton Emission

S. Messelt, J. Äystö[*], J. Honkanen[*], P. Taskinen[*], K. Eskola[**], A. Hautojärve[**]

Two beam periods were scheduled for these experiments last year. Most of the time were used trying to measure beta-delayed protons from ^{55}Ni and ^{54}Ni produced by ^{3}He + ^{54}Fe. Very little results were obtained, however, partly due to many problems with the computer and the cyclotron.

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[**] Dept. of Physics, University of Helsinki, Finland

7 THEORETICAL NUCLEAR PHYSICS

The aim of our work in nuclear theory is to understand the many features of nuclear structure revealed in nuclear reactions. Some efforts are devoted to the calculation of nuclear properties from first principles. This involves calculating the effective interaction and other effective operators from the free nucleon-nucleon interaction, using many-body perturbation methods. However, our nuclear structure work also employs phenomenological models, such as the shell model and various collective models. In particular, much work has been devoted to the particle-rotor model and is closely associated with our experimental work. A new interest added to our program during the last few years is the structure of highly excited states studied experimentally in the cyclotron laboratory.

7.1 Many-Body Theory

(The group is on leave at State University of New York, Stony Brook, N.Y.)

7.2 Collective Models

7.2.1 The Particle-Rotor Model and the Coriolis Attenuation problem in ^{167}Er

H. Hagen and T. Engeland

In our Annual Report 1983 we discussed this project and the initial details were formulated. Here we present our final results.

The rare-earth nucleus ^{167}Er is a particular interesting case to study Coriolis effects since experiments have revealed three rotational bands with $K = 5/2^+$, $7/2^+$ and $9/2^+$, all originated from the $i_{13/2}$ intruder orbit. Our calculation of the energy spectrum is based on two theoretical models: (1) The well-established Particle-Rotor Model with the BCS approximation for the pairing effect - in the following referred to as PRM. (2) Our alternative Particle-Rotor Model where the pairing effect is treated in more detail than the BCS approximation allows - in the following referred to as PPR.

It is well known that PRM usually requires an ad-hoc Coriolis reduction factor in order to reproduce the experimental data. The challenge and interesting question is to investigate to what extend PPR can reproduce the experiments without such a Coriolis reduction factor.

In fig. 7.1 we have collected our present results. We display four different cases: (A) PRM with the pairing delta, Δ = 1000 keV. (B) PRM with Δ = 650 keV. (C) PPR with the "Fermi surface" at the Nilsson orbit $[663]7/2^+$. (D) PPR with the "Fermi surface" at $[521]1/2^-$ which is located between the orbits $[642]5/2^+$ and $[663]7/2^+$. From the experimental odd-even mass differences the pairing delta can be calculated to Δ_{exp} = 667 keV. Thus, the case (B) should be the most realistic one of the two PRM calculations. The "Fermi surface" in the PPR calculations refers to the orbit of the last odd particle without pairing interaction. The single-particle Nilsson spectrum is shown in Table 7.1 and is based on standard parameters for this region[1]: χ = 0.0637, μ = 0.42, ε_2 = 0.267 and ε_4 = 0.015.

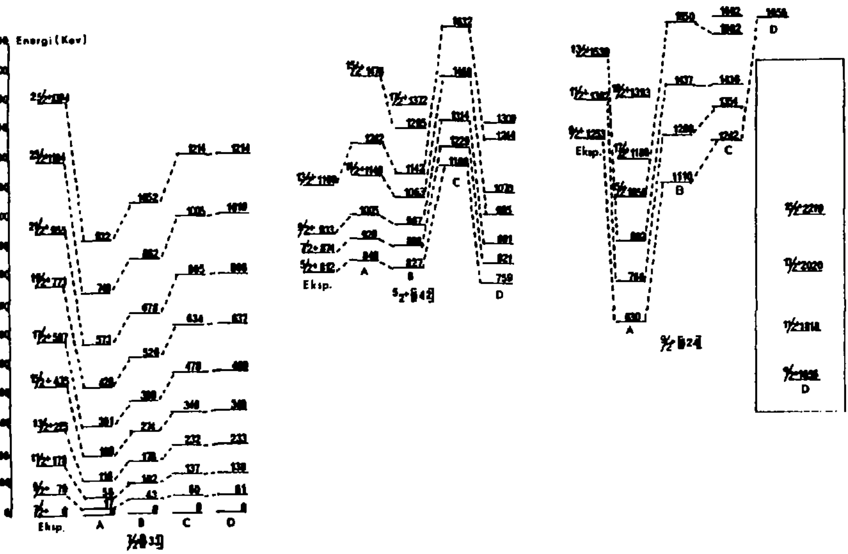

Fig. 7.1 Calculation of the energy spectrum of ^{167}Er and compared to experimental data. Details about the different cases are explained in the text.

