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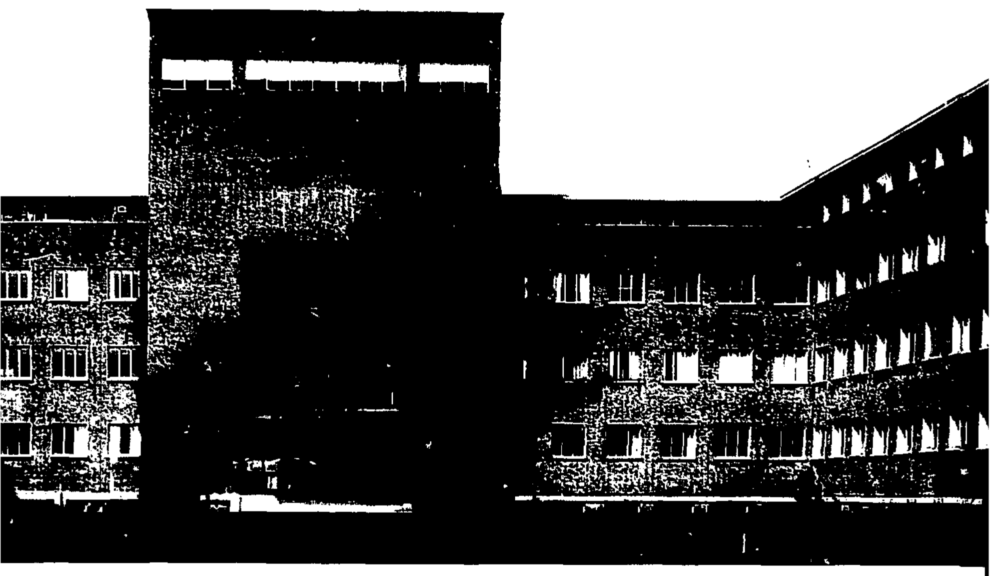
UNIVERSITY OF OSLO

DEPARTMENT OF PHYSICS

REPORT SERIES



SECTION
for
NUCLEAR PHYSICS
Annual Report

January 1 – December 31, 1987

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Contents

Chapter 1

Introduction

This annual report describes the activities at the Section for Nuclear Physics at The University of Oslo in 1987. It includes activities in experimental and theoretical nuclear physics, as well as other activities in physics which have occupied some of the members of the section.

The experimental activities in nuclear physics have, as in the previous years, mainly been centered around the Cyclotron Laboratory with the SCANDITRONIX MC–35 Cyclotron.

After eight years of more or less continuous operation it was now neccessary to perform an overall check and maintenance of the machine. Simultaneously the cooling system was altered. The open cooling water tower has been exchanged with a cooling machine, and the heat is regained and used for water heating in the heating system of the buildings. During the year the accelerator has only been used for test runs. The study of nuclear structure at high temperature has, however, proceeded with analysis of data accumulated in previous years.

Also during the year considerable effort has been made in order to prepare new experiments with a planned multidetector setup, CACTUS, consisting of up to 30 scintillation counters, four particle telescopes and one or two γ–ray Ge–detectors.

In February a new computer, SAMSON in the NORD–5800 serie, was installed as part of a deal between the firm Norsk Data and the Institute of Physics. The deal included that the Section of Nuclear Physics as well as other sections of the Institute should take part in the final test of the new computer.

Therefore considerable work has been put into adapting as well hardware as software to the new computer. Especially the planning of an VME–bus system for interfacing the multidetector system to the computer has proceeded throughout the year. The planning is done in close cooperation with the constructors of a similar system for the NORD–BALL project at the Niels Bohr Institute.

To ensure the diversity of our work we have also this year taken part in activities in some laboratories which have accelerators and instrumentation suitable for study of various problems. Thus we have maintained contact with the Niels Bohr Tandem Accelerator Laboratory at Risø and have started a cooperation with Kernfysisch Versneller Instituut in Groningen. In particular we are involved in the NORD–BALL project at the Niels Bohr Institute, where a complex detector arrangement is built up by contributions from the part–taking Nordic laboratories.

Theoretical studies of highly exited nuclei has continued. In this field there has been a fruitfull and inspiring cooperation between the experimental and theoretical physicists. The theoretical studies also enclose other problems within nuclear many–body theory in infinite nuclear matter and in limited systems.

In 1984 an evaluation of research in nuclear physics and chemistry in Norway, was made by an international panel appointed by the Council for Natural Science Research (RNF). In order to follow up the result of the evaluation, there has been further contact between members of the RNF and the nuclear research groups in Oslo and Bergen. So far this contact has resulted in the appointment by RNF of a National Commitee for Nuclear Research, NUK, (Nasjonalt utvalg for kjerneforskning) for the purpose of strengthening the national cooperation and getting optimal application and use of the national resources within the field.

Some of the members of the Section for Nuclear Physics have continued their participation in solar energy research. The study of solar heating systems for small houses and the development of simulating and analysing programs for heating systems in various types of houses has continued. A system for indoor hay–drying is studied and has been tested. 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 section members has, in cooperation with the National Institute of Radiation Hygiene (SIS) and the University Division of Occupational Health and Working Environment, continued his studies in radiation dosemetry and measurements of natural γ–ray background. Especially he has been involved in studies of radiation doses to the lungs after inhalation of radon gas and in measurements of the consentration of radon and radon daughter products in dwellings.

He has also taken part in a study of respirative 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 is demonstrated by the activity of graduate and post–graduate 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 four students in progress with their graduate work at the end of 1987, two are working in experimental nuclear physics, one in theoretical nuclear physics and one in electronics. Three Dr.Scient. students work in the field of experimental nuclear physics. In 1987 two students in experimental nuclear physics, two in theoretical nuclear physics and one in electronics completed their Cand. Scient. studies. One candidate completed his Dr. Scient studies at SIS.

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-funds, although relatively small, has made the collective use of the various resources available in Scandinavian accelerator laboratories more efficient. Furthermore, 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 our section visiting Copenhagen. The work in solar energy research has been made possible by support from various sources, especially from the Ministry of Petroleum and Energy, the Ministry of Environments and the Royal Norwegian Council for Scientific and Industrial Research (NTNF).

On the personnel side we give our thanks to our technical staff, E. A. Olsen and A. Kunszenti, for their untiring and persistent efforts to keep the cyclotron and other equipment in operation. Also the invaluable work of the members of the Section for Electronics and Measurements: B. Skaali, J. Wikne and G. Midttun on the computer and data acquisition system is highly appreciated.

Collaboration with physicists from Bergen and from Finnish and Polish laboratories has served as a stimulating effect to the work in the cyclotron laboratory. We thank them for valuable discussions during the year.

Blindern, April 1988

Trygve Holtebekk

Leader of the Section for Nuclear Physics

Chapter 2

Personnel

2.1 Research Staff

Ayse Atac, Research ass.
Torgeir Engeland, Assoc. prof.
Ivar Espe, Assoc. prof.
Ole Kristoffer Gjøtterud, Assoc. prof.
Magne Guttormsen, Assoc. prof.
Trygve Holtebekk, Assoc. prof. (Section Leader)
Finn Ingebretsen, Assoc. prof. (Head Physics Departement)
Svein Messelt, Assoc. prof.
Eivind Osnes, Professor
Tore Ramsøy, Research ass. (to May 31.)
John Rekstad, Professor
Anders Storruste, Senior scientist
Roald Tangen, Prof. emer.
Per Olav Tjørn, Professor
Trine Spedstad Tveter,Research ass. (NAVF) (from Sept.1.)

2.2 Technical Staff

Eivind Atle Olsen, Section engineer
Agnes Kunszenti, Section engineer (to Oct. 31.)
Tore Ramsøy, Section engineer (from June 1.)

2.3 Cooperators, Research Staff at Section for Electronics and Measurement

Gisle Midttun, Assoc. prof.
Bernhard Skaali, Professor
Jon Wikne, Section engineer

2.4 Visiting Scientists

Zbigniew Zelazny, on leave from Institute of Exptl. Physics, University of Warsaw, Poland (to Aug. 31.)

2.5 Students

As of December 31, 1987, 4 graduate students (for the degree Cand. Scient.) and 3 post-graduate students (for the degree Dr.Scient.) were associated with the section.

Chapter 3

The Cyclotron

3.1 Operation and Maintenance

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

The cyclotron was shut down for routine maintenance in December 1986. At that time several minor faults had been noticed. Especially the oscillator system was out of balance and some leakages in the vacuum system had been recorded. The cyclotron had then been in use since 1979 with only minor stop periods for maintenance work. The total running time amounted to about 8 000 hours. It was now found neccessary to undertake an overall check and maintenance of the machine.

A shut down of the cyclotron at this time also coincided with the installation of the new computer, which required considerably effort from the cyclotron staff. Furthermore the installation of a new cooling system for the cyclotron would bring the cyclotron to a stop for some periode during the year. However, to some extent scientific work could proceed by the analysis of a considerable amount of data that had been accumulated during the previous years.

In addition to the installation of the new computer the construction of a new multidetector system, CACTUS, has been given high priority.

As the maintenance work proceeded, it appeared to be more excessive than expected. By the end of the year there still remains unsolved problems with the oscillator system.

3.2 The Cyclotron Water Cooling System

T. Holtebekk and E. A. Olsen

The cyclotron was installed with the cooling water circulating in an open system through a water cooling tower. The system has, however, functioned rather badly. The return water has been carefully cleaned and filtered and chemicals has been added in order to inhibit growth of alges and neutralise and demineralise the water. In spite of this we noticed considerable dirt in the water and sedimentation in the cooling circuits. This resulted in insufficient cooling and overheatment of some of the electronic parts. A change of the cooling system therefore was imperative.

The electric power of the cyclotron, that is taken away by the cooling system, amounts up to 400 kW during running periodes. Instead of vasting this energy, it was proposed to use it in a heat regaining system. A spesial allowance from the Government ENØK program (Energi Economizing program) of kr 360 000.- made it possible to innstall such a system.

The system consists of an Hitachi RCU 100 SYI cooling machine with a cooling capasity of 370 kW. It is working with a water inlet temperature of 27°C and an outlet temperature of 15°C on the cooling water side and with inlet temperature of 35°C and outlet temperature of 45°C on the hot water side. The power consumption of the cooling machine is 90 kW. The hot water is used for preheating of consumption water and for heating of fresh air to the University buildings. Alternatively, when there is no need for heating, the hot water is sent to a dry cooler on the roof of the building.

The installment cost of the system is approximately kr 500 000.- The estimated annual saving of electric energy is, depending on running time and weather conditions, estimated to be between 200 and 300 MWh, corresponding to an annual reduction of between kr 50 000.- and kr 100 000.- on the electricity bill. Meassurements of the efficiency of the heat regaining system is now in progress.

Chapter 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 super–minicomputer with the CAMAC interface standard. The configuration is:

NORD–5800 computer with:
SINTRAN III operating system
20 Mb memory, 384 Kb cache memory

1	420 Mb disk drive
1	70 Mb removable cartridge
1	Floppy disk drive, high density
1	MT unit, 1600/6250 BPI
1	HP–7550A graphics plotter
1	Philips GP 300 printer
1	Genicom 340 line printer
1	Texas Instruments Omni–800 printer
1	Epson LX–80 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
30	Terminal connections via the local area network, NET/ONE
1	Ethernet connection, TCP/IP software
1	X.25 connection, Coloured Books file transfer protocol

4	Local terminals
3	CAMAC crates
15	ADCs interfaced via CAMAC, controlled in multiparameter mode by an ADC scanner module.

4.1.2 Data Acquisition Hardware

T. Ramsøy, G. Midttun, B. Skaali, J. Wikne

No changes have been done in the CAMAC data acquisition hardware in 1987. The system will be replaced by a VME based data acquisition system.

4.1.3 The Uninterruptable Power Supply (UPS)

J. Wikne

To encounter problems with temporary malfunctions of the computer and the data acquisition system a 5 kVA UPS, model Alpes 50, from Merlin Gerin, was purchased and installed in 1985[1]).

During the testing period of the new ND–5800 computer in 1987, a curious problem in connection with the UPS was discovered. The ND–5800, although only slightly more power–consuming than the old ND–10, seemed to provoke multiple breakdowns of the UPS. The technicians of the UPS supplier company were not able to correct this problem, which appeared to be due to an "overload" condition occurring at less than 80 % of nominal full load. Finally, the cause of the trouble was proved to be that the load of the more modern switch–mode power supplies of the ND–5800 gave a drastically lower $\cos\phi$ factor than that of the old computer's linear supplies. Thus, although the manufacturer was reluctant to admit it, the UPS did not conform to its original specifications.

With these problems at hand, together with the desire to accommodate future expansions of our computer and data acquisition facilities, it was decided to trade in the old UPS for a new, modern 10 kVA version from the same company. Their new design is technically much better as far as the $\cos\phi$ problem is concerned. Moreover, the firm was willing to give us a very nice trade–in price for the old UPS.

The new UPS became operative in December, and has been running painlessly since then.

References:

1. Nuclear Physics Group Annual Report 1985.
Institute of Physics Report **86–16** 13.

4.2 Data Aquisition Software

4.2.1 The Data Acquisition Program SHIVA

B. Skaali

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

The current version of SHIVA runs in the ND-120 front-end processor. The SHIVA system is comprised of a number of Real Time programs. The data acquisition is handled by special interrupt drivers that have been added to the SINTRAN operating system. The SHIVA programs have access to common data areas that contain 1-and 2-dimensional spectra (histograms). The communication between the programs is implemented by means of the real time facilities of the operating system SINTRAN-III.

The algorithms for sorting of multiparameter data are coded in an Algol-like language which is called TONE. This language has been described in previous annual reports. The TONE compiler generates executable machine code which is loaded as a procedure into the SHIVA system. The spectra which are defined by the sorting algorithm can be allocated in the ND-120 memory or on a virtual memory area on disc. The maximum size of this virtual memory is 512 K words. The access of spectra on the virtual memory is completely transparent for the user.

