PROGRESS REPORT
PHYSICS DIVISION
October 1 to December 31, 1978

PR-P-120

Chalk River Nuclear Laboratories
Chalk River, Ontario
January 1979
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PROGRESS REPORT

October 1 to December 31, 1978

PHYSICS DIVISION

Research Director - G.A. Bartholomew
Secretary - J.M. Jones

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PR-P-119  1 July to 30 September, 1978  AECL-6366
SUMMARY

G.A. Bartholomew

1.1 Nuclear Physics Research

MP Tandem Operation

Accelerator availability was exceptionally high during the quarter.

Experiments running 1462 hours 70.0%
Scheduled shutdowns 287 hours 13.8%
Unscheduled shutdowns 339 hours 16.2%
2088 hours 100.0%

The on-line isotope separator has been commissioned as an off-line device and requires only an appropriate ion source to be available on-line. Xenon beams of several milliamperes have been produced and the resolution, measured with argon, is twice as good as the specification.

Thirteen experiments were performed involving CRNL and eight visiting scientists. The visiting scientists were involved in experiments occupying 52% of the beam time and their participation averaged 40%.

Research Activities

Several experiments are in progress involving collaboration with several laboratories and using several different approaches to measure parity violation in strong interactions.
The reproducibility of measuring small $^{14}$C concentrations has been greatly improved and further improvements are possible. Attempts to measure $^{36}$Cl concentration were frustrated by the electrical failure of the velocity filter. A new and four times more powerful one is being assembled.

The g-factors of eight high spin isomeric states in four gadolinium isotopes have been added to the previously determined spin and parity data. These are of great importance in assigning detailed shell-model configurations to the states.

Further work on the use of the enhanced transient field effect in measuring g-factors in thulium and ytterbium isotopes has successfully determined one of the major corrections required. The g-factors so obtained indicate essentially rotational character of levels up to spin 10 in three ytterbium isotopes.

Existing data on neutron-capture M1 γ-ray widths have been analyzed to deduce the position and spreading width of the M1 giant resonance in heavy nuclei.

Solutions to long-standing differences between experimental and theoretical values for the thermal neutron capture cross sections of $^1$H and $^3$He are being sought in the framework of a more complete meson exchange theory.

The standards group has submitted a value to the Bureau International des Poids et Mesures (BIPM) in a major international comparison of the measurement of the activity of $^{134}$Cs. Twenty-four laboratories are participating.
1.2 Accelerator and Applied Physics

Research Applications

a) Fast Intense Neutron Source

The neutron source will now operate at $1.1 \times 10^{12}$ n/s. Modifications are in progress to increase source strength to the design value of $4 \times 10^{12}$ n/s.

b) Superconducting Cyclotron

- The magnet is being reassembled in preparation for detailed field mapping. An obstructed current lead has been repaired and the leaking bellows in the helium-can vent has been replaced.
- The helium can has been wrapped with superinsulation and the radiation shield is being installed.
- The liquefier is dismantled to repair a vacuum leak.
- The radiofrequency accelerating system has operated on both 0-mode and π-mode and has achieved 3/4 of the design voltage.

Nuclear Power Applications

a) Injector Test Experiment

Preliminary design work is complete and component fabrication is underway for a preaccelerator suitable for accelerator breeder applications.

b) Ion Source Development

Development is continuing on a multi-aperture ōuPIGatron ion source with beam current and emittance suitable for a high current accelerator.
c) **High Current Test Facility**

Commissioning of the Alvarez accelerator is proceeding; some overheating problems have been encountered as rf power is increased. The freon cooling circuit of the high power rf amplifier is operational.

d) **Electron Test Accelerator**

- Work on the new 100 kW beam stop is complete.
- A design for coupling rf power into the high power pancake-coupled structure has been successfully tested in an aluminum model, while machining of the copper segments for this structure continues.
- The computer program for automated startup of the $\beta=1$ structure is now in service. The real time operating system in the control computer has been extensively modified and a troublesome fault, which intermittently paralyzed the system, has been corrected.

e) **Fertile-to-Fissile Conversion Experiments at TRIUMF**

The relative counting efficiencies of the $\beta$-detectors used for proton beam monitoring and for neutron absorption rate measurement have been re-determined. Some inconsistencies remain to be resolved.

f) **Fusion Studies**

- A preliminary study has been made of anomalous energy loss mechanisms for high density relativistic electron beams interacting with matter.
- Calculations to develop reliable neutronic evaluation of fusion breeder blanket assemblies is proceeding.
A report summarizing the physics of the interaction of a laser beam with matter has been written.

1.3 **Solid State Physics**

Small angle neutron scattering techniques have been used to determine the radius of gyration of transferrin and haemoglobin molecules in Ringer solution.

In collaboration with scientists from Argonne National Laboratory measurements are underway to understand actinide magnetism. Work during the quarter involved studies of uranium telluride and uranium sulphide single crystals.

A long standing program to understand neutron magnetic scattering effects in uranium nitride has revealed new structure. Collective magnetic excitation studies in UPd₃ are giving information on the electronic ground state in the uranium atom.

Work is underway to investigate the structure and composition dependence of vacancy formation energies in stainless steels.

An ongoing study of electrical contacts on CdTe detectors has lead to the conclusion that contact properties are less important than bulk properties in determining detector performance.

1.4 **Applied Mathematics and Computation**

The redesign and re-writing of a data processing system for the analysis of fuel defect experiments has been
undertaken, and the development of models for characterizing measurement of radioactive constituents in CRNL effluents has begun.

A model to relate the energy deposition from a laser beam in a gas to microphone measurements of the resulting pressure pulse is being investigated; a very simple model, in which it is assumed that the energy deposition occurs in a rectangular pulse and that the microphone diaphragm acts like a one-dimensional lightly-damped oscillator shows good qualitative agreement with observation, and a more realistic model is being developed.

Applications of the FORSIM package for the automated solution of differential equations that were begun, or further developed, during the quarter included:

- further development of the MACKSIM code for simulation of the radiolysis of water
- a study of the effects of condenser water chemistry on corrosion in steam generators
- the computation of molten boundary migration in a fuel pin subject to central melting
- computation of organ burdens resulting from inhalation of radioactive nuclides.

The development of a device-independent system for graphical output continued. The system, called SEMBEGS, is now supporting all of the displays and plotters which were supported under the old DISPLAY system, and work on extensions to new devices has begun.
Computer usage during the quarter was as follows:

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2.1 Staff

Branch Head: J.C.D. Milton

Professional Staff

SECTION I

J.C.D. Milton
H.R. Andrews
T.K. Alexander
G.C. Ball
W.G. Davies
A.J. Ferguson
J.S. Forster (1)
E.G. Hagberg (2)
J.C. Hardy
O. Hausser
R. Kirchner (3)
A.B. McDonald
P. Taras (4)
W. Trautmann (5)
D. Ward

Technical Staff

Accelerator Group

J.S. Barsczewski
N.C. Bray
R.L. Brown
L.H. Bucholtz
J.J. Gallant
J.J. Hill
R.E. Howard
A.S.C. Hyde
K.T. McKee (6)
J.P.D. O'Dacre
L.L. Perry
F.J. Sharp
R.A. Surette
E.C. Waito
D.J. Yaraskavitch

SECTION II

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J.S. Geiger

R.B. Walker

SECTION III

Radioisotope Standardization Group

J.S. Merritt

F.H. Gibson
L.V. Smith a)
A.R. Rutledge b)

Students

E.T.H. Clifford (7)

Laboratory Services and Workshop

G.M. Boire (8)
M. Desrochers

Secretarial Staff

J.R.H. Bowes
R.J. Elliott

a) also has responsibilities in Sec. I and II
b) " " " Sec. I
(1) On leave of absence at University of Aarhus, Denmark

(2) Postdoctoral Fellow; arrived 1978 October 13

(3) Visiting scientist from GSI, Darmstadt, W. Germany; arrived 1978 October 17

(4) Visiting professor from University of Montreal

(5) Visiting scientist from University of Munich; left 1978 October 31

(6) Transferred to Accelerator Physics Branch on December 18, 1978

(7) Graduate student attached from the University of Toronto

(8) Retired 1978 December 29
2.2 Search for Parity Violating Decay of the 3562 keV Level of $^6$Li

A.B. McDonald, W.G. Davies, G.C. Ball, E.D. Earle (Neutron and Solid State Physics Branch), with R.G.H. Robertson, P. Dyer (Michigan State University) and T. Bowles (Argonne National Laboratory)

An experiment has been performed to test the feasibility of measuring the parity violating decay of $^6$Li (3562 keV, $0^+$) to $\alpha + d$ with the Chalk River MP tandem and QD3 magnetic spectrometer. Measurements were made of the background from scattered beam at the focal plane of the QD3 for 6.25 MeV $\alpha$'s incident on a CD$_2$ target. An 8 cm long focal plane detector was used which had been developed for previous measurements at the Michigan State cyclotron (R.G.H. Robertson et al, Bull. Am. Phys. Soc. 23 (1978) 518). The energy resolution of the alpha beam was determined to be $\sim 2$ keV by observation of the width of the 6919 keV, $2^+, T=1$ resonance in the $^{16}_O(\alpha,\gamma)$ reaction at the CRNL differentially pumped gas target. The results for background level, beam current and energy resolution were sufficiently encouraging that further measurements are planned with a longer focal plane detector and a deuterium gas jet target currently under construction.

2.3 Parity Violation in the Photodisintegration of Deuterium


Preparations are proceeding for the proposed experiment to search for parity violation in the photodisintegration of deuterium with circularly polarized $\gamma$-rays. The prototype polarized electron source has produced low currents of electrons by photoemission from single crystals of GaAs coated with thin layers of CsO$_2$ in an ultra high vacuum system. Activity is centered on improving surface preparation
techniques so as to increase photoemission efficiency, A D₂O target is under construction which will be used in the existing unpolarized bremsstrahlung beam at the Electron Test Accelerator to measure neutron and γ-ray fluxes and to test Monte Carlo calculations (See PR-P-120, 4.3: AECL-6452). Discussions are in progress with suppliers of gamma compensated neutron detectors to ascertain the characteristics and capabilities of recent technology in the field of highly efficient thermal neutron detection in a high γ-ray background.

2.4 An Upper Limit on Parity Mixing in $^{21}\text{Ne}$


A further measurement has been made at the University of Washington of the circular polarization of γ-rays from the $2789 \rightarrow 0$ keV transition in $^{21}\text{Ne}$. The experimental technique was identical to that used in the earlier measurement (PR-P-118: 2.3, AECL-6216 and K.A. Snover et al, Phys. Rev. Lett. 41 (1978) 145) but the beam current (14 microamps) and accumulated charge (15 coulombs) were substantially higher. Data analysis is in progress and preliminary results indicate no observable circular polarization with a statistical accuracy about a factor of two better than the accuracy in the earlier measurements.

2.5 Study of the 1.6 MeV Parity Doublet in $^{41}\text{K}$

A.B. McDonald, E.D. Earle (Neutron and Solid State Physics Branch) with B.C. Robertson, M. Maynard and S. Saha, Queen's University

Cross section measurements have been made for the $^{41}\text{K}(p,p')$ reaction populating the 1560 keV, $J^\pi = 3/2^+$
and 1582 MeV, $J^\pi = 3/2^-$ levels in $^{41}\text{K}$ and an upper limit has been measured for the lifetime of the 1582 level. Excitation functions obtained at the Queen's University KN Van de Graaf indicate nearly equal population of these levels at incident energies near 3 MeV. A direct timing measurement performed with a pulsed proton beam from the CRNL MP tandem resulted in a preliminary upper limit of 50 ps for the 1582 keV level. This may be combined with a previous lower limit of 5 ps for this level and a measurement of $0.6 \pm 0.15$ ps for the 1560 keV level (Lister et al J. Phys. G: Nucl. Phys. 2 (1976) 577) to determine the relation between the circular polarization of the 1582 keV γ-ray and the parity mixing matrix element between the levels. In this case, $^{41}\text{K}$, the observed M1 to E1 ratio is substantially smaller than for the $1/2^+ - 1/2^-$ doublet in $^{21}\text{Ne}$ (see PR-P-118: 2.3, AECL-6216) and would result in a 100 times smaller γ-ray circular polarization if the parity mixing matrix elements were the same.

2.6 The Decays of $^{35}\text{K}$ and $^{36}\text{K}$

E. Hagberg and J.C. Hardy

The results obtained previously on the decay of $^{35}\text{K}$ (PR-P-119: 2.15, AECL-6366) have been complemented by a multispectrum analysis and a precision energy determination of the beta-delayed gamma rays. The experiments have been performed at the CERN ISOLDE separator (work done in collaboration with Carraz, Ewan, Hansen, Jonson, Mattsson, Ravn and Tidemand-Petersson).

The analysis of the data obtained on the beta-delayed gamma rays is now completed. The half-life of $^{35}\text{K}$ has been determined to be $190 \pm 30$ ms based on the present multispectrum analysis and on the previous beta multispectrum data.
The superallowed beta branch of $^{35}$K populates the $3/2^+$ analogue state in $^{35}$Ar which we identify for the first time. From our measured excitation energy of this state $5572.5 \pm 0.3$ keV, the $d$ term in a cubic Isobaric Multiplet Mass Equation for the $A = 35$ chain has been determined to be $-2.9 \pm 3.7$ keV.

Assuming a log $ft$ value of 5.07 for the ground state to ground state transition, based on the log $ft$ value for the mirror transition in the decay $^{35}$S $\rightarrow$ $^{35}$Cl, the log $ft$ values for 6 beta-transitions to excited states in $^{35}$Ar, including the analogue state, have been determined.

The analysis of the beta-delayed particle data, which is now in progress, will provide complementary information on the beta transitions to states above the analogue state.

2.7 $\beta$-Decay Strength Functions Near $A = 70$

J.C. Hardy

The realization that the particle X-ray coincidence technique (PXCT) yields information on $\Gamma_\gamma$ as well as $\Gamma_p$ in a typical delayed proton emitter (see PR-P-119: 2.16, AECL-6366) has led to a re-examination of the decays of $^{69}$Se (McDonald et al, Nucl. Phys. A288 (1977) 1) and $^{73}$Kr (Asboe-Hansen et al, Phys. Lett. 77B (1978) 363). In a more positive sense than previously expected, the PXCT data determine $\Gamma_p$ and $\Gamma_\gamma$, leaving the intensity distribution of the $\beta$-delayed protons as a measure of the $\beta$-decay strength function.

While the PXCT data are very similar for $^{69}$Se and $^{73}$Kr, the proton spectra differ significantly at low energy. The "gross theory" of $\beta$-decay actually predicts a sharp change in $\beta$-decay strength near the proton separation energy, and the possibility that this feature is reflected in the proton spectrum is being examined.
Shell model calculations are also being made (with I.S. Towner) to probe the correlations between microscopic and macroscopic theories in explaining such gross features.

2.8 **Precision Mass Measurements**

V.T. Koslowsky (University of Toronto), J.C. Hardy, E.T.H. Clifford, E. Hagberg, H. Schmeing (Neutron and Solid State Physics Branch) and R.E. Azuma (University of Toronto)

We have performed a second experiment in a series directed towards making a precision mass measurement to determine the effective ionization of recoiling target nuclei in the reactions $^{14}_N(d,\alpha)^{12}_C$ and $^{15}_N(d,\alpha)^{13}_C$. The experiment was similar to the one described in PR-P-119: 2.12, AECL-6366 with the following modifications:

- NaCN targets replaced the adenine targets because of the availability of $^{15}_N$ enriched NaCN.
- The targets were 30-40 \( \mu g/cm^2 \), three times thinner than those in the previous experiment. This reduced the \( \alpha \)-peak width.
- The thickness of the standard 8.78 MeV \( \alpha \)-source (\(^{212}\)Po) was measured by rotating the source and determining the resulting \( \alpha \)-peak shift due to self-absorption.
- The object and image slits of the tandem were reduced in width from 0.200" to 0.020". This reduced the \( \alpha \) background at the detector by a factor of 4 while not affecting the overall production rate.

Analysis of the data is presently in progress.
2.9 Beta-Neutrino Correlations from the Kinematic Shift of Beta-Delayed Particles

E.T.H. Clifford, J.C. Hardy, E. Hagberg, H. Schmeing (Neutron and Solid State Physics Branch), with R.E. Azuma and V.T. Koslowsky (University of Toronto)

The response function of our $\beta$-telescope has been measured for positrons with incident energies covering the range from 0.8 to 4.0 MeV. The mono-energetic positrons were obtained from a $^{66}$Ga source prepared with the tandem accelerator and mounted in the $\pi \sqrt{2}$ $\beta$-spectrometer. The positrons entered the telescope situated in the focal plane at an angle of $6^\circ$ from normal incidence.

The spectrum of energy deposited in the telescope has the following features:
- a full energy peak from electrons which come to rest in the telescope, thus depositing all of their kinetic energy;
- a distribution on the high energy side of the peak occurring because additional energy can be deposited in the telescope if either one or both of the 511 keV annihilation quanta Compton scatter in the plastic scintillator;
- a flat low energy tail, partially due to backscattering of positrons from the detector, and partially due to annihilation in flight of the positrons in the scintillator.

Further measurements are planned at an incident angle of $20^\circ$. These are necessary in order fully to take into account solid angle effects in the $^{20}$Na experiment.

2.10 The On-Line Isotope Separator

J.C. Hardy, W.L. Perry and H. Schmeing (Neutron and Solid State Physics Branch)

On October 11, the first off-line beam was produced from the isotope separator. Within a few hours of start-up,
a xenon beam of several milliamps had been produced, and a preliminary scan of the separated isotopes in the focal plane yielded a resolution within a factor of two of our specifications.

Since the initial start-up, extensive tests have been performed, with the Bernas-Niers ion source, and final shimming of the main magnet is now well advanced. This work has benefited greatly from the help of Dr. J. Camplan from the Laboratoire René Bernas, Orsay, who spent three weeks at Chalk River. Dr. Camplan has collaborated with us throughout the construction of the separator.

In addition to xenon, beams of argon and nitrogen have been produced. Magnet shimming has so far led to a measured resolution with an N₂ beam of 5000 (where resolution R is given by $R = \frac{M}{\Delta M}$, $\Delta M$ being the full width at half maximum of a beam of ions with mass M in the focal plane) which is more than twice as good as we had specified. This has been achieved at beam currents of up to 15 mA, and an extraction voltage of 40 kV.

One novel feature of the separator is the use of two trim coils to adjust the first and second derivatives of the magnetic field as a function of radius; these are called the $\alpha$ and $\beta$ coils respectively. The $\alpha$ coil shifts the position of the focal plane by up to 50 cm, and the $\beta$ coil affects the quality of focus. Both have been shown to work as expected, and provide an enormous simplification in normal separator operation.

It is anticipated that when shimming has been optimized for the nitrogen beam, adjustments in the $\beta$-coil can maintain a high quality focus for heavier elements at least up to mass 100. Another set of shims, together with $\beta$-coil adjustments, will be used above this mass.

Magnet shimming and off-line tests are scheduled to be completed in time for on-line tests to begin with the FEBIAD ion source (see PR-P-120; 2.11, AECL-6452).
2.11 **Ion Source Development for the On-line Separator**
J.C. Hardy and R. Kirchner with H. Schmeing and R.J. Toone
(Neutron and Solid State Physics Branch)

The FEBIAD ion source has the reputation of being the most successful on-line source so far devised for isotope separators. Consequently this modified Nielson source is our first choice among the several options that we shall pursue successively (PR-P-118: 2.20, AECL-6216). We have settled on a high temperature version of the FEBIAD source, which is now working satisfactorily at GSI Darmstadt, and adapted drawings of this proven model have already been submitted to the workshops. Appropriate power supplies for the source have been ordered, and modifications to the design of the high current ion source magnet (PR-P-119: 2.14, AECL-6366) have been completed. The source is scheduled to be working on-line at the end of February, 1979.

