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ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

PROGRESS REPORT
PHYSICS AND HEALTH SCIENCES
PHYSICS SECTION

1986 July 01 - December 31

PR-PHS-P-2

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario

February 1987 février

ATOMIC ENERGY OF CANADA LIMITED

Chalk River Nuclear Laboratories

PROGRESS REPORT

1986 July 1 to December 31

PHYSICS AND HEALTH SCIENCES

PHYSICS SECTION[1]

PR-PHS-P-2

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1) For Health Sciences see AECL-9352

2) Shared with Radiation Applications and Isotopes

Chalk River, Ontario

1987 February

AECL-9351

TABLE OF CONTENTS
PR-PHS-P-2

SUMMARY - J.C.D. Milton

This is the second progress report since the reorganization of the AECL Research Company and marks the near completion of the first year of operation for Physics and Health Sciences (for details of the reorganization see PR-PHS-P-1 or PR-PHS-HS-1). Although funding uncertainties are still posing problems we have accomplished a great deal.

A highly successful opening ceremony for TASCC was held on October 3 followed by a symposium on the following day. The formal opening was performed by Robert Després, Chairman of the Board of AECL. With him on the platform were Professor D.A. Bromley, Yale, who gave the keynote address, The Hon. Greg Sorbara, Minister of Colleges and Universities (Ontario), Mr. Tom Campbell, Chairman of the Board of Ontario Hydro, Dr. W.M. Tupper, Chairman of the House Committee on Research, Science and Technology, Mr. Joe Bromberger, High Voltage Engineering Corporation, and Len Hopkins, MP for Renfrew North. Invited speakers at the Symposium were: Professor P. Braun-Munzinger, Stony Brook; Dr. R.M. Diamond, Lawrence Berkeley Laboratories; Professor Gregers Hansen, Aarhus; and Professor H. Blosser, MSU.

Phase II of the TASCC facility, approved by the Board of Directors in February 1986, is now well underway. It provides the beam transport system from the superconducting cyclotron to the target rooms. Present plans are to shut down the facility beginning January 1988 to complete the first part of the installation. After the shutdown a part of the new beam transport system can be used while the remainder is being installed. The construction of replacement 8-foot accelerating tubes for the MP tandem is now underway at HVEC. These will enable the tandem to operate at terminal voltages above 13 MV.

Analysis of the first experiment with the superconducting cyclotron has been completed and shows that the transition quadrupole moments of the yrast band in ^{174}Os are essentially constant implying a relatively constant nuclear shape up to spin 20 in apparent contradiction to recent data on ^{172}W.

In a second experiment analysis is nearly complete of the hitherto unknown alpha decays of ^{162,163}Ta. Decay properties of the little known isotopes $^{160-165}$Ta were obtained in the experiment and will permit the precise determination of masses of 8 nuclei far from stability.

The 8-pi spectrometer, a joint project with the Universities of Montréal and McMaster was completed on budget and on schedule. First experiments are being carried out at the end of the interim beam line. During the shutdown referred to above, the 8-pi will be moved to its permanent location.

The helium jet transfer source for ISOL was tested with outstanding results -- the overall efficiency is about 10 times better than any previously obtained. The jet source enables the ISOL to be used in its new location with the interim beam line.

Work is progressing well on the third piece of major equipment, now called SAPPHIRE (Spectrometer Array for Particles Produced in Heavy-Ion REactions). A workshop on the spectrometer and related physics will be held in conjunction with the Eastern Regional Nuclear Physics Conference at the University of Toronto, March 26-28. A proposal to AECL and NSERC for funding will be submitted late in 1987.

Substantial progress has been made on the detailed design of DUALSPEC, the double neutron spectrometer for neutron scattering at NRU. Completion is still scheduled for 1989. Both the new superconducting horizontal field magnet and the ^3He dilution refrigerator are operating well, enabling sample temperatures as low as 10 mK and horizontal fields as high as 3T.

Headway is being made on many aspects of the SNO project (Sudbury Neutrino Observatory) including measurement of the background from components, testing of photomultipliers and electronics, design of the acrylic vessel for the 1000 tonnes of D_2O and shielding calculations. A major proposal to Canadian, U.S. and U.K. funding authorities is planned for October 1987.

In theoretical physics, new work on fractals is beginning to bear fruit. Work continues on the non-topological soliton model of the nucleons, on meson currents in relativistic shell model theories, and on supergravity. A highly successful workshop directed by a member of Theoretical Physics Branch was held at Simon Fraser University in July on superfield theories.

Emphasis in the National Fusion Program (NFP) has been placed on obtaining new operating agreements with CCFM (Canada Centre de Fusion Magnetique - the Tokamak de Varennes) and CFFTP (Canadian Fusion Fuels Technology Project). Essential agreement has been reached in both cases.

A communication plan for the NFP has been developed and implementation has started to inform participants, funders and the public of the activities of the program. It consists of a brochure, a newsletter, an annual report, display boards and teaching aids for high school instruction on fusion.

A license issued to Shar-Buc Enterprises for a multiconductor cable tester is the first spin-off business of the Research Company. The company will be operated initially by two employees, F.J. Sharp and L.H. Bucholtz.

ANDI, Applied Neutron Diffraction for Industry is our major, and highly successful, commercial activity.

TABLE OF CONTENTS
(TASCC)

1. SUMMARY

J.C. Hardy, J.S. Geiger, N. Burn and J.A. Hulbert

1.1 GENERAL

The past six months saw the superconducting cyclotron complete its first operating period. Although much of the time was spent on commissioning tests, another nuclear physics experiment was completed with the full TASCC facility. It led to the characterization of six little-known isotopes of tantalum, each more than 15 neutrons lighter than the stable tantalum isotope. During the required two weeks of the experimental run, TASCC operation was remarkably trouble free, with the current of 5.6 MeV/u ^{127}I reaching above 70 nA at times - over 3 particle nA.

The cyclotron tests helped to define remaining limitations in the accelerator's operation. In particular, high voltages and high frequencies on the dees were observed to cause vacuum deterioration in the cyclotron midplane. Design improvements to rectify this difficulty and the one discovered in the last reporting period, which prevents π-mode operation, are being implemented during the cyclotron shutdown now in progress. Unfortunately, the vacuum problems prevented successful extraction of the planned third beam from TASCC, 20 MeV/u ^{79}Br.

As a result of the need for extensive cyclotron diagnostic tests and the beginning of the shutdown in early December, the full facility operated for only 201 hrs; this was 39% of its scheduled operating time. Of this time, 70 hrs were spent delivering beam to nuclear physics experiments. Whenever possible, experiments were also performed with beams from the MP tandem alone, delivered via the bypass line to the interim target line. Such experiments occupied 327 hrs and involved University scientists as well as Nuclear Physics Branch staff. The former contributed, on average, 40% of the total effort.

A real high point of University-Chalk River collaborative success was reached late in the year with the successful completion and first operation of the 8π γ-ray spectrometer. This instrument, jointly funded by AECL and NSERC, is a "national facility" at the forefront of its field. It was completed on time, within its budget and so far appears to meet all technical expectations.

On Friday, October third TASCC staff put aside their efforts of the past decade and celebrated with their colleagues the "opening" of TASCC. The official unveiling of a commemorative plaque was performed by AECL's chairman, Robert Després; the keynote address was delivered by D.A. Bromley, Henry Ford II Professor at Yale University. Platform guests at the formal ceremony also included Dr. W.M. Tupper, MP, Chairman of the Parliamentary Committee on Research, Science and Technology; the Hon. Greg Sorbara, Ontario Minister of Colleges and Universities; Len Hopkins, the riding MP; Tom Campbell, Chairman of Ontario Hydro; and Dr. J.F. Bromberger, President, Science Division, High Voltage Engineering Corporation. The ceremony was attended by nearly a hundred visiting dignitaries including prominent international and Canadian university scientists and science leaders. Afterwards all gathered with TASCC and construction staff at a reception and tour of the facility. A banquet was held in the evening at which the speaker was R.E. Bell, Professor Emeritus and former Principle of McGill University.

The next day, a symposium on heavy-ion nuclear physics was held, with speakers P. Braun-Munzinger (SUNY, Stony Brook), H.G. Blosser (Michigan State University), R.M. Diamond (LBL, Berkeley) and P.G. Hansen (CERN and Aarhus University). Overall, the two-day event was well received by locals and

1.2 RESEARCH

The data from the first TASCC experiment (Lifetime Measurements of High Spin States in ^{174}Os, section 3.1.8) have been analyzed and a draft paper produced. The measurements show that the transition quadrupole moments of the yrast band in ^{174}Os are essentially constant, consistent with a relatively constant nuclear shape up to spin 20. The results appear to disagree with recent data obtained for the isotone ^{172}W.

The TASCC experiment to produce and measure the decay properties of the little known isotopes $^{160-165}$Ta has been completed (3.1.7). The measurements on the hitherto unknown α-decays of ^{162,163}Ta will permit the precise determination of 8 masses of nuclei far from stability.

Mean lifetimes have been measured for the decay of high-spin states in the superdeformed bands of ^{132}Ce (3.1.3) and ^{152}Dy (3.1.5). The experiments were carried out at Daresbury Laboratory in collaboration with physicists from Daresbury, the University of Liverpool and Niels Bohr Institute. The results provide direct evidence for the existence, at high spin, of highly deformed prolate nuclei with approximately a 2:1 axis ratio. These measurements are representative of the new frontier in γ-ray spectroscopy that will soon be accessible to detailed study with the 8π spectrometer.

Analysis of ^{14}N projectile fragmentation has been completed (3.1.1). The results reveal distinct signatures for projectile breakup in both the entrance and exit channels.

Rutherford backscattering studies of the liquid/solid interface have continued with proton beams from the Queen's University 4 MV accelerator (3.1.11). The experiments use a small cell developed at CRNL, which has a 0.65 μm thick Si entrance window. In tests carried out with a 0.1 M $CsNO_3$ solution the Cs atoms were found to diffuse through the Si window over the area irradiated by the proton beam. This unexpected result could have technological implications, one possibility being a means of making contacts to semiconductor devices.

1.3 EXPERIMENTAL EQUIPMENT

Construction of the 8π spectrometer was completed on schedule (3.2.5-8). Assembly of the inner BGO ball of 72 detectors was completed in November and 19 of the 20 suppressed HPGe counters were installed and operating in December. The automatic LN_2 filling system is now in routine operation. Two runs with ^{34}S beams from the MP tandem were performed to begin commissioning and to explore the capabilities of the device (3.2.9). The performance of both the inner BGO ball and the Compton-suppressed Ge detector array met design expectation.

The He-jet ion source for the TASCC on-line isotope separator (ISOL) has been tested extensively under on-line conditions (3.2.4). Relative efficiencies were measured for 18 isotopes of twelve elements ranging in half life from 2 s to 1 h. The absolute efficiency of the source-plus-separator was measured for ^{115}In ions and found to be about 3%. This value is more than an order of magnitude greater than that achieved with comparable systems elsewhere.

The conceptual design, prototype module construction, testing and costing required to prepare a proposal for a "Spectrometer Array for Particles Produced in Heavy-Ion REactions" (SAPPHIRE) are nearing completion (3.2.10). The goal is to present this proposal to AECL and NSERC in the fall of 1987 for funding in early 1988.

1.4 ACCELERATORS

The tandem operated satisfactorily during the period, producing beams for cyclotron experiments and for nuclear physics experiments at three interim target-line locations. The tandem tank was evacuated on ten occasions, two of which were for scheduled maintenance.

The superconducting cyclotron operated for various sub-system performance tests and for one nuclear physics experiment with ^{127}I at 0.71 GeV. A ^{79}Br beam was successfully accelerated to approximately 1.6 GeV but could not be extracted because of technical problems with cryopumps and various extractio elements.

The operating records for the tandem and cyclotron appear in Table 1.4.1.

Table 1.4.1

Tandem and cyclotron operating record, 1986 June 29 - December 31

Use	Time (hours) a)	
	Tandem	Cyclotron
Operating	1269.0	200.5
Scheduled shutdown	2774.0	3943.5
Unscheduled shutdown	713.5	320.0
Beam available	726.0	70.0

a)Total elapsed time, 4464 hrs.

The cyclotron radio-frequency system has now been operated at frequencies covering the whole operating range in 0-mode to define its effect on the mid-plane vacuum. The results, together with low-power rf tests on an aluminum model cavity, have explained the limitations of the operation of the cryopumps at high frequencies. A new cryopump front baffle has been designed to reduce rf penetration. One will be installed on both cryopumps during the current shutdown.

The wall and probe heating effects observed during π-mode operation are being addressed by improvements in rf contacts on the cryostat wall and modifications in diagnostic probe cooling. Tests for a new probe were successfully concluded and two radial probes built to the new design are nearly completed.

The electrostatic deflector has been operated to full specification (100 kV) although a higher current power supply will have to be obtained to give fully reliable operation.

In preparation for the shutdown, highest priority has been placed upon those components of the system that must be in place in order to operate the TASCC accelerators from the control room on a 24 hours-per-day basis. This has also involved considerable effort being put into operator training.

The current status is that the cyclotron midplane has been opened and the magnet warmed to room temperature to permit maintenance and modifications following the first year's operation. The cyclotron is scheduled to be ready for renewed operation by early April.

2. TASCC STAFF

TASCC STAFF

2.1 ASSISTANT TO VICE-PRESIDENT, TASCC

J.C. Hardy
Secretary: R.J. Elliott

2.2 NUCLEAR PHYSICS BRANCH

Branch Manager: J.S. Geiger
Secretary: D.L. Brookes (1)
H.C. Yeas (2)

Professional Staff

T.K. Alexander (3)
H.R. Andrews
G.C. Ball (4)
W.G. Davies
J.S. Forster
E. Hagberg
D.W. Hetherington (5)
D. Horn
V.T. Koslowsky
D.C. Radford
H. Schmeing
X.J. Sun (8)
D. Ward

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R.L. Brown
L.H. Bucholtz
P. Dmytrenko
J.J. Hill
R.E. Howard
P.J. Jones
J. Lori
J.P.D. O'Dacre
W.L. Perry
D. Phillips
F.J. Sharp
W.F. Slater
L.V. Smith
A.R. Sprake
R.W. Stalkie
M.G. Steer
R.B. Walker
M.J. Watson (6)
J.S. Wills (7)

Attached University Staff

G. Ayotte	Montréal
F. Banville	Montréal
M. Beaulieu	Montréal
T. Drake	Toronto
A. Galindo-Uribarri	Toronto
J. Gascon	Montréal
R.L. Graham	Guelph
J. Johansson	McMaster
C. St. Pierre (9)	Laval
L. Potvin	Laval
C. Pruneau	Laval
D.D. Rajnauth	McMaster
R. Roy	Laval
K.S. Sharma	Manitoba
P. Taras (10)	Montréal
D.M. Tucker	McMaster
J.C. Waddington (11)	McMaster

Students

R.T. Fredericks	National	Queen's, terminated 86-09-12
N.T. Ranger	National	Concordia, terminated 86-08-22
S. Rioux	Co-op	CEGEP de la Pocatière, terminated 86-08-15
R. Schaefer	National	Alberta, terminated 86-08-29

2.3 TASCC OPERATIONS BRANCH

Branch Manager: N. Burn
Secretary: J.H. Neville

Professional Staff

T. Astarlioglu
L.B. Bender
B.F. Greiner
P.I. Hurley
Y. Imahori
E.H. Lindqvist
E.P. Stock
L.W. Thomson

Technical Staff

G.J. Corriveau
L.D. Hill
R.E. Milks
M.J. St. Aubin (12)
J.J.R. Tremblay (13)
S.G. Whittle

Operational Staff

Supervisors

F.A. Annand (14)
F.A. Galloway (15)
G. Hodgson
T.G. Kosmack
T.W.R. Ryan
R.E. Stresman

Operators

J.K. Barrington
D.A. Corriveau
M.J. Corriveau (16)
J.L. Dellaire (14)
F.A. Galloway (15)
J.M.L. Godin
R.J. Kennedy
H.C. Lafreniere
B.A. McMahon (16)
B.U. Noel
W.G. Schroeder
R.G. Schultz

2.4 CYCLOTRON GROUP (ACCELERATOR PHYSICS BRANCH)

Professional Staff

J.A. Hulbert
C.B. Bigham (17)
C.R.J. Hoffmann

Technical Staff

J.E.A. McGregor
R.E. Milks
J.F. Mouris
L.W. Shankland

(1) Terminated as Branch Secretary, Nuclear Physics Branch, 1986 September 30.

(2) Transferred from Business Development Branch to the position of Branch Secretary, Nuclear Physics Branch, 1986 September 29.

(3) On sabbatical leave at Queen's University for a period of one year commencing 1986 September 01.

(4) Returned from Science & Engineering Research Council posting for 3 months as Senior Visiting Fellow in the Dept. of Physics, University of Liverpool, 1986 September 01.

(5) Terminated post-doctoral fellowship at CRNL 1986 August 22.

(6) Transferred from E.I.&.P. Branch 1986 October 21.

(7) Transferred to Radiation Applications & Isotopes Branch 1986 July 16.

(8) Visiting scientist (from the Institute of Modern Physics, Lanzhou, Republic of China) at CRNL for one year commencing 1986 October 14.

(9) Terminated sabbatical leave at CRNL 1986 June 30.

(10) Visiting scientist at CRNL for the period 1986 May 01 to 1986 December 31.

(11) Visiting scientist at CRNL for the period 1986 May 01 to 1987 October 01.

(12) Transferred to Physical Chemistry Branch 1986 October 31.

(13) Transferred from Physical Chemistry Branch 1986 July 14.

(14) Retired from AECL 1986 July 15.

(15) Promoted from Operator to Supervisor 1986 July 16.

(16) Transferred from NRU Reactor Branch 1986 September 8.

(17) On sabbatical leave at the Research Institute of Physics, Stockholm, Sweden from August 1986 through July 1987.

3. NUCLEAR PHYSICS BRANCH

(Report edited by G.C. Ball)

3.1 RESEARCH

3.1.1 ^{14}N Projectile Fragmentation: Breakup in the Entrance and Exit Channels of a Heavy-Ion Reaction

D. Horn, G.C. Ball, R. Bougault and E. Hagberg with L. Potvin (McMaster University), C. Pruneau, R. Roy and C. St-Pierre (Laval University) and D. Cebra, D. Fox and G.D. Westfall (Michigan State University)

Analysis of coincidences between light and heavy projectile fragments from the ^{14}N fragmentation experiment is now complete. In addition to the previously reported conclusions (PR-PHS-P-1: 3.1.3; AECL-9262) that were drawn from the angular correlation results, we can now report on the analysis of the energy correlations.

A great deal of effort was expended in the energy calibration of the phoswich detectors, since the intrinsic non-linearity of the scintillators was worsened by pulse saturation and timing jitter; these problems will be minimized in future experiments by alterations to the setup. The calibrations obtained in this work, accurate to 10-20 percent, should also improve in future experiments. An analysis of the energy correlations for the in-plane array elements was performed to produce Galilean invariant yields in velocity space ($v_{\parallel}$, $v_{\perp}$). These results were combined with those from the angular correlation measurement (θ, ϕ space), providing a clear distinction between events originating as breakup in the entrance channel and those from sequential decay in the exit channel.

The sequential decay nature of the C-p channel is confirmed: the velocity distribution of the protons is well centered on the average velocity of the associated carbon fragment (note that the average velocities of carbon fragments are higher in the pure transfer than in the C-α channels). While the B-α angular correlations are consistent with sequential decay simulations, the velocity distribution of alpha particles coincident with boron is not: it is centered on the beam velocity rather than on the boron fragment velocity. The fact that these alpha particles have a sizeable peak at the speed and angle of the beam indicates that they dissociate from the projectile before much of the kinetic energy is dissipated in the collision. The angle (12.5°) and average energy per nucleon (32 MeV/u) of the coincident boron fragments show that they subsequently undergo an inelastic collision with the target, but the alpha particles very nearly follow their original, unperturbed trajectory. The symmetry of these events about the beam velocity excludes a sequential decay mechanism, since that would lead to an asymmetric correlation. The velocity distribution of protons coincident with boron fragments resembles closely the B-α pattern of entrance channel breakup rather than the C-p pattern for sequential decay. Finally, the C-α channel shows a crescent-shaped distribution of alpha particles in velocity space on the side of the beam axis opposite to the carbon fragment. This type of opposite-side distribution is common in peripheral reactions. The velocity pattern of the alpha particles cannot arise from entrance channel breakup, since the alpha particle velocities center on neither the angle nor the speed of the beam. In this reaction channel, the fragmentation products must pick up at least one proton and possibly one or more neutrons from the target nucleus, since the total atomic number of the products exceeds that of the nitrogen projectile. This produces a heavy-fragment velocity lower than that for the boron channels or for the other carbon channels. The question is whether the alpha particle is emitted during an orbiting process associated with a transfer reaction, or in sequential decay following a transfer reaction. To the accuracy afforded by the limited number of events in this reaction channel, it appears that the alpha particles are emitted from a source moving with the velocity of the coincident carbon nuclei, i.e. following the pickup of target nucleons, and after the exit trajectory of the transfer product is established.

Reaction Q values appear to be correlated with the favored sequential decay channels. The Q values for decay of nitrogen and oxygen quasi-elastic products into carbon isotopes (plus protons or alpha particles) are negative, but typically only half those for decay of carbon and nitrogen quasi-elastic products into boron isotopes. It is therefore reasonable that the C-p and C-α channels should show substantial signatures of sequential decay in the exit channel. However, the B-α and B-p channels face strong Q-value competition from more favorable sequential decay channels; their observation in dynamical entrance-channel breakup of the projectile could be because no sequential events obscure that process.

3.1.2 The ℓ-forbidden M1 Decay of the 2469 keV Level of ^{39}Ca

T.K. Alexander, G.C. Ball, J.S. Forster, I.S. Towner (Theoretical Physics Branch) with J.R. Leslie and H.-B. Mak (Queen's University)

The ℓ-forbidden M1 transitions from the $J^\pi=1/2^+$ first-excited state to the $3/2^+$ ground state in ^{39}Ca and in its mirror nucleus ^{39}K are special because in lowest-order impulse approximation their matrix elements are zero. Thus, finite values determined experimentally can be interpreted in terms of effects arising from core polarization meson-exchange currents and excitation of the nucleus into the Δ(1232) resonance. The calculations of Towner and Khanna [Jour. de Physique <u>45</u> (1984) 519] indicate that the M1 matrix elements are mainly isovector and dominated by contributions from the isobar excitation.

Experimentally, the M1 part of the $1/2^+ \rightarrow 3/2^+$ transition from the first excited level at 2469 keV to the ground state of ^{39}Ca has not been determined directly because of the difficulty of measuring the E2/M1 mixing ratio. Also, previous measurements of the mean lifetime, τ = 360 ± 80 fs and τ = 260 ± 80 fs [see Endt and Van der Leun, Nucl. Phys. <u>A310</u> (1978) 1], have not resulted in an accurate value of the total gamma-ray width. In the present work, first reported in PR-PHS-P-1: 3.1.5; AECL-9262, the mean lifetime of the 2469 keV level of ^{39}Ca has been measured by the Doppler-shift attenuation method with the ^{3}He(^{40}Ca,α)^{39}Ca inverse reaction. A full analysis of the lifetime data gives τ = 233 ± 25 fs. The partial width Γ(M1) is obtained from $\Gamma_\gamma=\Gamma(M1)+\Gamma(E2)$ where Γ(E2) has been estimated from theory [$\Gamma(E2) \ll \Gamma(M1)$]. The theoretical E2 width for the mirror transition in ^{39}K is in excellent agreement with inelastic electron scattering experiments [see Grundey et al., Nucl. Phys. <u>A357</u> (1981) 269 and Jager et al., Phys. Lett. <u>B150</u> (1985) 421]. Thus the M1 width in ^{39}Ca can be inferred from the total width with small uncertainty.

The gamma-ray widths are summarized in Table 3.1.2.1 for both ^{39}Ca and ^{39}K. The last three columns compare the experimental values of the matrix elements

$M(T_z) = \sqrt{B(M1,T_z)}$ with the calculations of Towner and Khanna and a new calculation of Towner (see PR-PHS-P-2: 8.11; AECL-9351). The E2 width for the ^{39}Ca transition has been calculated from the matrix elements of Brown, et al. [Phys. Rev. C26 (1982) 2247] and the mass-dependent effective charges [see Alexander et al., Nucl. Phys. A445 (1985) 189], $1+\epsilon_p = 1.27$ and $\epsilon_n = 0.59$ for the protons and neutrons, respectively. The theoretical value of ^{39}K, $\Gamma(E2) = 3.0$ meV, compares favourably with the experimental value 3.36 ± 0.15 meV. The theoretical value for ^{39}Ca, $\Gamma(E2) = 0.54$ meV, has been adopted and a ±50% uncertainty assumed.

Table 3.1.2.1

Partial Gamma-ray Widths for the $1/2^+ \to 3/2^+$ Transitions in ^{39}Ca and ^{39}K

Nucleus	Γ_γ (meV)	$\Gamma(E2)$ (meV)	$\Gamma(M1)$ (meV)	$[B(M1,3/2\to1/2)]^{1/2}$ (μ_N)		
				Exp't	Theory[1]	Theory[2]
^{39}Ca	2.8(0.3)[3]	0.54(0.3)[4]	2.3(0.4)	±0.081(0.008)	+0.047	+0.028(0.018)
^{39}K	7.9(1.7)[5]	3.36(0.15)[6]	4.6(1.7)	±0.11(0.02)	−0.047	−0.024(0.018)

1) Towner and Khanna (Jour. de Physique 45 (1984) 519) assuming the isoscaler component is small.
2) Towner PR-PHS-P-2: 8.11; AECL-9351.
3) Present work.
4) Theoretical estimate (see text).
5) Experimental value for an adopted τ=83±18 fs from all published measurements [Stander, et al., Z. Phys. A323 (1986) 47; Zijderhand et al., Nucl. Phys. A451 (1986) 61 and references cited therein].
6) Experimental value from electron scattering data (see text).

The matrix elements can be separated into isovector, M^1, and isoscalar, M^0, parts where $M(T_z) = M^0+T_zM^1$. If the signs of the experimental matrix elements are taken to be the same as theory, then M^1=−0.096±0.011 μ_N and M^0=−0.015±0.011 μ_N. The corresponding theoretical values are M^1=−0.047 μ_N from the calculation of Towner and Khanna and M^1=−0.026±0.018 μ_N and M^0=0.002±0.001 μ_N from the present calculation of Towner. The theoretical isovector part is about a factor of 2 to 3.5 smaller than the experimental value. The theoretical isoscalar component agrees with the small experimental value.

The discrepancy in the isovector component becomes more puzzling since the corresponding theoretical matrix element $\sqrt{B(GT)}$ = −0.035 for the Gamow-Teller decay of ^{39}Ca, although larger than the experimental value of $\sqrt{B(GT)}$ = −0.023± 0.003 [see Adelberger, et al., Nucl. Phys. A417 (1984) 269], is not in serious disagreement. The new calculation of Towner gives $\sqrt{B(GT)}$ = −0.032± 0.018 with a theoretical uncertainty sufficient to overlap the experimental value. As Towner and Khanna have pointed out, for isovector M1 transitions polarization and isobar current corrections to the spin operator are the same in both cases. No real explanation for this discrepancy is known.

A manuscript describing this work is being prepared.

3.1.3 Mean Lifetime Measurements Within the Second Minimum in ^{132}Ce: A New Frontier in Gamma-Ray Spectroscopy

G.C. Ball with A.J. Kirwan, B.J. Bishop, M.J. Godfrey, P.J. Nolan and D.J. Thornley (University of Liverpool) and D.J.G. Love and A.H. Nelson (Daresbury Laboratory)

The first experimental indication of a superdeformed structure that decays by discrete-line gamma transitions was found in ^{132}Ce [Nolan et al., J. Phys. G11 (1985) L17]. A sequence of states was observed which extended beyond spin 40 $\hbar$, whereas the ground state sequence was only seen to spin 30 $\hbar$. The deformation determined from the measured moment of inertia of this band, assuming a rigid body, was $\beta \approx 0.45$.

The determination of transition strengths is a much more reliable way of deducing the deformation. An experiment designed to measure the mean lifetimes of the states in this deformed band in ^{132}Ce has been carried out at the Nuclear Structure Facility at Daresbury with the TESSA3 γ-ray spectrometer. This device is similar to TESSA2 [Twin, et al., Nucl. Phys. A409 (1983) 343C] but has 12 bismuth germanate suppressed germanium detectors in addition to the 50-element BGO array. The states in ^{132}Ce were populated by the ^{100}Mo(^{36}S,4n)^{132}Ce reaction at a beam energy of 150 MeV; approximately 200 million events were recorded. The target consisted of 1 mg/cm^2 ^{100}Mo on a 15 mg/cm^2 gold backing.

Mean lifetimes were measured by the Doppler Shift Attenuation Method (DSAM). The results obtained for the superdeformed band in ^{132}Ce are consistent with a quadrupole moment Q_0 = 8.8 eb, which corresponds to in-band E2 transition strengths of 680 Wu (Weiskopf single particle units) and a deformation of $\beta \approx 0.5$.

A paper has been submitted to Phys. Rev. Lett. for publication.

3.1.4 The Decay of ^{141}Gd

E. Hagberg, V.T. Koslowsky, H. Schmeing, J.C. Hardy and X.J. Sun with R. Turcotte, H. Dautet and A. Al-Alousi (McGill University)

A previous test experiment at CRNL (PR-PHS-P-1:3.1.9;AECL-9262) proved that the production rate of ^{141}Gd is large enough and that the level of contaminants is small enough that conversion electrons and γ-ray coincidences can be studied in the decay of this nuclide. A conversion-electron spectrometer, based on a mini-orange and a Si(Li) detector, two HPGe detectors and a tape transport system were brought from McGill and set up at CRNL. Our He-jet transport system and pumping system was connected to the McGill tape station.

The decay of ^{141}Gd has been studied during a first experiment with this set-up. The activity was produced with a 167 MeV beam of doubly stripped ^{32}S incident on a 3.8 mg/cm^2 thick ^{112}Sn target. The activity was transported to a counting location by the He-jet and tape transport system where it was viewed in close geometry by the three detectors. The singles spectra from the three detectors as well as any two-fold coincidences were recorded. Nine million coincidence events were stored on magnetic tape during a 3-day experiment.

These data should allow us to construct a decay scheme for ^{141}Gd and to assign multipolarities to transitions in ^{141}Eu. Analysis of our data has just begun. Further experiments on the decays of ^{141}Gd and ^{140}Gd appear possible.

3.1.5 Lifetime Measurements for the Discrete-Line Superdeformed Band in ^{152}Dy

G.C. Ball with P.J. Twin and J. Simpson (Daresbury Laboratory); M.A. Bentley, P.D. Forsyth, D. Howe, A.R. Mokhtar, J.D. Morrison and J.F. Sharpey-Schafer (Universty of Liverpool) and G. Sletten (Niels Bohr Institute)

The first evidence for the existence of superdeformed structures in transitional rare earth nuclei was found in ^{152}Dy [Nyako et al., Phys. Rev. Lett. 52 (1984) 507]. Ridges 47 keV from the diagonal of an $E\gamma_1$-$E\gamma_2$ correlation plot were observed corresponding to a dynamical moment of inertia (2)=85 $\hbar$ MeV^{-1}, a quadrupole deformation parameter $\beta \approx 0.6$ and an axis ratio of 2 to 1. Recently, it was discovered [Twin et al., Phys. Rev. Lett. 57 (1986) 811] that this superdeformed structure consists mainly of a single deformed band of discrete lines extending up to a spin of approximately 60 $\hbar$.

An experiment to measure the superdeformed quadrupole moment of this band by measuring the in-band transition probabilities from level lifetimes has been carried out at Daresbury with the TESSA3 γ-ray spectrometer (see PR-PHS-P-2: 3.1.3; AECL-9351 for details). A 205 MeV ^{48}Ca beam was used to bombard a target consisting of 1 mg/cm^2 of ^{108}Pd on a 15 mg/cm^2 gold backing. Compton suppressed Ge-Ge coincidences gated by the detection of a delayed (60 ns isomer in ^{152}Dy) decay in the BGO array were recorded together with the prompt BGO sum energy and multiplicity.