A ND-5800 version of SHIVA is under design. This program will in particular be used for analysis of multi-dimensional spectra where the large address space of this computer is needed. The data acquisition will also in the future be handled by the ND-120 front-end processor.

4.3 DAISY, a VME based data acquisition system

T. Ramsøy and B Bjerke

4.3.1 Introduction

A new data acquisition system for the Oslo Cyclotron Laboratory is under construction. The proposed system must be able to handle a high number of parameters, the counting rate is estimated to about 7000 counts/s.

As an instrumentation standard the VMEbus is chosen. The VMEbus is a further development of Motorolas VERSABUS implemented in the Eurostandard. The data width can be dynamically chosen as 8,16 or 32 bit, the address width is 16,24 or 32 bit. The maximum transfer speed on the bus is 32 Mb/s.

It is known that the bus often becomes a bottleneck in a multiprosessor system, subsequently subsystem buses have been introduced. In the VME consept a parallel bus, the VSB, has recently been implemented. A serial bus, VMS, is used for interprocessor communication.

A large number of VME modules are available from several vendors, reducing the prices considerably. The high performance combined with a modest price level makes the VMEbus our choise.

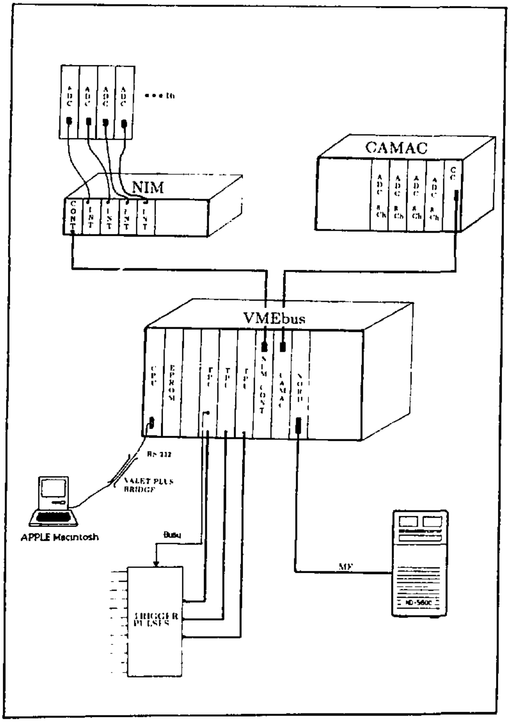

Figure 4.1: DAISY, A VME Based Data Acquisition System

4.3.2 Data acquisition architecture

A schematic drawing of the acquisition system is presented in fig.4.1. The CPU board handles the readout of the ADC's and formattes the data into an event list which is stored in the on-board memory. The event list will eventually be transfered to the ND–5800 super–minicomputer where on–line sorting and dump onto magnetic tape will be performed.

CPU:
The CPU board which will be used is the FIC 8230 from Creative Electronic Systems (CES). It is equipped with a MC68020 16 MHz microprocessor and its companion, the 68881 Floating Point Co–Processor. A 4 MB dual ported dynamic RAM (DRAM) is available with the module.

TRIGGER PATTERN UNIT:
The Trigger Pattern Unit is an interface between the experimental setup electronics and the VMEbus system. The module must be able to perform the following tasks:
- detection of an event
- generate a time window
- register which detectors that are part of an event
- transfer information to CPU on which ADC's to read out
- give interrupt to the acquisition system to initiate data readout

Such a module is at present under construction at the institute [1,2]. A block diagram for the TPU module is shown in fig.4.2. As can be seen from the figure the TPU has 16 inputs which is the maximum number of detectors a TPU can serve. However, several TPU's can be coupled together to serve any number of detectors. In order to coordinate the timing between the modules, one of them acts like a master end the others as slave modules. The master and the slave modules are quite similar, but in addition to the circuitry of the slave the master module has the following functions:
- Status register
- LED's to indicate the functions
- Pile–up input
- Inhibit output to block new events while the acquisition system is busy
- Program test of module

NIM ADC INTERFACE:
At present we have 14 NIM ADC's of SILENA 7420/G and 7411 type. These ADC's have very good characteristica as differential non–linearity ($< \pm 3\%$) and gain stability ($\leq 0.002\%\ ^0$C) is concerned. They are also quite fast, the conversion time is given as $T = (0.64 + 0.01 \cdot N)\mu$s for the 7411 and $T = (0.64 + 0.0025 \cdot N)\mu$s for the 7420/G. In applications where spectroscopic resolution is mandatory, these ADC's are usually considered to be the best

choice. In our system we will probably use such ADC's for the Ge counters and also for the particle detectors.

The interfacing of NIM ADC's to the VME system is developed at the Niels Bohr Institute [3]. The interface consists of three modules:

- VME–ADC INTERFACE
- VME–ADC CONTROLLER
- NIM–CONTROLLER

One such set of modules is able to handle 16 ADC's.

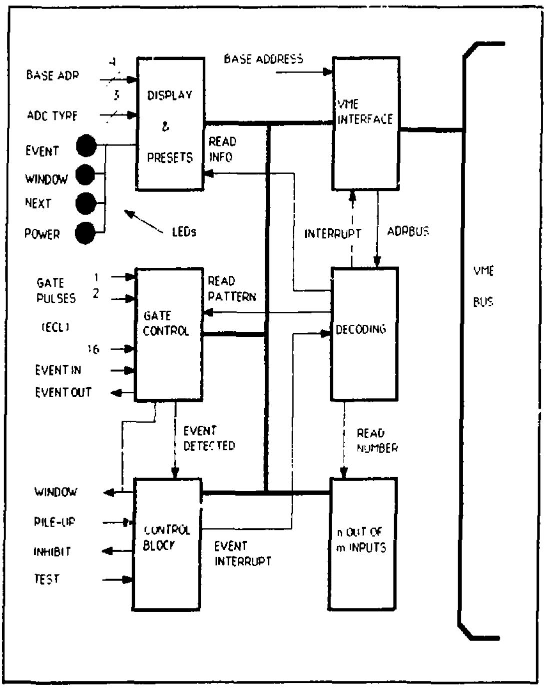

Figure 4.2: Trigger Pattern Unit (Master)

Each ADC is connected to its "VME–ADC INTERFACE" board through a 25 pin CANNON connector. These are controlled by the "VME–ADC CONTROLLER" which contains a slow timing unit. The time window is adjustable in the range from 1.5 to 50 μs. The unit has a time out set to 100 μs which is started by the trigger signal. If one of the active ADC's have not finished the conversion within the time out window, the event is skipped and the ADC's reset. The signals used to generate the pattern word are DATA READY* and DEAD TIME*. When DEAD TIME* has become active, it is latched into a mask register. If DATA READY* does not occur while DEAD TIME* is active, the mask register will be reset. Otherwise a bit in the pattern word corresponding to this ADC is set. After all the DATA READY* signals are present the CONVERT* signal will set up an EVENT READY flag which is detected by the "NIM-CONTROLLER".

The "NIM-CONTROLLER" is designed as a double heigth VME module and it is connected to the "VME-ADC CONTROLLER" by a flat cable using the 64 pins on the P2 connector allocated for user I/O. After detection of the EVENT READY flag it responds by sending a READ PATTERN signal. The module will then become master on the VMEbus and signal to the CPU by writing a semaphore to its on-board memory. The data readout is thus not initiated by interrupt on the VMEbus, instead polling is used. Since looping is restricted to the local memory only, heavy load on the bus is avoided.

We plan to use the NBI system in our own set-up without modifications. As we get the pattern word from the Trigger Pattern Unit, the pattern generated by the "VME-ADC CONTROLLER" is not needed and we will probably just skip it.

The PCB layout of the "VME-ADC CONTROLLER" and the "NIM-CONTROLLER" has been carried out at the institute on the Apollo DN-3000 workstations using the VISULA circuit design software from Racal-Redac.

CAMAC ADC INTERFACE:

Multichannel CAMAC ADC's with up to 48 channels are commericially available. The majority of these ADC's suffer from poor linearity and are rather slow with a typical conversion time of 50 μs. However, a 8 channel CAMAC ADC from Silena, 4418/V, with much better data has recently been introduced. This ADC has a mean conversion time of only 4 μs per active channel, and a non-linearity of less than 0.5 % . Inputs are in the ECLine standard. Due to the low price per channel, compared to the NIM ADC's, it is a good choise for the array of NaI detectors.

A VME to CAMAC link is available from CES. On the VME side a CAMAC Branch Driver (CBD 8210) which supports 16 or 24 bits data transfer from the CAMAC system is located. This module is connected to the CAMAC A2 Crate Controller (CCA2 2110) via cable.

The readout procedure of the CAMAC ADC's is not completely clear. The simplest and most time effective method will probably be to do the CAMAC readout after the NIM readout. At this time, the CAMAC ADC's will most probably have finished their conversion and LAM will be present.

If not, one can wait a period of time corresponding to the longest time which may occur, that is when all channels are active. With help of our pattern word, only the active channels in the event can be read out.

VME TO NORD LINK:
At present two different VME interfaces for ND–500/5000 computers are under development. Norsk Data are developing a DOMINO based module interconnecting VME devices to the MFbus (Multifunction bus) of the Nord computer [4,5]. (DOMINO is the name of I/O standard hardware and software architecture designed for the ND–500/5000 computers.) The VME device looks like a DOMINO to the MF system, and the MF system looks like a VME master to the VME device. The interface is equipped with a MC68020 processor. Unfortunatly, the module is designed to be "Master Only" in the VME system, hence the DIOC (DOMINO Controller) memory cannot be accessed from the VME bus. A prototype of the module together with the necessary software is expected the first quarter of 1988. In parallel, the french company MATRA DATASYSTEME are developing an interface, VME–MPM5 [6], which offers a direct connection between the Multifunction Bus System and the VME system. Data exchange from the VMEbus into the MFbus is done through a dual ported memory. The module offers a communication system by allowing interrupt between the two machines. The VME–MPM5 interface is composed of two boards, the VME 500 board is plugged into the MFB system crate on the Nord computer and the LDVME board is located in the VME crate. The boards are linked together with flat cables. Two prototypes are currently available from Norsk Data.

4.3.3 Software tools

As a development tool we intend to use the program language PILS (Portable Interactive Language System) written at CERN. This language has ANSI Minimal BASIC as a subset. It is, however, more powerfull as the modularity of the language allows large structured programs to be written in a sensible manner. It is also possible to incorporate routines written in other languages like FORTRAN or PASCAL. The code produced by the PILS compiler is efficient enough to be used in a real-time environment. Standard CERN libraries are accessible, the VMEbuslib provides access to physical memory. The PILS system and its libraries are stored in the VME system on EPROM's and can thus be started without time-consuming loading procedures.

User communication is provided through the VALET-Plus system which connects a personal computer, like the Apple MacIntosh, to the VME system. The application software executes in the MC68020 under the resident monitor MoniCa which is transparent to the user. The application programs have transparent access to all peripherals of the MacIntosh and the powerfull graphics of this PC can thus be utilised [7].

A MC68020 version of VALET–Plus/PILS is released in april 1988. The CPU board chosen to run this software is the FIC 8230/16 from CES.

References:

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4. S. Lied, Domino based MF–VME Interface, preliminary documentation, Norsk Data 1987.
5. Domino Standard Hardware Description, ND–14001.1 EN, Norsk Data 1987.
6. VME–MPM5 Interface, Hardware Spesifications and Programming Guide, preliminary documentation, Matra Datasysteme 1987.
7. T. Berners-Lee et al., The VALET–Plus, a VMEbus based microcomputer for Physics applications. IEEE Trans.Nucl.Sc., Vol.NS–34,4,1987.

4.4 Data Analysis Software

The following FORTRAN 77 programs are available for data analysis in addition to the SHIVA system:

CSMA:
Cranked shell model with asymetric nuclear shape.

DECAY:
Calculates the γ–decay for a Fermi gas system. The lowest excitation region is simulated using experimental data.

EMMA:
Calculates E1, M1, E2, M2 transition probabilities between single quasiparticle states from the RPC program (see below).

FOLD:
Folds γ–spectra with a NaI response function.

GAP:
Solves the BCS gap–equation.

HFBC:
Hartree–Fock–Bogoliobov Cranking model based on Nilsson orbitals from the RPC program (see below).

KINEMATIC:
Calculates relativistic energy loss at a given scattering angle. Bethes formula. Straggeling.

NUTE:
Fits first-generation γ–ray spectra with $E_\gamma^n \rho(E_x - E_\gamma)$. Estimates level density parameter and nuclear temperature.

PF:
Ge–spectrum manipulation program. Fast peak search, peak centroid and area estimation from observed data.

RPC:
Rotor particle coupling model based on Nilsson orbitals.

UNFOLD:
Unfolds NaI spectra with size up to 1024 channels by an iteration technique.

PROPLOT:
Plotting program based on the GPGS–F graphics package. Output on HP7550 flatbed plotter. Spectra stored on disc in Nordic format. Run on the ND–100 part of the computer.

PCPLOT:
Subset of PROPLOT. Output on IBM compatibel PC. Runs on the ND–100 part of the computer.

Chapter 5

Nuclear Instrumentation

Most of the available financial support for instrumentation in 1987 has been used for the ND–5800 computer installation. This investment is necessary in order to make complex experiments based on many–detector set–ups. The new computer system increases the data capacity with 20–30 times compared to the previous NORD–10/S computer. The new data acquisition system and corresponding software under development has been described in chapter 4 of this report.

At the end of 1987 it became clear that the Norwegian Research Council for Science and Humanities (NAVF) could support the CACTUS project (see below) with 1.77 mill kr. Much work have been devoted to the project and various activities have been initiated in the local workshops.

5.1 The CACTUS Project

M. Guttormsen and S. Messelt

The recent experimental work at the Oslo Cyclotron Laboratory has been devoted to the study of nuclear structure at high intrinsic excitation energy. The group has developed a very promising technique based on measuring γ-decay after single nucleon transfer reactions. This particle – γ coincidence technique has resulted in a large number of publications and represents a high potential for further projects.