2.12 **Heavy Ion Fusion Cross Sections**
A.J. Ferguson

A simple empirical formula has been found to represent accurately the energy variation of the total heavy ion fusion cross sections (D. Horn and A.J. Ferguson, Phys. Rev. Letters, in press). In an attempt to connect this relation with conditions at the nuclear surface, the total reaction cross sections that result from two simple models have been studied. The first model assumes a complex square well within a selected radius for the ion-ion interaction and the Coulomb interaction outside it. By adjusting the well parameters and the radius, a good representation of the threshold and of the maximum cross section can be obtained. However a characteristic drop in the cross section at higher energies is not reproduced.
The Blair-McIntyre model, which is successful in predicting elastic scattering cross sections was the second tried. This model gave total reaction cross sections considerably larger than observed. As it has effectively no adjustable parameters, the model appears to be inapplicable to this problem.

2.13 High Velocity DSAM Lifetime Measurements of the 1.982 MeV, $2^+$ Level in $^{18}O$


In the previous progress report PR-P-119: 2.9, AECL-6366, a summary of our measurements of the lifetime of the 1.982 MeV $2^+$ level in $^{18}O$ was given. The level was populated through the $^1H(^{18}O,p)^{18}O$ and $^4He(^{18}O,\alpha)^{18}O$ reactions. Targets consisted of $\sim 100$ gm cm$^{-2}$ of Er hydride on 25 $\mu$m thick Ag backing, of Zr implanted with $^1H$ on a 25 $\mu$m thick Au backing and of $^4He$ implanted targets i.e. ErH$_x$/Ag, Zr($^1H$)/Ag, Zr$^{1H}_x$/Au, and Cu($^4He$), Ag($^4He$) and Au($^4He$) respectively. The results from the $^1H$ targets on Ag backings were inconsistent with all other data.

We have now obtained data from a layered target consisting of 100 $\mu$g cm$^{-2}$ of Zr over 100 $\mu$g cm$^{-2}$ of Au deposited on a 25 $\mu$m thick Ag foil. This target was implanted with 35 keV $^1H_2^+$ to a dose of $1 \times 10^{17}$ molecules cm$^{-2}$ so that the dissociated $^1H$ distribution would be confined to the Zr layer. This target, designated Zr($^1H$)/Au/Ag, was bombarded with a 47.1 MeV $^{18}O$ beam and the Doppler-broadened 1.982 MeV $\gamma$-ray lineshape was measured at $\theta_\gamma = 0^\circ$. A preliminary analysis of the data gives $\tau = 2.75 \pm 0.16$ ps, a value consistent with that obtained from the $^4He$-implanted targets, $\tau = 2.93 \pm 0.1$ ps. (See PR-P-119: 2.9, AECL-6366). The shape of the line is also well reproduced by calculation; such was not the case for the Zr($^1H$)/Ag and Er$^{1H}_x$/Ag data.
This latest result eliminates incorrect stopping powers for $^{18}$O in Ag as a source of error and draws attention instead to macroscopic defects in some targets. There is some evidence to suggest that thin ErH$_x$ and Zr(H) do not adhere well to Ag. There is also some evidence that at high dose e.g. $5 \times 10^{17}$ H cm$^{-2}$ even the multilayered target develops large blister-like defects. Nuclear reactions initiated in or near such features will introduce vacuum or gas-recoil contributions into the Doppler-shifted $\gamma$ spectra exactly where we see an excess of events in the lineshape.

2.14 High Velocity DSAM Lifetime Measurements of Levels in $^{30}$Si and $^{30}$P

T.K. Alexander, G.C. Ball, W.G. Davies and I.V. Mitchell
(Solid State Science Branch)

To obtain an accurate comparison of the transition probability of the $^{30}$Si, $2^+ \rightarrow 0^+$ transition and its analogue transition in $^{30}$P we are measuring the lifetimes of these levels. Doppler-broadened lineshapes for transitions in $^{30}$Si were obtained with the $^4$He($^{27}$Al,p)$^{30}$Si reaction by bombarding a $^4$He implanted Au target with an $^{27}$Al beam. Levels de-exciting $^{30}$Si were selected by coincidences with protons detected in a $\Delta E$-$E$ counter telescope located at 0°. (See PR-P-115: 2.10, AECL-5966 for experimental details). Levels in $^{30}$P were also studied with the $^3$He($^{28}$Si,p)$^{30}$P reaction and similar techniques. The analysis of these data is in progress.
2.15 Measurements of the Relative Angular Efficiency of a Ge(Li) Detector

T.K. Alexander, G.C. Ball and W.G. Davies

The measurements of the relative angular efficiency of the Ge(Li) detector PGT VIII (see PR-P-119: 2.18, AECL-6366) have been used to calculate Doppler broadening caused by the finite size of the detector. The measurements, the calculations of the Legendre polynomial attenuation coefficients $Q_k$, and the calculated lineshapes have been summarized for publication in a report, AECL-6412.

2.16 The g-Factors of High-Spin Yrast Isomers in Gd Isotopes

P. Taras (Université dé Montréal), O. Häusser, T.K. Alexander, H.R. Andrews and D. Ward

Gamma-ray spectroscopic techniques have recently been successfully applied in studying the yrast line of several nuclei near the $N = 82$ closed neutron shell up to very high spins (see e.g. Khoo et al., Phys. Rev. Lett. 41 (1978) 1027). A detailed identification of the structure of these high-spin yrast states is of considerable current interest. This structure can best be investigated by measurements of g-factors since they depend on the coupling scheme for the individual particles. In particular, they are very sensitive to the relative contributions of protons and neutrons to the total angular momentum.

We have determined the g-factors of eight isomeric states in $^{144,146,147,148}$Gd by the time-differential spin-rotation method, using pulsed beams of $^{28}$Si and $^4$He. A summary of isomer half-lives, g-factors, strongly anisotropic $\gamma$-rays, and their corresponding $a_2$-coefficients, is shown in Table 2.16.1. The g-factor values were corrected for paramagnetic effects as was described in the previous report. Also shown in Table 2.16.1 is the most likely quasi-
particle structure for each isomer relative to a closed \(^{146}\text{Gd}\) core \((Z = 64, N = 82)\). Some of the low-spin isomers \((J \leq 10)\) deserve a brief discussion. The \(^{144}\text{Gd}\) isomer has a g-factor similar to that for the \(\pi(h_{11/2})\) state in \(^{141}\text{Pr}\) \((g = 1.30 \pm 0.08, \text{ Ejiri et al. NP A221(1974) 211})\), in disagreement with the previously suggested two-neutron hole configuration, \(\pi^{-2}_{11/2}\). (Mariscotti et al., Jülich annual report 1977). Our result is compatible with a very pure proton structure for this state and de-emphasizes the importance of the proton shell-closure at \(Z = 64\).

Another important g-factor, that for the \(13/2^+\) first excited state in \(^{147}\text{Gd}\), is considerably higher than that for the \(i_{13/2}^-\) neutron orbital in the \(\text{Pb-region} (g = -0.154)\). The difference can probably be explained by a large \(3^- (\delta\nu f_{7/2})\) octupole component in \(^{147}\text{Gd}\), which is also consistent with the reduced spectroscopic factors for \(\ell = 6\) single nucleon transfer reactions.

With the basic magnetic moments of single particle states from the present work and from a recent compilation (Fuller, 1976) we have calculated g-factors for several high-spin quasiparticle states in \(^{146,147}\text{Gd}\). In both cases comparison with experiment leads to a preferred quasiparticle configuration, although several would have spins in the experimentally required range. The quoted spins are the most likely, however an uncertainty of one unit of \(\pi\) must be conceded to allow for different vectorial couplings of the quasiparticle spins. The proposed spin-parity assignments should be of considerable value for future theoretical and experimental studies of the yrast properties in these nuclei. It should be noted that the high-spin yrast traps have approximately equal numbers of protons \((n_p)\) and neutrons \((n_n)\) contributing to the total spin, and that their g-factor can be estimated by \(g \approx n_p/(n_p + n_n)\) to an accuracy of 25%. Near doubly closed shells, the high-spin yrast states,
Table 2.16.1

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Reaction</th>
<th>E_{lab} (MeV)</th>
<th>T_{1/2} (ns)</th>
<th>E_{γ} (keV)</th>
<th>a_{2}(t=0)</th>
<th>suggested main configuration</th>
<th>J^{π}</th>
<th>g_{main} c)</th>
<th>g_{exp} d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>144Gd</td>
<td>28Si + 120Sn 130</td>
<td>130 ± 10</td>
<td>231,328, -0.62</td>
<td>(πd_{5/2}^{−2}h_{11/2}^{−2}) 10(νh_{11/2}^{−2}) 0</td>
<td>10^{+}</td>
<td>see text</td>
<td>1.278 ± 0.011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>146Gd</td>
<td>4He + 144Sm 30</td>
<td>6.7 ± 0.1</td>
<td>1079</td>
<td>0.28</td>
<td>(πd_{5/2}^{−1}h_{11/2}^{−1}) 7</td>
<td>7^{-}</td>
<td>1.39</td>
<td>1.283 ± 0.027</td>
<td></td>
</tr>
<tr>
<td></td>
<td>28Si + 122Sn 130</td>
<td>4.1 ± 0.2</td>
<td>766,865</td>
<td>-0.20</td>
<td>(πd_{5/2}^{−1}h_{11/2}^{−1}) 7</td>
<td>7^{-}</td>
<td>1.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>147Gd</td>
<td>28Si + 124Sn 108</td>
<td>22.2 ± 1.5</td>
<td>997</td>
<td>0.53</td>
<td>(νf_{13/2}^{+}) + (3^{-} ννf_{7/2}^{−})</td>
<td>13/2^{+}</td>
<td>see text</td>
<td>-0.037 ± 0.011</td>
<td></td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>5 ± 1</td>
<td>1491</td>
<td>0.24</td>
<td>(πd_{5/2}^{−1}h_{11/2}^{−1}) 7(νf_{7/2}^{−})</td>
<td>21/2^{+}</td>
<td>0.75</td>
<td>0.72 ± 0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>26.8 ± 0.7</td>
<td>183</td>
<td>-0.16</td>
<td>(πd_{5/2}^{−2}h_{11/2}^{−2}) 10(νf_{7/2}^{−})</td>
<td>27/2^{-}</td>
<td>0.88</td>
<td>0.840 ± 0.017</td>
<td></td>
</tr>
<tr>
<td></td>
<td>144</td>
<td>530 ± 30</td>
<td>254</td>
<td>0.27</td>
<td>(πd_{5/2}^{−2}h_{11/2}^{−2}) 10(νh_{11/2}^{−1} f_{7/2}^{−} f_{13/2}^{−}) 29/2 (49/2^{+})</td>
<td>0.45</td>
<td>0.446 ± 0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>148Gd</td>
<td>28Si + 124Sn 120</td>
<td>16.5 ± 0.3</td>
<td>395,482, 784,809</td>
<td>0.26</td>
<td>(νf_{13/2}^{−} f_{7/2}^{−}) 9</td>
<td>9^{-}</td>
<td>-0.12</td>
<td>-0.028 ± 0.009</td>
<td></td>
</tr>
</tbody>
</table>

a) only γ-rays exhibiting large and similar a_{2} coefficients are shown
b) relative to a closed 146Gd core (N = 82, Z = 64)
c) the following basic g-factors were used: protons d_{5/2}^{−1}h_{11/2}^{−1} neutrons h_{11/2}^{−1} f_{7/2}^{−} f_{13/2}^{−}: 1.66, 1.30, -0.18, -0.30, -0.04

typical uncertainties are ± 0.03.
d) paramagnetic correction factors have been applied as explained in the text.
whose configurations arise from excitations of both protons and neutrons, can apparently be described by the concept of an effective rigid body moment of inertia.

2.17 Measurements of g-factors in $^{169}\text{Tm}$, $^{170}\text{Yb}$, $^{172}\text{Yb}$ and $^{174}\text{Yb}$ by transient field interaction at high spin recoil velocities

D. Ward, O. Hausser, H.R. Andrews, P. Taras (Université de Montréal), P. Skensved (Queen's University), N. Rud (Aarhus University, Denmark) and C. Broude (Weizmann Institute, Israel)

In earlier reports we have presented data for the precessions of rotational levels in $^{169}\text{Tm}$ and $^{170,174}\text{Yb}$ recoiling through thin polarized iron (PR-P-115: 2.6, 2.7, AECL-5966). A difficulty with these experiments was the large correction for beam bending effects (PR-P-118: 2.14, AECL-6216). We have repeated the measurements with an improved arrangement that reduces beam bending effects by about a factor of fifty.

Expressing the transient field as a sum of Lindhard-Winther ($B_{\text{LW}}$) and enhanced ($B_{\text{E}}$) components:

$$B(v) = B_{\text{E}}(v) + B_{\text{LW}}(v)$$

with

$$B_{\text{E}}(v) = aZv/v_0$$

we find from the $^{169}\text{Tm}$ calibration $a = 11.8 \pm 0.5$ T. Here $Z$ is the atomic number of the recoil and $v/v_0$ its velocity in atomic units. This value is appreciably smaller than that given earlier namely $a = 18.0$ T (PR-P-115, 2.7, AECL-5966) and is in better agreement with other measurements in heavy nuclei. (O. Hāusser, Proc. Canberra Conference 1978).

The $^{169}\text{Tm}$ calibration was used to interpret the precessions observed for the Yb isotopes. Because of the feeding of levels from higher band members it was not possible to extract individual g-factors, however, if we assume that the rotational g-factors vary smoothly with spin e.g. $g(J) = g_0(1 + aJ^2)$, where $a$ is an empirical parameter,
then the results can be analysed in terms of the parameter $\alpha$ measuring deviations from rotational behaviour.

For the three Yb isotopes studied, the g-factors do not deviate from the rotational model predictions within the limits described by the uncertainty in the parameter $\alpha$, ($= \pm .002$) that is to say the $10^+$ levels are within 20%, $8^+$ levels within 13% etc. of the rotational value.

Comparing one Yb isotope with another, thereby eliminating the uncertainty in the absolute field calibration, we can say that all three isotopes behave in the same way to within 10% at the $10^+$ levels, and 6% at the $8^+$ levels.

This conclusion is interesting in that $^{170}$Yb does not back-bend at least to spin 20. The nucleus $^{172}$Yb is predicted to backbend at $J \approx 12$ in calculations by M. Sano et al, (private communication 1978), however the energy level spacings, known to spin 12, give no indication of an anomaly at such low spin. The experiment indicates a slight increase in the g-factors for $^{172}$Yb although a constant g-factor is also within the uncertainty. The significance of these differences can only be ascertained by extending the results to higher spins. By using heavier projectiles such as $^{86}$Kr, it should be possible to extend the measurements to spin $14^+$ with essentially the same methods.
Table 2.17.1
Summary of results in Yb isotopes

Satisfactory fits to the precession for states 4+ through 10+ could be obtained by assuming a constant g-factor (\( \bar{g}_{\text{exp}} \) in column 1). The parameter \( \alpha \) expresses deviation from rotational behaviour by \( g(J) = g_0 (1 + \alpha J) \) for which we take \( g_0 = g(2^+) \). Uncertainties in parentheses arise from including the uncertainty in the field calibration. The microscopic calculations of Sano et al can be described by this same expression for \( J < 12 \).

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>( \bar{g}_{\text{exp}} )</th>
<th>( g(2^+) ) a)</th>
<th>( \alpha ) exp x 10^{-3}</th>
<th>( \alpha ) (Sano et al b) x 10^{-3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ^{170}\text{Yb} )</td>
<td>0.34 ± 0.02</td>
<td>0.337 ± 0.004</td>
<td>-0.5 ± 1.1 (2.1)</td>
<td>-0.6</td>
</tr>
<tr>
<td>( ^{172}\text{Yb} )</td>
<td>0.33 ± 0.02</td>
<td>0.335 ± 0.008</td>
<td>+1.0 ± 1.1 (2.1)</td>
<td>-2.2</td>
</tr>
<tr>
<td>( ^{174}\text{Yb} )</td>
<td>0.35 ± 0.02</td>
<td>0.339 ± 0.004</td>
<td>+0.3 ± 1.1 (2.1)</td>
<td>-0.7</td>
</tr>
</tbody>
</table>

a) Compiled by V.S. Shirley and C.M. Lederer LBL-3450 (1974)
b) Private communication 1978
2.18 Paramagnetic Correction Factors for Gd-Recoils in Metals

O. Häusser, P. Taras (Université de Montréal), H.R. Andrews, T.K. Alexander and D. Ward

A recent study of the spin relaxation times for rare earth recoil nuclei in metals (PR-P-118: 2.10, AECL-6216) has shown that gadolinium recoils (Z = 64) experience by far the smallest hyperfine fields and hence spin relaxation times in excess of 100 ns can be achieved. In a preliminary experiment with an external magnetic field, spin rotation patterns have been observed for γ-rays de-exciting the 130 ns, J = 10+ isomer in $^{144}\text{Gd}$. However, the observed precession frequencies can only be interpreted in terms of nuclear g-factors provided the magnetic fields induced at the site of the paramagnetic recoil nuclei are known.

We have now investigated the dependence of the observed precession frequencies on the temperature of a suitable metallic host (Sn). The $^{144}\text{Gd}$ isomer and a new high-spin isomer in $^{147}\text{Gd}$ ($T_1 = 530$ ns) served as probes and were excited by ($^{28}\text{Si}, xn$) reactions on thick, isotopically enriched targets of Sn. Since the Zeeman splitting is small compared to the thermal energy $kT$, one may describe the paramagnetic correction factor, $\beta(T)$, by

$$\beta(T) = 1 + g_j u_B (J + 1) B_0 / 3kT$$

where $J = 7/2$ for the predominantly $^8S_{7/2}$ ground state of Gd$^{3+}$, the Lande factor $g_j = 1.9913$, and $B_0$ is the value of the induced internal magnetic field at $T = 0$ K. A total of eleven products of $g\beta(T)$ were determined and fitted by five parameters: $g(^{144}\text{Gd}, 130 \text{ ns}) = 1.278 \pm 0.011$, $g(^{147}\text{Gd}, 530 \text{ ns}) = 0.446 \pm 0.005$, $B_0 (\text{Gd Sn}) = -17 \pm 3T$, $B_0 (\text{Gd Sm}) = -16.9 \pm 1.3T$, and $B_0 (\text{Gd P6}) = -16.6 \pm 1.6T$. The results are summarized in Table 2.18.1.
Our absolute value for $B_0$ (Gd Sn) is smaller and more accurate than the one measured very recently by Faestermann et al, $B_0 = -31 \pm 15$ T. The measured hyperfine fields differ from those for free Gd$^{3+}$ ions ($B_0 = -34 \pm 2$T), indicating substantial conduction electron contributions; these appear to be the same within experimental errors, a somewhat surprising result considering that Sm has a very different electronic structure from that of Sn and Pb.

The data were well fitted assuming an exponential decay of the $\gamma$-ray angular distribution coefficient $a_2(t) = a_2(0) \exp(-t/\tau_2)$, where $\tau_2$ is the relaxation time. The observed relaxation times (see Table 1), measured for
two nuclear g-factors differing by nearly a factor of three, are useful indicators of the origin of the relaxation process. Above the melting point of Sn (505 K) the relaxation times depend only weakly on temperature, with the values for the two isomers inversely proportional to $g^2$. This dependence suggests an Abragam-Pound type relaxation process caused by fluctuating magnetic hyperfine fields. Below the melting point of Sn, $\tau_2$ becomes much shorter, probably as a result of additional effects from quadrupole interactions.

