The results and conclusions given here are not classified or restricted in any way; however, some of the information is of a preliminary nature. Readers interested in using the information in their own research are invited to consult with the contributors for further details. Copies of AECL publications referred to in this report may be obtained by writing to the Scientific Document Distribution Office, Chalk River Nuclear Laboratories.

Chalk River, Ontario
January 1974
PROGRESS REPORT

1 October to 31 December 1973

PHYSICS DIVISION

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

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RECENT REPORTS IN THIS SERIES

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1.1 Nuclear Physics Research

Tandem Operation

The accelerator was not available for experimental work during the strike but some maintenance work was done. Subsequent performance has been satisfactory.

The availability of the accelerator was:

<table>
<thead>
<tr>
<th>Type</th>
<th>Hours</th>
<th>Percentage</th>
</tr>
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<tr>
<td>Experiments running</td>
<td>676</td>
<td>62.6%</td>
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<tr>
<td>Scheduled shutdowns</td>
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<td>-</td>
</tr>
<tr>
<td>Unscheduled shutdowns</td>
<td>404</td>
<td>37.4%</td>
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<tr>
<td>Total</td>
<td>1,080</td>
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</tr>
</tbody>
</table>

Thirteen experiments involving seven visiting scientists were performed. The visiting scientists were involved in experiments requiring 71% of the available time and their participation averaged 32%.

The magnetic field control system for the QD^3 spectrometer has been tested. Fabrication and testing of a 902-wire section of the 5120-wire Charpak counter system is well advanced.

Findings

Magnetic properties of excited states can be measured by observing the time modulation of γ-ray intensity due to precession of the radiating nucleus in a magnetic field. In recent experiments, use is made of the intense field at the nucleus of the hydrogen-like ion formed by the passage of the recoiling target atom through the target foil. Certain refinements in the analysis of this technique have now been applied to earlier measurements on an excited state in ^14C and progress has been made in similar determinations in ^24Mg.

Determinations of the decay properties of ^34Ar have been further extended yielding a precise value for the ground state transition rate (ft-value). The difference between it and the corresponding ft-value for ^35Cl provides a measure of charge-dependent mixing in the wave functions of these mirror nuclei and a test of recent precise β-decay theories.
High spin states, to spin 16\(^+\), in \(^{130}\)Ce have been produced by bombardment of \(^{110}\)Pd by 108 MeV \(^{24}\)Mg ions and of \(^{115}\)In by 86 MeV \(^{19}\)F ions, and to spin 25/2 in \(^{165}\)Ho by Coulomb excitation with 133 MeV \(^{35}\)Cl ions. Lifetimes and other properties of the high spin states are being studied.

In preparation for the on-line isotope separator, a drift tube to transport recoil ions from a tandem target position to the ion source of the separator is under development.

The bremsstrahlung monochromator now coupled to the electron linear accelerator, University of Toronto, has been tested for resolution and efficiency and found to meet specifications.

1.2 Solid State Studies

In collaboration with scientists at the Brookhaven High Flux Beam Reactor, molecular motions in solid nitrogen in both its \(\alpha\) and \(\beta\) phases have been examined.

In a collaborative experiment with Swedish scientists using a spectrometer at the Studsvik reactor, magnetic excitations in \(\text{KMn}_{0.95}\text{Zn}_{0.05}\text{F}_2\) have been studied. It is found that the theory that well describes excitations in \(\text{Mn}_{0.95}\text{Zn}_{0.05}\text{F}_2\) surprisingly does not do so for \(\text{KMn}_{0.95}\text{Zn}_{0.05}\text{F}_2\).

In an experiment carried out on the Dido reactor, Harwell, a predicted energy transfer effect between magnetic excitations and itinerant electrons in \(\text{Pd}_3\text{Fe}\) was explored.

A theoretical model to describe the behaviour of positronium in small spherical cavities has been constructed and will be used to guide analysis of experiments on the angular correlation of annihilation radiation from positrons stopping in vycor glass.