One of the most exciting discoveries is the emission of low energy γ-radiation from heated rare earth nuclei (see chap.6). At excitation energies ranging from 5 to 8 MeV we observe γ-rays with energies around $E_\gamma = 0.4$ MeV. The γ-decay branch of this radiation is 10 - 20 %, which contradicts any present theory of heated nuclei. For example, the Fermi-gas model prediction gives γ-rays with a broad distribution centered around $E_\gamma = 2 - 3$ MeV.

A proper interpretation of the experimental results is difficult. The data suffer from bad statistics, and the need for a more powerful detection system is obvious. Hence, the CACTUS project has been initiated to obtain a

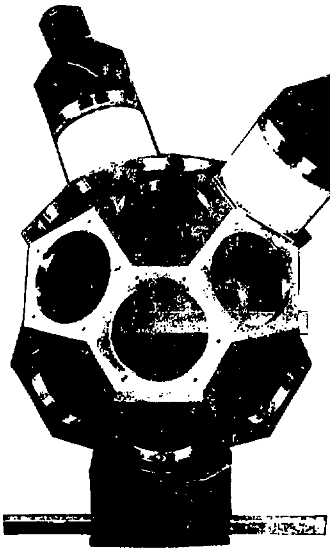

Figure 5.1: The NaI-detector frame, with space for 28 detectors.

better experimental basis. Of particular interest is reliable $p-\gamma$ as well as $p-\gamma-\gamma$ coincidences. Better angular distribution data is also important for the progress of this project.

Previous experiments have been run with four $\Delta E - E$ telescopes and six NaI counters. The plans are to extend the set-up to a total of 28 NaI counters and 8 particle telescopes. This multidetector set-up will increase the $p-\gamma$ coincidence rate with a factor of ≈ 10. The $p-\gamma-\gamma$ coincidence rate will increase with a factor ≈ 40 and opens new possibilities of multidimensional data analysis. With an estimated γ-ray multiplicity of $M_\gamma = 4$ and a solid angle of 1 % for each NaI counter, the various types of events will be distributed as follows:

55 %	$p-\gamma$
35 %	$p-\gamma-\gamma$
9 %	$p-\gamma-\gamma-\gamma$
1 %	$p-\gamma-\gamma-\gamma-\gamma$

The NaI counters will be mounted in a frame of 12 pentagons and 20 hexagons, each with a Ø = 134 mm hole (see fig. 5.1). In addition to the NaI counters there will be space for 2 Ge counters. The Si telescopes are mounted in a fixed frame of nylon placed within the target chamber. There will be

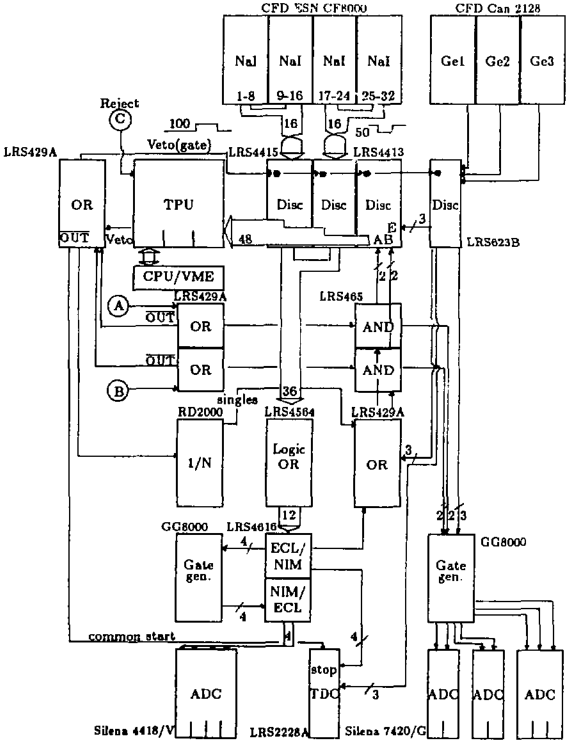

Figure 5.2: The timing set-up for CACTUS. Signals from the particle telescopes 1 – 4 and 5 – 8 are given as inputs at A and B, respectively.

produced various frames for the proper particle counter configuration. A frame with space for 8 telescopes at an angle of $\vartheta = 45°$ and at a distance of 4 cm from target will probably be used most frequently. The target chamber is constructed so it can be removed from the center of the NaI ball through the two remaining holes (32 holes in total). Beam focusing can be performed with a quartz plate at the target place, monitored by a TV camera.

In the workshop power supplies for the Si and NaI detectors are under construction. Dedicated preamplifiers and fast/slow amplifiers for 30 channels of NaI counters have been designed and will be tested before production. The mechanical set-up is under construction, and will be mounted at the beam line before summer.

The electronical set-up for CACTUS requires efficient timing logic. Of particular interest is the new generation of fast ECL electronics dedicated for CAMAC, which accommodates a high density of channels. Figure 5.2 shows the timing set-up which includes particle – γ coincidences as well as a given fraction of singles particle events. The parameters to be read by the CPU of the VME system are given externally to the TPU (trigger pattern unit) by fast ECL signals. The bit pattern of this unit tells the CPU which parameters are included in the event. After a certain inspection time the CPU starts to read out data from the respective modules placed in NIM (ADC's) and CAMAC (ADC's and TDC's) crates. For further details see chap.4.

The various components for CACTUS have been ordered, and we expect to start the first tests in the beginning of 1989.

5.2 The NORD-BALL Project

P.O. Tjøm and J. Rekstad

The NORD–BALL is a multidetector system which can accommodate up to 32 separate detector units. The project was initiated as a Nordic enterprise, but has now participation from outside the Nordic countries. It has therefore been decided that the committee for coordinating of the NORD–BALL projects should include representative members and deputies from Holland, Japan, Italy and West Germany.

The first basic detector configuration includes the inner ball structure of 60 BaF_2 elements as well as the 20 anti-compton spectrometers. In addition a particle detector telescope, a mini-orange electron spectrometer and a 16 neutron-detector wall will be available.

We hope that the first experiments can run this summer on the Tandem booster at Risø.

Chapter 6

Experimental Nuclear Physics

6.1 Introduction

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 particles 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 one ascribe statistical properties as temperature and entropy to a microscopical few-body system, e.g. nuclei with mass number $A \approx 160$? 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, a few MeV above the yrast line one is bound to use statistical concepts.

One of the most interesting discoveries is the presence of low energy γ–rays from the decay of heated nuclear matter. The existence of such γ–radiation have been confirmed in several nuclei, and a detailed study of the origin of this favoured γ-decay is in progress.

It is still an open question if chaotic particle motion can be produced in hot nuclear matter. Investigating this property is one of the greatest challenges remaining. However, our experiments so far suffer from poor statistics.

An increased coincidence efficiency is mandatory for the progress. We have installed a frame for a many-counter set-up at the beam line (see sect. 5.1, the CACTUS project). At present eight NaI detectors are used. A fully equipped system will be extremely powerful and should give reliable first-generation γ–ray spectra. In addition, an increased $p - \gamma - \gamma$ coincidence rate will give better γ–ray resolution and make many-dimensional analysis possible. The contributions during the year to the study of nuclei at low spin and high excitation energy are presented in sect. 6.2.

The work on high-spin states has also continued in 1987. The experiments are carried out at the Daresbury Laboratory in England, 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. The field is in strong development, and powerful detector systems with Compton-suppressed Ge detectors are now available. We participate in the Nordic collaboration, NORD-BALL, to build a Compton-suppressed γ-ray spectrometer. Experiments within the field of high-spin states are presented in sect. 6.3.

6.2 Nuclear Properties at High Temperature

6.2.1 The Decay of Hot Dysprosium Nuclei

A. Ataç, J. Rekstad, M. Guttormsen, S. Messelt, T. Ramsøy,
T.F. Thorsteinsen*, G. Løvhøiden* and T. Rødland*
* *Institute of Physics, University of Bergen, Norway*

The decay properties of several Dy nuclei were studied using the reactions ^{162}Dy(^{3}He,αxn)$^{161-x}$Dy and ^{163}Dy(^{3}He,αxn)$^{162-x}$Dy up to an excitation energy of 40 MeV above the ground states of ^{161}Dy and ^{162}Dy. The beam was 45 MeV ^{3}He ions from the Oslo Cyclotron. The dysprosium targets were enriched self-supporting metallic foils with a thickness of about 2 mg/cm^2. The charged ejectiles were measured with four $\Delta E - E$ silicon telescopes placed at 40° with respect to the beam direction. The front and end counters had thicknesses of 150 μm and 3000 μm, respectively. The coincident γ-rays were recorded with two 5" × 5" NaI(Tl) counters and two Ge counters.

The γ-transitions observed in the Ge spectra of the even-even Dy nuclei could be classified in three groups: (*i*) yrast transitions, (*ii*) transitions from vibrational band states into the ground band and (*iii*) transitions feeding directly into the ground band. With increasing number of neutrons emitted, the amount of decay via the vibrational states was found to decrease significantly realative to the amount of decay directly into the ground band.

This dependence is reflected in the NaI γ-ray spectra shown in fig. 6.1. The heaviest even-even nuclei produced directly or by one neutron emission exhibit two γ-ray bumps superimposed on a statistical spectrum, with γ-ray energies of 1 MeV and 2 MeV. The odd-even products feature a 2 MeV bump, only. Fermi-gas model calculations indicate that these bumps originate from the lowest excitation energy region where the low lying continuum states feed into the ground band either directly or via vibrational states. The bumps lose their strength in the spectra of the lighter reaction products. The change in decay pattern can be related to a temperature or spin effect which is not completely understood. However, supported by the consistent occurence of these structures in several nuclei, we conclude that they are characteristics in the γ-decay of highly excited low spin states.

The γ-ray multiplicity spectra exhibit the decay properties of states above and below the neutron threshold. The sudden drop in the multiplicity curve around the neutron binding energy demonstrates that neutron emission dominates as soon as it is energetically possible. Bumps associated with one and two neutron emissions are visible in the multiplicity spectra. Due to the competition between neighbouring neutron channels, three and four neutron emissions are not well separated by the multiplicity.

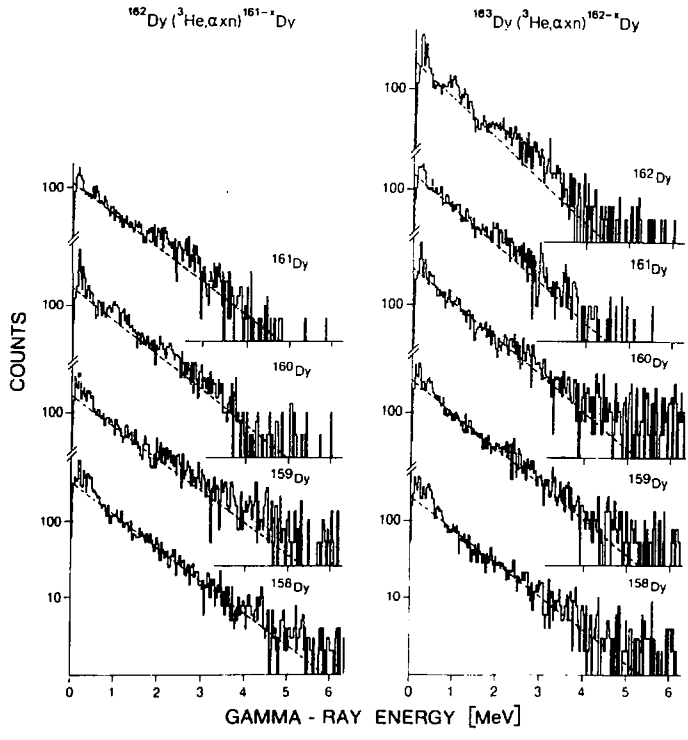

Figure 6.1: Gamma-ray spectra of various Dy isotopes.

The experimental data allow us to extract neutron energies as a function of the excitation energy in the $^{163}Dy(^3He,\alpha n)^{161}Dy$ reaction. Here, the average nuclear temperature is found to be $T = (0.65 \pm 0.15)$ MeV.

Furthermore, we have obtained estimates on the average neutron energy as a function of the number of emitted neutrons. Apart from a possible odd-even mass dependence, the results are consistent with statistical model calculations.

More information on this project is given in ref.[1]).

References:

1. A. Ataç et al., Nuclear Physics **A472** (1987) 269

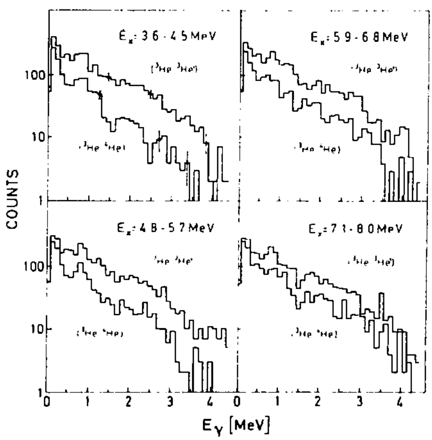

Figure 6.2: Spectra of γ-rays from the $^{163}Dy(\tau,\alpha)$ and $^{162}Dy(\tau,\tau')$ reactions measured in coincidence with ejectiles from four ranges of excitation energies in ^{162}Dy.

6.2.2 Reaction Dependence and Gross Structure of the γ-Decay of Highly Excited States in the Rare Earth Nucleus ^{162}Dy

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

* *Institute of Physics, University of Bergen, Norway*

The possibility of a reaction dependence for the γ-decay pattern has been investigated for the nucleus ^{162}Dy. The method is based on a comparison between the γ-decay pattern between the $^{163}Dy(\tau,\alpha)^{162}Dy$ single-particle transfer reaction and the $^{162}Dy(\tau,\tau')^{162}Dy$ inelastic scattering reaction. The inelastic process excites preferentially the collective quadrupole vibrational modes, while the (τ,α) reaction mainly populates two-quasiparticle states via pick-up of deep-lying neutrons with large orbital angular momentum. The experimental procedure described in sect. 6.2.1 was applied.