From a preliminary analysis of the centroid shifts observed for transitions in the superdeformed band it was found that a good fit to the data is obtained with a quadrupole moment Q_0=19 eb. This value corresponds to in-band E2 enhancements of 2500 Wu in agreement with transition strengths of $\approx$2390 Wu predicted by Ragnarsson and Aberg (to be published) for a deformation of ε=0.6 ($\beta \approx 0.8$).

3.1.6 Search for Superdeformation in ^{153}Ho

G.C. Ball with M.A. Bentley, P.D. Forsyth, D. Howe, A.R. Mokhtar, J.D. Morrison and J.F. Sharpey-Schafer (University of Liverpool), J. Simpson (Daresbury Laboratory) and G. Sletten (Niels Bohr Institute)

The recent discovery [Twin et al. Phys. Rev. Lett., 57 (1986) 811] that the superdeformed structure in $^{152}_{66}Dy_{86}$ consists mainly of a single deformed band of discrete states extending up to a spin of I$\approx$60 $\hbar$ has led to the realization of the opportunities for detailed study of the properties of deformed nuclei with a major-to-minor axis ratio of 2:1. Of particular importance are the systematics of superdeformed structures in the odd proton and odd neutron neighbours of ^{152}Dy. These data would provide a critical test of the theoretical models used to predict the properties of superdeformed nuclei.

An experiment to search for superdeformed bands in $^{153}_{67}Ho_{86}$ has been carried out at Daresbury with the TESSA3 γ-ray spectrometer [see PR-PHS-P-2: 3.1.3; AECL-9351 for details]. The nucleus was populated in the ^{109}Ag(^{48}Ca,4n)^{153}Ho reaction at a beam energy of 210 MeV. Both prompt and delayed (tagged by the decay of the 229 ns isomer in ^{153}Ho) Compton suppressed (Ge-Ge) coincidence events were recorded. However, hardware limitations resulted in a very low probability (<10%) for detecting isomer events. In addition, the odd-odd nucleus ^{154}Ho was found to be strongly populated at 210 MeV. Analysis of the data is in progress.

3.1.7 Decays of Neutron-Deficient Tantalum Isotopes

E. Hagberg, X.J. Sun, V.T. Koslowsky, H. Schmeing and J.C. Hardy

After our successful production test of neutron-deficient tantalum isotopes (PR-PHS-P-1: 3.1.11; AECL-9262) a full experiment with TASCC beams was performed. A 711 MeV beam of ^{127}I was directed onto a 1.1 mg/cm^2-thick target of natural calcium positioned in a He-jet target chamber. The energy of the beam striking the target was varied from 580 MeV to 711 MeV in six steps by the insertion of Mo degrader foils of various thicknesses. The products resulting from the beam-target interaction were swept out of the target chamber and transported into an adjacent target room with our He-jet transport system. The transported activities were deposited on the tape of our small tape-transport system. Collected samples were periodically moved to a counting location where they were viewed by a 100 μm-thick surface barrier detector and a 22% Ge(Li) detector. Simultaneous multispectra of α and γ-ray activities were collected.

The decays of $^{160-165}$Ta were studied. Our main interest concerns ^{162,163}Ta since they are the missing links in two α-decay chains. Determination of the decay schemes of the previously unknown α-decays of ^{162,163}Ta would permit the precise determination of the masses of 8 nuclei far from stability (PR-PHS-P-1: 3.1.11; AECL-9262).

During the course of our investigation, the α-decays of ^{162,163}Ta were reported in a brief note from an experiment performed at HMI, Berlin. The group at HMI observed two weak, previously unknown α-groups produced in reactions of ^{36}Ar with ^{133}Cs. They tentatively assigned these two α-groups to the decay of ^{162,163}Ta but could not base their assignment on half-life information or excitation functions because of the weak production rate.

Our preliminary results and assignments agree with those reported by the HMI group. We are, however, in a position where we can make a positive identification of the observed α-groups. Beta-delayed γ rays from the decay of $^{162-165}$Ta have been unambiguously identified by a group at Orsay in experiments performed with an on-line isotope separator. We have observed the same γ rays and we can correlate their intensities, for the six bombarding energies, with those of the simultaneously observed α-groups. An alpha group that tracks the intensity variations of a well-known γ ray can therefore be assigned to the same nucleus as that γ ray. In addition, we also verify that both decay modes exhibit the same half-life.

The analysis of our experimental data is nearing completion.

3.1.8 Lifetimes in ^{174}Os Yrast Band to Spin 20

T.K. Alexander, H.R. Andrews, G.C. Ball, D. Horn, D. Radford, and D. Ward with J. Gascon, F. Banville, P. Taras (Université de Montréal), J.C. Waddington (McMaster University) and A. Christie (Queen's University)

The experiment to measure lifetimes in ^{174}Os reported in PR-PHS-P-1: 3.1.12; AECL-9262 has been analyzed and a draft paper produced. We find that the extracted transition quadrupole moments are essentially constant ($Q_t \approx 7.7$ eb) up to spin $I^{\pi}=20^{+}$ (see Table 3.1.8.1).

To interpret this result we note that it is generally supposed in the literature that changes in transition quadrupole moments with increasing rotational frequency are caused by changes of nuclear shape induced by the rotation. One such phenomenon is the crossing of aligned bands (either proton or neutron structures) which, depending on the Fermi levels, can result in large changes in the triaxiality of the nuclear shape at rotational frequencies above the crossing. For example, at the beginning of a shell (low Ω orbitals)such crossings strongly drive the shape to increasing γ values, (in the Lund convention) i.e. producing an equatorial bulge around the rotational axis, thereby decreasing the collectivity of the rotation. At the end of a shell, the effects are reversed, and in mid-shell the driving forces to triaxiality are small.

From this discussion we could conclude that the results on ^{174}Os are consistent with expectations if we suppose that only the neutron $i_{13/2}$ crossing occurs below $\hbar\omega$ = 0.40 MeV, (i.e. spin 20). Since the neutron shell is approximately half-filled (N=98) this crossing should have little effect on the transition quadrupole moments. However, in comparing this behaviour with that observed in the N=98 isotone ^{172}W we note that the transition quadrupole moment in that nucleus decreases by ≈15% at a rotational frequency of $\hbar\omega$ = 0.22 MeV (spin 12) [M.N. Rao et al. Phys. Rev. Lett. 57 (1986) 667]. The effect in ^{172}W has been interpreted by Rao et al to be one of increased nuclear triaxiality owing to the postulated hidden crossing of an aligned $h_{9/2}$ $[541]_{1/2}$ proton band at $\hbar\omega$ = 0.22 MeV. The observed $i_{13/2}$ neutron crossing at $\hbar\omega$ = 0.29 MeV in ^{172}W produces a very strong upbend in the yrast transition energies; however, it does not appear to have any effect on the transition quadrupole moments. This interpretation would also be consistent with expectation, since the mid-shell neutron crossing should have little effect whereas the Ω = 1/2 proton orbital should increase the triaxiality. However, the argument centres on whether in ^{172}W there is a crossing at $\hbar\omega$ = 0.22 MeV and if so whether it has the character of a low-Ω proton orbital. We shall not discuss this argument further, but point out that if such a crossing occurs in ^{172}W it would be most surprising if it did not also occur in ^{174}Os below $\hbar\omega$ = 0.40 MeV. The present data therefore tend to conflict with the interpretation of the ^{172}W results.

In conclusion, we note that it is not feasible to predict quantitatively the effects of rotation on transition quadrupole moments. All that can be done is to note clear signatures of certain phenomena, such as the marked drop in collectivity at the neutron $i_{13/2}$ crossing in light rare earth (N=90) nuclei. However, there are many possible factors influencing these moments and it is unrealistic to attribute the observed effects to just one such phenomenon when the observed effects are rather small, as is the case for ^{174}Os and ^{172}W.

Table 3.1.8.1

Lifetimes and transition quadrupole moments for the ^{174}Os Yrast States

I^{π}	Lifetime [ps]	Q_t [eb][a]
2+	505.00 ± 60.0	6.8 ± 0.4
4+	26.3 ± 1.1	7.8 ± 0.2
6+	8.4 ± 0.8	7.9 ± 0.4
8+	3.9 ± 0.9	8.0 ± 0.9
10+	3.05 ± 0.27	6.6 ± 0.3
12+	1.42 ± 0.16	7.4 ± 0.4
14+	0.73 ± 0.17	8.2 ± 0.9
16+	0.63 ± 0.14	7.3 ± 0.9
18+	0.24 ± 0.11	10.1 ± 2.0
20+	0.36 ± 0.22	7.0 ± 2.0

(a) Electric quadrupole moments for the $\Delta I = 2$ transitions (K=0).

3.1.9 Beta-Delayed Proton and Alpha Radioactivities

J.C. Hardy and E. Hagberg

A survey of all known beta-delayed proton and alpha precursors has been completed and is being incorporated into a chapter commissioned for the book Charged Particle Emission from Nuclei to be published by CRC Press Inc. (editors: D.N. Poenary and M.S. Ivascu). There are now 110 known precursors, a threefold increase since previous reviews of the field (J.C. Hardy in Nuclear Spectroscopy and Reactions ed. J. Cerny, Pt. C., pp. 417-66, Academic Press 1974; J. Cerny and J.C. Hardy, Ann. Rev. Nucl. Sci. 27 (1977) 333).

The writing of the chapter is in progress.

3.1.10 The Direct Determination of the Masses of Unstable Atoms With the Chalk River On-Line Isotope Separator

H. Schmeing, E. Hagberg, J.C. Hardy, and V.T. Koslowsky with K.S. Sharma (University of Manitoba)

A paper with this title is in preparation, for publication in Nuclear Instruments and Methods in Physics Research. It describes a new technique (compare PR-P-139: 2.16; AECL-8554) developed to measure the spacing of atomic mass doublets of radioactive isotopes with an on-line isotope separator. The technique relies not on direct ion detection but on observation of the specific radioactive signature of the isotopes under study. Consequently, line shapes and centroids can be determined, free of interference and with great accuracy, even if the corresponding beams strongly overlap or if they are camouflaged by unwanted isobars or isomers. The paper is 85% complete.

3.1.11 Rutherford Backscattering Studies of the Liquid/Solid Interface

J.S. Forster and D. Phillips, with J. Gulens (General Chemistry Branch), R.L. Tapping (System Chemistry and Materials Branch), J.R. Leslie, T.K. Alexander (Queen's University) and J.A. Davies (McMaster University)

A study of ion scattering from liquids in contact with thin Si windows has been reported earlier (PR-PHS-P-1:3.1.2;AECL-9262). We have continued this work using proton beams from the Queen's University 4 MV accelerator.

Measurements were made in two separate experiments. In the first, a Si window, 0.65 μm thick and 1.5 mm diameter, was bombarded with a 1.6 MeV proton beam and backscattered protons were detected in a silicon surface barrier detector positioned at 165° to the beam direction. The cell was filled with a 0.1 M $CsNO_3$ solution, and a 20 minute bombardment with ≈5 nA of protons carried out. The backscattered spectrum showed the Si window signal as well as the thick target Cs and O signals. The surprising result was that the end point of the Cs signal indicated that the Cs had diffused through the Si window to the vacuum surface. The cell was flushed with water and another spectrum accumulated which showed that this indeed was the case. The cell was then translated 0.3 mm perpendicular to the beam direction and another spectrum accumulated, the cell again being filled with water. The Cs content in this case was considerably reduced.

The cell was then removed and the window examined by a scanning electron microscope which confirmed that Cs was only absorbed in the Si in a region the size of the beam. It was also possible, by eye, to see a deposit, of the order of the beam spot size, on the vacuum side of the window.

In the second experiment, the cell was put in the vacuum chamber with the window reversed i.e. what had been the liquid side in the first experiment was now facing the beam. The window was again bombarded with a proton beam, this time with 1.4 MeV energy, and the window translated until it was centered on the window position that contained the most Cs. A spectrum accumulated at this position indicated that most of the Cs was indeed on the vacuum side of the window, as used in the first experiment. A preliminary analysis indicates that the amount of Cs in the Si window itself is about 0.1 atomic %.

The window was then placed on the cell as in the first experiment and translated in the beam until a region of very little Cs was found. The cell was filled with a 0.1 M $Ba(NO_3)_2$ solution and a series of measurements made. Unlike the $CsNO_3$ experiment, the Ba did not diffuse through the window and when the cell was flushed with water the Ba signal essentially disappeared. However, a narrow peak on top of the thick target oxygen spectrum remained, indicating silicon nitride formation at the liquid solid interface.

The cell was then filled again with a 0.1 M $CsNO_3$ solution and the experiment repeated. The result this time was that the Cs did not diffuse through the window and, when the cell was flushed with water, the spectrum was similar to that when the cell was filled with water between the $Ba(NO_3)_2$ and $CsNO_3$ experiments. It appears that the beam-induced silicon nitride, formed when $Ba(No_3)_2$ was in the cell, inhibited the diffusion of Cs.

A final measurement was made with a 1.15 μm thick Ni window and a 3.0 MeV proton beam. When the cell was filled with 0.1 M $CsNO_3$ solution we obtained a result similar to that with the Si window in the first experiment; the Cs diffused through the window and built up a layer on the vacuum side of the window. The spectrum, when the cell was flushed with water, looked the same as when the $CsNO_3$ solution was in the cell (the same behaviour as observed in the case with a Si window). Unfortunately, the window ruptured before further measurements could be made.

All of the data are being analyzed in detail using the Cornell backscattering simulation program [L.R. Doolittle, Nucl. Instr. and Meth. in Phys. Res. B9 (1985) 344].

3.1.12 The Theory of Multipole Magnetic Fields and Their Measurement

W.G. Davies

The theory of the measurement of multipole magnetic fields has been derived starting with the general 3-dimensional solution of Maxwell's equations for the static magnetic field. The solution is expressed as a Fourier-Bessel expansion in cylindrical coordinates. The expansion shows explicitly that the fringe-field region of a perfect multipole (in dipoles, quadrupoles, etc.) introduces unavoidable aberrations, particularly in devices such as strong quadrupoles, and especially in short ones.

The EMFs generated by both a simple rectangular rotating coil magnetometer and a "tangential" coil magnetometer are derived for the cases where either all or part of the magnetic field is sampled by the coil. It is shown that a rectangular rotating coil which samples all of the fringe-field region is not sensitive to the fringe-field aberrations, but that a triangular coil is.

The errors in the measurement of the multipole coefficients have been analysed in detail. Specifically, the following types of errors have been investigated:

1. Radial misalignment of the apparatus. (See also PR-P-142:2.30; AECL-9103).
2. Rotational misalignment of the apparatus about the center of the multipole.
3. Finite size of the rotating coil.
4. Torsional error in the coil.
5. A z-dependent (cylindrical axis) radial error in the coil.

6. Uncertainties in the mean radius of the coil and in the winding density.
7. Differential radial errors in the tangential coil.
8. Error in the tangential coil "opening" angle Δ.

A comparison has been made of the relative sensitivities and errors of a simple rectangular coil and a tangential coil. The ratio of the sensitivity of the tangential coil ε_T to the radial coil ε_R is

$$\varepsilon_T/\varepsilon_R = 2 \sin (n\Delta/2)$$

where n is the harmonic number and Δ is the tangential coil opening angle. For the optimum harmonic where $\Delta = \pi/n$, then $\varepsilon_T/\varepsilon_R=2$.

If we assume that each leg of a tangential coil possesses the same errors as a simple radial coil, then the relative error in the signal derived from the tangential coil, with respect to the radial coil is given approximately by

$$\left(\frac{\sigma_\varepsilon}{\varepsilon}\right)_T \bigg/ \left(\frac{\sigma_\varepsilon}{\varepsilon}\right)_R = \{\frac{1}{2}\,[1 + \cot^2 (\frac{n\Delta}{2})] + \frac{1}{2} \cos^2 (\frac{n\Delta}{2})\}^{1/2}.$$

We see that when $n\Delta=\pi$, the ratio is $1/\sqrt{2}$ so for the optimized harmonic the errors are smaller for the tangential coil. In general, the relative error grows rapidly for values of n far from optimum.

3.1.13 Concurrent-Based AELIB Library Routines

V.T. Koslowsky with R. Roiha (Mathematics & Computations Branch)

The CDC-based AELIB routines MLSQQ and NLSPAR have been modified and placed on the systems area of the Concurrent data acquisition computer.

Both programs can be accessed by adding the following line in the calling program's .LNK file: LIB MAELIB.OBJ/S

The program MLSQQ performs weighted least-square fitting of data to a function of one or more independent variables. It is described in AECL-6076 page 1-11-20. One user-apparent change from the original program is that an optional COMMON block called MLSQOPT now has one additional parameter, LU, where LU represents the logical unit that will be assigned to all WRITE statements in this routine. The default value for LU is 5 (console).

The program NLSPAR solves a sparse system of non-linear equations. It is described in AECL-6076 page 1-10-31. No user-apparent alterations were made to this program.

3.1.14 A Concurrent-Based Gamma-Ray Identification Program

V.T. Koslowsky with R. Roiha (Mathematics & Computations Branch)

A program that identifies nuclei that emit γ-rays in a user-specified energy range has been written and placed in the systems area of the

Concurrent computer. The program searches through a γ-ray catalogue based on the catalogue in Atomic and Nuclear Data Tables 29 (1983) 1, by Reus and Westmeier. In addition to the energy range, five additional constraints may also be specified by the user. They are: (i) a mass window, (ii) an atomic-number window, (iii) a neutron-number window, (iv) a γ-ray branching-ratio window and (v) a half-life window.

The program is executed by typing GAMID; the user is then prompted for the search constraints.

3.2 INSTRUMENTATION AND FACILITY DEVELOPMENT

3.2.1 ISOL: Operation

H. Schmeing, E. Hagberg, J.C. Hardy, V.T. Koslowsky, W.L. Perry, X.J. Sun and M.J. Watson, with J.S. Wills (Accelerator Physics Branch)

The isotope separator has been used continuously over the report period for on-line and off-line tests. Seven on-line runs were devoted to the tests of the helium jet-skimmer source (see section 3.2.4). The remaining time was about equally distributed among system maintenance, operational improvements and instrument development.

A method of encoding mass scans over the full mass range (0-450) with wide dynamic range (10^{-2}A to 10^{-13}A) was implemented. The dynamic range is derived from using a logarithmic pico-ammeter to measure the separator's beam currents. The ammeter's recorder output is fed to a crystal controlled voltage-to-frequency converter which, in turn, addresses a pair of computer addressable scalers. By using two scalers in succession, dead-time losses due to scaler readout can be completely avoided. Although the method works to our full satisfaction, it blocks access to the data acquisition computer by other users when scans are executed at short sample times (e.g. 20 ms/point). We are investigating alternative methods with an intermediate memory.

Mass spectra are obtained by plotting the measured beam intensities versus the dipole excitation current. These spectra are not linear on a mass scale, as would be desirable, but follow an approximate $\sqrt{m}$ dependence. Attempts to linearize the spectrum mathematically failed, presumably because of mechanical irregularities in the magnet's potentiometric drive system. We have taken steps to set the magnet current by means of the computer and a high resolution digital-to-analog converter.

For many on-line measurements (e.g. measurement of the absolute ion source efficiency) it is important to reduce the intensity of parasitic beams originating from the ion source, that is all beams other than the 1^+ beam of the support gas. In an extensive program, the nature of all light parasitic beams (with effective mass between 1 and 100) was studied under a variety of operating conditions. In particular, argon, neon, helium and hydrogen were used as support gas, and chlorine and fluorine compounds were added to the support gas for analytic purposes. It appears that, by choosing the appropriate support gas, parasitic beams can be substantially reduced in the mass range from 40 to 100. Many of the remaining peaks stem from insulators used in the hot zone of the source. An investigation intended to reduce this influence has commenced.

We have implemented a motor driven, remotely controlled sensing wire to aid in the measurement of the instrument's high resolution performance. The isotope separator has in the past been operated with a mass resolution of up to 20 000 (at FWHM). This performance figure was measured with a sensing wire which could only be adjusted coarsely. The new device will make it much more convenient to optimize the instrument.

Finally, a fast acting straight-through valve for gas-transport capillaries was developed. It will be deployed between the target chamber and the skimmer stage of the helium-jet ion source. Its purpose is to switch from a capillary carrying reaction products in the transport gas to a capillary carrying only transport gas. This will allow us to study, and subsequently optimize, the time dependence of the accumulation of reaction products in the target chamber, transport times of the reaction products through various capillaries and release times of reaction products in the ion source. The switching time of the valve has been measured to be 15 ms, which is in accordance with our design goals.

3.2.2 ISOL: Instrumentation for Direct Mass Measurements

E. Hagberg, R.T. Fredericks, H. Schmeing, J.C. Hardy and V.T. Koslowsky with S. Whittle (TASCC Operations Branch), R. Roiha (Mathematics and Computation Branch) and K.S. Sharma (University of Manitoba)

The installation of hardware required for computer control of the ISOL (PR-PHS-P-1:3.2.2;AECL-9262) is complete. Two IGORs and one quad CAMAC scaler have been purchased by the University of Manitoba and delivered to CRNL. The CRNL-built IGOR-to-Digital Voltmeter (DVM) interface has been tested. Instructions have successfully been passed from the CONCURRENT computer to the DVM, and 48-bit data words read back to the computer. All hardware aspects of the computer-control system for the ISOL have now been commissioned.

An interactive program that assembles all the necessary parameters for the control of a mass scan has been completed and commissioned. It takes all user-supplied information and writes it onto a disc file. A master acquisition program that uses the contents on this disc file for control of the ISOL and of the data acquisition during a mass scan is nearing completion. The control part of this program has been tested and most of the remaining work to be done is in the merging of this part with our standard acquisition software.

Work on the analysis programs is continuing. An interactive program has been written and tested that prompts the user for information on the mass scans and for the decay signatures of the nuclides whose masses are to be compared. A second program that analyzes the acquired data based on the information supplied by the first program has also been written and tested.

This program generates mass spectra and voltage spectra from the raw data. A third program that calculates mass differences from these two types of spectra remains to be written.

3.2.3 ISOL: Status of Manitoba-Chalk River On-Line Mass Spectrometer

H. Schmeing, E. Hagberg, J.C. Hardy and V.T. Koslowsky with K.S. Sharma, R.C. Barber and H.E. Duckworth (University of Manitoba)

A "major installation grant application" was submitted to NSERC by the mass spectrometer group at the University of Manitoba on October 1, 1986. The proposal is aimed at adding a high-resolution mass spectrometer to the on-line isotope separator at Chalk River at a cost of approximately $900 k. A similar application was rejected by NSERC in March 1984, in March 1985, and again in March 1986, for lack of funds. Firmly convinced of the scientific merit of this proposal, and having been encouraged by NSERC's own scientific evaluation committee, we decided to re-submit the proposal.

At the time of our first submission to NSERC, no other instruments had been proposed aimed at precision mass measurements of a wide range of unstable nuclides. Now five such instruments are either in operation worldwide or very close to completion based on various design principles. Although the opportunity has been lost to assume the leading role in this important field, we still feel strongly that the unsurpassed resolution and the high sensitivity of the instrument we have proposed warrants the effort to implement it.

A paper describing the proposed instrument in detail has been presented to the 11th Int. Conf. on Electromagnetic Isotope Separators at Los Alamos and will be published in Nuclear Instruments and Methods in Physics Research (see PR-PHS-P-2:3.1.10;AECL-9351).

3.2.4 ISOL: Helium-Jet Ion Source

H. Schmeing, V.T. Koslowsky, E. Hagberg, J.C. Hardy, W.L. Perry and M.J. Watson with J.S. Wills (Radiation Applications and Isotopes Branch)

The helium-jet coupled ion source developed for the isotope separator (PR-P-134: 2.16; AECL-7778 and PR-PHS-P-1: 3.2.1; AECL-9262) was for the first time extensively tested under on-line conditions. Over the report period, seven runs of typically two days duration were allocated to this program. Overall, we obtained excellent results, with a yield about one or two orders of magnitude higher than previously reported from similar systems elsewhere. The source is characterized by slit geometry (3 mm x 30 mm extraction slit), small volume, large exit-to-entrance ratio, and high source temperature. The source was tested in two distinct series of experiments.

In the first series, the relative efficiency of the source was determined for various radioactive nuclides. The nuclides are produced when the accelerator beam impinges on a target. Reaction products recoiling out of the target were stopped in helium (≈1 atm) and transported through a capillary (1.55 mm i.d. 8.15 m long) to the skimmer stage of the helium-jet source, where reaction products were separated again from the helium transport gas. Those reaction products then ionized in the separator's ion source were extracted into the separator, mass analyzed, and implanted into the tape of a small tape transport station at the end of the separator's beam transport line. The accumulated sample was periodically moved to a well-shielded Ge detector. Both the nature and the strength of the sample were readily obtained by evaluating the measured γ-ray spectra. To obtain the relative efficiency of the system, in respect to a pure helium-jet transport arrangement, a second capillary was used which bypassed the separator and transported reaction products directly to the tape station. In this case, the samples were obviously not mass separated. For this comparison, care was taken to match both the target chamber pressure and the helium flow rates through the capillaries as closely as possible.

To date, the helium-jet source has been tested with eighteen isotopes of twelve elements, ranging in halflife from 2.2 s to 1 h. The results are summarized in Table. 3.2.4.1.

Table 3.2.4.1

The efficiency of the helium-jet ion source system, compared to a helium-jet transport system at the same flowrate. The source was usually operated in plasma discharge mode (pl.). One result has been measured with the source in surface ionization mode (s.i.).

Isotope	$t_{1/2}$	Efficiency	Isotope	$t_{1/2}$	Efficiency
^{23}Mg	11.3 s	3.2 ± 1.5 %	^{71}Se	4.7 m	5.9 ± 2.5 %
^{25}Al	7.2 s	6.0 ± 2.0 %	^{102}Ag	13 m	6.4 ± 2.1 %
^{26}Si	2.2 s	5.4 ± 3.0 %	^{104}Ag	33.5 m	11.5 ± 3.0 %
^{28}Al	2.2 m	3.1 ± 1.5 %	^{104}Cd	57.5 m	7.2 ± 2.5 %
^{38}K	7.6 m	7.5 ± 2.2 % (pl.) 22.0 ± 5.0 % (s.i.)	^{104}In	1.5 m	5.0 ± 2.0 %
^{52}Mn	21 m	1.0 ± 0.3 %	^{106}In	6.3 m	6.5 ± 2.0 %
^{53m}Fe	2.5 m	1.4 ± 0.4 %	^{107}In	32.4 m	5.2 ± 2.3 %
^{68}As	2.5 m	5.8 ± 2.3 %	^{108}Sn	10.3 m	5.2 ± 2.2 %
^{70}As	53 m	6.0 ± 2.5 %	^{109}Sn	18.0 m	4.3 ± 2.2 %

In the second series of experiments, the absolute efficiency of the system was determined in a new type of experiment. Indium was selcted as the sample species for this phase. An indium beam was developed at the TASCC facility and accelerated through the tandem accelerator. This beam entered the helium-filled target chamber through the entrance window (2.7 mg/cm^2 Mo). The beam, consisting of stable indium atoms, was stopped in helium, as were the radioactive indium nuclides observed in the previous series. The energy of the stable indium beam, 48 MeV, was chosen to result in a similar stopping range (5 cm) in the two cases. The indium atoms were again transported through the transfer capillary to the helium-jet ion source. The intensity of the resulting indium separator beam at mass 115 was readily measured with a Faraday cup at the end of the beam transport line, and compared with the intensity of the indium beam delivered by the accelerator. Various target chamber geometries were examined. The highest absolute yield measured was 3.5%. The highest yield obtained with the target chamber used for the first series of experiments was 2.8%. Thus the **relative** efficiency of the system, as given in Table 3.2.4.1, is about twice as high as the measured **absolute** efficiency, indicating a helium jet transport efficiency of ≈50%.

In addition to the absolute yield, the second series of experiments allowed us to study the time structure of the transport and ionization processes in great detail. The time response of the gas-transport system to a "beam-burst" was observed to depend critically on the target chamber geometry, capillary diameter and total gas flow rate. The time to observe 80% of all the activity released by the ion source was about one second under the best conditions where:

(i) the target chamber shape closely conformed to the recoil envelope;

(ii) the transport gas followed laminar flow lines;

(iii) the capillary diameter was selected to minimize the capillary transit time for a given gas throughput; and

(iv) the gas throughput was adjusted to coincide with the maximum flow tolerated by the separator pumping system while the ion source operated at 40 kV (about 30 atm-cc/s).

These conditions also led to the highest absolute yield. Any deviation from these conditions worsened the time response by as much as a factor of 20.

A paper describing the source and reporting on the first series of experiments has been given at the 11th Int. Conf. on Electromagnetic Isotope Separators at Los Alamos. It will be published in Nuclear Instruments and Methods in Physics Research.

3.2.5 8π Spectrometer: Status of Detectors

D. Ward, H.R. Andrews, N.C. Bray, J. Lori, D.C. Radford and L.V. Smith, with P. Taras (Université de Montréal) and J.C. Waddington, J. Johansson, D. Tucker, and D. Rajnauth (McMaster University)

The inner BGO ball of 72 detectors was completed in 1986 November. The suppressed array had 19 of the 20 systems installed and operating as of 1986 December. Completion is awaiting delivery of an HPGe detector returned to the manufacturer for repair. The BGO detectors (132 total, including ball and suppressor elements) are functioning very reliably and there have been no failures. The HPGe detectors caused some concern initially with 4 of the newly installed detectors failing. These have since been recovered by pumping for 24 hours at an external cryostat temperature of 70°C. It is possible that these failures were induced in the automatic LN_2 filling procedure, which was probably done too slowly during the critical first cool down, and resulted in excessive moisture condensation. The procedure has been changed to ensure rapid filling on first cool down, and following the Christmas shutdown (when the detectors were allowed to warm up) all detectors were returned to operating condition with no failures. Two in-beam commissioning experiments have been performed with 17 and with 19 suppressed detectors and are reported in 3.2.9.

3.2.6 8π Spectrometer: LN_2 Filling System

H.R. Andrews, D.C. Radford, D. Ward, J. Lori and N.C. Bray with F. Banville and P. Taras (Université de Montréal) and J. Johansson and J.C. Waddington (McMaster University)

The LN_2 filling system has been assembled, tested and is now in routine operation with manual initiation of LN_2 transfer every 8 hours. There is provision within the software for automatic filling but this will not be instituted until more experience has been gained with manual operation.

Initial performance of the system has been generally satisfactory although a few problems have been encountered. The long lines between the storage dewar and the delivery manifolds lead to a substantial fraction of gas in the liquid arriving at the manifolds. This has been ameliorated by the installation of phase separators just ahead of the manifolds. These bleed off much of the entrained gas. Related to this and to the fact that we have linear manifolds, there is a significant dispersion in the filling times for various detectors. It is believed that these problems will be solved by the introduction of new manifolds of a vertical cylindrical design. The feeds to the detectors will be symmetrically placed on the bottom cap of the cylinder and gas will be purged from the top. A two-level liquid sensing system and intermittent gas venting will be used to maintain liquid in the manifold at all times during the detector fill period. In this way all the detectors will be treated equivalently and the phase separation will be done efficiently. The ease with which the system can be modified and improved points up the advantage of a computer-based system with several spare input and output ports supplied on the controlling boxes.

The LN_2 system software has been made user-friendly and all the relevant parameters for each fill are logged automatically for future reference if necessary. A set of temperature sensors is being assembled for installation over the surface of the spectrometer. These will sense abnormally low temperatures and shut off the flow of liquid nitrogen in case of a leak.