1.3 Detectors

Attempts to produce high-purity germanium at Ontario Research Foundation have yielded some information on requirements of the process but production of good material seems unlikely without a major overhaul of furnace equipment. In view of present availability of high-purity germanium commercially it has been decided to shelve the germanium
crystal growth program in 1974.

Various detectors have been made from commercial high-purity germanium for reactor control and nuclear physics research applications. In general the performance and reliability of these units is satisfactory.

In collaboration with scientists at the University of Wisconsin, preliminary tests of the suitability of HgI$_2$ and CdTe detectors for measurement of bone mineral mass were carried out. Because of their small size and low sensitivity to temperature and voltage changes, these detectors show considerable promise for this application, but some development work remains.

1.4 Applied Studies and Computation

Work continued on several projects begun previously, including:
- the numerical solution of Poisson's equation in the region between a set of circles and enclosed by an outer circle.
- the study of re-wetting of reactor fuel elements following a loss-of-coolant accident.
- the temperature profile in a reactor fuel element with a molten core.

Effort has been directed to improving the efficiency of the steady-state models used by Chemical Engineering Branch for simulating D$_2$O plants, and savings in computer time of up to 35% have been achieved. Exploration of other approaches which may decrease the computer time have begun.

A dynamic model of the hydraulics of the Bruce Heavy Water Plant has been completed and tested. The working version is based on idealized flow controllers; it is planned to develop this model further using more realistic differential flow controllers.

Work has continued in the development of a detailed dynamic model of a single D$_2$O tower; a model for the "cold tower" portion has been completed, and the model for a complete tower is being developed.

The analysis of the two-phase flow conditions encountered during a loss-of-coolant accident is being handled by a simulation method. An extension to the FORSIM program to permit the solution of
systems of implicitly coupled partial differential equations has been applied to representative problems of this type, with encouraging comparisons with experimental data.

An improvement has been made to the approximations used for library routines for some special functions, including modified Bessel functions $I_0(x)$ and $I_1(x)$.

A new version of the program MAC/RAN for the analysis of time series data was acquired from University Software Systems. Adaptation of the program for the CRNL computer configuration has been completed, and a number of features added to improve the usefulness of the program for AECL users.

Miscellaneous programs and subroutines developed or improved during the quarter include:

- an extension to the library routine for $\Gamma(z)$ which also evaluates $\ln(\Gamma(z))$.
- routines to recast in a standard format data recorded by a SUCCESSI system and the ND3300 and ND4420 pulse height analyzers.
- a program to calculate power production and fuel burnup in the X2 and X5 loops in NRX.
- a program for "generalized" least squares fitting.
- a program to produce loading diagrams for NRX reactor startup.

During the quarter, the CDC 6600 central memory was increased by 32,768 words to its full size of 131,074 words, and the total disk storage capacity of the system was raised by $70 \times 10^6$ characters to $215 \times 10^6$ characters. The testing and adaptation to the CRNL configuration of the latest releases of CDC's operating system and compilers for the 6600 has begun. Development of the facilities accessible by keyboard terminals continued, and provision has been made for the display of Calcomp plot files by terminals equipped with a storage tube CRT.

The total work load of 53,367 jobs for the 6600 computer was distributed as follows:
<table>
<thead>
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<th>Department</th>
<th>Percentage of Number of Jobs</th>
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<td>Computing Centre</td>
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<tr>
<td>Commercial Products</td>
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<td>0.0</td>
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<tr>
<td>Power Projects</td>
<td>11.2</td>
<td>9.3</td>
</tr>
<tr>
<td>WNRE</td>
<td>6.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Technical Information and University Relations</td>
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<td>0.2</td>
</tr>
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<td>Biology and Health Physics</td>
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<td>1.9</td>
</tr>
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<td>Chemistry and Materials</td>
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<td>Others</td>
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NUCLEAR PHYSICS BRANCH

by

J.C.D. Milton

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2.2 The $^{26}$Mg + $^{19}$F Reaction