A study of the Ge spectra in the two reactions reveals that the pick-up reaction on an average populates a spin of $\approx 5.5\,\hbar$, whereas the inelastic scattering results in $\approx 3.5\,\hbar$. However, for excitation energies > 4.8 MeV the γ-decay pattern is found to be virtually independent of the formation process, as seen in fig. 6.2. The nucleus acts as a fully thermalized source of γ-radiation with sufficiently large level density for a statistical description to be applicable.

On the other hand, the γ-spectra differ from those expected from a statistical Fermi-gas model. A considerable fraction of the non-yrast γ-ray intensity (58 %) is observed in the broad bumps found at 1 MeV and 2 MeV in the γ-ray spectra. These bumps are not fully understood so far. More information on this project is given in ref.[1]).

References:

1. J. Rekstad et al., Nuclear Physics **A470** (1987) 397

6.2.3 First-Generation γ-Rays from Highly Excited Even Rare-Earth Nuclei

Z. Zelazny*, T.S. Tveter, A. Ataç, M. Guttormsen, T. Ramsøy and J. Rekstad

* *Institute of Exptl. Physics, Univ. of Warsaw, Poland*

The energy distribution of the primary γ-rays from a certain excitation energy gives information on the density of accessible final states and the transition matrix elements involved. However, the γ-ray decay from high excitation regions in general involves a cascade of transitions. With available timing techniques, there is no way to pick out the first γ-transition in a specific cascade.

The present method is based on particle-γ coincidences with one charged ejectile. The method[1]) rests on the assumption that states populated after the first γ-ray transition and states populated directly at the same excitation energy have identical decay properties.

For each excitation region (bin) we extract γ-ray spectra denoted f_i. The first generation γ-ray spectrum of the highest excitation energy (bin 1) is given by

$$h = f_1 - \sum_i n_i w_i f_i \,, \qquad (6.1)$$

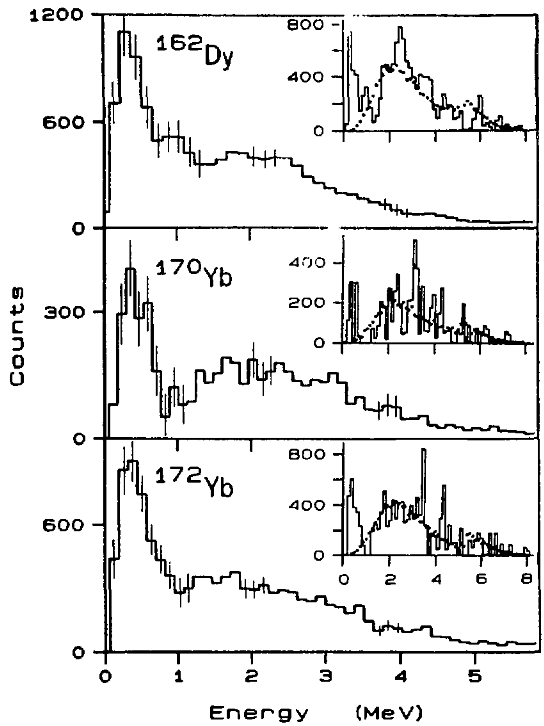

Figure 6.3: First-generation γ-ray spectra for ^{162}Dy, ^{170}Yb and ^{172}Yb, measured with NaI detectors. The corresponding excitation energy region is $\approx$ 5.6 – 8.2 MeV. Insert: Comparison between the unfolded experimental spectra (solid line) and the modified Fermi-gas model prediction (dotted line).

where the coefficients w_i are unknown and represent the decay probability from bin 1 to i. The coefficients n_i corrects for variations in the reaction cross section with excitaion energy, so that each spectrum f_i multiplied with n_i should correspond to the same number of cascades. They are given by $n_i = S_1/S_i$, where S_1 and S_i are the singles particle cross sections (arbitary units) at bin 1 and i, respectively. The weighting coefficients w_i can be found by iteration.

Figure 6.3 shows examples of first generation γ-ray spectra obtained in the (^{3}He,α) reaction. These spectra cover a broad excitation region, and are produced by summing up several first generation spectra from narrower excitation windows (350 keV). Two distinct components are clearly seen in the spectra, indicating two different decay paths. One component corresponds to the statistical decay expected from the Fermi-gas model. The energy distribution roughly agrees with model predictions using a level density parameter $a = 17$ MeV^{-1}, a pairing parameter $\Delta = 0.87$ MeV, a γ-energy exponent $n = 4$ and a simulation of the empirical level structure below 1.5 MeV excitation energy. The second component is represented by a characteristic low energy bump of unknown origin.

The low energy bump is centered aound $E_\gamma = 0.4$ MeV and the estimated branching is 10 – 20 % of the total first-generation intensity. Angular distribution data indicates a dipole or unstreched quadrupole character of the radiation. The bump can hardly be explained within the framework of current models for nuclear behaviour at high excitation energy and low spin. One of the most puzzling features is the position and width beeing independent of excitation energy. A possible interpretation might be given in terms of two adiabatically separated degrees of freedom, analogous to rotational or vibrational excitations superimposed on the various intrinsic states. However, at present this idea needs further experimental and theoretical support[2]).

References:

1. M. Guttormsen, T. Ramsøy and J. Rekstad,
   Nuclear Instrument Methods in Physics Research **A255** (1987) 518

2. Z. Zelazny et al., University of Oslo, Departement of Physics Report, **87 – 25**, (1987)

6.2.4 Particle-Vibration Coupled States in ^{161}Dy

T. Ramsøy, A. Ataç, T. Engeland, M. Guttormsen, J. Rekstad,
G. Løvhøiden*, T.F. Thorsteinsen* and J.S. Vaagen*
* *Institute of Bergen, Bergen, Norway*

States in ^{161}Dy have been populated using the inelastic (τ,τ') reaction. Discrete γ-ray spectroscopy was performed measuring the γ-rays in coincidence with the τ-particles. Strong particle groups are found in the $E_x \approx 0.9$ MeV region. These states are interpreted as γ-vibrations built on the $5/2^+[642]$ ground state in ^{161}Dy. The vibration-coupled states are classified according to their angular momentum projections on the nuclear symmetry axis: (i) the aligned structure with $K^\pi = 9/2^+$ and (ii) the antialigned structure with $K^\pi = 1/2^+$.

The $I = 1/2$ and $3/2$ spin members of the $K^\pi = 1/2^+$ band-head are found to be heavily mixed with other single-particle orbitals from the $N = 4$ and 6 oscillator shells. The interaction matrix element (30 keV) for these states is deduced from simple three state mixing calculations.

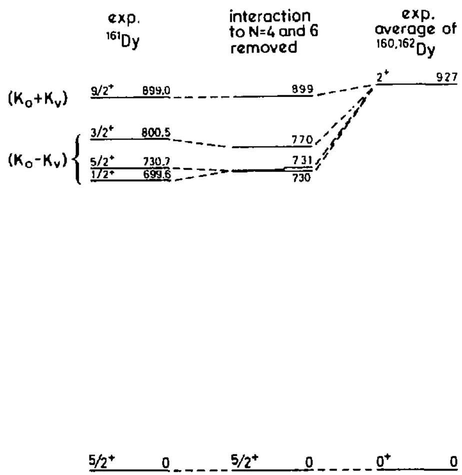

Figure 6.4: Experimental level scheme for excited $K_0 \pm K_\gamma$ states in ^{161}Dy. The middle part shows the unperturbed energies of the vibrational states when their interaction with the $N = 4$ and 6 states have been removed.

In fig.6.4 is shown the experimental levels based on the γ-vibrations. The extracted unperturbed energy position of the $K^\pi = 1/2^+$ structure shows a bunching around the $I, K^\pi = 1/2, 1/2^+$ band-head. The deduced energy gap of 169 keV between the band heads of the aligned and antialigned states is nicely reproduced by our calculations within the quasiparticle-core coupling model of Dönau and Frauendorf. The spin sequence is however not reproduced in a satisfactory way.

This work is described in ref.[1]), and comprehensive calculations with matrix elements from current more realistic core models are in progress.

References:

1. T. Ramsøy et al., Nuclear Physics **A470** (1987) 79

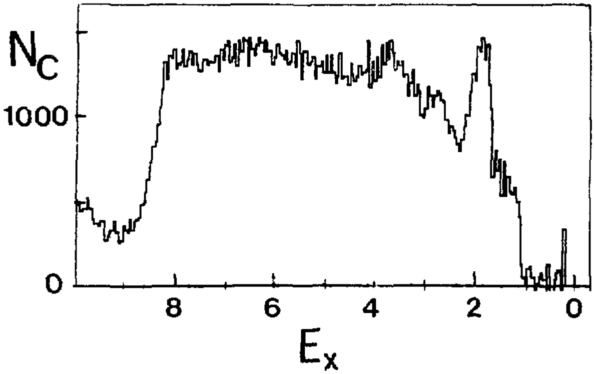

Figure 6.5: Inelastically scattered τ-particles in coincidence with γ-rays.

6.2.5 Gamma Decay from the ^{172}Yb Nucleus after the (τ, τ') Inelastic Reaction

A. Ataç, M. Guttormsen, J. Rekstad and T.S. Tveter

The ^{172}Yb nucleus have been excited through the (τ, τ') inelastic reaction where one expects the dominant process to be the excitation of collective quadrupole and octupole vibrational states. These vibrational modes are found at higher excitation energies in ^{172}Yb than in most other rare-earth nuclei. This is caused by the particular location of single particle orbitals near the Fermi level.

The experiment was carried out using the 45 MeV τ beam from the MC 35 cyclotron at the University of Oslo. The 2.2 mg/cm^2 thick ^{172}Yb target was isotopically enriched to 97 % . Charged particles from the reaction were detected in a set-up consisting of four Si particle telescopes which were placed at an angle of 52° relative to the beam direction. The thicknesses of the front and end Si detectors were 150 μm and 3000 μm, respectively and the total solid angle for the four telescopes was 0.26 sr. The average resolution (FWHM) for the particle detectors was 300 keV. The charged particles were recorded both as singles and in coincidence with the γ-rays which were measured with seven 5"×5" NaI counters.

The spectrum of inelastically scattered τ-particles recorded in coincidence with γ-rays detected by the NaI detectors is shown in fig.6.5 as a function of excitation energy. In the lower excitation region pronounced structures are observed. Above excitation energies of $\approx$ 4 MeV, the spectrum is fairly flat. The sudden drop above E_x = 8 MeV is related to the emission of neutrons for $E_x > B_n$ = 8.02 MeV. The immediate decrease in yield shows that the neutron channel completely dominates as soon as it becomes energetically possible. Thus, above the excitation energy of 8 MeV, the τ-particles are coincident with γ-rays from ^{171}Yb.

A γ-ray energy threshold of 430 keV was chosen for the NaI counters in order to obtain an almost constant detection probability as a function of γ-energy. Since the ground band transitions have energies below this threshold, population of these rotational states are not observed in fig. 6.5. The yield increases above the excitation energy of 1 MeV, due to the population of collective vibrational states. The particle group which is centered at about 1.37 MeV is related to the population of the $I, K^{\pi} = 2, 2^+$, 1466 keV γ-vibrational state, the $3, 1^-$, 1222 keV octupole vibrational state and the $4, 3^+$, 1263 keV state. The prominent peak which is centered at around 1.9 MeV is mainly related to the strong population of the $3, 2^-$, 1822 keV octupole vibrational state.

An increase in the τ-particle yield is observed between the excitation energies of 2.2 MeV to 4 MeV. This behaviour might be correlated to an increase in the level density above the excitation energy of 2 MeV where the two-quasiparticle regime starts. Furthermore, two bumps are observed at around $E_x = 2.7$ MeV and 3.7 MeV. They are probably due to more composite collective excitations.

In fig. 6.6 is shown the NaI γ-ray spectrum with gate on τ-particles from the $E_x = 2.3 - 8.0$ MeV region. In this excitation region, the γ-decay is expected to be governed by statistical laws which should lead to a spectrum with an exponentially decreasing intensity for increasing γ-ray energies.

For the lowest γ-ray energies, < 0.5 MeV, two distinct peaks which correspond to the $6^+ \rightarrow 4^+$ and $4^+ \rightarrow 2^+$ yrast transitions are observed. Apart from these yrast lines, a bump which is centered at $E_\gamma = 1.1$ MeV with a width of 0.14 MeV (FWHM) is superimposed on the statistical shape. The structure of this 1 MeV bump is even more pronounced in the unfolded spectrum (see bottom part of fig. 6.6). The dotted curve shows the γ-decay pattern obtained by a statistical Fermi gas model calculation. The 1 MeV bump is obviously not predicted by the statistical model.

Similar bump structures have been observed earlier in several deformed rare-earth nuclei and they are believed to represent a characteristic γ-decay pattern of highly excited low spin states. The 1 MeV bump originates from the lowest excitation region where a large variation in the level density is present. It represents transitions from the lowest lying two-quasiparticle states ($E_x = 2$ MeV) to the vibrational states ($E_x = 1$ MeV) and from these vibrational states to the ground band.

The 1 MeV bump is very dominant in the decay after the inelastic reaction and can serve as a fingerprint for the structure at higher energies. Probably, much of the decay of many-phonon states goes with a cascade of 1 MeV γ-rays. The intensity of the bump will be studied as a function of excitation energy in order to learn more about the population mechanism and decay properties of the ^{172}Yb nucleus.