3.2.7 8π Spectrometer: Status of Electronics

D. Ward, D.C. Radford, H.R. Andrews, F.J. Sharp, L.V. Smith and J. Lori, with J.C. Waddington and J. Johansson (McMaster University) and P. Taras, J.P. Martin, M. Beaulieu, and J. Gascon (Université de Montréal)

Cable installation was completed in 1986 November. Remarkably, none of the more than 2000 new cables installed was found defective. The front-end electronics is functioning as designed, although there were some failures initially, probably resulting from "burn-in". To date, it has been possible to maintain all channels fully operational using the overcapacity designed in.

The digitized energy and time channels show good long-term stability. The computer-controlled gain and zero matching of the BGO ball elements is particularly successful. It takes about 15 minutes to adjust the high voltages and ADC zeros for the 72 detectors in the ball.

Another feature, which has worked out very well, is the high electronic resolution obtained for the fast multiplicity trigger. The fast multiplicity trigger pulse is obtained by an analogue sum of 50 ns wide discriminated pulses from each element, which were aligned to a common time. During the in-beam tests of the instrument, we found that this pulse resolves individual folds (number of detectors fired) as high as k=30. It should be noted that the fold written to tape is not this trigger pulse digitized, but is evaluated from the FERA modules (see below). To date, we have not had sufficient beam time available to test the rate-handling capability. In a test experiment with about 1 pnA ^{34}S at 155 MeV on a 1 mg cm^{-2} ^{100}Mo target we observed the following rates:

		Observed	Observed Scaled	Proposal (1983)
BGO ball	K>1	205 ks^{-1}	310 ks^{-1}	200 ks^{-1}
	K$\geq$5	65 ks^{-1}	100 ks^{-1}	100 ks^{-1}
Individual ball elements		20 ks^{-1}	30 ks^{-1}	30 ks^{-1}
Individual HPGe (before supp.)		4 ks^{-1}	6.2 ks^{-1}	3.8 ks^{-1}
HPGe γ-γ (after supp.)		2.0 ks^{-1}	3.1 ks^{-1}	2.4 ks^{-1}
HPGe γ-γ-γ (after supp.)		0.2 ks^{-1}	0.3 ks^{-1}	0.16 ks^{-1}

The average fold was observed to be K=23. The "Observed Scaled" column refers to a scaling up to give the same number of K$\geq$5 nuclear events as assumed in the proposal. The rate limitation will probably be set by degradation of the BGO ball fold and sum-energy response due to electronic pile-up of two typical nuclear events of fold K=20. However, because we derive the fold from the number of hit detectors satisfying individually set time windows of typically 50 ns width, this limitation is not as severe as supposed by the authors when the proposal was drafted.

The results of tests so far confirm that the design rates will be met and it may be possible to exceed them without serious degradation of the response.

As mentioned in the previous report, the design of the LRS 2376 hit-pattern register has been changed by LeCroy, and the module no longer can serve our purposes. We have therefore replaced it with a hit-pattern register designed and built by J. Sharp, which outputs its results through an ECL-bus multiplexer into one of the Triple Port Memories on the CAB bus.

3.2.8 8π Spectrometer: Data Acquisition System

D.C. Radford, H.R. Andrews, G.C. Ball, and D. Ward, with M. Beaulieu, G. Ayotte, J. Gascon, F. Banville, and P. Taras (Université de Montréal), J.C. Waddington (McMaster University) and R. Roiha (Mathematics and Computation Branch)

LSI-11/73 and LeCroy CAB BG

The on-line data collection and monitoring system consists of a CAB BG microprocessor for data collection and a LSI-11/73 for monitoring and control. A complete and working version of the CAB assembler program, allowing for data acquisition and calibration modes (of both Ge and BGO detectors) as well as downloading of all CAMAC modules on the CAB parallel CAMAC highway, has been in routine use now for several months. All required programs for the LSI minicomputer are now essentially complete and debugged. These include the gain matching and stabilization program for the BGO detectors, the data monitoring program for the BGO detectors, the data monitoring program for all three operating modes, the liquid nitrogen control program and a program to calculate automatically and download Ge-detector gain coefficients for the CAB to use in matching the Ge-detector gains.

The complete system has now been used in two experiments and has provided essentially problem-free, reliable service. With the aid of the various programs, set-up of the 8π spectrometer for most experiments is simple and requires less than half a day.

Concurrent 3230

The main data-taking computer is the Nuclear Physics Branch Concurrent 3230, which receives the data from the CAB via a FIFO memory and writes it event-by-event to magnetic tape. This is done with the standard acquisition software, which also allows sorting of some fraction of the data for monitoring purposes.

For off-line sorting, and optionally also for on-line monitoring, a user subroutine has been written which allows sorting of the Ge-Ge coincidence data into 4096 x 4096-channel matrices, or 2-dimensional spectra, at a very fast rate (30 minutes per 6250 bpi tape). These matrices may then be analysed with a range of secondary programs to project and slice the contents, subtract backgrounds, and "unfold" in two dimensions (for example). A two-dimensional fitting program to find and fit coincident peaks in the matrix has also been written and is ready for testing.

3.2.9 Trial Runs with the 8π Spectrometer

D. Ward, H.R. Andrews, D.C. Radford, G.C. Ball, and D. Horn, with P. Taras, J. Gascon, F. Banville, S. Pilotte, and N. Nadeau, (Université de Montréal) and J.C. Waddington (McMaster University)

Two runs with beams from the MP Tandem were performed to begin commissioning and generally to explore the capabilities of the 8π spectrometer. In the first run (1986 December) a beam of ^{34}S at 145 MeV was incident on a self-supporting ^{100}Mo and a lead-backed ^{100}Mo target to produce ^{130}Ce by the 4n reaction. This nucleus has been extensively studied by the Daresbury group with the same reaction. In the second run (1987 January) a beam of ^{34}S at 155 MeV was incident on ^{100}Mo (backed and unbacked), ^{96}Zr and ^{94}Zr foils unbacked; and the same beam at 165 MeV was incident on ^{124}Sn and ^{122}Sn foils (both backed and unbacked).

In the first run, 17 suppressed HPGe detectors were active, on the second run 19 were active. Operation of the instrument proved remarkably simple and trouble free. Some count rates are given in section 3.2.7; however, even at 145 MeV the beam levels were never sufficient to exercise the full capability of the instrument. The highest data rates transmitted to tape were typically 2 ks^{-1} of suppressed γ-γ coincidences gated by a BGO ball trigger set at $K \geq 5$. Under these conditions, the CONCURRENT computer was able to histogram about 20% of the events on-line. These included i) 2-dimensional histograms of H versus K (where H=total γ-ray energy in the ball and K=number of detectors fired) gated on specific discrete lines, ii) HPGe histograms gated on specific regions of H and K, and iii) a 2-dimensional histogram of HPGe 1 versus HPGe 2 contracted into 1024 x 1024 channels gated on a selected region of H and K.

Preliminary analysis of the data showed that the BGO ball determination of H and K was sufficiently good to give almost complete separation of the various xn channels, in the cases studied. The quality of the HPGe spectra was excellent and comparable to data from the other large spectrometers where direct comparisons could be made, e.g. ^{130}Ce and ^{154}Dy.

3.2.10 The SAPPHIRE Proposal

D. Horn, G.C. Ball, J.S. Forster, E. Hagberg, V.T. Koslowsky, M.G. Steer, and D. Ward with M.A. Lone, M. Montaigne, G.A. Sims, G. Tapp and J.G.V. Taylor (NSSP Branch), L. Potvin, C. Rioux, R. Roy and C. St-Pierre (Laval University) and T. Drake and A. Galindo-Uribarri (University of Toronto)

The design and testing, which has been underway to develop a multiparticle detector facility for TASCC (PR-P-141: 2.16; AECL-8849), is now coming together as a proposal for a "Spectrometer Array for Particles Produced in Heavy-Ion REactions" (SAPPHIRE). The goal is to present this proposal to AECL and NSERC in the fall of 1987 for funding in early 1988. Substantial progress in design, testing, and costing has been made in the past half year.

Chamber and Supports

Design of the large, 3 m x 4 m vacuum vessel and the associated support structure (PR-PHS-P-1: 3.2.10; AECL-9262) for the spherical 4π array was refined to the point where manufacturers could quote on the work. Three quotes have been received from outside manufacturers for the chamber proper, and one estimate for the internal support structure has been obtained from our W.E.&P. Branch. Pumping and gas handling requirements are well understood and, as a result, costs for the chamber, vacuum system, and supports can be fairly closely estimated. The roughing system, miscellaneous feed-through flanges, and design of a forward array support system are not yet determined. A route through the TASCC complex has been identified to permit delivery of the bulky chamber to its location in Room 111. This route involves removal of concrete blocks in some places, strengthening a floor plate in another, and delaying construction of some Phase II shielding structures.

Light Particle Detection: Geometry and Efficiency

We wish to detect as many light ions as possible from each of the three major source velocity components: projectile, target, and intermediate. Furthermore, though the facility is largely aimed at charged particle detection, the ability to observe some fraction of the neutrons produced could be an asset. A Monte Carlo program for multiplicity response was run with parameters taken from an actual CERN experiment with a 48 MeV/u neon beam. The results suggest that forward array detectors should have a half angle of about 3° and extend to an azimuthal angle of about $\theta \approx 30°$ for projectile-like fragments. Intermediate-velocity events demand a granularity of about a 10° half angle out to $\theta \approx 60°$ and target-like sources such as compound nucleus/evaporation and explosive events should be observed with detectors of half angle around 13° for the balance of the solid angle. A 72-sided polyhedron (60 hexagons and 12 pentagons), with the forward angle pentagon and five surrounding hexagons removed to allow flight to a more finely segmented forward array, fits this description, providing that the next ring of 10 hexagons ($\theta \approx 34$-$56°$) can be subdivided into two segments each. A forward array of 128 detectors, arranged in eight concentric rings, each divided into 16 segments of 22.5° arc, would give the required granularity for fragmentation experiments. The neutron efficiency of BC-444 scintillator has been calculated in NSSP Branch (see PR-PHS-P-2: 7.30; AECL-9351), giving efficencies from 10 to 60% for our proposed detector configurations. Tests will be performed to see if the assumed detection thresholds are realistic.

Spherical Array

A prototype "ball" module with a stainless steel shell (one pentagonal Bragg/phoswich element) has been fabricated, largely in NSSP Branch (see PR-PHS-P-2: 7.39; AECL-9351). The unit is mechanically stiffer and can be made to closer tolerances than the previous fiberglass shell design. Front window support is effected by a grating of slats (edge-on relative to the target location) which gives greater strength per occluded detector area than a conventional wire grid. Vacuum tests indicate that the window and scintillator sections both seal more reliably than in the earlier version. The module has been partially tested with a 125 MeV ^{19}F beam from the tandem accelerator. Preliminary analysis indicates that particle range is well determined, while differential energy loss is no better than in the fiberglass test module. A second test with improved noise reduction and modification of the anode preamplifier is scheduled.

Forward Array

The forward array for SAPPHIRE will cover a cone of 34° half angle, intercepting nearly all projectile fragments and some particles from intermediate-velocity sources. The forward array test module, consisting of a gas ΔE detector and a segmented phoswich (fast BC-412, slow BC-444), is under construction. The test module is a simple cylinder containing gas (no effort has been made to produce a tapered geometry for the test module), backed by a cylindrical phoswich, optically isolated into four quadrants, each to be read by one phototube. The distance from the target to the array allows some staggering or overlap of detector edges, which in turn permits more generous flanges and window mounting schemes. As a result, few of the logistical problems encountered in the "ball" modules are present in the forward array.

Electronics and Acquisition

The electronics and data acqusition needs for the SAPPHIRE facility have only been identified in a global sense, and while order-of-magnitude costing can be made on this basis, the individual components proposed must be regarded as ad hoc suggestions. One aspect where detailed investigations have been performed is in selection and optimization of preamplifiers for the gas-filled detectors in the sphere and the forward array. NSSP Branch personnel (see PR-PHS-P-2: 7.33; AECL-9351) have developed an amplifier based on an AMPTEK A-250 preamplifier for the Bragg curve signal and are investigating the LeCroy TRA 510 and 1000 series for less sensitive applications such as cathode trigger and forward array ΔE integration.

Workshop

A workshop concerning the physics possible with a multiparticle array such as SAPPHIRE is being organized and will be held at the University of Toronto in conjunction with the Eastern Regional Subatomic Physics Meeting of the CAP, March 26-29. A number of recognized experts in heavy-ion reaction mechanisms will give their views and comment on our plans.

3.2.11 Total Reaction Cross Sections

A. Galindo-Uribarri, and T. Drake (University of Toronto) with G.C. Ball, W. Davies, J.S. Forster, E. Hagberg, D. Horn and M.G. Steer with L. Potvin (Laval University)

We plan to make direct measurements of heavy-ion total reaction cross sections. Preliminary measurements are needed on: beam alignment procedures, the reduction of beam current on target, the suppression of beam halo, multiple scattering and energy loss in the targets and the detectors, etc. Information is also needed on such properties as photomultiplier-tube gain saturation and count-rate stability associated with the very large energy loss for 50 MeV/u heavy ions in scintillators. The effect of minimal light output and collection in very thin plastic scintillators (used as flux monitors for the lighter ion beams) is being studied, and for heavier beams the use of a carbon foil and microchannel plates is being considered (when the statistics of secondary emission from thin foils is favourable).

Preliminary measurements of elastic scattering of heavy ions from thin targets with Si-counter telescopes are needed to determine their ultimate resolution. For this purpose, targets of Pb and C of different thicknesses have been prepared.

Beam optics calculations have been made to reduce the cyclotron beam intensity for our attenuation measurements to 10^3-10^4 particles per second. In the autumn of 1986 an internal cyclotron beam of ^{79}Br at 20 MeV/u was accelerated; however, difficulties with cyclotron beam extraction prevented us from confirming the calculated predictions. Instead, a tandem beam of 125 MeV ^{19}F ions was used for preliminary measurements. We were able to demonstrate that our small photomultiplier tube and scintillator configurations would perform well in vacuum in a heavy-ion beam of up to 10^5 particles per second without saturation or serious gain shift. Reduction of the tandem beam intensity by several orders of magnitude was achieved by "blowing up" the beam with the quadrupoles located between the stabilization slits and the BE1 dipole magnet and closing all the slits in the beam line to the minimum value. The tests were carried out in the large particle chamber located in the TASCC interim experimental area. The beam intensity was found to be highly sensitive to the quadrupoles QUB1Ah and QUB1Bh, allowing fine tuning to practically any value required. Further tests of our thin scintillator are progressing with this tandem beam.

The construction of a detector for attenuation measurements is underway in the workshops in the physics department of the University of Toronto.

3.2.12 Data Acquisition

G.C. Ball, E. Hagberg, J.S. Forster, D.C. Radford and F.J. Sharp with R. Roiha and M. Thompson (Mathematics and Computation Branch)

A number of hardware/software upgrades to the data-acquisition system have been implemented during the past six months. Hardware additions include: a second 6250 bpi tape drive, upgrade of the memory to 6 M bytes, a hardcopy printer for the Modgraph terminal and a Hewlett Packard 7475A six-pen plotter.

The CAMAC serial highway has been extended to the 8π spectrometer and TASCC interim experimental areas. The CAB FIFO required for high speed transmission of the data from the 8π spectrometer to the Concurrent 3230 computer was commissioned and a remote terminal was also installed in the 8π area.

The software needed to drive the HP 7475A plotter has been completed and the modifications required to use the SIMEX plotting package are in progress.

Finally, an XT-II (IBM-PC clone) was purchased for off-line data analysis. It has already been used as a terminal on the CDC computer and will in future also be linked to the data-acquisition computer.

3.2.13 Future Data Acquisition/Analysis Computing Facility

G.C. Ball, E. Hagberg, J.S. Forster, D.C. Radford, F.J. Sharp with R. Roiha (Mathematics and Computation Branch) and J.C. Waddington (McMaster University)

A committee with representatives from Nuclear Physics Branch, Mathematics and Computation Branch, and university users has been formed to evaluate our future computing requirements for data acquisition/analysis. The group is presently gathering the necessary information to prepare a report scheduled for completion by the end of February. Preparation and submission of an RFA for a facility satisfying the needs as established by this committee is planned for the first quarter of 87/88.

3.2.14 Data Acquisition and Hardware Development

F.J. Sharp and L. Bucholtz

CAMAC Serial Highway Problems

Recently, when we extended the Concurrent 3230 data acquisition computer CAMAC Serial Highway to the 8π spectrometer experimental facility and to the TASCC interim target area, we began to experience CAMAC data transmission errors; the most common types being "loss of sync" and "time out" errors. The problem was traced to the Bi-Ra L2 Crate Controllers. Apparently, these controllers do not contain any active resynchronization logic to realign the data byte transmissions, before passing them along to the next controller. Consequently, as more controllers are installed and the serial highway is extended, the data byte transmissions get out of sync with the serial highway master clock signal. Modifications to the serial highway bypass unit were required to correct the problem. However, all future L2 crate controllers purchased should have active resynchronization logic.

Miscellaneous

Several new CAMAC/NIM modules have been built for specific experimental applications.

1. A CAMAC module for the remote control and readout of the Norland 5400 multichannel analyzer has been designed and built.

2. A 72-detector Hit Pattern Identifier was designed and built for the 8π Spectrometer facility.

3. The LeCroy TR8837F Transient Recorder Auxiliary Controller, which controls data transfer between the transient recorder and a LeCroy 4302 Triple Port Memory module at twice the frequency of a normal CAMAC Dataway cycle (PR-PHS-P-1: 3.2.12; AECL-9262) was commissioned and used in a test experiment of the prototype Bragg curve detector module for the multiparticle facility.

3.2.15 TASCC Electronics Pool

E. Hagberg and R.L. Brown

Our capability for encoding signals furnished by detector arrays was improved during the time covered by this report. We acquired 4 CAMAC bit registers, one octal CAMAC ADC and an octal Gate Generator. The 12-channel input bit registers allow us to encode the hit pattern of a multiparameter event in a detector array and thus let the micro-processor service only those encoder channels that have received input data. This will speed up and simplify our CAMAC-based data-acquisition system.

3.2.16 TASCC Electronics Development

J.P.D. O'Dacre with L.D. Hill, S.W. Whittle and M. St. Aubin (TASCC Operations Branch)

The Cryogenic System Computer Interface has been completed and installed. Commissioning of the computer display facility is about to start. Eighteen modules are installed with monitor outputs to a Global Fault indicator and to the SCC magnet interlock chassis, in addition to the control computer.

A power supply monitor (so called "policeman circuit") has been developed and installed for protection of the SCC magnet. The safety circuits monitor the inner and outer coil currents, protect against improper current ratios, reverse current etc. and trip the magnet supplies under emergency conditions into a fast discharge to load resistors. Trip circuitry is redundant. Diagnostic signals are sent to the control computer indicating the nature of the fault. Commissioning will be undertaken during the present shutdown.

3.2.17 Target Laboratory

P. Dmytrenko and D. Phillips

The target laboratory has been actively involved in the production of target materials for experiments and carbon stripper foils for use in both the tandem accelerator and the superconducting cyclotron. The target laboratory hosted the Thirteenth World Conference of the International Nuclear Target Development Society 1986 September 17-19. Stripper foils, targets and radioactive materials were produced for commercial sales to research facilities in Canada and worldwide. Lab facilities were utilized for coating materials for other branches and assisting in the development of potential commercial ventures proposed by Unit 2000.

Preparation of Materials for Nuclear Physics Experiments

Thin targets and materials of the following elements/compounds were produced: Au, Ag, C, Ca, Mo, ^{25}Mg, ^{34}S, ^{100}Mo, ^{169}Yb, and $(CH_2)_n$.

Thin single-crystal silicon windows were prepared for liquid-solid interface studies.

Preparations of Materials for Other Branches

Laser mirrors were gold coated for the Physical Chemistry Branch. Further development of thermocouple material evaporations were carried out for the Physical Chemistry Branch working on a Unit 2000 idea.

Gold films were produced and mounted for the Dosimetric Research Branch.

INTDS Conference at CRNL 1986 September 17-19

The Thirteenth World Conference of the International Nuclear Target Development Society was held at Chalk River Labs from 1986 September 17-19.

Over fifty participants attended, representing the U.S., France, Germany, Belgium, Japan, Australia, Austria, Israel, Denmark and Canada. Peter Dmytrenko presented a paper entitled, "The Preparation of Tritium, Nickel-63 and Carbon-14 Large-Area Sources for Document Imaging". The proceedings will be published in an issue of Nuclear Instruments and Methods in 1987.

Commercial Activities in the Target Laboratory

Revenue was generated from the production and sale of natural and isotopic targets and carbon stripper foils. Canadian customers included the University of Toronto, the University of Manitoba and the Defence Research Establishment. Exports were made to the Austrialian National University, the University of Pittsburg, the University of Wisconsin in Madison, Duke University, Los Alamos National Laboratory, Daresbury Laboratory (United Kingdom), I.N.F.N. (Italy), I.N.I.N. (Mexico) and I.P.N. (France).

3.2.18 Neutron Detection Efficiencies of BC444 Scintillator

M.A. Lone with D. Horn (Nuclear Physics Branch)

See PR-PHS-P-2: 7.30; AECL-9351

3.2.19 Preamplifiers for the Bragg-curve Spectrometer and Other Detector Arrays for the Multiparticle Facility at TASCC

M. Montaigne, M.A. Lone with D. Horn (Nuclear Physics Branch) and L. Potvin (Laval University)

See PR-PHS-P-2: 7.33; AECL-9351

3.2.20 Bragg Curve Detector

G.A. Sims with L. Potvin (Laval University) and D. Horn and M.G. Steer (Nuclear Physics Branch)

See PR-PHS-P-2: 7.39; AECL-9351

3.3 PHASE II

3.3.1 TASCC Phase II

H. Schmeing, J.C. Hardy and K. Wittann (Project Management Branch)

For administrative purposes, Phase II of the TASCC facility is divided into subphases A and B. Subphase A is to provide the complete beam-delivery system for the first four target locations and subphase B for the remaining five target locations. A schedule for subphase A has been established, including all design work, construction of shielding walls and doors, and all infrastructure requirements. The schedule covers in detail all work to be accomplished before 1988 January 01, the date of the beginning of the shutdown period, during which all experimental work is suspended in order to allow for a speedy installation of the new beam line. The schedule for the shutdown period itself is still preliminary at this point. If at all possible, the shutdown period will not exceed five months duration. Work for subphase A is proceeding smoothly and on schedule. The bulk of the design work is scheduled to be complete by 1987 June and it is planned that most hardware required for subphase A will be delivered by 1987 October. Construction work has started on additions to shielding walls in Room 104. To date, procurement for subphase A is 30% complete.

3.3.2 Design of the Extraction Beam Lines for TASCC

W.G. Davies

A paper describing the design of the beam transport system which will deliver the extracted beam from the superconducting cyclotron to the experimental locations was submitted to the Eleventh International Conference on Cyclotrons.

The paper describes the design requirements and philosophy of operation of the subsystems used to achieve the requirements. The design is highly modular and will allow the experimentalists the choice of achromatic, high resolution, focused or emittance-matched beams at most target locations. In addition, the Q3D spectrometer will be operable in dispersion-free, dispersion-matched and emittance-matched modes.

A new derivation of the theory of dispersion, emittance and kinematic matching of a beam to the experimental requirements has been developed in terms of phase-space transformations (beam matrix). In this development, the RMS emittance parameters are convoluted with the appropriate nuclear reaction parameters in the target.

3.3.3 Beam Line and Vacuum System

J.J. Hill, P.J. Jones and V.T. Koslowsky

Progress has been steady on the beam line and vacuum system. We have issued purchase requisitions for all major components of the Phase II subphase A beam line and expect delivery of all these items by the end of this fiscal year. Work on the vacuum section control electronics is in progress and is expected to be completed well in advance of beam-line assembly.

3.3.4 Beam Transport System Magnets and Power Supplies

W.G. Davies and R.L. Brown

The contract with Scanditronix/Danfysik for the beam-transport dipoles, quadrupoles, power supplies and switch gear is on schedule except for the main power supplies which are delayed about 2 months. Delivery of the complete order is expected in the summer of 1987, well in advance of the shutdown for installation. A more detailed breakdown follows.

Dipoles:

- design complete;
- poles, yokes and coils being manufactured;
- production of field clamps, support systems and vacuum chambers scheduled to begin early in 1987.
  Status: ahead of schedule.

Quadrupoles:

- design complete;
- manufacture of poles, yokes and coils has begun;
- production of supports is scheduled for early 1987.

  Status: on schedule.

Power Supplies:

- Design of dipole and quadrupole power supplies is about two months behind as a result of a decision to make major design changes. Design progress and prototype testing is proceeding well and is holding to the revised schedule of 1986 September which projects completion by the end of 1987 June.
- design and production of the steerer power supplies and dipole degaussing units is on schedule.

  Status: slightly delayed from the original schedule.

Switch Gear:

- Design of switch gear is about 6 weeks to 2 months behind schedule. The start of production will be slightly delayed but completion is still expected on schedule.

  Status: design behind schedule but delivery expected on schedule.

The project is proceeding smoothly. No major problems have been encountered and none are anticipated.

3.3.5 Radiation Monitoring System and Safety Interlock System

D.C. Radford, G.C. Ball and J.P.D. O'Dacre with N. Burn (TASCC Operations Branch)

Since the design of the TASCC Phase I radiation monitoring and safety interlock systems was done allowing for the possibility of Phase II, their extension to include Phase II fortunately requires no major revisions. A purchase order has been issued for the required extra RMS monitors, but as yet none have been received. A purchase order for SIS electronics has also been issued, and drawings for the RMS electronics have been prepared and submitted to the E.I.&P Branch for a cost estimate.

A Preliminary Safety Analysis Report was presented to, and accepted by the CRNL Accelerator Safety committee in October.

3.3.6 Shielding Walls and Doors

E. Hagberg

The drawings of the proposed shielding walls and moveable shielding doors required for Phase II of the TASCC facility were sent to an outside engineering consultant. The impact of the proposed changes and additions on the structural integrity of the building and its foundation were investigated and their compliance with the Ontario building code was assessed. Numerous modifications and strengthenings of our original designs were required and their incorporation in our plans were discussed with the consultant.

A new set of more detailed drawings of the building modifications have been prepared and construction-approved drawings have begun to flow from the consultant to CRNL.

Preliminary designs have been completed for the two large moveable concrete shielding doors in building 137. Specifications for the airpad lifting mechanisms, the drive motor and the safety mechanisms have been formulated. Quotes have been received from four suppliers of such equipment.

The special requirements of our low background target room 104 have been investigated. A supplier of concrete containing unusually low amounts of radioactive material has been located in B.C. This concrete, as well as aggregate, sand and all other materials required for construction in room 104, have been tested for their radioactive content by Environmental Research Branch. All materials were found to meet our specifications and purchase orders for them have been placed.

3.4 PUBLICATIONS AND LECTURES

a) Publications

LEVEL STRUCTURE OF PROTON-RICH N=83 NUCLEI ^{150}Ho AND ^{152}Tm
J. McNeill, R. Broda, Y.H. Chung, P.J. Daly, Z.W. Grabowski, H. Helppi, M. Kortelahti, R.V.F. Janssens, T.L. Khoo, R.D. Lawson, D.C. Radford and J. Blomqvist
Z. Phys. A325 (1986) 27

EXCLUSIVE FRAGMENTATION STUDIES OF 40 MeV/u ^{14}N
D. Horn, G.C. Ball, R. Bougault, D. Cebra, D. Fox, E. Hagberg, L. Potvin, C. Pruneau, R. Roy, C. St-Pierre and G.D. Westfall
J. de Physique 47 C4 (1986) 83.

THE HALF-LIVES OF ^{41}Ar AND ^{111}In
A.R. Rutledge, L.V. Smith and J.S. Merritt
Appl. Radiat. Appl. Instrum., 10 (1986) 1029

A PROGRAM FOR AUTOMATICALLY MATCHING THE EMITTANCE AND DISPERSION OF THE BEAM INJECTED INTO THE CHALK RIVER SUPERCONDUCTING CYCLOTRON
W.G. Davies and E.A. Heighway
Nucl. Inst. and Meth. in Phys. Res. A244 (1986) 231

A METHOD OF DETERMINING THE RELATIVE IMPORTANCE OF PARTICULAR DATA ON SELECTED PARAMETERS IN THE LEAST-SQUARES ANALYSIS OF EXPERIMENTAL DATA
G. Audi, W.G. Davies and G.E. Lee-Whiting
Nucl. Instr. and Meth. in Phys. Res. A249 (1986) 443

LIFETIME MEASUREMENTS IN ^{184}Pt AND THE SHAPE COEXISTENCE PICTURE
U. Garg, A. Chaudhury, M.W. Drigert, E.G. Funk, J.W. Mihelich, D.C. Radford, H. Helppi, R. Holzmann, R.V.F. Janssens, T.L. Khoo, A.M. Van den Berg and J.L. Wood
Phys. Lett., B180 (1986) 319

EVAPORATION RESIDUE CROSS SECTIONS AND AVERAGE NEUTRON MULTIPLICITIES IN THE ^{64}Ni + ^{92}Zr and ^{12}C + ^{144}Sm REACTIONS LEADING to ^{156}Er
R.V.F. Janssens, R. Holzmann, W. Henning, T.L. Khoo, K.T. Lesko, G.S.F. Stephens, D.C. Radford, A.M. Van den Berg, W. Kühn and R.M. Ronningen
Phys. Lett. B181 (1986) 16

HEAVY-ION INDUCED FUSION-FISSION SYSTEMATICS AND THE EFFECT OF THE COMPOUND-NUCLEUS SPIN DISTRIBUTION ON FISSION-BARRIER DETERMINATION
R.J. Charity, J.R. Leigh, J.J.M. Bokhorst, A. Chatterjee, G.S. Foote, D.J. Hinde, J.O. Newton, S. Ogaza and D. Ward
Nucl. Phys. A457 (1986) 441

A NEW HEAVY-ION FACILITY AT CHALK RIVER
J.C. Hardy
In Nuclei Off the Line of Stability, American Chemical Society, Symposium Series, 324 (1986) 414

b) LECTURES

DESIGN, CONSTRUCTION AND TESTING OF A MODULE OF THE PROPOSED 4π MULTIPARTICLE DETECTOR ARRAY
L. Potvin, D. Horn, G.C. Ball, E. Hagberg, M.G. Steer, and G.A. Sims
Abstract submitted to the Annual Fall Meeting of the American Physical Society, 1986 October 9-11.

STATISTICAL MODEL OF SUBTHRESHOLD PION PRODUCTION
L. Potvin
Abstract submitted to the Annual Fall Meeting of the American Physical Society, 1986 October 9-11.

DEFLECTION OF GeV BEAMS OF PROTONS AND PIONS BY CHANNELING IN BENT SILICON CRYSTALS
J.S. Forster
Presented at Commemorative Symposium on Atomic Collisions in Solids, CRNL, 1986 July 11-12.

STUDIES OF THE LIQUID/SOLID INTERFACE BY RUTHERFORD BACKSCATTERING
J.S. Forster
Presented at Commemorative Symposium on Atomic Collisions in Solids, CRNL, 1986 July 11-12.

REVERSIBILITY IN CHANNELING: EXPERIMENTAL
J.S. Forster
Invited talk at Gordon Conference on Particle-Solid Interactions, Plymouth, New Hampshire, 1986 July 14-18.

BACKSCATTERING STUDIES OF THE LIQUID/SOLID INTERFACE
J.S. Forster, D. Phillips, J. Gulens, D.A. Harrington and R.L. Tapping
Invited poster at Symposium on Materials Research: One and Two Dimensional Systems, McMaster University, 1986 September 19.

THE NEW TASCC FACILITY AT CHALK RIVER
W.G. Davies
Seminar presented at the University of Oslo, Oslo Norway, 1986 September 8.

INFLUENCE AND SIGNIFICANCE, TWO NEW CONCEPTS IN THE STATISTICAL ANALYSIS OF DATA
W.G. Davies
Seminar presented at the University of Oslo, 1986 September 8.

DESIGN OF THE EXTRACTION BEAM LINES FOR THE CHALK RIVER SUPERCONDUCTING CYCLOTRON
W.G. Davies
Paper presented at the Eleventh International Conference on Cyclotrons and their Applications, Tokyo, Japan, 1986 October 13-17.