$\Omega\pi\,[N n_3 l_z]$	Relativ energi [MeV]	Kvadrupol moment [$\hbar/m\omega_0$]	Nilssonamplituder C_j 13/2	11/2	9/2	7/2	5/2	3/2	1/2
3/2-[532]	0.000	1.324		0.286	0.675	0.479	-0.418	-0.243	
1/2+[660]	0.580	2.834	0.904	-0.018	-0.405	0.015	0.124	-0.012	-0.028
3/2+[651]	1.004	2.438	0.922	-0.050	-0.372	0.032	0.089	-0.012	
11/2-[505]	1.183	-5.000		1.000					
3/2-[521]	1.257	1.495		-0.242	0.822	-0.680	-0.103	0.266	
5/2-[523]	1.784	-0.058		-0.328	-0.308	-0.863	-0.228		
5/2+[642]	1.804	1.651	0.946	-0.073	-0.312	-0.033	-0.044		
1/2-[521]	2.862	2.765		0.176	0.568	0.402	0.071	0.449	-0.483
7/2+[633]	2.967	0.468	0.969	-0.087	-0.231	0.029			
5/2-[512]	3.288	0.046		-0.037	0.905	-0.365	-0.214		
7/2-[514]	3.953	-1.523		0.146	0.952	0.287			
9/2+[624]	4.481	-1.148	0.987	-0.088	-0.137				
1/2-[510]	5.582	3.836		-0.077	0.498	-0.310	0.544	-0.564	-0.196

Table 7.1 The single-particle Nilsson wave functions. The parameters are given in the text.

The Coriolis effect is not as strong in ^{167}Er as found in more transitional-like nuclei, see for example ^{163}Er, ref.[2]. Thus the PRM calculation without Coriolis reduction does not invert the spin sequences compared to experiment. But the effect is seen as a compression of the states in the ground state rotational band. Some improvement is obtained from case (A) to (B) but the deviation is still clear. The two PPR calculation (B) and (C) show a definite improvement on this point but the Coriolis coupling is also here too strong. Within the framework of the two models we can define Coriolis reduction factors, for details see eq. (3.3) in ref.[2]. In table 7.2 we give the results for the four different cases. The improvement in the spectrum from (A) to (B) is due to an increased Coriolis reduction between [642]5/2$^+$ and [633]7/2$^+$, from 0.94 to 0.86. In PPR a further reduction is obtained. However, the result is very sensitive to the "Fermi surface". In (C) a large reduction is found between the 7/2$^+$ and 9/2$^+$ bands whereas the value between the 5/2$^+$ and 7/2$^+$ bands is essentially the same as in (B). In (D) it is opposite. The same sensitivity has been found in an earlier analysis[3] of ^{235}U. We believe that a satisfactory agreement with experiment requires that both reduction factors should be small simultaneously.

The excited bands show similar discrepancies. The PRM has some difficulties to reproduce the band-head properly due to a too strong Coriolis coupling with the ground band. In PPR case (C) reproduces well the $9/2^+$ band but not the $5/2^+$ band. Again case (D) shows the opposite feature and the reason is the Coriolis reduction factors. In conclusion, PPR does not satisfactorily describe the spectrum of ^{167}Er and further work should be done. We have tried to add a quadrupol pairing term which did not improve the result.

Table 7.2. The Coriolis reduction factors

	[660]1/2$^+$ [651]3/2$^+$	[651]3/2$^+$ [642]5/2$^+$	[642]5/2$^+$ [633]7/2$^+$	[633]7/2$^+$ [624]9/2$^+$
(A)	1.00	1.00	0.94	0.84
(B)	1.00	1.00	0.86	0.84
(C)	1.00	0.97	0.88	0.74
(D)	1.00	0.94	0.65	0.96

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(1) G. Løvhøiden, P. Tjøm, and L.O. Edvardson, Nucl. Phys. A194 (1972) 463

(2) T. Engeland, Phys. Scripta 25 (1982) 467

8 OTHER FIELDS OF RESEARCH

8.1 Production of Radionuclides for Medical and Technical Applications

T. Holtebekk and T. Bjørnstad

A prosject for application of the cyclotron for other fields than nuclear physics, especially for production of radionuclides for medical and technical use, was, with financial aid from NAVF, started in 1980. It was limited to a three years period, which expired by the end of 1983. In spite of considerable effort it has not been possible to obtain further economical support for the project.

The production of $^{81}Kr^{m}$-generators which evolved from this prosject, has, however, continued during the year with weekly delivery of one generator to Ullevål Hospital. At the end of the year the production was stopped due to lack of technical aid for maintainance of the equipment and performance of the production.

8.2 Thermoluminescent Dosimetry

A. Storruste and T. Strand

For the purpose of introducing thermoluminescent dosimetry as a supplement to film for personnal monitoring, various phosphors and holders have been tested. For general monitoring at the University the Harshaw TLD-100 LiF, the Harshaw 3000 A TLD system and the Studsvik holders were chosen. The equipment, our ^{137}Cs standard gamma-ray source together with the amount of scattering from the walls of our calibration room, were calibrated against equipments at the State Institute of Radiation Hygiene (SIS). A method for monitoring beta-radiation using the Studsvik holders was introduced. Various holders, when using combinations of TLD-600 and TLD-700 to monitor neutrons, have been examined and calibrated.