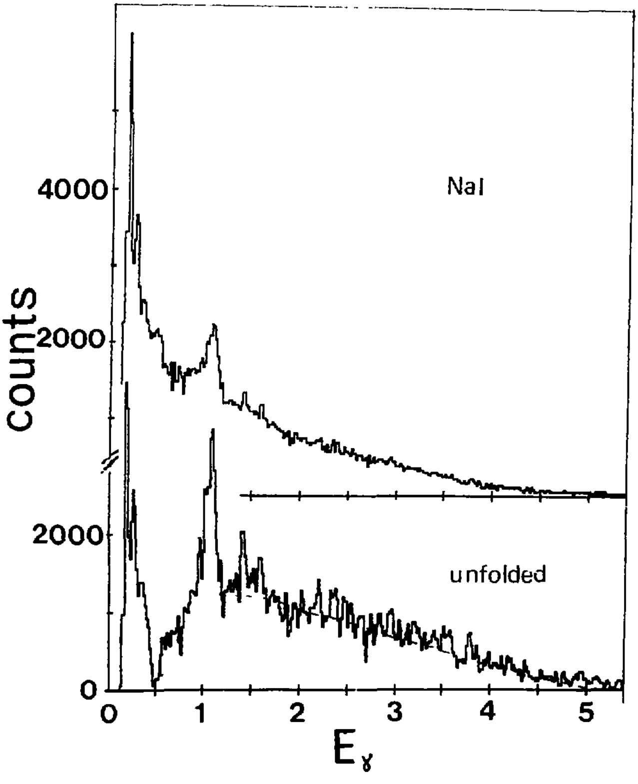

Figure 6.6: The NaI γ-ray spectrum from the $E_x = 2.3 - 8.0$ MeV region. In the lower part the same spectrum unfolded with the NaI response function is shown.

6.2.6 Deep-Lying $\nu s_{1/2}$ and $\nu d_{3/2}$ Strength in Dy and Yb Isotopes

H. Arnesen, M. Guttormsen, T. Ramsøy, J. Rekstad and T.S. Tveter

Previously[1]), (d,t) work on ^{160,162}Dy has shown that the largest contribution to the triton spectrum came from the pick-up of neutrons from the $1/2^+[400]$ and $3/2^+[402]$ Nilsson orbitals. These structures appear as huge particle groups located around 2.4 MeV of excitation energy, and the γ-decay from these states is affected by K-hindrance and $\Delta N = 2$ coupling phenomena. In order to investigate the systematics of these structures an experiment on ^{170}Yb has been performed. The experimental technique is similar to the one reported earlier.

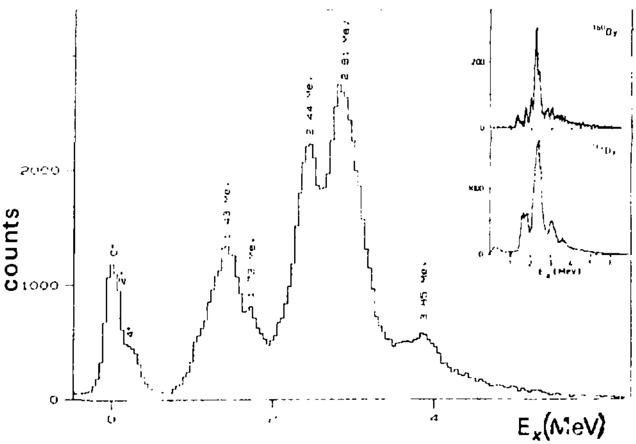

Figure 6.7: Singles triton spectrum from the ^{171}Yb(d,t)^{170}Yb reaction. In the insert is shown ^{160,162}Dy from ref.[1]).

The ground state of the target nucleus ^{171}Yb is built on the $1/2^-[521]$ orbital with $I^\pi = 1/2^-$. The (d,t) reaction favours the pick-up of low-j neutrons, and we predict large cross sections for states with the following spin/parity assignments

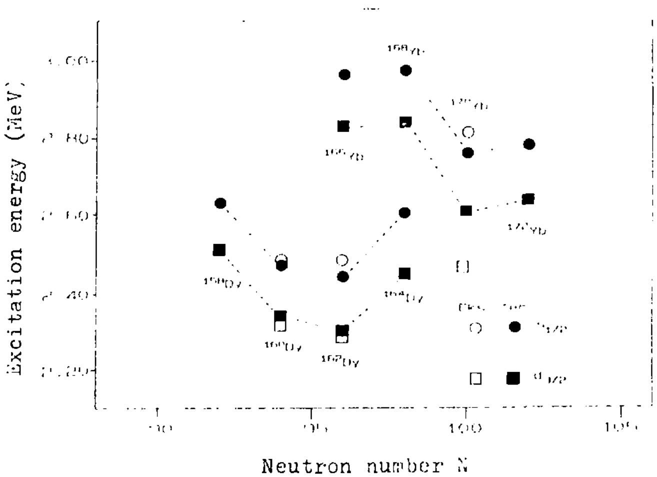

Figure 6.8: The excitation energy of the $s_{1/2}$ and $d_{3/2}$ pick-up strength in ^{170}Yb. The ^{160,162}Dy spectra are taken from ref.[1]).

- $1/2^-[521] + 1/2^+[400]$ with $K^\pi=1^-$
- $1/2^-[521] - 1/2^+[400]$ with $K^\pi=0^-$
- $1/2^-[521] + 3/2^+[402]$ with $K^\pi=2^-$
- $1/2^-[521] - 3/2^+[402]$ with $K^\pi=1^-$

The ^{170}Yb nucleus has a higher neutron number than the previously investigated ^{160,162}Dy isotopes, and the low-j structures should be expected at higher excitation energies. On the other hand, the nuclear deformation is larger in ^{170}Yb, bringing the $N = 4$ orbitals higher in the Nilsson well and, therefore, closer to the Fermi surface.

Indeed the singles triton spectrum of fig. 6.7 displays large pick-up strength in the $E_x \approx 2.0 - 3.5$ MeV excitation region. In addition, we find strength located at $E_x \approx 1.4$ MeV, which is probably due to the pick-up from $\Omega^\pi = 1/2^-$ and $3/2^-$ orbitals originating from the $f_{7/2}$ and $h_{9/2}$ spherical states.

Figure 6.8 shows the excitation energies predicted for the $\nu s_{1/2}$ and $\nu d_{3/2}$ structures in even Dy and Yb isotopes. The estimates are based on the Nilsson model, where pairing (BCS) has been included. The oscillator gap between the $N = 4$ and $N = 5$ shells had to be decreased by 1.2 MeV to obtain reasonable fits to the experimental data. For the Dy case the observed centroids are then quite well reproduced. However, the splitting of the $s_{1/2}$ and $d_{3/2}$ particle groups in ^{170}Yb is not reproduced. This larg splitting is not accounted for in the Nilsson model and indicates that residual interactions play a significant role already at these excitation energies. The states are probably influenced by other degrees of freedom than the simple 2 q.p. configuration.

References:

1. T. Ramsøy et al., Nuclear Physics A438 (1985) 301

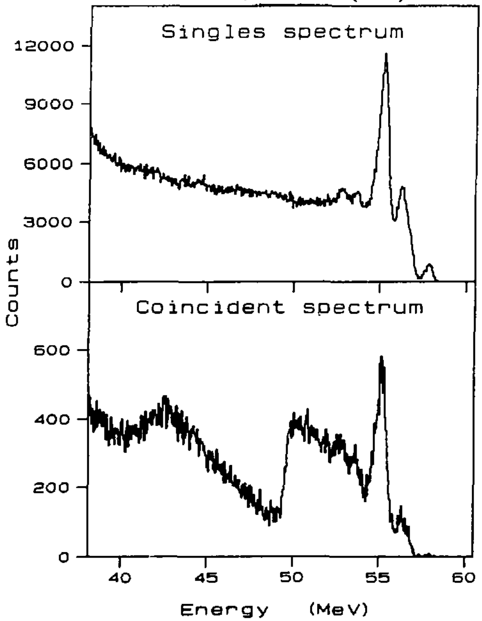

Figure 6.9: The α-particle singles (top) and γ-coincident (bottom) spectra for the ^{173}Yb(^{3}He,α) reaction.

6.2.7 Gamma-Decay of Highly Excited ^{172}Yb Nucleus

Z. Zelazny*, A. Ataç, M. Guttormsen, S. Messelt, T. Ramsøy and J. Rekstad

* *Institute of Exptl. Physics, Univ. of Warsaw, Poland*

Low spin states in ^{172}Yb were populated in the ^{173}Yb(^{3}He,α) reaction with 45 MeV beam energy. The γ-decay via the group of vibrational states around

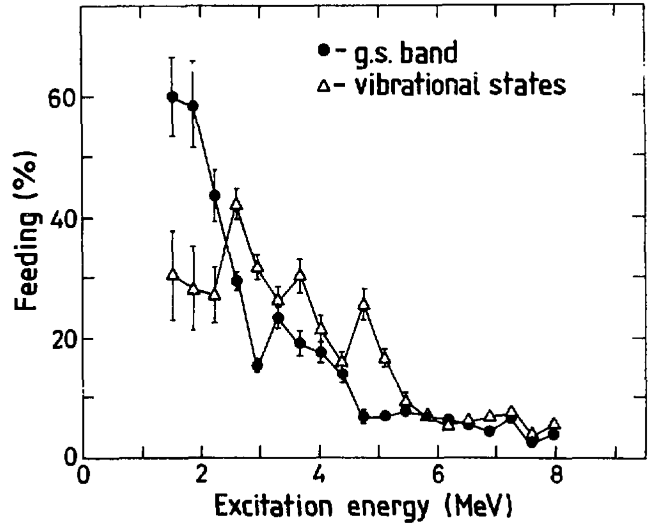

Figure 6.10: The direct γ-feeding to the ground band states and the vibrational states as a function of excitation energy. The data is normalized to the total γ-decay intensity in the first generation γ-radiation.

1.4 MeV of excitation energy gives rise to a 1 MeV bump in the γ-ray spectra. An extraction method for first generation γ-rays has been used to study decay routes from the highly excited states. In particular, the feeding of the vibrational states around $E_x = 1.4$ MeV and the ground band has been studied as a function of the initial excitation energy.

There are indications that some structural changes take place at 4.9 – 5.5 MeV of excitation energy. In fig. 6.9 we observe that the singles spectrum is completely structureless above 5.5 MeV. These phenomena have been studied closer by comparing the amounts of γ-decay to the vibrational states and directly to the ground band. Figure 6.10 shows that the decay branches to these excitation regions are different and oscillate below 5.5 MeV. Above this energy the feeding intensities are similar and amounts to 8 %. The investigations are in progress.

6.2.8 Determination of Average Neutron Energies as a Function of Excitation Energy

T.S. Tveter, A. Meling, ? Zelazny*, A. Ataç, M. Guttormsen and J. Rekstad
* *Institute of Exptl. Physics, Univ. of Warsaw, Poland*

Information concerning the statistical parameters of hot nuclei, such as level density and temperature, can be obtained from the energy distribution of evaporated neutrons. The probability of a compound nucleus C with excitation energy $E_x(C)$ emitting a neutron with kinetic energy E_n is given by the expression[1]:

$$P(E_x, E_n)dE_n \propto E_n \cdot \sigma_{nC}(E_x, E_n) \cdot \rho(E_x - E_n)dE_n \, , \tag{6.2}$$

where E_x is the initial excitation energy relative to the ground state of the daughter nucleus X: $E_x = E_x(C) - S_n(C)$ and S_n is the neutron separation energy. After neutron emission, the daughter nucleus is left with an excitation energy $E_x - E_n$. The factor $\rho(E_x - E_n)$ represents the level density at this final energy. The quantity $\sigma_{nC}(E_x, E_n)$ is the cross section for the inverse reaction $X + n \to C$. This cross section is usually a slowly varying function of excitation energy and neutron energy, and will in the following be replaced by a constant. By expressing the level density ρ in terms of the entropy S, expanding to the first order in E_n and utilizing the fact that $dS/dE_x = 1/T$, we obtain for the emission rate:

$$P(E_x, E_n) \propto \rho(E_x - \langle E_n \rangle) \cdot e^{-E_n/T}. \tag{6.3}$$

Here, T is the thermodynamical temperature of the daughter nucleus at the average final excitation energy $E_x - \langle E_n \rangle$. The validity of the approximations used may of course be subject to controversy.

The resulting distribution of neutron energies reaches its maximum at the point $E_n = T$. Due to the high-energy tail of the distribution, its centroid is located at $E_n = \langle E_n \rangle = 2T$. Consequently, the average neutron energy provides a measure for the temperature of the nucleus. The corresponding level density parameter a can be calculated by means of the formula $a = (E_x - E_\Delta - T)/T^2$, where E_Δ is the energy gap caused by the pairing correlations.

Average neutron energies can be estimated by comparing the γ-ray multiplicity spectra from two experiments using two neighbouring isotopes as targets for the same transfer reaction (a,b), where the ejectile b must be charged. The direct reaction (a,b) (I) on the lighter isotope and the reaction (a,bn) (II) on the heavier one, lead to the same product nucleus ^AX. By means of the coincident and singles ejectile spectra from each experiment, one can generate multiplicity spectra covering the whole range of open channels (a,bxn). These depict the average number of statistical γ-rays as a function of the ejectile energy, or equivalently, the excitation energy $E_x^{(0n)}$ of the first product nucleus immediately after the direct reaction. The excitation energy of the daughter nucleus after emission of x neutrons, but prior to γ-decay, is given by $E_x^{(xn)} = E_x^{(0n)} - S_{xn} - \sum E_n$. Our present aim is to study the reaction channel with $x = 1$.