### 2.19 Linear Polarization of the Gamma-Ray Continuum Feeding High Spin States in $^{156,158}$Er and $^{151,152}$Dy

W. Trautmann, J.F. Sharpey-Schafer (Oliver Lodge Laboratory, Liverpool), H.R. Andrews, B. Haas (Centre de Rechers Nucleaires, Strasbourg), O. Häusser, P. Taras and D. Ward

An attempt has been made to measure the linear polarization of the $\gamma$-ray continuum from (HI,xn) reactions, i.e. of the continuous spectrum of unresolved $\gamma$-radiation emitted by the excited product nuclei before discrete yrast states are populated. The interest in the properties of the continuum has been stimulated by the observation of high-spin isomers in rare earth nuclei near the N-82 shell closure ($^{Pr-P-118}$: 2.9, AECL-6216). The possibly oblate shape of these nuclei and the dominance of shell structure should lead to a rather direct feeding of yrast states by statistical cascades although collective M1 cascades have also been predicted (L.K. Peker et al., Phys. Rev. Lett. 41, 457 (1978)). This is in contrast to prolate nuclei where the role of collective $E2$ transitions high above the yrast line has recently been stressed (M. Wakai et al., Nucl. Phys. A307, 349 (1978)).

The reactions 150 MeV $^{32}$S on $^{130}$Te and $^{124}$Sn were employed to produce prolate $^{156,158}$Er and oblate $^{151,152}$Dy
nuclei. The linear $\gamma$-ray polarization was measured with a three Ge(Li) Compton-polarimeter and standard calibration techniques (B.A. Brown et al., Nucl. Phys. A306, 242 (1978)). The continuous background resulting from incomplete shielding of the absorbers from reaction neutrons and background $\gamma$-radiation was measured by suppressing true events with identical lead blocks of 1 cm thickness between the scatterer and absorber crystals. In the Er case a coincidence was required between the polarimeter and at least one of four 3" x 3" Na(Tl) event was accepted. This resulted in particularly clean spectra contaminated by only a small number of discrete $\gamma$-rays from above the Dy isomers.

As a first result the linear polarization of the background-subtracted total spectra, i.e. including discrete lines, is shown in figure 2.19.1. The large polarization of $P_\gamma = 0.2$ to 0.4 observed up to $E_\gamma = 1.2$ MeV in the Er case is typical for stretched E2 transitions. The polarization decreases at higher $\gamma$-ray energies where statistical cascades dominate the spectra. In the Dy case the polarization is small for $E_\gamma < 1$ MeV and not indicative of collective radiation of either multipolarity. This and the rather small intensity of the $\gamma$-ray continuum are consistent, however, with direct feeding of the yrast states by statistical cascades. The stretched E radiation near $E_\gamma = 1.2$ MeV would then have to be ascribed to non resolved yrast transitions at spins above $\approx 40 \hbar$. Further analysis is in progress.
2.20 An Annular Avalanche Detector for Transient Field Studies

The increase of the enhanced transient field at high recoil velocities can best be exploited by Coulomb excitation by very heavy projectiles and the backscattered particle-γ-ray coincidence method. Surface barrier detectors are of limited value for these applications because of their sensitivity to the copiously produced x-rays, because of rapidly accumulating radiation damage, and because they subtend only a relatively small solid angle in the centre-of-mass system as a result of unfavourable reaction kinematics. An annular parallel-plate valanche detector (APPAD) is being constructed which should overcome these difficulties. The APPAD consists of a fine anode mesh with a constant transparency of ~ 83% over the entire angular range (125°-160°), and seven concentric cathode rings of equal areas. The cathode signals are amplified individually to provide angular resolution. The APPAD will operate at a pressure of ~ 1.3 kPa (10 Torr) allowing a window thickness of ≤ 0.3 mg/cm².
2.21 An In-Beam Magnetic Lens Spectrometer
O. Häusser, N.C. Bray and A.S.C. Hyde

We have started the design and construction of a sweeping-current magnetic lens spectrometer which is to be used with a high-resolution Si(Li) detector. The spectrometer has an absolute efficiency of \( \approx 1.5\% \) of \( 4\pi \) and permits focusing of electrons up to \( \approx 2.5 \) MeV. It will be particularly suitable for detecting (in-beam and out-of-beam) conversion electrons and high-energy electrons from atom-atom collisions. The spectrometer is similar to the one developed at the University of Uppsala (Nucl. Inst. Meth. 61 (1975)).

2.22 The Velocity Dependence of Low Energy Stopping Powers
H.R. Andrews and D. Ward, with W.N. Lennard and I.V. Mitchell (Solid State Scien Branch)

The analysis of the stopping power data described previously (PR-P-118: 2.7, AECL-6218) is completed. The results at low velocities are linear in velocity, but not proportional to velocity as expected from the LSS theory (J. Lindhard et al, Kgl. Danske Videnskat. Selskab., Mat.-Fys. Medd. 33 No. 14 (1963)). The velocity axis intercepts are generally positive with the exception of the data in carbon stoppers where they are strongly correlated with the \( Z_1 \) oscillations: negative intercepts for \( Z_1 \)'s at the maxima and positive intercepts for those at the minima. Non-zero intercepts were previously observed by Brown and Moak (Phys. Rev. B6, 90 (1972)) for Br, I and U ions. These results, as well as those of Brown and Moak, cast doubt on the LSS velocity dependence for low energy stopping powers commonly assumed in the analysis of low recoil energy gamma ray line shape data.
2.23 Radioisotope Dating with the MP Tandem Accelerator


The accelerator dating system described previously (PR-P-119: 2.10; AECL-6366) has been improved by including in the counting cycle a step (typically every 10 minutes) to check the generating voltmeter (GVM) stability by shifting the terminal voltage to a value appropriate for $^{12}\text{C}$ of the same rigidity as the $^{14}\text{C}$. During this step the beam was observed on a beam profile monitor placed just in front of the image slits and small adjustments to the GVM reference voltage were made by the machine operator if necessary. This development, and the opening of the various slits in the transport system has overcome the earlier problems of GVM instability. The last serious problem is fluctuation in the transmission efficiency to the spectrometer which contribute up to 20% errors. In the present experiment this transmission efficiency was measured at the beginning and end of each run and was found sometimes to have changed. This problem will be remedied in the next experiment by the provision of a remotely controlled Faraday cup in the spectrometer chamber and automatic measurement of the transmission of $^{12}\text{C}$ as part of the counting cycle. Another improvement planned is the total automation of the cycle by using electronic methods rather than operator intervention to update the GVM reference.

Measurements were made on a number of $^{14}\text{C}$ samples with encouraging results. All results were determined relative to standard NBS oxalic acid whose $^{14}\text{C}$ activity is taken to be 105% that of modern organic carbon. A sample based on atmospheric CO$_2$ was found to have a $^{14}\text{C}$ content ~ 3 times that of the standard; a quantitative dilution to 6.25% and 0.39% by CO$_2$ from dry ice gave measured fractions of the original of (5.0 ± 0.3)% (a 25% discrepancy) and (0.35 ± .10)% (good agreement).
Another attempt to detect $^{36}\text{Cl}$ was made but half of the velocity filter failed, and fluctuating, sometimes large, $^{36}\text{S}$ levels were observed. A detailed analysis of the related address data has not yet been carried out. An improved velocity filter is planned with ~4 times better resolution, and additional chemical processing will be used to ensure lower $^{36}\text{S}$ contamination.

2.24 Tandem Electronics
J.P.D. O'Dacre

The beam current integrator described previously (PR-P-110: 2.16, AECL-5546 and PR-P-115: 2.24, AECL-5966) has evolved into a general purpose unit. Current ranges have been extended up to $10^{-1}$ amperes and the addition of an improved input amplifier has lowered its useful range below $10^{-10}$ amperes. Other modifications permit it to work with either input polarity and with continuous or pulsed beams. Switched meter sensitivity (without affecting charge range) of 1, 3 and 10 times has been added and four separate external meter connections, each with independently variable sensitivity are brought out. Also added are low and high current alarms with variable set points, front panel alarm indication and external connections. The fully floating, guarded input feature has been retained, as has been the eight decade preset charge. Readout is through an eight decade front panel scaler or by pulses fed to an external scaler. Unit of charge on the scaler ranges from $10^{-4}$ to $10^{-12}$ Coulombs (depending on the current range) and is indicated on the front panel.

Leaking shaft seals on the charge balancing voltmeter (PR-P-110: 2.16, AECL-5546 and PR-P-117: 2.17, AECL-6177) have continued to be a problem and it has been decided to move the drive motor inside the gas filled
enclosure. Improvements have been made to the associated electronics but machine shop work will have to be completed before meaningful tests can begin again.

2.25 **Computer and Instrumentation**

F.J. Sharp

**PDP-1**

A random access semiconductor memory bank has been built and partially tested on the computer; when completed this will bring the computer's memory up to its maximum capacity of 32K. The purpose of increasing the computer memory is two-fold: 1) to act as a replacement memory if any of the present core memory banks fail, and 2) to increase the storage capacity.

**PDP-10**

During the last 3 months a number of unexplained system crashes have occurred. Indications are that they may be due to unstable line voltage. Memory problems caused by overlong cables continue to plague the system. Methods for shortening and rerouting the data bus cables are being tried.

Recently write and block errors were experienced with one of the RP-02 Disk Packs, the problem was traced to a loose data bus connector on the disk pack.

**Coincidence Unit**

A mixed coincidence gate unit has been built for the PDP-1 Data Scanner. This 9 channel unit will replace the present 2 channel unit; giving the experimenter a more versatile system for multi-parameter experiments.
Printed Circuit Boards

Boards for the Microprocessor Modem Controller have been received from Doug MacNab Enterprises, Ottawa. The quality of the plated-through holes and etching is satisfactory. The overall quality of the boards is far superior to those produced locally.

2.26 Target Preparations

J.L. Gallant, D.J. Yaraskavitch

Terminal Stripper Foil Development

Four methods of increasing the lifetime of stripping foils are being investigated. In the first, carbon films of the thickness normally used in the MP Tandem terminal were irradiated in a gamma cell, the dose rate ranging from 10 to 50 kGy. The radiation treatment did not enhance the stripper foil lifetime and therefore the experiment was discontinued. In the second, slackened carbon films were prepared. This method, which consists of mounting a carbon film on a circular aluminum ring and reducing the ring diameter in a tufnol collet, was developed by B.H. Armitage of AERE, Harwell and presented at the Munich target conference in September 1978 (see also Daresbury Laboratory Preprint DL/NSF/P76). The slackened foils do have enhanced lifetimes. Thirdly, D.W.L. Tolfree (Daresbury Laboratory, Preprint DL/NSF/P86) suggested that ethylene gas cracked by glow discharge might produce foils with much greater lifetime. We have prepared carbon films 5 \mu g and 10 \mu g/cm^2 by radio-frequency cracking the following gases: ethylene, acetylene, methane, propane, iso-butane. These carbon polymer films will be tested shortly. Finally, carbon films, 5 \mu g and 10 \mu g/cm^2, were prepared by evaporating
carbon from an arc-discharge on a specially treated glass substrate heated to 300°C with nickel chloride as a parting agent. This method was developed by Suehiro Takeuchi et al., Japan Atomic Energy Research Institute. These films will also be tested.

In addition approximately 250 regular stripper foils were produced for normal use.

**Target Preparation**

The following targets were prepared for nuclear physics experiments during the quarter:

- 120Sn and 124Sn heated targets;
- 120Sn and 124Sn with 20 mg/cm² Pb backings;
- 6LiF; iron foils annealed at 800°C in hydrogen;
- 167Tm, 170Yb, 172Yb, 174Yb at a thickness of 1 mg/cm²;
- 15N targets prepared from a sodium cyanide labelled compound;
- 41K, 200 µg/cm² thick; 124Sn on thick gadolinium;
- 143Nd on 30 mg/cm² Pb.

**Work done for Universities**

Deuterium targets consisting of deuterated titanium on 1 mg/cm² copper backings were prepared for Dr. J.C. Kim of the Université de Montréal.

Aluminum 25 µg/cm² on tantalum backing and sodium tungstate targets were prepared for Dr. T. Drake, University of Toronto.

**Work done for other branches**

For the Solid State Science Branch several germanium self-supporting targets (Dr. D. Santry), and zirconium, gold, silver sandwich targets (Dr. I.V. Mitchell) were prepared.

For the Neutron and Solid State Physics Branch, four uranium fluoride targets (800 µg/cm²) were prepared (Dr. J.W. Knowles), and a technique for the fabrication of thin deuterated polyethylene bags for use as target holders for (n,γ) studies was developed. These holders are in regular use at the low background external thermal neutron facility at the NRU reactor (Dr. M.A. Lone).
Coated concave epoxy mirrors and glass slides were prepared for Dr. D. Smith of Physical Chemistry.

2.27 **MP Tandem Operation**

J.C.D. Milton

The accelerator operated very reliably during the quarter. The tank was entered thrice, once to change foils, once to replace failed Pelletron pulleys, once to remove some displaced hardware. The resulting availability (the highest since 1971) is shown in Table 2.27.1 for the period up to December 18.

Outside participation was normal after the high during the summer months. Thirteen experiments were run. Eight visiting scientists were involved in experiments occupying 52% of the available time and their average participation was 40%.

Some components of the accelerator were operated on a trial basis via the PDP 11/34 control computer.

<table>
<thead>
<tr>
<th></th>
<th>hours</th>
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<td>1462</td>
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<td>13.8</td>
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<td>339</td>
<td>16.2</td>
</tr>
<tr>
<td>Total</td>
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2.28 **International Comparison of $^{134}$Cs**

F.H. Gibson, L.V. Smith, A.R. Rutledge and J.S. Merritt

The Bureau International des Poids et Mesures (BIPM) has organized a major international comparison for the measurement of the activity concentration of a $^{134}$Cs
solution during the period October-December, 1978. This laboratory is among twenty-four laboratories that indicated its intention to participate. Our measurements with the $4\pi$(PC)-$\gamma$ coincidence system have been completed. The data from seventeen sources gave a standard error of ± 0.02%. Apart from the actual measurements, considerable effort was spent on tests of the counting equipment. Sources of systematic uncertainty were assessed as requested by BIPM and our estimate of the sum of these is ± 0.13%. A report has been prepared (AECL-5562) that describes these results.

2.29 Standardization of $^{133}$Ba
J.S. Merritt and F.H. Gibson

The $^{133}$Ba standard prepared earlier this year by the $4\pi$(PC)-$\gamma$ coincidence method (PR-P-118: 2.30, AECL-6216) has been registered with the international reference systems of BIPM and International Atomic Energy Agency (IAEA). The accuracy of the standardization was assessed as ± 0.4%. This includes three times the standard error of ± 0.05% and the sum of estimated systematic uncertainties, 0.25%, most of which is from uncertainty in extrapolation of the efficiency function to 100% $4\pi$-counting efficiency. We have been informed that this standard compares favourably with others of the same nuclide registered by international metrology laboratories.

2.30 Calibration of a Mettler M-5 Balance
J.S. Merritt and A.R. Rutledge

The sub-gram weights and the optical scale of a Mettler M-5 balance (serial no. 324387) were calibrated directly with a set of class M weights that had been calibrated with the electronic Mettler ME22 balance versus
three mass standards. These were 200-mg and 1-g weights certified by the Mass Measurement Section of National Research Council of Canada, and the 10-mg weight of the ME22 certified by the manufacturer. It was found that the ME22 gave a precision of ± 1 µg for the calibration of the set of class M weights; this good precision is attributed to the improved reproducibility and linearity of the electronic scale of the ME22.

The optical scale of the M-5 balance was calibrated directly with the 1-, 2-, 3-, 5-, 10- and 20-mg weights of the calibrated class M set. It was found that the response of the scale is adequately linear over the range 0 to 15 mg but deviates by several micrograms at higher loads. Similarly the dialed weights < 1 g were calibrated directly versus corresponding weights of the calibrated class M set. The correction factors obtained were within the balance's specifications, i.e. within both individual and group tolerances for class M weights.

These data were used as corrections to mass values observed in the preparation of sources with this balance for the BIPM $^{134}$Cs comparison (PR-P-120: 2.28, AECL-6451).

2.31 Stability of the Efficiency of the VIP$^{10}$ Ge(Li) Detector

L.V. Smith, F.H. Gibson and A.R. Rutledge with W.F. Slater
(Neutron and Solid State Physics Branch)

Monthly checks on the efficiency of the Ortec VIP$^{10}$ Ge(Li) detector indicated that it was stable within ≈ 0.2% from March 1977 until June 1978, when a gradual decline in efficiency commenced. By September the efficiency had decreased to 11.26% from its initial value of 11.33%, or a 0.6% decrease expressed relatively. Tests with a collimated source revealed that the effect originated from a small volume of the detector which, in addition to the photopeak, gave a small satellite peak at an energy about
10 keV lower. Experimentally it was observed that the effect is related to electric field voltage and that an increase of 100 V essentially eliminates the satellite peak. Therefore the detector is being operated at this higher voltage and its efficiency has remained satisfactorily stable during the last two months.

2.32 Standards Issued

J.S. Merritt, F.H. Gibson, A.R. Rutledge and L.V. Smith

$^{57}$Co - Accelerator Physics
- Environmental Research
- General Chemistry
- Health Physics
- Neutron and Solid State Physics
- Reactor Control
- Reactor Physics
- Radiation & Industrial Safety
- System Materials

$^{90}$Sr - R. & I.S.

$^{137}$Cs - R. & I.S.

2.33 Miscellaneous Services

J.S. Merritt

Sources prepared:

$^{152}$Eu(3) - Reactor Control
$^{241}$Am - R. & I.S.

