ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

PROGRESS REPORT
PHYSICS DIVISION
January 1 to March 31, 1976

Chalk River Nuclear Laboratories
Chalk River, Ontario
June 1976
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PROGRESS REPORT

January 1 to March 31, 1976

PHYSICS DIVISION

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

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SUMMARY

G.A. Bartholomew

1.1 Nuclear Physics Research

MP Tandem Operation

The reliability of the tandem again showed a modest increase over the previous quarter. The major cause of unscheduled down time is now ion-source failure. A combined effort by Operations and Physics Division personnel to improve performance and reliability of these sources is meeting with success.

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Twenty experiments were performed involving 12 visiting scientists. The visiting scientists were involved in experiments occupying 42% of the beam time and their participation averaged 19%.

A beam pulsing system extending available repetition rates of the tandem in pulsed mode has been added.

Full capability of the QD³ spectrometer nears realization with installation of two modules of the multiwire focal plane counter system.

Research Activities

A new method in which lifetimes for proton emitting levels are timed against known K X-ray lifetimes has been used to measure lifetimes of levels in $^{69}$As in the range $5 \times 10^{-17} \text{ s} < \tau < 2 \times 10^{-15} \text{ s}$. The only other technique operative in this short lifetime region employs crystal blocking.
Crystal blocking lifetime investigations on the $^{16}\text{O} + ^{W}$ compound system now underway involve Physics Division personnel in collaboration with scientists from Bell Labs., Aarhus University, Rutgers University and Solid State Science Branch, CRNL.

Pulsed beam techniques have been used to study nuclear isomerism in $^{N\sim50}$ nuclei, in $^{206}\text{Tl}$ and in $^{209}\text{Bi}$. Spins, lifetimes and $g$-factors are determined and compared with shell model predictions.

A gas scintillation detector has been developed which permits detection of highly ionizing recoil nuclei from heavy ion reactions in coincidence with $\gamma$-rays emitted by the recoils. The device has been used for detection of fission fragments, scattered projectiles in Coulomb excitation and recoiling compound nuclei following (HI,xn) reactions.

The ground state rotational band of $^{169}\text{Tm}$ was excited to spin 23/2 by bombardment with 140 MeV $^{32}\text{S}$ ions. Lifetimes of 10 levels to spin 21/2 were measured and electromagnetic transition probabilities of decay $\gamma$-rays deduced.

Measurements of the cross section for two-photon emission following neutron capture in $^{1}\text{H}(\sigma_{2\gamma} = -3\pm8 \text{ \mu b})$ have been supplemented by determinations of that cross section for $^{2}\text{H}$ capture ($\sigma_{2\gamma} = 8\pm15 \text{ \mu b})$ and of the total capture cross section for the $^{16}\text{O}(n,\gamma)^{17}\text{O}$ reaction ($202\pm27 \text{ \mu b})$.

1.2 Accelerator and Applied Physics

Research Applications

Commissioning of the Fast Intense Neutron Source has been delayed by a persistent sparking problem in the accelerating column; major column modifications appear necessary. Much improved operation of the ion source has been achieved.
The Heavy Ion Superconducting Cyclotron modelling program included the following:

- Most of the iron for the yoke has been delivered to the fabricator; machining will begin in April.
- Contract work to develop an adequate insert solder bond for the superconductor has been successfully completed.
- Drawing of the main-coil superconductor is nearing completion; end of May delivery is expected.
- The flutter poles have been modified to improve the value of the betatron frequencies at injection and extraction.
- The disposition of trim rods is being revised to reduce radial ripple in the magnetic field. The computer program that calculates the trim rod amplitudes has been improved to better correct isochronism of highly scalloped orbits.
- Experiments with a high-power 1/4 wave resonator have shown that the finger stock for the accelerating structure sliding shorts can carry the rf design current.
- Control circuits have been tested that maintain constant voltage and hold the frequency of the resonator within acceptable limits.
- Electrical and mechanical design of the electrostatic deflector system has started.
- Internal probes for measuring the position and phase of the beam are being designed.
- Tandem emittance measurements and tandem-to-cyclotron beam transport and injection orbit studies are progressing well.
- The refrigeration requirements have been reviewed and a prolonged production run on the liquifier suggests it is adequate to fulfil needs.
- Building construction for the model has begun.
Nuclear Power Applications

The program to increase the output and improve the reliability of the injector for the High Current Test Facility has been resumed following installation and testing of the SUCCESS II computer control. Commissioning of the 400 kW rf system continues; its 75 kW driver is operational.

The experiments carried out in this and previous quarters have achieved the objectives outlined for the first phase of the Electron Test Accelerator program. Upon completion of the experiments in January, commissioning of the second accelerating tank (Model 3) began. Reactive beam loading effects on the cavity phase and amplitude have been studied up to 50% beam loading. The amplitude and phase controls work well together to maintain the resultant accelerating field constant to within 1% in amplitude and 1° in phase as the beam current varies between 0 and 15 mA.

Analysis of the data from the first few irradiations of the fertile-to-fissile conversion experiments at TRIUMF is proceeding. The preliminary results indicate satisfactory agreement with predictions.

1.3 Solid State Physics

Measurements and analysis of neutron scattering from nonsuperfluid $^4$He are continuing.

Neutron scattering techniques have been used to study crystal vibrations and crystal structure in the neighborhood of a phase transition in K$_2$OsCl$_6$. This work, in collaboration with scientists from University of Toronto, is expected to elucidate dynamical and structural changes taking place at the transition.

Neutron diffraction studies of ultra violet light damage to nucleic acid bases have been extended in 1-methylthymine and also to samples of uracil, guanine, cytosine and ordinary
thymine. Damage by the uv similar to that noted previously for 1-methylthymine is noted for uracil but not, to significant degree, in the other bases studied.

Studies of magnetic and vibrational excitations in uranium oxide have been extended but development of a completely satisfactory interpretation of the data has yet to be achieved.

Studies of magnetic excitations in antiferromagnetic Mn$_{0.32}$Zn$_{0.68}$F$_2$ and related materials are continuing.

1.4 Detectors

Efforts to refine CdTe and to grow suitable high purity crystals of size and quality required for detectors are continuing by several methods.

A very compact battery-operated high-voltage supply in the range 500-1000 V, for portable germanium γ-ray spectrometers has been built and is under test.

1.5 Applied Mathematics and Computation

Neutron transport calculations for fusion reactor blankets are under way to compare results obtained by CRNL computation methods with certain benchmark calculations in the literature. Agreement is good; small departures are being investigated, and extensions and refinements of the calculations are under consideration.

A linear accelerator structure without axial symmetry is being studied. The structure shows some promise at low energies. Improvements in the theoretical representation of the structure are being developed.

Methods of converting partial differential equations for two- and three-dimensional problems into sets of ordinary differential equations which can be handled by automatic integration codes such as FORSIM are being investigated.

An application of FORSIM has been found in obtaining a solution to a set of non-linear algebraic equations.
Two major stress analysis codes are now available in the Computing Centre - MARC and SAP IV. Comparison of the two codes has been carried out to establish some guidelines for use. SAP IV is much faster than MARC, but generally less accurate, for elastic problems. The more expensive (to run) MARC code must be used for non-elastic cases or when its improved accuracy is essential.

A model for the rate of flow of coolant entering a fuel void through a defect in the sheath has been developed, and applied for two different assumptions about the geometry of the defect.

Work has begun on two aspects of the Gentilly-1 steam system. One problem is to estimate the natural acoustic frequencies in the system of steam mains, the other is to investigate the dynamic behaviour of the system resulting from perturbation of a steady-state steam flow condition.

Finite difference approximations for the term \( \nabla \cdot D \nabla \alpha \) in the diffusion equation in polar co-ordinates have been derived for the case of \( D \) discontinuous in \( n \) and \( \alpha \) non-axisymmetric.

Miscellaneous programs and subroutines developed or modified during the quarter include
- improvements to the program LIRA for handling extended precision integers and rational fractions
- further investigation of techniques for analyzing stress relaxation data
- a special version of the heat transfer code TRUMP was prepared for a problem requiring 500 nodes
- improvements to a program for forecasting specific activity in an isotope production rod
- a new version of a table look-up routine
- the provision for using metric units when specifying plot dimensions and scales.

Extensive testing of new versions of CDC's FORTRAN and COBOL compilers took place during the quarter. Required
local additions or changes have been made, and the languages are to be changed on 1 April. At the same time, subroutine libraries and utility programs, compiled with the new versions of the languages, will be installed. Testing of a new version of the SNOBOL compiler has begun.

During the quarter, a memory increment of 16,384 words was added to the CDC 3300, used as an input-output processor in the Computing Centre. The memory increase was required by the growing size number of the network of remote terminals. The disc storage subsystem was also increased by the addition of two more CDC 841 disc drives.

The user's work room in the Computing Centre has been provided with a CDC 734 terminal for use as a self-serve card reader/printer facility, and with a Vocom 1 keyboard/display terminal.

The total workload of 65,724 jobs for the 6600 computer during the quarter was distributed as follows:

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Nuclear Physics Branch
T.K. Alexander

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2.1 Staff

Branch Head: J.C.D. Milton
Acting Branch Head: T.K. Alexander

Professional Staff

SECTION I Accelerator Group

J.C.D. Milton (1)
T.K. Alexander
G.C. Ball
J.R. Beene (2)
W.G. Davies
T. Faestermann (2)
A.J. Ferguson
J.S. Forster
J.C. Hardy
O. Hausser
K.P. Jackson (3)
A.B. McDonald
W. McLatchie (4)
H. Schmeing (5)
D. Ward

SECTION II Beta Ray Group

R.L. Graham
H.R. Andrews
J.S. Geiger (7)

SECTION III Radioisotope Standardization Group

J.G.V. Taylor

Laboratory Services and Workshop

G.M. Boire
M. Desrochers
C. Johnson
K.T. McKee

Secretarial Staff

J.R.H. Bowes
S.M. Carlos
(1) On leave of absence at Centre d'Etudes de Bruyères-le-Châtel, France, returns August 1976

(2) NRC postdoctoral fellow

(3) Visiting research associate from University of Toronto

(4) Visiting professor from Queen's University

(5) Transferred to Neutron and Solid State Physics Branch on 16 February 1976

(6) Student from University of Waterloo

(7) On leave of absence for a period of one year at the University of Rochester, returns January 1977
2.2 The Masses of $^{19}$N and $^{22}$O

G.C. Ball, W.G. Davies, J.S. Forster, H.R. Andrews and W. McLatchie

The experiment reported in PR-P-108: 2.5, AECL-5315 has been repeated using the improved heavy-ion detector described in PR-P-109: 2.20, AECL-5508. The experimental arrangement was identical to that used earlier (ibid) in which a 93 MeV $^{18}$O$^{7+}$ beam bombarded a 200 $\mu$g/cm$^2$ $^{208}$Pb target. As before the $^{19}$N and $^{22}$O events were analyzed with the QD$^3$ spectrometer operating at 11 msr solid angle.

A preliminary analysis of these data confirms the earlier observation of $^{19}$N and $^{22}$O. Our preliminary results for the mass excess of $^{22}$O is consistent with the recent results of Hickey et al. (private communication) who obtained a value of $9.5 \pm 0.12$ MeV for the mass of $^{22}$O. Analysis is in progress.

2.3 Decay Properties of $T = 2$ Levels in Light Nuclei

A.B. McDonald with S.J. Freedman, M. Oothoudt, H. Robertson and F.J. Zutavern (Princeton University) and E.G. Adelberger (University of Washington)

In a series of measurements performed with the Princeton cyclotron, branching ratios have been determined for charged particle and neutron emission from the lowest $T = 2$ levels in $^8$Be, $^{12}$C, $^{16}$O, $^{24}$Mg, $^{32}$S, $^{36}$Ar, $^{44}$Ti and $^{58}$Ni. The $0^+$, $T = 2$ levels were populated by $(p,t)$ reactions at 42 or 46 MeV and coincidences were detected between tritons observed with a QD$^3$ magnetic spectrometer and charged particles detected in a surface barrier detector telescope or neutrons observed in a plastic scintillator at a distance of 0.6 meters. For $^{44}$Ti, gamma ray branching ratios were also measured by observing coincidences with a 12 cm diam by 12 cm long NaI(Tl) detector.
Data analysis is in progress and preliminary results indicate that the lowest $T = 2$ level in $^{36}$Ar decays predominantly by proton emission to the ground state of $^{35}$Cl, explaining our failure to observe it previously as a resonance in the $^4$He($^{32}$S,γ) reaction (PR-P-101: 2.6, AECL-4773; PR-P-102: 2.7, AECL-4841). The lowest $T = 2$ level in $^{44}$Ti decays with measurable branches for gamma emission and for alpha emission to the ground state of $^{40}$Ca. The present measurement together with recent measurements on the $^{40}$Ca(α,γ) reaction (W.R. Dixon, R.S. Storey, J.J. Simpson and R.D. Lawson to be published) will define the total and partial widths for this level.

2.4 Fusion Evaporation Reaction Products at A ≥ 60

W. McLatchie, J.S. Forster with B.E. Cooke, R.L. Kozub, J.R. Leslie, D.J. Martin and B.C. Robertson (Queen's University)

Isotopically enriched 100 μg/cm$^2$ targets of $^{46}$Ti and $^{48}$Ti evaporated onto 50 mg/cm$^2$ Ta backings were bombarded by $^{18}$O ions with energy in the range 40 MeV - 60 MeV. Gamma rays in coincidence with charged particles observed in a counter telescope (ΔE: 50 μm Si surface barrier, E: 5 mm intrinsic Ge) at 0° were observed in two Ge(Li) detectors at $\theta_\gamma = 90^\circ$ and $125^\circ$. Twenty-four hours were devoted to each target with beam currents held typically at less than 15 nA (for acceptable neutron background).

Over the energy range investigated the reaction yield is fragmented into many channels. For example, in coincidence with alpha-particles we observed gamma rays from the nuclei $^{54,55}$Mn, $\cdot ^{55,56}$Fe and $^{57}$Co produced by bombarding the $^{46}$Ti target. The $^{55}$Fe lines were strongest and represented population of Yrast states up to spin 15/2. For the same target, proton coincidence data demonstrate the population of Yrast
states in $^{60}\text{Ni}$ up to spin 9.

Further analysis is in progress.

2.5 **Production of Heavy Superallowed Positron Emitters**

K.P. Jackson, R.E. Azuma (University of Toronto), I. Berka (University of Toronto), T. Faestermann, J.C. Hardy and H. Schmeing (Neutron and Solid State Physics Branch)

Experiments initiated to study the decay of new members of the series of nuclei characterized by $A = 4n + 2$, $T_z = 0$ (PR-P-108: 2.7, AECL-5315) have been extended by a study of the activity produced with the $^{40}\text{Ca}(^{28}\text{Si,apn})^{62}\text{Ga}$ reaction and by the use of a semiconductor counter telescope for the detection of energetic positrons. In the initial portion of the experiment, the positrons emitted in the decay of $^{62}\text{Ga}$ were observed using a plastic scintillator for direct comparison with our previous production of this nucleus using other heavy-ion induced reactions. The plastic scintillator was then replaced by a $\Delta E-E$ telescope consisting of a 0.07 cm thick by 3 cm$^2$ area silicon surface barrier detector and a 1.15 cm thick by 6.6 cm$^2$ area intrinsic germanium counter (supplied by the Neutron and Solid State Physics Branch). As anticipated, the use of the telescope dramatically reduced the background due to both gamma rays and cosmic radiation. The inherent energy stability of the semiconductor devices should permit useful measurements of positron end-point energies. For calibration purposes, the telescope was also used to record standard positron spectra for the decays of $^{46}\text{V}$, $^{54}\text{Co}$ and $^{58}\text{Cu}$ following their production in $(p,n)$ reactions. The analysis of these data is in progress.
2.6 Decay Properties of $^{69}\text{Se}$


The decay of the $\beta^+\text{-delayed}$ proton precursor $^{69}\text{Se}$ has been studied in more detail:

a) The electron-capture decay energy, $Q_{\text{ec}}$, has been measured to be $6817 \pm 75$ keV by determining the endpoint energy of positrons in coincidence with gamma-ray transitions in $^{69}\text{As}$. This result corresponds to $Q_{\text{ec}} - B_\text{p} = 3422 \pm 90$ keV (where $B_\text{p}$ is the proton binding energy of $^{69}\text{As}$).

The latter quantity has also been determined by a measurement of the proton spectrum in coincidence with annihilation radiation. The ratio of intensity in this spectrum to that in the total proton spectrum, which is related only to the ratio of electron capture to positron decay, is strongly energy dependent and yields $Q_{\text{ec}} - B_\text{p} = 3364 \pm 75$ keV, in very good agreement with the other independent result.

b) By detecting protons in coincidence with gamma rays from the $2^+_1 - 0^+_1$ transition in the daughter nucleus $^{68}\text{Ge}$, the fraction of delayed proton decays to the first excited state in $^{68}\text{Ge}$ has been determined as $I_\text{p}(2^+)/I_\text{p}(\text{g.s.}) = (1.4 \pm 0.7)\%$.

c) In order to complete the decay scheme of $^{69}\text{Se}$, gamma-ray intensities have been measured for all observed transitions in $^{69}\text{As}$ relative to the annihilation radiation, yielding a ground state feed of $(20 \pm 7)\%$ for the beta-decay of $^{69}\text{Se}$. The observation of an allowed ground state decay branch restricts the spin of $^{69}\text{Se}$ to $1/2^-$, $3/2^-$ or $5/2^-$. The properties reported here provide essential constraints to statistical model calculations of beta-delayed proton decay.
2.7 Nuclear Lifetimes in the Region of $10^{-16}$ s Measured by a New Technique


A paper has been written summarizing our new technique for measuring nuclear lifetimes in the region of $10^{-16}$ s. It involves comparison of the proton decay of a nuclear state with the filling of a vacancy in the atomic K shell. The method, which has been described in PR-P-103: 2.14, AECL-4931, in principle applies to the lifetime range from $\sim 10^{-14}$ s to $\sim 10^{-18}$ s and thus abuts the region conventionally accessible, extending it downward over three orders of magnitude. The only other technique of direct lifetime measurement in this region employs crystal blocking, and has so far been restricted to a few favourable materials.

We have used the technique to measure lifetimes of states in $^{69}$As between 5 and 7 MeV produced in the beta decay of the delayed proton precursor $^{69}$Se. The measured lifetimes ($5 \times 10^{-17}$ s $\lesssim \tau \lesssim 2 \times 10^{-15}$ s), in conjunction with statistical model calculations, have been used to derive level density parameters in close agreement with those deduced for $^{71}$As and $^{73}$As from blocking measurements (Clark et al., Nucl. Phys. A173 (1971) 73).

2.8 A Study of Isomerism in N \sim 50 Nuclei Using Pulsed $^{32}$S Beams

O. Häusser, D. Ward, T. Faestermann, J.R. Beene and H.R. Andrews

We have initiated a study of isomers in nuclei near the N \sim 50 closed neutron shell. The use of pulsed, heavy-ion beams has two advantages compared to conventional light-ion induced reactions. Firstly, a larger number of residual nuclei can be populated appreciably, including proton rich
nuclei. Secondly, the energetic recoils can be implanted into a suitable host. For the present study, pulsed $^{32}$S beams of 120 - 140 MeV and 1.8 mg/cm$^2$ thick targets of $^{64}$Ni and $^{65}$Cu were used. The recoils were stopped in backings of liquid Hg to achieve sufficiently long spin relaxation times.

The isomers of very high spin in $^{91,92}$Mo reported previously (PR-P-108: 2.10, AECL-5315) were not observed, probably because of the lower beam energy. We have measured the g-factor of the well-known 11$^-$ state in $^{92}$Mo (Lederer et al., Nucl. Phys. A169 (1971) 449). From an analysis of time-distributions of six de-excitation gamma rays, $g$(uncorrected) = 1.29 ± 0.04 and $T_\chi = 9.3 ± 0.4$ ns were obtained. The g-factor is in excellent agreement with the value calculated from a proposed {$(g_9^2/2)^{1/2}$, $p_{1/2}$} 11$^-$ proton structure for this isomer.

In $^{91}$Mo an isomeric state with $T_\chi = 46 ± 1$ ns was observed. The isomer decays by three $L = 2$ gamma rays of 199, 654 and 1414 keV, suggesting a $J^\pi = 21/2^+$ assignment. The uncorrected g-factor, $g = 0.860 ± 0.004$, is however substantially larger than expected from a weak coupling description of this state, {$(g_9^2/2)^{1/2}$, $p_{1/2}$}. This, and a lowering of the level energy by about 210 keV compared to the 6$^+$ state in $^{92}$Mo, suggests substantial configuration mixing.

A new isomer with $T_\chi = 12 ± 1$ ns, $g = 0.36 ± 0.03$, has also been observed. Gamma-gamma coincidence data and excitations functions have to be analyzed further before an assignment for this isomer can be attempted.