QUADRUPOLE ABERRATIONS
W.G. Davies
Seminar presented at the Los Alamos National Laboratory, 1986 October 20.

TASCC, THE FACILITY AND RESEARCH PROGRAM
W.G. Davies
Invited paper presented at the Engefest conference to honour Prof. Harold Enge, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1986 May 16.

THE THEORY OF MULTIPOLE MAGNETIC FIELDS AND THEIR MEASUREMENTS
W.G. Davies
Presented at the Superconducting Super Collider Workshop on Magnetic Field Measurements, 1986 November 18-20.

RECENT DEVELOPMENTS IN THE STATISTICAL ANALYSIS OF DATA
W.G. Davies
Presented at the Superconducting Super Collider Workshop on Magnetic Field Measurements, 1986 November 18-20.

DISCRETE LINE SUPERDEFORMED BANDS IN NUCLEI AT HIGH SPIN: A NEW FRONTIER IN GAMMA-RAY SPECTROSCOPY
G.C. Ball
Seminar presented at Queen's University, 1986 October 21.

LIFETIME MEASUREMENTS OF LEVELS IN s-d SHELL NUCLEI: ISOSCALAR AND ISOVECTOR MATRIX ELEMENTS FOR ANALOGUE E2 TRANSITIONS
G.C. Ball
Seminar presented at Daresbury Laboratory, United Kingdom, 1986 July 31.

HIGH-SPIN γ-RAY SPECTROSCOPY AND THE CHALK RIVER TASCC FACILITY
D.C. Radford
Invited talk at Gordon Research Conference on Nuclear Structure Physics, Tilton, New Hampshire, 1986 July 7-11.

CHERNOBYL AND NUCLEAR SAFETY
H.R. Andrews
Lecture given to following Kiwanis Clubs: Brockville, 1986 September 30, Oshawa Area Clubs, 1986 November 04, Kingston, 1986 November 10 and Cornwall, 1986 November 11.

CHERNOBYL AND ITS IMPLICATIONS
H.R. Andrews
Lecture given to St. George's Cathedral Task Force on Peace, Kingston, 1986 October 09.

CHERNOBYL AND NUCLEAR SAFETY
H.R. Andrews
Lecture given to the Ottawa Chapter of Canadian Meteorological and Oceanographic Society, 1986 October 22.

AN OVERVIEW OF ENERGY
H.R. Andrews
Presentations made at seven Nova Scotia High Schools, 1986 November 15-21.

THE CHALK RIVER HELIUM-JET ION SOURCE
H. Schmeing, J.S. Wills, J.C. Hardy, E. Hagberg, V.T. Koslowsky and W.L. Perry
Talk presented at 11th International Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications, Los Alamos, 1986 August 18-22.

DIRECT MASS MEASUREMENTS AT THE TASCC FACILITY: THE MANITOBA-CHALK RIVER ON-LINE MASS SPECTROMETER
K.S. Sharma, R.C. Barber, H.E. Duckworth, G.R. Dyck, C.A. Lander, H. Schmeing, J.S. Guo, E. Hagberg, J.C. Hardy and V.T. Koslowsky
Talk presented at 11th International Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications, Los Alamos, 1986 August 18-22.

A NEW HEAVY-ION FACILITY AT CHALK RIVER
J.C. Hardy
Lecture given three times: (i) GANIL, France, November 14, 1986; (ii) University of Guelph, December 2, 1986; (iii) Triumf User's meeting, December 9, 1986.

4. TASCC OPERATIONS BRANCH

(Report edited by N. Burn)

4.1 NEGATIVE ION INJECTOR

Y. Imahori

4.1.1 Operation

The HICONEX 834 sputter source operated routinely to produce ion beams for cyclotron experiments and nuclear physics experiments at three interim target-line locations.

Commissioning of the HICONEX 860 sputter source was carried out after the electronics for the source were tested. Thirty μA of carbon beam was produced and delivered to the Faraday cup (CUP1.Ad) at the entrance of the tandem accelerator.

4.1.2 Ion Production

During the period, the following beams were produced and measured on CUP1.Ad:

Ion	Current(μA)	Source
Protons (^{1}H)	0.7	HICONEX 834
Boron (^{10}B)	0.9	"
Carbon (^{12}C)	1.4	"
Carbon (^{12}C)	30.0	HICONEX 860
Oxygen (^{16}O)	2.0	HICONEX 834
Fluorine (^{19}F)	1.9	"
Silicon (^{28}Si)	1.4	"
Sulphur (^{32}S)	1.8	"
Sulphur (^{34}S)	2.0	"
Sulphur (^{36}S)	0.015	"
Chlorine (^{35}Cl)	2.0	"
Nickel (^{58}Ni)	0.2	"
Bromine (^{79}Br)	2.0	"
Indium (^{115}In)	0.6	"
Iodine (^{127}I)	4.0	"

4.2 TANDEM ACCELERATOR

L.B. Bender

4.2.1 Operation

The tandem operated satisfactorily during the period, producing beams for cyclotron experiments and nuclear physics experiments at three interim target locations. The following beams were accelerated:

Ion	Energy (MeV)
Oxygen (^{16}O)	70 to 84
Fluorine (^{19}F)	120 to 125
Sulphur (^{32}S)	160 to 167
Sulphur (^{34}S)	145
Chlorine (^{35}Cl)	21 to 150
Bromine (^{79}Br)	84.7
Indium (^{115}In)	48
Iodine (^{127}I)	42

4.2.2 Generator

The tandem generator operated satisfactorily during the period. The generator tank was evacuated on ten occasions, two of which were scheduled for stripper foil replacement and terminal Ti-Ball pump replacement. The eight unscheduled openings were generally due to minor problems including failure of the high-energy Pelletron drive belt on two occasions. Two failures of the terminal shorting cables were experienced during voltage conditioning procedures.

Degradation of the VIVIRAD resistors was experienced when operating at terminal voltages above 10 megavolts. The resistors, which were being tested for future installation throughout the generator, were subsequently removed and replaced by the original HVEC resistors. VIVIRAD Corporation has recognized the problem and claims to have made corrective changes to the resistor elements. When the new resistors are received, they will be tested in the tandem to verify their performance.

An order for new "extended" accelerator tubes was placed with High Voltage Engineering Corporation during the period, with delivery expected in 1987 August. These tubes will be installed during the planned shutdown for subphase A of Phase II in 1988.

4.2.3 Sulphur Hexafluoride (SF_6) Insulating Gas

The SF_6 gas system operated normally during the period. Twenty-five cylinders of gas were added to the system. The activated alumina dessicant was replaced in the gas drying towers.

4.3 RADIOFREQUENCY SYSTEM

E.P. Stock, G. Corriveau with J. McGregor and R. Hutcheon (Accelerator Physics Branch)

4.3.1 *Operation*

The complete RF system operated for a total of 155 hours during the period. Five system failures were recorded:

1. Failure of the driver amplifier filament power supply.
2. High temperature in the cyclotron due to a partially blocked cooling water line.
3. Midplane vacuum deterioration due to leaks at various instrumentation feedthroughs.
4. Failure of the Low Energy Buncher (LEB) grid during a vacuum transient.
5. Failure of an output transformer in the Intermediate (400 W) Power Amplifier.

Operation of the dees at high voltages and high frequencies resulted in frequent midplane vacuum transients and RF trips. This behaviour has been attributed to marginal performance of the only serviceable cryopump under these RF conditions. Scale-model experiments at low power levels have tended to confirm suspicions that the design of the cryopumps should be revised. Both cryopumps will be modified during the shutdown started in December.

Operation of the cyclotron in the π-mode was limited to experiments designed to confirm decisions on the redesign of the diagnostic probes and also to gauge the effectiveness of the existing automatic frequency control (AFC) system.

TASCC operators are now routinely responsible for shutdown of the RF system.

Inspection of the accelerating structure was completed towards the end of the period. Modifications are now underway to eliminate the causes of observed heat damage to both the radial probe holes and to a hill lens cover.

4.3.2 Power Amplifiers and Control

The power amplifiers were operated for a total of 702.7 hours.

Load tests on a suspect 3-phase transformer in the driver amplifier cathode power supply indicated no failure (as reported previously). An intermittent connection was eventually discovered and repaired.

One section of the Intermediate Power Amplifier failed, requiring rewinding of a coaxial output transformer. Previous failures of this kind have occurred, indicating the need for a more reliable amplifier.

AFC, which uses the balance capacitors, has proved successful to date. Modifications completed on the lower balance capacitor motor-drive assembly have made it operable until improved drive mechanisms can be designed and fabricated. AFC is needed to track resonances during temperature transients and also during motion of the diagnostic probes while operating in the ?-mode.

4.3.3 Bunchers and Phase Control

The bunchers and phase control system have performed reliably. The LEB grid was replaced once because of erosion by the ion beam. Experience to date indicates a grid lifetime of about six months. A new grid assembly, designed to simplify the rewiring procedure, is presently being fabricated.

RF breakdown occurred in the LEB when operation at high power was continued after a vacuum seal had failed. The resulting disassembly and rebuilding required many days with the entire complex shut down.

The phase control system operated properly. Variations in the transit times of the beams from the tandem to the cyclotron were observed during development of the ^{79}Br (20 MeV/u) beam. These variations were frequently too large for the phase-control system to correct. The source of the transit time variations is not known and will be investigated.

4.4 CRYOGENIC SYSTEM

L.W. Thomson, R.E. Milks and R. Tremblay

4.4.1 Operation

The system maintained liquid helium (LHe) in the cryostat for tests and experiments throughout the period, except for one occasion when the liquefier was shut down for engine de-icing. Only one power failure occurred, in off-hours, and was handled promptly by operators. A short shutdown of service air caused a system trip when a pneumatic control valve lost its signal.

Operators now routinely operate cryopumps on request and can charge and discharge the main magnet, as well as operate the extraction-channel magnet power supplies.

A total of 345 cylinders of helium gas was added to the system (compared to 367 cylinders during the previous six months), mainly to replace gas lost through static leaks. These leaks are expected to be significantly reduced after installation of a permanent flowmeter panel during the year-end shutdown.

Liquid nitrogen deliveries totalling 387,000 L were made to the storage tank, compared to 331,000 L the previous six months. This increase reflects a greater use of cryopumps for cyclotron operation during this period.

A transfer of 100 L of LHe was made from the storage dewar to a mobile dewar to enable a NSSP branch experiment to continue when the commercial supplier was unable to make a delivery.

The cryostat pressure was raised several times in an effort to increase liquid flow to the cryopumps, but this did not reduce the frequency of midplane vacuum trips during RF operation as was hoped. Improved RF shielding grids will be fitted in both cryopumps during the year-end shutdown. After unreliable operation of #1 cryopump shutoff valve, its Kel-F plug was replaced with a modified version.

In October, a cryogenic trainee for the Indonesian BATAN contract started six months of lectures and training on the TASCC system.

In early December, the liquefier was shut down and the cryostat allowed to empty and warm slowly so that the cyclotron could be opened for repairs, modifications and maintenance.

4.4.2 Cryostat

The cryostat boiled dry once because engine repairs took longer than expected; the return gas temperature only increased to 30 K. On two occasions, the cryostat pressure increased to abnormally high levels (35-40 kPa). A de-rime (warming and flushing) of the cold gas return transfer tube "H" was required on one occasion and warming and vacuum pumping of the "H" transfer tube insulating jacket was required on the other. After both these actions, the cryostat pressure returned to its normal 30-31 kPa.

The extraction-channel heater was partly rebuilt to enable its continued use in de-icing the channel after midplane ventings that introduce moisture.

Prior to warming of the cryostat after the bottom pole was lowered for the year-end shutdown, leakchecking confirmed a suspected vacuum leak between the midplane region and the cryostat vacuum jacket. The leak, which was first detected during the midplane venting to investigate the effect of π-mode RF tests, was found in a weld in the copper cover that shields the entrance to the extraction channel.

Following the year-end shutdown, cryostat vacuum pressures rose in bursts during warming of the cryostat, corresponding to evaporation of frozen gases trapped in the insulation jacket. After warming for 20 days, the magnet coil temperatures had only risen to about 150 K. At this time, forced warming was implemented by first increasing the vacuum pressure with helium gas and later by flowing warm gas to the bottom of the helium can.

4.4.3 Helium Liquefier

Low LHe production prompted an advance in the scheduled 5000 h maintenance on engine 5 because of ice-up problems. The 7500 h maintenance on engine 7, 10000 h major maintenance on both engines and the newly instituted 350 h lubrication checks, were all performed on time. Unscheduled repairs were required to replace the main bearings and the jackshaft and its bearings on engine 5; the jackshaft bearings were replaced three times on engine 7.

A leaky cryogenic supply valve resulted in a complete liquefier shutdown to access engine 7 for its 7500 h maintenance. This leaky valve seat and others will be replaced during the cyclotron shutdown.

4.4.4 Helium Compressors

The screw compressor ran continuously and trouble-free throughout the period. One scheduled absorber change was made.

Three of four reciprocating compressors underwent a planned absorber change each. Compressor 3 was sent off-site for a rebuild after an internal failure. Compressor 2 failed once on a low oil pressure trip. Compressor 4 had an internal failure and will be sent off-site for cylinder reboring.

An improved compressor control/monitor unit will be installed during the cyclotron shutdown.

4.4.5 Piping and Instrumentation

No modifications to piping were required. Leakchecking identified several piping leaks which will be repaired during the shutdown. An electronic flow metering/control panel will be installed during the shutdown and will replace the existing panel, which was leaking badly.

A new pressure-gauge panel will be installed during the shutdown.

4.4.6 Computer Interface

Instrumentation that enables 17 parameters to be read in the control room is currently being installed. Thirty trip/limit signals are interfaced to the control room Fault Annunciator Panel.

4.5 CYCLOTRON OPERATION

E.H. Lindqvist

4.5.1 Foil Lifetime

Experimental values for foil lifetimes, equilibrium thicknesses and charge-state distributions have been compared with estimated or calculated values in Table 4.5.1.1.

Table 4.5.1.1

Comparison between Experiment and Calculation for Cyclotron Foil Measurements

Property (units)	Results for beams:			
	^{127}I-5.12	^{127}I-5.6	^{127}I-10	^{79}Br-20
Injected energy (MeV)	44.2	42.1	70.9	84.6
Lifetime (h) estimated	1-1.5	1-1.5	2-4	4.5-7
observed	not measured	≈5	≈8	not measured
Equilibrium thickness (μg/cm^2)				
estimated	13	13	18	30
observed	not measured	10-20	≈20	not measured
Average charge state				
estimated	18.0	17.6	21.9	20.5
observed	18.1	18	21.9	19*

*probably not at equilibrium

Because the observed lifetimes are two or three times longer than the values estimated with E. Baron's semi-empirical formula (ref. The Beam-Stripper Interaction Studies for GANIL, 8th Int. Conf. on Cyclotrons, Bloomington 1978), a foil lifetime of about one hour might be expected for the most damaging ion, ^{238}U (3 MeV/u) injected at an energy of 52 MeV.

Experimental charge-state distributions for ^{35}Cl at several energies have also been compared with estimated or calculated values for three foil thicknesses in Table 4.5.1.2.

Table 4.5.1.2

Comparison between Experiment* and Calculation for Charge State Distributions

Property (units)	^{35}Cl Energy (MeV)			
	21	63.74	108	150
Equilibrium thickness ($\mu g/cm^2$)				
estimated	19	43	64	81
observed	≤ 10	≤ 10	≥ 30	≥ 30
Average charge state				
estimated	9.9	13.5	14.9	15.5
observed	9.8	12.8	14.0**	14.8**

* Experiment performed by H.R. Andrews and W.G. Davies using foil thicknesses of 10, 20 and 30 $\mu g/cm^2$

**30 $\mu g/cm^2$ foils used; probably not at equilibrium

4.5.2 Orbit Dynamics With ^{127}I(5.6 MeV/u)

A series of experiments was carried out with an ^{127}I(5.6 MeV/u) beam to investigate the problem of beam loss at injection and extraction as well as foil behaviour.

After carefully calibrating the two radial probes and properly accounting for the dark current entering the cyclotron, we observed that no beam was lost during injection or during the first few turns.

Extraction efficiency has seldom been better than 50% in spite of concerted efforts to optimize the extraction parameters. The beam exits the cyclotron significantly below the midplane; as the extraction channel gradient is increased, the beam moves out and down. Because the gradient is horizontally focussing, the beam must be on the average too far out and down in the channel. If the beam is somewhat low entering the channel (caused by earlier misalignments of the hill lenses; see Section 4.5.4) the vertically defocussing gradient will enhance this effect. A vertically low extracted beam is probably the major reason for the low extraction efficiency because the beam will hit the end of the channel.

With an injection energy of 42.1 MeV, the 20 $\mu g/cm^2$ foils were apparently becoming thicker and after approximately one hour, extraction efficiency had decreased because of decentering of the beam; after approximately four hours, incoherent betatron oscillations due to emittance growth and/or energy spread was observed and the foil would have to be changed. Ten $\mu g/cm^2$ foils were tried but broke in less than one hour.

An experiment was performed to confirm calculations that simulate the dee-voltage anticipated for ^{79}Br(20 MeV/u)(see Section 4.5.3). The beam cleared the foil shroud but the extraction efficiency was decreased to between 10 and 45%, depending on the settings of the extraction parameters.

4.5.3 ^{79}Br(20 MeV/u) Setup

An attempt was made to run ^{79}Br(20 MeV/u), even though known problems with the vacuum system were limiting the RF voltage to approximately 60% of the required value. After optimization of the cyclotron parameters, analysis of the turn pattern showed a very strong radial dependence of the dee-voltage along the dee, decreasing with decreasing radius. (The nominal dee-voltage is measured at an outer radius.) At the foil shroud, the dee-voltage was only 30% of the nominal value so that approximately 85% of the beam was intercepted by the shroud on the second turn.

The turn patterns of three different beams at three different frequencies all showed the same radial dependence of dee-voltage with frequency. This effect was much more pronouned for high frequencies, (^{79}B 20 MeV/u, f=59.9 MHz) than for lower frequencies (^{127}I 5.6 MeV/u, f=32.1 MHz). Attempts to extract the beam were unsuccessful. Unfortunately the trial was terminated by the failure of the electrostatic deflector before a setup that could have been more favourable was tried.

4.5.4 Conclusions from Measurements made after Opening the Cyclotron

When the cyclotron midplane was opened up at the end of the period, the positions of the beam-induced marks on the RF liner and of all accessible extraction elements were accurately measured. Analysis of the beam marks indicated that the beam had been in the midplane under operating conditions. Measurements of the electrostatic deflector and the two hill lenses showed all three to be misaligned. The vertical misalignment of the deflector was probably not sufficient to result in a vertical deflection of the beam. However, the horizontal misalignment of hill lens 1 would create enough outward offset of the beam in the extraction channel to cut the beam (see Section 4.5.2). This effect could in principle be reduced by optimizing appropriate extraction parameters.

The vertical misalignment of hill lens 2 is under investigation but could well be the reason for the vertical error in the extracted beam.

Both probes were found to be drooping more at their inner radii than at their outer radii. This could explain some earlier concerns about apparent vertical misalignment of the beam.

4.6 BEAM TRANSPORT SYSTEM

L.B. Bender

4.6.1 Magnets

The dipole and quadrupole magnets all operated normally during the period. There have been no further occurrences of broken flexible couplings since the mechanical limit switches were reset during the previous period.

4.6.2 Vacuum System

The vacuum system operated normally during the period.

4.6.3 Beam Diagnostic Devices

These devices operated normally during the period. Tests are continuing on the new digitized beam-profile display device.

4.7 COMPUTER CONTROL SYSTEM

B.F. Greiner with R.B. Walker and W.F. Slater (Nuclear Physics Branch)

4.7.1 Operation

The control system suffered numerous upsets from tandem breakdowns during the period. Actual damage to the system occurred only during two lightning storms and beam delivery was halted on only one of these occasions. Since several beam-line devices were commonly affected as well as the control system, no measures were taken to protect the control system alone. The installation of π-filters on electrical feedthroughs at the high-energy end of the tandem has nearly eliminated the effects of breakdowns on the CAMAC crate most directly connected to those feedthroughs. Additional filters have been ordered for the low-energy feedthroughs.

The computer is still running on a single disk because of the manufacturer's software problem reported in the previous progress report and control desk response is noticeably degraded during busy periods, probably because of disk access bottlenecks. Manpower limitations have prevented any effort from being directed towards correcting this problem.

4.7.2 Software

A simple, tolerant system for setting up beam transport magnets in TASCC has been commissioned and is in routine use. Extensive use was made of existing general purpose software for this system, which sets magnet fields based on the operator's specification of the ion type, charge states, tandem and cyclotron energies and beam destination.

A project to upgrade the operating system proceeded steadily but slowly because effort was transferrred to operation of the cyclotron at times. The project is presently on hold because of a nontrivial compatibility problem in the MUMTI interpreter and because of developments regarding collaboration with W. Busse of the Hahn-Meitner Institute for Nuclear Research.

An additional 93 system variables have been commissioned during the past year, bringing the total to 1744. Improvements were made to the mimic diagram software in response to user comments, and minor corrections have been made to a few control system programs to prevent control desk hangups.

4.7.3 Hardware

The major effort was on preparation of documents and procurement of parts for serial highway bypass and loop collapse units for TASCC Phase II. Several purchases of hardware for Phase II were also made.

A long-standing inconsistency in the stepping motor controller test procedure was corrected and two documents describing custom built hardware were issued in the TASCC report series. Diagnosis and repair of faulty CAMAC and related modules continued, with a lower failure rate than in previous reporting periods. The computer hardware continued to perform extremely reliably, with regular preventive maintenance by the manufacturer.

4.7.4 Collaboration

In November, during a visit by B.F. Greiner to the Hahn-Meitner Institute (HMI) for Nuclear Research in Berlin, the TASCC version of the mimic diagram software was installed and largely commissioned. (The mimic diagram software originated at the Juelich Nuclear Research Centre in West Germany.) This installation at HMI represents a significant contribution by TASCC to a control system collaboration which began ten years ago. The possibility of further collaboration was also discussed, as a solution to severe manpower problems at both laboratories; the costs and benefits of such a program are being evaluated.

4.8 BEAM DYNAMICS

E.H. Lindqvist

4.8.1 Calculations

All cyclotron and beam-line setting parameters have been calculated for ^{79}Br(20 MeV/u) for two different charge state combinations 7/22 and 6/20.

4.9 BUILDING SERVICES

P.I. Hurley

4.9.1 De-Ionized Water System

The de-ionized water system was changed from summer to winter mode in mid November. During the first week of December, the NRU reactor heat recovery system started to increase the incoming raw water temperature by almost 10°C. There were short periods when the water temperature was raised into the range where the chiller would have been required for normal TASCC operation. Heating of the raw water to this level by the NRU heat recovery system has been discontinued until better temperature control can be achieved.

To enable the purification column requirements for Phase II to be finalized, a digital resistivity meter was installed downstream of the two resin columns which had been on stream for five months. The meter indication continued to be stable at 18.3 megohms per centimeter for the remaining three months of the period. After six months of operation in series, each resin column was placed on stream singly for a twenty-four hour test. The outlet water resistivity readings for the single columns were unchanged from the reading with the two columns in series. Based on these results, the Phase II purification system will consist of two sets of three columns in series.

4.9.2 Electrical

Surge suppression was installed on all the feedthroughs at the high-energy end of the tandem tank.

The building emergency lighting was rearranged to be more useful for "as installed" equipment access.

4.9.3 Safety

Oxygen monitors are installed in five areas where the buildup of helium, nitrogen or sulphur hexafluoride might present an asphyxiation hazard. The power supply of one of the five oxygen monitors failed and was replaced.

Photocell-controlled contacts were added to the series of interrupts for 60 Hz power to all high voltage power supplies on the negative ion injector main deck.

4.10 PUBLICATIONS

TASCC Inst. No.	Title	Author	Date
1.1.04	Safety Interlock System	N. Burn	1986 Nov
2.01	Sputter Source Operation	Y. Imahori	1986 Nov
2.02	Sputter Source Maintenance	Y. Imahori	1986 Nov
4.2.06	350 Hour Liquefier Maintenance	L. Thomson	1986 Aug
4.2.07	Ultraprobe Readings of Liquefier Components	L. Thomson	1986 July
4.2.08	Unplugging of H Transfer Tube	L. Thomson	1986 Aug
4.2.09	Removing Cryopump Transfer Tubes	L. Thomson	1986 Sept
4.2.10	System Leak Check and Identification	L. Thomson	1986 Dec
4.3.01	Cyclotron Startup	H. Lindqvist	1986 Sept
4.3.02	Recovering from Beam Loss	H. Lindqvist	1986 Oct

4.3.03	Startup Procedure for a New Beam	H. Lindqvist	1986 Dec
4.4.01	Emergency Shutdown of Main Magnet Power Supply	L. Shankland	1986 Oct
4.4.02	Main Magnet Power Supply Operation	L. Shankland	1986 Oct
4.5.01	Operation of Electrostatic Deflector Power Supply	J. Mouris	1986 Dec
4.6.01	Operation of Extraction Channel Power Supplies	J. Mouris	1986 Dec
5.01	Beam Steering Procedures	L. Bender	1986 Oct
6.01	Computer Control System	B. Greiner	1986 Nov
7.02	De-ionized Water Resin Column Replacement	P. Hurley	1986 Dec

5. CYCLOTRON GROUP (ACCELERATOR PHYSICS BRANCH)

(Report edited by J.A. Hulbert)

5.1 CYCLOTRON OPERATION

J.A. Hulbert, C.R.J. Hoffmann with E.H. Lindqvist, E.P. Stock, B.F. Greiner, R.E. Milks (TASCC Operations Branch) and W.G. Davies (Nuclear Physics Branch)

The operating schedule in the current report period has been coordinated with the requirements of the TASCC work schedule, which aimed at full cyclotron control from the control room by the calendar year's end. Time has been allocated for sub-system tests, particularly during periods when staff vacations have made it difficult to maintain a complete cyclotron operating team. TASCC Operations has put a high priority on training. There are now six "cyclotron supervisors" and four people capable of setting up the injection beam line.

RF tests have revealed two problems that require solution before the full capability of the cyclotron can be realized. At present, operation of the rf structure in π-mode causes overheating of the midplane cryostat wall and the probes; in addition, movement of the probes detunes the accelerating cavity. Inability to operate in π-mode means that beams below 5.2 MeV/u and above 21.5 MeV/u cannot be developed.

The second problem is vacuum instability, in part due to a thermal instability in the one operating cryopump, when the rf is running. At 31 MHz the rf may be run to 90% of maximum voltage but at 62 MHz only 50% voltage is possible without frequent vacuum trips. Studies on a "cold test" rf model indicate that improvements to the cryopump rf screen will overcome this problem and remodeling of both cryopumps is in progress.

Cyclotron experiments have been run to study stripper-foil lifetimes, probe calibration and stripper efficiency. With the rf voltage limitation at 62 MHz the question arose as to whether it would be possible to develop the next nuclear physics experiment beam, 20 MeV/u ^{79}Br. A test was carried out with the 5.6 MeV/u ^{127}I beam, turning the rf volts down until the first turn was close to scraping on the foil shroud. This gave about 250 turns to the extraction radius but it was still possible to extract 45% as much current as was extracted with 100-turn acceleration. This indicated that a useful Br beam might be extracted using a high number of turns, provided that the possible change of dee-voltage radial distribution at higher frequency did not lead to stripper frame interception at attainable rf voltage.

The 5.6 MeV/u ^{127}I beam was used to complete an experiment on the alpha decay of a series of light Ta isotopes. Over the period September 22 to October 01, approximately 60 hours of beam time at the experimental target was achieved. For the latter half of this time currents of 40-50 nA (measured at CUP1-1p) were sustained over periods of 2-3 hours between foil changes. To define the parameters for this improved performance, experimenters on the variation of cyclotron parameters were carried out with the 5.6 MeV/u, ^{127}I beam. Following this, detuning tests at 32 and 50 MHz in π-mode were carried out with the dummy probe.

Considerable effort has been given to developing a 20 MeV/u, ^{79}Br beam. This beam extends cyclotron operation to new limits because it requires the operation of the rf system to 59.9 MHz (close to the upper limit of 62 MHz), it requires operation of the electrostatic deflector to over 12 kV/mm (design target is 15 kV/mm) and 100-turn acceleration would require over 80 kV on the dees (design target 100 kV).

Difficulties were experienced with tandem hardware and mass selection at the ion source, low energy buncher mismatch, and tandem transit-time instability, believed due to high secondary emission with the Br beam. Problems with rf/vacuum interactions limited the indicated dee voltage to 57 kV. With this voltage a beam of 35 nA (charge state 20+) was accelerated to the extraction radius in about 250 turns and about 70% transmitted through the deflector to the stub probe.

Clearly defined separated turns were observed out to about 300 mm radius. These were masked by axial betatron oscillations of about 6 mm peak-to-peak until a probe finger-sum signal was obtained. The full number of turns out to extraction radius was estimated by a count of axial betatron cycles.

Even after a considerable effort had been expended no beam could be detected emerging from the extraction channel. Since no temperature change could be observed on the channel beam pipe thermocouples it seems likely that no beam was entering the channel. The circumstances of these trials with turn behaviour obscured by betatron oscillations (due to minimal rf voltage) and the current lack of information about the variation of rf voltage with radius make it of little value to draw any conclusions from this disappointing result. Improvements in the rf/vacuum operation of the midplane will improve the definition of the beam at extraction radius and a systematic study of beams over a range of energy in future operation will enable the proper calibration of the radial variation of accelerating field to be made. At present our orbit code SUPERGOBLIN contains only a simple approximation to the radial variation of accelerating field and is of limited value in studying detailed beam orbits to unravel channel entry problems.

Orbit computations were made in preparation for acceleration of the 22^+ charge state of ^{79}Br, which should have better injection properties than the 20^+ state, but operation was terminated by a failure of the deflector insulation and it was decided on December 01 to open the midplane and proceed with the planned maintenance of the cyclotron.

Initial inspection of the midplane showed the following:

1. More oxidation of the rf surfaces than found at previous openings. This is due to a combination of the long period of closure (over 12 months), the large number of rf vacuum trips sustained during Br beam development, and leaks into the mid-plane vacuum, which developed in feed-throughs on the tuner assembly during October and early November.

2. There was remarkably little beam-marking visible except where the beam should have gone, which is a further confirmation of the design of the machine and the orbit codes used.

3. Despite care taken in assembly, there was vertical misalignment of the order of several millimetres in the dees and the deflector.

4. As anticipated the #2 cryopump had suffered a swelling of the liquid helium tank in the pressure excursion (see PR-PHS-P-1: 5.2.2; AECL-9262) but there was no rf or other damage.

5. The boron nitride low emission ring on the deflector was broken and the deflector insulator swollen.

6. The copper weld in the channel rf cover was cracked causing the major leak between cryostat and midplane vacua. No other leaks, other than the small inaccessible leak in the channel beam pipe were found.

7. The #2 hill lens has been badly heated by rf, and redesign of the rf shielding there and around the radial probe ports is necessary.

8. The locations of hill lens #1 and #2 both require some correction.

9. The probes do not move in the midplane throughout their travel. Probe #1 in particular is several millimeters high passing through the 'five port box' and this accounts for most of the apparent downward deflection of the beam in traversing the magnetic channel.

Item 6 requires access to the cryostat vacuum, and a complete warm-up of the magnet has been initiated for repair. This means that the cyclotron will not be ready for operation again until early April.

5.2 CRYOGENIC SUBSYSTEMS

5.2.1 Automatic Lead Flow Control Panel

L.W. Shankland with D.R. Proulx (Plant Design)

The piping design changes are now complete and the main panel is now ready for installation. A sub-panel for regulation of main lead flow during mains outage is 50% complete.

5.2.2 Cryopump Development

5.2.2.1 RF Baffle Tests

J.G. Gibson, J.A. Hulbert and R.M. Hutcheon

A full-scale model of 1/4 of the rf cavity, with radial rather than spiral edges, was made to study rf penetration of the cryopump front baffle as a function of frequency and rf mode. The effects of π-mode operation were simulated by rotating the model baffle relative to the rf current direction.