2.34 Laser Magnetic Resonance (L.M.R.)

D.R. Smith and J.D. Bonnett (Physical Chemistry Branch) with J.S. Geiger

See PR-CMa-47: 3.2.4
2.35 Charge State Dependence of K-Ionization Cross Sections
I.V. Mitchell, W.N. Lennard, P. Mokler (Solid State Science Branch) with G.C. Ball
See PR-CMa-47: 1.2.1

2.36 Quenching of Projectile Charge States for Highly-Stripped Projectiles in Gas Targets
W.N. Lennard, I.V. Mitchell, P. Mokler (Solid State Science Branch) with G.C. Ball
See PR-CMa-47: 1.2.2

2.37 MP Tandem Accelerator Measurements of Natural Isotope Ratios
See PR-B-120: 3.16

2.38 Publications, Reports and Lectures

a) Publications

ISOSPIN-FORBIDDEN PARTICLE DECAYS IN LIGHT NUCLEI (IV);
TOTAL WIDTH OF THE LOWEST T=2 LEVEL OF $^{24}$Mg
A.B. McDonald, E.D. Earle, W. McLatchie, H.B. Mak,
D.J. Martin, P.G. Ikossi
Nuclear Physics A305 (1978) 151

SOME RECENT EXPERIMENTS AT ISOLDE
J.C. Hardy
Proceedings of Isotope Separator Conference, Brookhaven National Labs., Upton, L.I. New York, October 31-
November 1, 1977

EXCITED STATE LIFETIMES IN $^{73}$Br MEASURED BY THE PARTICLE X-RAY COINCIDENCE TECHNIQUE
P. Asboe-Hansen, E. Hagberg, P.G. Hansen, J.C. Hardy,
P. Hornshøj, B. Jonson, S. Mattsson, P. Tidemand-Petersson
Physics Letters 77B (1978) 363

COMPOUND NUCLEUS CROSS SECTIONS FROM NUCLEAR CHARGE DENSITY DISTRIBUTIONS
D. Horn, A.J. Ferguson
Physical Review Letters 41 (1978) 1529

THE ESSENTIAL DECAY OF PANDEMONIUM: $\beta$-DELAYED NEUTRONS
J.C. Hardy, B. Jonson, P.G. Hansen
Nuclear Physics A305 (1978) 15-28
YRAST TRAPS AND VERY HIGH SPIN YRAST STATES IN $^{152}$Dy
Physical Review Letters 41 (1978) 1027

ELASTIC EXCITATION FUNCTION OF $^{12}$C ON $^{40}$Ca AT 180°
T.R. Renner, J.P. Schiffer, D. Horn, G.C. Ball and W.G. Davies
Physical Review C18 (1978) 1927

b) Reports

RESULTS SUBMITTED TO BUREAU INTERNATIONAL DES POIDS ET MESURES (BIPM) FOR INTERNATIONAL COMPARISON OF $^{134}$Cs ACTIVITY
F.H. Gibson, L.V. Smith, A.R. Rutledge, J.S. Merritt
AECL-5562, December 1978.

c) Lectures

LOW ENERGY STOPPING POWERS DETERMINED BY TIME-OF-FLIGHT TECHNIQUES
Paper presented by H.R. Andrews at Fifth Conference on Applications of Small Accelerators, North Texas State University, Denton, November 6-8, 1978

HYPERFINE INTERACTIONS IN RECOILING IONS: MONTE CARLO PREDICTIONS AND EXPERIMENTAL RESULTS
Colloquium presented by H.R. Andrews at Oak Ridge National Laboratories, November 3, 1978

RADIOISOTOPE DATING WITH ACCELERATORS
Colloquium presented at the University of Arizona, Dept. of Geosciences, Tucson, November 9, 1978

THE CHALK RIVER SUPERCONDUCTING CYCLOTRON PROJECT
Seminar presented by W.G. Davies at Max Planck Institute, Heidelberg, October 25, 1978; Gustaf Werner Institute, Uppsala, November 7, 1978 and Nobel Institute, Stockholm, November 8, 1978

$^{14}$C DATING EXPERIMENTS WITH THE CHALK RIVER TANDEM
Seminar presented by W.G. Davies at University of Aarhus, November 15, 1978

PARITY MIXING IN NUCLEI
Paper presented by A.B. McDonald at Michigan State University, November 14, 1978

PARITY VIOLATION EXPERIMENTS
Seminar presented by A.B. McDonald at Queen's University November 29, 1978
VERY HIGH SPIN STATES IN NUCLEI
Seminar presented by O. Häusser at Queen's University
December 20, 1978

The text of the above lectures may not be available in print.
NEUTRON AND SOLID STATE PHYSICS BRANCH
A.D.B. WOODS

3.1 Staff
3.2 Phonons in Deuterated Ammonia
3.3 Small-Angle Scattering from Transferrin
3.4 Neutron-Scattering Response from Al at 800 K
3.5 Actinide Magnetism: UTe and US
3.6 New Structure in the Neutron Scattering from Uranium Nitride
3.7 Collective Magnetic Excitations in the Actinide Intermetallic Compound UPd₃
3.8 Temperature Dependence of the Condensate Fraction in Liquid ⁴He
3.9 Temperature Dependence of S(Q) for Liquid ⁴He
3.10 Lattice Dynamics of Cu(Ge)
3.11 Structure Dependence of the Vacancy-Formation Energy in Stainless Steels
3.12 Influence of Hydrogen in Zr - 2.5% Nb Pressure Tubes on Positron Annihilation
3.13 N4 External Thermal-Neutron Facility
3.14 M1 Giant Resonance in Nuclei with 100 < A < 200
3.15 Search for Parity Violating Decay of the 3562 keV Level of ⁶Li
3.16 Parity Violation in the Photodisintegration of Deuterium
3.17 An Upper Limit on Parity Mixing in ²¹Ne
3.18 Study of the 1.6 MeV Parity Doublet in ⁴¹K
3.19 Reactor Beam-Hole Use
3.20 Supply and Servicing of Semiconductor Detectors and Systems
3.21 Gas Counters
3.22 Electrical Contacts on CdTe
3.23 Photoconductivity Measurements of CdTe
3.24 Glassblowing, Machine Shop and Miscellaneous Services
3.25 Precision Mass Measurements
3.26 Beta-Neutrino Correlations from the Kinematic Shift of Beta-Delayed Particles
3.27 The On-Line Isotope Separator
3.28 Ion-Source Development for the On-Line Separator
3.29 Stability of the Efficiency of the VIP$^{10}$Ge(Li) Detector
3.30 Publications and Lectures
## 3.1 Staff

**BRANCH HEAD: A.D.B. Woods**

### SECTION I  SOLID STATE PHYSICS  TECHNICAL STAFF

- A.D.B. Woods
- W.J.L. Buyers
- G. Dolling
- T.M. Holden (1)
- S.M. Kim
- P. Martel
- A.F. Murray (2)
- B.M. Powell
- E.C. Svensson

- R.S. Campbell (4)
- H.F. Nieman
- M.M. Potter
- D.C. Tennant

### SECTION II  NEUTRON NUCLEAR PHYSICS

- J.W. Knowles
- E.D. Earle
- M.A. Lone

- W.M. Inglis
- R.N. King
- W.F. Mills

### SECTION III  COUNTER DEVELOPMENT

- J.G.V. Taylor
- R.G.C. McElroy (3)
- H. Schmeing

- M.A. Gulick
- W.F. Slater
- R.J. Toone

### GLASSBLOWING  WORKSHOPS

- J.G. Wesanko

- R.R. MacLanders (5)
- A.H. Hewitt
- H.C. Spenceley

### DESIGN  SECRETARIAL STAFF

- W. McAlpin

- Mrs. Dianne Mitchell

---


(3) Postdoctoral Fellow from University of Toronto.


3.2 Phonons in Deuterated Ammonia
B.M. Powell and G. Dolling, with B.H. Torrie
(University of Waterloo)

The experiments previously described (PR-P-119:3.6, AECL-6366) have been continued and we have now measured a nearly complete set of phonon-frequency data for ND$_3$ at 20 K at the $\Gamma$, R and M points in reciprocal space. Several zones in both the (110) and (112) scattering planes have been studied and all six R mode frequencies, and 8 of the 12 M modes are now established; the remaining 4 M modes consist of two close doublets which we are unable to resolve satisfactorily. The data will allow a detailed comparison to be made between the measured phonon frequencies and neutron-scattering intensities and those calculated by Righini et al. (unpublished), on the basis of an intermolecular force model involving short-range "6-exponential" potentials, specific hydrogen bonds, and electrostatic forces acting between point dipoles, quadrupoles and octopoles situated at the molecular centres of gravity.

3.3 Small-Angle Scattering from Transferrin
B.M. Powell, S.M. Kim and P. Martel

The small-angle neutron scattering (SANS) from transferrin molecules in Ringer solution* has been measured on the C5 spectrometer operated in the optimal experimental configuration previously determined (PR-P-119:3.2, AECL-6366). Measurements were made with transferrin concentrations of ~40 g/l in D$_2$O Ringer solution, in H$_2$O Ringer solution, and in mixtures of the two containing 70% D$_2$O and 20% D$_2$O by volume. The effect of transferrin concentration was examined by measuring the SANS for transferrin concentrations

* a salt solution with the pH of blood
of 38 g/l, 22 g/l and 4 g/l in D₂O Ringer solution. The SANS from haemoglobin in D₂O Ringer was also measured as an additional calibration since the result for this molecule is known (J. Mol. Biol. 41 (1969) 231).

After subtraction of the appropriate pure Ringer solution and empty container backgrounds the data were found to fit the Guinier approximation reasonably well. Preliminary analysis with this approximation determines the radius of gyration of transferrin molecules to be ~29 Å and independent of the D₂O concentration of the Ringer solution. The same analysis suggests that the radius is weakly dependent on the transferrin concentration in D₂O Ringer. When analysed with the same approximation the radius of gyration of haemoglobin is found to be 23.8 ± 0.3 Å, in agreement with published values. A more detailed analysis removing the Guinier approximation and including the effect of spectrometer resolution is in progress.

3.4 Neutron-Scattering Response from Al at 800 K

W.J.L. Buyers and G. Dolling, with M.L. Klein (National Research Council) and H.R. Glyde (University of Ottawa)

Previous experiments (PR-P-118:3.4, AECL-6216) have shown that the neutron-scattering response in the region of a particular longitudinal (L) mode at \( a\vec{q}/2\pi = (2.25,2.25,2.25) \) in Al at 800 K consists of a single broadened peak at 6.59 THz superposed on a rather intense multiphonon background. There is no experimental evidence of the two additional satellite peaks at lower frequencies predicted by recent computer-simulation calculations. Calculations of the one- and two-phonon response functions by self-consistent phonon theory exhibit a
single broad peak in good overall agreement with experiment. In fact, if we judiciously "smooth out" the simulation response, to replace the two satellite peaks by an average curve, the agreement with experiment becomes quite acceptable.

A new series of experiments has been performed with the PG(002) analyser crystal of the previous series replaced by Si(111), in order to eliminate undesirable second-order scattering processes at high frequencies (>8 THz). The experiments extended to much higher Q values than before, and wider ranges of frequency were also covered. Several different values of scattered-neutron energy, $E_\perp$, were required for these extended scans. After correction for the changes in $E_\perp$, these results are in good qualitative agreement for all frequencies and Q values with both the self-consistent phonon theory and the "smoothed" computer-simulation calculations. Data taken at larger Q values, where no theoretical results exist, show that the one-phonon L peak disappears before the T peak into the rapidly growing multiphonon background.

3.5 Actinide Magnetism: UTe and US
W.J.L. Buyers and A.F. Murray, with P. de V. DuPlessis and G.H. Lander (Argonne National Laboratory)

As part of a continuing search for spin excitations in actinide rock-salt structure compounds, measurements were made at the N5 triple-axis spectrometer of the neutron scattering from the ferromagnets uranium telluride ($T_C = 100$ K) and uranium sulphide ($T_C = 178$ K). These are the world's largest single crystals of these materials but they are small by normal neutron-scattering
standards (~0.2 - 0.3 cm^3). A resolution optimized for ~6 THz and a harmonic-free experimental arrangement was obtained with a Ge(113) monochromator at 0.8° collimation and a Si(111) analyser at 1.0° collimation set to receive 7 THz neutrons. Sharp spin-wave peaks were observed at 4.2 K in the telluride (a = 6.141 Å) but not in the sulphide (a = 5.481 Å). This is consistent with the elementary notion that interactions with the conduction electrons damp out the localised 5f spin response when the lattice constant is small because the increased overlap of the uranium wave-functions broadens the 5f band. The spin excitations in UTe (ν = 3.5 ± 0.1 THz at (111)) interact with an optic phonon at 5.1 ± 0.2 THz, whose intensity at low angles of scattering largely arises from transferred magnetic amplitude.

3.6 New Structure in the Neutron Scattering from Uranium Nitride
W.J.L. Buyers and E.C. Svensson

Using the spectrometer configuration with which sharp spin excitations were seen in UTe (PR-P-120:3.5, AECL-6452) we have shown that the broad continuum previously observed in UN (PR-P-116:3.8, AECL-6083 and PR-P-117:3.10, AECL-6177) can be resolved at the (110) antiferromagnetic zone centre and at 8.5 K into a sharp peak at 4.5 ± 0.2 THz and, possibly, a high-frequency tail. This peak is distinct from the 3.5 THz TA,LA zone boundary phonon but lies close to the LA phonon branch at (0.5,0.5,0). The close relationship between spin-wave peaks and phonon excitations observed in all actinide rock-salt compounds studied to date (UN, Usb, UTe) is perhaps more than fortuitous.
3.7 Collective Magnetic Excitations in the Actinide Intermetallic Compound UPd$_3$
A.F. Murray and W.J.L. Buyers

For actinide compounds where the valency and hence angular momentum, $\tilde{J}$, are unknown, neutron crystal-field spectroscopy provides a unique tool for identifying the pattern of crystal-field split transitions, and hence determining, through $\tilde{J}$, the electronic ground state of the actinide atom. To this end we have measured the neutron inelastic scattering from a single crystal of UPd$_3$, a hexagonal intermetallic where the four uranium atoms of the unit cell lie in positions of hexagonal or cubic symmetry. The C5 triple-axis spectrometer, equipped with a Ge(111) monochromator and graphite(002) analyser, was operated at constant momentum-transfer and at fixed scattered neutron energies of 3.60 THz, 2.80 THz and 2.01 THz. Well-defined magnetic excitations were observed with closely similar frequencies at 77 K and 4.2 K. The frequency of the stronger excitation, which lies at 3.33 ± 0.07 THz at wave vector (1.9,0,0) reaches a maximum of 4.15 ± 0.10 THz at (0,0,4). The observed dispersion indicates that the magnetic excitations are collective modes rather than single-ion transitions. Appreciable exchange coupling therefore exists despite the absence of long-range order. The double peak near $3\frac{1}{2}$ THz previously observed in polycrystalline UPd$_3$ (Shamir et al., preprint) is thus shown to arise, not from two transitions, but from the density of states of a single dispersion-broadened transition. The intensity of the mode tends to be large when its frequency is small. The present single-crystal measurements reveal in addition a new low-frequency mode, a typical frequency for which is 0.50 ± 0.02 THz at 0.25,0,3). From the temperature dependence of the peak
intensities both transitions are found to originate in the ground state. At room temperature the intensity of the main transition is unobservably small. Analysis is underway to determine if the valency can be uniquely determined from the data.

3.8 Temperature Dependence of the Condensate Fraction in Liquid $^4$He

The measurements begun in the previous quarter (PR-P-119:3.10, AECL-6366) were continued and complete sets of results have now been obtained for temperatures of 1.0 K and 4.2 K. The study has been temporarily suspended while measurements of the temperature dependence of $S(Q)$ are carried out (see PR-P-120:3.9, AECL-6452) but will be resumed on completion of these measurements.

3.9 Temperature Dependence of $S(Q)$ for Liquid $^4$He

As part of the program (see PR-P-119:3.10, AECL-6366 and PR-P-120:3.8, AECL-6452) to determine the temperature dependence of the condensate fraction in liquid $^4$He, accurate values of the static structure factor, $S(Q) = \int S(Q,\omega)d\omega$, are required for a wide range of wave vectors $Q$ at each temperature. Since values for only restricted ranges of $Q$ at a few temperatures are at present available, we have undertaken a study of the temperature dependence of $S(Q)$ using the L3 spectrometer operated in a 2-axis mode with a fixed incident-neutron energy of 26.87 THz. Measurements have been carried out at 1.00, 1.77, 1.97, 2.15 and 4.2 K for scattering angles
1.0° < φ < 124.0° (0.1° steps), and the scattering from the empty specimen container has also been determined. The fast-neutron background was also automatically measured at selected points of each scan. The measurements are continuing and a computer program to reduce the results to S(Q) values is being written by V.F. Sears of Theoretical Physics Branch (see PR-P-120:4.4, AECL-6452).

3.10 **Lattice Dynamics of Cu(Ge)**
E.C. Svensson with E.D. Hallman (Laurentian University)

A study of the lattice dynamics of a fcc alloy of Cu and Ge is underway at the C5 triple-axis spectrometer. Our determination of the lattice constant, 3.6432 Å, indicates that the Ge concentration is 8.6 at.% which is just below the maximum Ge concentration at which the fcc phase is stable at the temperature (296 K) of the measurements. We would expect the change in the average mass to cause a lowering of the phonon frequencies (relative to those for copper) of less than 1% and to have a negligible effect on the lifetimes. However, the different electronic structures of Cu and Ge should give rise to substantial force-constant disorder in the alloy which in turn should lead to considerable perturbation of the phonon frequencies and lifetimes. Preliminary results for the [00c]L branch indicate that the phonon frequencies are, on average, about 5% lower than those for copper.

3.11 **Structure Dependence of the Vacancy-Formation Energy in Stainless Steels**
S.M. Kim

Recent positron-annihilation measurements on the pure iron and CuZn alloys indicate that the vacancy-formation
energy, $E_f$, is strongly influenced by the crystallographic structure. In both systems $E_f$ in the bcc phase was found to be about 0.3 eV lower than in the fcc phase. We have extended previous positron measurements of $E_f$ in a fcc (type 316) stainless steel (PR-P-119:3.11, AECL-6366) to a bcc (type 430) stainless steel in order to investigate the structure as well as the possible composition dependence of $E_f$ in stainless steels.

The temperature dependence of the peak coincidence rate has been measured from 20°C to 1340°C. The S-shaped rise was seen at above 620°C and saturation was observed at 1320°C. The trapping model analysis of the data yields $E_f = 1.39 \pm 0.09$ eV, which is about 0.2 eV lower than that in the fcc type 316 stainless steel. This decrease in $E_f$ is most likely due to the difference in the structure. Further measurements are planned on other bcc and fcc stainless steels.

3.12 Influence of Hydrogen in Zr-2.5% Nb Pressure Tubes on Positron Annihilation
S.M. Kim and W.J.L. Buyers, with G. Van Drunen
(Quality Control Branch)

The possibility of using positrons as a tool to monitor the hydrogen content variation in Zr-2.5% Nb pressure tubes has been investigated. The angular correlation of annihilation photons in normal cold-worked pressure-tube specimens containing 10 μg/g and 40 μg/g hydrogen respectively, has been measured at 10°C and 300°C, the latter being the in-service temperature in the
reactor. It is believed that at 10°C most of the hydrogen is in the form of hydride while at 300°C the hydrogen is in solution.

At each temperature the angular correlation distributions for the two specimens were found to be nearly identical, indicating that positrons are insensitive to the hydrogen content variation between 10 µg/g and 40 µg/g. We find that any change in the peak counting rate up to 40 µg/g hydrogen is less than 0.5% in the normal cold-worked pressure-tube alloy. However a strong temperature dependence was observed. The normalized peak rate at 300°C was (2.7±0.3)% lower than that at 10°C for both specimens. Further angular correlation measurements on the 40 µg/g hydrogen specimen at 150°C and 225°C show that the peak rate decreases continuously as the temperature is increased. The results were reproducible on successive thermal cycles showing that the effect does not arise from annealing processes. Rather it seems likely that as the temperature is raised the positron is removed from the deepest traps because they become occupied with hydrogen atoms that have migrated from the hydride precipitates.

3.13 N4 External Thermal-Neutron Facility
M.A. Lone and W.M. Inglis

Investigation of the Zr isotopes is in progress. In order to select an optimum beam filter further measurements (PR-P-118:3.12, AECL-6216) of the neutron attenuations and the cadmium ratios were performed with various combinations of filters. The results are given in Table 1. The orientation of the cylindrical filters with respect to the beam axis showed no significant effect on the neutron attenuation or the Cd ratio. The Cd ratios were measured
with a $^{235}\text{U}$ fission monitor and various thicknesses of Cd. The results in Table 1 are for 1 mm thickness.