2.9 Neutron and Gamma Spectra from $^{130}$Te($^{32}$S,xn)Er
A.J. Ferguson, O. Häusser, D. Ward, H.R. Andrews, J.R. Beene, C. Broude (Queen's University)

An investigation of the neutron and gamma-ray spectra produced by the reaction $^{130}$Te($^{32}$S,xn)Er at a bombarding energy of 145 MeV has been made. The neutron spectra were determined
by time of flight over a 1 m flight path using a 12.7 cm diam by 12.7 cm long NE213 scintillator with pulse shape discrimination to select the neutrons. Gamma rays were measured by a Ge(Li) detector that also provided the start pulse for the time of flight measurement and by a 12.7 cm diam by 15.2 cm long NaI(Tl) detector. Neutron and NaI(Tl) spectra associated with the stronger lines from $^{157}$Er and $^{158}$Er were separated by windows on the Ge(Li) spectra. The neutron spectra from all groups decreased exponentially with increasing energy with a slope corresponding to a nuclear temperature of 1.3 MeV. Measurements at 0°, 40° and 70° (lab) show that the angular distributions are approximately isotropic. The NaI(Tl) spectra also show an exponential decrease above 2 MeV with a slope corresponding to a temperature of about 1 MeV. However, unfolding of the NaI(Tl) response functions, which is in progress, is necessary to give an accurate result, and the above result is a lower limit. The temperature obtained from the neutrons agrees reasonably with the theoretical value of 1.5 MeV obtained by Grover and Gilat (Phys. Rev. 157 (1967) 802) but the gamma-ray temperature is in poor agreement with their values of 0.65 to 1.0 MeV.

2.10 Electromagnetic Properties of the Ground State Rotational Band in $^{169}$Tm


The experiments described in PR-P-103: 2.7, AECL-4931 have now been analyzed. With beams of $^{32}$S ions at energies up to 140 MeV, the ground state band of $^{169}$Tm ($K = 1/2^+$) was excited to spin 23/2 by multiple Coulomb excitation. Lifetimes for the levels to spin 21/2 were measured using the recoil distance and Doppler broadened lineshape methods. Gamma-ray angular distributions and branching ratios were
determined. From these data we have extracted, without assuming the rotational model, absolute values for \( B(E2) \) and \( B(M1) \) values connecting the band members. The level of agreement with the rotational model is exceptionally good for all the measured quantities, as shown in Table 2.10.1.

The parameters determining the \( B(M1) \) values by:

\[
B(M1; J_i \rightarrow J_f) = \frac{3}{4\pi} (g_K - g_R)^2 <I_{\frac{J_i}{2}}|I_{\frac{1}{2}}^0|I_{\frac{1}{2}}^0 > \left[ 1 + (-1)^i J_i b_0 \right]
\]

were obtained from the static moments of the first three excited states:

\[
\mu = g_R J + \frac{(g_K - g_R) K^2}{J-1} (1+(2J+1)(-1)^J b_0)
\]

For the quadrupole decoupling term \( q/Q_o \) we find \( q/Q_o = -0.007 \pm 0.007 \) whereas from analysis of the low spin states, Kaufmann et al. (Nucl. Phys. A119 (1968) 417) gave \( q/Q_o = -0.03 \pm 0.008 \).

2.11 Detection of Gamma Rays in Coincidence with In-beam Recoils

We have made a study of the feasibility of detecting gamma rays in coincidence with their associated product nucleus recoiling close to the beam in \((HI,xn)\) reactions. The object of such an arrangement is to isolate gamma rays associated with complete fusion-evaporation reactions from the background of other events. This might prove to be a valuable tool for gamma-ray spectroscopy in the actinide region. The problem is to detect low energy, heavy recoils (say \( E \ll 5 \text{ MeV}, A \ll 200 \)) at forward angles in the presence of scattered beam particles \((E \ll 100 \text{ MeV}, A \ll 8-32)\) which may be \(10^3\) to \(10^4\) times more intense.

We have used the gas scintillation counter described in PR-P-109: 2.22, AECL-5508 for this purpose. The entrance
Table 2.10.1
Reduced Electromagnetic Transition Probabilities in $^{169}\text{Tm}$

<table>
<thead>
<tr>
<th>Transition</th>
<th>$B(E2)$</th>
<th>$e^2 b^2$</th>
<th>$B(M1)$</th>
<th>$2^+_N$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exp.</td>
<td>Theory</td>
<td>Exp.</td>
<td>Theory</td>
</tr>
<tr>
<td>$3/1 \to 1/2$</td>
<td>1.43*</td>
<td>1.13</td>
<td>0.065 ± 0.006*</td>
<td>-</td>
</tr>
<tr>
<td>$5/2 \to 3/2$</td>
<td>0.39 ± 0.03*</td>
<td>0.335</td>
<td>0.128 ± 0.006*</td>
<td>0.127</td>
</tr>
<tr>
<td>$5/2 \to 1/2$</td>
<td>1.14 ± 0.07*</td>
<td>1.173</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$7/2 \to 3/2$</td>
<td>1.62 ± 0.09*</td>
<td>1.51</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$9/2 \to 7/2$</td>
<td>0.079 ± 0.015</td>
<td>0.101</td>
<td>0.139 ± 0.006</td>
<td>0.141</td>
</tr>
<tr>
<td>$9/2 \to 5/2$</td>
<td>1.61 ± 0.11</td>
<td>1.68</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$11/2 \to 7/2$</td>
<td>1.79 ± 0.09</td>
<td>1.78</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$13/2 \to 11/2$</td>
<td>0.053 ± 0.012</td>
<td>0.049</td>
<td>0.155 ± 0.011</td>
<td>0.147</td>
</tr>
<tr>
<td>$13/2 \to 9/2$</td>
<td>1.82 ± 0.12</td>
<td>1.85</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$15/2 \to 11/2$</td>
<td>1.85 ± 0.08</td>
<td>1.90</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$17/2 \to 15/2$</td>
<td>0.034 ± 0.009</td>
<td>0.0292</td>
<td>0.17 ± 0.02</td>
<td>0.149</td>
</tr>
<tr>
<td>$17/2 \to 13/2$</td>
<td>2.03 ± 0.25</td>
<td>1.93</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$19/2 \to 15/2$</td>
<td>2.34 ± 0.24</td>
<td>1.96</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$21/2 \to 17/2$</td>
<td>2.18 ± 0.25</td>
<td>1.99</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Reduced transition probabilities determined from measured photon transition strengths. The theoretical values were obtained from the rotational model with the $Q_o = 7.69 ± 0.08$ barns. The magnetic parameters were $g_R = 0.407$, $g_K - g_R = -2.01$ and $b_o = -0.148$.

* Quoted by Kaufmann et al. (loc cit)
window to the counter was situated about 15 cm from the target and defined an acceptance angle of $3^\circ - 10^\circ$ with respect to the beam. In this configuration there were $\sim 15$ cm of gas in which to stop the recoils. The entrance window was $30 \mu g/cm^2$ of VYNS plus $50 \mu g/cm^2$ of aluminum supported on a 90% transmission mesh, and the counter was operated at 1.33 kPa (10 torr) of pressure. With this arrangement we expect to detect recoils of up to mass $\sim 200$ with energies greater than 3 MeV.

The reactions $^{154}$Gd($^{16}$O,4n)$^{168}$Hf and $^{110}$Pd($^{16}$O,4n)$^{124}$Xe, using d.c. and pulsed beams at 80 MeV, were studied to obtain the best parameter for recoil detection. Gamma rays were detected in a Ge(Li) counter at $130^\circ$. Fast signals from the Ge(Li) detector were used to start a TAC which was stopped by fast signals from the recoil detector. A time peak associated with the arrival of recoils was observed and the related gamma rays were shown to be associated with the 4n products. In a second experiment we used the beam pulser to chop the beam at 800 ns intervals with a pulse length of $\approx 5$ ns. In this mode we could take advantage of the substantial difference in arrival times between the beam particles and the recoils, which amounted to $\sim 70$ ns. A signal related to the beam trigger pulse was used to veto the output of the gas counter for the period of the beam burst and for $\sim 20$ ns thereafter. With the $^{110}$Pd + $^{16}$O reaction we observed extremely clean gamma-recoil time signals with a peak-to-background ratio of about 50:1. The overall efficiency of the arrangement was estimated from the ratio of gamma-recoil events to gamma-ray singles events as about 10%. In later experiments we observed gamma recoil time spectra from the reaction $^{208}$Pb($^{16}$O,4n)$^{222}$Th at 93 - 103 MeV. However very little structure was observed in the coincident gamma-spectrum, and this might indicate that the fusion-evaporation channel was fragmented into other than the 4n processes.
2.12 A 10 ns, $7^+$ Isomer in $^{206}\text{Tl}$ Measured by Pulsed Beam Techniques

O. Häusser, J.R. Beene, A.B. McDonald and T.K. Alexander

We have recently reported an 80 ns, $5^+$ isomer in $^{206}\text{Tl}$ at 1406 keV (PR-P-108: 2.12, AECL-5315). Continued analysis has revealed an isomeric state at 1621.3 keV with a halflife of $10.1 \pm 0.6$ ns, which populates the $5^+$ isomer by a 216.3 keV transition. The isomer is most likely the $J^\pi = 7^+$, $(s_{1/2}^{-1}(\pi) i_{13/2}(\nu))$ state expected in this excitation region. The experimental $B(E2; 7^+ \rightarrow 5^+) = 90 \pm 5$ e$^2$fm$^4$, is well reproduced by the wave function of Kuo and Herling, approximation 3 (U.S. Naval Research Laboratory report 2258) if we use the most reliable E2 matrix elements (experimental values or predictions by Ring et al., Nucl. Phys. A206 (1973) 97).

Inclusion of the $7^+ \rightarrow 5^+$ feeding slightly changes the previously reported results for the $5^+$ isomer, which are now $T_1 = 78 \pm 1$ ns, and $g$(uncorrected) = $0.853 \pm 0.008$. From the experimental $5^+$ g-factor and the wavefunction for the $5^+$ state mentioned above, we derive $\mu = 6.2 \pm 0.4$ nm for the $h_{11/2}$ single proton magnetic moment. This value is substantially smaller than either the Schmidt value (7.79 nm) or recent theoretical predictions.

A new isomeric state has been found in $^{205}\text{Tl}$. It has a halflife of $4.5 \pm 0.4$ ns and decays by a gamma cascade of 720.1, 505.9 and 203.9 keV.

2.13 A $19/2^+$ Isomeric State in $^{209}\text{Bi}$

J.R. Beene, O. Häusser, T.K.Alexander, A.B. McDonald and E.D. Earle (Neutron and Solid State Physics Branch)

The $\{(208\text{Pb})3^- \otimes h_{9/2}(\text{proton})\}$ multiplet in $^{209}\text{Bi}$ provides one of the best available examples of weak particle-vibration coupling. In view of this, considerable effort has
been applied to the identification and study of multiplets built on other collective states of \(^{208}\text{Pb}\). We have previously reported (PR-P-106: 2.7, AECL-5226) the observation of an isomeric state in \(^{209}\text{Bi}\) which was tentatively identified with the \(19/2^+\) member of the \(\{(^{208}\text{Pb})\frac{1}{2}^- (3.20\text{ MeV}) \otimes \hbar_{9/2}\text{(proton)}\}\) multiplet. The analysis of the data is now complete. The results together with additional information obtained from pulsed beam gamma-gamma coincidence data support our earlier assignment. The excitation energy of the \(19/2^+\) isomer has been determined to be 2986 keV and it is observed to decay solely, within experimental limits, by 235 keV, \(L = 2\) gamma-ray emission to the \(15/2^+\) \(\{3^- \otimes \hbar_{9/2}\}\) state at 2741 keV. The measured half-life of the state is \(17.8 \pm 0.6\) ns, and the uncorrected \(g\)-factor is \(0.357 \pm 0.008\).

The 2986 keV state has also been observed by several groups using the \(^{209}\text{Bi}(p,p')^{209}\text{Bi}\) reaction, and identified, along with several other states in the range 2.7 to 3.3 MeV as belonging to the \(\{5^- \otimes \hbar_{9/2}\}\) multiplet. They obtain internally consistent spin assignments for the levels based on the \((2J + 1)\) intensity rule of the weak coupling model, but find the 2986 keV state to be about half as strongly excited as would be expected for \(J = 19/2^+\) (see Wagner et al. Phys. Rev. C11 (1975) 486 and references therein). However, the experimental results for \(g\) and \(T_2\) as well as the reduced intensity in \((p,p')\) can be accounted for within a weak coupling basis if a small core admixture of the \(5^-\) state at 3.71 MeV in \(^{208}\text{Pb}\) is allowed.

2.14 Magnetic Relaxation of Excited \(^{212}\text{Fr}\) and \(^{214}\text{Ra}\) Nuclei in Liquid Metals

O. Häusser, J.R. Beene, T.K. Alexander, A.B. McDonald and A.J. Ferguson

The uncertainty of predicting the Knight shift (K)
for isolated impurities in metallic targets limits the accuracy with which magnetic moments of heavy nuclei can be determined. The hyperfine contact interaction provides the dominant contribution to the Knight shift and is also responsible for the bulk of magnetic spin relaxation processes. In cases where quadrupole relaxation is unimportant (high nuclear spin and small quadrupole moment), the spin relaxation time can be used to estimate $K$ using the modified Korringa relation (Rossini and Knight, Phys. Rev. 178 (1969) 641).

We have used the 27 $\mu$s, $1^+$ isomer in $^{212}$Fr and the 67 $\mu$s, $8^+$ isomer in $^{214}$Ra as probes to estimate $K$ (Fr in Tl) and $K$ (Ra in Pb). Both isomers are expected to have nearly vanishing quadrupole moments. A new slow beam-pulsing system (PR-P-109: 2.24, AECL-5508) was used to produce the isomers by ($^{12}$C,4n) reactions. From data taken with molten targets at several temperatures, and using weak external fields of 3 to 6 mT (30 to 60 Gauss), relaxation times $\tau_2 \sim 80 \mu$s were obtained; they correspond to $K$ (Fr Tl) = (0.85 ± 0.11)% and $K$ (Ra Pb) = (1.05 ± 0.15)%. The former value of $K$ is in excellent agreement with previous determinations of $K$ (Fr Tl) by independent methods (PR-P-107: 2.12, AECL-5256).

2.15 An Observation of the Spin Precession of the $T_\chi = 238$ ns, $J^\pi = 29/2^+$ State of $^{213}$Fr in Ar Gas

J.R. Beene, O. H"{a}usser, T.K. Alexander, A.B. McDonald and A.J. Ferguson

Lack of knowledge of local microscopic corrections to applied magnetic fields such as the Knight shift in metallic solids and liquids is the principal limit on the accuracy with which magnetic moments of trans-bismuth nuclei have been determined. An attempt to observe the spin precession of the $T_\chi = 238$ ns, $J^\pi = 29/2^+$ state of $^{213}$Fr in a particularly simple Knight shift free environment, namely in free $^{213}$Fr$^+$ ions in Ar gas, has been previously reported (PR-P-107: 2.12, AECL-5256). This measurement has been repeated to obtain
better accuracy. With an external applied field of 1.0000 T a Larmor frequency of 49.29 ± 0.16 MHz was observed, consistent with the value 49.26 ± 0.10 MHz for the same state in a T2Ck host. This supports the contention that the latter provided a well understood Knight shift free environment (PR-P-107: 2.12, AECL-5256).

The fraction of ions in Ar which contribute to the spin rotation pattern can be deduced by comparing the measured amplitude of oscillation near t = 0 with that obtained for the 29/2$^+$ state produced under the same experimental conditions but in a liquid T2 metal host. The result is 0.28 ± 0.04. We interpret this as the fraction of ions which survive thermalization in the hyperfine interaction free Fr$^+ 1S_0$ atomic state. Our data also provide a measurement of the mean time for spin orientation relaxation after thermalization of 0.7 ± 0.2 μs. This result implies an electron capture cross section σ(+ + 0) for Fr ions in Ar gas at thermal velocities of ~ 3 x 10^{-18} cm^2 (± 60%). This small value is consistent with the suggestion of Wittkower and Betz (Phys. Rev. A7 (1972) 159).

2.16 Observation of Gamma Rays in $^{232,234}$U Following ($^4$He, xn) Reactions


In order to study high spin states in actinide nuclei it would be desirable to form them in (heavy ion , xn) reactions. Unfortunately such systems have a high probability of fission, and to date it has not been possible to observe discrete gamma-ray transitions because of the very high background associated with prompt gamma rays accompanying fission. We have employed the high geometry gas scintillation counter described in PR-P-109: 2.22, AECL-5508 to provide fast signals when fission fragments are detected in order to reject prompt
fission gamma events observed in a Ge(Li) detector. The reaction $^{232}\text{Th} + ^4\text{He}$ at 25-39 MeV was used. The success of this technique depends upon detecting fission fragments at a very high count rate with a total efficiency including geometry considerably in excess of 90%. A thin (500 $\mu$g$\cdot$cm$^{-2}$) thorium target was positioned inside the cavity defined by a thin aluminized mylar window ($\sim$ 500 $\mu$g$\cdot$cm$^{-2}$) which separated the volume of the scintillating gas from the high vacuum. This window was supported on thin ribs which were arranged such that if a fragment struck one rib, then the complementary fragment, which must be closely coplanar, would travel through a gap. The sensitive volume of the detector covered the entire azimuthal range, with the support ribs occupying $\sim$ 8% of the available space. The $\theta$-range extended from 30° to 178°. Because of the kinematics of fission mentioned above, the geometrical efficiency for detecting at least one fragment was calculated to be 98%. The main contribution to the 2% loss was calculated to be due to fragments travelling close to the plane of the target and losing so much energy that they could not penetrate the mylar window.

The device reduced the gamma-ray background in the $^{232}\text{Th}(^4\text{He},2n)^{234}\text{U}$ (25 MeV) and $^{232}\text{Th}(^4\text{He},4n)^{232}\text{U}$ (39 MeV) reactions by about a factor of five, and gamma rays depopulating the ground state rotational bands in $^{232,234}\text{U}$ were then clearly observable to at least spin $12^+\rightarrow 10^+$ (see Table 2.16.1). Improvements to the system are currently being studied.
Table 2.16.1

Rotational Transition Energies (keV) in $^{234}\text{U}$ and $^{232}\text{U}$

<table>
<thead>
<tr>
<th>Transition</th>
<th>$^{234}\text{U}$</th>
<th>$^{232}\text{U}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 $\rightarrow$ 0</td>
<td>43.5 †</td>
<td>47.6 †</td>
</tr>
<tr>
<td>4 $\rightarrow$ 2</td>
<td>98.5 †</td>
<td>108.9 †</td>
</tr>
<tr>
<td>6 $\rightarrow$ 4</td>
<td>152.7</td>
<td>166.1</td>
</tr>
<tr>
<td>8 $\rightarrow$ 6</td>
<td>200.9</td>
<td>218.0</td>
</tr>
<tr>
<td>10 $\rightarrow$ 8</td>
<td>244.2</td>
<td>264.8</td>
</tr>
<tr>
<td>12 $\rightarrow$ 10</td>
<td>283.0</td>
<td>307.0</td>
</tr>
</tbody>
</table>

† From M. Sakai, Atomic and Nuclear Data Tables 15 (1975).

2.17 Crystal Blocking Lifetime Measurements for the $^{16}\text{O} + \text{W}$ Compound System

J.S. Forster, W.M. Gibson (Bell Labs.), K. Jorgensen (Aarhus University), D. Kellewe (Rutgers University), I.V. Mitchell (Solid State Science Branch) and D. Ward

We have made further measurements of lifetimes of fissioning compound nuclei using $^{16}\text{O}$ beams to bombard single crystals of W (PR-P-105: 2.11, AECL-5121). Fission fragment blocking patterns were observed at 130° and 170° to the beam direction using incident $^{16}\text{O}$ energies of 94, 97 and 102 MeV. The W crystal, with the 〈111〉 axis normal to the surface, was oriented so that the recoiling compound nuclei were directed at an angle of 30° to the {110} plane in order to study the effect of recoil angle on the blocking pattern. Analysis of the data is in progress.
2.18 Statistical Model Calculations of Beta-Delayed Proton Spectra
J.C. Hardy

The statistical model calculations first described in PR-P-108: 2.14, AECL-5315 have been extended and improved. The computer program for calculating the properties of beta-delayed proton emission now utilizes beta strength functions, either of the Gaussian or Lorentzian form, calculated within the framework of the "gross theory" of beta decay (Takahashi et al., Nuclear Data 12 (1973) 101). In addition the partial gamma-decay widths, $\Gamma_\gamma$, while still calculated assuming only $E_1$ decay, now incorporate the generally accepted Lorentzian strength function (Bartholomew et al., Advances in Nucl. Phys. 7 (1973) 229).

Apart from the beta-delayed proton spectrum shape, it is now possible to compute: a) the total beta-branching ratio from the precursor ground state to proton emitting states in the emitter; b) the proton branching ratio to states in the daughter; c) the spectrum of X-rays in coincidence with protons; and d) the fluctuations predicted as a result of the Porter-Thomas distribution of matrix elements.

Calculations of the decay properties of $^{69}$Se show good agreement with experiment.