Plots of the field transmitted through the baffle were made as a function of distance above the baffle, and of distance from the edges of the baffle; these were made with the baffle unbacked and with it backed by a ground plane simulating the pump thermal chevron baffle. These measurements were referenced to the "valley" field near the baffle.

The "valley" field was referenced to the field with the baffle aperture closed, and to the accelerating gap field. Absolute field calibrations were estimated and the coupling coefficient for the fixed coupling capacitor was determined. The cavity was tuned in the range 30-60 MHz for these measurements with fixed lengths of RG-214-U cable to simulate the coaxial tuner in the cyclotron.

The measurements showed that the transmission of the cryopump Mark III parallel-rod baffle is independent of frequency in the range 30-60 MHz. However the ratio of valley field to accelerating-gap field increases by 6 dB between 30-60 MHz. This corresponds with the behaviour of the real pump which operates marginally at full rf power at 31 MHz and only to 1/4 rf power at 60 MHz.

A baffle with crossed parallel rod arrays at the same pitch as the Mark III pump baffle provides an additional 13 dB of rf attenuation, and works equally well in both 0-mode and π-mode simulations. The loss of pumping speed with the crossed-rod baffle is estimated at about 35% to the 100 K chevron and about 5-10% for pumping at the liquid helium cooled surface.

5.2.2.2 Cryopump Modification and Redesign

J.A. Hulbert with D.R. Proulx (Plant Design)

The remaining operating cryopump appeared to have a sensitivity to radio-frequency above 40 MHz. This was not apparent in development tests and it is possible that it resulted from damage. RF tests were carried out on a cold test model to look for possible design defects (see 5.2.2.1).

With efficient de-riming of the 'H' helium exhaust transfer tube the cryostat pressure can be maintained at 29-30 kPa (gauge). The cryopump, at this fill pressure, dries out in a 6-1/2 minute cycle, which can be stopped only by raising the cryostat pressure to 35 kPa. This again may be due to a heat leak caused by damage incurred during the pressure surge (see PR-PHS-P-1: 5.2.2.; AECL-9262). The cryopump transfer tube operates at present under an 'impaired' syphon action with the liquid transfer driven by a gravitational 'negative' pressure differential of four inches of water-equivalent head, of which two inches is taken up by gas evolution. It is not surprising therefore that helium transfer is precarious. To improve this situation, the current (Mk III) design has been reviewed. A new Mk IV design has been developed in which the shield cooling lines have been shortened to reduce the exit pressure drop, a direct gas exit has been added to enable the temperature of the shield to be controlled more effectively during filling, and some tight clearances have been opened.

The #2 cryopump (Mk II) has been removed from the cyclotron. The expanded liquid-helium tank will be replaced by a modified design in which the supporting posts are TIG welded through the skin rather than spot welded. Both the #1 and #2 pump rf baffles will be modified to the crossed-rod design during the cyclotron maintenance outage.

The Mk IV design is complete, and detailing is in progress. This pump will be held as a spare and used to replace #2 pump at the next midplane opening.

5.3 MAIN MAGNET SYSTEM

5.3.1 Power Supply Instrumentation

L.W. Shankland with D. O'Dacre (Nuclear Physics)

Hardware interlocks have been designed to trip the magnet power supply for the following conditions:

(1) Reverse current greater than 3 A in either coil.
(2) Outer coil current greater than 50 A when inner coil current is less than 600 A.
(3) Liquid helium level in the cryostat below the magnet top pressure plate.
(4) Liquefier engines stopped running.

These conditions were formerly avoided or corrected by administrative control; the interlocks are necessary for operation from the control room.

The interlock circuits have been completed, and are undergoing commissioning tests.

5.3.2 New Microprocessor Controller for Main Magnet Power Supply

C. Belanger, J.A. Hulbert and L.W. Shankland

A control system for the voltage-tap monitor, which uses an LSI-11/23 microprocessor and IGOR CAMAC modules, was assembled. As a first implementation stage, FORTRAN IV software was written to emulate the existing system with additional informative diagnostic messages on the system teletype. The hardware interface has been debugged but installation and commissioning are awaiting the availability of technical effort.

5.4 RADIOFREQUENCY SYSTEM

5.4.1 Accelerating Structure and Midplane Vacuum

E.P. Stock (TASCC Operations Branch) with J.E. McGregor

The dee voltage in the 0-mode at 59.9 MHz is limited to about 45 kV by vacuum pumping problems. The voltage could be raised to 80 kV but the vacuum remained stable only for 5-10 minutes. Retuning to 32.1 MHz showed that voltages up to 90 kV could be run "indefinitely". At 46 MHz the vacuum limit is reached for a dee voltage of 80 kV.

5.4.2 Tests of π-Mode Operation

J.E. McGregor and J.A. Hulbert with E.P. Stock and E.H. Lindqvist (TASCC Operations Branch)

Π-mode structure tests were carried out at 32.1 and 50 MHz. Power is limited by cryostat wall heating near hill lens #2. At 45 kW the wall temperature rises to 70°C in about one hour with no sign of stabilizing. The closest copper wall panel to that hill lens shows the highest panel temperature of 30°C. It is not clear whether that temperature rise is due to conduction from the hill lens region or caused by the presence of the injection pipe. Other "hot spots" were the two probe holes. At low powers (12-15 kW) both holes show a rise of about 10°C but at the 45 kW level the hole with the dummy probe protruding rises a further 10°C above the empty hole. A stable cryostat wall temperature of 50.5°C at the hill lens #2 position was reached for a power level of 12 kW. Since the structure operated during development at over 50 kW in π-mode without excessive wall heating the problem appears to be a local one related to the hill lens cover contacts.

The ability of the automatic frequency control to compensate for the detuning effect of a moving dummy probe was demonstrated for probe travel from 150-500 mm radius for maximum probe speed in both directions at 45 kW.

The dummy probe was instrumented to test the effectiveness of the water cooling of a new probe. At 32.1 MHz, for a dee voltage of 40 kV, the temperature rise of the fully inserted probe was 30°C after one hour. Measurements at 50 MHz extrapolate to a maximum temperature of 80°C at full power. Redistribution of cooling lines in the new probes should give only half this temperature rise.

The cavity was kept on tune during probe insertion at both 32.1 and 50 MHz, with either a single compensating balance capacitor or both balance capacitors. For the single compensator, dee voltage varied over about 1%, but with both compensators, dee voltage was maintained to 1 part in 3000. Initially the probe tip was bent and contacted the hill intermittently during its travel. On these occasions the system went off tune suddenly then recovered over a period of about one minute.

5.4.3 Buncher Tests

E.P. Stock (TASCC Operations Branch) with J.E. McGregor

Buncher tests with the high energy buncher in the 4f mode have been carried out with a 32 MeV carbon beam. Bunch lengths of 13 ns were measured in the cyclotron injection line during the tests. At the higher drive levels required to set proper phase stabilization feedback, both the low energy buncher and high energy buncher showed inadequacies in their automatic frequency control (AFC) systems. A new modularized AFC unit was installed in the high-energy buncher control panel and has worked well provided that the 2f and 4f drives are properly isolated.

Failure of the low-energy buncher vacuum occurred when the two-year-old teflon seal between 1f and 2f resonators developed a leak. This was replaced, without damage to the buncher gap insulators being noticed. Finally the teflon seal, the ceramic gap insulators and the fingerstock at the 2f resonator end-flange were all renewed. Normal reverse power readings were then obtained only by readjustment of the coupling loops.

A new inter-resonator seal with Macor and O-rings has been designed to eliminate the creep of the teflon seal.

A new grid assembly method is being tested. The new assembly uses solderable gold-plated tungsten wire and it is hoped that it will reduce assembly time for a grid from days to minutes.

5.4.4 RF Amplifier and Cavity Improvements

E.P. Stock (TASCC Operations Branch) with J.E. McGregor

The amplifier metering is being modified to permit accurate repositioning of the amplifier tuners. Four-and-one-half digit meters will replace the analog meters and a read-back indicator for the 'trombone' tuner is being added. The balance capacitor drives for the cyclotron cavity have been completely redesigned to improve mechanical reliability and precision, and correct cooling problems. The push-rod vacuum seals on the main cyclotron tuners are showing signs of wear. Design studies on a possible modified seal have been carried out.

5.5 INJECTION

5.5.1 Foil Changer

C.R.J. Hoffmann and J.F. Mouris

Operation of the foil changer in a modified mode to avoid jamming was continued until the scheduled shutdown started. Toward the end of the operating period calibration was lost when a pin in the chain driveline broke. Since the scheduled shutdown has started, the unloader-loader vacuum envelope has been removed from the cyclotron to provide access to the upper pole.

5.6 EXTRACTION

5.6.1 Electrostatic Deflector

C.R.J. Hoffmann and J.F. Mouris

Development and extraction of a bromine beam at 20 MeV/u was curtailed when the electrostatic deflector failed at 80 kV. Leakage current dramatically increased. After failure, the leakage current reached the power supply limit of 1.25 mA at 40 kV. Subsequent disassembly and inspection of the deflector system showed that the boron nitride sleeve on the teflon main high-voltage feed insulator had shattered. It is believed that most of this damage occurred much earlier when the high-voltage cable was damaged through overheating: water to form the isolating resistor had not been flowing while the rf dee voltage was on. Minor deformation of the teflon insulator body is also consistent with overheating. A new high-voltage feed insulator will be made and installed.

5.6.2 Magnetic Channel

C.R.J. Hoffmann and J.F. Mouris

Three of the five modules to interface extraction system power supplies with the computer control system have been tested and are ready for operation. Modifications required to three of the power supplies have been made.

Inspection of the hill lenses has shown that arcing has occurred to the copper cover of hill lens #2. Also, fingerstock in the vicinity of this lens has been damaged. Methods of increasing the gaps between hill lens cover and pole liners are being studied.

5.7 DIAGNOSTIC PROBES

J.A. Hulbert with D.R. Proulx (Plant Design), R.E. Howard (Nuclear Physics Branch), E.P. Stock and R.E. Milks (TASCC Operations), and J.D. Hepburn (Physics and Health Sciences)

The dummy probe with improved cooling contact area was found adequate for high power operation. Detuning tests at moderate power levels (limited by cryostat wall heating problems) showed that the AFC system copes well with probe detuning effects in π-mode.

With these results it was decided to proceed with the same 25.4 mm diameter for the new probes. The new design has the capability of modification to 19 mm diameter should detuning become intolerable at high power and the 19 mm design is complete in full detail.

Rear housings for the new probes are complete and the 25.4 mm diameter probe tube assemblies about 30% finished. Two extra signal cables have been incorporated into the 25.4 mm design to allow the future addition of a PIN diode phase probe.

5.8 CONFERENCE PRESENTATIONS AND LECTURES

FIRST YEAR'S OPERATION OF THE CHALK RIVER SUPERCONDUCTING CYCLOTRON
J.A. Hulbert, C.B. Bigham, W.G. Davies, B.F. Greiner, J.D. Hepburn, E.A. Heighway, C.R.J. Hoffmann, E.H. Lindqvist, J.H. Ormrod, E.P. Stock and L.W. Thomson
Paper presented at the Eleventh International Conference on Cyclotrons and Their Applications, Tokyo, Japan, 1986 October 13-17.

DEVELOPING AND COMMISSIONING THE CHALK RIVER SUPERCONDUCTING CYCLOTRON
J.A. Hulbert
Talk presented at the Symposium on Heavy-Ion Nuclear Physics, AECL, Chalk River Nuclear Laboratories, Chalk River, Ontario, 1986 October 4.

ACCELERATOR ACTIVITIES AT CRNL - A PROGRESS REPORT
C.R. Hoffmann
Paper presented at the Canadian Accelerator Physics Conference, University of Saskatchewan, Saskatoon, 1986 September 8-9.

6. PHYSICS SUMMARY

G. Dolling

Assistant to Vice-President - G. Dolling
Secretary - J. Vaudry

PHYSICS SUMMARY

Neutron and Solid State Physics Branch
and
Theoretical Physics Branch

6.1 Condensed Matter Physics

Substantial progress has been made toward the detailed design of the Dual Beam Neutron Spectrometer, and field tests have been successfully completed of two of its major components (a) an analyzer unit of simplified design in which the analyzer crystal and neutron detector are contained in one shield instead of the conventional two-shield system and (b) a neutron polarization system of Heusler alloy monochromators, guide field magnets and neutron spin flippers (7.2, 7.3, 7.4).

A new type of clathrate hydrate structure has been determined from neutron diffraction measurements on the deuterated double hydrate of t-butyl methyl ether and H_2S at 5 K. It is isostructural with the clathrasil 1 H structure and its very existence calls into question the current theories of clathrate stability (7.9).

Measurements of the static structure factor of liquid ^4He in both normal and superfluid phases have been made, over a range of density from 0.149 to 0.169 g/cm^3 and temperature between 1.05 and 3.92 K. Detailed analysis of the results is in progress to determine the pair correlation function g(r) and to obtain information on the density and temperature dependence of the condensate fraction (7.10).

Neutron diffraction has been used to assess the quality of GaAs wafers used as substrates for integrated circuit manufacture. Various types of defects are conventionally observed by optical microscopy following a KOH etch, a time-consuming process. A strong correlation has been found between diffracted neutron intensity and observed defect concentration: further work is in progress to assess the speed and reliability achievable by the neutron diffraction technique (7.13).

Phonon measurements in the equiatomic alloy NiAl have been made along the principal symmetry directions, at 296 K and 1073 K. A marked "kink" in the $[\zeta\zeta 0]$ T_1 branch, seen clearly at 296 K, is virtually absent at the higher temperature; aside from the phonons in this "kink" region, the ratios of all measured phonon frequencies at the 2 temperatures (1073 K/296 K) were almost the same, with a mean value 0.943 ± 0.020. The effect on the lattice vibrations of various types of defect is being studied by comparing the NiAl results with analogous measurements made on a non-stoichiometric sample $Ni_{0.58}Al_{0.42}$, in which excess Ni atoms are located on Al sites and some Al vacancies may also exist. Analysis of the data is in progress (7.15, 7.16).

Recent molecular dynamics simulations indicate that well-defined long wavelength phonons should exist in the high-temperature orientationally disordered phase of SF_6. Although previous medium-resolution measurements had shown no evidence for such modes, a new series of experiments at high resolution have revealed well-defined modes of longitudinal character for very small reduced wave vectors ζ. For both [001] and [110] directions, the intensity of the peak corresponding to these modes falls to zero at $\zeta \simeq 0.2$ (7.17).

A search has beem made for neutron Bragg reflections at wave vector A(0 0 1/2) $PrCl_3$, that would indicate dimerization of the Pr chains along the crystallographic c axis below the spin-Peierls transition at 0.4 K. No evidence for A-point satellites was found; rather, the results suggest that the transition involves a Γ-point distortion, i.e. an internal distortion of the unit cell (7.20).

A re-examination of lattice parameter and density data in relation to theories of vacancy formation in the refractory oxides TiO_x and VO_x has cast considerable doubt on the conventional picture of their defect structure. Our new analysis shows that the metal- and oxygen-vacancy concentrations are equal for all values of x, and that the quantities of primary interest are rather the concentrations of vacancies and atoms of the other type ("anti-structure" atoms) on each sublattice (7.22).

6.2 Neutron and Neutrino Physics

Monte Carlo simulations have been made of the neutron detection characteristics of the phoswich detectors that form part of the multiparticle facility at TASCC. The results suggest that an optimum choice of plastic scintillator thickness can be made to enable the phoswich devices to detect both charged particles and neutrons with acceptable efficiencies (7.30).

A project grant application for $300 000 has been submitted by the Sudbury Neutrino Observatory Group to NSERC for the 1987/88 fiscal year. Progress on many aspects of the SNO project is being made, including improved measurements of the radioactive background of detector components, construction and testing of photomultipliers and electronics, design of the acrylic vessel that will contain the 1000-tons of D_2O, and light transmission by various acrylic samples. Detailed shielding calculations have been performed at CRNL (7.34). The SNO group is scheduled to prepare by 1987 October a major facility grant application to the Canadian, U.S. and U.K. granting agencies (7.32).

Analysis of the data collected during measurements of the photodisintegration of the deuteron is now complete. The circular polarization dependent component of the cross section has been determined to be $(2.7 \pm 2.8) \times 10^{-6}$ and $(7.7 \pm 5.3) \times 10^{-6}$ for bremsstrahlung with end point energies of 4.1 and 3.2 MeV respectively. The results are thus consistent with zero parity violation in this photodisintegration reaction (7.35).

6.3 Theoretical Physics

The concepts of fractional dimensionality and self-similarity are finding wide application to topics as diverse as neutron scattering from fumed silica to cascades following the collision of energetic particles. An interactive computer program is being developed to study the density of vibrational states of a model diamond lattice having any arbirary set of broken bonds so as to simulate fractal behaviour. The program allows construction of stereoscopic viewing of three-dimensional objects and minimization of multi-parameter functions (8.5).

A non-topological soliton model involving vector coupling of 3 quarks to certain coherent states of pion and sigma fields has been used to calculate the masses, the axial-vector coupling constant, the pi-nucleon coupling constant, the magnetic moments and the mean square charged radii of the nucleons. Reasonable agreement is obtained with experiment, except for the neutron charge radius which turns out to be ten times too small. A possible reason for this discrepancy is suggested (8.6).

An attempt has been made to explain the experimental observation of non-zero M1 matrix elements between $1s_{1/2}$ and $0d_{3/2}$ single-hole states in ^{39}K and ^{39}Ca, transitions that are forbidden within the standard impulse approximation one-body operator formalism. Although good agreement with experiment has been obtained for the Gamow-Teller rate, the theoretical result for the isovector M1 transition is too small by a factor 3.7. There is at present no satisfactory explanation for this discrepancy (8.11).

Undesirable enhancements to the magnetic moment and weak axial charge of a nucleon in a nuclear medium obtained in relativistic mean field theories can be understood in a nonrelativistic approach as arising from heavy-meson σ-pair graphs. A cancelling mechanism can be found for isoscalar operators, but not for isovector operators. More detailed analysis of the short range behaviour of nucleons is required in future relativistic models (8.12).

Ward identities were used to complete a proof stating that the N=4 supersymmetric theory is finite, or free from ultraviolet divergences to all orders of perturbation expansion. The N=4 supersymmetric theory is the only gauge theory believed to have such a property (8.15).

Recent experiments have revealed a discrepancy between (a) the sum of the branching ratios of all exclusive channels for the decay of the τ particle, and (b) the inclusive branching ratio for this decay. Theoretical analysis shows that the missing exclusive strength could come from the decay of the τ into 3 pions and a neutrino (8.19).

6.4 Radionuclide Metrology and Detectors

The results of the recent international comparison of ^{109}Cd standard solution by 17 laboratories (27 reported values) have been published: they show excellent agreement between the CRNL values and the worldwide mean of all 27 (7.42). A full-scale standardization of ^{88}Y has been undertaken, with a stock solution obtained from Amersham Corporation. Two samples have been shipped to the International Bureau of Weights and Measures for registration, and others are available for interested users (7.43).

A completely assembled Bragg curve detector has been mounted in the 1.75 m scattering chamber: initial in situ testing indicated a need for further development of the detector electronics (7.39).

7. NEUTRON AND SOLID STATE PHYSICS BRANCH

edited by E.D. Earle

NEUTRON AND SOLID STATE PHYSICS BRANCH

edited by E.D. Earle

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7.2 Design of DUALSPEC

NSSP Staff with W.A. Mellors (Mechanical Equipment Development Branch) and J. Morralee and K. Tait (Mechanical Design Branch)

Detailed DUALSPEC design began in September. A new method of moving wedges in a shielding drum has been developed. The wedges are rotated horizontally across the white neutron beam, instead of being raised, thereby avoiding the cavities required for jacking mechanisms in conventional drum designs. A mockup of the wedge mechanism has shown the method to be feasible and attractive. Another change is an improved collimator assembly. The previously separate inpile gate and horizontally translating yoke collimator have been combined into a simple four position rotating assembly in the biological shield. This requires a cut out of the reactor wall and combines the gate function with three possible collimating functions.

7.3 Test of the Prototype Analyzer for DUALSPEC

D.C. Tennant, E.D. Hallman and E.C. Svensson

The prototype analyzer (PR-P-141: 3.5; AECL-8849) is being critically tested by being used in an actual experiment to measure phonons in a Ni-Aℓ alloy (PR-PHS-P-2: 7.16; AECL-9351). This larger analyzer causes a reduction of ≈ 10° in the maximum scattering angle, Ø, but this can be regained in the final design by a modification to the shape of the shielding. The fast neutron background for Ø > 36° is ≈ 0.1 counts per minute for the DUALSPEC analyzer while it varies from ≈ 0.7 to 15 counts per minute for the conventional analyzer. The fast neutron background increases as the analyzer shield begins to intercept the monochromatic beam but remains at less than 3 counts per minute even when Ø ≈ 10°. The observed intensity on the wings of phonon peaks varies from 1 to 3 counts per minute. The intensity of the phonon peaks is reduced by ≈ 25% in the prototype analyzer because the distance from the specimen to the detector is 127 cm. (cf. 102 cm in the conventional analyzer). The background with this analyzer is, in general, appreciably better than that obtained with the conventional analyzer and the fast neutron background at large scattering angles is more than six times better.

7.4 Design, Construction and Tests of Components for a New Polarized Neutron Spectrometer

E.D. Hallman, T.M. Holden and P. Gerlach

Two polarizing monochromators, a set of guide magnets and two spin flippers have been assembled and characterized, in order to provide design information and operating experience for the DUALSPEC polarized neutron spectrometer and to prepare for polarized neutron experiments on the N5 triple axis spectrometer.

Neutron beam guides with ALNICO permanent magnet sides and mild steel pole plates (top and bottom) were constructed and magnetic fields were mapped both inside and in front of the entrance to each guide. A 107 cm long magnetic insert was designed and constructed to fit the incident collimator of the N5 spectrometer drum, to provide a guide field from monochromator to specimen. A short 15 cm guide with a mounting plate was made to fit in the analyzer collimator. Typically, fields of between 100 and 300 Gauss could be obtained inside the guides, with variations generally less than 10%.

Two double coil spin flippers were constructed to dimensions that were optimized by magnetic field calculations. A flipper consists of a flat coil of enamelled copper wire wound on an aluminum frame about a horizontal axis inside a second flat coil wound about a vertical axis. The current in the inner coil is adjusted so that the neutron spin precesses through 180° in its passage through the coil.

Tests of these components were first carried out on the C4 spectrometer, with an unpolarized monochromatic beam incident on a polarizing crystal of Heusler alloy, $Cu_2MnA\ell$, at the sample position. A magnetic guide, the flipper and a second analyzer guide were installed between the sample and analyzer and a second Heusler crystal was used as analyzer. Guide lengths and separation distances between guides and flipper were varied to optain optimum polarization of the beam and best flipping efficiency (highest ratio of the flipper off intensity to that for flipper on). Flipping ratios as high as 16:1 were observed. Assuming a polarizing efficiency of 94% for the Heusler crystal (as quoted in the literature), a spin flip efficiency of up to 100:1 may be derived. Best results were observed when the fringe field from the adjacent guides was reduced to < 4 Gauss, and the flipper coils were located at the field minimum. For this configuration, the vertical axis compensating currents were close to zero and effects of this trimming field were small.

At the N5 spectrometer, a Heusler crystal was installed as monochromator, and the 107 cm long magnetic collimator insert was used to produce a polarized monochromatic beam at the specimen table. Short magnet guides were used to maintain neutron polarization up to the flipper, located in front of the analyzer shield, and to maintain polarization up to the analyzer (a second Heusler assembly). With the short specimen-analyzer arm, some depolarizing fields appeared to be present (possibly from the steel of the analyzer shield), and only for a 1 mm diameter neutron beam was adequate polarization and spin flip performance observed. The monochromatic beam intensity for spin up neutrons was about 20% the intensity of a similar wavelength beam from a high-reflectivity graphite monochromator. Because 2nd order (unpolarized) scattering is possible from the (222) Heusler crystal planes, tests were carried out at a monochromator scattering angle of 19° (λ = 1.15 Å), where the 2nd order neutron intensity is small.

On the basis of these tests, several modifications in the components are being made, including the construction of a set of Helmholtz coils to give a uniform magnetic field in the vicinity of the specimen table and flipper. Further tests and measurements of magnons in a cobalt-iron specimen, using polarized neutrons, are planned.

7.5 L3 Spectrometer

H.F. Nieman, W.J.L. Buyers and B.M. Powell with C. El. Minyawi (COM attached to Mechanical Design Branch)

Design is underway to extend the range of the monochromator angle for the L3 spectrometer beyond its present limit of 45°. A cooled filter is also being designed. It will be a simplified version of the Be and sapphire filter at N5.

7.6 Book Chapter on Solid and Liquid Helium

E.C. Svensson with H.R. Glyde (University of Delaware)

The condensed phases of ^{3}He (Fermi particles of spin 1/2) and ^{4}He (Bose particles of spin 0) continue to be of high interest to scientists in general and to neutron scatterers in particular. This interest stems from the fact that these substances form the prototype examples in nature of quantum solids and liquids of interacting bosons and fermions.

A prodigious wealth of information on solid and liquid helium has been accumulated from a multitude of neutron scattering studies dating back to 1951 for liquid ^{4}He and to 1958 for solid ^{4}He. Liquid ^{4}He has in fact been studied far more extensively by neutron scattering than any other material, with the lion's share of this work being done at Chalk River. A book chapter in which extensive coverage is given to the results of the neutron scattering measurements on helium and their theoretical interpretation has recently been completed. Emphasis is placed on the work of the last decade. This has been a particularly exciting period even for the much-studied liquid ^{4}He with, for example, the existence of the Bose condensate finally being unambiguously confirmed, and the condensate fraction determined.

The book chapter has major sections on solid helium, liquid ^{4}He, liquid ^{3}He and liquid ^{3}He-^{4}He mixtures. It will appear in the book "Neutron Scattering", eds. K. Sköld and D.L. Price (Methods of Experimental Physics, Vol. 23, Part B) to be published by Academic Press, New York.

7.7 Low Temperature Structure of SF_6

B.M. Powell with M.T. Dove (University of Cambridge), G.S. Pawley (University of Edinburgh) and L.S. Bartell (University of Michigan).

The crystal structure of sulphur hexafluoride (SF_6) in its low temperature phase has been solved from neutron powder diffraction measurements. The solution necessitated development of a new procedure to index the diffraction profiles of low symmetry structures. When applied to the original diffraction data (PR-P-126: 3.5; AECL-7055) this procedure succeeded in indexing the profile in terms of a triclinic unit cell. New powder diffraction data was measured at 23 K and 85 K and analysed in detail assuming these triclinic unit cell parameters as initial values in the refinements. The molecules were constrained to have O_h symmetry and the initial molecular centre of mass positions and molecular orientations were those predicted by molecular dynamics simulations.

The crystal structure is confirmed to be triclinic, space group $P\bar{1}$, with three molecules in the unit cell. It is in good agreement with that predicted by the simulation calculations. The transition from the high temperature, orientationally disordered, cubic phase is interpreted in terms of two separate lattice distortions from the cubic structure which couple to different stages of orientational ordering. An initial contraction along a cubic <111> direction forms an intermediate hexagonal structure and results in the orientational ordering of 2/3 of the molecules in the unit cell. A shear of the hexagonal structure towards the $[1\bar{1}0]$ direction then forms the triclinic structure. This results in the orientational ordering of the remaining molecule in the unit cell. We searched for evidence of the intermediate structure, without success. Thus we conclude that, at least in bulk samples, both distortions occur together at the first order transition at 96 K. The mechanism driving the transition is the resolution of orientational frustration as the temperature is lowered.

7.8 Neutron Diffraction Studies of Amorphous and Crystalline D_2O Ice

E.C. Svensson and E.D. Hallman with V.F. Sears (Theoretical Physics Branch) and M.A. Floriano, E. Whalley and D.D. Klug (National Research Council)

Further analysis of the diffraction results for amorphous and crystalline ice obtained earlier (PR-PHS-P-1: 7.4; AECL-9262) was carried out. New measurements were also made on two separate wafer samples ($\approx$ 70 mm diameter by $\approx$ 1.7 mm thick) of high-density amorphous (hda) ice produced by a different technique, namely by pressurizing low-density amorphous (ℓda) ice to $\approx$ 6 kbar at 77 K. [The hda samples studied previously had been produced by pressurizing hexagonal ice (Ice Ih) to $\approx$ 10 kbar at 77 K.] The new samples were mounted in a Displex closed-cycle refrigerator using the special holder and transfer procedure described previously (PR-P-142: 3.15; AECL-9103). The total neutron scattering was determined for momentum transfers $Q < 12$ Å^{-1} using 0.9 Å neutrons from a Ge(331) monochromator at the N5 spectrometer. Measurements were first carried out on the hda samples after cooling directly from liquid N_2 temperature to 17 K. Measurements (all at 17 K) were also carried out on one sample after a short anneal at ≈ 102 K, on both samples after they were transformed irreversibly to the ℓda form by heating to ≈ 135 K, on both samples after transformation to the cubic crystalline phase (Ice Ic) by heating to ≈ 170 K, and on one sample after transformation to the hexagonal crystalline phase (Ice Ih) by further heating to ≈ 240 K. Extensive testing showed that the cubic and hexagonal crystalline specmens were "ideal" powders. Measurements were also carried out on the empty cells.

The results were analyzed to obtain static structure factors S(Q) and pair correlation functions g(r). S(Q) and g(r) for the new hda specimens are essentially identical to those for the earlier hda specimens indicating that the same hda structure is obtained by two completely different routes, i.e. by phase transformations (apparently first order) from either crystalline Ice Ih or ℓda ice. The sample that had been annealed at ≈ 102 K had a structure intermediate between that of the hda and ℓda forms with, for example, the position of the principal peak of S(Q) having moved about 1/3 of the way from that of hda to that of ℓda. Such intermediate samples give crucial information on the difference in structure of the two amorphous forms, but they are extremely difficult to produce because the transition from hda to ℓda is exothermic and the sample usually transforms completely through self heating before the transition can be arrested by cooling.

Many diffraction measurements on both single-crystal and polycrystalline ice have indicated that the intramolecular O-D distance is 1.01 - 1.02 Å, much larger than the value, 0.973 Å, for the vapour. It has been argued (E. Whalley, Mol. Phys. 28 (1974) 1105) that these large values cannot be correct and that the O-D distance must be about 0.98 Å. Our pair correlation functions for the two samples of ice Ic and the sample of ice Ih give values of 0.978 ± 0.003 Å, 0.973 ± 0.003 Å and 0.976 ± 0.003 Å in strong support of this claim. It seems not to have been recognized previously that the technique we have employed to obtain these values, namely the Fourier inversion of the complete static structure factor for a powder specimen, can be used to determine interatomic distances in disordered crystalline materials directly and accurately.

7.9 A New Clathrate Hydrate Structure

B.M. Powell with J.A. Ripmeester, J.S. Tse and C.I. Ratcliffe (National Research Council)

Clathrate hydrates, the ice-like host-guest systems formed by guest molecules in cages of hydrogen-bonded water molecules, are known to exist in two well characterized cubic structures. Recently, clathrasils, clathrates with SiO_2 as the host unit instead of H_2O, have been prepared and many are isostructural with the clathrate hydrates. However, several clathrasils have no hydrate analogue and this suggests that new hydrate structures may exist.

The double hydrate of methylcyclohexane and Xe was prepared. The results of ^{129}Xe and ^{2}H NMR measurements with the deuterated guest molecule suggest the hydrate contains three types of cages, one large and anisotropic cage and two different small cages. Subsequently, neutron diffraction measurements were made on the deuterated double hydrate of t-butyl methyl ether and H_2S. The diffraction pattern was measured at 5 K on the L3 spectrometer with a wavelength of 1.9888 Å. Nineteen diffraction peaks were observed and these could be indexed on the basis of the hexagonal space group P6/mmm. The lattice parameters were found to be a = 12.15 (7) Å and c = 10.05 (6) Å. This double hydrate thus exists in a new type of structure not previously found for clathrate hydrates. It is isostructural with the clathrasil 1H structure and its existence implies that theories of the stability of clathrates must be re-examined.