As an introduction to a countrywide investigation of the natural gamma-ray radiation in Norwegian houses, various phosphors and holders have been examined. Of the various commercial phosphors available CaF_2:Dy was chosen. This project will continue in collaboration with SIS.

T. Strand, Thermoluminecent Dosimetry (Cand.Scient. thesis 1984, In Norwegian).

8.3. Solar Energy Research

8.3.1 Solar Heating Systems under Development

M. Mehlen, J. Skjæret, J. Rekstad

a) Project "Soltun" in Moss, seven low-energy houses.

This project is initiated by Østfold Power Company, and is described in more details elsewhere[1,2]. We were involved on an early stage to calculate the expected energy gained from the solar system. On this background the houses were decided to be buildt. For more technical and practical solutions, the Norwegian Institute of Building Research (NBI), was involved as consultants. Their analysis based on a normal-year-climate data set, indicated an energy gain of 6400 kWh/year. The solar system is optimized with respect to the need for energy and the structure of the buildings. A construction firm has submitted an offer on the price of the houses, where the solar energy system can be set up to the cost of ca. 25 000 kr. This means that the solar energy price will be as low as 0.35 kr/kWh.

One of us (J.R.) is engaged as a solar system consultant, and the research group will be responsible for installation of data-logging equipment and analysis.

b) Solar hot water system at the ZEB-building

During the year there has been mounted 90 m^2 double-plate collectors at this building. (Inclination = 55^o, south $+15^o$). The system is analysed and described elsewhere[2,3]. The collector system is connected to a heat exchange system, which consists of three units: 1 m^3 water tank, 0.8 m^3 double tank and a plate heat-exchanger. Fig. 8.1 gives an overview of the system. The last unit will be used in order to get maximum temperature decrease in the collector fluid before returning to the panels.

There has been performed several tests on heat exchangers on laboratory scale. By these tests we were able to rule out some alternatives which turned out to have poor thermal characteristics.

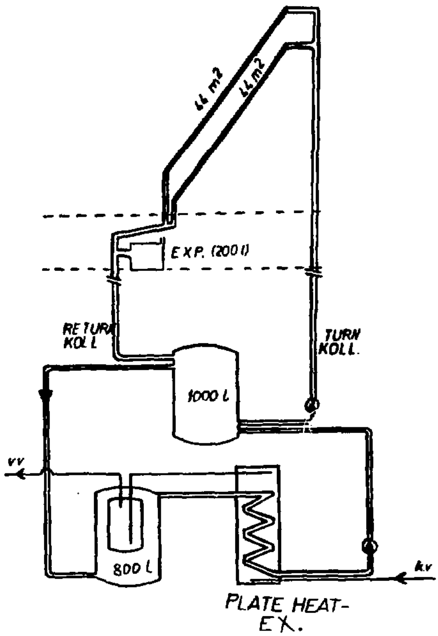

Fig. 8.1 View of solar system for hot water production at the ZEB-building. Cold water (k.v.) is fed into the plate heat exchanger in order to reduce the fluid temperature before returning to the panels.

Computer simulation on the decided system gives a yield of 25 000 kWh/year. This represents an annual coverage of 54 %.

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1) Annual report 1983. Report 84-19, Institute of Physics, University of Oslo

2) Årsrapport 1983-84, Solenergiforskning. Report 84-32, Institute of Physics, University of Oslo (in Norwegian)

3) Annual report 1982. Report 83-19, Institute of Physics, University of Oslo.

8.3.2 Measurements on Solar Energy House in Drammen

M. Mehlen, J. Rekstad, J. Wikne, J. Skjæret

This is an air-based solar system for room heating and domestic hot water production. The house is buildt on initiative of the Drammen Community's Power Company[1,2]. Measurements have been taken during 1983-84. The results[2] show a coverage of 23 % (1000 kWh) during Sept.-Dec. 1983. The results for 1984 are about to be published (Feb. 1985).

As a rough estimate, we expect a yearly gain of 2000-2500 kWh.

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1) Annual report 1982. Report 83-19, Institute of Physics, University of Oslo
2) Årsrapport 1983-84, Solenergiforskning. Report 84-32, Institute of Physics, University of Oslo

8.3.3 Other Solar Energy Projects

M. Mehlen, J. Skjæret, J. Rekstad

We have installed double plate collectors in a couple of other houses:

a) O. Næssets's house in Drammen. This is a system for domestic hot water production. The panels cosists of 10 m^2 double plate collectors connected to a 250 liters st. age tank (preheater).
b) "Housing in the Future", in Kristiansand, southern Norway. This is a low-energy house, with partly passive solar heating and partly domestic hot water production. The research group has installed double plate collectors, about 15 m^2. The house is situated in a housing exhibition area, and is buildt by the contracting firm T. Furuholmen A/S.