2.19 A Computer Program for the Analysis of Time Dependent Perturbed Angular Correlation Data
H.R. Andrews

A computer code for fitting time dependent perturbed angular correlation data has been written and is based on the theory of Blume (Nucl. Phys. A167 (1971) 81). This theory is valid for arbitrary values of the interaction strength and correlation time. Closed-form solutions for Blume's equations only exist for those cases where either the atomic or nuclear
angular momentum is equal to 1/2. The present code, which relies on finding all the real and complex roots of high order polynomials numerically, is designed to handle any combination of atomic and nuclear spins. The program is now in the initial stages of debugging.

2.20 Improvements to the New Position Sensitive, Heavy-Ion Detector for the QD$^3$ Spectrometer
W.G. Davies, N.C. Bray, G.C. Ball and J.J. Hill

Experience with the new Heavy-Ion Counter for the QD$^3$ spectrometer (PR-P-108: 2.15, AECL-5315) indicated that it would be easier to achieve definite particle identification if the 0.5 mg/cm$^2$ aluminized mylar cathodes of the two ΔE proportional counters were replaced by wire grids. This modification improved the total resolution from 2% to 1.4%. The position resolution was also improved by using an Ortec 125 preamplifier with the position-sensitive counter instead of the PC109 proportional counter preamplifiers; a position resolution of 12 mm for $^{18}$O ions scattered from Pb was achieved and indicates that the intrinsic position resolution of the counter is of the order of 10 mm. A further improvement in both the position and energy resolution of the counter could be made if the high capacitance of the "umbilical cable" connecting the moveable counter inside the vacuum chamber to the outside could be reduced.

2.21 Progress on the QD$^3$ Focal Plane Counter System
G.C. Ball, W.G. Davies, J.J. Hill, F.J. Sharp, D.J. Yaraskavitch, J.S. Forster and W. McLatchie

A two module (70 cm long) back Charpak counter system has been successfully used to detect 15 MeV $^4$He ions scattered
from a thin \(^{208}\text{Pb}\) target and analyzed with the QD\(^3\) spectrometer operating at 0.6T (6 kG). The data were accumulated with the new PDP 10 scanner operating in both the singles and coincidence mode. The counter was operated at a voltage of 4000 V, using a 50% Ar, 50% isobutane gas mixture. The mean number of wires firing per event was found to be five for a time gate of 180 ns. To ensure that the overlap signal and the higher order bits were always present for every event these pulses were strobed into the latches of the receiver module (PR-P-103: 2.18, AECL-4931) 30 ns later. When the address computer was set to accept all 2-wire to 6-wire events the counter efficiency was determined to be > 95% and the position resolution was found to approach the ultimate minimum value of half the wire spacing (i.e. 1 mm). This counter system, which is also capable of operating at reduced pressures, is now available for use in experiments; further testing with lower ionizing particles will be carried out shortly.

2.22 Construction of a High Geometry Gas Scintillation Detector

D. Ward and R.B. Walker

Gas scintillator counters offer several advantages for in-beam detection of highly ionizing particles. For example, they can operate at counting rates in excess of \(10^6\) s and have excellent timing properties. For very heavy ions, such as fission fragments and energetic recoils, they exhibit no measureable pulse height defect. Other ionizing radiations such as X-rays and electrons do not cause any background problems.

The present device basically comprises a cylindrical chamber 16 cm in length by 16 cm diam. The beam enters and exits from the chamber along the cylindrical axis. A variety of thin windows supported on ribbed structures can be used to construct any desired topology for the gas volume. Scintil-
lations produced in the gas volume are viewed with two photomultipliers. Since much of the light produced by gas scintillation is in the ultra violet region we use reflecting paint coated with the wave-shifter p-quaterphenol on the walls.

Various scintillating gases have been tried in the chamber and pure nitrogen appears to give the best timing, although the amplitude of the pulse is \( \sim 1/2 \) that obtained with pure argon and \( \sim 1/4 \) of that obtained with optimum argon-nitrogen mixtures.

The device has been used successfully in three kinds of experiment involving very different geometries: the detection of (i) fission fragments (PR-P-109: 2.16, AECL-5508) (ii) scattered projectiles in Coulomb excitation and (iii) recoiling compound nuclei following (HI,\( x^n \)) reactions (PR-P-109: 2.11, AECL-5508).

2.23 The Chalk River Helium Jet and Skimmer System


We have developed and extensively tested a helium jet and skimmer system intended as an interface between a target location at the Chalk River tandem accelerator and the ion source of an on-line separator presently under construction. The system consists of a versatile target chamber, a 125 cm long capillary, and a one stage skimmer chamber. Helium loaded with \( H_2O \) or \( AgCl \) aerosol particles flows continuously through the target chamber. Recoils from nuclear reactions attach themselves to the aerosol particles and are transported through the capillary to the skimmer chamber where they are separated from the bulk of the helium by a skimming orifice. The designs (PR-P-103: 2.15, AECL-4931) of the target and skimmer chambers allow us to vary a large number
of independent flow and geometrical parameters with accurate reproducibility.

Experiments with the beta-delayed proton emitter \( \text{Si}^{25} \) \((T_{1/2} = 218 \text{ ms})\) produced in the reaction \( ^{24}\text{Mg}(^3\text{He},2\text{n})^{25}\text{Si} \) show that under optimized conditions, about 25\% of the reaction products leaving the target are transported to the skimmer. Of those, more than 90\% pass through the skimmer orifice, which separates off 97.5\% of the helium. By introducing an additional - perpendicular - helium flow across the skimming orifice the amount of helium separated from the transport jet can be increased to beyond 99.85\%, leaving the high throughput of recoils unaffected.

The time required for the recoils to travel from the target to the skimmer has been measured for different target chamber configurations. It is of the order of 200 ms.

2.24 Pulsed Beam Experiments in the Microsecond Regime

A system for pulsed beam experiments requiring beam repetition times in excess of 1 \( \mu \text{s} \) has been built. The development was necessary because the existing Ortec chopper-buncher system allows beam repetition times longer than the basic 400 \( \text{ns} \) only at the expense of reduced beam intensity.

Pulses from a 50 MHz clock are used to derive a beam deflection signal of chosen width and repetition time and to increment the scalers in a digital timer unit. Fast pulses from out-of-beam events are used to either stop the scalers or to initiate readout of their contents "in flight". The digital timer unit can be interfaced to both computers.

The system has performed satisfactorily in a recent two-parameter experiment to measure \( g \)-factors and spin relaxation times of high-spin isomers (see PR-P-109: 2.14, AECL-5508).
2.25 Target Preparation Laboratory  
J.L. Gallant  

Targets for Nuclear Physics  

The following targets were prepared by the laboratory for experiments carried out during this period: self-supporting calcium targets, natural silicon and calcium on tantalum substrates, $^{46}\text{Ti}$, $^{48}\text{Ti}$, natural lead, $^{208}\text{Pb}$, gold, tellurium, $^{50}\text{Cr}$ on tantalum substrates, natural uranium (500 µg/cm$^2$) on carbon, thorium (500 µg/cm$^2$), self-supporting $^{24}\text{Mg}$, $^{63}\text{Cu}$, $^{65}\text{Cu}$, $^{64}\text{Ni}$ on lead backings 13 mg/cm$^2$ thick, and liquid mercury targets. Targets of $^{18}\text{O}$ in the form of self-supporting Ta$_2^{18}$O$_3$ films and W$^{18}$O$_3$ on carbon backings were prepared for use in a collaborative experiment at Princeton University.

A total of 330 carbon films, 2 µg/cm$^2$ thick, were prepared for three stripper foil loadings in the MP tandem terminal during this period.

Work for other branches and outside organizations  

Laser reflector mirrors were gold coated for Dr. Keith Evans of the Physical Chemistry Branch.

Silver was vacuum deposited on quartz optical substrates to be used in an atomic absorption spectrophotometer. This work was requested by M. Hurteau of the General Chemistry Branch.

Gold and tungsten targets were prepared for Dr. D.C. Santry of Solid State Science Branch.

Several $^{205}\text{Tl}$ targets were prepared for Dr. T. Drake, Physics Department, University of Toronto for use in electrofission experiments. These consisted of thallium deposited between two protective films of aluminum.
The prototype Digital TAC has been used in a pulsed-beam experiment (see PR-P-109: 2.14 and 2.24, AECL-5508). A prescaler has been added to the TAC module, since it was found desirable to prescale the gated clock by a selected factor of 1, 2, 5 or 10. Extensive testing of the module has demonstrated the unit will operate reliably on the PDP-1 Coincidence Scanner. Three of the four Stepper/Router Modules to complement the Digital TAC system have been completed and tested on the PDP 10 Scanner.

PDP 1

The LA-36 Decwriter terminal and control interface (PR-P-108: 2.22, AECL-5315) has been installed on the PDP 1 computer and now replaces the Soroban typewriter originally used.

A Double Channel Marker Identifier, for setting digital windows on spectra displayed by the PDP 1 Main Console Display has been built and installed. Present software accepts only one channel, so for the time being only one channel marker can be used.

PDP 10

Two of the three Charpak Address Computers for the QD$^3$ Data System have been modified to recognize single line events. Further testing of the system and the 10 Scanner has been done with G.C. Ball and J.J. Hill, during their testing of the multiwire counter.

The Calendar Clock for the PDP 10 was installed last January and has behaved reliably in spite of power interruptions to the PDP 10 computer and monitor crashes.

Since last December, there have been two faults in the Intel 10/10 semiconductor memory. Both faults were
traced to failures of 1103 memory chips.

Two new modules have been added to the "Master" data analysis program: 1) HP45, which simulates a Hewlett-Packard 45 calculator and 2) CONSTANT, which scales the contents of a spectrum channel by channel and simultaneously adds an integer constant to each channel. The "human interface" to most of the "Master" modules has now been standardized by the use of several common input routines.

A user's handbook for "master" has been written. It is in looseleaf form for ease in updating and contains brief descriptions and illustrative outputs of the many modules in "Master".

The tandem data logging program is continuously expanding and improving as a result of feedback from the Operations staff.

**MP Tandem**

A power supply designed with the necessary "track" and "trim" controls for the low energy quadrupole lens (see PR-P-107: 2.17, AECL-5256) has been built and installed on the tandem. All relevant voltages are logged into the computer. No electrical failures have been experienced since installation of the power supply over six weeks ago.

The terminal voltage stabilization servo loop involving the generating voltmeter has been modified to produce separate control and readout paths. Previously, increasing the speed of the control loop to hold the terminal voltage within closer limits caused the last two digits of the readout digital voltmeter to jitter. This jitter has been substantially reduced. The accuracy of the readout has also improved with a maximum deviation of 80 kV between indicated and true terminal voltage over the range of 2-12 MV.

The fibre-optic controlled power supply for the Penning source has been installed in the ion source cage and is running under test.
Sixteen accelerator ion-source parameters are now being logged continuously by the PDP 10 computer scanner which is steadily increasing its usefulness since the improved power supplies and controls permit easy duplication of earlier, logged, settings.

2.27 MP Tandem Operation
T.K. Alexander

The availability of the tandem beam improved slightly in the past quarter (see Table 2.27.1). Shutdowns were scheduled for routine stripper foil replacements, inspection of charging chains, maintenance and ion source development. The main sources of unscheduled down time were failure of the timing belt driving the Pelletron chains and problems associated with the ion sources.

Table 2.27.1

<table>
<thead>
<tr>
<th>Description</th>
<th>Hours</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam available</td>
<td>1277.1</td>
<td>59.1%</td>
</tr>
<tr>
<td>Scheduled shutdown</td>
<td>441.4</td>
<td>20.4%</td>
</tr>
<tr>
<td>Unscheduled shutdown</td>
<td>441.5</td>
<td>20.5%</td>
</tr>
<tr>
<td>Total</td>
<td>2160.0</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

During the quarter, 20 experiments were performed involving CRNL and 12 visiting scientists. Non-CRNL scientists collaborated on experiments occupying 42% of the beam time, their average participation being 19%.

2.28 Ion Source Development
Y. Imahori (Operations Division) and H.R. Andrews

The General Ionics LCE Negative Ion Source

This source has been used successfully in the production of $^{18}$O beams (PR-P-108: 2.24, AECL-5315) for several
experiments in the last quarter. An outstanding problem has been short duoplasmatron filament life thought to be due to the presence of oxygen in the discharge. A fact of two improvement has been gained by adding an auxiliary gas feed to supply pure He or H₂ gas to the filament region.

Attempts were made to reproduce the results for ¹¹B and ²⁸Si reported previously (op. cit). These were not successful when the old gas mixtures were used but a fresh SiH₄ + H₂ mixture produced comparable results for ²⁸Si⁻. An attempt to produce B⁻ from 2% mixtures of B₂H₆ in H₂ and He failed. A mixture of nickel carbonyl and He was tried in order to generate a Ni beam but this was also not successful. The source has been very reliable and stable for ⁴He, ³He and ¹⁸O beams but more experience will be necessary to judge its usefulness for other species.

UNIS source

The oven and ionizer assembly has been rebuilt with a new design which provides greater ease of assembly and alignment and promises greater freedom from Cs leaks into the vacuum. The new version corrects misalignments found in the original model. The first tests of the rebuilt source are planned in the near future.

2.29 Emittance Measurements of ³²S Beams from the MP Tandem
J.S. Forster, T.K. Alexander, N. Burn and W.G. Davies

A new emittance measuring apparatus has been constructed using two moveable slits. The slits (each 0.127 mm wide and separated by 143.3 cm) are moved across the beam by stepping motors controlled by the PDP 1 computer. Mounted behind the second slit, and at 45° to the vertical, is an NE 901 glass scintillator which is viewed from above by an XP 1110 phototube. The complete slit and phototube assembly is mounted in a single length of beam tube with seals that allow rotation through 90° in order to make separate measure-
ments of $\varepsilon_x$ and $\varepsilon_y$. Emittance measurements are made by stepping the first slit (which defines the position) across the beam and at each point the second slit (which measures the divergence) is scanned across the beam which passes the first slit. The amount of beam falling on the glass scintillator is measured by the phototube, the signal from which is amplified and read into the PDP 1 computer.

A two dimensional display of intensity for position vs angle is generated for simple on-line analysis. The 2-d spectra are written onto magnetic tape for more sophisticated analysis later on the PDP 10 computer.

Table 2.2.1 summarizes results for $\varepsilon_x$ and $\varepsilon_y$ for 55 MeV $^{32}$S$^6^+$ and 80 MeV $^{32}$S$^7^+$ beams as well as the effect on the measured emittance of a 10 $\mu$g/cm$^2$ and a 20 $\mu$g/cm$^2$ carbon foil placed directly in front of the first slit. All measurements were made using the Heinicke-Penning ion source and N$_2$ gas stripping.

Attempts were also made to measure the emittance of a 100 MeV $^{79}$Br$^8^+$ beam but we had problems with two analyzed $^{79}$Br beams probably due to Br$^-$ and HBr$^-$ being produced by the source. Since all measurements were made using very wide object slits ($\pm$ 7.5 mm) it is possible for both $^{79}$Br beams to reach the image slits as their rigidity differs only by 1 part in 710. Future experiments will use smaller object slit settings in order to resolve this problem.

Table 2.29.1

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>Foil Thickness ($\mu$g/cm$^2$)</th>
<th>$\varepsilon_x$ (mm·mrad·MeV$^1$)</th>
<th>$\varepsilon_y$ (mm·mrad·MeV$^1$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>-</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>55</td>
<td>10</td>
<td>24</td>
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<td>55</td>
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<td>48</td>
<td>56</td>
</tr>
<tr>
<td>80</td>
<td>-</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>
Further fine tuning of the D3 injection line design for the superconducting cyclotron (PR-P-108: 2.26, AECL-5315) has been done making use of the latest beam emittance information (see PR-P-109: 2.29, AECL-5508). Although the numbers differ by a few percent from those published previously (ibid) the design remains unchanged. The results of these calculations do show, however, that the quality of the solution is very sensitive to the values of the emittance used to calculate the most difficult cases, i.e. 3 and 10 MeV/A uranium.

An extensive set of calculations has been made to determine magnetic and mechanical tolerances for all the beam transport elements in the injection line. These calculations show that some of the quadrupoles, mainly those near the cyclotron must be very accurately aligned (< 0.05 mm displacement and 0.4 mrad rotation) if the beam at the stripping foil is to be accurately matched to the acceptance requirements of the cyclotron. Magnetic field setability and stabilities of the order of 1 part in $10^4$ are required for most of the elements in the injection line. This should not be a serious problem.

A new series of $^{60}$Co reference sources has been prepared with the active material sandwiched between thin, commercially available, aluminized mylar foils. These sources are much more rugged and hence are expected to be more durable than reference sources formerly prepared on VYNS or
thin aluminum foil, yet the sandwich is thin enough to give good beta efficiencies (≈ 73%) for 4πβ-γ coincidence counting. They are not quite so rugged as the gamma-ray point sources sandwiched between polyester tape, but the latter is too thick to permit 4πβ-γ coincidence counting.

2.32 **Intercomparison of High-counting-rate Sources**

J.G.V. Taylor and F.H. Gibson

A third set of ⁶⁰Co sources has been received from the NPL (PR-P-107: 2.21, AECL-5256, PR-P-108: 2.28, AECL-5315). No new conclusions have been reached since the last report, but work on this intercomparison will continue for several months.

2.33 **International Comparison of ⁵⁷Co**

J.S. Merritt, F.H. Gibson and J.G.V. Taylor

Two ⁵⁷Co solutions were distributed by the NPL for a BIPM-sponsored international comparison. One solution was free of detectable amounts of ⁵⁶Co and ⁵⁸Co but was of low specific activity; the second was of higher specific activity but contained 0.15% ⁵⁶Co and 0.03% ⁵⁸Co activities relative to ⁵⁷Co at the time of measuring as determined by Ge(Li) spectrometry.

A total of several hundred 4πβ-γ coincidence measurements were made on 24 sources, 12 from each solution. The final ⁵⁷Co activity concentrations were determined with 0.07% standard error and 0.17% total systematic uncertainty for the higher specific activity solution and 0.26% standard error and 0.47% total systematic uncertainty for the low specific activity solution. It was concluded that, despite the presence of the isotopic activities, the higher specific activity solution allowed the more accurate ⁵⁷Co assay. The
additional uncertainty in determining and subtracting the small $^{56}$Co and $^{58}$Co activities was insignificant compared to the increased extrapolation uncertainty resulting from the lower average $4\pi$-counting efficiencies of sources prepared from the lower specific activity solution.

As an exercise in the state-of-the-art, care was taken to minimize and estimate the systematic uncertainty in determining the source masses. Mass measurements were made in duplicate on two calibrated microbalances in an unbroken sequence for each solution. Thus the total mass dispensed was the sum of the source masses and was determined with a smaller fractional error than the masses of individual sources. For each solution, the fractional difference in total mass obtained with the two calibrated balances was taken to be the systematic uncertainty due to weighing that was applicable to the final result derived from measurements on all the sources. Including the uncertainty in the buoyancy correction it amounted to < 0.006% and made a negligible contribution to the total systematic uncertainty. The uncertainties in the individual source masses were up to 5 times as great and made a small contribution to the statistical error in the final result.

Other experiments compared the efficiency functions obtained using self-absorption and foil absorption (no statistically significant difference was found) and compared the activity concentrations of the two solutions by relative gamma-ray measurements. These experiments gave a more accurate $^{57}$Co assay of the lower specific activity solution, by relating it to the more accurately determined higher specific activity solution, than did the direct measurements.
2.34 **Standardizations**
J.S. Merritt and F.H. Gibson

\[ ^{24}\text{Na} - \text{Neutron and Solid State Physics (twice)} \]
\[ ^{57}\text{Co} - \text{Environmental Research} \]
\[ ^{57}\text{Co} - \text{NPL (intercomparison)} \]
\[ ^{60}\text{Co} - \text{Fuel Engineering (9 flux monitors)} \]
\[ ^{147}\text{Pm} - \text{Medical Research} \]

2.35 **Miscellaneous Services**
J.S. Merritt, F.H. Gibson and J.G.V. Taylor

Six counter windows of VYNS films laminated to a thickness of 30 µg cm\(^{-2}\) were made for Nuclear Physics.

A 450-page draft of a forthcoming NCRP (U.S.) manual on radioactivity procedures was reviewed in detail and corrections and suggested changes sent to the editor.

Using \(^{24}\text{Na}\), radioactivity handling procedures were demonstrated for the Science Teachers' Seminar.

Calculations were made deducing activities from exposure-rate measurements for some nuclides in waste sent from CP to R. & I.S. branch.

2.36 **Coulomb Correction to Fermi Beta Decay**
I.S. Towner and J.C. Hardy

See PR-P-109: 4.9.