### TABLE 1. Characteristics of Bi and Quartz Filters

<table>
<thead>
<tr>
<th>Filter</th>
<th>Thickness (cms.)</th>
<th>Temp.</th>
<th>n. flux ($10^7$)</th>
<th>Cd Ratio ($10^4$)</th>
<th>Neutron Attenuation</th>
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<td>-</td>
<td>-</td>
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<tr>
<td>Bi</td>
<td>15</td>
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<td>4.4</td>
<td>3.6</td>
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<tr>
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<td>Liq. N$_2$</td>
<td>3.8</td>
<td>7.9</td>
<td>2.1</td>
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<tr>
<td>Quartz</td>
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<td>room</td>
<td>3.3</td>
<td>5.2</td>
<td>2.4</td>
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<tr>
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<td>15</td>
<td>Liq. N$_2$</td>
<td>4.2</td>
<td>12</td>
<td>1.9</td>
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<td>22</td>
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<tr>
<td>Bi + Quartz</td>
<td>15 each</td>
<td>Liq. N$_2$</td>
<td>2</td>
<td>75</td>
<td>4</td>
</tr>
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</table>

3.14 **M1 Giant Resonance in Nuclei with $100 < A < 200**

M.A. Lone with F.C. Khanna (Theoretical Physics Branch)

An estimate of the giant magnetic-dipole resonance (GMDR) energy and the spreading width is obtained from the energy dependence and the absolute magnitude of the average partial widths of the M1 transitions observed from excited states populated in the $(n,\gamma)$ reactions. The intensities of these primary transitions is influenced by the presence of the giant resonance as is well established (G.A. Bartholomew et al., Adv. Nucl. Phys. 7 (1973) 229) in the E1 case.

For most nuclei with $A > 100$ the $(n,\gamma)$ data from the Argonne group (L.M. Bollinger, Proc. Int. Conf. Photonuclear Reactions and Applications, Ed. B.L. Berman, USAEC Report CONF-73-301, Vol. II (1973) p. 783) show that
the average M1 partial width $\Gamma_{M1} \propto E_\gamma^5$ at $E_\gamma \approx 6$ MeV and the ratio $\frac{\Gamma_{E1}}{\Gamma_{M1}} = 7 \pm 1$. The absolute value of $\Gamma_{M1}$ varies from nucleus to nucleus but the M1 strength function $K_{M1} \equiv \frac{\Gamma_{M1}}{DF_\gamma^3} = 1.8 \pm 0.9 \times 10^{-8}$ MeV$^{-3}$ at $E_\gamma \approx 6$ MeV. This is equivalent to $(1.55 \pm 0.77) \mu_0^2$ of $B(M1)\dagger$ per MeV. In a majority of the cases the existing $(n,\gamma)$ data on the well identified transitions cover a limited energy range of 5 to 8 MeV. The only exceptions are in the mass 140 region where in $^{141}$Ce, $^{138}$Ba and $^{136}$Ba the values of $K_{M1}$ at $\sim 9$ MeV are known to be a factor of 2 to 4 higher than the mean value of $1.8 \times 10^{-8}$ MeV$^{-3}$ at 6 MeV.

In order to estimate the GMDR energy $E_g$ and the spreading width $\Gamma_g$ one assumes that, like the giant electric dipole resonance (GEDR), the GMDR has a Lorentzian line shape. Then

$$K_{M1} \equiv \frac{\Gamma_{M1}}{DE_\gamma^3} = 2.45 \times 10^{-9} \frac{gE_\gamma [\sum B(M1)\dagger]}{(E_g^2 - E_\gamma^2)^2 + \Gamma_g^2 E_\gamma^2}$$

where $\Gamma_{M1}$ and the level spacings are in eV and all other energies are in MeV. The sum $\sum B(M1)\dagger$ is the energy weighted sum of the M1 reduced transition probabilities, in units of $\mu_0^2$, due to the spin-flip valence transitions giving rise to the GMDR.

In the mass region $100 < A < 200$ one expects that the sum $\sum B(M1)\dagger$ would be in the range of 300 to 600 $\mu_0^2$ MeV. Assuming this one finds (M.A. Lone and F.C. Khanna, to be published) that the observations $\Gamma_{M1} \propto E_\gamma^5$, $K_{M1} \approx 1.8 \times 10^{-8}$ MeV$^{-3}$ at 6 MeV and the value of the ratio $\frac{\Gamma_{E1}}{\Gamma_{M1}} = 7 \pm 1$ indicate that the GMDR lies between 8 and 9 MeV and its spreading width, is between 4 and 6 MeV. In Ba and Ce the observed values of $K_{M1}$ are at the peak of the GMDR and consequently are higher than in other nuclei.
3.15 **Search for Parity Violating Decay of the 3562 keV Level of $^{6}\text{Li}$**  
E.D. Earle et al.

See PR-P-120:2.2.

3.16 **Parity Violation in the Photodisintegration of Deuterium**  
E.D. Earle et al.

See PR-P-120:2.3.

3.17 **An Upper Limit on Parity Mixing in $^{21}\text{Ne}$**  
E.D. Earle et al.

See PR-P-120:2.4.

3.18 **Study of the 1.6 MeV Parity Doublet in $^{41}\text{K}$**  
E.D. Earle et al.

See PR-P-120:2.5.

3.19 **Reactor Beam-Hole Use**  
A.D.B. Woods

The McMaster and Guelph University spectrometers were in use during the period. The C2 fast-neutron chopper shutdown continued.

The following table summarizes utilization of operating CRNL facilities at NRU beam holes.
<table>
<thead>
<tr>
<th>Beam Hole</th>
<th>No. of Experiments</th>
<th>No. of Participating CRNL scientists</th>
<th>No. of Participating non-CRNL scientists</th>
<th>Efficiency (% of available reactor operating time used for experiments)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>C4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>91</td>
</tr>
<tr>
<td>C5</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td>97</td>
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<td>L3</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>96</td>
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<td>N4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>N5</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>94</td>
</tr>
</tbody>
</table>

Total reactor operating time was 80 days.

3.20 **Supply and Servicing of Semiconductor Detectors and Systems**

R.J. Toone, W.F. Slater and J.G.V. Taylor

The high-purity Ge double diode detector system (No. 4 in the series) has been assembled. After initial tests the detector was removed for reworking to improve its characteristics. Two Ge(Li) detector cryostats were repumped (one of them twice) for Section II. Two commercial Ge(Li) detectors were installed at a test loop for System Materials Branch and an older system was repumped and returned to the same branch. A high-purity Ge detector cryostat was serviced for Accelerator Physics Branch. A Ge(Li) unit returned by Environmental Research Branch was dismantled and the detector put in cold storage.

Three experimental Ge "photon drag" laser pulse detectors were tested by Physical Chemistry Branch. It is not yet clear if an optimum device can be made from the germanium on hand.
3.21 **Gas Counters**
W.F. Slater, M.A. Gulick and J.G.V. Taylor

A high-pressure HP-7 $^3$He counter (0.7 MPa $^3$He + 0.2 MPa Kr) delivered to Section I had much better resolution than the first counters in this series. Two CFIS-2 counters and seven replacement wire assemblies were supplied to Analytical Science Branch, WNRE. Work is continuing on recommissioning the BF$_3$ line.

3.22 **Electrical Contacts on CdTe**
R.G.C. McElroy and R.J. Toone

A number of CdTe surface barrier detectors have been fabricated using electroless deposition techniques. The majority of these devices had Pd contacts deposited from a PdCl$_3$ solution. In general, as $\gamma$-ray spectrometers, they are comparable in performance to detectors with vacuum evaporated Au contacts. To date, however, the best Au-contacted devices are superior to the best Pd-contacted devices. These results are consistent with the fact that, for covalent semiconductors, the surface barrier formed by the deposition of a metal contact is only weakly dependent upon the identity of the contacting metal.

The results show that the performance of a particular piece of CdTe as a $\gamma$-ray detector is primarily determined by the properties of the bulk material, not by the nature of the contacts. The surface preparation is, of course, important when the device is used as an $\alpha$-particle detector.

On the basis of the present measurements, contacts prepared by electroless deposition do not give
better detector performance than vacuum evaporated contacts. The advantage of using electroless contacts is in ease and speed of fabrication that makes them particularly useful for material evaluation.

Although surface properties are undoubtedly important in the fabrication of CdTe γ-ray detectors, they do not appear to be the limiting factor for the currently available material.

3.23 Photoconductivity Measurements of CdTe
R.G.C. McElroy, W.F. Slater and R.J. Toone

The construction of the second version of the marginal oscillator for contactless photoconductivity measurements (PR-P-119:3.23, AECL-6366) has been beset by a number of minor design problems. It is anticipated that it will be completed shortly.

3.24 Glassblowing, Machine Shop and Miscellaneous Services
J.G. Wesanko, R.R. MacLanders, M.A. Gulick, H.C. Spenceley, R.J. Toone and W.F. Slater

A small, portable glass system has been made for Chemical Engineering Branch for extraction of dissolved gases from moderator D₂O at Pickering G.S.. The components are connected with hemispherical joints to facilitate assembly on site. A glass manifold for handling fission product gases has been supplied to Fuel Engineering Branch. Three double-walled quartz and pyrex systems were constructed for Physical Chemistry Branch to be used in low-temperature flash photolysis studies. The amount of glass equipment required for the extraction of ⁹⁹Mo has doubled to one complete system per week.
During this period ninety percent of the machine shop effort went into Nuclear Physics Branch jobs, mostly target holder, ion source and generating voltmeter components.

Miscellaneous services included machining Si sources for NRX Reactor Branch (Van de Graaff Operations), cutting ferrite forms for Quality Control Branch, and cutting semiconductor slices for Solid State Science Branch.

3.25 **Precision Mass Measurements**  
H. Schmeing et al.

See PR-P-120:2.8.

3.26 **Beta-Neutrino Correlations from the Kinematic Shift of Beta-Delayed Particles**  
H. Schmeing et al.

See PR-P-120:2.9.

3.27 **The On-Line Isotope Separator**  
H. Schmeing et al.

See PR-P-120:2.10.

3.28 **Ion-Source Development for the On-Line Separator**  

See PR-P-120:2.11.

3.29 **Stability of the Efficiency of the VIP$^{10}$Ge(Li) Detector**  
W.F. Slater et al.

See PR-P-120:2.31.
3.30 **Publications, Lectures and Reports**

**Publications**

TEMPERATURE DEPENDENCE OF $S(Q,\omega)$ IN SUPERFLUID $^4$He
A.D.B. Woods and E.C. Svensson
Atomic Energy of Canada Limited publication AECL-6259

INTERMOLECULAR DYNAMICS OF DEUTERATED BENZENE
B.M. Powell, G. Dolling and H. Bonadeo
J. Chem. Phys. 69 (1978) 2428
Atomic Energy of Canada Limited publication AECL-6148

ANHARMONIC INTERFERENCE IN SCATTERING EXPERIMENTS
W.J.L. Buyers
in "Correlation Functions and Quasiparticle Interactions in Condensed Matter", edited by J. Woods Halley
Atomic Energy of Canada Limited publication AECL-6147

THE RESONANT SCATTERING OF GAMMA RADIATION FROM LEAD ISOTOPES
J.W. Knowles, A.M. Khan and W.F. Mills
Atomic Energy of Canada Limited publication AECL-6144

**Lectures**

RECENT NEUTRON SCATTERING EXPERIMENTS ON MOLECULAR SOLIDS AT CHALK RIVER
B.M. Powell
University of Lille, Lille, France
September 13, 1978

ORIENTATIONAL DISORDER IN CBr$_4$
G. Dolling
Symposium on Methane, McMaster University, Hamilton, Ont.
October 13, 1978

INTERMOLECULAR DYNAMICS OF C$_6$D$_6$ AND ND$_3$
G. Dolling, B.M. Powell, H. Bonadeo, J.W. Leech and G.S. Pawley
Workshop on Molecular Crystals, Institut Laue-Langevin, Grenoble, France
October 16, 1978
MOLECULAR ORIENTATION IN PLASTIC CRYSTALS
G. Dolling
Imperial College of Science and Technology, London, England
October 24, 1978

MOLECULAR ORIENTATION IN PLASTIC CRYSTALS
G. Dolling
University of Edinburgh, Edinburgh, Scotland
October 25, 1978

NEUTRON SCATTERING FROM ITINERANT FERROMAGNETS AND ANTIFERROMAGNETS
T.M. Holden
Imperial College of Science and Technology, London, England
October 11, 1978

NEUTRON SCATTERING FROM ITINERANT FERROMAGNETS AND ANTIFERROMAGNETS
T.M. Holden
Leeds University, Leeds, England
November 8, 1978

THE MAGNETISM OF URANIUM PNICTIDE COMPOUNDS
T.M. Holden
Queen Mary College, London, England
November 6, 1978

VALIDITY OF THE PHONON APPROXIMATION IN ANHARMONIC CRYSTALS
W.J.L. Buyers
Eastern Fall Symposium, Condensed Matter Physics Division, Canadian Association of Physicists, Hamilton, Ontario
November 11, 1978

RESISTIVITY AND SPECIFIC HEAT IN AN INDUCED MOMENT FERROMAGNET NEAR THRESHOLD: Pr$_3$Tl
P. Bossard, S. Bakanowski, J.E. Crow, T. Mihalisin and W.J.L. Buyers
24th Annual IEEE Conference on Magnetism and Magnetic Materials, Cleveland, Ohio
November 14-17, 1978
MAGNETIC INCOHERENT ELASTIC SCATTERING OF NEUTRONS
FROM AN ANTIFERROMAGNETIC CrFe ALLOY
E. Fawcett and T.M. Holden
24th Annual IEEE Conference on Magnetism and Magnetic
Materials, Cleveland, Ohio
November 14-17, 1978

NEUTRON SCATTERING AND LIQUID HELIUM
A.D.B. Woods
Centro de Investigacion del IPN, Mexico City
November 21, 1978

TEMPERATURE DEPENDENCE OF THE DYNAMIC STRUCTURE FACTOR
OF LIQUID HELIUM
A.D.B. Woods
McMaster University, Hamilton, Ontario
November 29, 1978

SOFT MODES AND CENTRAL PEAKS AT MAGNETIC PHASE TRANSITIONS
W.J.L. Buyers
University of Toronto, Toronto, Ontario
November 23, 1978

INTERMOLECULAR FORCES AND NEUTRON SCATTERING
B.M. Powell
University of Waterloo, Waterloo, Ontario
December 14, 1978

The lectures above may not be available in print.

Reports

A BATTERY POWERED HIGH VOLTAGE BIAS SUPPLY FOR Ge DETECTORS
R.J. Dinger and W.F. Slater
Report No. AECL-5846 (November 1978)
THOORETICAL PHYSICS BRANCH

G.E. Lee-Whiting

4.1 Staff
4.2 Calculations Related to Fusion Reactor Blanket Studies
4.3 Leakage Neutron and Gamma-Ray Spectra from D$_2$O Samples Subjected to Gamma Irradiation
4.4 Neutron Scattering in Liquid Helium
4.5 Penetration of Heavy Ions in Solids
4.6 Meson-Exchange Effects in Thermal-Neutron Radiative Capture
4.7 $\gamma_{pol} + N \rightarrow \pi^+ + N$ and the Hadron Weak Neutral Current
4.8 Anomalous Stopping Power for Intense Relativistic Electron Beams
4.9 Generalised Gauge Models
4.10 Properties of a Shape-Consistent Deformed Oscillator
4.11 M1 Giant Resonance in Nuclei with $100 < A < 200$
4.12 Reports, Publications, and Lectures
4.1 Staff

Branch Head: G.E. Lee-Whiting

M. Harvey
F.C. Khanna
S.A. Kushneriuk
H.C. Lee
V.F. Sears
I.S. Towner
K.B. Winterbon

Visitor

M. Vassanji (1)

Secretarial Staff

M.E. Carey

(1) NRC Post-Doctoral Fellow; from the University of Pennsylvania, arrived September 18, 1978.
4.2 Calculations Related to Fusion Reactor Blanket Studies
S.A. Kushneriuk and P.Y. Wong (Math. & Computation Branch)
a) The Monte Carlo calculations of neutron fluxes and reaction rates in a uranium metal sphere (PR-P-119: 4.2 (AECL-6366)) were completed. Good agreement with measurements, and with the results of previous calculations using the discrete ordinates code ANISN (CRNL report PASS-17-2 (1977)), was obtained.

b) The preliminary neutronic evaluations of graphite-thorium assemblies irradiated by 14 MeV neutrons (PR-P-119: 4.2 (AECL-6366)) were also completed. The evaluations were extended to include Monte Carlo calculations. A report summarizing the results obtained to date has been written.

4.3 Leakage Neutron and Gamma-Ray Spectra from D2O Samples Subjected to Gamma Irradiation
S.A. Kushneriuk and P.Y. Wong (Math. & Computation Branch)

Monte Carlo, gamma-ray and neutron-transport calculations are being undertaken to determine the temporal resolution and the energy spectra of the gamma rays and neutrons that escape out of a stainless steel vessel containing several litres of heavy water, following a pulse of bremsstrahlung radiation incident on the heavy water. The maximum energy of the incident gamma rays is about 2.6 MeV. The neutrons of interest are those produced via the d(\gamma,n)p reaction by gammas whose energies are greater than 2.223 MeV.

The spectra of the emergent radiation and the temporal characteristics of this radiation could be of interest in the design of a D2O target for bremsstrahlung radiation in the experiment proposed by A.B. McDonald et al. (PR-P-119: 2.2 (AECL-6366)) to study parity violation in the photodisintegration of deuterium.
4.4 Neutron Scattering in Liquid Helium

V.F. Sears

A program library, ATMLIB, is being developed for the investigation of neutron scattering in monatomic liquids and gases. The immediate application of ATMLIB will be in the analysis of neutron diffraction and neutron inelastic scattering data for liquid helium (see PR-P-119:4.5 (AECL-6366), PR-P-120:3.9 (AECL-6452)).

Program units have been written and tested for performing the following tasks:
- interpolation of thermodynamic data,
- calculation of shielding and multiple scattering corrections,
- calculation of the double differential scattering cross section, including multiple scattering, for the analysis of neutron inelastic scattering data,
- calculation of the differential scattering cross section, including multiple scattering, for the analysis of neutron diffraction data,
- calculation of the total scattering cross section for the analysis of neutron transmission data.

The calculations depend on suitable models for the coherent and incoherent scattering functions, \( S(Q,\omega) \). At present two types of models have been incorporated in the program: (1) gaussian models, with parameters determined from the low-order sum rules, and (2) a "realistic" model for liquid helium, with parameters determined experimentally. We have also written a package of 15 subroutines to facilitate the output of the results in graphical form.
4.5 Penetration of Heavy Ions in Solids
K.B. Winterbon

In considering recoil motion in a thin slab (PR-P-119:4.6 (AECL-6366)) a reasonable starting point is the calculation of the reflected-particle flux from a semi-infinite medium, starting from the flux distribution in an infinite medium. A program is being written to see if this is feasible.

In two composite targets of technological importance, SiO$_2$ and Si$_3$N$_4$ overlayers on Si substrates, it is an acceptable approximation to calculate the depth distributions of recoil-implanted O or N from the overlayer as if the target were uniform SiO$_2$ or Si$_3$N$_4$, respectively. In calculating the moments of these distributions, some subtle errors in the program were detected and corrected, and various improvements were made in the program. It remains to obtain useful distributions from the moments.