8.2.4 Data Acquisition System Developments

J. Wikne and student M. Wangen

We refer to earlier reports[1,2] for description of the general GPIB-based data acquisition system, which have been developed on this project. An extensive documentation is found in ref[3]. The equipment has been used for data logging in a solar energy house, (see 8.2.2). During 1984, work has been concentrated on adaption of the acquisition system on a new micro-computer, the TIKI-100.

In connection to the data logging device, one graduate student made his thesis on software development for use in data analysis. This program system is designed to manipulate "raw" data and to present results graphically. The analysis can be carried out on the same computer that performed the data acquisition.

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1) Annual Report 1982. Report no 83-19, Institute of Physics, University of Oslo.

2) Annual Report 1983. Report no 84-19, Institute of Physics, University of Oslo.

3) J. Wikne, Report 83-13, Institute of Physics, University of Oslo.

8.4 Wet Breathing Gas

N.T. Ottestad and A. Storruste

The project Wet Breathing Gas[1] was started in 1978 when Cand.Real. N.T. Ottestad was a member of the staff at the University of Oslo. Later on Ottestad has erected his own firm: Ottestad Breathing System A/S, Tønsberg, for the purpose of producing equipments for divers in cooperation with the firm Vinghøg Mek. Verksted A/S, Tønsberg. The main participator during the testing of the equipments has been NUTEC (Norsk Undervannsteknologisk Senter, Bergen). The project has been financially supported by NTNF (Royal Norwegian Council for Scientific and Industrial Research).

The basic idea was to eliminate the divers respiratory heat loss by using saturated, warm breathing gas. Thus we expected to improve the divers physiological conditions at intermediate and large depths, and also to extend the actual depth for dry-suit diving.

A lot of experiments have been carried out with breathing gas temperature of 37 - 40 °C. The experiments strongly indicate that moisted, warm breathing gas (compared to traditional conditioned breathing gas) contributes to the maintenance of the divers heat balance, mental ability and lung functions. Three university students have been doing their graduate work on these experiments which have been carried out in the facilities of NUTEC and Dykker og froskemannskolen, Bergen.

The experiments have shown that the respiratory heat loss probably can be eliminated at any depth - without discomfort for the diver. Thus, thermal balance can be maintained with lower skin temperature (approx. 32-34 ^{o}C). The temperature of the hot-water in the hot-water suit can be lowered, and this should reduce problems with hot-water scolds. Alternatively, the hot-water suit may be replaced by an electric heated suit. The last alternative is assumed to be the best in the longer run and is the object for further studies. A scheme for a collaboration with the Solid State group at the Institute of Physics, and also with The Center for Industry Research (SI) for this project has been discussed on the assumption that financial support is granted.

Various modifications and improvements of the gas humidifier have been made. It is now quite effective and incorporated in a breathing system design for deep diving. The goal is to fulfill the requirements of NEDU for dives to depth of 500 m. The humidifier is patented in several countries: NO 140 173. A breathing regulator is patent-pending in several countries: Application NO 812 928.

The experimental activities is centered around the laboratory of Ottestad, Tønsberg. This year a 300 litre water tank for 10 atm pressure is completed and a breating simulator is built into the tank. With this device the equipment with its various components and various valves are modified in order to reduce the breathing resistance. Thus, using air at 10 atm, its density corresponds to $He-O_2$ breathing gas at a depth of 650 m.

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1) Norwegian Underwater Research News, No 1, 1980 p. 10.

9 SEMINARS AND LECTURES

Date

06.01 J. Gomez, Spain: Fermionic Structure of Interacting Bosons in ^{20}Ne.

26.06 D. Strottman, Los Alamos National Laboratory: High-Temperature Nuclear Matter from $\bar{P}$-Annihilation and Relativistic Heavy Ions.

24.08 T. Ramsøy: First Generation Gamma-Ray Spectra from Transfer Reactions.

31.08 S. Messelt: External Pulsing of the Cyclotron Beam.

07.09 T. Engeland: Temperature Dependent Shell-Model Calculations.

14.09 T. Engeland: Temperature Dependent Shell-Model Calculations.

18.09 F. Janouch, FIA, Stockholm: Alpha-radioactivity - new Approaches to an old Problem.

21.09 L. Ihler: A Description of the new TONE-Version.

21.09 F. Sørensen: A Virtual Memory System for the Storage of External Spectra under SHIVA.

24.10 T. Engeland: Temperature Dependent Shell-Model Calculations.

13.11 O.K. Gjøtterud: Discussion of a Statistical Treatment of the Fermi Gas with Respect to Application on Quasiparticle Excitations in Nuclei.

16.11 O. Aspelund: Essential Differences between Non-Relativistic and Relativistic Spin-½ Particle Dynamics.

20.11 O.K. Gjøtterud: Discussion of a Statistical Treatment of the Fermi Gas with Respect to Application on Quasiparticle Excitations in Nuclei.