2.37 **Search for Two-photon Emission in Thermal Neutron Capture in Deuterium**
M.A. Lone, E.D. Earle and A.B. McDonald

See PR-P-109: 3.14
2.38 Upper Limit on the H(n,γγD Cross Section
E.D. Earle, M.A. Lone and A.B. McDonald

See PR-P-109: 3.13

2.39 Thermal Neutron Capture in 16O
M.A. Lone, E.D. Earle and A.B. McDonald

See PR-P-109: 3.15

2.40 Publications and Lectures

(a) Publications

RECOIL-DISTANCE LIFETIME MEASUREMENTS OF LEVELS IN 36Ar AND 36Cl
G.J. Costa, T.K. Alexander, J.S. Forster, A.B. McDonald and I.S. Towner

USE OF THE 208Pb(18O, 21O)205Pb REACTION TO MEASURE THE MASS OF 21O
G.C. Ball, W.G. Davies, J.S. Forster and H.R. Andrews

INITIAL STATE DISTORTION AND FINAL STATE INTERACTIONS IN THE 2H(3He, 3He p)n AND 2H(3He, 3H p)p REACTIONS
Nucl. Phys. A255 (1975) 95

SUPERALLOWED 0+ → 0+ NUCLEAR BETA DECAYS AND CABIBBO UNIVERSALITY
J.C. Hardy and I.S. Towner

LIFETIME OF THE 1.89 MeV 2+ LEVEL OF 18Ne: TWO BODY CONTRIBUTIONS TO E2 TRANSITION RATES
SPECTROSCOPY OF THE GAMMA DECAY OF HIGHLY EXCITED HIGH-SPIN STATES BY ANGULAR CORRELATION AND FEEDING-TIME MEASUREMENTS
W. Trautmann, D. Proetel, O. Häusser, W. Hering and F. Riess

(b) Lectures

A PROPOSAL FOR A COMPUTER BASED CONTROL SYSTEM FOR THE MP TANDEM AND SUPERCONDUCTING CYCLOTRON
R.L. Graham and L.D. Hansen
Physics Division Colloquium on 22 January 1976

NUCLEAR BETA DECAY: FROM QUARK CHARGES TO GIANT RESONANCES
J.C. Hardy
Seminar at McGill University on 2 February 1976

NUCLEAR BETA DECAY: FROM QUARK CHARGES TO GIANT RESONANCES
J.C. Hardy
Seminar at Texas A & M University on 10 February 1976

STUDIES OF HIGH SPIN STATES AND QUADRUPOLE MOMENTS
T. Faestermann
Physics Division Colloquium on 12 February 1976

COMPARISON OF ALPHA TRANSFER AND ALPHA DECAY IN THE LEAD REGION
W.G. Davies
Seminar at the Université de Montréal, 12 February 1976
3.1 Staff
3.2 Neutron Scattering from Nonsuperfluid Liquid \(^{4}\)He at Small Wave Vectors
3.3 Analysis of \(S(Q,\omega)\) for Nonsuperfluid Liquid \(^{4}\)He
3.4 Phase Transition in Potassium Hexachloro-osmate
3.5 Ultraviolet Radiation Damage in Crystals of the Nucleic Acid Bases
3.6 Magnetic Excitations and Phonons in UO\(_2\)
3.7 Excitations of Isolated Clusters of Magnetic Ions
3.8 Magnetic Scattering from Mn\(_{0.32}\)Zn\(_{0.68}\)F\(_2\) and Mn\(_{0.25}\)Zn\(_{0.75}\)F\(_2\)
3.9 High Temperature Positron Annihilation Apparatus
3.10 Interpretation of Structure in the \(^{232}\)Th Photofission Spectrum
3.11 Improvement of the Multiwire Fission Counter Facility
3.12 N4 Thermal Facility
3.13 Upper Limit on the H(n,\(\gamma\gamma\))D Cross Section
3.14 Search for Two-photon Emission in Thermal Neutron Capture in Deuterium
3.15 Thermal Neutron Capture in \(^{16}\)O
3.16 A 19/2\(^{+}\) Isomeric State in \(^{209}\)Bi
3.17 Reactor Beam Hole Use
3.18 Supply and Servicing of Semiconductor Detectors
3.19 Synthesis of CdTe
3.20 CdTe Sublimation
3.21 CdTe Crystal Growth by the Slow-cooling Method
3.22 CdTe Crystal Quality
3.23 CdTe Crystal Growth with the Travelling Heater Method
3.24 Electronics for Semiconductor Detectors
3.25 Miscellaneous
3.26 The Chalk River Helium Jet and Skimmer System
3.27 Nuclear Lifetimes in the Region of $10^{-16}$s Measured by a New Technique
3.28 Decay Properties of $^{69}$Se
3.29 Electromagnetic Properties of the Ground State Rotational Band in $^{169}$Tm
3.30 Production of Heavy Superallowed Positron Emitters
3.31 Publications and Lectures
3.1 **Staff**

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

**SECTION I**  **SOLID STATE PHYSICS**  **TECHNICAL STAFF**

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>A.D.B. Woods</td>
<td>R.S. Campbell</td>
</tr>
<tr>
<td>W.J.L. Buyers</td>
<td>H.F. Nieman</td>
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<tr>
<td>G. Dolling</td>
<td>M.M. Potter</td>
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<td>D.C. Tennant</td>
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<td>P. Martel</td>
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<td>B.M. Powell</td>
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<td>T.C. Svensson</td>
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**SECTION II**  **NEUTRON NUCLEAR PHYSICS**

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<td>E.D. Earle (1)</td>
<td>R.N. King</td>
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<td>S.T. Lim (2)</td>
<td>W.F. Mills</td>
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<td>M.A. Lone</td>
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**SECTION III**  **COUNTER DEVELOPMENT**

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<td>R.J. Dinger (3)</td>
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<td>H. Schmeing (4)</td>
<td>W.F. Slater</td>
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<td>R.J. Toone</td>
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<td>W.J. Woytowich</td>
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**GLASSBLOWING**  **WORKSHOPS**

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<tr>
<td>J.G. Wesanko</td>
<td>R.R. MacLanders</td>
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<tr>
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<td>A.H. Hewitt</td>
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<tr>
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<td>H.C. Spenceley</td>
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**DESIGN**  **SECRETARIAL STAFF**

<table>
<thead>
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</tr>
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<tbody>
<tr>
<td>W. McAlpin</td>
<td>Mrs. Dianne Mitchell</td>
</tr>
<tr>
<td>K. Tait (5)</td>
<td></td>
</tr>
</tbody>
</table>

(1) On leave of absence for approximately 3 months at TRIUMF, Vancouver, B.C.; left February 11, 1976.
(2) NRC Post-doctoral Fellow from University of British Columbia, Vancouver, B.C.
(3) NRC Post-doctoral Fellow from University of Basel, Switzerland.
(4) Transferred from Nuclear Physics Branch February 16, 1976.
(5) Seconded from Design Engineering.
3.2 Neutron Scattering from Nonsuperfluid Liquid $^4$He at Small Wave Vectors


Measurements of frequencies and widths of phonons in nonsuperfluid liquid $^4$He (PR-P-106:3.3, AECL-5266; PR-P-107:3.4, AECL-5256; and PR-P-108:3.2, AECL-5315) were continued. At $T = 2.3$ K under the saturated vapour pressure (SVP) extensive measurements were made in the wave vector range $1.5 \text{ nm}^{-1} \leq Q \leq 7.0 \text{ nm}^{-1}$ and the results confirmed that at this temperature and pressure there is a transition near $Q = 2.5 \text{ nm}^{-1}$ from the first-sound to the zero-sound mode of propagation. For $Q \geq 3.0 \text{ nm}^{-1}$ the phonon velocity is about 10% higher than the velocity of ultrasonic (first-sound) waves while for $Q \leq 2.0 \text{ nm}^{-1}$ the phonon velocity is essentially the same as for ultrasonic waves. Similar experiments have been started at $T = 2.5$ K and $P = 1.0 \text{ MPa}$ ($\approx 10 \text{ atm}$).

3.3 Analysis of $S(Q,\omega)$ for Nonsuperfluid Liquid $^4$He


Detailed analysis of the results of neutron-scattering measurements on nonsuperfluid liquid $^4$He (PR-P-106:3.2, AECL-5226) in the range $1.1 \text{ nm}^{-1} \leq Q \leq 26 \text{ nm}^{-1}$ has been carried out to obtain absolute values of the resolution-broadened scattering function $S(Q,\nu)$ and of the Laplace transform of the relaxation function $R'(Q,\nu)$. Arbitrary background levels, which included the effects of multiple scattering, were chosen so that (1) $S(Q,\nu)$ integrated over all frequencies gave the X-ray value of the static structure factor $S(Q)$, generally to better than 1%, and (2) the first moment theorem was obeyed to $\approx 0.5%$
or better. The spectrometer efficiencies were specified by one normalization parameter only for each independent set of measurements which were typically carried out at about 10 separate Q values.

The values of \( S(Q,v) \) and \( R'(Q,iv) \) so obtained were then used to calculate other frequency moments. In particular the quantities \( v_0(Q) \) and \( v_\infty(Q) \), the so-called isothermal and high-frequency dispersion laws for a liquid, which are directly related to fundamental quantities such as the interatomic potential, were obtained to an accuracy which is believed to be \( \approx5\% \).

3.4 Phase Transition in Potassium Hexachloro-osmate

B.M. Powell and W.J.L. Buyers with R.L. Armstrong and D. Mintz (University of Toronto)

Potassium hexachloro-osmate \((K_2\text{OsCl}_6)\) crystallizes in the cubic antifluorite structure. At \( T_c = 45 \) K it undergoes a phase transition to a structure which is not known in detail but is probably tetragonal. This phase transition is thought to be caused by a small (-2°) rotation of the (rigid) chlorine octahedra from their high temperature orientation. Since several branches of the normal mode dispersion relation involve pure librational modes of the chlorine octahedra, the transition is thought to be analogous to the "soft-mode" transitions in the perovskites.

Calculations of the one-phonon structure factors on the basis of a simple shell model for the lattice dynamics of \( K_2\text{OsCl}_6 \) indicated where the scattering due to the librational modes was strong. However, these modes are always observed in the presence of acoustic modes. Several of the acoustic branches have been measured at 77 K in order to estimate their contribution to the observed scattering as
the phase transition is approached. The intensity of 32 Bragg reflections has been measured as a function of temperature between 4.34 K and 55 K. Few of the strong reflections show dramatic changes on passing through T_c, but many show intensity changes (~10%) between 4.3 K and 55 K. Some of the weaker reflections show more marked intensity variations (a factor of ~2) and the (771) reflection decreases by ~10 when the temperature changes from 4.34 K to 55 K. Several reflections, e.g. (220), which are allowed by the crystal symmetry, are found to have vanishingly small structure factors when calculated for the static lattice. However, these reflections are experimentally observed to have weak, but finite, intensity at all temperatures. The measurements of Bragg intensity will be analysed to derive the temperature dependence of the crystal structure and the Debye-Waller factors. It is hoped that this dependence can be correlated with the appearance of the "accidentally absent" reflections and with the onset of the transition.

3.5 Ultraviolet Radiation Damage in Crystals of the Nucleic Acid Bases
P. Martel and B.M. Powell

We have continued the neutron diffraction studies of UV radiation damage in nucleic acid bases, reported in PR-P-108:3.9, AECL-5315. In addition to the 1½ and 80 hour irradiations of 1-methylthymine reported there we have made diffraction measurements on specimens irradiated for 6, 12, 47 and 72 hours. Spectrophotometric measurements have been carried out on these specimens and the linear relationship between dimer concentration and the intensity of the (102) powder peak has been confirmed.
We have carried out similar measurements on uracil and have found that it is also damaged by 254 nm radiation. In this case it is evident from the structure (G.S. Parry, Acta Cryst. 7 (1954) 313) that it will be the (001) powder peak which will reflect deviations from the parallel stacking of the pyrimidine molecules in the unirradiated sample. The dimer type formed is likely to be the same as that formed in RNA.

Experiments on guanine, cytosine and ordinary thymine showed that these bases sustained negligible structural damage when subjected to 40 hours of 254 nm radiation. Further measurements are planned for iso-cytosine and adenine and the nature of the damage in uracil will be studied in more detail.

3.6 Magnetic Excitations and Phonons in UO₂
W.J.L. Suyers, T.M. Holden and G. Dolling

A search has been made for a soft TA phonon (M₅), invoked by Faber et al. (Phys. Rev. Lett. 35 (1975) 1770) to explain their anomalous form factor results. The frequency of this M₅ mode remained close to 3.30 THz from 296 K down to the phase transition at 30.8 K, and decreased by less than 2% in the antiferromagnetic phase. There is therefore no significant softening of this mode, and alternative explanations of the form factor anomaly must be sought. The phonon and magnon dispersion curves below 30.8 K are, however, more complex than previously supposed (PR-P-68:4.4, AECL-2612; PR-P-71:4.3, AECL-2639); at the M point (001), at 4.3 K, the strong excitation seen at 2.88 THz is now interpreted as being largely magnetic in character, and there is evidence of splittings of the two lower magnetic modes near 2.30 and 0.57 THz respectively.
The existence of at least 3 magnetic excitations from the ground state may require reconsideration of the currently accepted $\Gamma_5$ triplet ground state of the $U^{4+}$ ion. A definitive interpretation of the results is difficult, however, on account of possible domain effects.

3.7 Excitations of Isolated Clusters of Magnetic Ions
E.C. Svensson, W.J.L. Buyers and T.M. Holden

Magnetic excitations in a single-crystal specimen of $\text{KMn}_{0.1}\text{Zn}_{0.9}\text{F}_3$, which does not exhibit long-range magnetic order, have been studied by means of neutron inelastic scattering. At 4.3 K, the frequency, $v$, of the strongest peak in the inelastic scattering is independent of wave vector ($v = 0.20 \pm 0.01 \text{ THz}$) but its intensity varies markedly being a maximum near $(\frac{1}{2}\frac{1}{2}\frac{1}{2})$ and essentially zero near $(001)$ and $(111)$. The observed intensity variation is consistent with that expected for the scattering by an isolated pair of magnetic ions. An exact calculation of the pair frequency gives $2J$ where $J$ is the exchange interaction. Using the $J$ determined by EPR measurements (J.J. Krebs, J. Appl. Phys. 40 (1969) 1137) one obtains $2J = 0.21 \text{ THz}$ in excellent agreement with our value. On the other hand, mean-field theory applied to the dilute antiferromagnet gives a pair frequency of $5J$ indicating the expected breakdown of this theory for low concentrations of magnetic impurities. A second peak which is observed at about $0.4 \text{ THz}$ at 4.3 K, but which is absent at 2.0 K, is identified as an excitation between the first and second excited states of the isolated pair. The exact theory gives $4J = 0.41 \text{ THz}$ for its frequency. The frequency, about $0.7 \text{ THz}$, of a third peak is consistent with the prediction ($7J = 0.72 \text{ THz}$) of the exact theory for an isolated
cluster of three Mn ions. Measurements have also been carried out at 20, 50, 100 and 300 K. The intensity of the peak at 0.2 THz decreases with increasing T, but it, and also the peak at ≈0.4 THz, are still clearly visible at 100 K, indicating that a substantial energy is required to break up the correlations of the isolated pair. Additional scattering which corresponds to the many allowed transitions between excited states appears as the temperature is raised making it difficult to interpret the spectra especially at higher frequencies.

3.8 Magnetic Scattering from Mn$_{0.32}$Zn$_{0.68}$F$_2$ and Mn$_{0.25}$Zn$_{0.75}$F$_2$
W.J.L. Buyers, T.M. Holden and E.C. Svensson

The structure in the lineshape observed in earlier measurements (PR-P-106:3.9, AECL-5226) at 5 K on antiferromagnetic Mn$_{0.32}$Zn$_{0.68}$F$_2$ has been studied under conditions of higher resolution and at both lower and higher temperatures, 1.9, 4.2 and 20.0 K. Corresponding measurements have also been carried out on a single-crystal specimen of Mn$_{0.25}$Zn$_{0.75}$F$_2$ which does not exhibit long-range magnetic order. As before, most of the measurements were carried out at a reduced wave vector ζ = 0.45 in each of the [00ζ] and [ζ00] directions. The structure in the lineshape for Mn$_{0.32}$Zn$_{0.68}$F$_2$ is considerably more marked at 1.9 K than at 4.2 K and has essentially disappeared at 20.0 K, which is about twice the Néel temperature, although there is still a broad spectrum of inelastic scattering. The structure in the lineshape for the non-magnetic specimen, Mn$_{0.25}$Zn$_{0.75}$F$_2$, is substantially less distinct than for the magnetic specimen but is still clearly discernible at the lowest temperature, 1.9 K.
3.9 High Temperature Positron Annihilation Apparatus
D.C. Tennant, S.M. Kim and W.J.L. Buyers

In order to study the vacancy properties in high melting point metals, a high temperature positron annihilation sample chamber has been built and tested. Preliminary measurements have been made on a five nines pure iron specimen. Two rectangular shaped iron bars (32 mm x 6.4 mm x 1.6 mm) were welded at each end of the specimen (38 mm x 6.4 mm x 1.6 mm) to a U shape so as to produce a uniform temperature distribution across the length of the specimen. The specimen was tilted 4 degrees and was heated directly by electrical resistance heating. Four $W_{0.95}Re_{0.05}W_{0.76}Re_{0.26}$ thermocouples were attached to the sample and one of them was fed to a Thermae Model 625 Temperature Controller.

Because of the high vapour pressure of iron, tests were made in pure He gas at a pressure of 10 kPa (0.1 atm). A temperature of 1400°C was attained with about 500 watts power (68 V and 7.5 A). A thin (0.013 mm) tantalum foil was placed between the sample and the Cu$^{64}$ positron source in order to prevent contamination of the positron source and also to act as a radiation shield. Taking only the photo-peak coincidence events, about $3 \times 10^5$ peak coincident counts were obtained in 10 minutes with a long slit geometry (93 mrad x 2 mrad). Tilting the specimen by 4 degrees reduced variation of the singles count rate due to the annihilation photon self-absorption to a few percent throughout the angular range of ±20 mrad.
3.10 Interpretation of Structure in the $^{232}$Th Photofission Spectrum

J.W. Knowles with T.E. Drake and B.O. Pich (University of Toronto)

The photofission spectrum of $^{232}$Th (PR-P-108:3.14, AECL-5315) obtained with a resolution of 75 keV shows a prominent peak at 6.30 MeV. This peak, observed previously in both photo and transfer reactions with resolutions >200 keV, was attributed to neutron competition arising from the proximity of the neutron separation energy, $E_n = 6.364$ MeV. However, our measurements of this peak, which is at 6.28 ± 0.03 MeV, cannot be accounted for by neutron competition; the calculated fission transmission factor, $T_f$, shows a broad peak at 6.28 MeV with a maximum value of $1.5 \times 10^{-2}$. For the calculation we used the measured photofission cross sections $\sigma_f$, the photo-absorption cross sections $\sigma_a$, and $\gamma$-ray and neutron transmission factors $T_\gamma$ and $T_n$ obtained previously by A.M. Khan and J.W. Knowles (Nucl. Phys. A 179 (1972) 333, AECL-4050). Neither the shape nor the position of this peak are sensitive to the known uncertainties in $E_n$ and $T_n$. The peak cannot be interpreted as a plateau which would indicate an open channel in the fission spectrum, because $T_f$ is much less than unity.

3.11 Improvement of the Multiwire Fission Counter Facility

J.W. Knowles and S.T. Lim with T.E. Drake and B.O. Pich (University of Toronto)

The 5000 wire fission counter facility described in PR-P-107:3.17, AECL-5256, has been improved by reducing the width of the fission pulse from 40 to 5 ns. In the original arrangement, where 8 modular counters were
connected to a single, ORTEC-118A, charge sensitive preamplifier and an ORTEC-260 pick-off and discriminator circuit, the input capacitance limited the risetime of the pulse. In the present arrangement only 1 modular counter (50 wires) is connected to each preamplifier. This 8-fold improvement in response time means a corresponding increase in the counting rate of the fission chamber used with a bremsstrahlung monochromator. The new system will be used to measure photofission cross sections of $^{238}$U and $^{232}$Th following electric quadrupole absorption known to occur at about 5.0 MeV. Our previous measurements, described in PR-P-108:3.14, AECL-5315, were limited to energies above 5.5 MeV.

3.12 N4 Thermal Facility
M.A. Lone and W.M. Inglis

Work is in progress on the design of a high flux external thermal neutron beam at the N4 hole at the NRU reactor for double photon (PR-P-108:3.15, AECL-5315) and coincidence $(n,\gamma)$ experiments.

3.13 Upper Limit on the $H(n,\gamma\gamma)D$ Cross Section
E.D. Earle and M.A. Lone with A.B. McDonald (Nuclear Physics Branch)

From recent measurements with two Ge(Li) detectors (PR-P-108:3.15, AECL-5315) we have further reduced the upper limit on the two-photon cross section. By subtracting from the observed yield the contribution from the cross registration of $\gamma$-rays, which primarily arises from positron annihilation-in-flight, we obtain $\sigma_{2\gamma} = -3 \pm 8 \mu$b for $600 \text{ keV} < E_{\gamma} < 1620 \text{ keV}$. This value may be
compared to conventional theoretical predictions of 0.07 ub (J. Blomqvist and T. Ericson, Phys. Lett. 57B (1975) 117; H.C. Lee and F.C. Khanna, PR-P-109:4.7, AECL-5508). The measured limit is lower than the theoretical prediction obtained if one assumes (R.J. Adler, Phys. Rev. C 6 (1972) 1964) that the 3S np continuum state and the D ground state are not orthogonal by an amount sufficient to contribute 8% to the singly radiative np cross section. With this assumption the calculated cross section for 600 keV < E_γ < 1620 keV is 13 ub.