2.3 Use of Ion Implanted Targets for DSAM Lifetime Measurements

2.4 Hyperfine Interactions in Helium-like Ions - Effects on the $^{14}$C g-factor Measurement

2.5 Experiment to Determine the g-factor of the First Excited State of $^{24}$Mg

2.6 The Decay of $^{34}$Ar: A Mirror Comparison of Superallowed Beta Decay

2.7 The Half Life of $^{30}$S

2.8 A Low Spin Isomer in $^{74}$Br

2.9 Measurement of Lifetimes and Vacuum Deorientation of High Spin States in $^{130}$Ce

2.10 Lifetimes for High Spin States in $^{165}$Ho by Doppler Broadened Lineshape Analysis

2.11 A Study of the 14.75 MeV Analogue Resonance in $^{208}$Bi

2.12 Lifetimes for Fission by the Blocking Method

2.13 Progress on the QD$^3$ Spectrometer

2.14 Ion Transport with Gas Flow and Electrostatic Focussing

2.15 Electronics, Computer and Instrumentation

2.16 MP Tandem Operation

2.17 Intercomparison of $^{60}$Co Standards

2.18 $^{18}$F

2.19 Half Life of $^{169}$Yb

2.20 Tests of Random Pulse Generator

2.21 Standardizations

2.22 Influence of Coulomb Forces on Superallowed $\beta$ Decay

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2.1 Staff

Branch Head: J.C.D. Milton

Professional Staff

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</tr>
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<td>G.C. Ball</td>
<td>L.H. Bucholtz</td>
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<td>J.G. Costa (1)</td>
<td>J.L. Gallant</td>
</tr>
<tr>
<td>W.G. Davies</td>
<td>J.J. Hill</td>
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<tr>
<td>A.J. Ferguson</td>
<td>A.S.C. Hyde</td>
</tr>
<tr>
<td>J.S. Forster</td>
<td>J.C. Kiteley</td>
</tr>
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<td>J.C. Hardy</td>
<td>J.P.D. O'Dacree</td>
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<tr>
<td>O. Hausser (2)</td>
<td>Miss A.R. Rutledge</td>
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<td>F.J. Sharp</td>
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<td>A.B. McDonald</td>
<td>R.A. Surette</td>
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<tr>
<td>H. Schmeing (4)</td>
<td>R.B. Tomlinson</td>
</tr>
<tr>
<td>D. Ward</td>
<td>E.C. Waito</td>
</tr>
<tr>
<td></td>
<td>F.K.Y. Wong (5)</td>
</tr>
<tr>
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<td>W.J. Woytovich</td>
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SECTION II

β-ray Group

R.L. Graham       W.L. Perry
H.R. Andrews      L.V. Smith
J.S. Geiger       R.B. Walker

SECTION III

Radioisotope Standardization Group

J.G.V. Taylor     F.H. Gibson
                   Mrs. J.S. Merritt

Laboratory Services and Workshop

G.M. Boire        K.T. McKee
M. Desrochers     Mrs. M. Beeching (6)
C. Johnson        Mrs. M. A. Trecartin

Secretarial Staff

Mrs. S.M. Carlos
Mrs. M.A. Trecartin

(1) Attached staff from Laboratoire des Basses Energies C.R.N. et U.L.P., Strasbourg/3, France
(2) On Leave of Absence at the University of Munich, Germany
(3) NRC Postdoctoral Fellow; arrived 27 November 1973, from Lawrence Berkeley Laboratory
(4) NRC Postdoctoral Fellow; arrived 1 June, 1972
(5) University of Waterloo Student; left December 21, 1973
(6) Attached to Physics Division from Design Engineering
2.2 The $^{26}\text{Mg} + ^{19}\text{F}$ Reaction