23.11 T. Engeland: Temperature Dependent Shell-Model Calculations.

27.11 O.K. Gjøtterud: Discussion of a Statistical Treatment of the Fermi Gas with Respect to Application on Quasiparticle Excitations in Nuclei.

30.11 T. Engeland: Temperature Dependent Shell-Model Calculations.

04.12 O.K. Gjøtterud: Energy and Temperature.

10 VISITORS

Long-term visitors are listed in Sect. 2, and guest lecturers in Sect. 9. The following visiting scientists have participated in experiments at the cyclotron:

University of Bergen:	G. Løvhøiden T. Rødland T. F. Thorsteinsen
University of Helsinki:	K. Eskola A. Hautojärvi
University of Jyväskylä:	J. Äystö J. Honkanen P. Taskinen
University of Aarhus	H. Knudsen P. Hvelplund
Research Institute of Physics, Stockholm	K.G. Rensfelt.

11 COMMITTEES, CONFERENCES AND TALKS

11.1 Committees and Various Activities

External committees and activities only are listed.

T. Engeland	Member of the board of the Norwegian Physical Society (NPS). Chairman of the Nuclear Physics Committee of NPS. Member of the Council of the European Physical Society (from April 15). Referee for Nuclear Physics and Physics Letters.
K. Gjøtterud	Secretary for Norwegian Friends of the Hebrew University, Jerusalem, and Norwegian-Israeli Research Fund. Referee for Nuclear Physics and Physica Scripta. Member of "International Committee of Scientists for Soviet Refusniks".
T. Holtebekk	Chairman of The Norwegian Standardization Organization Sub-committee for Technical and Physical Units.
F.Ingebretsen	Chairman of the Nordic Committee for Accelerator Based Research (NOAC). Deputy member of the Science Council of The Norwegian Research Council for Science and Humanities. Member of Energy Research Advisory Committe, Dept. of Oil and Energy. Referee for Nuclear Instruments and Methods.
S. Messelt	Referee for Nuclear Instruments and Methods.
E. Osnes	President of the Norwegian Physical Society. Member of the Advisory Committee of Nuclear Physics of NORDITA. Referee for Nuclear Physics, Physics Letters B and Physica Scripta.

J. Rekstad	Associate Editor Physica Scripta. Referee for Nuclear Physics. Member of a solar house committee in the community of Drammen as a representative for the Department of Oil and Energy. Member of a solar house committee in Østfold fylke. Course leader and lecturer on "Energy Planning and Environment" at the International Summer School of the University of Oslo. Member of the board of directors of Innovasjonssentret A/S. Member of a committee directed by Oslo Commune designing an "industriell green-house" in Oslo. Member of the committe of Chalmers University of Technology, Göteborg, Sweden, proposing the successor of professor Göran Andersson. Member of a research position committee at Statistisk Sentralbyrå.
R. Tangen	Member of the Norwegian Academy of Science.
P.O. Tjøm	Referee for Nuclear Physics.

11.2 Conferences

T. Engeland and M. Mehlen participated in the EPS General Conference, Prague, August 25-29, 1984.

M. Guttormsen participated in Workshop on Nuclear Structure with Heavy Ions, Risö, May 21-25, 1984.

T. Engeland, M. Guttormsen, F. Ingebretsen, M. Mehlen, E. Osnes and J. Rekstad participated in the Annual Meeting of Norwegian Physical Society, Bergen, June 4-7, 1984.

F. Ingebretsen, S. Messelt, J. Rekstad and P.O. Tjøm participated in 5th Nordic Meeting on Nuclear Physics, Jyväskylä, Finland, March 12-16, 1984.

F. Ingebretsen participated in First Meeting on Physics in Industry, Tammersfors, Finland, May 15-17, 1984.

J. Skjæret participated in Solar Energy Conference, Edinburgh, September 3-5, 1984.

J. Rekstad participated in the XIV Winter School on Physics, Zakopane, Poland, April 3-15, 1984.

J. Rekstad participated in 1984 EPS-conference on nuclear reactions, Crete, Grece, June 24-30, 1984.

J. Rekstad participated in CELSIUS-information meeting, Uppsala, Sweden, October 2, 1984.

J. Rekstad participated in Conference on industry and trade in Oslo, November 23, 1984.

11.3 Visits and Talks

T. Engeland and K. Gjøtterud: Visit at NORDITA, Copenhagen, October 29-November 2, 1934.

M. Guttormsen: Talk in Die Aktuelle Runde, HMI, Berlin, June 26, 1984: Nuclear Structure at Low Spin and High Temperature.

J. Rekstad: Lecture series on "Energy" at the International Summer School, University of Oslo, July 1984.

J. Rekstad: Talk at the Norwegian Academy of Science, "Norwegian Nuclear Physics - 50 years anniversary", Oslo, May 9, 1984.