3.14 Search for Two-photon Emission in Thermal Neutron Capture in Deuterium

M.A. Lone and E.D. Earle with A.B. McDonald (Nuclear Physics Branch)

We have determined an upper limit for the ratio of the cross section for double photon emission to that for single photon emission following thermal neutron capture in deuterium. The measurements (PR-P-107:3.16, AECL-5256) were carried out with two Ge(Li) detectors which subtended an angle of 85° at the target and were shielded from one another to reduce γ-ray scattering from one detector to another. A value σ_γγ/σ_γ = (1.5 ± 2.8) × 10^{-2}, or σ_γ = 8 ± 15 µb was determined for γ-rays in the energy region 0.7 MeV < E_γ < 5.55 MeV.

3.15 Thermal Neutron Capture in 16O

M.A. Lone and E.D. Earle with A.B. McDonald (Nuclear Physics Branch)

The thermal neutron capture cross section and the gamma-ray branching ratios for the 16O(n,γ)17O reaction
were measured in a coincidence experiment with two Ge(Li) detectors at the NRU reactor. H\textsubscript{2}O and D\textsubscript{2}O targets were used. Gamma rays of energies 870.89 ± 0.22, 1087.88 ± 0.17, 2184.47 ± 0.12 and 3272 ± 1 keV were observed in the singles and the coincidence spectra.

The branching ratios of the M1 transition to the 871 keV 1/2\textsuperscript{+} level and the E1 transition to the 3055 keV 1/2\textsuperscript{−} level were determined to be (18 ± 3)% and (82 ± 3)% respectively. A total capture cross section of 202 ± 27 \textmu b for the $^{16}\text{O}(n,\gamma)^{17}\text{O}$ reaction was determined relative to the cross section (521 ± 9 \textmu b) for the D(n,\gamma)T reaction (S. Friarman and S.S. Hanna, Nucl. Phys. A 251 (1975) 1).

Our measured branching ratios and the capture cross section for $^{16}\text{O}$ are in good agreement with the M1 branching ratio (19%) and the total capture cross section (178 ± 25 \textmu b) reported by Jurney and Motz (Proc. Int. Conf. on Nuclear Physics with Reactor Neutrons, Argonne, Illinois, 1963, Ed. P.F. Throw, ANL 6797, p. 236).

The large observed ratio (~120) between the reduced widths of the 1088 keV E1 transition and the 3272 keV M1 transition (the former from the capturing 1/2\textsuperscript{+} level to the 1/2\textsuperscript{−} 3055 state and the latter from the 1/2\textsuperscript{+} capturing level to the 1/2\textsuperscript{−} 870 keV level) would imply that the reaction proceeds via simple core + s\textsubscript{1/2} configuration in the capturing state. Then, since the M1 transition s\textsubscript{1/2} + s\textsubscript{1/2} is forbidden, the observed M1 transition is weaker than the competing s\textsubscript{1/2} + p\textsubscript{1/2} E1 transition.

### 3.16 A 10/2\textsuperscript{+} Isomeric State in $^{209}\text{Bi}$
E.D. Earle et al.

See PR-P-109:2.13 .
3.17 Reactor Beam Hole Use
A.D.B. Woods

The McMaster University double monochromator triple axis spectrometer was used for two experiments during the period. Installation of the Guelph University spectrometer at D3 is progressing. The out-of-pile monochromator shielding has been installed and preliminary tests of γ-ray and fast neutron levels have been made. The np double photon decay experiment at C4 is complete and the spectrometer is now being used for solid state neutron scattering experiments. The fast chopper system at C2 has been recommissioned.

The following table summarizes utilization of operating CRNL spectrometers 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>C4</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>97</td>
</tr>
<tr>
<td>C5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>99.5</td>
</tr>
<tr>
<td>L3</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>96</td>
</tr>
<tr>
<td>N5</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>96</td>
</tr>
<tr>
<td>Cl</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>85</td>
</tr>
</tbody>
</table>

Total reactor operating time was 76 days.

3.18 Supply and Servicing of Semiconductor Detectors
R.J. Toone, W.F. Slater and I.L. Fowler

One high purity germanium detector system was serviced (cryostat re-pumped and baked out) for Reactor
Control Branch following a warm-up. The detector was not removed and, after the service procedure, the spectrometer characteristics were the same as when originally installed.

Discussions and design work have continued on the double high purity Ge detector system required by the Reactor Control Branch.

3.19 Synthesis of CdTe
R.J. Dinger and W.J. Woytowich

The CdTe used for crystal growth is now synthesized in our laboratory from 99.999% pure elements in order to obtain purer starting material. Experience shows that explosions can and do occur in this reaction. The melting points of Cd, Te, and CdTe are, respectively, 320°C, 450°C, and 1100°C and the reaction takes place at about 500°C. Large local fluctuations in the Cd and Te concentrations lead to inclusions of the elements in the solid CdTe as the latter forms on heating the ampoule. During further heating to 1100°C, which is done to ensure complete reaction, any enclosed Cd will give rise to a vapour pressure of about 5 atmospheres at 900°C and can cause the ampoule to explode. To reduce the possibility of explosions, an arrangement designed to stir the contents of the ampoule during heating up is being fitted to the furnace. If this results in a homogeneous mixture of the (liquid) elements at the reaction temperature, the problem should be solved.
3.20 CdTe Sublimation
R.J. Dinger

In order to improve the detector quality of our crystals, further refining of the CdTe before the crystal growth is attempted is necessary. Following good experience in other laboratories, a sublimation furnace was installed and its temperature has been adjusted to give the best separation between the charge, the sublimed CdTe and any impurities (such as Cd and Te which may be present at the percent level in material which has been synthesized). The separation distances between each of the three zones is about 15 cm and the sublimed material can thus be removed relatively easily without contamination from the remnants of the charge or impurity elements. The sublimation is carried out in an atmosphere of hydrogen purified by passage through a palladium thimble.

3.21 CdTe Crystal Growth by the Slow-cooling Method
R.J. Dinger, W.J. Woytowich, I.L. Fowler, H. Schmeing and J.G. Wesanko

Three more crystals (#17 to #19) were grown in this period by the slow-cool, growth from solution technique. In an attempt to get larger crystals a temperature cycling system superimposed on the controlled cooling was tried. Parasitic crystal growth frequently occurs from nucleation at a point formed on the ampoule wall by, for example, a carbon particle from the ampoule coating. The ampoule temperature was cycled in such a way that the same fraction of the crystal was forced to melt and recrystallize 5 to 10 times - thus giving the CdTe molecules a chance to crystallize at the energetically best place, i.e. to
continue growth at an existing crystal. Although this technique has been used with success in the growth of large single crystals from the vapour phase, it had no significant effect under our growing conditions.

A study of all the crystals grown so far by the slow-cool method shows that the dominant parameter for the size of the single crystals is the temperature gradient within the molten CdTe and Te mixture. A different cooling arrangement which should increase this gradient is currently being designed.

On the CRNL contract to grow and evaluate CdTe crystals, Aptec Engineering Ltd. have grown five boules in flat bottomed crucibles; one showed promise. They are currently experimenting with shaped crucibles in attempts to get larger crystals.

3.22 CdTe Crystal Quality
M.M.L. Racicot and R.J. Dinger

Several contact materials were tested to determine the influence of the contact fabricating technique on the mobility-lifetime (μτ) product values obtained with our crystals. Evaporated contacts of gold, aluminum, indium and carbon, as well as painted-on carbon (dag) contacts, were made on samples with etched and polished surfaces. The results all agreed within one order of magnitude and it is thought that the differences observed, as well as those observed earlier (PR-P-108:3.27, AECL-5315), are mainly due to inhomogeneities in the material.

Material from three of the crystals grown by the slow-cool method show a μτ-product for electrons which approaches an acceptable value for detectors (~10⁻³ cm·V⁻¹). The μτ-product for electrons for the other crystals and for holes for all the crystals is in the 10⁻⁵ cm·V⁻¹ range.
3.23 **CdTe Crystal Growth with the Travelling Heater Method**
I.L. Fowler, R.J. Dinger and R.J. Toone

Some initial troubles were experienced with the small hot zone furnace of this crystal grower. The furnace heater was re-designed and appears to be satisfactory. Preliminary growth tests are underway. One crystal has been grown so far but, due to a problem with a furnace shield, the crystal size was smaller than we need for satisfactory quality tests. We are using the boule for Te inclusion studies until the next crystal can be grown. The hot zone temperature profile has been changed for the next crystal growth attempt in order to enhance the gradient on the crystal growth side of the furnace.

3.24 **Electronics for Semiconductor Detectors**
W.F. Slater and R.J. Dinger

The preamplifier design mentioned in PR-P-107:3.28, AECL-5256, is now completed and a first unit has been assembled in its final version for use in laboratory testing of detectors. For a 1 cm³ high purity Ge detector, with a standard 2N 4861A transistor at room temperature as the first stage, the resolution for the 1333 keV gamma rays from a $^{60}$Co source is 2.3 keV (FWHM); 1.6 keV is the electronics contribution to the resolution in this arrangement.

A small high-voltage power supply for germanium detectors has been built and is in use in the laboratory on life test. It is 190 mm × 64 mm × 38 mm and provides stabilized high voltages of either polarity between 500 V and 1000 V via a DC to DC converter from two small 9V batteries (type TR146X). The lifetime of the batteries is expected to be about one year. The fact that the unit is
small and self-contained makes it very convenient for semi-portable Ge gamma-ray spectrometers, e.g. those used for activity monitoring. An additional advantage is that, unlike many mains operated high-voltage power supplies, it contributes negligible noise at the detector input.

3.25 Miscellaneous

A new cryostat has been constructed and tested; this will simplify the testing of Ge spectrometers of larger sizes on the scanning equipment.

A new turbo-molecular vacuum pumping system has been set up specifically for the pumping of detector cryostats and other special jobs where fast pumping and a 'clean' vacuum are needed.

A camera attachment for the metallurgical microscope has been installed and tested. This is being used with the infra-red converter in studies of Te inclusions in crystals of CdTe.

Glassblowing work, in addition to quartz ampoules, etc., for the CdTe crystal growth, included several glass systems - one for \( \text{H}_2\text{S} \) calibration for Chemical Engineering Branch, one for \( \text{N}_2\text{O} \) determinations for Mechanical Equipment Development Branch, and one for dissolved gas analysis for Ontario Hydro (NPD). Apparatus for studies of Zircaloy reaction to gases and vapours was made for Fuel Engineering Branch, other cells and reaction vessels for Physical Chemistry Branch, and an electrolosis cell for General
Chemistry Branch. A technologist from Ontario Hydro (NPD) spent one week in the Section learning glassblowing fundamentals.

3.26 The Chalk River Helium Jet and Skimmer System

H. Schmeing et al.

See PR-P-109:2.23.

3.27 Nuclear Lifetimes in the Region of $10^{-16}$s Measured by a New Technique

H. Schmeing et al.

See PR-P-109:2.7.

3.28 Decay Properties of $^{69}$Se

H. Schmeing et al.

See PR-P-109:2.6.

3.29 Electromagnetic Properties of the Ground State Rotational Band in $^{169}$Tm

H. Schmeing et al.

See PR-P-109:2.10.

3.30 Production of Heavy Superallowed Positron Emitters

H. Schmeing et al.

See PR-P-109:2.5.
3.31 Publications and Lectures

Publications

THE PRESSURE DEPENDENCE OF PHONON DISPERSION IN SUPERFLUID $^3$He
Phys. Lett. 55A (1975) 151
Atomic Energy of Canada Limited publication AECL-5290

RESONANCE EFFECTS IN MIXED HYDROGEN-DEUTERIUM CRYSTALS
B.M. Powell and M. Nielsen

LATTICE DYNAMICS OF GaSe
S. Jandl, J.L. Brebner and B.M. Powell
Atomic Energy of Canada Limited publication AECL-5210

ELECTRON-POSITRON MOMENTUM DISTRIBUTION IN CADMIUM:
EVIDENCE FOR SELF-TRAPPED POSITRONS BELOW THE VACANCY TRAPPING REGION
S.M. Kim and W.J.L. Buyers
Atomic Energy of Canada Limited publication AECL-5343

TEMPERATURE DEPENDENCE OF MAGNETIC EXCITATIONS IN Pd$_3$Fe
T.M. Holden
Atomic Energy of Canada Limited publication AECL-5153

DETECTOR CROSS REGISTRATION IN RECENT DOUBLY RADIATIVE np CAPTURE MEASUREMENTS
H.C. Lee and E.D. Earle
Nucl. Instr. and Meth. 131 (1975) 199
Atomic Energy of Canada Limited publication AECL-5326

THE $^{205}$Tl $\gamma$-RAY STRENGTH FUNCTION BELOW 7.5 MeV
E.D. Earle, J.W. Knowles, M.A. Lone and G.A. Bartholomew
Atomic Energy of Canada Limited publication AECL-5342
CHARGE COLLECTION IN SURFACE CHANNELS IN HIGH-PURITY GERMANIUM
H.L. Malm and R.J. Dinger
IEEE Trans. NS-23, No. 1 (1976) 76
Atomic Energy of Canada Limited publication AECL-5276

Lectures

WHY STUDY (n,γ) REACTIONS?
M.A. Lone
Pinstech, Pakistan
December 24, 1975

GAMMA RAY STRENGTH FUNCTIONS
M.A. Lone
Pinstech, Pakistan
December 26, 1975

ENERGY DEPENDENCE OF REDUCED GAMMA RAY WIDTHS AND THE ROLE OF SIMPLE CONFIGURATIONS IN NEUTRON RESONANCES
M.A. Lone
Queen's University, Kingston, Ontario
February 27, 1976

ANHARMONIC INTERFERENCE EFFECTS IN POTASSIUM
G. Dolling
University of Waterloo, Waterloo, Ontario
March 9, 1976

A series of 12 lectures on "Magnetism and Neutron Scattering" was given by W.J.L. Buyers and T.M. Holden at the International School on the Theory of Magnetism in Transition and Rare Earth Metals and Their Alloys, Mexico, March 15-26, 1976.
THEORETICAL PHYSICS BRANCH

G.E. Lee-Whiting

4.1 Staff
4.2 Neutronic Calculations for a Fusion Reactor Blanket
4.3 Time Behaviour of the Response of Fluoride Electrodes
4.4 Secondary Extinction in Neutron Diffraction
4.5 Penetration of Heavy Ions in Solids
4.6 Characterization of Effective Nuclear Interactions
4.7 Doubly Radiative n-p and n-d Capture
4.8 Magnetic Moments for N=126 Isotones
4.9 Coulomb Corrections to Fermi Beta Decay
4.10 Magnetization of Saturated Prismatic Poles
4.11 A Linac Structure without Axial Symmetry
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

Secretarial Staff

M.E. Carey
4.2 Neutronic Calculations for a Fusion Reactor Blanket

S.A. Kushneriuk and P.Y. Wong (Math. & Computation Branch)

The standard blanket calculation discussed in PR-P-108:4.2 (AECL-5315) has been completed. Generally there is good agreement between the results we obtained and those derived at BNL, LASL and ORNL as reported in ORNL-4177 (1973). As anticipated, there were also certain specific deviations in the results relevant to low (i.e. thermal) energy neutrons. These deviations are of minor significance for the particular benchmark system being considered, but indicate a source of possibly significant errors if identical calculational procedures are extended to the neutronic evaluation of systems in which thermal neutrons have a more important role.

The main problem in the procedures used lies in the processing of the ENDF/B energy-dependent neutron-cross-section data into a group-structured data set suitable for use in ANISN, our neutronics code. The program we use, ETOG-1, is really only suitable for processing data for energies greater than about 0.4 eV. Thermal neutron data, if required, must be introduced into the group structure by other means.

We have now received from Oak Ridge a description and listing of a code SUPERTOG which allows for more direct inclusion and processing of thermal neutron data as well. In its present form the code assumes a CDC 6600 central memory of 94K, which is beyond the capacity of our computer. An effort is being made to reduce the core requirement of the code.
4.3 Time Behaviour of the Response of Fluoride Electrodes

S.A. Kushneriuk (with R.C. Hawkings and L.P.V. Corriveau, General Chemistry Branch)

This investigation (PR-P-106:4.2 (AECL-5226)) is being continued. A summary of the current status of the analyses, and the type of experimental results that are available, is given in PR-CMa-36:2.4 (AECL-5511).

4.4 Secondary Extinction in Neutron Diffraction

V.F. Sears

A program (REFLECT) has been written to study some properties of neutron-monochromator crystals: specifically, the dependence of the reflectivity, wavelength resolution and order contamination on wavelength, crystal thickness, mosaic spread, block size and on the Miller indices and orientation of the Bragg planes relative to the crystal surface. The program has been applied to Al, Cu, Pb, Si, Ge, Be and graphite and the results compared with available reflectivity data.

In many cases the comparison is as yet impeded by effects of finite instrumental resolution. However, for one of the Si and three of the pyrolytic graphite crystals the mosaic spread is large enough that resolution effects are not too serious. It is found that for four reflections, each at two different wavelengths, the calculated peak reflectivity for Si agrees with experiment to within 25%. The only adjustable parameter is the mosaic spread which was determined from the average widths of the Bragg peaks. The observed peak reflectivities of graphite are found to be consistently 30% less than the calculated values. This discrepancy is attributed to the combined effects of primary extinction and parasitic reflections which are neglected in the
calculations and are expected to be more important in gra-
phite than in Si.

It has been shown that for asymmetric reflections a simple relation between the reflectivities for the
two time-reversed scattering geometries follows from the
time-reversal invariance of the scattering cross section. The experimental data are in general agreement with this relation.

It has long been known that the large increase
in reflected flux, which might at first sight be expected for
Fankuchen geometries (M.J. Buerger, Crystal-structure analysis,
Wiley, 1960), is not found in practise. In X-ray diffraction
this result is attributed to effects of absorption. For neu-
tron diffraction we have found that, even in the absence of
absorption, the enhancement for Ge(113) is only 32%. The
point is that, while the area of the reflected beam approaches
zero, secondary extinction causes the reflectivity to do the
same, so that the reflected flux remains finite and does not
diverge.

4.5 Penetration of Heavy Ions in Solids

K.B. Winterbon

The programs for calculating moments of range
and energy-deposition distributions are being rationalized
and rewritten so that they may be described in a report. The
rewriting is complete subject only to a final retesting.
These programs 1) construct the power-series representation
of the moment, 2) sum these series, and 3) construct the
spline representation of the moment. The first and third
programs have had added to them the provision for saving
certain data so that higher moments can be calculated in a
later run without re-computing lower moments.
4.6 Characterization of Effective Nuclear Interactions

M. Harvey

Computer programs are being written to determine the tensorial character of effective interactions that are usually only represented by a (large) set of two-body matrix elements in jj-coupling. The motivation for this is to discover how the character of the interactions changes as the methods and approximations for the determination of the interaction change. Such knowledge is useful in understanding the effect of the interactions in the nucleus. That such an analysis was needed was pointed out by me at the Montreal Conference (1969), but the analysis was never carried out in detail.

Phenomenological fits to the interactions are being sought in order that they can be (a) more easily described, (b) more easily transported from laboratory to laboratory, and (c) used with bases other than the harmonic oscillator.

This is a collaborative venture with effective interactions being supplied by B.R. Barrett (U. of Arizona) and J.P. Vary (U. of Iowa), and phenomenological interactions by I.S. Towner; it arose out of a recent visit of Barrett and Vary to CRNL.

4.7 Doubly Radiative n-p and n-d Capture

F.C. Khanna and H.C. Lee

The cross section for the dominant - i.e. the (El,El)-mode-in doubly radiative np-capture has been calculated with np wavefunctions of various degrees of sophistication. When the dipole operator proportional to \( j_1(\omega r/2)\hat{r}\cdot\hat{\mathbf{e}} \) is used, the result (0.12 \( \mu \)b) is to within a few percent independent
of details of the wavefunctions, provided that they have the correct asymptotic behavior, and that the experimentally determined normalization of the asymptotic approximation to the deuteron wavefunction is employed. When the velocity operator is used instead, the result varies between a high of 0.21 μb (asymptotic wavefunctions) and a low of 0.07 μb (wavefunction with hard core).

Because experiments on doubly radiative n-d capture are in progress PR-P-109:3.13 (AECL-5508), we are now calculating the cross section for the (E1,E1)-mode of this reaction.