4.6 Meson-Exchange Effects in Thermal-Neutron Radiative Capture
I.S. Towner, F.C. Khanna, and M. Vassanji

The 10% discrepancy between the experimental value of the thermal-neutron radiative capture cross-section by protons and the theoretical value calculated in a single-particle approximation has been explained by Riska and Brown (Phys. Lett. 38B(1972)193) as arising from one-pion exchange processes. Riska and Brown calculated the pion-current process, pair excitation and isobar excitation. We are repeating this calculation including in addition one-rho exchange processes, which we have found in our study of mesonic effects in $\beta$-decay to be important. We shall also use a quark model description of the isobar and compare this with the method based on pion-nucleon scattering amplitudes used previously.
Radiative neutron capture by deuterium and \(^3\text{He}\) nuclei may be even more revealing for meson-exchange effects, because the single-particle approximation gives zero cross-section in these cases providing \(^3\text{He}\) and \(\alpha\) are described by spatially symmetric wavefunctions. Hadjimichael (Phys. Rev. Lett. 31(1973)183) finds half the n+d \(\rightarrow \, ^3\text{H} + \gamma\) cross-section comes from the mixed-symmetry S' state in the single-particle approximation and half from meson-exchange effects. There are no calculations to date to explain the 60 \(\mu\text{b}\) thermal cross-section for n+\(^3\text{He}\) \(\rightarrow \, \alpha + \gamma\), but the single-particle contribution is expected to be negligibly small as it can only arise from the fully antisymmetric spatial components of both \(^3\text{He}\) and \(\alpha\) wavefunctions. We are attempting to explain the entire cross-section as a meson-exchange phenomenon.

4.7 \(\gamma_{\text{pol}} + N \rightarrow \pi^+ + N\) and the Hadron Weak Neutral Current

H.C. Lee

Recent model-independent analyses of neutrino and antineutrino scattering data have shown that, as far as u and d quarks are concerned, the description of the hadron weak neutral current (WNC) in the SU(2) \(\times\) U(1) model of Weinberg and Salam is consistent with all such data provided the mixing angle satisfies \(\sin^2 \theta_{WS} = 0.30 \pm 0.08\). In contrast there has as yet been no experimental determination of the s- and c-quark content of the hadron WNC. We have shown that the weak NN\(\pi\) coupling constant \(f^W_\pi\), which has a strong dependence on these undetermined components, can be directly measured in the asymmetry of the reaction \(\gamma_{\text{pol}} + N \rightarrow \pi^+ + N\) near threshold, with circularly polarized photons. The model dependence of \(f^W_\pi\) is explored in some detail. Further details of this work can be found in a Letter being submitted for publication.
4.8 Anomalous Stopping Power for Intense Relativistic Electron Beams

H.C. Lee

A recently reported, (R.A. McCorkle and G.J. Iafrate, Phys. Rev. Lett. 39(1977)1263), energy-loss mechanism for high-density relativistic electron beams has been examined. This mechanism appears to explain the anomalous plasma heating by a relativistic e-beam in the "collision-less thermal explosion" experiment of Altyntsev et al. (A.T. Altyntsev et al., JETP 13(1971)139). A preliminary attempt to relate this mechanism to the reported enhancement in energy disposition in e-beam fusion experiments is inconclusive. Details of this study can be found in the CRNL report PASS-2-1.

4.9 Generalised Gauge Models

M. Harvey

A study has been made of the recent progress in the unification of the weak and electromagnetic interactions and the subsequent speculations on the gauge structure of the strong interactions. A series of lectures has been given to interested members of Physics Division on fundamental theory leading up to these current developments.

4.10 Properties of a Shape-Consistent Deformed Oscillator

M. Vassanji and M. Harvey

This study is a continuation of an earlier one (PR-P-108:4.5 (AECL-5315)) in which the deformation of a non-axially symmetric oscillator (determined by a shape-consistent condition) changes with angular momentum. The purpose of the present study is to understand, in such a model, how different bands can arise and hence how the moments of inertia for different states depend on the self-consistent condition.
4.11 $M_1$ GIANT RESONANCE INNUCLEI WITH $100 < A < 200$

F. C. Khanna and M. A. Lone (N. S. S. P. Branch)

See PR-P-120:3.14 (AECL-6452).

4.12 Reports, Publications, and Lectures

Reports

LASER-MATTER INTERACTION
F. C. Khanna
AECL-6343 - PASS-6-1

Publications

MIXED FERMI AND GAMOW-TELLER BETA-TRANSITIONS AND ISOSCAIAR MAGNETIC MOMENTS
S. Raman, C. A. Houser, T. A. Walkiewicz and I. S. Towner
Atomic Data and Nuclear Data Tables 21(1978)567

QUENCHING OF AXIAL-VECTOR COUPLING CONSTANT IN THE BETA-DECAY OF FINITE NUCLEI
F. C. Khanna, I. S. Towner and H. C. Lee
Nuclear Physics A305(1978)843

DYNAMICAL THEORY OF NEUTRON DIFFRACTION
V. F. Sears
Canadian Journal of Physics 56(1978)1261

WEAK INTERACTION AND PARITY-NONCONSERVATION IN THE PHOTO- AND ELECTRODISINTEGRATION OF THE DEUTERON NEAR THRESHOLD
H. C. Lee
Physical Review Letters 41(1978)843

DETERMINING PARAMETERS OF THE JOHNSON $S_u$ DISTRIBUTION
K. B. Winterbon
Communications in Statistics, Simulation and Compt. B7(1978)223

Lectures

WEAK INTERACTION STUDIES WITH ELECTRON BREMSSTRAHLUNG
H. C. Lee
given at CAP-Theoretical Physics Division meeting at Univ. of Montreal, November 11, 1978
TEST OF QED WITH NEUTRON CAPTURE GAMMA-RAYS
H.C. Lee
given at Queen's University, November 30, 1978

THE CHALK RIVER HEAVY ION SUPERCONDUCTING CYCLOTRON PROJECT
M. Harvey
given at the Relativistic Heavy Ion Workshop, Edmonton,
December 12-13, 1978

BETA-DECAY OF LIGHT NUCLEI
F.C. Khanna
given at Carleton University, October 30, 1978

The lectures above may not be available in print.
MATHEMATICS AND COMPUTATION BRANCH

D. McPherson

5.1 Staff
5.2 CDC CYBER 170/6600 System
5.3 CDC 3300 System and Communications System
5.4 PDP-10 System
5.5 Statistical Evaluation of Radioactive Constituents in CRNL Effluents
5.6 Data Processing System for Analysis of Fuel Defect Experiments
5.7 Chemical Reaction Simulation
5.8 Simulation and Integration of Differential Equations
5.9 Transient Response of a Microphone to a Laser-Generated Sound Pulse
5.10 Stress Analysis Program
5.11 Information Systems
5.12 Calculations Related to Fusion Reactor Blanket Studies
5.13 Leakage Neutron and Gamma Ray Spectra from D₂O Samples Subjected to Gamma Irradiation
5.14 Miscellaneous Programs and Subroutines
5.15 Operations
5.16 Publications, Reports and Lectures
5.1 Staff

Branch Head: D. McPherson

Section I: Systems

Head:
D. McPherson

Programmer/Analysts:
J.A. Edgecombe
L.D.J. Hansen (1)
J.F. Steljes
C.J. Tanner

Programmer:
E.A. Okazaki

Section II: Operations

Head:
G.N. Williams

Programmer/Analyst:
B.B. Ostrom

Operations Supervisor:
P. McGandy

Operator Supervisor:
A.A. Laroche

Computer Operators:
K.M. Bjarbo
M.H. Burke
L.P.L. Cybulski
M.E. Edwards
C.M. Hepburn
N.E. Oelke
D.L. Roach
M. Robertson
L.J. Sutton

Section III: Mathematical Services and Applications

Head:
J.M. Blair

Mathematical Analysts:
G.H. Keech
W.N. Selander

Programmer/Analysts:
M.B. Carver
L.E. Evans
P.Y. Wong

Programmers:
K.R. Chaplin
K.D. Clark
E.G. Long
B.E. Purcell (2)
B.V. Riff
D.G. Stewart
J.W. Wendorf (3)

Secretarial Staff

K.F. Barnard

(1) One-year assignment at Hahn-Meitner Institute, Berlin, Federal Republic of Germany.
(2) Transferred to Reactor Physics Branch, 1978 October 30.
(3) Waterloo student, terminated 1978 December 22.
5.2 CDC CYBER 170/6600 System

(i) Operating System and Programming Languages

(a) QUERY UPDATE

C.J. Tanner

As reported earlier (PR-P-119; 5.2(i)(a); AECL-6366), the present system version of QUERY UPDATE (QU) contains serious errors and deficiencies, many of which are reputedly cured by the latest release of QU. The new QU, however, cannot be installed in the present operating system, and a revision of the operating system at the present is not feasible. Selected modifications, mainly to the loader, have been made which do not affect any users of the present system but will allow full testing of the new QU.

(b) SPITBOL

G.H. Keech

Two improvements were made to the SPITBOL compiler, version 3.1, for CRNL users: the maximum allowed size of input records was increased to 600 characters from 200, and both input and output routines were modified so that an end-of-file is treated in the same fashion as it is by the SNOBOL compiler-interpreters. Copies of these changes have been sent to the SPITBOL authors.

Installation tests for version 3.3 have not been successful, and no further updates will be attempted until version 3.4 is available. A considerable reduction in execution times is anticipated with this newer version.
(c) "Device Independent" Graphics System

G.N. Williams, J.W. Wendorf and E.A. Okazaki

The SEMBEGS (PR-P-118; 5.2(i)(c); AECL-6216) system is now being used to support device independent graphics. It has been introduced with a minimum of disturbance to users, and all displays and plotters operable in the old system are now being accommodated by the new system. Work is starting on preparing drivers for devices which users have acquired but which could not be supported fully before.

(ii) Subroutine Libraries

(a) New AELIB Manual

L.E. Evans

The work reported in PR-P-119; 5.2(ii)(a); AECL-6366 was completed. The new AELIB Users' Manual has been printed and will be distributed to users prior to the AELIB system change scheduled for 1979 January 22.

(b) Library Improvements

M.B. Carver and D.G. Stewart

Modifications to incorporate improvements in the AELIB integration routines SPARSE, STIFFZ, COSIMP, and QUAD have been tested and installed.

5.3 CDC 3300 System and Communications Systems

(i) Multiple Copies of Output Files Using "Repeat Count"

E.A. Okazaki, J.F. Steljes and C.J. Tanner

A method of transmitting a repeat count from the CYBER 170 or 6600 to the 3300 was implemented, and the 3300 system was modified to enable the handling of multiple
copies of output files as declared by a user on a ROUTE control card. This method is more convenient for both users and operators than the previous "special setup" method.

(ii) Card Input Checking

E.A. Okazaki

The 3300 system was modified so that cards read at the central site are checked for validity before being sent to the CYBER 170 or 6600. Checks are made for valid Hollerith characters for a BCD file, and for correct checksum and card sequence numbers for a standard binary file.

(iii) Keyboard Terminal Support

J.F. Steljes

The editor for BCD input files has been revised and enlarged, removing some inconsistencies present in the old system and providing the user with some new facilities. It is planned to make a similar revision to the editor for ASCII input files.

5.4 PDP-10 System

J.A. Edgecombe

Two upgrades to the monitor were made during the period in order to correct many errors.

The ability to run automatically a pre-processor before, say, a FORTRAN compilation of its output was added to the system, and various pre-processors are being modified to take advantage of this feature.

A memory increment of 65,536 words has been obtained from WNRE, and a magnetic tape controller and two drives have been ordered from DEC. In addition, plans were formulated for relocation of some computer hardware to permit modifications to the Tandem control room stairways, and
plans for supporting the entire computer above the floor, so as to shorten cable runs and enhance cooling airflow, were advanced.

The microprocessor-controlled display were demonstrated by implementing a "window" into the spectrum being examined on the normal display.

5.5 Statistical Evaluation of Radioactive Constituents in CRNL Effluents

L.E. Evans and D.F. Dixon (CRNL Environmental Authority)

The problem is to develop statistical models to characterize measurement of the radioactive constituents in CRNL effluents (i.e. in air borne, ash and process sewer wastes). Preliminary studies have been carried out using as data the tritium emission readings from the process sewer over the past five years. A two-parameter log normal model appears to fit this data reasonably well. The work is continuing with an extreme-value analysis of the same data.

5.6 Data Processing System for Analysis of Fuel Defect Experiments

E.G. Long and J.M. Blair

A data processing system for the analysis of fuel defect experiments at CRNL has been designed by the Reactor Control Branch, and has operated successfully for a number of years. The main users of the system are the Fuel Materials, System Materials, and Reactor Control Branches. As a result of changing requirements and increasing demands on the system, the Mathematics and Computation Branch has been asked to modify the existing software to make it more flexible, to reduce the processing time, and to improve the analytical capabilities.
The present software consists of three separate programs. The first, MTCOPY, copies the field tape containing the γ-ray spectra to a second tape; the second, GRAAS, locates and identifies the peaks in each spectrum; and the third, SUMRT, tabulates the strengths of selected isotopes as functions of time.

The processing time for running MTCOPY can be appreciable, for several reasons. First, because the program requires two tape units, it has to wait until two units are available. Second, the field tapes frequently contain parity errors, and each one may require a program re-run. Third, the tagword information identifying the spectra may be incorrect, and may require editing. To overcome these delays, a new version, X2FM, of the first program has been written, the main objective being to read the field tape once only, recovering from parity errors whenever possible, and to store the data on disk in a random access format ready for editing. In addition, X2FM performs validation checks on the tagword information.

At the present time X2FM is working successfully for field tapes originating from the main X2 reactor loop. The tapes contain eight blocks of 518 words, 6 tagwords and 512 channel counts, per spectrum. Editing of the mass storage file is straightforward, and GRAAS has been modified to read spectra from the disk file rather than from magnetic tape. An alternative input routine is being written to read sidestream data tapes. For these tapes the tagwords are stored with the first block only, and the channel counts are in binary rather than BCD format.
5.7 Chemical Reaction Simulation

(i) Mass Action Kinetics

M.B. Carver and A.W. Boyd (Physical Chemistry Branch)

Work continues on the simulation of the radiolysis of water, and comparison with available experimental data. Good comparisons have been obtained with the original 39-reaction model for low pH values but some discrepancies appear at very high pH. As the MACKSIM codes have been checked rigorously against independent solutions to benchmark reaction sets, the discrepancy is believed to originate in the 39-reaction model. Further reactions have been added and an assessment is underway on the sensitivity of the results to uncertainties in the values of reaction rate constants.

(ii) Chemical Equilibria

M.B. Carver, K.R. Chaplin and P.V. Balakrishnan (System Materials Branch)

A study of the effects of condenser water chemistry on corrosion in steam generators is underway. This involves the solution of a number of chemical equilibrium equations which may be solved by the non-linear equation solver ZSYSTM. However, preliminary work has showed this method of solution, although fast, is extremely sensitive to choice of parameters and convergence is not always obtained.

As an alternative approach, the problem has been formulated in terms of kinetics by computing the individual rate constants of the forward and back reactions from the equilibrium constant, and a base rate which is large in comparison to the input and output rates. This procedure which gives comparable results and is numerically stable, was performed in a modified version of the MACKSIM program. This required several extensions incorporated to compute
kinetic rates from the equilibria, permit input and output feedwater, and identify and handle correctly the formation of volatiles and precipitates of the above; precipitate formation was most difficult to handle numerically, as it involves a dynamic discontinuity in which the precipitate reaction does not occur until critical ionic concentrations are reached, but then occurs extremely rapidly. A ramp increase was found suitable.

Computed results are satisfactory, and further development of the model is underway.

5.8 Simulation and Integration of Differential Equations

(i) Ordinary Differential Equation Integration

M.B. Carver and D.G. Stewart

Some of the evaluation criteria for the test equation sets mentioned in PR-P-119; 5.10(i); AECL-6366, have been modified to reflect a more equivocal assessment of integration algorithms. About half of the algorithms initially tested have been rejected as unsuitable. Tables comparing the remaining algorithms have been prepared.

(ii) Method of Lines Solution of Hyperbolic Partial Differential Equations

M.B. Carver

The pseudo-characteristic method of lines solution of the conservation equations of compressible flow was described in PR-P-119; 5.10(iii); AECL-6366. The generality of the method has been confirmed by using similar techniques on the equations governing shallow water flow. These have been tested against an independent method of characteristics solution of flow over an obstacle. The pseudo characteristic method is the only finite difference method which guarantees a stable solution under these conditions.
(iii) Computation of Molten Boundary Migration in a Fuel Pin Subject to Central Melting

M.B. Carver, W.N. Selander and H.E. Sills
(Applied Mathematics Branch)

The equations governing the transient heat conduction in a fuel element have been written allowing the possibility of melting in the centre. As it is difficult to track the migration of the molten boundary in a discrete grid system, the boundary is immobilized by a coordinate transformation, and the new coordinate system is permitted to expand and contract following boundary movement.

The model includes flux depression and current correlations for specific heat and conductivity. Preliminary runs without melting have been compared to the fuel modelling program ELESIM, and some slight discrepancies are yet to be rationalized.

(iv) Computation of Organ Burdens Arising from Inhalation Exposure to Radiation

M.B. Carver, D.G. Stewart and J.R. Johnson
(Medical Research Branch)

The differential equations describing organ burdens and excretion rates during and following inhalation exposure to a radioactive nuclide have been written in general form for FORSIM to compile current and accumulated total doses in individual organs and systems of the human body.

The program will be used to establish annual limits of intake for members of the public for over 100 isotopes. Prototype runs using uranium with a half life of $10^6$ days have been successfully completed and other isotopes will be assessed on completion of the requisite input database at WNRE.
5.9 Transient Response of a Microphone to a Laser-Generated Sound Pulse

W.N. Selander and K.R. Chaplin

A pulsed laser beam is propagated through a gas. The energy deposition along the beam, in the form of molecular excitations, causes a pressure pulse to propagate into the gas. This pulse is recorded on a sensitive microphone located some distance from the path of the beam.

The analytical task is to solve the wave equation to obtain the shape of the pressure pulse, and to determine the response of the microphone to it. For the present calculations it has been assumed that energy deposition occurs in a rectangular pulse, and that the microphone diaphragm acts like a one-dimensional lightly-damped oscillator. The computed response shows good qualitative agreement with experiment. More detailed comparisons are being made, and a more complicated model is being investigated.

The purpose of these calculations is to provide calibration for the microphone signal which is being used to measure the energy deposited by the laser beam. The work is being done on behalf of D.K. Evans and R.D. McAlpine of Physical Chemistry Branch.

See PR-CMa-47, 3.2.3, AECL-6455.

5.10 Stress Analysis Programs

(i) MARC - General

B.V. Riff

No changes were made to MARC and no problems were encountered.

During this period MARC was used an average of six times a day.
(ii) **TPIPE - General**

B.V. Riff

Changes were made to the program to fix some minor problems and to bring the code up to level 4.1.

During this period, TPIPE was used an average of 40 times a day.

5.11 **Information Systems**

(i) **Computer-aided Design (CAD) System**

**Drawings Index File Program - CADRAW**

K.D. Clark

A COBOL program (CADRAW) was written for the Design and Technical Service Branch to maintain a data base file involving CAD drawings. Records in the random file (referenced by drawing number) contain the information required to retrieve drawing files from the magnetic storage tapes written by the CAD system. Sorted lists of data base contents may be generated based on drawing numbers, designers' names, dates of drawings, numbers of storage tapes containing drawing files, and trades involved in drawings.

(ii) **CRNL Bell Telephone Equipment Data Base**

K.D. Clark

Work continued on programs of the data base project for Protective Services Branch involving the management of equipment rented from Bell Canada by CRNL. Equipment records consisting of equipment type, quantity, monthly rate, etc., are contained in two random access files. For each data file, four data manipulation COBOL programs have been completed. These consist of a data insertion program, a data editing program, an equipment listing program, and an equipment removal program. Project documentation remains to be completed.
(iii) Personnel Radiation Recording System

C.J. Tanner, E.G. Long and B.V. Riff

All personnel dosimetry processing is now being performed at the CRNL Computing Centre. The system is not completely operational yet but should be shortly. Tasks that remain are:

(a) Ability to enter radiation data by employee number rather than badge number.
(b) Ability to process radiation data for employees who have left AECL.
(c) Create tape copies of radiation data for historical purposes.
(d) Documentation for the system.