After careful normalization, the multiplicity spectra $\langle M_\gamma^I \rangle$ and $\langle M_\gamma^{II} \rangle$ are shifted relative to each other along the excitation energy axis so that the

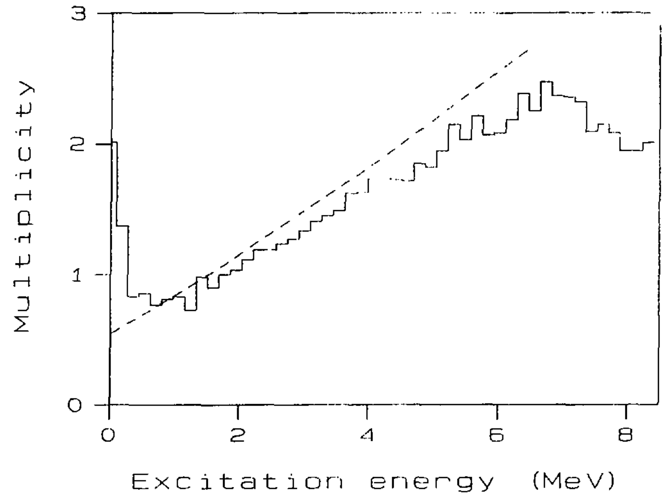

Figure 6.11: Multiplicity curves for the reactions ^{173}Yb(^{3}He,αn)^{171}Yb (histogram) and ^{172}Yb(^{3}He,α)^{171}Yb (dashed line). The latter is the result of a quadratic fit to the experimental spectrum. Excitation energies are measured relative to the ground state of ^{171}Yb.

points $E_x^{I(0n)} = 0$ and $E_x^{II(0n)} = S_n(^{A+1}X)$ coincide. A quadratic expression $\langle M_\gamma^{II} \rangle = a_0 + a_1 E_x + a_2 E_x^2$ is then fitted to the experimental spectrum $\langle M_\gamma^I \rangle$ by the least square method. The average neutron energy as function of the excitation energy $E_x^{II(0n)}$ is then identified with the horizontal distance between the points $\langle M_\gamma^{II} \rangle (E_x^{II(0n)})$ and the fitted curve: Granted that there exists a one-to-one relationship between excitation energy and average statistical multiplicity for a given nucleus ^AX, the equation

$$\langle M_\gamma^{II} \rangle (E_x^{I(0n)}) = \langle M_\gamma^{II} \rangle (E_x^{II(0n)} - S_n - \langle E_n \rangle) , \tag{6.4}$$

implies that

$$\langle E_n \rangle = E_x^{II(0n)} - S_n - E_x^{I(0n)} . \tag{6.5}$$

For this statement to be correct, three conditions must be fulfilled:

(i) As already mentioned, the average statistical γ-ray multiplicity must be a monotonously increasing function of the excitation energy, so that E_x at any point is uniquely determined by the corresponding value of $\langle E_\gamma \rangle$.

(ii) Because of the spread in neutron energies, the average γ-ray multiplicity $\langle M_\gamma^{II} \rangle$ is a result of averaging over a range of excitation energies $E_x^{II(1n)} = E_x^{II(0n)} - S_n - E_n$, as well as over a number of γ-cascades with

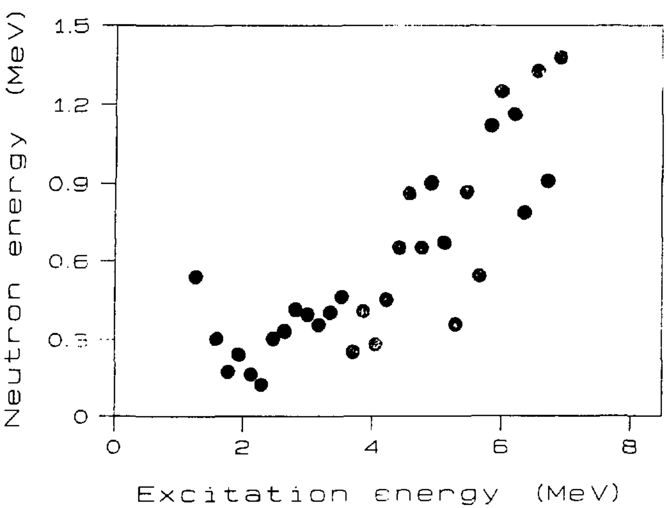

Figure 6.12: Average energies of neutrons emitted from ^{172}Yb, estimated by means of the procedure described in the text. Excitation energies are measured before neutron decay, relative to the ground state of ^{171}Yb.

different individual multiplicities. Generally, one can set $\langle\langle M_\gamma\rangle(E_x - E_n)\rangle = \langle M_\gamma\rangle(E_x - \langle E_n\rangle)$ only if the multiplicity is a linear function of excitation energy.

(iii) The states of the nucleus ^{A}X populated directly in the transfer reaction and those populated at the same excitation energy after neutron emission from the nucleus ^{A+1}X, must have identical decay properties, at least as far as the average statistical multiplicity is concerned.

Several experiments with one-neutron pick-up reactions on deformed rare-earth nuclei indicate that the requirements (i) and (ii) are reasonably well satisfied above $E_x \approx 2\Delta$. According to the Fermi gas model, the assumption (iii) should also be valid to a good approximation at high excitation energy: The great complexity of the nuclear states and the thermalization of the nucleus before γ-emission, ensures that the decay pattern is independent of the entrance channel, being mainly governed by the initial spin and parity. Besides, the average statistical γ-ray multiplicity is only very weakly influenced by the initial spin distribution.

Figure 6.11 shows the observed multiplicity spectra from the ^{172}Yb(^{3}He,α)^{171}Yb (dashed line) and the ^{173}Yb(^{3}He,αn)^{171}Yb reactions (histogram), shifted in energy as described above. The neutron energies E_n can then be extracted and are shown in fig. 6.12. The results must be considered tentative: The normalization and excitation energy calibration of the multiplicity curves and possible shape distortions due to the finite solid angle of the γ-detectors, might be sources of systematical errors.

Further investigations are planned.

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1. M.A. Preston, Physics of the Nucleus
Addison-Wesley Publishing Company Massachusetts, 1963, p. 524

6.2.9 Gamma-Decay Properties of ^{171}Yb

A. Meling, T.S. Tveter, H. Arnesen, A. Ataç, M. Guttormsen, T. Ramsøy and J. Rekstad

The decay-pattern of even-even nuclei reveals γ-ray bumps of 1 MeV and 2 MeV in the spectra. These are known to be partly due to the abrupt changes in the level density close to the ground band. The transitions found are from the beginning of the 2 quasi-particle regime to the vibrational states and from the vibrational states to the ground band. These steps are characteristics of the even-even nuclei and one would expect other decay routes in the odd-A case.

The odd ^{171}Yb isotope was populated in the ^{172}Yb(^{3}He,α) reaction with a beam energy of 45 MeV. In fig.6.13 are shown unfolded NaI spectra with gates on various excitation regions in ^{171}Yb. The total γ-spectra, including all generations, are displayed on the r.h.s. of the figure. Due to the low γ-ray multiplicity at these excitation energies, the first-generation spectra (l.h.s.) and the total spectra are very similar.

One of the most interesting features of the spectra of fig. 6.13 is the appearance of a $E_\gamma \approx 0.85$ MeV bump. This bump corresponds to the 1.1 MeV bump found for the even-even isotopes (see sect.6.2.5). This mean that the average vibrational oscillator quanta $\hbar\omega$ is reduced by 30 % in the odd-A case. The unpaired valence q.p. is likely to produce blocking effects which influence the pairing gap and thereby the oscillator energy.

Another interesting topic is to what extent the odd 1 q.p. affects the statistical properties at higher excitation energies. Probably, the system exhibits statistical properties already at quite low excitation energy. In fig.6.14 is shown the γ-ray multiplicity spectrum deduced from the singles and coincident α-particle spectra according to the formula

$$\langle M_\gamma \rangle \propto \frac{N_c}{N_s} . \qquad (6.6)$$

Here, the ground state of ^{171}Yb ($E_x = 0$) is close to 56 MeV of particle energy. The functional form of the spectrum is surprising: It is approximatelly linear from $E_x = 1$ MeV up to 5.5 MeV. In addition, at the highest excitation energies the multiplicity seems to have a bump-like shape. These observations are puzzling, and indicate that the odd-A systems display decay routes of non-statistical nature. The investigations are in progress.

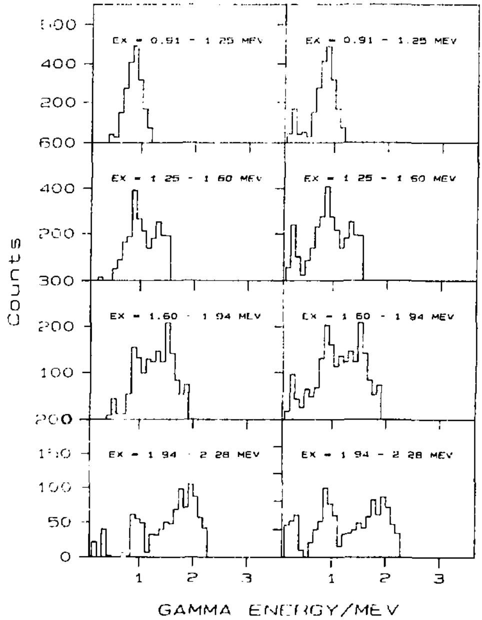

Figure 6.13: Unfolded NaI spectra from various excitation regions in ^{171}Yb. Spectra including the total cascade of γ-transitions (right part) and the first generation γ-rays (left part) are shown.

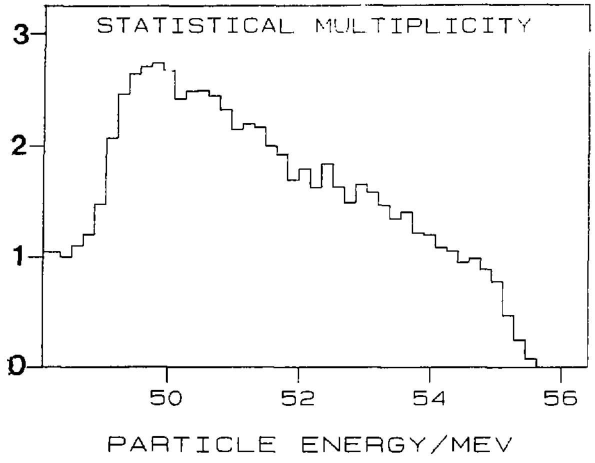

Figure 6.14: Gamma-ray multiplicity (E_γ > 0.43 MeV) as a function of excitation energy in ^{171}Yb.

6.2.10 Level Structure of ^{89}Y from the $(\alpha, 2n)$ Reaction

T. Bartsch*, J. Kownacki* Z. Zelazny*, M. Guttormsen, T. Ramsøy and J.Rekstad
* *Institute of Exptl. Physics, Univ. of Warsaw, Poland*

As a part of a research program concerning the the Zr-Y-Sr region, we have performed the $(\alpha, 2n)$ reaction in order to extend the knowledge of the decay modes of the ^{89}Y nucleus. As typical for nuclei in the vicinity of closed shells the level structure has been observed up to about 7 MeV of excitation energy. In this work we were able to observe levels up to the 9 MeV excitation region. These uppermost levels constitute high spin (31/2 or $32/2\hbar$) and have been arranged into a rotational-like sequence suggesting a nuclear shape change.

Using present and previously[1,2]) known data we have tried to locate experimentally and calculate theoretically the members of the $1g_{9/2}\times$core multiplets. The empirical two-body matrix elements necessary for the shell-model calculations relative to the ^{88}Sr core nucleus have been compiled. These results are presented in ref.[3]).

In order to obtain reliable spin and parity assignment of several states in this nucleus, conversion electrons have to be measured. Thus, a new Si(Li) electron detector has been bought for our mini-orange spectrometer and we hope to get the apparatus in to operation this year.

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2. C.A. Fields and L. Samuelson, Physical Review C20 (1979) 2442

3. T. Batsch et al., Physica Scripta, in press

6.3 High-Spin Properties of Nuclear States

6.3.1 Lifetimes of High-Spin States in ^{158}Er

P.O. Tjøm, H. Hübel[*], K.H. Maier[**], R.M. Diamond[***],
F.S. Stephens[***], M.A. Deleplanque[***], J. Bacelar[****] and E.M. Beck[*]
[*]*Institut für Strahlen- und Kernphysik, University of Bonn, W.-Germany*
[**]*Hahn-Meitner-Institut für Kernphysik, Berlin, W.-Germany*
[***]*Lawrence Berkeley Laboratory, Berkeley, Cal. 94720, USA*
[****]*Kernfysisch Verschneller Instituut, 9474AA Groningen, The Netherlands*

Previously, experiments at Lawrence Berkeley Laboratory have shown a fast (< 1 ps) and slow (> 2 ps) component feeding the 38^+ state in ^{158}Er. The lifetime of the slow component was measured, in a new experiment, using the Doppler-shift recoil-distance method (RDM). The reaction used was 175 MeV ^{40}Ar + ^{122}Sn. The ^{40}Ar beam was provided by the 88-in. cyclotron of the Lawrence Berkeley Laboratory. A special plunger set-up which fits into the Berkeley 21 Compton-suppressed Ge detector array HERA has been built in Bonn. The analysis is not finished, but the preliminary results show that at most only 15 s.p.u. are left at the spin 40^+ state in the slow branch.

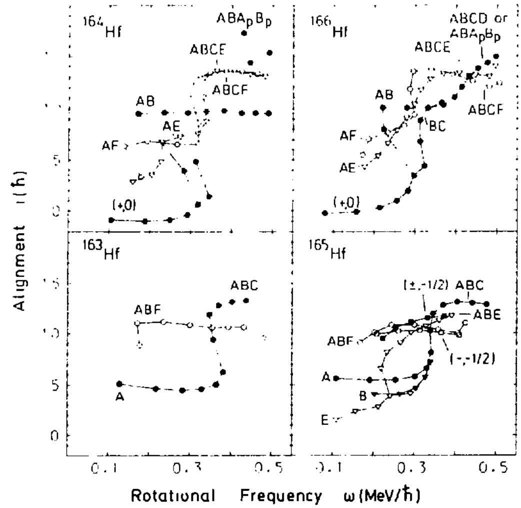

Figure 6.15: Experimental alignment i_x as a function of rotational frequency for $^{163-166}$Hf.

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

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

**Institut für Strahlen- und Kernphysik, University of Bonn, W.-Germany*
***Hahn-Meitner-Institut für Kernphysik, Berlin, W.-Germany*
****Institute of Nuclear Physics, Pl-31-342 Cracow, Poland*
*****Departemento de Fisica da Universidade, P-3000 Coimbra, Portugal*

High-spin states in $^{163-166}$Hf, populated in ^{148,150}Sm(^{20,22}Ne,xn) reactions, have been studied by in-beam γ-ray spectroscopy using the first six Compton-suppressed Ge-detectors from the OSIRIS set-up. The suppressors are of the asymmetric type and a peak/total ratio of 0.5 was obtained. The experiments were typically run with 100 mill. events. Angular correlation information was extracted from the coincidence spectrum in the following way: The ratios $I(30°)/I(90°)$ were derived by setting gates on several known E2-transitions in the 90° detectors to derive $I(30°)$ and in the 30° detectors to derive $I(90°)$. For E2 transitions and unstretched dipoles this ratio is close to 1.0, and for stretched dipoles close to 0.5.