J. Rekstad: Invited talk at the 5th Nordic Meeting on Nuclear Physics, Jyväskylä, Finland, March 12-16, 1984. "Nuclear Structure Effects in the Dy-nuclei at High Excitation and Low Spin."

J. Rekstad: Invited talk at the XIX Winter School on Physics, Zakopane, Poland, April 3-15, 1984. "Nuclear Structure Effects in the Dy-nuclei at High Excitation and Low Spin.

J. Rekstad: Talk at a meeting of Norwegian industry leaders, Industrifondet, Oslo, February 28, 1984. "Innovation - Perspectives in a closer Collaboration between Industry and the University".

J. Rekstad: Talk at a meeting of research leaders, Industrifondet, Oslo, April 25, 1984. "The Interplay between the Innovation Center and the Research Institutes."

J. Rekstad: Talk and panel discussion at Trondheim University of Technology, March 7, 1984. "How does Research for the Industry Affect the Teaching?"

J. Rekstad: Talk at a meeting about nordic cooperation on innovation, Industriforbundet, Oslo, July 6, 1984. "About the Innovation Center in Oslo".

J. Rekstad: Participation in a panel discussion on the relation between industry and the universities. Annual meeting, NPS, Bergen, June 5, 1984.

J. Rekstad: Talk at the 17th national meeting of information workers in universities and high-schools, October 4, 1984. "About the Innovation Center in Oslo".

J. Rekstad: Talk at a meeting of participants and owners of the Innovation Center, Industrifondet, November 9, 1984. "How can the Research Side Benefit from the Innovation Center?"

M. Mehlen: Talk at the Solar Energy Association, Norway, March 4, 1984.

J. Skjæret: Talk at the Solar Energy Association, Norway, November 29, 1984.

12 THESES, PUBLICATION and REPORTS

12.1. Theses

1. Ayse Atac:
   Nuclear Level Densities in a Pairing Model. Cand.Scient. thesis.

2. Helge Hagen:
   Coriolis Coupling in Deformed Nuclei. An Investigation of ^{167}Er. Cand.Scient. thesis (in Norwegian).

3. *Reidun Renstrøm Pedersen:*
   ^{162}Dy at High Energy and Low Spin. An Investigation by the Reaction ^{163}Dy (^{3}He, ^{4}He) ^{162}Dy. Cand.Scient. thesis (in Norwegian).

4. Terje Strand:
   Thermoluminescent Dosimetry. Cand.Scient. thesis (in Norwegian).

5. F. Sörensen (Electronics):
   A Virtual Memory System for Multi-Parameter Data Structures. Cand. Scient. thesis (in Norwegian).

6. Arnfinn Ruud (Nuclear Chemistry):
   Production and Separation of ^{81}Rb from ^{3}He-induced Reactions in Bromine. Cand.Scient. thesis (in Norwegian).

12.2. Scientific Publications

12.2.1 Nuclear Physics and Instrumentation

1. J.C. Bacelar, M. Diebel, C. Ellegaard, J.D. Garrett, G.B. Hagemann, B. Herskind, H. Holm, C.-X. Yang, P.O. Tjøm and J.C. Lisle: Single-Neutron States in Odd-N Ytterbium Isotopes and the Disappearence of Neutron Pair Correlations. Proceedings of the 5th Nordic Meeting on Nuclear Physics, Jyväskylä, Finland, March 1984

2. J.C. Bacelar, J.D. Garrett, G.B. Hagemann, B. Herskind, G. Sletten, R. Shapman, J.C. Lisle, J.N. Mo, J.C. Willmott, L. Carlén, J. Lyttkens, H. Ryde, W. Walus and P.O. Tjøm: A Microscopic Dissection of Pair Correlations from High Spin Studies. Contribution to 4th International Conference on Clustering Aspects of Nuclear Structure and Nuclear Reactions, Chester, UK. July 1984

3. T. Engeland: The Particle-Rotor Model. In "Collective Phenomena in Atomic Nuclei", Proc. Nordic Winter School on Nuclear Physics 1983 (World Scientific, Singapore, 1984)

4. M. Guttormsen, J. Rekstad, A. Henriquez, F. Ingebretsen and T.F. Thorsteinsen: Non-Statistical Cooling of Highly Excited ^{161}Dy Nucleus. Phys. Rev. Lett., 52 (1984) 102
   M. Guttormsen, H. Hübel, A.v. Grumbkow, Y.A. Agarwal, J. Recht, K.H. Meier, A. Maj, M. Menningen and N. Roy: A Superconducting Electron Spectrometer. NIM 22 (1984) 489

5. G.B. Hagemann, J.D. Garrett, B. Herskind, J. Kownacki, B.M. Nyako, P.L. Nolan, J.F. Sharpy-Schafer and P.O. Tjøm: Signature-Dependent M1 and E2 Transition Probabilities in ^{155}Ho and ^{157}Ho. Nucl. Phys. A424 (1984) 365