5.12 Calculations Related to Fusion Reactor Blanket Studies

P.Y. Wong and S.A. Kushneriuk (Theoretical Physics Branch)

See PR-P-120; 4.2; AECL-6452.

5.13 Leakage Neutron and Gamma Ray Spectra from D₂O Samples Subjected to Gamma Irradiation

P.Y. Wong and S.A. Kushneriuk (Theoretical Physics Branch)

See PR-P-120; 4.3; AECL-6452.

5.14 Miscellaneous Programs and Subroutines

(i) Recrystallization of Zircaloy

K.R. Chaplin

New data were fitted to a model suggested by C.E.L. Hunt, Fuel Engineering Branch, for the recrystallization of zircaloy (see PR-P-118; 5.8; AECL-6216).
(ii) **JAGPREP**

G.H. Keech

This program, which edits and prepares data for the spectrum-fitting program JAGSPOT, was modified by the addition of its own table look-up function, since the AELIB routine LOCINT was inadequate for JAGPREP's purposes.

(JAGPREP creates DATPAK tapes under the control of user data cards.)

(iii) **MICROD**

G.H. Keech

Assistance was provided to Paul Lee, Theoretical Physics Branch, in preparing the nuclear physics code MICROD for off-site users.

5.15 **Operations**

(i) **DAYFILESCAN**

B.V. Riff

A SPITBOL program was written to scan the old-dayfile files for attaches of specified permanent files and system program names. This program is being used to record the number of attaches of MARC and TPIPE in a day.
(ii) Computer Use by Division

The following table is an analysis of the jobs processed during the quarter:

<table>
<thead>
<tr>
<th>Division</th>
<th>Number of Jobs</th>
<th>Equivalent Commercial Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Products</td>
<td>0 (0.00%)</td>
<td>0.00 (0.00%)</td>
</tr>
<tr>
<td>Heavy Water Projects</td>
<td>791 (0.82%)</td>
<td>11460.05 (0.56%)</td>
</tr>
<tr>
<td>Power Projects</td>
<td>20542 (21.24%)</td>
<td>747354.50 (36.79%)</td>
</tr>
<tr>
<td>Whiteshell</td>
<td>1960 (2.03%)</td>
<td>189404.69 (9.32%)</td>
</tr>
<tr>
<td>CRNL:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computing Centre</td>
<td>31502 (32.57%)</td>
<td>291744.13 (14.36%)</td>
</tr>
<tr>
<td>Contracts</td>
<td>1374 (1.42%)</td>
<td>26530.75 (1.31%)</td>
</tr>
<tr>
<td>Tech. Inform. Univ. Rel'ns</td>
<td>2690 (2.78%)</td>
<td>15200.84 (0.75%)</td>
</tr>
<tr>
<td>Office of the Vice President</td>
<td>0 (0.00%)</td>
<td>0.00 (0.00%)</td>
</tr>
<tr>
<td>Biology and Health Physics</td>
<td>2034 (2.10%)</td>
<td>18343.22 (0.90%)</td>
</tr>
<tr>
<td>Chemistry and Materials</td>
<td>3261 (3.37%)</td>
<td>118668.25 (5.84%)</td>
</tr>
<tr>
<td>Physics</td>
<td>3751 (3.88%)</td>
<td>61120.31 (3.01%)</td>
</tr>
<tr>
<td>Electronics Inst. and Control</td>
<td>985 (1.02%)</td>
<td>14058.48 (0.69%)</td>
</tr>
<tr>
<td>Adv. Projects, Reactor Physics</td>
<td>7845 (8.11%)</td>
<td>206831.69 (10.18%)</td>
</tr>
<tr>
<td>Fuels and Materials</td>
<td>10096 (10.44%)</td>
<td>208773.97 (10.28%)</td>
</tr>
<tr>
<td>Administration</td>
<td>740 (0.76%)</td>
<td>5548.41 (0.27%)</td>
</tr>
<tr>
<td>Medical</td>
<td>160 (0.17%)</td>
<td>473.17 (0.02%)</td>
</tr>
<tr>
<td>Finance</td>
<td>2907 (3.01%)</td>
<td>46257.81 (2.28%)</td>
</tr>
<tr>
<td>Operations</td>
<td>3647 (3.77%)</td>
<td>33616.80 (1.65%)</td>
</tr>
<tr>
<td>Maintenance and Construction</td>
<td>0 (0.00%)</td>
<td>0.00 (0.00%)</td>
</tr>
<tr>
<td>General Services</td>
<td>55 (0.06%)</td>
<td>375.06 (0.02%)</td>
</tr>
<tr>
<td>Plant Design</td>
<td>534 (0.55%)</td>
<td>10942.94 (0.54%)</td>
</tr>
<tr>
<td>Special Projects</td>
<td>1849 (1.91%)</td>
<td>24591.08 (1.21%)</td>
</tr>
<tr>
<td>Others</td>
<td>11 (0.1%)</td>
<td>5.92 (0.00%)</td>
</tr>
<tr>
<td></td>
<td>96734</td>
<td>2031302.07</td>
</tr>
</tbody>
</table>
5.16 Publications, Reports and Lectures

Publications

A SIMPLY EXTENDED AND MODIFIED BATCH ENVIRONMENT GRAPHICAL SYSTEM (SEMBEGS)
J.W. Wendorf
First Place in the 1978 ACM Student Paper Competition

RATIONAL CHEBYSHEV APPROXIMATIONS FOR THE BICKLEY FUNCTIONS \( K_i(x) \)
J.M. Blair, C.A. Edwards and J.H. Johnson

HYDRODYNAMIC OSCILLATIONS IN THE GENTILLY-1 REACTOR STEAM MAINS
W.N. Selander, E.O. Moeck and P.Y. Wong
Also published as AECL-6229.

NUMERICAL SIMULATION OF A SYSTEM DESCRIBED BY IMPPLICITLY DEFINED ORDINARY DIFFERENTIAL EQUATIONS CONTAINING NUMEROUS DISCONTINUITIES
M.B. Carver and S.R. MacEwen (Materials Science Branch)

EFFICIENT INTEGRATION OVER DISCONTINUITIES IN ORDINARY DIFFERENTIAL EQUATIONS SIMULATIONS
M.B. Carver

SIMULATION, MODELLING AND DECISION IN ENERGY SYSTEMS
M.B. Carver

Reports

EXPLICIT FORMULAS FOR THE COMPUTATION OF FRICTION FACTORS IN TURBULENT PIPE FLOW
W.N. Selander
AECL-6354, November 1978.

ACOUSTIC ANALYSIS OF HYDRODYNAMIC OSCILLATIONS IN THE GENTILLY-1 STEAM MAINS
W.N. Selander and P.Y. Wong
AECL-6176, October 1978.

AELIB USERS' MANUAL
L.E. Evans (Editor)
AECL-6076, September 1978.
ACCELERATOR PHYSICS BRANCH

J.S. Fraser

6.1 Staff

6.2 Nuclear Power Applications
  6.2.1 Injector Test Experiment
  6.2.2 Ion Source Development
  6.2.3 High Current Test Facility
  6.2.4 Electron Test Accelerator
  6.2.5 Fertile-to-Fissile Conversion Experiments at TRIUMF

6.3 Research Applications
  6.3.1 Fast Intense Neutron Source
  6.3.2 Heavy-Ion Superconducting Cyclotron

6.4 Mechanical Laboratory
  6.4.1 Injector Test Experiment
  6.4.2 Ion Source Development
  6.4.3 High Current Test Facility
  6.4.4 Electron Test Accelerator
  6.4.5 Fast Intense Neutron Source
  6.4.6 Heavy-Ion Superconducting Cyclotron
  6.4.7 Reactor Physics

6.5 Publications, Reports, Papers, Lectures and Patents
6.1 Staff

BRANCH HEAD: J.S. Fraser

Professional Staff

C.B. Bigham
J.C. Brown
B.G. Chidley
L.W. Funk
E.A. Heighway
J.D. Hepburn
S.B. Hodge
C.R.J. Hoffmann
J.A. Hulbert
R.M. Hutcheon
J. McKeown
G.E. McMichael
J.H. Ormrod
H.R. Schneider
S.O. Schriber (1)
M.R. Shubaly
J. Ungrin

Technical Staff

R.T.F. Bird
L.F. Birney
R.J. Burton (2)
H.F. Campbell
D.W. Clements
M.R. Cox
K.A. Dobbs
L.E. Geoffrey
K.J. Hohban
A.B. Hood
J.C. Jones
S.H. Kidner
P.J. Metivier
W.L. Michel
R.A. Vokes
A.E. Weeden

Mechanical Laboratory

J.E. Anderchek
R.J. Bakewell
R.J. Kelly
N.I.G. Labrie
D.W. Warren
J.F. Weaver

Laboratory Services

J.H. Hewitt (3)
K.T. McKee (4)
J.J. Murphy

Secretarial Staff

Mrs. M.A. Trecartin

(1) Posted to Los Alamos Scientific Laboratory effective 1978 July 10.
(2) Joined Branch 1978 November 06.
(3) Transferred to Chemistry and Materials Division effective 1978 December 11.
(4) Transferred from Nuclear Physics Branch effective 1978 December 11.
6.2 Nuclear Power Applications

6.2.1 Injector Test Experiment
M.R. Shubaly

Phase I of the Injector Test Experiment covers the design, construction and commissioning of a preaccelerator to give a high quality 50 keV, 0.5 A dc proton beam. Design work is essentially complete and component fabrication is underway. The air-conditioned enclosure, located in the # 1 high bay of Bldg. 145 is nearly completed. Design of the high voltage enclosure fence, the high power wiring and the cooling water circuit is complete. Some beam line components have been completed. All major components, except the high voltage power supply, are on hand.

6.2.2 Ion Source Development
M.R. Shubaly

Development of high-current dc ion sources suitable for an accelerator breeder is continuing. Emittance measurements on multiple beams have been made.

a) Ion Source Test Stand

Modifications to the test stand during the past quarter include the replacement of the Ultek ion pump with a 300 l/s (for hydrogen) diffusion pump system to improve operation at high gas flow rates, installation of a large viewport with a measuring grid for more accurate estimation of beam size, and upgrading of the filament power supply. A major problem encountered during the past quarter has been the failure of the epoxy ceramic-to-metal bond on the extraction column. Efforts to resolve this problem are underway.

b) High-Current Ion Source

Development of the duoPIGatron ion source continues.
7-aperture source are restricted to single apertures or up to 3 at a time. There is no indication of beam-beam interaction leading to a growth in emittance. This is not surprising as the area in phase space enclosing the beam from three apertures is no larger than the area that one would expect from the superposition of the three beams run separately. Values for emittances are summarized in Table 6.2.2.1. The high emittance of the single hole at + 0.3" was found to have been caused by damage to the aperture edge.

Table 6.2.2.1

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>Voltage kV</th>
<th>Current mA</th>
<th>Fraction of beam</th>
<th>Emittance ( \pi ) mm-mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single hole side (-0.3&quot;)</td>
<td>39</td>
<td>39</td>
<td>1.00</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(37)</td>
<td>0.96</td>
<td></td>
<td>0.43</td>
</tr>
<tr>
<td>Single hole centre (0)</td>
<td>42</td>
<td>48</td>
<td>1.00</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(46)</td>
<td>0.96</td>
<td></td>
<td>0.49</td>
</tr>
<tr>
<td>Single hole side (+0.3&quot;)</td>
<td>42</td>
<td>41</td>
<td>1.00</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(38.5)</td>
<td>0.94</td>
<td></td>
<td>0.46</td>
</tr>
<tr>
<td>3 holes</td>
<td>42</td>
<td>132</td>
<td>1.00</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(126)</td>
<td>0.96</td>
<td></td>
<td>8.1</td>
</tr>
<tr>
<td>3 holes (higher current)</td>
<td>45</td>
<td>180</td>
<td>1.00</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(175)</td>
<td>0.97</td>
<td></td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>(171)</td>
<td>0.95</td>
<td></td>
<td>9.0</td>
</tr>
<tr>
<td>3 holes (masked 7-aperture plate)</td>
<td>188</td>
<td>1.00</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>179</td>
<td>0.95</td>
<td>8.6</td>
<td></td>
</tr>
</tbody>
</table>
Measurements with the emitting apertures rotated 60° from the plane of the EMU showed that, in the plane of the EMU, the phase space area enclosing these beams falls within the phase space area of the three in-line beams. Thus the full design beam current of 455 mA should have a normalized emittance of ≤ 10 π mm.mrad.

A study of beamlet focusing by aperture displacement was carried out. If the outer plasma apertures are displaced inwards a small amount, δ, the beamlets will cross at a distance L ∝ 4 ad/δ, where "a" is the spacing of the apertures in the accel and decel electrodes and "d" is the spacing between plasma aperture plate and accel electrode. This focusing effect was observed with a slight improvement in emittance, and no discrete beamlet structure was observed.

Ion source and extraction column behaviour at high current using all seven apertures is currently being studied. At present, currents of more than 425 mA can be produced for spark free periods of greater than half an hour. The main limitation is the filament emission current.

A lanthanum hexaboride cathode gives improved arc stability and cathode lifetime at high arc currents, and a multipole cusp containment system at the base of the source improves plasma uniformity and reduces the level of noise on the beam. Measurement on a test jig indicate that a 12 pole cusp is optimum for a field free extraction area of about 16 cm². At 400 mA arc current and 30% electrode transparency, this should give about 1.9 A beam current. Material is on hand to fabricate a redesigned source incorporating these modifications.

**c) Other Studies**

An improved version of the simulation code AXCEL is now in use. This version calculates a self consistent emission (plasma) surface shape given the characteristics of the source plasma. One of the first uses of this code was to
study the optics in the Fast Intense Neutron Source (FINS) accelerating column. No problems were found at the low currents presently being run, but a potential problem at the design current was identified. A suitable modification to the column geometry was devised and has been implemented.

6.2.3 **High Current Test Facility**

B.G. Chidley

Work continues on the commissioning of the 3 MeV 100% duty factor proton linear accelerator which will be used to study problems associated with the low energy portion of an accelerator for an accelerator breeder.

a) **Injector**

J. Ungrin

The 10 kHz motor generator set was returned to operation late in the quarter. The output excitation curve up to 15 kW follows the original curve supplied by the manufacturer and indicates that the rehabilitation of the damaged windings has been successful.

Voltage conditioning of the 7 electrode 3.1 MV/m column, which was installed but only partially conditioned before the generator failure, has been completed. Low intensity beams have been accelerated but no conclusion can be reached yet on the effect of the change from 10 to 7 electrodes. The column drain was increased during the shut-down to 2.25 mA from 0.25 mA by the addition of new resistor chains.

The 2.1 MV/m column has been completely fabricated. Testing of this column will take place after the present series of tests on the 3.1 MV/m column.
b) **The rf System**  
J.C. Brown and B.G. Chidley

Repairs to the tetrode driver plate resonator were completed with the installation of a new teflon insulating sleeve on the resonator inner wall thereby permitting resumption of Alvarez tank rf conditioning.

The circulating pump for the freon system was delivered in late September but cooling system commissioning could not be completed due to poor pump performance. Circulation tests established that the pump is capable of delivering the required flow at the specified head but the net pump suction head (NPSH) needed to prevent cavitation in the pump inlet was excessively high. This head is provided by a gas overpressure and results in the elevation of the tube cooling channel inlet pressure above the maximum allowed by the tube manufacturer.

A number of attempts to reduce the NPSH by impeller modification and replacement have proven unsuccessful. The piping arrangement was modified to place the tube cooling channel at the lowest possible pressure in the circuit thereby allowing the flow to be increased sufficiently for triode filament operation.

The solid state alarm and control was completed and installed however there have been a few spurious shutdowns due to noise leakage during injector arc downs.

Triode vacuum conditioning is now in progress and power operation is planned to start when the gas level is satisfactory.

A new 12-channel turbine flowmeter monitoring unit was completed and installed. Also the final version of the lock-in amplifier section of the Alvarez tank frequency controller was completed. Initial performance during rf conditioning of the Alvarez tank has proven satisfactory.
The freon loop is shown in Fig. 6.2.3.1.

c) Alvarez Tank

J.C. Brown, B.G. Chidley and J. Ungrin

The rf conditioning of the Alvarez tank has proceeded up to 28 kW cw using the 75 kW tetrode amplifier. At this point severe heating of the drift tube bellows occurred and an air leak developed. The bellows on this tank are external and can be cooled fairly effectively but the assemblies contain "O" ring seals which will leak if overheated. The rf shields on the drift tube stems to eliminate currents on the bellows appear to be effective and tests are in progress to determine the most satisfactory form of these shields.

6.2.4 Electron Test Accelerator

J. McKeown

Work continues on testing the characteristics of this two-tank 4 MeV 100% duty factor electron accelerator intended to study problems associated with the main portion of an accelerator breeder based on a proton linear accelerator.

a) Accelerator Operation

G.E. McMichael

A new beam stop, designed for up to 100 kW beams, has been built and installed. A two-dimensional beam scanner, to cause the beam to uniformly illuminate an area of 530 cm$^2$ at a 1 Hz rate, will be ready for testing by early January. A program of upgrading the beam line to protect against inadvertent beam spill is underway. Currently the 3.8 cm ID, 0.3 cm wall stainless steel pipe between the β=1 structure and beam stop has been replaced with 5 cm ID, 0.6 cm wall OFHC copper pipe. It is planned at a later time to change the pipe between the two accelerating structures.
Fig. 6.2.3.1 Freon 113 Cooling System showing Main Circulating Pump at Centre
A much improved computer program for automated start-up of the $\beta=1$ accelerating structure is now in service. It is able to have the structure ready for beam within 6 minutes from a room-temperature start, and in 3-4 minutes after a trip. A similar program for the graded-$\beta$ structure is undergoing tests.

b) High Power Pancake-Coupled Structure

J. McKeown

Experiments continued with the aluminum model to find a suitable design of coupling iris in the central accelerating cell. A large hole was cut in the cell and the iris, supported on a WR-975 waveguide flange, attached. The size of the iris terminating the tapered waveguide section was increased and measurements made of the voltage standing wave ratio (VSWR). As expected coupling increased until an oval shaped iris of width 7.0 cm provided critical coupling. This width exceeded the dimensional constraint imposed by the cooling channels in this cell, hence a new iris only 5.7 cm wide was fabricated and step measurements taken as before. The measurements show that the design requirement of an over-coupled structure with a VSWR of 1.5 can be achieved with an elliptical shaped iris having a major axis of 8.4 cm.

Machining of the ten copper segments has begun and is proceeding ahead of schedule. Design of the cooling system is complete and the structure assembly drawings are well advanced.

c) Computer Data Acquisition and Control System

G.E. McMichael

Major modifications have been made to the real-time operating system "RTOS" and the new version was installed November 2. This replaces a patched version dating from
June 1976. All identified problems in the old version have been corrected, as well as the previously reported but unidentified problem of occasional lock-up of tasks using the analog multiplexor. This latter problem occurred only when the system was heavily loaded and required a three-fold coincidence of two tasks trying to do analog I/O simultaneously with a third task doing digital input under interrupt control. A complete rewriting of the digital I/O handler was necessary.

In addition to the fault corrections, numerous modifications were made for ease of operation and improved efficiency. These include such things as: new operator commands for disk and magnetic tape files, additions and corrections to the re-entrant subroutine library, and code optimization in the Executive, Supervisor and Loader modules of the operating system. The new package has exhibited a zero failure rate since installation.