The experimental alignments i_x for all the bands observed in $^{163-166}$Hf are plotted as a function of the rotational frecuency in fig.6.15. The decoupling of the first pair AB is found to be close to $10\hbar$ for both ^{164}Hf and ^{166}Hf. The blocked alignment which is observed in the positive-parity sequences in ^{163}Hf and ^{165}Hf ($A \rightarrow ABC$) and in the negative-parity bands in ^{164}Hf and ^{166}Hf ($AE \rightarrow ABCE$) and ($AF \rightarrow ABCF$) occurs at higher frequency and gives a gain of $\approx 6.5\hbar$. The alignment in the ground bands of the even-even isotopes above the first band crossing is probably due to the crossing with the BC neutron bands.

The cranked shell model (CSM) calculations for the two and three quasi-neutron band crossings give good agreement with the experimental values for the critical frequencies, alignments and interaction energies. For the second band crossing in the even mass isotopes the situation is more complicated and the interpretation is less straightforward. The available experimental evidence in the Hf isotopes and their neighbours and a comparison to the results of our CSM calculations favours an interpretation of the second backbend in ^{164}Hf as alignment of a proton pair ($AB \rightarrow ABA_pB_p$) while the upbend in ^{166}Hf is probably caused by the decoupling of the second neutron pair ($AB \rightarrow ABCD$). More details on this work is found in ref.[1]).

References:

1. H. Hübel et al., Nuclear Physics **A464** (1987) 445

Chapter 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 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 particle–rotor model and is closely associated with out experimental work. We are also interesed in the structure of highly excited states studied experimentally in the cyclotron laboratory.

In the field of nuclear reactions our interest during the last few years have focussed on the understanding of light–ion induced particle transfer reactions, in particular (t,p) reactions, in terms of nuclear structure models. A recent interest is the study of heavy–ion reactions with proximity interactions.

With the Bergen group we are going to study the collective properties of nuclear matter as they appear in relativistic heavy–ion collisions, and we have sumitted a joint project proposal to the Norwegian Research Council for Science and Humanities (NAVF).

We do also study problems related to the foundations of quantum physics such as the non–separability of systems in a pure quantum state and the completeness of quantum mechanics. Further studies will be made of some of the main interpretations of the quantum theory and of alternative theories. An analysis will be attempted on the basis of Bohr's complementarity concept and his understanding of the nature of measurements involving actions of the order of the Planck constant.

A critical study will be made of the validity of the arguments known as "Schrödinger's cat" and "Wigner's friend". These arguments play a central role in some attempts at an analysis of the characteristic features of a quantum measurement and with wide consequences for the interpretation of quantum mechanics.

7.1 The Nuclear Many-Body Problem and Nuclear Structure

7.1.1 Realistic Effective Interactions in Nuclei

E. Osnes and T.T.S. Kuo*
* *State University of New York, Stony Brook, USA*

We review[1]) the efforts made over the last two decades to calculate the effective interaction for the nuclear shell model, starting from the free nucleon–nucleon interaction and using many-body theory. We begin by a brief description of the interactions and the many-body methods used. Then, we review the early calculations of the effective interaction based on the phenomenological nucleon–nucleon potentials obtained from fits to two-nucleon data by Hamada and Johnston and by Reid. We go on to discuss the results obtained with the more recent Paris and Bonn–Jülich potentials derived from meson–exchange theory. In particular, we point out how serious problems encountered in the early calculations, such as the slow convergence of the intermediate–state summation in various perturbation diagrams, have been resolved in the recent calculations, due to a weakening of the tensor-force component in the new interactions. Thus, we believe that one can have some confidence in the effective interactions obtained. In fact, these seem to be well described by the second–order approximation introduced by Kuo and Brown some 20 years ago. Compilations of useful effective interaction matrix elements throughout the periodic table will be given.

References:

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7.1.2 Hartree–Fock and Shell Model Calculations in the (sd) Shell with Realistic Effective Interactions

F. Brut*, E. Osnes and D. Strottman**
* *Institut des Sciences Nucléaires, Grenoble, France*
** *Los Alamos National Laboratory, Los Alamos, USA*

We have performed projected Hartree–Fock and shell model calculations of the positive parity states in the $A = 21$ and $A = 23$ nuclei using three different realistic effective interactions. One of these was evaluated in the so–called screened Tamm–Dancoff approximation[1]) using the Hamada-Johnston potential while the other two were evaluated from the Bonn–Jülich and Paris potentials including essentially all important long-range correlations to all orders[2]). The HF and shell model spectra are fairly close to each other and show reasonable agreement with the experimental spectra. Also, the results compare favourably with those obtained using the Kuo–Brown and Preedom–Wildenthal interactions[3]). Further, the HF calculation approximately reproduces the results of particle-rotor model calculations and thus accounts for the rotational features of these nuclei[4]). The results have been presented at several conferences[5]) and a complete report is being written up.

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5. F. Brut, E. Osnes and D. Strottman, Bull.Am.Phys.Soc. **31** (1986) 815 and Proc.Int.Nucl.Phys. Conf., Harrogate, Vol. **1** (1986) 77

7.2 Nuclear Reactions

7.2.1 Proximity Interaction between Deformed Nuclei

K. Idland and T. Engeland

The nuclear interaction potential plays a central role in the description and analysis of collisions between heavy ions. In reactions with light ions the interaction potential is a function of the distance between the fragments along the center line. However, when heavy deformed nuclei are involved, substantial corrections to such a description are expected. One alternative approach is the so-called proximity treatment of the interaction potential.

In the present project we investigate the effect of the proximity potential method when both target and projectile are deformed. The basic theory is discussed in refs.[1-4]). Our first step is to develop a prescription and a computer code to calculate the proximity distance between two deformed fragments. Next, this will be used to calculate the interaction form factor for the reaction. Once these problems are solved we will use standard coupled-channel analysis to calculate the reaction cross section. Some preliminary work on the proximity distance has been done.

As a first test of the method we will investigate the effect on reactions involving nuclei with well developed hexadecapole deformation.

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7.3 The Foundation of Quantum Physics

7.3.1 The Non–Separability in Quantum Physics

K. Gjøtterud and H. Andås

Questions concerning the completeness of quantum theory, as first raised by the famous EPR – paper[1]), have gained renewed interest due to the results of the polarization correlation experiments published by Aspect et al.[2]) and the delayed choice experiment published by Hellmuth et al.[3]). The Aspect experiment demonstrates the non–separability, even for systems with a space extension of about 10 meters, as described by quantum theory. It violates the Bell[4]) inequality and falsify thereby local extravariable theories for quantum phenomena. The Hellmuth experiment demonstrates the impossibility, even with a delayed choice of the appropriate boundary conditions, to appoint a definite orbit to an electromagnetic quantum in an interferometer. So far all attempts at constructing an experiment giving a more detailed information about a system than afforded by quantum mechanics seems futile. In this respect the practical realizations of the Einstein – Bohr – Weeler "gedanken" experiments supports the completeness of quantum theory[5]).

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   Phys. Rev. **48** (1935) 696
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   ed. P. A. Schilpp, Tudor, New York (1951)199
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6. H. Andås, *Cand. Scient Thesis, University of Oslo* (1987)

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Chapter 8

Other Fields of Research

8.1 Natural Background γ–radiation Survey and the Fall–out from the Chernobyl Accident

A. Storruste, S. Strøm*, E. Larsen** and T. Strand***
*Section for Electronics, Institute of Physics.
**Division of Occupational Health and Working Environment, University of Oslo.
***The National Institute of Radiation Hygiene, Bærum, Norway.

After the Chernobyl accident the National Institute of Radiation Hygiene, SIS, asked for equipments to be used for continuous measurements of the environmental γ–radiaton and early warning of radioactive plumes in various plases throughout the country

For this purpose one of us (S.Strøm) has developed a new linear amplifier for small currents, LASC. Coupled to an ionisation chamber the instrument measures ion currents from 0,01 pA to 1 nA. The construction of LASC is based on a new idea which makes resistors of extremely high resistens superfluos. Further, no expensive components are needed. The construction is relatively simple, so that the instrument is made rather cheap.

A few instruments of the type LASC–4 are made. They are coupled to a 4 litres ionization chamber filled with nitrogen or argon to 20 atm. The instrument is connected to a PC for continuous measurements of the environmental γ–radiation. One instrument of this type is installed at SIS. Another type, LASC–3, is in use at the University Division of Occupational Health and Working Enviroment, OHWE, for momentary or continuous measurements of radon concentration in the enviromental air. This instrument is coupled to a 10 litres ionization chamber and an ordinary small plotter, and the whole equipment is easily moved from place to place.

Elena Larsen, at the OHWE, has measured very high radon consentrations inside the University buildings at Tøyen. The highest values were found in some wooden old apartment buildings. In a sleeping room a value of 4 600 Bq/m^3 and in a basement room a value of 24 700 Bq/m^3 was measured. Most of these measurements are done with an ETB dosemeter, which is a passiv integrating meter combining activated charcoal and TLD. In collaboration with the University Division for Maintenance actions are now taken to reduce the radon concentration in the buildings.

8.2 Wet Breathing Gas

N.T.Ottestad * and A. Storruste
**Ottestad Breathing System A/S, Tønsberg.*

The project "Wet Breathing Gas" started in 1978, when N. T. Ottestad was a staff member at the University Division of Occupational Health and Working Environment. Later Ottestad has erected his own firm: Ottestad Breathing System A/S, Tønsberg, for the purpose of producing equipment for divers in cooperation with Vinghøgs Mekaniske Verksted A/S, Tønsberg.

The main participants during the testing of this equipment, the OBS system, has been the Norwegian Underwater Technology Center (NUTEC), Norsk Hydro and Statoil. The project has financially mainly been supported by Statoil, Industrifondet (repayable grant) and NTNF.

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 and physical 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 30° – 40° C. The experiments have strongly indicated that moistened, warm breathing gas (as 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 at the facilities of NUTEC and the Divers and Frogmens School in Bergen.

The experiments have shown that a higher breathing gas temperature is accepted if the gas is moistened. Thus the respiratory heat loss can be strongly reduced at any depth without any discomfort for the diver. Thermal balance can therefore be obtained with lower skin temperature (32° – 34°C) compared to the traditional conditioned breathing gas. The temperature inside the hot–water suit can be lowered. This should reduce problems with hot–water scolds. To have the respiratory heat completely eliminated seems to cause discomfort for most divers.

In the longer run the hot–water suit may be replaced by an electric heated suit. This alternative is the object for further studies. A scheme for a collaboration with the University Section for Condensed Matter Physics and the Center of Industrial Research (SI) for this project has been discussed on the assumption that financial support is granted.

During the last two years the OBS system has been thoroughfully tested unmanned at 400 m and manned at 360 m sea–water depth. The performance has proved to be bether than for any other breathing system tested at these depths. It is now accepted for operational use down to 360 m. Thus the basic ideas has been succesfully demonstrated and OBS breathing systems are installed in chambers and welding habitats to be used on "OSEBERG" at maximum 360 m in the North Sea. The humidifier as well as the regulator in the system is patented in several countries (NO 140 173 and NO 812 928 respectively).

The experimental activity is centered around the laboratory of OBS A/S in Tønsberg. Most of the tests are carried out in a breathing simulator, which is build into a 300 litres pressure vessel. In addition the firm has a small pool whwere simple manned testing is carried out.

8.3 Solar Energy Research

S. L. Andersen, M. Mehlen* and J. Rekstad.
* *Solar Tech, Blindern.*

The Solar Energy research project at the Department of Physics has in 1987 been financed from the Ministry of Petroleum and Energy, the Ministry of the Environment, Østfold Energy Supply, NTNF and the Institute of Physics. A post doctor fellow, a civilian engineer from Østfold Energy Supply and a farmer have parts of the year been involved in the project.

The main topics of research this year are:

Construction and testing of a new data–loging system.
Data–loging og the hot water solar system in the University ZEB building.
Construction and calculations of an industrial hay dryer system.
Construction, testing and data–loging of a hay dryer in an old barn.
Data–loging of SOLTUN.

The results from the hay dryer in the old barn was sucsessfull. The efficiency of the solar panel had an average of 40 %. The temperature of the drying air raised from 2° to 10°C above ambient air temperatur during the day for an air volume of 45 000 m^3/h.

The ZEB plant has been working well all through the year. It produces about 35 % of the necessary energy for the hot water.

In SOLTUN the logging has not yet been working continously, but the results show that the solar energy systems are working according to plans.

For details see Annual Report from Solar Energy Group 1987, Department of Physics Report 88 – 01, 1988.

Chapter 9

Seminars and Lectures

9.1 Seminars

Date :		
12.01	E. Hammaren:	The Monster Code
13.01	T. T. T. S. Kuo:	First and Second Order Phase Transitions of Nuclear Matter.
17.03	G. Løvhøiden:	Heavy Ion Reactions in the Intermediate Energy Region.
31.03	G. Midttun:	Colourbook. What is that? Last news about data communication.
09.04	G. Løvhøiden:	Heavy Ion Reactions in the Intermediate Energy Region. (cont.)
11.05	J.M. Hansteen:	Some Viewpoints on the Semi–Classical Description of Ion–Atomic Collisions.
12.04	G. Løvhøiden:	Heavy Ion Reactions in the Intermediate Energy Region. (cont.)
18.05	R. Zelazny:	Magneto–Hydroelectric Equilibria with Plasma Flows.
18.05	R. M. Diamond	Recent Experiments with HERA.
19.05	R. M. Diamond:	High Spin Nuclear Spectroscopy.
02.07	K. Nybø:	Octopole Deformed Nucleus.
21.07	I. Talmi	The Nucleon Shell Model - of Nucleons or Quarks ?
22.07	I. Talmi	Status and Perspectives of the Interacting Boson Model.