G.C. Ball, J.G. Costa, W.G. Davies, J.S. Forster, J.C. Hardy and A.B. McDonald

A preliminary investigation of the $^{26}\text{Mg} + ^{19}\text{F}$ reaction has been carried out to determine the usefulness of this reaction for studying neutron rich isotopes of B and C such as $^{15}\text{B}$ and $^{17}\text{C}$. A 99 MeV $^{19}\text{F}$ beam was used to bombard scintillator-supporting $^{26}\text{Mg}$ targets ~ 120 µg/cm$^2$ thick. The reaction products were detected in two $\Delta E_1 - \Delta E_2 - E$ counter telescopes positioned at 10° and 12°. The data were recorded on magnetic tape and analyzed with the aid of range energy tables to provide particle identification.

Typical evaporation spectra were observed for the $^{10-13}\text{B}$ and $^{12-15}\text{C}$ isotopes with virtually no population of levels below ~ 10 MeV and ~ 5 MeV, respectively. In addition the total yield of the heavier isotopes of B and C decreased rapidly above $^{12}\text{B}$ and $^{14}\text{C}$ and no events attributable to $^{15}\text{B}$ or $^{17}\text{C}$ were observed in a 4 hour run with ~ 40 na of $^{19}\text{F}$. These results indicate that the total cross sections for producing heavy neutron-rich isotopes of B and C using the $^{26}\text{Mg} + ^{19}\text{F}$ reaction are < 1 µb/sr and are probably too small to permit meaningful mass measurements.

2.3 Use of Ion Implanted Targets for DSAM* Lifetime Measurements

J.S. Forster, G.C. Ball, W.G. Davies, D. Ward and M.W. Greene (McMaster University)

In the measurement of nuclear lifetimes using DSAM techniques a problem regularly encountered is the insufficient knowledge of the stopping power for the recoiling nuclei produced in the reaction, e.g. $^{19}\text{F}(\alpha,\gamma)^{22}\text{Ne}$. To overcome these difficulties we have attempted to measure lifetimes in $^{22}\text{Ne}$ via the $^4\text{He}(^{19}\text{F},\gamma)^{22}\text{Ne}$ reaction. The $^{22}\text{Ne}$ recoils produced in this way have velocities ~ 5% of the velocity of light and reliable stopping power data is available (Northcliffe

*Doppler shift attenuation method
and Schilling, Nuclear Data Tables A7 (1970) 233).

The targets were produced by bombarding thick foils of Ti, Ni and Au with 40 kev alpha-particles from the Solid State Science Branch mass separator until a concentration \( \sim 3 \times 10^{17} \) atoms/cm\(^2\) was reached. These foils, as well as unimplanted foils, were bombarded with 30 MeV \(^{19}\)F ions from the McMaster FN tandem accelerator. De-excitation gamma rays were observed in a 35 cm\(^3\), 8% efficient Ge(Li) detector at angles of 0° and 90°.

Gamma rays from \(^{22}\)Ne and \(^{22}\)Na were observed from the \( ^4\)He\(^{(19}\)F,p\(^{22}\)Ne and \( ^4\)He\(^{(19}\)F,n\(^{22}\)Na reactions respectively. However there was also a large background from reactions between \(^{19}\)F and \(^{12}\)C, which probably built up on the surface of the targets during implantation of alpha-particles. In particular the 1.275 Mev gamma ray from the \( ^{12}\)C\(^{(19}\)F,pn\(^{29}\)Si reaction to the first excited state of \(^{29}\)Si obscured the 1.275 Mev gamma ray from the \(^{22}\)Ne \( 2^+ \rightarrow 0^+ \) transition.

Further experiments are planned with foils containing \( \sim 10^{18} \) atoms/cm\(^2\) of \(^4\)He. Also, precautions will be taken to prevent build up of carbon during implantation.