7.10 Static Structure Factor of Liquid ^{4}He at Elevated Pressures

E.C. Svensson, E.D. Hallman and D.C. Tennant

The study of the static structure factor, S(Q), of liquid ^{4}He at elevated pressures (PR-P-141: 3.12; AECL-8849) was continued, again using the L3 spectrometer operated so as to measure the total scattering for a fixed incident neutron energy of 111.1 meV. Complete scans ($2° \leq \phi \leq 116.4°$, where ϕ is the scattering angle) were carried out at 15 temperatures in the range 1.05 - 3.92 K for a density, ρ, of 0.161 g/cm^3, at 2 to 3 temperatures each for densities of 0.149, 0.153 and 0.157 g/cm^3 and, as a check, at 1.05 K for 0.169 g/cm^3, the density of the earlier measurements. Additional short scans, usually for 2 to 4 temperatures in the region of the λ-point for each density, were also carried out over the main peak ($\phi \approx 16°$) in the total scattering and at large ϕ ($\approx 93°$, where S(Q) = 1) for normalization purposes. Four complete scans of the scattering from the empty cell were also carried out over the course of the measurements. For each density, the λ-point was determined from plots of temperature vs. time while slowly warming and/or cooling as a check on the calibration of the temperature and pressure sensors. Typically, the observed and nominal values of T_λ agreed to better than 0.01 K.

As observed earlier at ρ = 0.169 g/cm^3, and also at saturated vapour pressure ($\rho \approx$ 0.146 g/cm^3) by Svensson et al. (Phys. Rev. B21 (1980) 3638 and Physica 108B (1981) 1317), the main peak in the total scattering at a constant density of 0.161 g/cm^3 increases with decreasing temperature above T_λ and then decreases steadily with decreasing temperature below T_λ, the reversal at T_λ being caused, at least in part, by the appearance of the zero momentum Bose condensate. The height of the main peak increases with increasing density, but does not scale linearly with density. For example, the ratio of the peak heights for densities of 0.149 and 0.161 g/cm^3 is 0.869 while the density ratio is 0.925. The intensity for $\phi \approx 93°$ does, however, scale almost linearly with density, as expected, and, for a given density, is very nearly independent of temperature with just a slight indication of structure near T_λ. Detailed analysis of the results to obtain corrected values of S(Q) and, by Fourier inversion, the pair correlation function, g(r), as well as to obtain information on the density and temperature dependence of the condensate fraction, is in progress.

Prior to commencement of this study, the helium pressure line (which passes through the main helium reservoir in the cryostat) was replaced by one of much smaller diameter. This increased the "hold-time" from 42 to 72 hours, but the new line, which also carries the electrical leads to the temperature sensor inside the pressure cell, was found to be prone to blockage during the experiments. Several additional delays and interruptions were caused by other technical problems, and the experiments have been temporarily suspended for major modifications to the cryostat and the pressure apparatus.

7.11 Wide Angle Neutron Diffraction Studies of Drug-Membrane Interactions

P. Martel

At temperatures near 30°C the hydrocarbon tails of dipalmitoylphosphatidylcholine (DPPC) membranes are arranged on a distorted intraplanar hexagonal lattice with a Bragg repeat spacing of about 4.2 Å. In the present experiment the effects on this lattice of adding 10 mol percent of cholesterol and Δ^9-tetrahydrocannabinol (Δ^9-THC) are compared. Dispersions of the three samples were made by adding 30 wt% D_2O to the samples. Previous measurements of the interplanar characteristics of such samples have been reported (PR-P-141: 3.19; AECL-8849).

In all three cases a double peak was observed but with decreased intensities when inclusions were present. If I(1) and I(2) represent the integrated intensities of the two peaks, C(1) and C(2) the values of the corresponding lattice spacings (in Å), and W(1) and W(2) the full widths at half maximum in degrees as determined by Gaussian fits, the following table of values results:

Sample	I(1)	I(2)	C(1)	C(2)	W(1)	W(2)
Pure DPPC	3.31±0.18	0.68±0.08	3.98±0.02	4.14±0.01	1.35±0.07	0.27±0.02
With cholesterol	1.57±0.15	0.51±0.13	4.06±0.03	4.16±0.02	1.24±0.11	0.41±0.06
With Δ^9-THC	2.13±0.14	0.36±0.08	4.02±0.02	4.13±0.01	1.12±0.08	0.24±0.04

The spacings observed for pure DPPC correspond to a hexagonal model (J. Mol. Biol. 75 (1973) 711) where each rod-like hydrocarbon is surrounded by 4 "rods" distant some 4.78 Å and 2 others at 4.60 Å, all tilted by ≈ 30° from the normal to the bilayer. The result is a quasi-hexagonal lattice with a unit cell containing two long and four short sides.

The total integrated intensity is decreased marginally more by cholesterol than by Δ^9-THC because of the production of mixed disordered regions. This indicates that only slightly more of the pure DPPC phase is removed by cholesterol. However, the double peak observed for the remaining DPPC membrane is less distorted by Δ^9-THC and this is reflected in the similarity of the I(1)/I(2) ratio for pure DPPC and the specimen containing Δ^9-THC. Thus the remaining DPPC phase is less disturbed by the presence of Δ^9-THC. Also the greater peak width, W(2), for cholesterol suggests that there is more disorder induced by this molecule among the hydrocarbons separated by $4.14 \times 2/\sqrt{3} = 4.78$ Å.

7.12 Cellulose Structure of Wheat Straw Subjected to Alkaline Hydrogen Peroxide Treatment

P. Martel with J.M. Gould (U.S. Department of Agriculture, Peoria, Illinois)

According to Kerley et al. (Science 230 (1985) 820) the rate and extent of lignocellulosic degradation by microbes in the stomachs of ruminants can be greatly enhanced by alkaline hydrogen peroxide (AHP) treatment of straw which normally has low food value because lignin binds to the cellulose and renders it inaccessible for monomerization by cellulase. In an earlier report (PR-PHS-P-1: 7.12; AECL-9262) we indicate that alkaline hydrogen peroxide treatment of various pure cellulose samples did not change their neutron diffraction profiles.

However, in an experiment on wheat straw samples prepared by one of us (J.M.G.), we have observed altered diffraction profiles. For these samples several diffraction peaks were found which corresponded in angle to those from pure cellulose. In particular a strong peak was observed at the (020) position. The integrated intensity of this peak increased by a factor of two after AHP treatment. There were also increases in the region of the ($1\bar{1}0$) and (110) peaks.

The structure of pure cellulose can be envisioned as hydrogen-bonded sheets of glucose extending in the (020) planes. The increase in intensity of the (020) diffraction peak in straw suggests that these planes are less distorted after alkaline treatment because significant amounts of lignin have become detached from the cellulose fibrils in the straw. The present results tend to confirm biochemical measurements (J.M. Gould, Biotechnology and Bioengineering, 27, (1985) 893) which indicated that an important component of AHP treatment is the liberation of increased amounts of highly-polymerized cellulose for hydrolysis by cellulase.

7.13 Neutron Diffraction from Gallium Arsenide Wafers

P. Martel with D. Rogers (Cominco Ltd., Trail, B.C.)

Neutron diffraction measurements have been carried out on four GaAs wafers chosen with defects typical of the High Pressure Liquid-Encapsulated Czochralski (HPLEC) growth process used in obtaining substrates for integrated circuit manufacture. The defects are called Low-Angle Poly or "LAP", "slip" and "lineage". They become visible under the optical miscoscope after etching in KOH solution. "LAP" consists of small crystallites that have slightly different orientations from the bulk of the wafer. "Slip" appears as lines of etched pits that seem to follow the natural $\{110\}$ cleavage planes of GaAs. The lines are actually intersections with the surface of $\{111\}$ glide planes, and form as the newly-grown crystal cools. "Lineage" like "slip" also appears as lines of etch pits but the lines tend to wander away from the $\{110\}$ directions.

In assessing the quality of GaAs wafers it has been found (as with Si wafers) that the reflected neutron intensity from the faces of these single crystal wafers is very sensitive to extinction effects. The more perfect the crystal, the lower the reflected intensity. Since all wafers from a given ingot are cut to the same size and orientation, a rapid assessment of wafer quality can be made by looking at the reflected intensity with a neutron beam which bathes the entire crystal. Results to date appear below. The specimens were characterized in order of increasing specimen number as best-to-worse by Cominco.

Specimen Number	Visual Inspection at Foundry			Diffracted Neutron Intensity (Relative Values)
	LAP	Lineage	Slip	
1	no	no	little	0.56
2	no	no	medium	0.65
3	yes	yes	little	0.80
4	yes	yes	little	0.80

Subsequent to the neutron measurements we were informed that specimens 3 and 4 are nearly adjacent slices from the same crystal. Specimens 1 and 2 are from two other crystals.

It should be pointed out that this type of measurement can be carried out at a rate faster than one wafer per minute. Although many workers are attempting to correlate GaAs device performance with defects in or on GaAs wafers, little work has been done with lineage and slip. One reason for the lack of attention may be the absence of a method to measure these two defects apart from laborious (and highly subjective) counting of lines using an optical microscope.

Further collaborative work with Cominco is in progress to see if lattice parameter variation and etch pit densities can be reliably assessed with neutrons. Small angle neutron scattering measurements indicated no detectable scattering from defects with dimensions less than 200 Å, the upper detection limit of the equipment.

7.14 Analysis of Small Angle Neutron Scattering (SANS) from Thoria Oligomers

P. Martel and B.M. Powell with C.W. Turner (System Chemistry and Materials Branch)

Analysis of the SANS data resulting from the formation of aggregates due to the hydrolysis of Th^{4+} (PR-PHS-P-1: 7.13; AECL-9262) has been completed. For this experiment polynuclear species were formed according to the reaction

$$xTh^{4+} + yOH^{-} \rightarrow Th_x(OH)_y^{[4x-y]+}$$

The degree of hydrolysis is characterized by $r = y/x$. Hydrolysis of the Th^{4+} is complete when $r = 4$.

For the cases where the scattering is monotonic in scattering vector, Q, a Maxwellian distribution of radii of gyration (R_g) was assumed (Guinier and Fournet, "Small Angle Scattering of X-rays", John Wiley & Sons, New York, 1955, p. 152). Computer fits suggested that the most satisfactory fit to all the data could be obtained with a Gaussian distribution, a special case of the Maxwellian distribution of R_g's. The results are summarized as follows, where R is the arithmetic mean of the R_g's:

r	Molar Concentration	R(Å)
3.12	1.0	7.7±0.5
3.12	1.8	15.3±0.2
3.12	3.0	18.3±0.3
3.20	1.8	7.9±0.2
3.56	1.8	11.8±0.2

These results suggest that aggregate size increases with concentration. However, for any particular concentration (1.8 M), there is little indication from our results of any trend in R as a function of the degree of hydrolysis (r).

7.15 Lattice Dynamics of $Ni_{0.5}A\ell_{0.5}$

E.D. Hallman and E.C. Svensson

Work on the ordered bcc equiatomic alloy $Ni_{0.5}A\ell_{0.5}$ first reported in PR-P-131:3.7; AECL-7510 has been continued. The specimen crystal used previously was remounted and aligned for investigation of phonons in the (001) plane. A primary objective was to determine the [ζζ0] T_1 branch of the dispersion relation, and hence to complete measurements in the principal symmetry directions, [00ζ], [ζζ0] and [ζζζ]. A total of 64 phonon groups were measured at 296 K and 1073 K, using the N5 spectrometer. A marked "kink" in the dispersion curve at ζ = 0.3 (i.e. at a phonon frequency of 2.7 THz) is present at 296 K in the [ζζ0] T_1 branch. This structure is virtually absent at 1073 K. Measurements were also made in other symmetry directions to complete the investigation of the dispersion relation in this alloy at the two temperatures. The phonon frequency ratio at the two temperatures (1073 K/296 K) had an average value of 0.943 ± 0.020. This ratio was quite constant for individual phonons, except in the vicinity of the anomalous "kink" in the [ζζ0] T_1 branch. There are no noticeable disorder effects at high temperatures - phonons are still well-defined and, aside from the general lowering of phonon frequencies, the only significant change in the dispersion curves is the disappearance of the "kink" referred to above. A Born-von Karman force constant fitting procedure has been developed for this structure. Results of fits to the earlier data give large first neighbour (Ni-Aℓ) force constants (0.7 times those for bcc iron), and second neighbour force constants which are very small for Ni-Ni and large (twice as large as those for iron) for Aℓ-Aℓ. Significant forces appear to extend beyond fourth neighbours. The fitting procedure has recently been modified to include fifth neighbour interactions and fits to the entire data set at each temperature are in progress.

7.16 Phonons in the Alloy $Ni_{0.58}Al_{0.42}$

E.D. Hallman and E.C. Svensson

Measurements of phonons in the non-stoichiometric alloy $Ni_{0.58}Al_{0.42}$ have been made with the L3 triple axis spectrometer. The single crystal specimen, prepared by J. Garrett at McMaster University, has an ordered beta (CsCl) structure, but excess nickel atoms are located on aluminum sites and some aluminum vacancies may also exist. This study is being carried out to look for effects of the changes in atom configuration on the phonon dispersion curves and on the interatomic forces. Results will be compared with those from extensive measurements made previously on stoichiometric $Ni_{0.50}Al_{0.50}$ (PR-PHS-P-2: 7.15; AECL-9351). The alloy lattice constant was carefully measured by neutron diffraction for different 1 cm long sections of the 8 cm long specimen. The measurements showed that the alloy composition varied from 50 atomic % Ni to 60 atomic % Ni along the specimen length. A 3 cm length near the Ni-rich end had quite uniform composition and was also a good single crystal. This section, having a volume of about 3 cm^3 and a mosaic width of 0.5°, was chosen for the phonon measurements. A new analyzer module (PR-P-141: 3.5; AECL-8849 and PR-PHS-P-2: 7.3: AECL-9351) with the analyzer crystal and detector both mounted inside a single large polyethylene and cadmium shield was used for these measurements. Sixty phonon groups have been measured in the principal symmetry directions of the (110) plane at 296 K. Frequencies for longitudinal phonons and for optical-branch transverse phonons are about 4% higher than those for $Ni_{0.5}Al_{0.5}$. Acoustic branch transverse phonons are from 1% to 20% lower in frequency than in $Ni_{0.5}Al_{0.5}$. There is evidence of a "kink", or possibly even a splitting of the dispersion curve, near $\zeta = 0.25$ in the transverse acoustic branches in the $[00\zeta]$, $[\zeta\zeta0]$ and $[\zeta\zeta\zeta]$ directions. These anomalies may be similar to the one observed in the $[\zeta\zeta0]$ T_1 branch in $Ni_{0.5}Al_{0.5}$.

7.17 Excitations in SF_6

B.M. Powell with M.T. Dove (University of Cambridge)

Previous measurements of the collective excitations in the high-temperature orientationally disordered phase of SF_6 showed broad, overdamped modes centred at zero frequency, with no evidence for discrete, well-defined excitations (PR-P-132: 3.2; AECL-7605). However, recent molecular dynamics simulations (M.T. Dove, G.S. Pawley, G. Dolling and B.M. Powell, Mol. Phys. 57 (1986) 865) showed that at smaller propagation vectors than those studied experimentally, well-defined, long wavelength phonons should exist. Inelastic neutron scattering measurements have been made to observe these phonons.

The measurements were made on a single crystal of SF_6 at 200 K oriented with the $[1\bar{1}0]$ direction perpendicular to the scattering plane. The experiments were carried out on the C5 spectrometer with Si(111) and graphite (0002) as monochromator and analyzer respectively and with 15 cm of cooled Be placed in front of the analyzer. With an analyzing frequency of 1.2 THz the spectrometer resolution, defined as the FWHM of the incoherent scattering from vanadium, was 0.043 THz. Measurements were made along the [001] and [110] directions in the (002) and (110) Brillouin zones respectively.

Well-defined lineshapes were observed in longitudinal configurations for both propagation directions. As the propagation vector, ζ, increases, the intensity of the peak rapidly decreases and the lineshape develops a doublet structure. The latter effect is more pronounced along the [110] direction. For both directions the intensity of the peak decreases to zero for $\zeta \simeq 0.2$. The detailed lineshapes are being analyzed to give information about the various orientational and translational correlation functions and the translational-orientational coupling.

7.18 Phonons in Sym-$C_6F_3Cl_3$

B.M. Powell with M.T. Dove (University of Cambridge) and G.S. Pawley (University of Edinburgh)

Measurements of phonon dispersion curves in sym-$C_6F_3Cl_3$ at 4.2 K have been continued with the crystal reoriented to have the c-axis and [110] directions in the scattering plane. With the aid of inelastic structure factors calculated from an assumed rigid-molecule model, the six branches of the dispersion relation along [110] which were unobservable in the previous orientation (PR-P-140: 3.12; AECL-8648) have now been determined. As in the earlier data, the agreement between the observed and calculated frequencies is only fair. The compete set of dispersion curves along the major symmetry directions has now been measured and refinement of the parameters specifying the interatomic potentials is in progress.

7.19 Temperature Dependence of S(Q,ω) for Liquid ^{4}He at High Pressure

E.C. Svensson with W.G. Stirling (Institut Laue-Langevin, Grenoble)

In an extensive study at saturated vapour pressure (svp) Woods and Svensson (Phys. Rev. Lett. 41 (1978) 974) found that one-phonon excitations were unique to the superfluid phase of liquid ^{4}He and that, for all temperatures below T_λ and for a wide range of wave vectors Q, the total observed dynamic structure factor $S(Q,\omega)$ could be very well described as the sum of a superfluid part $S_s(Q,\omega)$ and a normal-fluid part $S_n(Q,\omega)$ with respective temperature-dependent weights n_s and $n_n = 1 - n_s$ where $n_s = \rho_s/\rho$, ρ_s being the macroscopic superfluid density. A very interesting question is whether or not this empirical description still works at high pressures where the relative weights of the one-phonon modes are very different than at svp. For example, the intensity of the maxon mode ($Q = 1.13$ Å^{-1}) decreases by more than a factor of 2 between svp and 24 bars while the intensity of the roton mode ($Q \approx 2$ Å^{-1}) increases somewhat (Svensson et al., Can. J. Phys. 54 (1976) 2178). In an attempt to answer this question, detailed measurements of $S(Q,\omega)$ for liquid ^{4}He at a pressure of 20 bars have been carried out at the IN12 spectrometer at the Institut Laue Langevin, Grenoble. This spectrometer is situated on a neutron wave guide on the Grenoble cold source and hence has a much cleaner beam (few higher-order neutrons) than the spectrometers at NRU, a great advantage for this study. The spectrometer was operated with a fixed scattered-neutron wavelength of 4.19 Å and a beryllium filter in the scattered beam. The resolution at the elastic position, as determined from the scattering by vanadium, was 0.034 THz. Measurements were carried out at Q = 1.13 $Å^{-1}$ and 2.03 $Å^{-1}$ (the maxon and roton positions at 20 bars) for 6 and 8 temperatures respectively below T_λ (1.928 K) and for 3 temperatures above T_λ. The scattering from the empty cell was also determined. In spite of the difficulties caused by the maxon mode being much weaker at 20 bars than at svp and the roton mode being substantially lower in frequency so that, as the temperature was raised, it tended to renormalize and merge with the strong elastic peak from the pressure cell, it is clear from the results that, as was observed at svp, the one phonon peaks disappear at or very close to T_λ. Detailed analysis of the results to determine the quantitative variation with temperature of the different components of the scattering is now being carried out in collaboration with Drs. H.R. Glyde and E. Talbot of the University of Delaware.

7.20 Spin-Peierls Transition in the XY Chain Compound $PrC\ell_3$

W.J.L. Buyers, B. Schmid (Swiss Federal Institute of Technology)
R.L. Donaberger (McMaster University), T.P. Matthews and D.R. Taylor (Queen's University) and R.L. Armstrong (University of Toronto)

Nuclear quadrupole resonance (NQR) measurements in $PrC\ell_3$ have shown that there is a lowering of the symmetry at the chlorine site below 0.4 K but no magnetic long range order. The ground state of the Pr^{3+} ion is a doublet described by a pseudo-spin, S = 1/2. It is associated with a high electric dipole moment interacting along the Pr chain by means of an XY coupling. A search was carried out to test the group theoretical prediction based on a two-line NQR spectrum that the Pr chains dimerize below 0.4 K with an A-point ordering wave vector (0 0 1/2). Neutron diffraction experiments with E_0 = 3.65 THz, 11.0 THz and 20 THz showed no evidence for the occurrence of A-point Bragg satellites below 0.4 K; any satellite intensity at (0 0 5/2) is less than 1 cpm compared with the full-structure-factor (0 0 2) Bragg peak whose intensity is 840,000 cpm. This excludes any dimerization of the hexagonal c plane spacing larger, in order of magnitude, than 10^{-3} in $\Delta c/c$.

A decrease was, however, observed in the intensity of the main Bragg peaks. On cooling below 0.4 K, following a lag of several hours caused by the poor thermal contact and low conductivity of this insulating crystal in the milli Kelvin range of temperatures, several Bragg intensities decreased. Most notably the (222) peak decreased 13 ± 3% between temperatures of 1.00 K and 0.015 K on the specimen can. The large uncertainty arises from the unknown effect of thermal lag between the temperature of the copper can containing the specimen and the internal temperature of the large 1 cm crystal. The statistical uncertainty in the percentage decrease is only 0.4%. Other peak height decreases are (112) 5.2%, (221) 5.6%, (220) 3.9% and (002) 0.0%. The results suggest that a Γ-point distortion may occur in $PrC\ell_3$, i.e. an internal distortion of the unit-cell. Calculations show that the dimerization suspected previously would produce a decrease in the allowed Bragg peaks, but it would be much smaller than that observed.

7.21 The Heavy-Fermion Superconductor URu_2Si_2

T.P. Matthews (Queen's University) with W.J.L. Buyers

The antiferromagnetic satellites of type (100) observed in experiments at Riso were found to have a finite angular width. They extend along the c* direction indicating that the antiferromagnetic ordering of (001) planes is not complete even at 1.5 K, well below the 17 K of the phase transition. The peaks previously observed (PR-PHS-P-1: 7.9; AECL-9262) have been confirmed to be of magnetic origin by observing that their intensity follows a uranium magnetic form factor.

7.22 Vacancy Properties in TiO_x and VO_x

S.M. Kim

The refractory monocarbides, mononitrides and monoxides have wide applications in industry because of their high strength and chemical inertness. These compounds crystallize in rock-salt structures and are known to contain large concentration (up to ≈ 25%) of the vacancies. A theory of vacancy formation has been formulated in TiO_x and VO_x. Several groups have measured the lattice parameter and density of these compounds and reported that the metal vacancy concentration increases and the oxygen vacancy concentration decreases as x is increased from 0.8 to 1.3 (e.g. Phys. Rev. B5 (1972) 2775). At stoichiometry they found that the metal- and oxygen-vacancy concentrations are equal. This defect structure has been widely accepted and has formed a basis for theoretical calculations and for the interpretation of other experiments (Phys. Rev. B5 (1972) 2764; Phys. Rev. B22 (1980) 991; Phys. Rev. B29 (1984) 6890).

However, a detailed examination of these experiments shows that the above defect structure is invalid because it was obtained by incorrect analysis. The metal- and oxygen-vacancy concentrations can be shown to be equal at all compositions. The quantity of interest is not the metal- or oxygen-vacancy concentration but, for each sublattice, the concentration of vacancies and atoms of the other type on that sublattice. In other words anti-structure atoms are important. Indeed comparison of theoretical calculations with experiments shows that appreciable vacancy and anti-structure atom concentrations should exist on both sublattices. We also find that some fraction (of order a few percent) of metal atoms most likely goes to the interstitial sites in metal-rich compositions. Neutron scattering measurements are planned on these compounds to clarify the defect structure experimentally.

7.23 NSERC Dilution Refrigerator

R. Donaberger (McMaster University) and H.F. Nieman, D.C. Tennant and W.J.L. Buyers with R. Pavier (Oxford Instruments)

First neutron experiments were carried out in the Oxford Instruments Model 200 Dilution Refrigerator and Superconducting Magnet on specimens of $PrBr_3$ and $PrCl_3$ (PR-PHS-H-2: 7.20; AECL-9351). The liquid helium hold time of the dilution refrigerator cryostat was ≈ 115 hours with a mixing chamber temperature 4.2 K, and 100 hours at base-temperature operating conditions. An improvement in hold time was achieved by eliminating liquid oscillations in the helium pot by drilling additional holes in the guide tubes that had been installed for the withdrawable magnet leads. The continuous fill 1.2 K pot required filling every 2 1/2 - 3 days, depending on ^{3}He circulation rate.

Temperature measurements were obtained using a calibrated carbon resistor and a Linear Research (LR-400) resistance bridge which was interfaced to the neutron spectrometer control computer. This enabled temperature measurements to be made under computer control down to 5 mK. During the three week operating period an average base temperature of 16 mK was obtained. Temperatures from 0.250 K to 1 K were successfully maintained using the Oxford Instruments temperature controller and the LR-400 resistance bridge.

The recently installed retractable magnet leads were tested successfully by energizing the superconducting magnet to 2 Tesla.

The fail-safe interlocks operated satisfactorily when the flow of cooling water to the vapour booster pump and diffusion pump was accidentally restricted. Normal operating conditions were quickly restored. The temperature, which was being controlled at 1 K, did not deviate during this time. Also a superfluid ^{4}He leak, suspected to have emanated from the sample can, resulted in an increased ^{3}He circulating rate, eventually boiling off the helium in the 1.2 K pot and resulting in an automatic shut-down. The helium was pumped out, the pot refilled and base temperature for normal operating conditions restored.

The dilution refrigerator performed reliably and can maintain the base temperature for at least a week.

7.24 Preparation of Silicon Monochromators

H.F. Nieman

Several single crystal slabs were hot-pressed (PR-P-137: 3.21; AECL-8106) using facilities at the Department of Energy, Mines and Resources, Ottawa. Five silicon slabs 11.4 cm O.D. by ≈ 2 cm thick, cut with the (111) crystal planes parallel to the faces, were hot-pressed at 1175°C to 1225°C at a pressure of 30 MPa. Four of these slabs have been assembled as monochromators and preliminary measurements indicate very high reflectivities in the order of 45% for the (111) and 20% for the (331) reflections.

In addition three silicon slabs with the (331) crystal planes parallel to the faces were hot-pressed at pressures of 5.5 to 17 MPa. The mosaic width (FWHM) of the (331) reflections varied between 0.06° and 1.4°.

Hot-pressing of new silicon slabs along the (111) and (331) planes is planned for the future.

7.25 Temperature Control for Neutron Scattering and Positron Annihilation Experiments

D.C. Tennant

The development of a digital temperature control system to extend the accuracy and temperature range of our temperature control systems is near completion. The new system utilizes an IBM-PC compatible computer which has appropriate plug-in boards to interface with a 5 1/2 digit voltmeter, a sensor current source, a sensor scanner and a heater power supply. The digital system has 5 1/2 digit accuracy as compared with the 4 1/2 digit accuracy of the existing analog systems. Also, the new system operates with any voltage type sensor (thermocouple, resistor, diode, etc.) whereas the analog system operates only with a diode sensor. The IBM-PC is programmed to operate in a stand-alone mode in which input commands are received from the keyboard or in a slave mode where input commands are received from the spectrometer computer through an RS232 link. Software has been written for the stand alone mode but further software is required to operate in the slave mode.

7.26 Neutron Furnace

D.C. Tennant

The operating temperature of the furnace for neutron scattering studies has been increased from 1300 K to 1520 K to meet the requirements of proposed experiments. The tantalum heater element has been replaced by a graphite unit. Tests conducted on the new element included controlling at various temperatures up to 1500 K for one week and then maintaining the temperature at 1520 K for a week. The new heater seems capable of even higher temperatures, however the use of chromel-alumel thermocouples prevented such testing. A power of 750 watts was required to maintain the 7.5 cm diameter by 7.5 cm long hot zone at 1520 K.

7.27 Multidetector Arrays

R.J.E. Deal, M.M. Potter and B.M. Powell

Both the 30 and the 13 element multidetector arrays are composed of 0.5 cm diameter cylindrical ^{3}He detectors. The high voltage feed to each detector passes through a ceramic insulator. Detailed tests confirmed that a noise problem associated with the detectors was due to leakage across the insulator (PR-PHS-P-1: 7.20: AECL-9282). A procedure of cleaning the insulator, adding extra insulation and hermetically sealing the detector ends has reduced this noise problem. A second noise problem arises from cross talk between the detectors when mounted in the array. The cross talk is caused by the close proximity of the detectors in the array and electrical coupling through common power lines. This noise has been substantially reduced by changes in circuit layout, but further reduction is required.

7.28 Neutron Spectrometer Data Analysis

M.M. Potter and B.M. Powell with G.H. Keech (Mathematics and Computation Branch)

The plot programs have been modified to use virtual arrays (PR-PHS-P-1: 7.18; AECL-9282), a system feature that uses extended memory to store large data arrays. This has made it possible to expand the plot programs to manipulate up to six scans each containing 1200 data points.

Subroutines have been added to fit a single observed peak to a Gaussian lineshape and to plot and print the resulting curve. The "HELP" facility has been enlarged considerably and other features have been enhanced to allow new user options and more user control over the plotter data.

7.29 Reactor Beam-Hole Use

H.F. Nieman

Total NRU reactor operating time was 149 days. The C-2 fast-neutron chopper, the N-4 thermal neutron facility and the C-1 Compton spectrometer were shut down for the period. The Guelph University spectrometer and the McMaster University spectrometers operated for 98% and 15% of the available reactor operating time respectively. Utilization of the other occupied beam holes was as follows:

Beam Hole	No. of Experiments	No. of Participating CRNL Scientists	No. of Participating Non-CRNL Scientists	Efficiency (% of available reactor operating time used for experiments)
C4	5	3	3	80
C5	11	7	7	99
L3	8	6	5	98
N5	11	5	9	96

7.30 Neutron Detection Efficiencies of BC444 Scintillator

M.A. Lone with D. Horn (Nuclear Physics Branch)

Phase II of the multiparticle facility at TASCC (PR-P-141: 2.16; AECL-8849) envisages the installation of a Spectrometer Array for Particles Produced in Heavy Ion Reactions (SAPPHIRE). The detector arrays will form a 4π ball of radius 30 cm consisting of Bragg-curve/Phoswich detector modules for heavy ions (PR-P-142: 2.32; AECL 9103 and PR-PHS-P-1; 3.2.10; AECL-9262) and a forward angle phoswich detector array for light ions (PR-P-141: 2.17; AECL-8849).

In exclusive experiments detection of neutrons can be very important for an understanding of the heavy ion induced reaction mechanisms. For this reason we are investigating the practicality of using the thicker BC444 plastic scintillator section of the phoswich detector for neutron detection. As a first step in this investigation the neutron detection efficiencies of various thicknesses of BC444 were calculated as a function of the neutron energy (0.5 to 200 MeV) and the pulse height threshold settings.

The Monte Carlo simulations of the efficiencies were made with the Kent State University Code (Cecil et al. NIM 161 (1979) 431) modified locally for a point source with isotropic angular distributions. Comparison of the calculated efficiencies with our previously measured (Lone et al. NIM 189 (1981) 515) efficiencies of a 13.2 cm^3 stilbene detector showed excellent agreement to within 5%. The code is widely used and gives excellent results for neutron energies up to 400 MeV. Table 1 shows the calculated efficiencies for 7.5, 12.5 and 17.5 cm thick BC444 scintillators for various neutron energies and threshold values.

The 4π ball elements surrounding the target will receive mostly evaporation neutrons (few MeV energy) from the excited residual heavy fragments. For these neutrons the detection efficiency of a 15 cm thick BC444 scintillator will be about 50% if the electronic trigger level can be set at a pulse height equivalent to that from a 200 KeV electron. The 30 cm flight path would provide a reasonable time separation between the pulses due to prompt gamma-rays and evaporation neutrons.