4.8 Magnetic Moments for N=126 Isotones

I.S. Towner

Core-polarization calculations for magnetic moments (PR-P-108:4.7 (AECL-5315)) using a phenomenological central force fail to explain consistently the following data: the M1 radiative widths of 1+ states in 208Pb, the magnetic moment of 209Bi, and the magnetic moments of high-spin isomers in the N=126 isotones with proton configuration predominantly $h_{9/2}^n$. The influence of the non-central vector spin-orbit and tensor force components is small and of the wrong sign to reconcile the data. Other second-order contributions to core polarization, the so-called 'number-conserving sets' (diagrams 4 to 13 of Siegel and Ellis, Phys. Lett. 34B(1971)177), are currently being evaluated. This requires a high-speed computer subroutine to calculate two-body matrix elements; a factor of four improvement in computer time has been achieved using careful programming techniques.
4.9 Coulomb Corrections to Fermi Beta Decay

I.S. Towner and J.C. Hardy (Nuclear Physics Branch)

In the presence of charge-dependent forces the Fermi matrix element for superallowed beta decay can be written: $|M|^2 = |M_F|^2 (1 - \delta_c)$ where $M_F$ is the charge-independent value and $\delta_c$ is a correction of order $\sim 0.5\%$ (Towner and Hardy, Nucl. Phys. A205(1973)33). Recently, Wilkinson (Nature 257 (1975)189) has suggested that these estimates could be reduced by as much as a factor of two by taking account of the detailed parentage expansions in our binding energy prescription. We are currently recomputing the correction $\delta_c$ and find that, rather than reducing its value, the inclusion of parentage has the effect of increasing $\delta_c$ by approximately 30%.

4.10 Magnetization of Saturated Prismatic Poles

G.E. Lee-Whiting and B.E. Purcell (Math. & Computation Branch)

Work has recommenced on the two-dimensional idealization of the problem of the Superconducting-Cyclotron flutter poles explained in PR-P-103:4.11 and 4.12 (AECL-4931) and continued in PR-P-104:4.10 (AECL-5032) and in PR-P-105: 4.10 (AECL-5121). Previously programs were developed for calculating the magnetic field at exterior and interior points of a rectangular prismatic pole with rounded corners for a given distribution of internal magnetization. The codes for surface points have now been corrected and completed. The results obtained via a scalar-potential calculation agree with those from a vector-potential calculation within the prescribed error. The calculated field discontinuities at the surface are in at least rough agreement with results calculated at neighbouring internal and external points. Work on the code for the iterative calculation of the angle...
between the field direction and the magnetization vector has begun.

4.11 A Linac Structure without Axial Symmetry

G.E. Lee-Whiting

Some calculations have been carried out for a radio-frequency linac structure in which each tank consists of a rectangular parallelepipedal box with a row of parallel tubes joining one pair of opposite sides; the beam passes through a series of holes in the middle of the tubes. If alternate tanks are rotated through 90° about the beam axis, the structure might exhibit useful self-focusing effects. The tanks are excited in a TEM mode propagated parallel to the tube generators; the wave-equation in the transverse plane degenerates to Laplace's equation, thus facilitating calculations. Conformal mapping has been used to calculate the effective shunt impedance per unit length ($ZT^2$) for optimized tubes of rectangular and of approximate circular and elliptical section. The $ZT^2$ falls off as $\beta (\equiv v/c)$ is increased; it is comparable to the LAMPF structure at $\beta = .5$, but definitely inferior for $\beta = 1$. Calculations in which each tube is replaced by a pair of tubes with a gap between them to accommodate the beam are in progress. In an effort to improve $ZT^2$ a structure in which the tube diameter is greater in the middle than at the ends is being investigated.
4.12 Reports, Publications and Lectures

Publications

SUPERALLOWED $0^+ \to 0^+ \text{NUCLEAR } \beta\text{-DECAYS AND CABIBBO UNIVERSALITY}$
J.C. Hardy and I.S. Towner
Nuclear Physics A254(1975)221

RECOIL-DISTANCE LIFETIME MEASUREMENTS OF LEVELS IN $^{36}\text{Ar}$ AND $^{36}\text{Cl}$
G.J. Costa, T.K. Alexander, J.S. Forster, A.B. McDonald and I.S. Towner
Nuclear Physics A256(1976)277

DETECTOR CROSS REGISTRATION IN RECENT DOUBLY RADIATIVE np CAPTURE MEASUREMENTS
H.C. Lee and E.D. Earle
Nucl. Inst. & Meth. 131(1975)199

ELECTRIC TRANSITION STRENGTHS AND (e,e') FORM FACTORS FOR THE FIRST $2^+$ AND $3^-$ STATES IN THE EVEN Sn ISOTOPES
H.C. Lee
Nuclear Physics A255(1975)86

NEUTRON SCATTERING FROM SUPERFLUID HELIUM AT LARGE MOMENTUM TRANSFERS
J. Low Temp. Phys. 23(1976)285

SLOW-NEUTRON INELASTIC SCATTERING IN ABSORBING MEDIA WITH APPLICATION TO LIQUID $^3\text{He}$
V.F. Sears
MATHEMATICS AND COMPUTATION BRANCH

D. McPherson

5.1  Staff
5.2  Operating Systems and Programming Languages
5.3  Wigner Solid
5.4  Numerical Solution of Partial Differential Equations
5.5  Non-Linear Algebraic Equations
5.6  Integration of Ordinary Differential Equations
5.7  Stress Analysis
5.8  Capillary Flow Through a Small Opening
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5.10 Steady-State Simulation of the Gentilly-1 Steam Supply System
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5.17 Finite Difference Approximations in Polar Coordinates
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5.1 Staff

Branch Head: D. McPherson

Section I: Systems
Head:
D. McPherson
Programmer/Analysts:
J.A. Edgecombe
L.D.J. Hansen
J.F. Steljes
C.J. Tanner

Programmer:
Mrs. E.A. Okazaki

Computer Operator:
Mrs. M.D. Cowhey

Section III: Mathematical Services and Applications
Head:
J.M. Blair
Mathematical Analysts:
G.H. Keech
W.N. Selander

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

Programmers:
K.R. Chaplin
E.G. Long
Mrs. B.E. Purcell
B.V. Riff
D.G. Stewart
J.W. Wendorf

Secretarial Staff
Mrs. K.F. Barnard

Section II: Operations
Head:
G.N. Williams
Programmer/Analyst:
B.B. Ostrom
Programmer:
C.D. Price

Operator Supervisor:
Mrs. V.L. Tomlinson

Computer Operators:
Miss K.M. Bjarbo
Miss L.P.J. Cybulski
Miss M.E. Edwards
Miss K.M. Farnsworth
Mrs. C.M. Hepburn
Miss A.M. Jardine
Mrs. A.A. Laroche
Mrs. B.A. Payette
Mrs. B.H. Scott
Miss G.P. Smith
Mrs. T. Spear
Mrs. N.M. Ward

(1)
(2)
(3)
(4)
(1) Terminated 31 January 1976.
(2) Transferred to Finance Division 12 January 1976.
(3) Joined Branch 1 March 1976.
5.2 Operating Systems and Programming Languages

(i) CDC 6600 Systems

(a) FORTRAN Compiler

M.B. Carver and D.G. Stewart

Testing of the new version of CDC's FORTRAN Extended Compiler, Version 4.5, has continued, and a large number of production programs have been successfully compiled. Local modifications and additions to FORTRAN have been incorporated in the new version to ensure a maximum degree of compatibility with older editions, and the new compiler is scheduled to become the standard version on 1 April. The main reasons for updating the FORTRAN compiler are the improved code optimization and resulting speed-up in execution that CDC has achieved, and the fact that a number of errors in the older FORTRAN's have been corrected by re-written portions of the new compiler.

The former version of FORTRAN will be retained for as long as necessary as an alternative compiler in case of unexpected errors in the new version.

(b) Subroutine Libraries

(1) AELIB

L.E. Evans

Procedures for the maintenance of AELIB, the library of AECL-developed subroutines for the CDC 6600, have been revised and improved. The entire library has been re-compiled and tested with the new version of FORTRAN, and will be installed concurrently with installation of the new FORTRAN Compiler on 1 April. A number of routines which have become redundant, or which have been superceded by improved, equivalent programs, have been removed from the new AELIB.
(2) **Table Look-up Routines**

D.G. Stewart and L.E. Evans

This routine was written to replace the existing table-look-up routine with entries ITABLK, ITABGR, ITABS, which does not work correctly with FORTRAN Version 4.5 because of its nonstandard return sequence. The new routine has two entries, LOCRL for table look-up in a real array and LOCINT for look-up in a real array and LOCINT for look-up in an integer array. It can locate an entry in an array equal to, less than or equal to, greater than or equal to, or closest to a given element.

(3) **PLOT**

C.J. Tanner

In the Computing Centre, one area where English units (inches) are used is in the dimensioning of plotted output produced by calls to the AELIB routine PLOT or other AELIB routines which call PLOT.

To allow for conversion to metric units for specifying plot dimensions, a new entry point, PLOTM has been added to PLOT. Calls to PLOTM will result in the same action as calls to PLOT except that any parameters interpreted as inches by PLOT will be interpreted as millimetres by PLOTM. The millimetre was chosen to conform to accepted engineering practice.

(4) **IMSLIB**

L.E. Evans

A new version of IMSLIB was created for installation as a system library on 1 April. This new library contains all the routines from our current IMSLIB (i.e. Edition 4) version which were deleted at the Edition 5 release.

All IMSL routines have been compiled using the new FORTRAN Compiler, FORTRAN Version 4.5.
(c) **New SNOBOL Compiler**

G.H. Keech

An advanced version of SNOBOL4, Version 4.D, has been obtained from the University of Arizona. Several new language features have been incorporated. Further, this new compiler-interpreter loads in less memory than our previous SNOBOL, and it does not use FORTRAN I/O routines.

This version is now undergoing various tests and will be added to the CRNL system for general use once certain local modifications have been completed.

(d) **Cyber Record Manager**

C.J. Tanner

CRM Version 1.2 has been tested and will be installed in the system on 1 April 1976. This version includes:

(a) **Multiple-Index Capability:** This feature adds an alternate-key processing capability for Index Sequential, Direct Access and Actual Key file organizations.

(b) **Enhancements to Word Address File Organization:** The programs which manage these files have been rewritten to improve performance. No external changes were made.

(c) **Read-only Modules are Available for IS and DA files:** These modules reduce the memory required for programs which are just reading Indexed Sequential and Direct Access Files.
(e) **QUERY UPDATE**

C.J. Tanner

A new version of QUERY UPDATE was installed in February. This version fixed a few errors which were present in the old version.

(f) **COBOL**

C.J. Tanner

On 1 April 1976, COBOL Version 4.5 will be installed in the system after some months of testing. This version includes many corrections plus support for the Multiple-Index feature of the Cyber Record Manager.

(ii) **CDC 3300 System**

D. McPherson, E.A. Okazaki and J.F. Steljes

Development and testing of enhancements to the Editor, and of the additions to the 3300/6600 interface system to provide for access to 6600 permanent files from keyboard terminals, have been completed, and the new features are being made available for use on 1 April.

(iii) **DEC System-10**

J.A. Edgecombe

All software drivers for local, special-purpose input/output have been converted to the new communication protocol. Attempting to find and eliminate an elusive monitor error discovered during the above conversion process took up most of the quarter. It has now been eliminated.

The computer now reads the date and time from a clock (constructed on-site), eliminating inconsistencies previously encountered when the date and time were entered manually.
Preliminary work has been done on integrating a 10-microsecond resolution clock into the system. The hardware is complete; the monitor problems mentioned above have delayed the software.

Agreement has been reached with the users (Nuclear Physics Branch) on scheduling systems development. Development work with its attendant risk of system instability will take priority before 10:30 AM; the remainder of the time will be devoted to production. A one-week trial during daytime hours will precede installation of modified software.

(iv) Computer-Aided Cyclotron Control System

L.D. Hansen

(a) MUMTI

The Multi-User Multi-Task Interpreter which was obtained from the Hahn-Meitner Institute was installed on the PDP11/45 of the Reactor Control Branch. Early experience with it has shown that it is still in the development stages.

(b) PL/11

The programming language PL/11 was obtained from the CERN Laboratories. It is a cross-compiler, written in FORTRAN, which in principle can be executed by any FORTRAN system producing DOS11 format object modules for a PDP11. However, it appears that considerable effort would be required to prepare a version that could run on the CDC 6600.

(c) PDP-11/34 Test Programs

A set of programs to run on a PDP-11 was made in order to test the compatibility between the PDP-11/34 and the PDP-11/40. These programs exercise the assembler and loader and, finally, run the MUMTI interpreter. It is planned to run the programs on both an 11/40 and 11/34 to gain confidence in the ability to transfer programs from the 11/40 to the 11/34 before making the final recommendation to purchase one of the machines.
5.3 Wigner Solid (See PR-P-108, 5.3, AECL-5315)

G.H. Keech and H.R. Glyde (University of Ottawa)

For the Bose case, the cubic term has been included in the self-consistent harmonic evaluation of the force constants. In this instance, frequency calculations indicate that the solid is mechanically unstable at $r_s \sim 175$ in the $T = 0$ K limit.

Convergence tests on the Bose integrations show that it is not efficient (in computer time) to consider $r_s$ values much past $r_s \sim 500$. Fortunately, however, the $r$-integrations in the Fermi case seem to be much better behaved in this large $r_s$ region.

5.4 Numerical Solution of Partial Differential Equations

M.B. Carver

The method of lines, which converts partial differential equations to ordinary differential equations using a finite difference disintegration of the spatial derivatives, has proved extremely successful for one-dimensional problems. It has also been used for two dimensions, but the number of points required for higher dimensions, and the associated Jacobian matrix, both become very large. Alternative means of converting PDE's into ODE's are being investigated with a view to reducing the requisite number of points. Some results have been obtained using a differential quadrature based on Legendre polynomials, but this does not greatly improve efficiency.

Functional approximation techniques with residual minimization seem more promising if applied in a piecewise sense, particularly if spline basis functions are used. Some preliminary results in this area have been obtained.
using a collocation method derived from Gaussian integration of a Galerkin formulation. In general, the technique is to represent the unknown \( u(x,t) \) in the equation

\[
\frac{\partial u}{\partial t} = \psi(x,t,u,u_x, \text{etc.}) \quad (1)
\]

\[ u(x,0) = u_0(x) \]

by a trial solution

\[
\sum_{i=1}^{n} a_i(t) f_i(x)
\]

and minimizing the residual errors in the initial conditions, equations, and boundary conditions. This converts equation (1) into a set

\[
[F \frac{da}{dt}] = [\psi(x,t,u^*,u_x^*, \text{etc.})]
\]

which must now be solved as

\[
[\frac{da}{dt}] = [F^{-1}] [\psi]
\]

where \( F \) is a banded matrix whose bandwidth depends on the order of the spatial functions \( f_i \).

This approach has been shown to require fewer points for a given accuracy in many particular cases, but whether it can be efficiently generalized remains to be seen.

5.5 Non-Linear Algebraic Equations

M.B. Carver, B.E. Purcell and E. Rossinger (WNRE)

For the steady state, the set of ordinary differential equations describing chemical reaction kinetics
\begin{equation}
\dot{x}_i = \sum_{j=1}^{N-1} a_{ij} x_j x_{j+1} \quad i = 1, N
\end{equation}

reduces to the set of non-linear algebraic equations

\begin{equation}
\sum_{j=1}^{N-1} a_{ij} x_j x_{j+1} = 0 \quad i = 1, N
\end{equation}

Because of the multiplicity of possible solutions, the available library routines for non-linear algebraic equations failed to determine a physically valid solution for (2).

The problem was instead treated as an ordinary differential equation initial value problem using FORSIM. This gave good results in the departure from initial conditions but could not converge on a true steady-state solution as the \( \dot{x}_i \) could not approach zero closer than the arithmetic round-off error resulting from the computation of the right-hand side of (1).

This estimation of the steady state was, therefore, then fed from FORSIM to the non-linear algebraic equation routines NLSPAR and ZSYSTM. The local routine NLSPAR was able to improve the results and obtain a satisfactory answer. ZSYSTM, the IMSL routine, still produced spurious results. Full information has been passed to IMSL for investigation.

5.6 Integration of Ordinary Differential Equations

M.B. Carver

Several sets of equations arising from different fields have encountered integration problems associated with solutions which start from an initial condition of zero and proceed to transient values which remain absolutely small \((0(10^{-20}))\) but not zero. A basic fallacy concerning this scaling problem was detected
in the Hindmarsh-Gear integration algorithm, and corrections have been made to FORSIM and the AELIB library routines involved.

5.7 Stress Analysis

(i) SAPIV: Structural Analysis Program

E.G. Long and J.M. Blair

The SAPIV program performs static and dynamic stress analyses of two- and three-dimensional elastic structures. An updated version of the program has been obtained from the Earthquake Engineering Research Center, Berkeley, California, and is available for general use. It differs from the previous version in that the 16-node thick shell element has been replaced by an 8 to 21-node general three-dimensional element. The program has been checked against the seven sample problems supplied with the code, and solves correctly a problem on which the previous version failed. A comparison with an analytical solution and with the MARC code has been made (see below).

The program is being maintained by the Branch and information regarding its availability and capabilities is being distributed to potential users. Eight user manuals are on order.

Modifications to the previous version of the program by P. Khor and G.G. Worthington of Power Projects, to allow pre- and post-analysis plotting, are being considered for inclusion in the new version.

(ii) MARC Stress Analysis Code

B.V. Riff and J.M. Blair

A meeting of users of the MARC code was held in January 1976, and was attended by six people from CRNL. A number of successful analyses were reported,
including a thermal stress analysis of the Pickering Generating Station tube sheet, a thermal stress analysis of the G2 boiler thermal plate, and the calculation of the natural frequencies of the Glace Bay Heavy Water Plant flare stack.

Several errors or ambiguities in the code and documentation were identified, and these were reported to the MARC Corporation for resolution. In addition, a number of requests for additional capabilities or increased flexibility were made.

Over the period January to March 1976 the program usage has remained steady at 16-20 runs per day. Because of this high usage and the heavy demands made by the code on the CDC 6600 system, measures to reduce the system requirements are being investigated. First, expensive recompilations can be avoided in parameter studies by compiling the program once and executing the absolute file repeatedly. Second, a program to copy selected increments from a restart file has been written and made available to users. This program will help to reduce the permanent file disk space used by restart files. Third, it has been found that in dynamic analyses an excessive amount of IO time is spent in searching the overlay file. One remedy is to convert the file from sequential to random form, by making it a system library. Fourth, in elastic-plastic analyses most of the IO time is spent reading and writing an intermediate scratch file. This time could be reduced by using extended core storage instead of disc for the intermediate file. The latter two suggestions will be discussed with the MARC Corporation, since they require access to the source code for their implementation.

The demonstration programs supplied initially with the code have been stored on magnetic tape and made available to program users.
(iii) Normal Modes of a Cantilever Beam Computed by MARC and SAPIV

J.M. Blair and H. Hatton (Applied Mathematics)

A comparison of the natural frequencies of a cantilever beam computed by MARC and SAPIV was made with theoretical values. The beam was divided into ten elements, and the first ten natural frequencies were computed. Element 16 was used by MARC. The maximum error incurred by MARC was 1.6% and by SAPIV was 11.0%, both in the tenth frequency. We conclude that for this application, MARC is more accurate than SAPIV, but is more costly to run.

5.8 Capillary Flow Through a Small Opening

W.N. Selander

A simple model was developed for the rate of flow of coolant which enters a fuel void through a defect in the sheath. The model takes account of the liquid flashing to steam as the pressure decreases to the saturation value, and of the increasing pressure in the fuel void as it fills up.

Two different geometric cases were considered. In the first one it was assumed that the defect was in the shape of a tube, and the usual parabolic flow profile was used. In the second case, the defect was assumed to be in the shape of a semi-circular or fan-shaped crack, and a new formula relating mass flow and pressure drop for capillary flow in this geometry was derived. The mass flow rate was found to be approximately exponentially decaying after an initial period and an expression for the time constant was obtained.
5.9 Analysis of Acoustic Phenomena in a System of Steam Mains

W.N. Selander

In response to a request from Power Projects, an analysis of acoustic waves in the G-l main steam supply system has been undertaken. This is of concern since the length and complexity of the system makes possible the propagation of waves of periods comparable to response times required for pressure-control signals. Standing waves could also create a noise problem if pressure sensor taps were located near a node.

The equations describing acoustic waves have been obtained by the usual linearization of the equations of motion for a compressible fluid. First-order effects of convection and friction have been retained, but a preliminary analysis shows that these are unlikely to alter the natural frequencies of the system by more than 10%; consequently, these effects will be neglected in the initial approximation. Boundary conditions have also been derived for the various branches and terminations in the system. This problem has not yet reached the computational stage.

5.10 Steady-State Simulation of the Gentilly-1 Steam Supply System

P.Y. Wong

The stability of the G-l steam supply system is presently being investigated by E.O. Moeck of the Reactor Control Branch. To tackle this problem, Moeck has proposed to examine the dynamic behaviour of the system in the neighbourhood of any steady-state conditions. This approach requires a steady-state model for the system and we have been asked to provide such a model.

Three preliminary case studies based on a schematic diagram provided by Moeck have been carried out. A computer program is being planned that should provide the steady-state conditions for Moeck's analysis.
5.11 Large Integer and Rational Fraction Arithmetic

G.H. Keech

In the first version of LIRA (See PR-P-107, 5.7, AECL-5256), user instructions were compiled and executed in sequential order. The interpreter scheme has been generalized to permit DO-loop constructions, IF-tests and GO TO instructions. These will be particularly useful for operations on arrays which have also been introduced.

Further, the arithmetic functions have been extended to treat combinations involving negative integers.