2.4 Hyperfine Interactions in Helium-like Ions - Effects on the \(^{14}\)C g-factor Measurement

G.J. Costa, T.K. Alexander, J.S. Forster and A.B. McDonald

Further calculations have been carried out in an attempt to interpret our results on the g-factor of \(^{14}\)C\( (3^-) \) (PR-P-98:2.5, AECL-4595). The main purpose was to establish the influence of the large fraction (\( \sim 48\% \)) of helium-like ions on the experimental modulation curve. For helium-like ions in their atomic ground state there is no hyperfine interaction, although there is for excited configurations with unpaired S electrons.

All excited helium ions were assumed to be in the
The state which gives 3 hyperfine frequencies closest to the hydrogen-like frequency. Other configurations, such as \(^3P_2\), which leads to 10 hyperfine frequencies, were not included.

Therefore, by using the estimated values (14\% to 37\%) of the helium-like ions in unpaired S configurations (G. Goldring et al., Phys. Rev. Lett. 28 (1972) 763) and calculating the hyperfine frequencies of the \((1s^2s)^S\) state (H.A. Bethe and E.E. Salpeter in "Quantum Mechanics of One- and Two-electron Atoms", Academic Press Inc., New York, 1957), we were able to show that, by including fields from such helium-like ions, the effect on the dominant hyperfine frequency from hydrogen-like ions was negligible (<< 1\%), even for an excited-state occupancy as high as 37\%.

A FORTRAN program has been written that evaluates the modulated intensity vs time, taking into account the unperturbed angular distribution, the charge fraction for hydrogen- and helium-like ions and the excited-state occupancy of the helium-like ions.

### 2.5 Experiment to Determine the g-factor of the First Excited State of \(^{24}\)Mg

T.K. Alexander, G.J. Costa, J.S. Forster and A.B. McDonald

The experiment to measure the magnetic moment of the first excited state of \(^{24}\)Mg (PR-P-99: 2.11, AECL-4697) has been continued. The reaction \(^{12}\)C\((^{16}\)O,\(\alpha\gamma\))\(^{24}\)Mg was employed to excite the \(I^\pi = 2^+\), 2 ps, 1369 keV level. The 1369 keV gamma rays were observed in three 12.7 cm diam by 15.24 cm long NaI(Tl) detectors in coincidence with alpha particles detected in an annular detector subtending angles between 173° and 177°. The targets were self-supporting carbon foil 400 μg/cm\(^2\) thick. The plunger stopper consisted of a 3.2 mg/cm\(^2\) layer of gold on a 3.4 mg/cm\(^2\) layer of copper deposited on a thick titanium plate. The unperturbed
angular correlation was determined at $E_0 = 47$ MeV using a 400 $\mu g/cm^2$ dag target deposited directly on a backing similar to the stopper. The coefficients of the Legendre polynomials are $A_{2Q} = 0.59 \pm 0.06$ and $A_{4Q}\bar{4} = -0.87 \pm 0.08$. Gamma-ray coincidence intensities were measured at $\theta_\gamma = 0^\circ$, $50^\circ$ and $90^\circ$ as a function of the target-to-stopper distance. The perturbation caused by hyperfine interactions in hydrogen-like $^{24}\text{Mg}$ ions was observed. Better counting statistics and more data at distances shorter than $10^{-3}$ inch are required to obtain an accurate measurement of the g-factor.

2.6 The Decay of $^{34}\text{Ar}$: A Mirror Comparison of Superallowed Beta Decay

J.C. Hardy, H. Schmeing, J.S. Geiger and R.L. Graham

A paper has been written summarizing the data we have obtained over the past 2-1/2 years on the decay of $^{34}\text{Ar}$. Through observation of the spectrum of $\beta$-delayed gamma-rays, the half life of $^{34}\text{Ar}$ was determined to be $844.5 \pm 3.4$ ms with $94.44 \pm 0.23 \%$ of the $\beta$-decays proceeding by the superallowed branch; four other decay branches were observed and their intensities measured. The branching ratios and log $ft$-values are listed in Table 2.6.1.