6.2.5 Fertile-to-Fissile Conversion Experiments at TRIUMF

B.D. Pate (University of British Columbia), I.M. Thorson, F.M. Kiely (Simon Fraser University) with J.S. Fraser and P.M. Garvey (Reactor Physics Branch)

This work is intended to provide experimental measurements of neutron and fissile material production in spallation targets for an accelerator breeder and to provide a verified base for calculations of yields.

A close collaboration has been established with the Los Alamos Scientific Laboratory (LASL) where a parallel program will extend measurements to 800 MeV incident energy protons.

Most of the period has been spent in a redetermination of the sensitivities of the β-counters used to assay for foil activities in the water bath measurements. Additional water bath neutron production measurements were
made for 480 MeV protons on solid and 7 element nested cylinder lead targets during the period.

a) \( \beta \)-Counter Calibrations

Recalibration measurements have been carried out during the period to clarify and confirm the relative counting sensitivities of the \( \beta \)-detectors used for neutron production measurements in the water bath. Two methods were used on both the gold and aluminum foils to determine these factors for the range of foil thicknesses used; calibration foils were \( \gamma \)-counted on the Ge-Li spectrometer used for the conversion measurements and on a standard 7.6 cm x 7.6 cm NaI(Tl) spectrometer, as well as the three silicon surface barrier \( \beta \)-detectors. The \( \gamma \)-detection sensitivity as a function of \( \gamma \)-ray energy for the Ge-Li detectors was measured independently by counting calibrated standard sources of \( ^{57}\text{Co}, \, ^{54}\text{Mn} \) and \( ^{137}\text{Cs} \) in the same geometry as the gold and aluminum foils, and a radium source to extend the \( \gamma \)-ray energy range. The dependence on \( \gamma \)-ray energy of the sodium iodide detector sensitivity was taken from Heath's (USAEC Report IDO-16880-l (1964)) tables as described previously (PR-P-111, 6.2.3 b); AECL-5614) for the 412 keV line from \( ^{198}\text{Au} \) decay and the 1369 keV and 2754 keV lines from \( ^{24}\text{Na} \) decay.

Two sets of measurements have been done on gold and aluminum foils irradiated at TRIUMF. Preliminary results from these measurements indicate that the sensitivity ratios used to produce neutron source strength data are substantially correct. The internal consistency of some of these data are not as close as expected; checking and analysis are continuing.

Recently a set of 7 gold foils covering the thickness range used in our experiments have been irradiated at Los Alamos Scientific Laboratory, assayed by \( \beta \)-counting there.
and shipped to TRIUMF for comparison of our detection system sensitivities. The counting of these foils at TRIUMF is nearly complete on all three detection systems cited above.

b) **Water Bath Measurements**

Experimental data on the neutron production from 480 MeV protons on 10.2 cm diameter and equivalent 7-element nested cylinder lead targets were taken during the period. The data are ready for final processing as soon as the detector calibration analysis is completed.

6.3 **Research Applications**

6.3.1 **Fast Intense Neutron Source**

J.D. Hepburn and B.G. Chidley

Commissioning of the 4 x 10^{12} n/s neutron source continued. Design calls for a 300 keV, 25 mA D\(^+\) beam incident on a TiT target to achieve this source strength.

Modifications were done to alleviate the target overheating problem discussed in PR-P-118, 6.3.1 (AECL-6216) by increasing the beam diameter.

The accelerator was operated, using an ion source capable of producing 0.5 to 10 mA of H\(^+\) ions from a 6 mm plasma aperture and 0.46 mm (0.018") anode aperture, to test beam shapes and ion optics. The main analyzing magnet was repositioned to maximize the beam spot size on target. An electron sweeper, consisting of a 300 mm long electrode parallel to, and just outside of, the beam, was biased at \(+350\) V to draw space charge neutralization electrons from the beam, allowing the beam to expand. While its use is not essential, it provides some control over beam power density on target. Previously, beam currents on the quadrant aperture and Faraday cup have been measured without the use of electron suppressors. Installation and tests of a suppressor shows that readings have been 15% high up to now; future measurements will be made using the suppressed system.
Following the above tests, deuterons were accelerated onto the TiT target. For all beams up to the maximum of 9.5 mA D\textsuperscript+ at 300 keV, with or without the electron sweeper in use, neutrons were produced without target damage. Iron foil activation method calibrations showed an output of 1.1 \times 10^{12} n/s which is consistent with the current level, the previous use of the target, and the tritium decay since the target was produced.

Although FINS could now be used at $1 \times 10^{12}$ n/s, future users stated that they would like the maximum neutron yield possible, so development work is continuing. The ion source was changed to incorporate a 7.5 mm plasma aperture and 0.56 mm (0.022") anode aperture, which should increase the output current range by 2.3. However, beam instabilities have prevented neutron production trials.

Investigations of beam instability when the larger plasma aperture is used, have continued. In spite of upgrading several system components the underlying cause has not been identified. In conjunction with M.R. Shubalys, computer simulations of ion beams in the ion source and accelerating column were carried out (see section 6.2.2 c). A minor modification to the ion source focus plate was indicated as giving improved plasma surface stability. The modification was tested but had not effect on the present problem.

6.3.2 Heavy-Ion Superconducting Cyclotron
J.H. Ormrod

Design and development of a superconducting cyclotron for a post-tandem accelerator continues. The magnet is being reassembled with improved insulation in preparation for detailed field mapping. The radiofrequency accelerating system tests continue in the dummy vacuum vessel.
a) Code Development

E.A. Heighway

Now that measurements of the cyclotron magnetic field have begun, the study of the orbit dynamics for any particular ion may eventually be based on measured fields rather than calculations.

To prepare for this a new version of the isochronization code TRIUMF has been created which is divided into two main program components to stay within available memory.

The first component has access to an expected data bank of up to 49 individually measured field maps made at several coil current settings. By an interpolative search it then makes a first fit to the appropriate isochronous field and determines the best coil current settings.

The second component then continues the fit using the trim rods, calculates the orbit parameters for the fitted field and stores the field for later more detailed study by GOBLIN, the accelerated orbit code.

Both components have been written and successfully tested with fictitious field data.

b) Cryogenic System

(i) Cryostat

Reassembly

J.A. Hulbert

Structural modifications to the cryostat proposed in the last report (PR-P-119, 6.3.2 b); AECL-6366) have been effected and reassembly is in progress.
These changes were as follows:

(1) The leaking tower \(^3\) bellows assembly was replaced with a single, two-ply bellows. This provides a better clearance to the vacuum can, but necessitated reshaping the upper shield cooling manifold.

(2) Tower 1 was removed to expose the highest current magnet lead which had overheated during trials. It was found that the fibre-glass tape adhesive of the insulating jacket had melted and blocked the cooling channel. The lead was reassembled using a thermosetting adhesive and the tower welded back in place. The overheating will be treated by selective plating of the upper lead contact surfaces.

(3) Clearance between the shield and the radial bracing has been improved and the bar sections carrying strain gauging are now detachable to permit assembly without regauging.

(4) A special miniature electrical octal connector has been designed to give protection to the magnet lead monitoring wires.

(5) The superinsulation now used is 0.0025 cm or 0.0012 cm smooth double aluminized mylar interleaved with 0.008 cm dexiglas. The insulation of the helium can is complete with 19 mylar layers on the ends and outer circumference and 10 layers on the inner circumference. Application was made layer by layer with particular care taken to avoid thermal contacts bridging layers.

Consideration of the restrictions imposed in the future assembly of the cryostat with the rf system have led to a revision of the inner vacuum wall design by which the copper rf clearance "bulges" are fitted in frames and are demountable.
Calculation of Helium Boil-off Rate
E.A. Heighway

Calculations have been made in an attempt to understand the high rate of boil-off of liquid helium from the cyclotron helium can. These took the form of several separate calculations of conductive and radiative processes followed by a construction of a mathematical model to fit the boil-off curve (E.A. Heighway, J.A. Hulbert and J.H. Ormrod, Atomic Energy of Canada Limited, Report CRNL-1877 (unpublished)).

The model assumed that heat enters the liquid through the wetted surfaces of the helium can, the heat entering through the unwetted surfaces being carried away by the boil-off gas. Heat may also enter the liquid down the magnet current leads and through the helium can support structure at the midplane.

Figure 6.3.2.1 shows the measured volume versus time data (crosses) compared with the model fit (solid line). Figure 6.3.2.2 shows the fitted boil-off rate curve which is obtained by differentiating the data of Fig. 6.3.2.1. From the fit, a total of 32.5 watts is calculated to leak into the helium can when it is full. This is comprised of 20 watts entering through the superinsulation, 8 watts entering through the support structure at the bridge and 4.5 watts being conducted down the current leads.

(ii) Liquefier
J.A. Hulbert

The two former SF$_6$ tanks from the tandem Van der Graaff have been erected near the development building, cleaned and connected into the helium recovery system.
Fig. 6.3.2.1 Comparison of Calculated Liquid Volume (solid line) to the Measured Volume (crosses) as a Function of Time
Fig. 6.3.2.2 Comparison of Calculated Boil-off Rate (solid lines) to the Measured Boil-off Rate (crosses) as a Function of Liquid Volume
Two failures in the helium liquefier system have necessitated maintenance. A valve reed in compressor # 3 snapped and a new valve plate has been installed. A leak developed in the helium purifier causing failure of the cold box vacuum. The cold box was opened with the help of a CTI field engineer, when it was found that a weld in the final stage filter had cracked. After two attempts to seal the crack the filter was removed, and rebuilt with new tubing. Reassembly and tests are in progress.

The breakdown in liquid helium supply has prevented completion of cryopump tests.

(iii) Camac Interface
J.A. Hulbert

Eventually, liquefier and cryostat monitoring will be assigned to the system computer. Since no Camac modules exist which will cope with the variety of signal levels involved, a 128-way wide-range multiplexer has been designed and is about 30% complete.

The multiplexer selects any one of the input signals at levels from 0.1 mV to 5 V dc, conditions the level and digitizes the resulting analog voltage. Digital communication between a Camac crate and the multiplexer proceeds through the 50-way Cannon connectors of an IGOR (Input Gate Output Register) Camac module, with each IGOR connector coupling to 64 channels of the multiplexer. The IGOR selects the signal channel and gain and relays the resulting digital output.
c) Magnet

(i) Yoke

Q.A. Walker (Civil & Mechanical Design Branch)

The methods for guiding the upper and lower yoke poles into place have been modified to eliminate the need for optical alignment. Hardware for mechanically measuring reseating errors has been added and the dowel pins of the lower pole modified in an effort to prevent damage to the bushings caused by misalignment. The precision of reseating has been demonstrated at ± 25 µm.

Two alternate designs of 60 mm trim rod drives have been detailed and are in the fabrication stage. In one unit the lifting screw will be powered directly by a hydraulic motor and in the second by an electric motor through a roller chain and clutch. The intention is to evaluate the performance during the next series of cyclotron tests. Tests with pneumatic load lifting assistance demonstrated that it is possible to support about 2/3 of the load by air pressure before seal friction became unacceptable. Attempts to improve this load factor by using a sealless piston were not successful.

The potentiometers to be used as rod positioning transducers have been tested to determine their precision and the manner in which the signal should be handled.

(ii) Field Measuring Apparatus

J.H. Ormrod

A spur gear has been added to the main azimuthal drive of the field measuring apparatus that activates protective limit switches. The field measuring program has been modified to operate with this change.

The new operating system for the computer has a different binary to decimal conversion. All programs used
for field measurements and magnet cool down have been modified to operate with the new system.

(iii) Magnet Power Supply

H.R. Schneider

Several modifications have been made to the power supply. Most important of these is a redesign of the compensation in the feedback circuits. When first tested with the magnet as a load, the power supply oscillated in current regulation mode. This was cured by the simple expedient of reducing the loop gain by an order of magnitude, so that magnet testing could continue in July.

During the current magnet shut down an analysis of the regulation circuits has revealed insufficient phase margin in the original design as the cause of the problem. Therefore new lead-lag compensation circuits have been designed and installed. The loop gain in the current regulation mode has been restored to its original value and the phase and gain margins in the feedback loop are now greater than 40° and 2+ dB respectively, when the magnet is connected as the load.

Along with these modifications a feedback loop that senses the ac voltage across the load has been modified to increase its loop gain and bandwidth and so reduce the ripple voltage. During the initial magnet testing a ripple voltage of approximately 100 mV amplitude interfered with the voltage tap monitor electronics. The voltage ripple should now be reduced by almost an order of magnitude and thus alleviate some of the monitoring problems.

With these modifications in place and a 1.3 mΩ load connected (shorted bus bars) the power supply has been successfully tested in both current regulation and voltage regulation modes up to the maximum design current of 2500 A.
d) **Accelerating Structure**
C.B. Bigham

Tests of the rf accelerating structure in the dummy vacuum vessel continue and results to date indicate that it will satisfy specifications with improved vacuum conditions.

The structure was reassembled after repairing the upper tuner (see PR-P-119, 6.3.2 (d); AECL-6366). A liquid nitrogen trap was added to improve the pumping rate. The lowest pressure was $\sim 0.7 \text{ mPa (} 5 \times 10^{-6} \text{ Torr) but with rf drive it was usually in the range 1-7 mPa (1-5 \times 10^{-5} \text{ Torr).}$

The multipactor break through circuit requirements were further investigated and improvements made to the circuit. For reliable break through, an rf drive pulse which produces a resonator voltage greater than 30 kV was required.

Following some pulsed operation conditioning, the resonator was operated for $\sim 2$ hour periods at voltage levels up to 73 kV at 50 MHz in 0-mode and in $\pi$-mode resonances. Vacuum pressure rises limited the operating times and voltage levels with a gradual improvement over some 60 hours of operation.

Tests were stopped by the failure of the lower tuner. Inspection after disassembly showed that about one half of the outer finger contacts on the sliding short had failed. The upper tuner in which the sliding short tolerances had been improved previously showed no visible damage on the walls of the conductors. The lower short has now been rebuilt to similar tolerances.

There were two other locations in the structure with rf damage. The teflon vacuum barrier in the rf drive line was damaged by heat on the vacuum side - probably by
discharges due to a vacuum leak. About 10 large finger contacts between the cryostat wall and hill No. 3 liner near the glass viewport were melted and the glass was cracked. The finger contacts were probably melted by a discharge in the gas leaking through the crack. The copper plating on the stainless cryostat wall also appeared damaged. Copper covers were fitted over the plated regions in all four hills and the glass viewports replaced with copper.

During the tests, the dee voltmeter was calibrated by measuring the x-ray end point with an intrinsic germanium spectrometer. The results agreed with the rather less accurate rf voltage probe measurements used earlier.

Extrapolating to the specified 100 kV dee voltage (from 73 kV) indicates that for this frequency (50 MHz) the rf power required will be \( \sim 50 \) kW and the maximum structure temperature will be \( \sim 100^\circ\text{C} \). The resonator frequency shift from room temperature to 100 kV will be about 12 kHz.

Voltage stability from dc to 100 Hz was better than 0.01% with and 0.1% without voltage feedback. Striking the assembly excited a weak mechanical resonance at about 10 Hz; the fine tuner partially corrected this modulation but 10 Hz is near the top of its effective frequency range.

Modifications have been completed and the structure reassembled but still without a cryopump. It is hoped that the required operating range can be demonstrated without the cryopumps in time for installation of the structure in the magnet after the next series of magnet tests.

e) Extraction

C.R.J. Hoffmann

Detailed mechanical design of the electrostatic deflector system is almost complete. The main components
are a deflector electrode, septum, sparking plates, high voltage input cable and a transition piece. The transition piece is essentially a short length of vacuum and ceramic insulated coaxial line which connects the cable to the deflector electrode. This system is located in a dee which has been modified to make sufficient space. The transition piece and a ceramic post support the deflector electrode from above. The transition piece, post, septum and sparking plates attach to a common structure which then mounts onto lugs provided in the dee.

Electrostatic fields in the deflector system have been studied using the SLAC gun code (W.B. Herrmannsfeld, SLAC-166 (1973)). Using this code a stress relief cone has been designed to terminate the cable at the transition piece. The maximum electric fields at conductor surfaces in the transition piece are less than the fields existing at the septum and deflector electrode surfaces.

Specifications have been written for power supplies to drive superconducting windings in the magnetic elements of the extraction system and quotations have been requested.

6.4 Mechanical Laboratory

J.E. Anderchek

The Mechanical Laboratory operates the machine shop and furnaces in Bldg. 145 and carries out mechanical construction, assembly, repairs and vacuum testing for the Accelerator Physics Branch and the Reactor Physics Branch.

Total laboratory time breakdown in the quarter is as follows:

Accelerator Physics Branch - 97.9%
Reactor Physics Branch - 2.1%
6.4.1 Injector Test Experiment

Fabrication of beamline components for the Injector Test Experiment is continuing. Water cooled shields for the bending magnet chamber and spherical washer units for the ion source adjustment flange were completed.

6.4.2 Ion Source Development

A set of magnet poles and an alignment jig were fabricated for a cusp source.

A viewport with a beam measuring strip, two plasma aperture plates and a set of teflon O-rings for the ion source were made.

The extraction column electrode and rings were modified and a column clamping system was installed. Repairs were made to four filament holders, an anode plate, and the drive roller for the Friden Flexo writer.

6.4.3 High Current Test Facility

New extraction electrode insulator mounts were manufactured for the low gradient injector column and a number of screws altered to allow usage in vacuum.

Two replacement rf windows were made for the Alvarez tank coupling loop and four rf drift tube contact washers were fabricated.

A number of gaskets and spacers were made to adapt a modified impeller for the circulating pump of the triode filament freon cooling system and several small components were manufactured or altered for the triode amplifier and its protect and power supply systems.

6.4.4 Electron Test Accelerator

An X-Y traversing mechanism for experiments with the beam position monitor was fabricated but the design was unsuccessful and the work discontinued.
A new design of beam stop capable of handling 100 kW was manufactured and brazed. The design is a water cooled 33 cm diam. copper cylinder and the scanned beam will deposit most of its energy on a water cooled plate normal to the beam. The plate was machined to accommodate a 2-dimensional array for self-powered radiation detectors. A support was made for the beam dump and the whole assembly positioned in the accelerator tunnel.

Work on the machining of the coupling iris for the aluminum Model 5C was completed. Parts for eleven 60 Hz rf isolating transformers together with several small vacuum components were made during the period.

6.4.5 Fast Intense Neutron Source

Work this quarter concentrated on ion source repair and development: two intermediate electrodes and two anodes were rebuilt, a focus plate and plasma aperture plate were modified and a new focus plate was fabricated. In addition actuating cams and mounting pads were made for three micro-switch assemblies.

6.4.6 Heavy-Ion Superconducting Cyclotron

Modifications were carried out to the field measuring apparatus to allow the installation of limit switches and several items were changed to assist in the reassembly of the cryostat.

Some components were fabricated and/or repaired for tests on the radiofrequency accelerating structure and a special adaptor for transfer-tube heat influx measurements was made.

6.4.7 Reactor Physics

An aluminum fission chamber holder was manufactured for use in the PTR reactor and components were fabricated for two element hot channel experiments carried out in the ZED-II reactor.
6.5 Publications, Reports, Papers, Lectures and Patents

Papers

HIGH POWER, LOW ENERGY LINAC FOR RADIATION PROCESSING
J.S. Fraser

BEAM ANALYSIS TOMOGRAPHY
J.S. Fraser

Patents

FRENCH PATENT NO. 75/23837
LAYERED, MULTI-ELEMENT ELECTRON-BREMSSTRAHLUNG PHOTON CONVERTER TARGET
S.O. Schriber and L.W. Funk
ISSN 0067 - 0367

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