5.12 Magnetization of Saturation Prismatic Poles

G.E. Lee-Whiting and B.E. Purcell

See Section 4.10, PR-P-109, AECL-5508.

5.13 Neutronic Calculations for a Fusion Reactor Blanket

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

See Section 4.2, PR-P-109, AECL-5508.

5.14 Data Reduction Programs

(i) Analysis of Stress Relaxation Data

B.V. Riff and J.M. Blair

A technique for smoothing the raw $\sigma$ and $\varepsilon$ (see PR-P-108, 5.8(i), AECL-5315) by means of local least squares polynomial approximations has been used, and much improved plots of $\ln \xi_p$ vs $\sigma$ have been obtained. The accuracy of the results is, however, uncertain, and depends on the degree of smoothing, the number of points in the least squares fit, and on the degree of polynomial used. The work is continuing.
(ii) **NPD Gamma Spectrometer**
E.G. Long and W.T. Bourns (Systems Materials)

A program to analyze gamma spectra from NPD source has been requested.

Currently the methods of existing spectra analysis program (GRASS, SUSPECT) are being evaluated to determine their suitability for inclusion in the requested program.

(iii) **Fuel Element Profilometer**
E.G. Long and J. Christie, L. Herbert (Fuel Engineering)

Development has begun on a program to locate significant maxima in fuel element profiles.

5.15 **Information Handling Programs**

(i) **Central Personnel Records System**
C.J. Tanner

Assistance is being given to Head Office Data Processing staff to expand the CRNL personnel records system to handle personnel records for all of AECL.

(ii) **Leave Recording System**
C.J. Tanner

The computerized leave recording system which has been running for two branches in parallel with the manual system, is being expanded to handle Administration and Physics Divisions on a test basis.

(iii) **Staff List and Organization**
D. McPherson

A program to assist with the preparation and maintenance of the Staff List and Organization report has been written for Administration, Head Office.
5.16 Miscellaneous Programs and Subroutines

(i) TRUMP
D.G. Stewart

A special version of TRUMP was set up for use with 500 nodes. This increased the central memory requirements significantly. Several methods are being investigated to allow TRUMP to operate dynamically thereby using much less memory for most runs and eliminating the need for special versions for the occasional large run.

(ii) Forecast Plots of Specific Activity of Isotope Production Rods
B.V. Riff for L.C. Ault (Nuclear Materials Control)

This program (PR-P-106, 5.9(iv), AECL-5226) has been modified so that the change in the specific activity of a radioactive isotope production rod can be taken over a period of 1 to 23 months previous. The specific activity at the start and end of the period is read in and an average per month is found. This average value is used to plot an eight-month forecast of specific activity and to predict the removal date from the reactor.

(iii) SPECROL
G.H. Keech

Modifications have been made to SPECROL to permit punching of paper tapes for the C4 spectrometer at the Terminet terminal in NRU. A correction has been made in the specimen output, and a check inserted for invalid code values.
5.17 Finite Difference Approximations in Polar Coordinates

J.M. Blair

Finite difference approximations to the term $V.DV\alpha$ in the diffusion equation have been derived for the case when $D$ varies discontinuously with the radius $r$ and when $\alpha$ is non-axisymmetric. The approximations are being used by H.W. Hinds, Reactor Control Branch, in a program to simulate the behaviour of a reactor under a variety of transient conditions.

5.18 Operations

(i) CDC 734 Terminal in the User Work Room

G.N. Williams

A CDC 734 Remote Job Entry Terminal has been installed in the User Work Room in Building 508. The terminal has been set up for self-serve operation, and an abbreviated set of operating instructions appropriate to the self-serve mode of operation has been prepared.

The terminal has now been operating very satisfactorily for six weeks, and no major problems have been encountered in running it in self-serve mode.

(ii) Equipment Changes

B.B.W. Ostrom

During the quarter an extra 16,384 words of central memory were added to the 3300 to bring its total memory size to 65,536 words. The additional memory provides the buffer space needed to handle the growing number of terminals.

Two additional 841 disk units were installed, bringing the total amount of disk space available on the 841 subsystem to 280 million 6-bit characters.
(iii) **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>Utilization, System Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computing Centre</td>
<td>12050 (18.33%)</td>
<td>131934.05 (7.93%)</td>
</tr>
<tr>
<td>Commercial Products</td>
<td>64 (0.10%)</td>
<td>406.56 (0.22%)</td>
</tr>
<tr>
<td>Power Projects</td>
<td>10059 (15.30%)</td>
<td>511206.75 (30.73%)</td>
</tr>
<tr>
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Publications, Reports and Lectures

Publications

THE FORSIM SYSTEM FOR AUTOMATED SOLUTION OF USERS OF IMPLICITLY COUPLED PARTIAL DIFFERENTIAL EQUATIONS
M.B. Carver

Reports

PDPCODE: A CODE CONVERSION PROGRAM FOR THE PDP-11/40
B.V. Riff
AECL-5382, March 1976

Lectures

NUMERICAL SOLUTION OF ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS USING FORSIM
M.B. Carver, J.M. Blair, W.N. Selander and D.G. Stewart

FAULT TREE ANALYSIS
P.Y. Wong
1976 Educational Course, Society of Reliability Engineers
Ottawa, 5 February 1976

A PROPOSAL FOR A COMPUTER-BASED CONTROL SYSTEM FOR THE MP TANDEM AND SUPERCONDUCTING CYCLOTRON
R.L. Graham (Nuclear Physics) and L.D. Hansen
CRNL, 22 January 1976

THE USE OF COMPUTERS IN PHYSICS AND MATHEMATICS
D. McPherson
Science Teachers' Seminar, CRNL, 28 February 1976

COBOL PROGRAMMING COURSE
C.D. Price
Algonquin Collge of Applied Arts & Technology
CRNL, February to May 1976

HYDRODYNAMICS
M.B. Carver
Algonquin Collge of Applied Arts & Technology
CRNL, February to May 1976
ACCELERATOR PHYSICS BRANCH

P.R. Tunnicliffe

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6.1 Staff

**BRANCH HEAD: P.R. Tunnicliffe**

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<td>J.F. Weaver</td>
<td>Mrs. M.A. Trecartin</td>
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(1) NRC Post Doctorate Fellow.
(2) Attached from Commercial Products, South March.
6.2 Nuclear Power Applications

6.2.1 High Current Test Facility

B.G. Chilley

The 75 kW driver of the rf system for this 3 MeV 100% duty factor proton accelerator is operational and commissioning of the 400 kW output stage continues. Assembly of the Alvarez tank has resumed.

a) Injector

J. Ungrin

The program of increasing accelerated beam intensity and improving reliability has resumed now the SUCCESS computer control and data acquisition system is operational.

A four week shutdown early in the period was necessary to repair an electrical short in one of two 1000 l/s ion pumps in the high voltage dome and to replace a leaking oil seal on a gear box in the dome ac generator assembly. The injector beam line was also dismantled and the first two sets of quadrupole magnets after the column were realigned.

A low frequency (10-20 Hz) oscillation of the beam position and intensity has been periodically observed on capacitive pickup electrodes in the beam line and in a beam dump beyond the first 45° bending magnet. The cause of this oscillation, which has not been observed since the realignment of the beam line magnets, is being sought.

Serious voltage tracking has been found on the highest voltage ceramic ring of the accelerating column. The cause of this tracking, which has occurred since a recent 10% increase in the operating voltage (PR-P-106, 6.2.1 a), AECL-5226), is not yet known. Present effort is concentrated on determining the effects of this tracking on operating reliability and on a possible method of potential redistribution that will reduce the voltage across the damaged
ceramic without seriously affecting the beam optics of the accelerating column.

b) **Emittance Measuring Unit (EMU)**

M.R. Shubaly

Measurements of beam emittance were curtailed by the shutdown of the injector for repairs and will not be resumed until a new bending magnet chamber is installed.

Some possible causes of the "tails" on the emittance photographs (PR-P-108, 6.2.1 b), AECL-5315) were studied. Operation at 10 mA proton current to the EMU showed that the maximum divergence of the particles in the "tail" was greater than 130 mrad. The "tails" were found independent of background gas pressure between $10^{-4}$ and $10^{-3}$ Pa and of changes in the fields in the focusing triplet before the second bending magnet. They were not caused by the low frequency ripple sometimes seen on the ion beam. Studies of effects of variation of other beam transport system parameters continue.

c) **Alvarez Linac**

B.G. Chidley and J.C. Brown

Commissioning of the rf source has begun.

False firing of the ignitron switch tube trigger circuit of the new fast crowbar switches for the triode and tetrode amplifiers was traced to high frequency ringing of the high voltage lines for a short period following application of a simulated tube short. The resulting $dV/dt$ firing of the trigger SCR would eventually cause it to fail. The coupled transients were reduced to acceptable levels by capacitive by-passing and careful adjustment of circuit grounds. The crowbars now perform satisfactorily.

The internal gas level of the A2548 75 kW driver tube was good after a very long idle period and high power operation was readily achieved. An output of 50 kW, the
limit of the available dummy load, was attained with a plate
efficiency of 62%. The metering and protect circuits of the
screen grid power supply were modified to correct inadequacies
of the original unit. The fast crowbar was rebuilt to provide
reliable triggering on overcurrent and plate-to-cathode arcs.
A fast ac solid state switch was installed in the transformer
primary circuit to avoid grid damage by follow-on current
after the filter capacitors were discharged by the thyratron
crowbar. With these improvements, efficiencies approaching
that achieved during RCA's development rests were obtained.

Conditioning and power operation of the triode
amplifier is expected to start now.

6.2.2 Electron Test Accelerator
J.S. Fraser

This experimental 4 MeV 100% duty factor electron
accelerator is intended to study problems associated with
the main portion of a spallation neutron factory based on a
proton linear accelerator.
a) Accelerating Studies
J.S. Fraser, J. McKeown and G.E. McMichael

(i) Focussing

The injector beam line of the accelerator includes
three solenoid lenses. The beam dynamics calculations
referred to previously (see PR-P-108, 6.2.2(a), AECL-5315)
predicted a restricted range of excitation currents in the
three lenses for maximum transmission. Qualitative experi-
mental agreement with the calculations was found. Quantita-
tive agreement was not expected because the transfer matrix
used for the solenoids does not include the spherical
aberration known to exist.
(ii) Phase Disturbances

A study of the accelerator phase disturbances with 50% beam loading \((\text{beam power}/\text{beam power} + \text{structure power}) = 1/2\) was made. As expected, the klystron was responsible for most of the phase shifts and its characteristics dominate the control loop design in both amplitude and bandwidth. These phase shifts arise from transit time effects, the effects of under-bunching the klystron beam when driving the klystron below saturation, and from thermal effects. Currently, we operate the klystron at constant potential during accelerator operation, hence only the latter two effects are important. Figure 6.2.2.1(a) shows how the phase shift across the klystron changes with time when the accelerator beam is slowly cycled between 0 and 15 mA. The rapid periodicity in the klystron phase shift is due to the cycling of a valve in the klystron cooling system. When the accelerator current decreases, less rf power is demanded from the klystron hence the collector must dissipate more dc power. No attempt has been made to control the klystron water temperature accurately; the "constant-flow" to the primary side of the system heat exchanger is interrupted to keep the secondary water within a range of 7°C. The general trend of the curve follows the accelerator current because the beam bunching of the unsaturated klystron changes with increasing drive. The cause of the thermally created phase shift is unknown; the collector and body phase sensitivity to changes in temperature are being measured separately.

Reactive effects of beam loading have been studied by measuring the change in the accelerating cavity admittance angle as a function of beam current. Over a 15 mA current range, the 4° change observed is equivalent to a frequency shift of 3.2 kHz. Using the coupled-resonator model we conclude that the mean phase angle of the electron bunch is 11° when the accelerator is tuned for optimum transmission. The
Figure 6.2.2.1 Phase shifts versus beam current with control loops closed.
(a) Beam current (□) and klystron phase shift (x) during a 10 min. run.
(b) Model 4 accelerating field phase (□) and klystron drive phase (x) for the same period.
The corresponding change in relative phase between the bridge and an end cell of only 0.15° demonstrates the stability of the \( \pi/2 \) mode for high power operation.

The phase control loop uses the accelerating field as the controlled variable and responds to the above disturbances by changing the rf phase of the drive to the klystron. The upper curve of Figure 6.2.2.1(b) shows how the phase of the klystron drive relative to the phase reference line is varied to compensate for all of these changes. The lower curve is the phase of the accelerating field during the corresponding period. The results show that the design aim of controlling the phase of the accelerating field to 1° from all disturbances has been achieved up to 50% beam loading.

(iii) Field Level Control

The field-level controller was functioning during the experiments just described. At 50% beam loading the field level was depressed by less than 0.3%, well within design expectations.

(iv) Beam-induced Fields in the Side Couplers

The coupler fields have been studied under 50% beam loading and their behaviour is understood in general but not in detail. All show a well-defined systematic change with beam current. Coupler fields in section A (of Model 4) increased while those in section B decreased although the relative changes varied widely. These changes were very similar in both magnitude and sign to those observed when the structure was perturbed with the tuning plunger in the bridge (see J.S. Fraser et al., Proc. 1972 Proton Linear Accel. Conf., LA-5115, p. 226). The coupled-resonator model suggests that fields in the couplers are caused by frequency errors in the accelerating cells and by the additional power flow required for the beam but mainly the former. The
present results confirm this. The same experiment showed that side-coupler temperatures are independent of beam current, hence the fields in the couplers are small.

(v) Transmission Dependence on Tuning Plunger Position

Resonance control of a multi-tank accelerator must hold the tank in tune at a fixed frequency. This is accomplished in ETA with a combination of water temperature control and the tuning plunger movement in the bridge coupler. An experiment was performed at 10 mA where the tuning plunger varied the structure frequency over a range of 160 kHz with the master oscillator locked to the structure resonant frequency. An important result from this experiment is that transmission remained unchanged. Hence, for ETA the function of the structure coolant in the 12-cell structure can now be relegated to removing the dissipated heat provided only that the temperature is kept within a range of 13°C.

The result further confirms the stability of the π/2 mode and is consistent with the predictions of our coupled-circuit models. However the phase acceptance of the Model 4 tank is large and transmission is not expected to be sensitive to small field perturbations. Nevertheless, the result reinforces the approach of using mechanical tuning in one cell to control the resonant frequency of the tank. The temperature limits of the coolant in a proton accelerator cannot yet be specified but the implication is that sophisticated temperature control (as at LAMPF) can be eliminated.

b) Shutdown for Model 3 Commissioning

J.S. Fraser, J. McKeown and G.E. McMichael

These experiments complete the first phase of the ETA study program using one accelerating tank (Model 4). Commissioning of the second tank (Model 3) has begun.

The injector beam line and Model 4 have been re-positioned to provide more working room in the shielded
tunnel. Model 3 has been aligned on the new reference line. The water-cooling plumbing lines for both tanks have been relocated. The waveguides have been re-routed through the ceiling of the tunnel eliminating a major source of radiation leakage.

The Model 3 has been lagged to reduce heat losses; this will facilitate a detailed accounting of the power distribution in the structure.

The beam spill monitoring system has been modified to service the full complement of spill monitors for the complete accelerator. The monitors have been integrated with the fast annunciator system. New solid-state interlock modules have been installed for both of the 100 kW klystrons and improved 100 W bipolar programmable supplies have been built for the beam transport controls.

As a precaution, module A of the high voltage supplies in Building 467 has been modified to limit at 36 kV rather than 40 kV; the latter voltage exceeds the klystron manufacturer's specification.

Varian "Ti-Ball" titanium sublimation pumps have been installed in the vacuum manifolds of both Models 3 and 4.

An improved set of water-cooled solenoid lenses has been made for use in the injector beam line and at both ends of each section of both accelerator tanks.

c) Computer System (ETACON)

J.S. Fraser and G.E. McMichael

(i) General

During the past quarter, apart from normal maintenance and shutdowns for minor modifications, the computer system has operated without fault except for some problems with the teletype printers.

(ii) Accelerator Control

Setup and recording programs for the beam transport
control system have been commissioned. For each transport magnet set-point, four values (BEST, LOW, CURRENT, HIGH) are maintained in the memory. The latter three are updated at two-second intervals whenever the accelerated current exceeds an operator-selected value (typically 10-10 μA). LOW and HIGH are extrema in the values recorded, not fixed limits. A switch, operated at the control desk, causes the storing of the "CURRENT" values as "BEST" values. The operator can set all set-points to the stored "BEST" values, print out all values, or reset "LOW" and "HIGH" values to "CURRENT" from the control-console teletype. Thus the operator can save "CURRENT" values as "BEST" before trying to optimize the beam transport settings; if his attempt at further optimization is unsuccessful, he can restore the old values.

(iii) Data Acquisition

The data acquisition system was used extensively during recent accelerator operation. Approximately 100 analog variables are read and stored at one to two minute intervals during routine operation and more frequently during specific experimental runs. A typical day's operation yields 500 to 1000 sets of values for later analysis. This "blanket" coverage fully utilizing our mass storage capacity has proved invaluable. Often, correlations not anticipated at the time of the experimental run have been found during later analysis of the data.

The fully automated emittance measurement and analysis system (see PR-P-107, 6.2.2(e), AECL-5256) was tested. It functioned properly although the steering coils available were too weak to permit a complete emittance scan in the horizontal plane.

(iv) Data Analysis

The "PLTPTS" task, used for plotting analog scanner data, has been modified to display selective correlations.
For example, the forward and reverse rf power can be plotted as a function of beam current only when the structure temperature lies between specified limits during an experimental run. Some types of data analysis exceed the capabilities of the ETACON system. These can now be carried out on the CDC 6600 by transferring selected data to 9-track magnetic tape in a format readable by a FORTRAN program.

6.2.3 Fertile-to-Fissile Conversion Experiments at TRIUMF (FERFICON)
B.D. Pate, I.M. Thorson and F.M. Kiely (Simon Fraser University) with J.S. Fraser

This work is intended to provide experimental checks of neutron and fissile material production in spallation targets for a neutron factory. The results are being correlated with calculations being carried out at CRNL.

a) Equipment

(i) Self-powered Detector

As indicated in the previous report (PR-P-108, 6.2.3(b), AECL-5315) the resistors used in the assembly were too low to provide a suitable voltage; they were replaced by $10^{10} \, \Omega$ resistors, ten times larger.

(ii) Target Storage and Handling Facility

Detailed design of this unit has been completed and a contract let for its construction. Delivery is expected about March 1.

A license to possess the uranium and thorium target materials has been obtained from the AECB. A submission, being prepared now, which details the experimental arrangements, is required before a license to irradiate the materials can be granted.

(iii) Beam Monitor

A multi-wire chamber for monitoring the proton beam profile has been installed in the monitor box located
immediately upstream of the irradiation facility. The detector has 3 mm wire spacing providing suitable solution for the FERFICON irradiations.

(iv) Computer System

A Nova 3 computer system has been ordered by SFU. System components for the experiment include: Nova 3/12 computer with 16 K core memory, real time clock, 75 IPS 9-track magnetic tape drive, and a DECWriter II typewriter console. This system will be linked with a similar one (having a magnetic disk unit instead of a tape transport) being purchased by another TRIUMF/SFU experimental group. The ADC's and display, currently being designed, will be constructed in-house.

(v) $\beta$-detection Systems

The analysis of the data from the first few irradiations, detailed below, indicated the need for more data from certain regions in the tank. With the repairs on two of the $\beta$-detectors now complete (giving a total of four counting systems), more foils can be accommodated. An additional quantity of gold foils was acquired to permit a longer decay period before re-use. Copper foils will also be used in future runs. The disadvantages of using copper (most notably a lower cross section and a more complex decay scheme) are offset by the ability to complete decay measurements on the copper before beginning to count the gold.

b) Calculations and Results

The neutron leakage from the target is obtained by measuring the capture rate in a water bath surrounding the target and correcting the absorption in the target and loss through the beam pipe. Gold foils were activated by neutron capture in the water and the proton flux was monitored by activation of aluminum foils in the beam.
The counting data for the gold foils and the aluminum monitors were fitted by least squares, using the FRANTIC code, to decay curves corresponding to a half life of 2.70 days for gold and 15.0 hours for aluminum. The results indicated no other components were present.

The neutron capture rate in the water is given by the flux integrated over the volume of the tank multiplied by the macroscopic absorption cross section in water:

\[
CR = \left[ \int_{0}^{\infty} \int_{0}^{\infty} \int_{-\infty}^{\infty} \phi_{H_2O}(r,z) \, dz \, rdr \, d\theta \right] \Sigma_{H_2O}
\]

The logarithms of the fluxes calculated from the gold decay data were least squares fitted to polynomials

\[
\log \phi(r,z) = \sum_{i=0}^{N} a_i z^i
\]

for constant values of \( r \).

A polynomial with \( N = 4 \) generally provided a satisfactory fit. However, certain data sets were better represented by polynomials of some other order. The "best fit" polynomials were then integrated using Simpson's rule to obtain \( \phi(r) \). These data were then fitted to polynomials of the form:

\[
\log \left[ r \phi(r) \right] = \sum_{i=0}^{N} a_i r^i
\]

Polynomials of order 4 or 5 were found to give satisfactory fits. These were then integrated and multiplied by \( \Sigma_{H_2O} \) to give the capture rate in the water.