The forward angle detector array at a distance of 1 m from the target, will receive the forwardly emitted neutrons of relatively higher energies (mostly 20-50 MeV). Results shown in Table 1 indicate a reasonable detection efficiency of about 30% for a 15 cm long scintillator. The separation between the gamma rays and the neutron pulses can be improved by a judicious choice of the threshold setting and time of flight discrimination.

The simulations have shown an encouraging possibility of utilizing an optimum thickness BC444 scintillator both as an E detector for the phoswich telescope for charged particles and as a stand alone neutron detector. We are currently investigating timing and pulse height characteristics of a 7.5 cm thick prototype detector.

Table 1. Calculated Neutron Detection Efficiencies per 100 Incident Neutrons for a BC444 Cylindrical Scintillator

Length	7.5 cm			12.5 cm			17.6 cm		
Threshold (MeV)	0.1	0.2	0.4	0.1	0.2	0.4	0.1	0.2	0.4
E_n(MeV)									
1.0	27.5	0.7	0.0	30.6	0.9	0.0	31.4	1.0	0.0
2.0	52.5	42.0	12.3	64.0	50.3	14.4	66.6	52.4	15.0
5.0	43.8	40.1	36.5	56.8	53.8	48.0	63.5	60.5	54.8
10.0	33.7	30.4	27.4	46.7	41.7	37.5	54.7	50.0	45.2
20.0	27.6	27.0	25.5	40.4	39.6	37.6	49.7	48.5	46.0
50.0	15.3	14.9	14.4	24.4	23.4	22.9	30.9	30.0	29.2
100.0	10.4	10.1	9.8	16.0	15.8	15.3	20.9	20.5	20.0
200.0	8.7	8.6	8.5	13.6	13.5	13.3	19.2	19.0	18.7

7.31 Preamplifiers for the Bragg-curve Spectrometer and Other Detector Arrays for the Multiparticle Facility at TASCC

M. Montaigne, M.A. Lone with D. Horn (Nuclear Physics Branch) and L. Potvin (Laval University)

Several types of commercially available integrated preamplifiers e.g. (the Lecroy TRA510 and TRA1000 and the Amptek A250 were tested for their potential use with the particle detector arrays planned for the multiparticle facility at TASCC (PR-P-141: 2.16; AECL-8849). The fast timing requirements of the planned experiments necessitated the fabrication of properly grounded printed circuit boards for the tests. This task was expedited by our recently implemented IBM PC based schematic drawing and layout package.

The extremeley low noise and fast timing capabilities of the Amptek A-250 preamplifier made it the best for use with the Bragg-curve spectrometer. An electronic package with current mode amplification of the signal and with provision for calibration of gain and timing spread was assembled and fine tuned for in-beam tests at the particle facility at TASCC with the prototype Bragg-curve spectrometer (PR-P-142: 2.32; AECL-9102). With a feedback resistance of 33 kΩ, the rise and decay times of the output signal were better than 20 and 60 ns respectively.

For optimum fast timing response, special care was taken to avoid integration of the signal. However, in tests with the beam, the best signal-to-noise ratio was obtained with a 100 ns integration time constant. This integration did not degrade the timing response appreciably.

7.32 The Solar Neutrino Observatory Project

E.D. Earle with G.T. Ewan, H.C. Evans, H.W. Lee, J.D. MacArthur, H.-B. Mak, W. McLatchie, B.C. Robertson and P. Skenveld (Queen's University), R.C. Allen, H.H. Chen and P.J. Doe (University of California, Irvine), D. Sinclair (Oxford University), J.D. Anglin, M. Bercovitch, W.F. Davidson, C.K. Hargrove and R.S. Storey (National Research Council, Ottawa), P. Jagam and J.J. Simpson (University of Guelph), E.D. Hallman (Laurentian University), A.B. McDonald (Princeton University) and A.L. Carter and D. Kessler (Carleton University)

A project grant application for $300,000 has been submitted to NSERC for the 1987/88 fiscal year. A report (SNO-86-6) called "Update to Feasibility Study SNO-85-3" accompanied this application and contains details of the progress made by the SNO group since 1985 July when the feasibility study was published.

The potential of the heavy water Cerenkov detector to perform fundamental neutrino physics experiments of a unique nature has been realized by the physics community (S. Weinberg, Proc. XXIII Int. Conf. on High Energy Physics, 1986 July, Berkeley, to be published). Improved measurements of the radioactive background of detector components have been made at CRNL, Guelph, NRC and NBS and these will continue. Photomultipliers and electronics are being tested and built at Queen's University. The design of the acrylic vessel, PMT supports, H_2O tank, concrete shielding and laboratory services are proceeding, primarily at CRNL. Light transmission measurements on various acrylic samples have been performed at NRC. A small water purification system has been installed at Oxford University. A small test detector containing 44 12.5 cm photomultipliers in a water tank has been installed on the NRC electron linac to detect the Cerenkov light from low energy electrons. INCO has started drilling a tunnel to the proposed laboratory location where geotechnical surveys must be performed.

The collaboration is scheduled to prepare by 1987 October a major facility grant application to the Canadian, US and British granting agencies. This schedule places significant demands on INCO to complete the underground tunnel. In addition, the feasibility of the detector to measure the neutrino neutral current interaction can not be verified by 1987 October. In fact this feasiblity may never be verified until the SNO detector is built and operating in a charge current detection mode.

7.33 Reduction of Acrylic Components by Evaporation

E.D. Earle and R.J.E. Deal

In order to measure the minute amounts of Th and U in acrylic it is necessary to concentrate the acrylic impurities. Since acrylic can not be safely reduced large quantities of its components were reduced by evaporation so that trace amounts of Th and U could be detected by alpha counting the residue (PR-PHS-HS-2: 3.5.2; AECL-9352). A 50 cm long tube-oven placed vertically in a fumehood and containing a quartz tube was used to reduce the crosslinker and the monomer, which comprise 1.15% and 45.8% respectively of acrylic. To reduce the polymer (53% of acrylic) the oven had to be placed horizontally and the quartz tube replaced by a long boat with an extended surface for evaporation. This boat could also be used for crosslinker and monomer reduction. To reduce 10 kg of polymer and monomer, repeated 300 g loadings of the boat were required.

The reduction procedure requires careful attention to the temperature cycle if fires and explosions are to be avoided. The crosslinker was initially heated to 250°C for 4 hours and then ashed at 600°C for 4 hours. The monomer was initially heated at 150°C for 4 hours, then at 200°C for 3 hours and, after several loadings at 600°C for ashing. The polymer was heated rapidly to 400°C and after several loadings ashed at 600°C.

7.34 Shielding Calculations for the SNO Detector

E.D. Earle with P.Y. Wong (Mathematics and Computation Branch)

Calculations have been performed using the SANDYL Monte Carlo code for γ-ray attenuation and the discrete ordinates code, ANISN, for neutron transport, to predict the γ-ray background in the D_2O vessel of the SNO detector. Neutrons from (α,n) reactions in the detector materials are captured and produce γ-rays which are tracked until they reach the D_2O. The α-particle flux is determined by the Th and U content of the materials.

In addition to the Th and U content of all construction materials, the elemental composition of all materials and the γ-ray spectrum in absolute intensity per MeV for neutron capture in each element must be known. In the calculations, the SNO detector was simulated to be a right cylinder 24 meters in diameter and 24 meters high and containing from the center, 5.25 m D_2O, 3.75 m H_2O, 1 m concrete and 2 m of rock. A 5 cm thick acrylic vessel contained the D_2O, a 1.25 cm stainless steel tank contained the H_2O and a 0.3 cm thick stainless steel cylinder supported 2400 Hamamatsu phototubes at a radius of 7.75 m.

For the charge current measurements a detection threshold of 5 MeV is assumed for background gamma rays. The use of 0.5 to 1 m of low background concrete easily reduces the background from the rock to below 0.2 γ-rays per day but the contributions from the capture of neutrons in the concrete and the stainless steel tank can approach 1 per day. Boron loading (0.5%) of the concrete reduces this significantly to a total of less than 0.3 per day with either 0.5 or 1 m of concrete.

For the neutral current measurements γ-rays over 2.2 MeV, the deuteron photodisintegration threshold, must be considered. The Th and U in the photomultiplier glass is the dominant source of this background yielding about 250 γ-rays into the D_2O or 0.5 background neutrons per day (the ratio of the deuteron photodisintegration cross section to the Compton scattering cross section is 0.01 and the deuteron to electron ratio in D_2O is 0.2) if the PMT's are 2.5 m from the acrylic vessel.

The shielding calculations must continue with cost optimization of paramount importance.

7.35 Measurements of Parity Violation in the Photodisintegration of the Deuteron and in the Production of Bremsstrahlung on Tantalum

E.D. Earle, R.J.E. Deal and S.H. Kidner with E.T.H. Clifford (Triumf)
G.H. Keech (Mathematics and Computation Branch), A.B. McDonald,
M.S. Schneider and T.C. Chupp (Princeton University)

Analysis of the parity violation data collected on the ETA (PR-P-142: 3.20; AECL-9102) is complete. The circular polarization dependent component of the total cross section for photodisintegration of the deuteron has been measured to be $(2.7 \pm 2.8) \times 10^{-6}$ for bremsstrahlung with an end point energy of 4.1 MeV and $(7.7 \pm 5.3) \times 10^{-6}$ for an end point energy of 3.2 MeV. The helicity dependent component of the total cross section for the production of bremsstrahlung on tantalum by longitudinally polarized electrons has been measured to be $(0.63 \pm 0.70) \times 10^{-6}$ for 4.1 MeV electrons and $(3.1 \pm 1.5) \times 10^{-6}$ for 3.2 MeV electrons. All results are consistent with zero at the two standard deviation level.

The results have been corrected for all known systematic effects (the major source of error) and for the values of the γ-ray circular polarization and of the electron longitudinal polarization, both measured to be 30%.

7.36 A High Resolution Measurement of the Photofission Cross Section of ^{238}U near Threshold

W.F. Mills and J.W. Knowles with T.E. Drake (University of Toronto),
J.C. Kim (Seoul National University) and P. Rullhusen (Physikalisches
Institut der Universität Göttingen)

The analysis of the data for this measurement (PR-PHS-P-1: 7.26; AECL-9262) and resultant drawings have been revised.

7.37 CTI CRYO-TORR 7 High Vacuum System

W.F. Mills and G.A. Sims

During the month of October, the CTI CRYO-TORR 7 high vacuum pumping station ceased to function. A series of tests indicated trouble with the compressor unit, although the specific problem was not revealed. After telephone consultation with engineers from TASMAN and CTI, followed by further tests, it was determined that the failure was due to a locked rotor in the compressor unit, a sealed system. The advice from CTI was to take advantage of their flow exchange program, whereby after receipt of order, they would ship to us a new model 21SC compressor unit and we would return the defective one. Upon receipt of the new unit and power hook-up modifications between the compressor unit and the cold head, the cryo-pumping station was checked and returned to operation.

7.38 Nuclear Material Inventory - Physics MBA CN-E-3

W.F. Mills

1985 MBA Inventory

Nat. U	Enr. U	^{235}U	Depl. U	Pu	Th
20.0 kg	153.6 g	142.9	0.5 kg	5.5 g	5.7 kg

Transferred material to NMC, reducing accountability to:

1986 MBA Inventory

Nat. U	Enr. U	^{235}U	Depl. U	Pu	Th
3.2 kg	103.6 g	96.3 g	0.3kg	5.5 g	0.6 kg

7.39 Bragg Curve Detector

G.A. Sims with L. Potvin (Laval University) and D. Horn and M.G. Steer (Nuclear Physics Branch)

The front window support-grid problem (PHS-P-1: 7.32; AECL-9262) has been solved by replacing the wire grid with 0.38 mm × 2.5 mm stainless strips mounted on edge. The assembly was pressure cycled several times in order to test the support grid design. No failures were encountered.

Bench tests were conducted on the Bragg curve detector module after it was completely assembled. All components appeared to be working satisfactorily. The module was then installed into the 1.75 m scattering chamber for further tests and development of experimental techniques.

Initial results indicated that further development of the electronics associated with the assembly will be needed.

7.40 Personal Computer Acquisition

R.H. Martin, J.P. Bolduc and G.A. Tapp

An IBM PC-XT compatible microcomputer was acquired with 640 K memory, 2 flexible disk drives, a 20 Mb fixed-disk drive, a high resolution monochrome graphics adapter, a monochrome monitor, a dot-matrix printer and the MS-DOS operating system.

This unit has been used for data analysis, to draw electronic circuits and as a database facility for radioactive sources and electronic equipment. The PC can serve as backup for our PDP 11/23 terminal by a simple cable change using serial I/O ports on each computer.

7.41 New 4π Proportional Counter

J.G.V. Taylor, H.C. Spenceley, J. Bolduc and R.H. Martin

A recent proportional counter design for the automatic sample changer was modified to allow for replaceable gamma/x-ray windows. Since our proportional counters operate near atmospheric pressure, it was possible to construct the new stainless steel counter with ≈ 1 $mg.cm^{-2}$ aluminized Mylar windows. Support brackets were included for the thin NaI crystals used in the type of counting this detector was designed for. This version allows for automatic sample changing while still detecting low energy x-rays in coincidence.

An 8-channel programmable digital-to-analog converter has been added to control the high voltage supply to the proportional counter by means of software. This provides a means of varying the HT with a precision of ≈ 1 volt during an automatic counting run, a great advantage in setting up equipment where voltage plateaus must be measured and where efficiency extrapolations are needed.

7.42 ^{109}Cd Comparison; Preliminary Results

R.H. Martin

As a test of a newly acquired digital-to-analog converter and of a new proportional counter, a standardization measurement was repeated on a ^{109}Cd solution received earlier this year for the BIPM comparison. The results confirmed that this method (PR-PHS-P-1: 7.37; AECL-9262) was more precise than the method previously used (PR-P-141: 3.46; AECL-8849). In the following list, the last two items refer to preliminary results from the BIPM comparison involving 17 laboratories and 27 reported results as detailed in Rapport BIPM 86/13.

Method	Date of Work	Result ($MBq\cdot g^{-1}$)
$^{109}Pd/^{109}Cd$	86 May	(6.026 ± 0.042)
^{109}Cd e-X-ray (Man)	86 May	(5.995 ± 0.041)
^{109}Cd e-X-ray (Auto)	86 Oct	(5.990 ± 0.007)
BIPM Comp Unwtd	86 Dec	(6.033 ± 0.024)
BIPM Comp Wtd	86 Dec	(5.992 ± 0.008)

7.43 Standardization of ^{88}Y

R.H. Martin and J.G.V. Taylor

Since a request was made for ^{88}Y standards and since ^{88}Y provides good calibration points for both our GeLi detector and ionization chamber, it was decided to do a full-scale standardization, to distribute ^{88}Y standards to interested users and to register solutions with the International Bureau of Weights and Measures (BIPM). A stock of ^{88}Y solution was obtained from Amersham Corporation. Gamma-ray spectrometry showed no impurities at a 0.1% detection limit. The concentration of the stock solution was measured using the 4π proportional counter-gamma coincidence method and was 2101.9 ± 6.3 $Bq.mg^{-1}$ at 1200 hrs on 1986 September 1. The statistical uncertainty in the measurements was 0.07%.

Two ampoules of the standardized solution were prepared and shipped to the BIPM in France for registration. Standards from the same solution were used to improve our Ge(Li) calibration curve.

7.44 Standardization of ^{55}Fe

R.H. Martin and J.G.V. Taylor

Some work was done to test a method for standardizing ^{55}Fe using a technique similar to that described previously for ^{109}Cd (PR-PHS-P-1: 7.37; AECL-9262). Our thin-window 4π proportional counter filled with methane gas and two 1 mm NaI crystals were used to detect Auger electrons in coincidence with x-rays. Sources were used from a 1979 intercomparison solution having an activity concentration of 4075 ± 29 $Bq\cdot mg^{-1}$. The measurements indicated 4270 ± 125 $Bq\cdot mg^{-1}$. This preliminary work shows that more investigation is required when time permits and new stock solution is available.

7.45 Standards Issued

R.H. Martin

(a) **Solid Sources**

Solid Sources		Branch	
^{54}Mn	-	System Chemistry & Materials	(1)
^{57}Co	-	" " "	(1)
^{60}Co	-	" " "	(1)
^{88}Y	-	" " "	(1)
	-	Nuclear Physics	(2)
^{94}Nb	-	" " "	(1)
^{109}Cd	-	System Chemistry & Materials	(1)
^{133}Ba	-	" " "	(1)
^{137}Cs	-	Radiation and Industrial Safety	(6)
	-	Nuclear Physics	(1)
	-	System Chemistry & Materials	(1)
	-	Instrumentation & Control	(1)
^{152}Eu	-	Dosimetric Research	(1)
^{239}Pu	-	" "	(3)
^{241}Am	-	" "	(1)

(b) **Sources in Solution**

Sources in Solution		Branch	
^{3}H	-	Dosimetric Research	(1)
^{54}Mn	-	System Chemistry & Materials	(2)
^{60}Co	-	" " "	(3)
	-	Environmental Research	(1)
^{88}Y	-	System Chemistry & Materials	(2)
^{90}Sr	-	Environmental Research	(1)
	-	Dosimetric Research	(1)
^{109}Cd	-	Queen's University	(1)
^{133}Ba	-	System Chemistry & Materials	(2)
	-	Environmental Research	(1)
^{137}Cs	-	System Chemistry & Materials	(2)
	-	Environmental Research	(1)
^{152}Eu	-	System Chemistry & Materials	(2)
^{207}Bi	-	Queen's University	(1)
^{239}Pu	-	Dosimetric Research	(1)
^{241}Am	-	" "	(1)
	-	Environmental Research	(1)

7.46 Glassblowing Laboratory

D.A. Doering and J.G. Wesanko

Major jobs performed during the period are grouped by branches or organizations as follows.

Chemical Operations (^{99}Mo production)

Eighteen product-recovery headers and twenty-four ^{99}Mo headers were fabricated. Forty-six alumina columns were built.

Mechanical Equipment Development

An array of glassware was built and later modified for the Slowpoke Safety Valve Experiment.

Neutron and Solid State Physics

Various pieces of quartz glassware were made for acrylic component reduction in a tube oven for the Sudbury Neutrino Observatory project.

System Chemistry and Materials

Several quartz Pulse Radiolysis Optical Cells were modified and the necessary glassware to allow for reaction rate studies in the Candu reactor coolant experiment were added to existing equipment.

Physical Chemistry

An assortment of complex glassware was made for the CO sensor program and to measure CO oxidation rates in catalysts. Seven infrared cells were fabricated for the study of catalyst materials.

Chemical Engineering

An apparatus was constructed to collect hexane in the hexane adsorption experiment.

Environmental Research

Numerous pieces of glassware were crafted for experiments on tritium and air analysis.

N.A.S.A.

Assorted glassware projects were undertaken to enable various research groups and branches to undertake further studies of rubber O-rings for the Space Shuttle Program.

Unit-2000

As a result of an idea from Unit 2000, various styles of glass accelerator bodies were built and assembled so that studies could be continued on the development of an accelerator for accelerating liquids.

7.47 Mechanical Laboratories

A.H. Hewitt and H.C. Spenceley

Building 459

To facilitate the quick and accurate alignment of various components and accessories of the neutron spectrometers, an alignment fixture incorporating a laser was made and adjusted.

A test chamber was made to accommodate 13 BF_3 counters to be used for residual strain measurements.

An improved alignment fixture incorporating a miniature twin arc goniometer was developed for the alignment of specimens to be studied in the dilution refrigerator.

Incident beam and collimator magnet guides were made for the N5 spectrometer, to enable polarized-neutron tests to be carried out. The incident beam guide was 5 cm × 5 cm × 107 cm long and shorter guides were prepared for the specimen and analyzer sections.

During the review period 13 specimens were mounted for neutron diffraction studies including two for the horizontal field magnet cryostat and one for the dilution refrigerator. In addition, ten specimens were mounted for residual strain measurements.

Building 116

During the last six month period, the Building 116 Mechanical Laboratory work load was divided as follows: counter fabrication and modifications 40%, Bragg curve spectrometer and forward array assembly 27%, custom components for the glass-blowing shop 11%, crystal-cutting 7% and numerous miscellaneous jobs for several branch projects 15%.

7.48 The SAPPHIRE Proposal

M.A. Lone et al.

See PR-PHS-P-2: 3.2.10; AECL 9351

7.49 Measurement of Ultra-Trace Levels of ^{228}Th

E.D. Earle et al.

See PR-PHS-HS-2: 3.5.2; AECL-9352

7.50 Publications and Lectures

Publications

A Temperature-Dependent Angular Correlation Study of Positron Annihilation in Single Crystal Zinc
J.A. Jackman, S.M. Kim, W.J.L. Buyers and M.J. Stott
J. Phys. F: Met. Phys. 16 (1986) 1319

Proposal to Build a Neutrino Observatory in Sudbury
D. Sinclair, A.L. Carter, D. Kessler, E.D. Earle, P. Jagam, J.J. Simpson, R.C. Allen, H.H. Chen, P.J. Doe, E.D. Hallman, W.F. Davidson, R.S. Storey, A.B. McDonald, G.T. Ewan, H.-B. Mak and B.C. Robertson
Nuovo Cimento C9 (1986) 308

A D_2O Cerenkov Detector for Solar Neutrinos
E.D. Earle, G.T. Ewan, H.W. Lee, H.-B. Mak, B.C. Robertson, R.C. Allen, H.H. Chen, P.J. Doe, D. Sinclair, W.F. Davidson, C. Hargrove, R.S. Storey, G. Aardsma, P. Jagam, J.J. Simpson, E.D. Hallman, A.B. McDonald, A.L. Carter and D. Kessler
AIP Conference Proceedings 150, Lake Louise, Canada 1986, page 1094.

The Sudbury D_2O Neutrino Detector
E.D. Earle, G.T. Ewan, H.W. Lee, H.-B. Mak, B.C. Robertson, R.C. Allen, H.H. Chen, P.J. Doe, D. Sinclair, W.F. Davidson, C. Hargrove, R.S. Storey, G. Aardsma, P. Jagam, J.J. Simpson, E.D. Hallman, A.B. McDonald, A.L. Carter and D. Kessler
Proceedings of the International Symposium, Heidelberg, 1986 July 1-5, page 737.

Vacancy Formation Energies in Disordered Alloys
S.M. Kim
Positron Annihilation, edited by P.C. Jain, R.M. Singru and K.P. Gopinathan (World Scientific, 1985). p. 899.

Structure of Oxygen Clathrate Hydrate by Neutron Powder Diffraction
J.S. Tse, Y.P. Handa, C.I. Ratcliffe and B.M. Powell
J. Inclusion Phenomena 4 (1986) 235

Structure of High-Density Amorphous Ice by Neutron Diffraction
M.A. Floriano, E. Whalley, E.C. Svensson and V.F. Sears
Phys. Rev. Lett. 57 (1986) 3062

Analysis of Neutron Small Angle Scattering Data for Molecules of Arbitrary Shape
F.U. Ahmed and P. Martel
AECL-9185

Lectures

The Sudbury D_2O Neutrino Detector
E.D. Earle
Weak and Electromagnetic Interactions in Nuclei, Max-Planck Institute, Heidelberg, W. Germany, 1986 July 1-5

The Magnetism of the Uranium Chalcogenides: The Localized Model Starting Point
T.M. Holden, J.A. Jackman, W.J.L. Buyers, K. Hughes, M.F. Collins, P. de V. DuPlessis and O. Vogt
International Conference on Anomalous Rare Earths and Actinides, Grenoble, France, 1986 July 7-11

Heavy Fermion Ground States and Superconductivity
W.J.L. Buyers
Plenary Lecture, Annual Congress South African Institute of Physics Johannesburg, South Africa, 1986 July 9

The Neutron as a Microscopic Probe of Magnetic Systems
W.J.L. Buyers
Lecture given at the National Institute for Materials Research, CSIR, Pretoria, South Africa, 1986 July 15

Magnetism in Metals
W.J.L. Buyers
Lecture given at the University of the Witwatersrand, Johannesburg, South Africa, 1986 July 16

Neutron Spectroscopy of Magnetic and Superconducting Systems
W.J.L. Buyers
Lecture given at Atomic Energy Corporation at Pelindaba, South Africa, 1986 July 17

The Haldane Gap in Spin Systems
W.J.L. Buyers
Lecture given at the University of Capetown, Capetown, South Africa, 1986 July 17

Solitons and Goldstone Modes in One-Dimensional Magnetic
W.J.L. Buyers
Lecture given at the University of Stellenbosch, Stellenbosch, South Africa, 1986 July 21

Neutron Spectroscopy of Magnetic and Superconducting Systems
W.J.L. Buyers
Lecture given at the University of Port Elizabeth, Port Elizabeth, South Africa, 1986 July 23

The Bohr Model of the Atom
W.J.L. Buyers
Lecture given at the University of the Transkei, Umtata, South Africa, 1986 July 24

Magnetism in Metals
W.J.L. Buyers
Lecture given at the University of Natal, Durban, South Africa, 1986 July 25

Axial Strain at a Girth-Weld in a 914 mm Gas Pipeline
T.M. Holden, B.M. Powell, S.R. MacEwen and R.B. Lazor
2nd International Symposium on the Non-Destructive Characterization of Materials
Montreal PQ, 1986 July 21-23

High-Density Amorphous Ice
E. Whalley, D.D. Klug, M.A. Floriano, E.C. Svensson and
V.F. Sears
Gordon Conference on The Chemistry and Physics of Water and Aqueous
Solutions, New London, New Hampshire, 4-8 August 1986

Structure and Dynamics of D-Ethanol in the Liquid and Glass Phases
P.N. Gerlach and B.M. Powell
Gordon Research Conference, Tilton, N.H., 1986 August 18-22

Solution of the Low Temperature Structure of SF_6
B.M. Powell, M.T. Dove and G.S. Pawley
Gordon Research Conference, Tilton, N.H., 1986 August 18-22

Recent Work on High-Density Amorphous Ice
E. Whalley, D.D. Klug, M.A. Floriano, E.C. Svensson and V.F. Sears
Symposium on the Physics and Chemistry of Ice, Grenoble, France,
1-5 September 1986

Vacancies in FeAℓ and NiAℓ: Theory and Experiments
S.M. Kim
International Conference on Vacancies and Institials in Metals and Alloys
Hahn-Meitner-Institut, Berlin, West Germany
1986 September 14-19

Vacancies in Cu_2Au and CuAu by Positron Annihilation
S.M. Kim
International Conference on Vacancies and Institials in Metals and Alloys
Hahn-Meitner-Institut, Berlin, West Germany
1986 September 14-19

Sudbury Neutrino Observatory
E.D. Earle
Argonne National Laboratory, Argonne, Illinois, U.S.A., 1986 September 22-24

High Density Amorphous Ice
E. Whalley, D.D. Klug, M.A. Floriano, E.C. Svensson and
V.F. Sears
Meeting of the International Association for the Properties of Steam,
Dusseldorf, West Germany, 25 September 1986

Spin Waves in the Triangular Antiferromagnetic $CsMnBr_3$
B. Gaulin, M.F. Collins and W.J.L. Buyers
Magnetism and Magnetic Materials, Baltimore, Maryland, U.S.A.,
1986 November 17-21

8. THEORETICAL PHYSICS BRANCH

G.E. Lee-Whiting

THEORETICAL PHYSICS BRANCH

by

G.E. Lee-Whiting

8.1 Staff

Professional Staff

G.E. Lee-Whiting
M. Couture[1]
H.R. Fiebig
M. Harvey[2]
H.X. He
H.C. Lee
V.F. Sears
I.S. Towner
K.B. Winterbon[3]
Z.Y. Zhu

Students

M. Newton	National	Dalhousie, 86.6.12 - 86.8.28

Secretarial Staff

M.E. Carey

[1] Visiting Scientist from Florida International University, 86.7.28 - 86.8.15
[2] Visiting Scientist from Inst. of Atomic Energy, Beijing, 85.12.20 - 86.12.19
[3] Visiting Scientist from Academia Sinica, Beijing, 86.11.18

8.2 Neutron Optics

V.F. Sears

Four chapters of a book on the theory and application of coherent elastic neutron scattering (i.e. neutron optics) have now been written. These chapters are entitled: general theory of thermal neutron scattering, geometrical optics, rigorous theory of dispersion, and kinematical theory of neutron diffraction. The remaining four chapters on the dynamical theory of neutron diffraction, neutron interferometry, transport effects in neutron diffraction, and the introductory chapter are scheduled for completion by December 1987.

8.3 Neutron Diffraction Studies of Amorphous and Crystalline D_2O Ice

E.C. Svensson and E.D. Hallman with V.F. Sears (Theor. Physics Branch) and M.A. Floriano, E. Whalley and D.D. Klug (National Research Council)

See PR-PHS-P-2:7.8 (AECL-9351).

8.4 Penetration of Heavy Ions in Solids

K.B. Winterbon

Collaboration with W. Lennard at the Univ. of Western Ontario on pulse heights in semiconductor detectors is continuing; earlier work was published in Nucl. Instr. & Meth. in Physics Research A 248(1986)454. Also some moments of ion implantation distributions of astrophysical interest have been calculated in a collaborative project proposed by Prof. R.E. Johnson of the Univ. of Virginia. Some minor program development has been done to make the programs easier to use and to modify.

8.5 Fractals

K.B. Winterbon

Neutron scattering from fumed silica, a material having fractal properties, has shown some anomalies (P.N. Gerlach et al., PR-P-141:3.2 (AECL-8849). Results for bulk amorphous quartz were intermediate between those for crystalline and fractal materials. In an attempt to understand the structure and dynamics of this fractal material, a research programme is being developed to study the structure and properties of amorphous materials.

The initial project is to construct a computer model of a material that can be disordered and to study its phonon spectrum and wavefunctions as the model is altered from ordered to disordered. It is expected that the model can then be altered to represent the fractal. An interactive program is being written to construct a small piece of a diamond lattice, interchange or break bonds, and relax the atoms to a minimum-energy configuration with the new bond topology. A copy of the Cambridge Recursion Library, a set of FORTRAN (sub)programs for calculating densities of states, has been obtained and portions of it have been incorporated into this program. New subprograms already working in this program include ones to construct stereo-pair views of three-dimensional objects and to minimize a function of a potentially enormous number of variables.

It was observed some time ago (K.B. Winterbon, Rad. Eff. 60(1982)199) that collision cascades are fractal objects. A paper on various fractal aspects of collision cascades, with M.H. Urbassek (Braunschweig Univ.), P. Sigmund (Univ. of Odense), and A. Gras-Marti (Univ. of Alicante and ORNL), has been written and submitted for publication.

8.6 Chiral Soliton Model with Quantum Pions

M. Harvey (with K. Goeke (Institut für Kernphysik, Jülich, West Germany) and J. Urbano (Univ. of Coimbra, Portugal))

Properties of the nucleon and delta have been calculated using two parameter-sets of a non-topological soliton model in which the Fock-states consist of three quarks vector-coupled to coherent-pair states of the pion (pseudo-scalar, isovector) field, with up to one unpaired pion, and a coherent state of a sigma (scalar, isoscalar) field (see PR-142:4.7 (AECL-9103)). The amplitudes of the states have been determined self-consistently. Properties that have been calculated include the masses, the axial-vector coupling constant (g_A), the π-nucleon coupling constant, the magnetic moments and the mean square charged radii of the nucleons. Reasonable agreement with experiment is achieved with both parameter-sets with the exception of the neutron charge-radius, which is too small by a factor of ten in both cases. This latter result we suspect is a consequence of restricting the Fock state to one unpaired pion. Comparisons with the topological (Skyrmion) model show our model to have as good or better (in the case of g_A) agreement with experiment. Comparison with the calculations of Birse (Phys. Rev. D33(1986)1934), who used the same non-topological soliton Lagrangian but with a hedgehog Fock state, shows the latter model to be a better variational prescription, although it appears to have too many pions to be considered fully satisfactory.