A comparison of the mass $^{34}$ superallowed $ft$-values is shown in Table 2.6.2. The resultant asymmetry of $\Delta = -0.23 \pm 0.64\%$ is now consistent with the calculated effects of charge-dependent mixing and lends confidence to those calculations (Towner and Hardy, Nucl. Phys. A205 (1973) 33). The final corrected $ft$-values for $^{34}\text{Cl}$ and $^{34}\text{Ar}$ are in complete agreement with the other accurately known results for $^{14}\text{O}$ and $^{26}\text{Al}$, and between them these results yield a credible value for the vector coupling constant of nuclear $\beta$-decay, viz $G_V = (1.4131 \pm 0.0005) \times 10^{-49}$ erg.cm$^3$. 
Table 2.6.1
$^{34}$Ar $\beta^+$-decay Branches

<table>
<thead>
<tr>
<th>Final State in $^{34}$Cl ($E_x$ in kev)</th>
<th>Absolute $\beta^+$ branching ratio (%)</th>
<th>log ft-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>94.44 $^{+0.23}_{-0.26}$</td>
<td>3.4837 ± 0.0024</td>
</tr>
<tr>
<td>461</td>
<td>0.91 ± 0.10</td>
<td>5.31 ± 0.05</td>
</tr>
<tr>
<td>666</td>
<td>2.49 $^{+0.13}_{-0.10}$</td>
<td>4.78 ± 0.02</td>
</tr>
<tr>
<td>2580</td>
<td>0.86 $^{+0.10}_{-0.04}$</td>
<td>4.11 $^{+0.02}_{-0.05}$</td>
</tr>
<tr>
<td>3129</td>
<td>1.30 $^{+0.12}_{-0.06}$</td>
<td>3.45 $^{+0.02}_{-0.04}$</td>
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</table>

Table 2.6.2
Mirror Comparison for $\Lambda = 34$

<table>
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<tr>
<th>$^{34}$Ar value</th>
<th>ref</th>
<th>$^{34}$Cl value</th>
<th>ref</th>
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</thead>
<tbody>
<tr>
<td>Half life, $t_{1/2}$(ms)</td>
<td>$^{34}$Ar 944.5 ± 3.4</td>
<td>a</td>
<td>$^{34}$Cl 1530 ± 4</td>
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<tr>
<td>Branching ratio (%)</td>
<td>94.44 ± 0.23</td>
<td>a</td>
<td>100</td>
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<td>End-point energy, $E_{\beta_{max}}$(kev)</td>
<td>$^{34}$Ar 5037.2 ± 3.4</td>
<td>c, d, e</td>
<td>$^{34}$Cl 4468.3 ± 1.5</td>
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<tr>
<td>Statistical rate function f</td>
<td>3405 ± 11</td>
<td></td>
<td>1994 ± 3</td>
</tr>
<tr>
<td>Partial half life</td>
<td>$^{34}$Ar 894.7 ± 4.2</td>
<td></td>
<td>$^{34}$Cl 1531 ± 4</td>
</tr>
<tr>
<td>ft-value (sec)</td>
<td>3046 ± 17</td>
<td></td>
<td>3053 ± 9</td>
</tr>
<tr>
<td>Mirror asymmetry, $\Delta$(%)</td>
<td>-0.23 ± 0.64</td>
<td></td>
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</tbody>
</table>

a) This work.
d) Graber and Harris, Phys. Rev. 188 (1969) 1685.
e) Hardy et al. (PR-P-99: 2.6, AECL-4697).
g) The partial half life includes a correction for electron capture.
2.7 The Half Life of $^{30}$S