Normally, the integrations were done over the region covered by the data points. These limits were expanded for a number of data sets to determine the effect of this incomplete integration. Figure 6.2.3.1 displays such an extrapolation. It was concluded that \( \sim 3\% \) of the
Figure 6.2.3.1  Flux distribution at $R = 19.6$ cm.
total area was neglected by integrating only within the experimentally measured region.

The data were also integrated in reverse order, i.e. integrated along the r-axis first and then along the z-axis. The results of the two procedures differed by less than 1% and are listed in Table 6.2.3.1. Also listed in Table 6.2.3.1 are the calculated multiplicities obtained by P.M. Garvey (private communication), about 15% less than the measured values.

Table 6.2.3.1 results have also been corrected for neutron absorption in the target and neutron losses in the beam pipe using Garvey's estimates. They have not been corrected for recoil losses in the aluminum monitor foils (estimated to be ~ 2%), for self-scattering of the β-particles in the detector foils, nor for resonance absorption; which may account for the discrepancy with the calculations.

6.3 Research Applications

6.3.1 Fast Intense Neutron Source (FINS)

B.G. Chidley, J.D. Hepburn and M.R. Shubaly

Effort was mainly devoted to investigating beam dependent sparking in the accelerating column, in which the mean time between sparkdowns decreases with increasing beam current and accelerating voltage (see PR-P-108, 6.3.1, AECL-5315). Because satisfactory operation could not be obtained by modification of the ion source apertures, accelerating gradient, and electron suppression electrode, the ion source was moved to the ion source test stand so that the source and accelerating column could be tested independently.

Ion source problems, found on the test stand and discussed below, were probably not responsible for most of the sparkdown problem.
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<td>10.16 cm diam Pb (BNL)</td>
<td>470</td>
<td>7.96</td>
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Table 6.2.3.1. Neutron Leakage Data
A thoriated tungsten filament was installed at the base of the column and electrons were accelerated up to the extractor electrode held at +250 to +300 kV. A small electron current is normally associated with the proton beam and is suspected to be mechanism by which sparkdown rate depends on beam current. Typically 20 μA electrons produced the same externally observed X-radiation dose rate and caused the same sparkdown rate as did 10 mA of protons. Experiments with $^{60}$Co and $^{241}$Am sources showed that gamma radiation with characteristic energies of ~ 1 MeV or 60 keV does not induce sparkdowns.

The column was removed from the accelerator and dismantled. Each ceramic had a number of tracks extending across the vacuum surface from one electrode to the other. The column sparking is thought to be the result of surface charge buildup on the ceramics from photo electrons emitted by X-radiation sufficiently energetic to penetrate the insulator shields or by reflected ultra violet light from ion-electron recombination in the beam region.

A new column has been designed which will reduce these effects by improving the shielding from the beam and by changing the direction of the surface gradient on the insulator.

The rotating target assembly has been modified to solve vibration and water leak problems and is now considered operational. An improved water baffle for the interior of the target drum which will allow faster disassembly has been fabricated and is being evaluated.

The ion source test stand, which is used to study the operation of ion sources and to measure their emittance and mass distribution was recommissioned. The test stand electrodes were modified to more closely simulate the fields in FINS. Source operation was limited to low currents.
(≤ 10 mA) because of plasma flashover to the extraction electrode. This was caused by a drop in the extraction voltage because of sparks between the source can and extraction electrode. To reduce this sparking, the face of the can was trimmed to increase the spacing between source can and extraction electrode (Fig. 6.3.1.1). This modification permitted operation at currents of 45 mA (FINS requires 40 mA). This current was achieved at source settings lower than expected. The reason for this improved operation is being studied.

6.3.2 Heavy-ion Superconducting Cyclotron
J.H. Ormrod

Design and development work on a superconducting cyclotron for a post-tandem accelerator continues. Fabrication and delivery of major components have slipped two weeks from the schedule reported last quarter; field mapping of the full-scale model magnet is scheduled for mid-summer, 1977.

a) Building for Experiments
J.H. Ormrod

Construction of the extension to Bldg. 467 to house the cyclotron model has started. The excavation is complete and the concrete for the pit under the cyclotron is partially poured.

b) Code Development
E.A. Heighway

TRIUMF: The trim rod optimization routine has been improved to better handle ions with highly non-circular orbits, e.g. carbon 15 MeV/u. For these ions the rods introduce field perturbations at radii significantly larger than the average radius of the equilibrium orbit.
Figure 6.3.1.1  Ion source can and extraction electrode.
A routine to calculate $v_r$ and $v_z$ (the radial and axial betatron frequencies) semi-analytically has been added. The formalism of Smith and Garren (UCRL-8598) is used. The agreement with the exact calculation is good and the analytic approach gives an appreciation of the importance of high order terms on $v_r$ and $v_z$.

c) **Cryogenic Systems**

J.A. Hulbert

The requirements on output and reliability of the helium liquefier system have been reviewed. The currently anticipated cooling requirement of the magnet cryostat is

$$13 \text{ W at 4.5 K with enthalpy of boil-off gas}$$
$$\text{ full utilized}$$
$$+ 2 \text{ W at 4.5 K with boil-off gas returned}$$
$$\text{ through liquefier heat exchanger}$$
$$+ 200 \text{ W at 100 K.}$$

The last item includes 100 W to remove the thermal effects of beam spill in the extraction channel.

By operating the liquefier in a dual refrigeration/liquid storage mode the standard operational cycle would consist of

$$49 \text{ hours at 4.5 K followed by}$$
$$37 \text{ hours warming, clean-up and cooldown.}$$

If the liquefier operates at less than 100% of rated output then the 49 hour period is extended. For example at 90% output the 'active' period required is 61 hours.

During the 'inactive' period the 4.5 K cooling is provided by stored liquid but an additional liquid nitrogen cooled heat exchanger may be necessary for the 100 K cooling.

To provide a rough test of the system's capability to meet the duration requirement without blocking, a long production run was carried out. 750 litres of liquid helium
were made at an average of 0.72 of maximum rate. The liquefier ran unattended for two full nights and remained at 4.5 K for over 40 hours. The unattended period accounts for most of the production rate reduction. The run terminated when the gas supply ran out. We now believe that, with augmented instrumentation, it is reasonable to anticipate 50-60 hour runs at 90-100% production.

The liquid nitrogen transfer line developed a leak in the flexible section at the liquefier end and has been returned to the manufacturer for warranty repair. Water contamination of repumped helium appears to be caused by diffusion from the atmosphere through the recovery gas bag. The diffusion rate is several times that to be expected from manufacturer's data.

A 100 W thermal load has been prepared for use in a 30 litre dewar on loan from Chemistry Division. This will be used in future liquefier tests as a refrigeration load.

Magnet cryostat design has continued, including revisions to the cryopumps, modifications to the helium can to allow construction in 57S aluminum, layout of the transfer lines, and complete revisions of the injection and extraction channel vacuum penetration through the cryostat.

Modifications to the insulation test cryostat to minimize unmonitored radiation heat leaks have been carried out and tests are now in progress.

Detailed analysis of the measurements of free convection heat transport to sub-critical helium gas, reported in PR-P-108 (AECL-5315), reveals a systematic error due to finite thermal conductivity of the test sample. Further measurements on a sample with improved geometry are in progress. The error accounts for a factor of two discrepancy between the mean heat transfer coefficient measured and the Squire correlation, previously tested under supercritical conditions above room temperature, but does not account for
an "anomalously" high transfer coefficient in the sub-critical region above the normal boiling point. This high transfer coefficient may be related to stratification currents in the helium gas whose effects are apparent in the measurements.

d) Magnet

(i) Orbit Dynamics

1) Isochronism

E.A. Heighway

The redesign of the flutter pole and skirt is now complete. This was necessary to extend the region of real \( v_z \) radially inwards, improving axial focussing at small radii, and to increase \( v_r \) at large radii, improving extraction.

This has been accomplished by reducing the mid-plane flutter pole gap at inner radii while at larger radii iron has been incorporated into the cryostat wall.

\( v_r \) at the entrance to the deflector has been increased to 0.72 from \(~0.6\) and the \( v_z \) real to imaginary transition point moved from 175 mm to 147 mm.

2) Magnetic Field Trimming

J.H. Ormrod and E.A. Heighway

The radial betatron frequency is given by

\[
\nu_r^2 = 1 + k + \text{higher order terms}
\]

where the average field index \( k = \frac{\partial B}{\partial R} \cdot \frac{R}{B} \). The field gradient of course maintains isochronism. For more relativistic ions \( k \sim \gamma^2 - 1 \) while for less relativistic ions \( k \) includes terms which make \( k \) rise more rapidly than \( \gamma^2 - 1 \). The higher order terms are important and are functions of the flutter and its first and second radial derivatives.

Magnetic field trimming introduces radial ripple in the field which may reverse the local radial gradient.
(especially at low specific energies), but the higher order terms are usually sufficient to maintain \( v_r > 1 \). Beyond 450 mm radius the sum of these higher order terms is negative, imposing a severe restriction on the allowable trimming ripple. This is not a problem for higher final specific energies (10 MeV/u) but it is for low specific energies (3 MeV/u). Several arrangements of trim rods have been tried but all have failed to maintain \( v_r > 1 \) in the neighbourhood of 550 mm radius. This is a potential worry because there are several components contributing significant first harmonic magnetic fields (which cannot be perfectly compensated). A first harmonic field drives the integral radial resonance and decenters the beam. Locating the trim rods closer together is not a solution because there is an optimum spacing as far as field ripple is concerned - at least for the larger diameter rods. A solution is being sought with smaller diameter rods (\( \phi = 40 \text{ mm} \)).

(ii) Yoke
Q.A. Walker (Civil and Mechanical Design Branch)

Most of the flame cut, 20" steel plate sections for the yoke structure have arrived in Toronto. Machining is due to start about mid-April for delivery at the end of September.

Samples of the steel for tests of magnetic properties are to be cut from the plates by milling at a specified distance from flame cut surfaces. This work will start as soon as all the plates are received.

(iii) Pole Jacking System
Q.A. Walker (Civil and Mechanical Design Branch)

Drive train items for the lower pole jacking system are now on order and work is in progress on the design of shear pin couplings and main motor slipping clutch. In the case of the upper pole guide system a purchase order for
parts has been issued and a work order for fabrication will be issued shortly.

(iv) Trim Rods
Q.A. Walker (Civil and Mechanical Design Branch)

The development of a trim rod drive mechanism continued with the testing of a stepping motor/harmonic gear unit under full load (10 kN) for the 40 mm diameter rods. Preliminary layouts of the drive mechanisms have been made to see if they will fit within the available space on the pole pieces. Comparative studies of the stepping and non-stepping type motor drives and their compatibility with the computer control system are being made. There is currently no clear advantage to either system.

(v) Superconducting Coils
H.R. Schneider

1) Superconductor

Problems with the supplier's soldering line were solved in December and an eighty metre length of superconductor composite was soldered as a final condition of the CRNL solder-line development contract.

The soldered conductor was inspected, and evaluated at CRNL by X-radiography and by pulling the conductor apart to examine the fractured solder bond. It was concluded that the line is running well and should be capable of producing the conductor within the maximum solder bond voidage specification.

Work is proceeding on the manufacture of the conductor. Production of the superconducting insert is now at the final drawing stage. The scheduled completion date for the conductor is now April 15, 1976, two weeks later than reported previously.
2) **Fiberglass Clamps**

The fiberglass radial clamp for the magnet coil was described in PR-P-108 (AECL-5315). A development contract now has been arranged: a) to find a combination of glass fiber cloth and mat which, when fabricated into a laminate with NASA Resin 2 epoxy, has a thermal contraction from 293 K to 4.2 K matching that of copper, and b) to produce prototype T clamps for evaluation at CRNL.

3) **Interturn Insulation**

An order has been placed for the manufacture of a special ridge "Mylar" insulation tape to be used for interturn insulation in each pancake coil winding. The tape is 0.127 mm thick and the same width as the superconductor (17 mm). Transverse "Mylar" ridges 0.355 mm high, 3 mm wide and spaced 3 mm apart are attached to the tape so that when it is wound into the coil, interturn channels are formed for cooling and ventilation.

Delivery of the insulation is expected in April 1976.

e) **Accelerating Structure**

C.B. Bigham

A work order has been issued for construction of the copper liners, dees and tuners of the full-sized high-power accelerating structure model. Experiments continue on component and control circuit testing using the Collins 205G-1 20 kW amplifier and a high-power quarter-wave resonator.

During circuit testing experiments, the resonator has been operated about 50 hours at the 5 kW level (the sparking limit without SF₆ in the resonator) and about 5 hours at the 20 kW level. Parameters of the test resonator and cyclotron are compared in Table 6.3.2.1. At 20 kW in the test resonator, the maximum current on the tuning short matches that in the cyclotron at 100 kW and therefore tests
the spring contacts (Instrument Specialties Co. Inc., Cat. No. 97-380-KS) on the tuning short to design levels. In addition, the automatic frequency control was by movement of the main tuning short and the experiments demonstrated that the spring contacts can be moved under power. After these tests, there was no indication of damage to the contacts and only light wear marks on the walls of the resonator.

Control circuits now "bread boarded" include the automatic frequency controller which keeps the resonator within a few kHz of the drive frequency (46 MHz), an automatic voltage control on the amplifier input which stabilizes the resonator voltage to a few parts in 10⁴ and safety circuits limiting reverse power levels. The resonator will track the drive oscillator frequency at the set power level but the Collins amplifier must be retuned manually (four stages) for frequency changes larger than 0.1 MHz.

Table 6.3.2.1
Comparison of Test Resonator and Cyclotron
Resonator Parameters

<table>
<thead>
<tr>
<th></th>
<th>Cyclotron</th>
<th>Test Resonator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tuning system dimensions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Outer conductor I.D. (mm)</td>
<td>280</td>
<td>152.4</td>
</tr>
<tr>
<td>- Inner conductor O.D. (mm)</td>
<td>180</td>
<td>76.2</td>
</tr>
<tr>
<td><strong>Unloaded Q₀</strong></td>
<td>3400</td>
<td>3000</td>
</tr>
<tr>
<td><strong>Shunt impedance Zₜ (kΩ)</strong></td>
<td>50</td>
<td>160</td>
</tr>
<tr>
<td><strong>Power (kW)</strong></td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td><strong>Voltage (kV)</strong></td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td><strong>Maximum currents on tuning short (A/cm)</strong></td>
<td>53</td>
<td>57</td>
</tr>
</tbody>
</table>
f) Injection

   (i) Injection Orbits
   E.A. Heighway

   Injection orbits for carbon, chlorine, bromine, iodine, tantalum and uranium ions at the upper and lower bounds of their respective energy range have been found. These orbits, which must pass through the centre of the last deflecting magnet and be tangential to an equilibrium orbit at the stripper, are unique for each ion-energy. These calculations have allowed the position of the last deflecting magnet and the orientation of the injection beam transport line to the cyclotron to be specified. The last deflecting magnet deflects the ions onto their respective injection orbits by a maximum of $\pm 2^\circ$.

   (ii) Foil Changer
   D.L. Beaulieu (Civil and Mechanical Design Branch)

   The preliminary design of foil changer components contained within the web is being reviewed to optimize the cooling channel arrangement and changer elements within the web.

g) Extraction

   C.R.J. Hoffmann

   Electrical and mechanical design of the electro-static deflection system is in progress. The design voltage is $-100$ kV and the system radial aperture is 8 mm.

   A code has been added to the EXMAP program to calculate bias magnetic fields for various dipole conductor configurations added to the magnetic channel (see PR-P-106, AECL-5226).

   Magnet field perturbations have been calculated for the magnetic channel parameters adjusted for a 10 MeV/u uranium beam ($-0.45$ T bias, 12 T/m gradient). The first
harmonic amplitude at a 600 mm radius (roughly where \( v_r = 1 \)) is \(< 0.3 \) mT. The estimated smallest first harmonic amplitude to be imposed to achieve resonant extraction is \( \sim 0.6 \) mT and will probably dominate this perturbation.

h) **Internal Beam Probes**

F.W. James

Two internal beam probe lines will be provided, one in each of hills 1 and 2. The probes will enter the cyclotron midplane along straight lines parallel to, but at a distance of 40 mm from, radius vectors at angles of 53° and 143° to the magnet reference '0'. Holes in the magnet yoke and the cryostat wall will be provided at these locations to allow for vacuum pipes with an outside diameter of 6.03 cm (2.375").

Two types of movable vacuum seals are being designed. One is based on a double teflon knife-edge vacuum seal while the other uses a welded stainless steel vacuum bellows. Both permit the probe to be moved a distance of 2 m which is the distance required to extract the probes outside the vacuum gate-valves located in the probe lines outside the yoke.

The probes will be moved by a lead screw or ball screw drive having an accuracy of \( \pm 0.1 \) mm.

The integral beam current probe will consist of a tungsten target to intercept the ion beam, 20 mm high, 5 mm thick and 25 mm in radial extent. It is designed to capture any electrons that are emitted from its surface.

The differential current probe, intended to measure the relative beam intensity over the radial width of the beam, will be a 0.5 mm diameter tungsten wire. The charge of the stopped ions and the electrons escaping from the surface will be measured. The diameter of the wire was chosen to give a reasonable resolution yet be large enough to
stop all ions except 20 to 50 MeV $^6_3$Li and 37 to 50 MeV $^{12}_6$C.

A beam-phase probe, accurate to a few degrees, is being designed; it uses $\gamma$ rays produced when the ion beam is stopped in a suitable target (copper or aluminum). The time delay of the $\gamma$ rays, detected by a scintillator and fast photomultiplier, from a standard rf timing signal is then a measure of the phase.

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 was as follows:

- Accelerator Physics Branch 87.7%
- Reactor Physics Branch 12.3%

6.4.1 High Current Test Facility

New titanium cathodes for a vac-ion pump were fabricated together with crumflat flanges and copper gaskets for the vacuum system.

Modifications were made to an ion-source can and repairs were made to two ion source anodes.

6.4.2 Electron Test Accelerator

In support of this program several modifications were carried out and some new components were fabricated. These included:
- The fabrication of three water-cooled solenoid lenses for the injection beam line.
- Manufacturing limit switch brackets and cams for six reciprocating beam scanners and modifying two sets of slits for the emittance measuring apparatus.
6.4.3 Fast Intense Neutron Source

Work required for commissioning the rotating target assembly occupied much of the effort - several bearing and water seal housing modifications were made, and a new water baffle was fabricated.

Ion source work included mounting a new gas metering system, modifying the ion source can, replating two anodes and fabricating a new anode.

Several adapter flanges and a set of ceramic stand-offs were made for accelerating column tests.

6.4.4 Heavy-Ion Superconducting Cyclotron

A method was developed for making large Belleville washer vacuum seals and several small-scale seal models were fabricated.

The 1/10 scale rf model was modified for cryopump and balancing capacitor perturbation measurements.

Mechanical components for the short-sample superconductor test-apparatus, special cleaning brushes and a decimetre counter were fabricated for the magnet winding line.

A full-scale model of the magnet vertical support bar and mounting together with numerous bits of hardware for the insulation test cryostat were manufactured.

6.4.5 Reactor Physics

Counting Room

Major modifications were carried out to an existing sample changer to accommodate a germanium detector and a $^10_B$-analyzer automatic sample changer was fabricated.
PTR Reactor

Ten special lucite containers for anion exchange resin used in swing capsule experiments were made.

ZED-11 Reactor

Rod sheath adapters, special rod hanging studs and miscellaneous hardware were manufactured for the flux peaking factor experiment.

6.5 Publications, Reports, Lectures and Patents

Publications

SPACE CHARGE FIELDS OF ELLIPTICALLY SYMMETRICAL BEAMS
Murray R. Shubaly
Nucl. Instr. & Meth. 130/1 (1975) 19 (AECL-5267).

THE SLOW-NEUTRON FISSION CROSS SECTIONS OF THE COMMON FISSIONABLE NUCLIDES (Revised 1975)
C.B. Bigham

THE CHALK RIVER SUPERCONDUCTING HEAVY ION CYCLOTRON
J.H. Ormrod, C.B. Bigham, J.S. Fraser, E.A. Heighway, C.R.J. Hoffmann, J.A. Hulbert, H.R. Schneider and Q.A. Walker
Seventh Int. Conf. on Cyclotrons and their Applications, p. 595, Zurich, 1975 (Ed. - W. Joho).

TURBULENT HEATING OF PLASMA IN TOROIDAL EXPERIMENTS

MAGNETIC TRIM RODS FOR SUPERCONDUCTING CYCLOTRONS
C.B. Bigham
Nucl. Instr. & Meth. 131 (1975) 223 (AECL-5283).

Reports

THE HIGH CURRENT TEST FACILITY INJECTOR, OPERATION TO 40 mA dc
J. Ungrin, J.H. Ormrod and W.L. Michel
Patents

CANADIAN PATENT NO. 982708
ION SOURCE WITH REDUCED EMITTANCE
J.H. Ormrod
Issued 27 January 1976.
The International Standard Serial Number

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