6. H. Hübel, A.P. Byrne, S. Ogaza, A.E. Stuchbery and M. Guttormsen: The Second and Third Backbending in ^{194}Hg. Phys.Lett. 145B (1984) 29

7. T.T.S. Kuo and E. Osnes:
Introduction to the Microscopic Theory of Giant Resonances.
In "Collective Phenomena in Atomic Nuclei". Proc. Nordic Winter School on Nuclear Physics 1983 (World Scientific, Singapore, 1984)

8. J.R. Lien, G. Løvhøiden, J. Rekstad, A. Henriquez, C. Gaarde, J.S. Larsen and S.Y. van der Werf:
High-Spin Particle States in ^{153}Sm Studied with the (α,^{3}He) Reaction.
Nucl. Phys., A412 (1984) 92

9. T. Ramsøy, J. Rekstad, A. Henriquez, F. Ingebretsen, M. Guttormsen, E. Hammaren and T.F. Thorsteinsen:
Deep-Lying $\nu h_{11/2}$ Hole States in ^{145}Nd.
Nucl.Phys. A414 (1984) 269

10. J. Rekstad, M. Guttormsen, T. Ramsøy, F. Ingebretsen, T.F. Thorsteinsen, G. Løvhøiden and T. Rødland:
Nuclear Structure Effects in the Dy-Nuclei at High Excitation and Low Spin.
Proc. 5th Nordic Meeting on Nuclear Physics, Jyväskyla, Finland March 1984. (Invited talk)

11. J. Rekstad, M. Guttormsen, T. Ramsøy, F. Ingebretsen, T.F. Thorsteinsen, G. Løvhøiden and T. Rødland:
Nuclear Structure Effects in the Dy-nuclei at High Excitation and Low Spin.
Proc. XIX Winter School on Physics, Zakopane, Polen, April, 1984. (Invited talk)

12. J. Rekstad, M. Guttormsen, T. Ramsøy, T.F. Thorsteinsen, G. Løvhøiden, F. Ingebretsen and B. Skaali:
Nuclear Structure Effects in the Decay of Highly Excited Low Spin States in Dy-nuclei.
Proc. Int.Conf. on Nuclear Physics, EPS, Creete, June 1984

13. J. Rekstad, B. Nordmoen, A. Henriques, F. Ingebretsen, S. Messelt, T.F. Thorsteinsen and E. Hammarén:
The (^{3}He,α) Strength Functions in Rare-Earth Nuclei.
Nucl.Phys. A417 (1984) 376

14. J.C. Wikne:
A GPIB-Based, Modular Data Acquisition System.
Interfaces in Computing, 2 (1984) 99

12.3 Scientific and technical reports

12.3.1 Nuclear Physics and Instrumentation

1. Nuclear Physics Group Annual Report.
   Report 84-19, Institute of Physics, University of Oslo

2. J.C. Bacelar, M. Diebel, C. Ellegaard, J.D. Garrett, G.B. Hagemann, B. Herskind, A. Holm, C.-X. Yang, J.-Y. Zhang, P.O. Tjøm and J.C. Lisle:
   Single Neutron States of High Spins in Ytterbium Nuclei. Evidence for the Quenching of Static Neutron Pair Correlations.
   Subm. to Nucl. Phys.

3. J.C. Bacelar, M. Diebel, O. Andersen, J.D. Garrett, G.B. Hagemann, B. Herskind, J. Kownacki, C.-X. Yang, L. Carlén, J. Lyttkens, H. Ryde, W. Walus and P.O. Tjøm:
   Configuration-Dependent Pairing and Deformation in ^{163}Er.
   Subm. to Phys. Lett.

4. T. Bjørnstad, T. Holtebekk, J.P. Rambæk and A. Ruud:
   Measurement of Mechanical Wear in Hydraulic Motors by Means of the TLA-technique.
   Report No IFE/KR/F-84/027

5. D.J. Decman, H. Grawe, H. Kluge, K.H. Maier, A. Maj, N. Roy, Y.K. Agarwal, K.P. Blume, M. Guttormsen, H. Hübel and J. Recht:
   Decay of the Ground State and the $29/2^+$ Isomer in ^{217}Ac and g-Factor Measurements by Perturbed Angular Distribution of α-Particles.
   HMI-report HMI-P 6/84 HF(1984) Berlin. (Subm. to Nucl.Phys. A)

6. M. Guttormsen:
   Gamma-Decay of Heated Nuclei.
   Workshop on Nuclear Structure with Heavy Ions, Niels Bohr Institute, Risø 21.5. - 25.5, 1984

7. M. Guttormsen, H. Hübel, A.V. Grumbkow, Y.K. Agarwal, J. Recht, K.H. Maier, H. Kluge, A. Maj, M. Menningen and N. Roy:
   A Superconducting Electron Spectrometer.
   Report 84-11. Institute of Physics, University of Oslo (In press, Nucl.Instr. and Methods)