A letter containing the results has been submitted for publication and a full paper containing details of the calculation is now ready for submission.

8.7 Comparison between the Coherent-Pair Approximation and the "Hedgehog" Ansatz in a Chiral Model

M. Harvey

Additional calculations have been performed using the coherent-pair ansatz in a schematic model (c.f. PH-PHS-P-1-8.9) to examine the relative importance of paired and unpaired pions in a nucleon or delta Fock state. A paper on the whole study has now been submitted for publication.

8.8 Interpretation of a Repulsive Core between Fermion Clusters

H.R. Fiebig (Florida International Univ.) and M. Harvey

The notion of relative distance between composite clusters of fermions, such as nucleons in a quark model, is ambiguous at small distances. We have examined the consequences of defining relative distance as the largest relative coordinate of all possible clusterings of the constituent particles. We have found that such a definition naturally yields a repulsive core in the effective potential between the so-defined composite systems. The analysis has relevance to the interpretation of the flip-flop model that purports to simulate the low energy aspects of QCD (F. Lenz et al., Ann. Phys. (N.Y.) 170(1986)65). A paper has been submitted for publication.

8.9 Corrections to the Axial-Vector Coupling Constant in the Skyrme Model

H.X. He and M. Harvey

The topological soliton (Skyrmion) description of baryons is given entirely in terms of bosons for which a topological "winding number" is interpreted as the baryon number. This model has the features of quantum chromodynamics when the number of colors (N_c) is large. With the Skyrmion, calculated properties of the nucleon are within about 30% of the experimental values with the exception of the axial-vector coupling constant (g_A), which differs by about a factor of two. Formalism has been derived for corrections to the Skyrme Model predictions for g_A when N_c is not large, as is actually the case for $N_c = 3$. Numerical calculations are beirg performed.

8.10 Gordon Research Conference on Nuclear Structure

M. Harvey

M. Harvey, as elected chairman, organized the 1986 Gordon Research Conference on Nuclear Structure held in Tilton, New Hampshire, July 7-11, 1986.

8.11 Calculation of the ℓ-forbidden M1 and Gamow-Teller Rates in A=39 Nuclei

I.S. Towner

The M1 matrix element between $1s_{1/2}^{-1}$ and $0d_{3/2}^{-1}$ single-hole states is identically zero with the standard impulse-approximation one-body operator. A non-zero measurement therefore signals an inadequacy either in the single-hole description of the nuclear state or in the impulse-approximation operator. We have made a calculation of both inadequacies in an attempt to explain the experimental result of Alexander et al. (PR-PHS-P-2:3.1.2 (AECL-9351)).

Making some allowance for uncertainties in parameter choices we estimate the ℓ-forbidden M1 and Gamow-Teller matrix elements in mass A = 39 to be

$$\text{Isoscalar:}\quad [B(M1;\, d_{3/2} \rightarrow s_{1/2})]^{1/2} = 0.002 \pm 0.001$$

$$\text{Isovector:}\quad [B(M1;\, d_{3/2} \rightarrow s_{1/2})]^{1/2} = -0.026 \pm 0.018$$

$$\text{Gamow-Teller:}\quad [B(GT;\, d_{3/2} \rightarrow s_{1/2})]^{1/2} = -0.032 \pm 0.018.$$

The theoretical result is in agreement with the experimental Gamow-Teller rate, $[B(GT)]^{1/2} = -0.023 \pm 0.003$ (negative sign assumed), but is a factor of 3.7 too small for the isovector M1 transition, $[B/M1)]^{1/2} = -0.096 \pm 0.011$ (sign assumed) measured by Alexander et al. This discrepancy is puzzling, because the two principal ingredients of the calculation, core polarisation and isobar excitation, are common to both the M1 and the GT calculations. For example, increasing the isobar content, while improving the B(M1) calculation, will at the same time worsen the agreement with B(GT). We have no good explanation for the discrepancy between theory and experiment. This work has been written up for publication.

8.12 Relativistic Shell Models and Meson-exchange Currents

I.S. Towner and J. Delorme (Université Claude Bernard, Lyon)

A connection has been established between fully relativistic shell models and relativistic corrections in nonrelativistic theories through a class of meson-exchange processes described by Feynman pair diagrams (see (PR-PHS-P-1:8.13 (AECL-9262). In a nuclear medium heavy-meson pair graphs, especially those involving the σ-meson, have been shown to yield strong enhancements to the matrix element of 'odd' Dirac operators such as γ and $\gamma_4\gamma_5$, in complete analogy to the strong enhancements obtained in relativistic mean field theories.

For isoscalar operators there is a cancelling contribution from ω-pair diagrams, but for isovector operators the equivalent ρ-pair diagram is very weak. Thus agreement between traditional nonrelativistic calculation and experiment is worsened by the introduction of heavy-meson pair diagrams. Some improvements in the situation can be obtained by adding vertex form factors and short-range correlation functions that reduce the heavy-meson pair contribution by about a factor of three. A paper that emphasizes the differences in relativistic and nonrelativistic shell models and discusses possible experimental tests has been submitted for publication.

8.13 Velocity-dependent Terms in a Phenomenological Lagrangian Model of Meson-exchange Currents

I.S. Towner

With the phenomenological Lagrangian of Ivanov and Truhlik (Nucl. Phys. A316, 437) which describes the interaction of the isovector mesons A_1, ρ and π with nucleons, and with the assumption of vector meson dominance, we have been constructing the two-nucleon vector and axial-vector meson-exchange current (MEC) operators. The model has a number of interesting features: the Lagrangian is chirally invariant; the deduced current satisfies the conserved vector current and partially conserved axial-vector current hypotheses; and the results from current algebra and soft-pion theorems are contained in the appropriate limits. The advantage of this scheme is that pions and heavy mesons are treated on an equal footing and a prediction for the energy dependence of the MEC operators is obtained.

In the two-nucleon system MEC operators have terms that depend on the relative momentum and terms that depend on the centre-of-mass momentum. The former, on transforming to coordinate space, lead to local operators, the latter to non-local or velocity-dependent operators. The non-local terms are usually discarded in MEC theories. We are examining these non-local terms and estimating their contribution to magnetic moments and Gamow-Teller beta decay.

8.14 Tadpoles and Analytic Regularization

M. Couture and H.C. Lee

Tadpoles, or Feynman integrals with no explicit dependence on external momenta, are encountered in massless field theories. In most circumstances they are innocuous and can justifiably be ignored. In the method of dimensional regularization tadpoles are given zero values by definition, since they are impossible to regulate consistently. In a continuation of a program reported in PR-PHS-P-1 (AECL-9262), it is shown that the nonzero nature of tadpoles becomes important when the conservation of more than one symmetry is at stake. In other words, there appears to be an intimate relation between tadpoles and anomalies, which are manifestations of symmetry breaking by quantum fluctuations. It is possible to preserve the nonzero nature of tadpoles using the method of analytic regularization. We are using this method to conduct a systematic study of the relation between anomalies and tadpoles.

8.15 Finiteness of N=4 Supersymmetric Theory

H.C. Lee and J.C. Taylor, Univ. of Cambridge

The N=4 supersymmetric theory is the only known gauge theory that is believed to be finite, meaning that all ultraviolet divergences in the theory cancel among themselves to all orders. Proofs of the finiteness that have appeared in the literature (S. Mandelstam, Nucl. Phys. B213(1983)1493; L. Brink et al., Nucl. Phys. B212(1983)401), carried out in the light-cone gauge and relying on Ward identities, are incomplete. This is because the usual forms of the Ward identities, assumed in the proofs, are not valid in the light-cone gauge. We have shown that though the Ward identities are badly mangled in the light-cone gauge, enough relations survive to permit, after careful examination, the completion of the proof. This work is reported in the preprint CRNL-TP-86-IX-VIII.

8.16 Anomalies in Supergravity

H.C. Lee and Q. Ho-Kim, Laval University

Supergravity is a theory whose action is invariant under spacetime-dependent supersymmetric transformation. Such theories contain both gauge theories and gravity and therefore are candidates for a unified theory. Alvarez-Gaumé and Witten (Nucl. Phys. B234(1983)264) pointed out that in certain theories containing matter particles and gravity quantum fluctuations prevent gauge invariance and general coordinate invariance from being simultaneously preserved, thereby inducing what are known as gravitational anomalies. It is now recognized that, generally, for theories possessing a number of symmetries, sets of these symmetries are violated by quantum fluctuations in such a way that in each set it is not possible to restore all the violated symmetries. The presence of gravitational and other anomalies renders a theory inconsistent, thereby removing it as a candidate for a unified theory. We are conducting a study of anomalies in a number of two-dimensional supergravity theories for the purpose of identifying the characteristics of anomaly-free theories. Currently we are computing the anomalies of N=1/2 supergravity, which is equivalent to N=1 supergravity with self-dual scalar and Majorana-Weyl spinor fields.

8.17 Super Field Theories - a NATO Advanced Research Workshop

H.C. Lee (Director of Workshop)

This NATO ARW was held at Simon Fraser University, Burnaby, B.C. from July 25 - August 5. Members of the organizing committee were: V. Elias (U. Western Ontario), G. Kunstatter (U. Winnipeg), HCL, R.B. Mann (U. Toronto) and K.S. Viswanathan (Simon Fraser). The workshop was attended by 85 registered participants from 15 countries plus about 15 local graduate students. About 40 papers on supersymmetry, supergravity, Kaluza-Klein theories, anomalies, nonlinear sigma-models, string and superstring theories provided a good account of the current status of unified field theories. The proceedings of the workshop are being prepared for publication. The workshop was also supported by grants from NSERC, TRIUMF, Simon Fraser Univ., AECL, the Institute of Particle Physics, and Univ. of Winnipeg.

8.18 Conformal Invariance and Two-Dimensional Field Theories

Z.Y. Zhu and H.C. Lee

Recently it has been discovered that certain conformally invariant field theories in a two-dimensional manifold admit exact solutions. This is particularly interesting since string theories, which are currently the most promising candidates for a unified field theory, belong to a subclass of conformal two-dimensional theory (whose exact solution is not known). The exactly soluble theories have also led to a better understanding of the critical phenomena of two-dimensional systems such as the Ising model. We have initiated a study of conformal two-dimensional theories with an emphasis on establishing a relation between the perturbation expansion and the exact solution for those theories that are exactly soluble. Such relations may provide useful insight in the study of theories that are not exactly soluble.

8.19 Decay of the τ Particle

Z.Y. Zhu and H.C. Lee with S.W. Gao (Inst. Theo. Phys., Beijing)

The τ particle is the heaviest (1784 MeV) electron-like lepton, with a neutrino partner ν_τ. Recent experiments show some discrepancy between the sum of the branching ratios of all exclusive channels and the inclusive branching ratio. Our analysis shows that the missing exclusive strength could come from the $\tau \to \nu_\tau\pi\pi\pi$ decay. Making the assumption of π' (1300) and $A_1(1270)$ dominance in the decay scheme

$$\tau \to \nu_\tau \; \pi' \text{ (or } A_1\text{)}, \qquad \pi' \text{ (or } A_1\text{)} \to \pi\pi\pi$$

we have estimated the $\tau \to \nu_\tau\pi\pi\pi$ branching ratio. The result shows that the contribution from A_1 is larger than that from π', but that π' gives a significant branching ratio for $\tau \to \nu_\tau\pi(\pi\pi)_s$ - where the subscript indicates s-wave - which can be measured. Calculations of the branching ratios for other multipion channels are in progress.

8.20 Nonleptonic K^0-Decay and K^0-$\bar{K}^0$ Mixing

Z.Y. Zhu with B. Zhang (Inst. Theo. Phys., Beijing)

There are some long standing problems related to $\Delta I = 1/2$ enhancement (over $\Delta I = 3/2$, where I is the isospin), "direct" CP-violation (characterized by the parameter ε') in $K^0 \to \pi\pi$ decays, and K^0-$\bar{K}^0$ mixing (characterized by the parameter ε). It is shown that all these effects are sensitive to the off-shell matrix element $\langle 0|H_W|K^0\rangle$ which, in the quark model where K^0 is treated as an antiquark-quark bound state $\bar{s}d$, is proportional to the off-shell amplitude for the process

$$s \to W^- + (t,c \text{ or } u) \to d ,$$

which vanishes on-shell. We obtain sufficient $\Delta I = 1/2$ enhancement when typical QCD parameters are used. If one assumes the Kobayashi-Maskawa phase to be the only source of CP-violation, then we obtain $|\varepsilon'/\varepsilon| \simeq 1/20$ which appears large when compared with empirical values

$$\varepsilon'/\varepsilon = -0.0046 \pm 0.0053 \pm 0.0027 \text{ and } 0.0017 \pm 0.0082 .$$

The predicted value for $|\varepsilon'/\varepsilon|$ can be substantially reduced if, instead of the Kobayashi-Maskawa model, a superweak CP-violating force is used.

8.21 Reduction of the SU(5) Enveloping Algebra

M. Couture and R.T. Sharp (McGill University)

The enveloping algebra of a Lie algebra has proved to be a useful concept in theoretical physics. When the states of a physical system are classified according to some group-subgroup chain $G \supset H$, operators acting on these states are elements of the enveloping algebra of G, which is defined as the set of all possible polynomials in the elements of the Lie algebra of G. A good example of such operators is provided by the Casimir operators of G, whose eigenvalues are used to label the representations. Vector operators are also elements of the enveloping algebra; a knowledge of a basis for these tensor operators has proven useful for the derivation of mass formulas, such as the well known Gell-Mann-Okuba SU(3) mass formula or Okubo's SU(4) and SU(8) mass formulas. When classifying physical states according to some chain of groups $G \supset H$ one often faces a labelling problem; there are several examples of this in nuclear physics. Subgroup scalar operators in the enveloping algebra of G can be used to solve this problem. Casimir and vector operators as well as subgroup scalars, are only a few examples of the types of tensor operators in the enveloping algebra of a group; in fact there is an infinite number of them.

The object of our investigation is to give a complete description of the enveloping algebra of SU(5) in terms of a generating function. SU(5) has been proposed by Georgi and Glashow as a possible means of unifying electromagnetic weak and strong interactions. This function will not only enumerate all possible irreducible tensors in the enveloping algebra but will also indicate how one can construct them from a finite set of elementary tensors known as the integrity basis.

We have approached the problem in two ways. In the first approach the integrity basis is obtained by a step by step procedure; at every step of the calculation some elements of the basis are obtained. Once the complete basis is known one can write down the desired generating function. In this method the number of steps needed to obtain the complete integrity basis is finite but unknown. Most of the calculations have been done on the computer, the program Schoonship being very useful. We estimate that so far half of the elementary tensors have been found. Since it may be difficult to obtain the remaining half with this method, we are considering a second approach in which the generating function is obtained directly. Although tedious, the algebra in this case is straightforward.

8.22 Reports, Publications and Lectures

Publications

A METHOD OF DETERMINING THE RELATIVE IMPORTANCE OF PARTICULAR DATA ON SELECTED PARAMETERS IN THE LEAST SQUARES ANALYSIS OF EXPERIMENTAL DATA
G. Audi, W.G. Davies and G.E. Lee-Whiting, Nucl. Phys. A249(1986)443

FLUCTUATIONS IN RECOIL NUMBERS
K.B. Winterbon, Nucl. Inst. & Meth. B18(1986)1

CALCULATING MOMENTS OF RANGE DISTRIBUTIONS
K.B. Winterbon, Nucl. Inst. & Meth. B17(1986)193

ELECTROMAGNETIC NEUTRON-ATOM INTERACTIONS
V.F. Sears, Phys. Rep. 141(1986)281

NEUTRON SCATTERING LENGTHS AND CROSS SECTIONS
V.F. Sears, in: Methods of experimental physics, Vol. 23. Neutron scattering, Part A, p.521. Eds. K. Sköld and D.L. Price, Academic Press, New York, 1986

MESON-EXCHANGE CURRENTS IN TIME-LIKE AXIAL-CHARGE TRANSITIONS
I.S. Towner, Ann. Rev. Nucl. & Part. Sci. 36(1986)115

REPORT OF THE GORDON RESEARCH CONFERENCE
M. Harvey, Phys. in Canada, 42(1986)116

UNIFICATION OF FUNDAMENTAL FORCES
G. Kunstatter, H.C. Lee and G. McKeon, Phys. in Canada 42(1986)15

THE GENERAL THREE-VERTEX, BRS IDENTITIES AND RENORMALIZABILITY OF THE LIGHT-CONE GAUGE
H.C. Lee, M.S. Milgram and A. Andrasi, Z. Phys. C - Part. & Fields 33(1986)33

Lectures

PANELS AND PUBLIC AFFAIRS TALKS ON NUCLEAR ISSUES
M. Harvey, Aug. 13, Oct. 1, 14, 21, 29, Nov. 18, Dec. 1, 3, 8, 1986

PARTICLE PHYSICS UPDATE
M. Harvey, invited talk at the Science Teachers Association of Ontario Biennial Convention, Toronto, Nov. 7, 1986

USE OF THE COHERENT-PAIR APPROXIMATION IN CHIRAL SOLITON MODELS
M. Harvey, invited talk, University of Maryland, Nov. 19, 1986

ANALYTIC REGULARIZATION FOR SUPERSYMMETRY ANOMALIES
H.C. Lee, talk given at NATO Adv. Res. Workshop on Super Field Theories, Vancouver, July 25-Aug. 5, 1986

INSTABILITY AND CHAOS IN MOLECULAR MULTIPHOTON EXCITATIONS
H.C. Lee, talk given at Univ. Western Ontario, Sept. 21-22, 1986

MESON-EXCHANGE CURRENTS
I.S. Towner, Nuclear Theory Workshop, Univ. Manchester, Aug. 20, 1986

AXIAL-CHARGE TRANSITIONS IN RELATIVISTIC NUCLEAR MODELS AND NONRELATIVISTIC MESON-EXCHANGE CURRENTS
I.S. Towner, Int. Nucl. Phys. Conf., Harrogate, Aug. 29, 1986

MESON-EXCHANGE CURRENTS
RELATIVISTIC SHELL MODELS AND MESON-EXCHANGE CURRENTS
I.S. Towner, two lectures given at Univ. Maryland, Oct. 22-23, 1986

9. FUSION OFFICE

D.P. Jackson

STAFF LISTING

FUSION OFFICE

Manager, Fusion Office/ Director, National Fusion Program	D.P. Jackson
Manager, Fusion Fuels	G.J. Phillips
Manager, Magnetic Confinement	C.C. Daughney[1]
Secretary	M.V. Boland

Professional Staff

J.A. Sawicki[2]
M.L. Swanson[3]

[1]Hired 1986 September 08.
[2]Terminated 1986 August 26.
[3]Retired 1986 August 5.

9. FUSION

9.1 Background

AECL has been given the responsibility by the federal government for operating the National Fusion Program (NFP). Funding for the NFP is obtained through the federal interdepartmental Panel on Energy Research and Development (PERD) which is administered by the Ministry of Energy, Mines and Resources. The Fusion Office in the Physics and Health Sciences Program Responsibility Centre is the AECL organization that manages the program. In order to put the reports that follow in their proper context, the objectives and strategy of the NFP are given as a preamble.

9.1.1 Objectives

The objectives of the R&D in this area are:

- to establish and maintain in Canada the necessary expertise to provide a foundation from which the capability of building fusion power systems can be developed;

- to gain, in the shorter term, effective access to international knowledge in fusion technology by making a recognized contribution to the international effort; and,

- to develop, in the intermediate term, sufficient technological capability to allow Canadian industries to supply subsystems, components, fuel and services for foreign fusion power developments (whether they be experimental, demonstration or commercial units).

9.1.2 Strategy

The strategy employed to meet these objectives recognizes the long-term nature of fusion R&D and the high-level (> $2 billion annually) of international effort. The Canadian effort is narrowly focused with projects that meet the following criteria: i) the possibility of interim industrial benefits is high; ii) there is an indigenous Canadian advantage that will provide a basis for Canadian leadership in the technological speciality; and iii) the interest to foreign programs is sufficiently high to make exchange of technology a likely outcome. Matching funding by the provinces in the major projects ensures sharing of the R&D risks. Participation in them by electrical utilities, industries, universities, and federal laboratories assures an appropriate level of technical involvement and interest.

9.2 National Fusion Program

Coordination of the total Canadian effort in the National Fusion Program (NFP) is essential to achieve both the optimum use of domestic resources and the maximum leverage for the program internationally. The NFP was initiated by the National Research Council (NRC), but government decisions taken in 1985 have resulted in the staged and orderly transfer of responsibility for the program from NRC to AECL which will be completed by 1987 April 1. This transition has been accomplished to date with minimum disruption to the program. AECL has formed a Strategic Advisory Committee to assist in guiding the long-term strategy of the NFP. Consultation and coordination with other departments, the provinces and the fusion community in general is achieved through ad hoc groups assembled to advise on specific issues. The original plan for the NFP called for Canadian participation in each of the three major thrusts of international fusion R&D: magnetic confinement, and inertial confinement, and materials/engineering. Significant projects in the first (Tokamak de Varennes) and last (Canadian Fusion Fuels Technology Project) of these are well established. A small but vigorous International Program is an essential element of the NFP.

Highlights

Highlights for the reporting period are as follows.

- A briefing on progress in the National Fusion Program was given to the interdepartmental Panel on Energy Research and Development (PERD) in 1986 December. An initial request was made for additional program funding for 88/89 and subsequent fiscal years.

- A communications action plan was developed for the National Fusion Program and implementation started. The objectives are to inform participants, funders and the public of the activities of the program and to promote it technically and commercially to domestic and foreign audiences. Its essential features are (i) a brochure describing Canadian activities in fusion, (ii) a national newsletter, (iii) an annual report, (iv) display boards for the CRNL Public Information Centre, and (v) support for a program of teaching aids on fusion for high school instruction. All material will be in both official languages.

- AECL coordinated the review of the fusion proposals submitted to the NSERC Strategic Grants panel on energy. Referees' reports on each proposal were obtained and an ad hoc consulting group with representatives from AECL, NSERC, EMR, NRC, CFFTP, and the Tokamak de Varennes met to discuss and rank the proposals. Minutes of this meeting were given to NSERC; the grants ultimately awarded were in exact accordance with the recommendations of the AECL-coordinated process.

9.3 Tokamak de Varennes

The Tokamak de Varennes is a magnetic confinement fusion experiment jointly funded by the NFP and Hydro Québec with collaboration from industrial and university partners. The project is directed by a steering committee with technical review provided by an international advisory committee.

The device is a medium-sized tokamak nearing completion at IREQ's Varennes site with first operation expected by early 1987. The construction phase has required that industry acquire specialized technological capabilities previously unavailable in Canada. In parallel with this expansion of the technology base, a world-class team of fusion scientists and engineers has been assembled for the R&D program.

The machine has unique features: for example, it is the world's only fusion experiment operated by an electrical utility and the only one powered directly from transmission lines, both of which stemmed from IREQ's historical expertise in high power electrotechnology. Since it is designed to maintain its magnetic fields for much longer than most other tokamaks, long time-scale effects in plasma confinement can be studied. This important feature together with its impurity control systems, advanced diagnostics and equipment for plasma materials interactions ensure that the Tokamak de Varennes will have an important role in international fusion research. The high level of collaboration in place before its operation is already indicative of significant world interest - the challenge in future years will be to upgrade and improve the machine in order to sustain its relevance.

Highlights

Highlights for the reporting period are as follows.

- Dr. C.C. Daughney was appointed Manager, Magnetic Confinement, in the Fusion Office with responsibility for managing the NFP role in the Tokamak de Varennes.

- An interim agreement between AECL and IREQ was concluded for the operation of the Tokamak in the 86/87 fiscal year. This agreement recognizes equal cost-sharing between the federal and Québec funders of the project up to a total budget level of 10 M$.

- The negotiations for a joint venture agreement between AECL, IREQ and INRS (Institut National de la Recherche Scientifique - Université de Québec), establishing the CCFM (Centre Canadien de la Fusion Magnétique), has been brought to an advanced stage. The agreement structures the operations phase of the Tokamak as a partnership with full participation for AECL in the R&D activities and the physical and intellectual property of the project.

- By the end of 1986 December, assembly of the Tokamak was within six weeks of completion, with first operation expected in 1987 February.

9.4 Canadian Fusion Fuels Technology Project (CFFTP)

CFFTP's objective is to capitalize on the domestic expertise in tritium technology established in the CANDU fission reactor program - tritium is the major fuel for future fusion reactors. It is funded 50% by the federal government (AECL), 25% by Ontario and 25% by Ontario through the Ministry of Energy. Project management is provided by Ontario Hydro. CFFTP is directed by a steering committee, consisting of representatives of the funding partners, that is advised on technical matters by a committee of Canadian and foreign experts.

The project plans and supervises fusion fuels R&D work in industry, utilities, universities and federal laboratories, and markets Canadian technology abroad. R&D programs in tritium technology, fusion blankets, materials, health and safety, and equipment development have been successful in achieving international recognition for Canada. This work, together with staff attachments, participation in international study teams and representation at conferences has been used effectively to gain access to the major world programs and to broaden the indigenous fusion technology base.

CFFTP has also had good success in gaining foreign markets for Canadian industry for fusion-related goods and services in the US and particularly Europe. This business is currently expanding, since several foreign fusion fuels laboratories are planned or under construction. Canadian products such as tritium pumps and tritium monitors are also being vigorously promoted by CFFTP, with promising results.

Highlights

Highlights for the reporting period are as follows.

- Negotiations for the new CFFTP agreement were completed. In analogy to the present one, the format of the new agreement was originally three-party (AECL, Ontario Hydro, Ontario government). However, the extent and manner of the Ontario government's participation is still uncertain and the format was revised to a two-party agreement (AECL, Ontario Hydro). It is anticipated that a separate Ontario Hydro-Ontario government agreement will be concluded when the issue of provincial funding is resolved.

- A separate joint marketing agreement between AECL and Ontario Hydro is under discussion which would make CFFTP the marketing agent for the fusion fuels technology of both parties.

- Attachments of a remote-handling expert to NET (EEC), partial support for a tritium engineer for NET and a tritium process design engineer for JET (EEC) were arranged by the National Fusion Program in cooperation with CFFTP.

9.5 International Program

The program stresses international collaboration as an essential part of its strategy with the aim of forging links with the major world programs in order to acquire information, encourage technology transfer into Canada, foster commercial opportunities, and increase the relevance and leverage of the NFP.

Canada is active in several International Energy Agency (IEA) fusion committees and study groups and participates in the TEXTOR joint experiment and the BEATRIX materials exchange through this agency. The NFP also takes part in the Economic Summit process of the Western heads of state, since fusion is one of the areas identified in the Technology, Growth and Employment thrust initiated at the Versailles summit of 1982. Bilateral fusion agreements between Canada and Japan and Canada and the EEC have been concluded; a Canada-US agreement is under study.

Since the achievement of fusion power will be a large and expensive process, perhaps too large for any one country, large-scale international projects are under discussion. A new initiative of this type resulted from the recent Reagan-Gorbachev summit. The NFP has an important role in the assessment of these projects, with respect to the opportunities for Canada, and coordination of Canadian participation in them.

Highlights

Highlights for the reporting period are as follows.

- The Reagan-Gorbachev Initiative for East-West fusion cooperation was approved by the US and USSR leaders at their Iceland summit meeting. Following this, a proposal for a cooperative study of an international fusion Engineering Test Reactor (ETR) was issued by the US. It is planned that Canada will participate in this project through one or more of the larger Western programs.

- Representation at the Western Economic Summit groups on fusion - Technical Working Party (Germany, 1986 September) and Fusion Working Group (Tokyo, 1986 November) - furthered Canada's position in international fusion collaborations. In particular, at the latter meeting the role of smaller programs such as Canada's in the international ETR project was recognized and assurances were given by the US, the EEC and Japan that there would be opportunities for Canadian participation.

- The bilateral agreement between Canada and Japan on fusion cooperation, expired 1986 November, was renewed on an interim basis until 1987 March. A revised bilateral is being negotiated to widen the scope of the first agreement (intended for preliminary exploration of potential collaboration) to one more appropriate for on-going cooperative activities.

- A visit to China by representatives of the National Fusion Program, CFFTP, and the Tokamak de Varennes in 1986 November showed that there were opportunities for collaboration in fusion between the Chinese and Canadian programs. Methods for implementing this potential collaboration are now under consideration.

- A strong Canadian delegation attended the International Atomic Energy Agency (IAEA) world conference on Plasma Physics and Controlled Thermonuclear Fusion held in Kyoto, Japan in 1986 November. Canadian participation in IAEA specialists conferences on Nuclear Data for Fusion (Dresden) and Safety and Environmental Effects of Fusion (Culham) was also sponsored by the National Fusion Program.

9.6 Inertial Confinement

The original plan for the NFP included inertial confinement fusion as a program area. A major project in this area has not yet been assembled, but the option is retained in the NFP. Activity is now confined to a monitoring role and in providing assistance to Canadian researchers. Research programs in inertial confinement are currently carried out in several Canadian universities and at NRC.

Highlight

A highlight for this period is as follows.

- Discussions were initiated on the possibility of arranging an inertial confinement consortium agreement between AECL and the university and NRC groups active in this area. This would allow a limited degree of support from the National Fusion Program for work in the international area and allow joint publicity and promotional activities. If this concept is successful, further responsibility for inertial confinement work could be undertaken by the National Fusion Program in the absence of a major federal-provincial project in this field.

10. COMMERCIAL OFFICE

W.A. Seddon

10. Commercial Office

10.1 Staff

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Secretary	Y.W. Stothers

Professional Staff

G.A. Leakey
D.V. Parsons
M.C. Wolfgram

Clerical Staff

B.A. McCarthy

Co-Op Student

D.V. Link (4 month term)

10.2 Physics

The Neutron and Solid State Physics (lead branch) and Advanced Materials Research Branch are co-operating in the application of neutron diffraction to industrial problems. Marketing and technical efforts during 1986 are expected to yield revenues of 300 k$ for 1986/87. A BOD Team was formed to assess the size and characteristics of the potential market and to assess the need for and viability of a dedicated test facility at CRNL.

Contracts accepted *(86.07.01 - 86.12.31)

NSSP	237 k$
Nuclear Physics	1 k$ (approx.)

* Excludes work for Business Units and other PRCs.

11. BUSINESS DEVELOPMENT

R.N. Hargreaves

BUSINESS DEVELOPMENT - PHYSICS

by

R.N. Hargreaves

11. BUSINESS DEVELOPMENT OFFICE

by

R.N. Hargreaves

11.1 STAFF

Manager	R.N. Hargreaves
Secretary	Bev Drouin (1) Elsie Abbot (2)

Professional Staff	Summer Student
P.A. Browne	Suzanne Smith (3)
R.B. Boulton	
K.W. Gullen (4)	
T.B. Kimmel (4)	

(1) On strength as of September 22, 1986

(2) Off strength as of September 31, 1986

(3) National Summer Student, term ended August, 1986.

(4) On strength as of January 1, 1987.

11.2 PHYSICS

11.2.1 Transmutation Doping of Gallium Arsenide

- P. Martel (Neutron and Solid State Physics Branch)

Test samples from Cominco have been irradiated, cooled, and returned to the supplier for evaluation. We await Cominco's assessment.

11.2.2 Cable Tester

- J. Sharp, L. Bucholtz (Nuclear Physics Branch)

Sharp and Bucholtz have incorporated as Shar-Buc Enterprises Inc. The licensing agreement between AECL and Shar-Buc has been executed.

11.2.3 Inspection of Semiconductor Wafers

- P. Martel (Neutron and Solid State Physics Branch)

The technique has been widely publicized, with interest being shown by Alcan, Spectrum, and Cominco. Comparative assessment versus present methods is in progress.

11.2.4 Neutron Diffraction

S. MacEwen, T. Holden (Neutron and Solid State Physics Branch)

A market survey has been undertaken with preliminary indications of a North American market of several $ millions, but one which is diffused through many industrial sectors. Marketing strategy will need to address this. Revenue estimates for the current fiscal year are 330 k$.

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