26.08	Z. Zelazny:	Gamma-Decay of Highly Excited ^{172}Yb Nucleus.
22.09	T. Engeland:	Gamma-Deexitation of Highly Excited Nuclear States.
06.10	T. Engeland:	Gamma-Deexitation of Highly Excited Nuclear States.(cont.)
20.10	M. Guttormsen:	Studies of Gamma-Deexitation of Highly Excited Nuclear States at the Cyclotron Laboratory.
27.10	E. Osnes:	Nuclear Physics into the -90s.
30.10	J. Rekstad:	Report from a Visit at Kernfysisch Versneller Instituut, Groningen.
03.11	A. Storruste:	About Radon Gas and Radon Measurements.
10.11	T. Ramsøy and P. O. Tjøm:	Report from the NORD-BALL Meeting at the Niels Bohr Institute.
08.12	A. Atac:	Nuclear Shapes and the Macroscopic-Microscopic Approach.

Chapter 10

Visitors

Long–term visitors are listed in chapter 2 and guest lectures in chapter 9. The following visiting scientists have participated in experiments at the cyclotron:

University of Bergen:	G. Løvhøiden T. F. Thorsteinsen
Warsaw University:	J. Kownacki

The following visiting scientists have participated in the theoretical activities at the Section for Nuclear Physics:

University of Bergen:	J. Vaagen
State University of New York at Stony Brook:	T.T.S. Kuo
Weizmann Institute of Science, Rehovot:	I. Talmi

Chapter 11

Committees, Conferences and Talks

11.1 Committees and Various Activities

External committees and activities only are listed.

T. Engeland:	Member of the Board ot the Norwegian Physical Society (NPS). Referee for Nuclear Physics and Physics Letters.
K. Gjøtterud:	Referee for Nuclear Physics and Physica Scripta. Chairman of the committee for The Lisl and Leo Eitinger prize. Member of the committee for The Knut Rand Scholarship. Member of The Norwegian Physical Society's Human Rights Committee. Member of "International Federation of Scientists for Soviet Refusniks".
M. Guttormsen:	Member of the Board of the Nuclear Physics Committee of the Norwegian Physical Society. Deputy Member of the National Committee for Nuclear Research. Referee for Nuclear Physics and Zeitschrift für Physik. Referee for Nuclear Physics.
T. Holtebekk:	Chairman of The Norwegian Standardization Organization Sub-Committee for Technical and Physical Units.
F. Ingebretsen:	Deputy member of the Science Council of The Norwegian Research Council for Science and Humanities. Member of Energy Research Advisory Committee, 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 Board of the Norwegian Council of Physics (Norsk Fysikkråd)
Member of the Advisory Committee of Nuclear Physics of NORDITA.
Member of the Council of the European Physical Society.
Co-editor (with T.T.S. Kuo) of International Review of Nuclear Physics, published by World Scientific Publ. Comp..
Referee for Nuclear Physics, Physics Letters B and Physica Scripta.

J. Rekstad: Referee for Nuclear Physics.
Member of a Solar House Committee in Østfold Fylke.
Member of the Board of Directors of Innovasjonssentret A/S.
Member of the Board of Directors of "Industriell Incubator in Oslo".
President of the Board of Directors of "FOSFOR" (Research Foundation for the Oslo Region).
Member of the Board of Directors of NAVF.

R. Tangen: Member of the Norwegian Academy of Science.

P.O. Tjøm: Member of the Nordic Committee for Accelerator Based Research (NOAC).
Referee for Nuclear Physics.

11.2 Conferences

T. Engeland, I. Espe, M. Guttormsen, F. Ingebretsen, E. Osnes, T. Ramsøy, J. Rekstad and J. Wikne participated in the Annual Meeting of the Norwegian Physical Society, Stavanger, June 15. - 18. 1987.

M. Guttormsen, T. Ramsøy and P. O. Tjøm participated in The NORDBALL User Group Meeting in Copenhagen Oct. 12. - 14. 1987.

J. Rekstad participated in a study conference: "Haugaland towards the year 2000", Haugesund, Sept. 17. 1987.

11.3 Visits and Talks

J. Rekstad:

Invited talk: "Organization of University /Industry Research Collaboration in Oslo" for a Canadian Mission led by the president of the Natural Science and Research Council of Canada. Oslo Febr. 25. 1987.

Invited talk: "The Science Park, the Innovation Center, the Research Foundations, what sort of information do they need from the University?" at Nordic Conference for Information Offisers at Universities in the Nordic Countries, June 9. – 11. 1987.

Invited talk: "The Function of Science and Priorities in Research Policy" at a one day conference arranged by the Norwegian Research Policy Council. Oslo June 12. 1987.

Seminar: "Research Evaluation and Research Statistics: Who are Right?" at the Institute for Studies in Research and Higher Education, NAVF. Oslo June 22. 1987.

Participant in Panel Debate: "Strategic Planning of Science and Technology" at the Annual Meeting in the Norwegian Physical Society, Stavanger, June 15 – 18. 1987.

Invited talk: "Solar Energy" at the Energy Conference (ENØK) arranged by "Buildings for the Future" in Oslo Aug. 19. 1987.

Invited talk: "New Science Parks – a Coupling between University and Industry" at the Blindern Conference 1987, arranged by NIFF and the University of Oslo, Aug. 19. 1987.

Invited talk: "FOSFOR – Challenges for SIFO" at a Conference arranged by SIFO (Statens institutt for forbruksforskning) at Klekken Hotel Sept. 30. - Oct. 1. 1987.

Invited talk: "Solar Energy Future in Norway" at the Official Opening Ceremony for the Solar Heated Houses SOLTUN at Jeløya, Moss, Oct. 2. 1987.

Invited talk: "Technology Parks in Oslo" at a Morning Conference arranged by Byforum. Oslo, Oct. 20. 1987.

Participant in an official Norwegian delegation to Canada on the occasion of a new research and technology collaboration – agreement between Canada and Norway. Visits to several universities and science parks. Nov. 14. – 22. 1987.

Chapter 12

Theses, Publications and Reports

12.1 Theses

1. Harald Andås:
   An Inquiery into the Origin of the Non–Separability in Quantum Mechanics.
   Cand. Scient. thesis.

2. Espen Johansen:
   Quasiparticle–Plus–Core Coupling Model in Well Deformed Nuclei.
   Cand. Scient. thesis.

3. Linda Appel Rønning:
   ^{143}Nd at High Internal Energy Studied by the Reaction ^{144}Nd(^{3}He,^{4}He)^{143}Nd.
   Cand. Scient. thesis (in Norwegian).

4. Terje Strand:
   Doses to the Norwegian Population from Naturally Occuring Radiation and from the Chernobyl Fall–out.
   Dr. Scient. thesis.

5. Trine Spedstad Tveter:
   ^{162}Dy at High Exitation Energy Studied by the Reaction ^{163}Dy(^{3}He,^{4}He)^{162}Dy.
   Cand. Scient. thesis (in Norwegian).

12.2 Scientific Publications

12.2.1 Nuclear Physics and Instrumentation

1. A. Atac, J. Rekstad, M. Guttormsen, S. Messelt, T. Ramsøy, T.F. Thorsteinsen, G. Løvhøiden and T. Rødland: The Decay of Hot Dysprosium Nuclei. Nuclear Physics **A472** (1987) 269.

2. E.M. Beck, J.C. Bacelar, M.A. Deleplanque, R.M. Diamond, F.S. Stephens, J.A. Draper, B. Herskind, A. Holm and P.O. Tjøm: High-Spin State Spectroscopy in ^{165,166}Yb. Nuclear Physics **A464** (1987) 472.

3. K.P. Blume, H. Hübel, M. Murzel, J. Recht, K. Theine, H. Kluge, A. Kuhnert, K.H. Maier, A. Maj, M. Guttormsen and A.P. De Lima: High–Spin State in $^{163-166}$Hf. Nuclear Physics **A464** (1987) 445.

4. M. Guttormsen, T. Ramsøy and J. Rekstad: The First Generation of γ–rays from Hot Nuclei. Nuclear Instruments and Methods **A225** *(1987) 518.*

5. J. Honkanen, J. Äystö, K. Eskola, V. Koponen, S. Messelt, P. Taskinen and K. Ogawa: Gamow–Teller Strength in the β–decay of Mirror Nuclides. Proccedings "5th Int. Conf. on Nuclei far from Stability", Sept. 14. – 19. 1987, Ontario, Canada.

6. E. Osnes : What Happened to the Kuo–Brown Interaction ? in Windsurfing the Fermi Sea, Proc. int. Conf. and Symp. on Unified Concepts of Many–Body Problems, Stony Brook, 1986, eds. T.T.S. Kuo and J. Speth, vol. **2** (North–Holland, Amsterdam, 1987) p. 226–238

7. J. Rekstad, A. Atac, M. Guttormsen, T. Ramsøy, J.B. Olsen, F. Ingebretsen, T.F. Thorsteinsen, G. Løvhøiden and T. Rødland: Reaction Dependence and Gross Structure of the γ–Decay of Highly Exited States in the Rare Earth Nucleus ^{162}Dy. Nuclear Physics **A470** (1987) 397.

8. T. Ramsøy, A. Atac, T. Engeland, M. Guttormsen, J. Rekstad, G. Løvhøiden, T.F. Thorsteinsen and J.S. Vaagen: Particle–Vibration Coupled States in ^{161}Dy. Nuclear Physics **A470** (1987) 79.

12.3 Scientific and Technical Reports

12.3.1 Nuclear Physics and Instrumentation

1. Nuclear Physics Group Annual Report 1986.
   University of Oslo, Departement of Physics Report 87–11, 1987.

2. T. Batsch, J. Kownacki, Z. Zelazny, M. Guttormsen, T. Ramsøy, and J. Rekstad:
   Particle–Core Multiplets in ^{89}Y.
   University of Oslo, Departement of Physics Report 87 – 31, 1987.

3. T. Ramsøy, B. Bjerke, M. Guttormsen and B. Skaali:
   DAISY - A VME-based Data Acquisition System.
   Preprint, 1987.

4. A. Sturruste:
   Radioactive Isotopes. Experimental and Theoretical Excercises in Determination of Radioactive Doses for the High School.
   University of Oslo, Departement of Physics Report 87 – 14 (in Norwegian)

5. Z. Zelazny, T.S. Tveter, A. Atac, M. Guttormsen, T. Ramsøy and J. Rekstad:
   First Generation γ–rays from highly Excited Even Rare–Earth Nuclei.
   University of Oslo, Departement of Physics Report 87 – 25, 1987.

6. J.C. Wikne:
   The SAT-rack Readout.
   Electronics Abstract, Delphi Meeting, CERN,
   Geneva February 9 - 13, 1987.
   Abstract, Ann. Meeting, Norw. Phys. Soc., Stavanger 1987.

7. J.C. Wikne:
   An Intelligent GPIB Controller.
   University of Oslo, Department of Physics Report 87 - 42, 1987.

12.3.2 Solar Energy

1. Research in Solar Energy at the Department of Physics. Annual Report 1986.
   University of Oslo, Departement of Physics Report 87 - 07, 1987 (in Norwegian).

2. S.L. Andersen, I. Espe, O. Herbjørnsen, O. Lie and M. Mehlen:
   Solar Energy Hay Dryer in Lie, Flesberg.
   University of Oslo, Department of Physics Report 87 - 32, 1987 (in Norwegian).

3. C. Choudhury and S.L. Andersen.
A Solar Air Heater for Low Temperature Applications.
Solar Energy, in press.

4. C. Choudhury, S.L. Andersen and J. Rekstad:
Optimum Design of a Solar Air Heater.
University of Oslo, Department of Physics Report, **87 – 03**, 1987.

5. M. Mehlen and S.L. Andersen:
Energy–Economical Analysis of an Industrial Solar Energy Hay Dryer Plant.
Unpublished (in Norwegian).

6. J. Rekstad:
Solar Energy.
Conferense Compendium (in Norwegian)
Edited by "Bygg for Framtida", Bærum, 1987.

12.4 Non–Scientific Publications (In Norwegian)

1. H. Andås og K. Gjøtterud:
Kvanteteorien - Er den fullstendig?
Fra Fysikkens Verden **49** (1987) 76

2. T. Holtebekk:
Several articles on physics in "Aschehoug og Gyldendals Store Norske Leksikon". (Second edition).

3. E. Osnes :
Årsmelding fra NorskFysisk Selskap 1986–87
Fra Fysikkens Verden **49** (1987) 67–68

4. E. Osnes og T. Riste:
Gerd Jarret 60 år
Fra Fysikkens Verden **49** (1987) 75

5. J. Rekstad:
Research Recruitment and Fields of Priority.
Report to Innovasjonssenteret, Nov. 1985.
Fra Fysikkens Verden, **49** (1987) 20.

6. J. Rekstad:
RNF evaluates Research Disiplines - Why?
Chapter in: Evaluation of Research - Nordic Experiences.
Nordic Science Policy Counsil, FPR–publication **5**, (1987) 35 - 44.

12.5 Mass Media, Interviews and Reports

1. J. Rekstad:
   Guest in the Radio Program "Markedsplassen", NRK Febr. 2. 1987.
   Information about FOSFOR. Interview in ACEM radio Sept. 9.
   1987.

2. Ø. Holter og F. Ingebretsen:
   Fra Redaktørene.
   Fra Fysikkens Verden **49** (1987) 2

3. Ø. Holter og F. Ingebretsen:
   Fra Redaktørene.
   Fra Fysikkens Verden **49** (1987) 26

FYSISK INSTITUTTS 8 FORSKNINGSGRUPPER	DEPARTMENT OF PHYSICS RESEARCH SECTIONS
Allmennfysikk og didaktikk	General Physics
Biofysikk	Biophysics
Elektronikk	Electronics
Elementærpartikkel-fysikk	Experimental Elementary Particle physics
Faste stoffers fysikk	Condensed Matter physics
Kjernefysikk	Nuclear physics
Plasma-, molekylar- og kosmisk fysikk	Plasma-, Molecular and Cosmic physics
Teoretisk fysikk	Theoretical physics

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