8. M. Guttormsen, J. Rekstad, T. Ramsøy, F. Ingebretsen, G. Løvhøiden. T.F. Thorsteinsen and T. Rødland:
Neutron Emission in Highly Excitated Nuclei.
Norwegian Physical Society Meeting, Bergen 1984

9. H. Hübel, A.P. Byrne, S. Ogaza, G.D. Dracoulis, A.E. Stuchberg and M. Guttormsen:
Hocspinzustände in $^{190-184}Hg$.
Verhandlungen der DPG, Innsbruck March 1984, 951

10. H. Kluge, K.H. Maier, A. Maj, M. Menningen, N. Ray, H. Hübel, J. Recht and M. Guttormsen:
Hochspinzustände in ^{152}Er.
Verhandlungen der DPG, Innsbruck March 1984, 1052

11. A. Maj, M. Kluge, K.H. Maier, N. Roy, K.P. Blume. H. Hübel, J. Recht and M. Guttormsen:
Spectroscopy of $^{198,200}Po$.
Verhandlungen der DPG, Innsbruck March 1984, 1090

12. S. Messelt:
Pulse selection system for the Oslo Cyclotron.
Report 84-23, Institute of Physics, University of Oslo

13. T. Ramsøy, J. Rekstad, M. Guttormsen, A. Henriques, F. Ingebretsen, T. Rødland, T.F. Thorsteinsen and G. Løvhøiden:
Gamma-Deacy from Two-Quasiparticle States Populated in the $^{161,163}Dy$ (d,t) Reactions.
Report 84-30, Institute of Physics, University of Oslo.
(Subm. to Nucl.Phys. A)

14. J. Recht, Y.K. Agarwal, K.P. Blume, M. Guttormsen, H. Hübel, H. Kluge, K.H. Maier, A. Maj, N. Roy, D.J. Decman, J. Dudek and W. Nazarewicz:
High-Spin Structure in ^{169}W.
Preprint ISKP, University of Bonn, 1984

15. J. Rekstad, M. Guttormsen, T. Ramsøy, F. Ingebretsen, T.F. Thorsteinsen, G. Løvhøiden and T. Rødland:
Nuclear Structure Effects in the Dy Nuclei at High Excitation and Low Spin.
The 5th Nordic Meeting on Nuclear Physcis, March, Jyväskylä, Finland, March, 1984 and The XIX Winter School on Physics, Zakopane, Polen, April 1984

16 J. Rekstad and T. Vaagen:
Outlook for Norwegian Nuclear Physics in the nearest 5 years.
Report 84-03, Institute of Physics, University of Oslo (in Norwegian)

17. J. Simpson, P.D. Forsyth, D. Howe, B.M. Nyako, M.A. Riby, J.F. Sharpy-Schafer, J. Bacelar, J.D. Garrett, G.B. Hagemann, B. Herskind, A. Holm and P.O. Tjøm:
Signature-Dependent Proton Alignments at High Rotational Frequency and the Persistence of Proton Pairing Correlations.
Phys. Rev. Lett. (in press)

18. J.C. Wikne and F. Ingebretsen:
A NIM Module for Efficient Amplifier Pile-up Rejection.
Report 84-31. Institute of Physics, University of Oslo

19. J.C. Wikne:
Is BASIC "worse than nothing"? - Experience made with the data-acquisition program NITA for a microcomputer/GPIB system.
Abstract, Ann.Meeting, Norw. Phys.Soc,. Bergen 1984

12.3.2 Solar Energy

1. Research in Solar Energy at The Institute of Physisc.
Annual Report 1983/84.
Report 84-32. Institute of Physics. University of Oslo (in Norwegian)

2. M. Mehlen, J. Skjæret and J. Rekstad:
A new Integrated Solar Collector Design.
Report no.84-22. Institute of Physics. University of Oslo

12.4. Non-Scientific Publications

1. T. Holtebekk:
Kjerneenergi.
Aschehoug og Gyldendals store norske leksikon, Suplement 1984

2. J. Rekstad:
Innovasjonssentret i Oslo.
Intervju
Nytt fra universitetet nr.9 - mai 84

3. J. Rekstad:
Om samarbeid mellom industri og forskning. Innovasjonssenter i Oslo stiftet.
Pressekonferanse 20.10.1984.
Referert i Aftenposten og Norges Handel og Sjøfartstidende.
Intervju i NRK-Østlandssendingen

J. Rekstad:
Solvarmeanlegg.
Intervju i forbindelse med utstillingen "Bolig for fremtiden"
Kristiansand 1984.
Referert: ENØK-avisen fra OED, nr.2, 1984.

Reportasje "Bolig for fremtiden",
Aftenposten 1.6.84.

M. Mehlen, J. Skjæret and J. Rekstad:
Ny solfangerkonstruksjon kan gjøre solvarmen konkurransedyktig.
Teknisk Ukeblad nr. 21, 1984.