H. Schmeing, J.C. Hardy, R.L. Graham and J.S. Geiger

An experiment to study the decay of $^{30}$S was described some time ago (PR-P-91: 2.16, AECL-4068). The data have now been analyzed and yield a half life of $1.181 \pm 0.013$ sec for $^{30}$S. This result compares favourably with $1.18 \pm 0.04$ sec (Barker et al., Proc. Phys. Soc. 91 (1967) 587) and $1.22 \pm 0.03$ sec (Moss et al., Nucl. Phys. A174 (1971) 408) giving a final average of $1.187 \pm 0.011$ sec. When combined with earlier branching ratio measurements (summarized by Towner and Hardy, Nucl. Phys. A205 (1973) 33) and the mass measurements of Hardy et al. (Phys. Rev., to be published; PR-P-99: 2.6, AECL-4697) this lifetime yields an $\frac{A}{t}$-value of $3033 \pm 50$ sec. The corrected $\frac{A}{t}$-value is $3049 \pm 50$ sec which agrees well with $3081.6 \pm 2.0$ sec, the average of the best known values for transitions in nuclei with $A < 40$.

2.8 A Low Spin Isomer in $^{74}$Br

H. Schmeing, R.L. Graham, J.C. Hardy and J.S. Geiger

The isotope $^{74}$Br has recently been studied in detail by several experimenters (S. Göring and M.V. Hartrott, Nucl. Phys. A151 (1970) 241 and A. Coban, J.C. Lisle, G. Murray and J.C. Willmott, Particles and Nuclei 4 (1972) 108). In all these measurements $^{74}$Br was produced directly in heavy ion reactions and its $\beta^+$-decay was seen to originate from a $4^-$ state with a half life of $41.5 \pm 1.5$ min.

We produced $^{74}$Br as the daughter of $^{74}$Kr, whose $\beta$-decay had not been studied before. This indirect production mode leads to an isomer in $^{74}$Br with a half life of $26.1 \pm 0.3$ min. Both the $41$ min and the $26$ min isomers decay to a large number of states in $^{74}$Se. Of these, only the lowest lying states are common to both decay schemes. The spin and parity of the $26$ min isomer are deduced to be $0^-$ or $1^-$. Which of the two isomers constitutes the ground state of $^{74}$Br is not yet established.
2.9 Measurement of Lifetimes and Vacuum Deorientation of High Spin States in $^{130}$Ce


The nucleus $^{130}$Ce was produced in the reactions $^{110}$Pd($^{24}$Mg,4n)$^{130}$Ce at 108 Mev and $^{115}$In($^{19}$F,4n)$^{130}$Ce at 86 Mev. On the basis of $\gamma-\gamma$ coincidences, relative intensities and angular distributions the ground state band levels have been identified to spin $16^+$. The transition energies in kev are as follows, beginning with the $2^+ - 0^+$ transition: 252, 457, 614, 730, 757, 503, 547 and 693. The ground $\gamma$-band of this isotope shows a pronounced backbending.

Lifetime data were obtained using the recoil distance method. The results of a preliminary analysis of the singles gamma spectra are $\tau_{12^+} = 4.7 \pm 0.8$ ps, $\tau_{10^+} = 1.1 \pm 0.6$ ps and $\tau_{0^+} < 1.1$ ps. The $12^+$ lifetime is to be compared with the 4.3 ps rotational prediction based on the known lifetime of the $2^+$ state (P. Taras et al., Communication 11.66, European Conference on Nuclear Physics, Aix-en-Provence, 1972). This result is consistent with the small retardation found in $^{158}$Er, the other case for which data exist (Ward et al., Phys. Rev. Lett. 30 (1973) 493). Vacuum deorientation measurements have also been made in order to detect a possible increase in the nuclear $g$ factor in the vicinity of the back bend. Results are not yet available from the analysis of these data.

2.10 Lifetimes for High Spin States in $^{165}$Ho by Doppler Broadened Lineshape Analysis (DBLS)

D. Ward, H.R. Andrews, J.S. Geiger, R.L. Graham and S.H. Sie (Queen's University)

A thick target of $^{165}$Ho was bombarded with $^{35}$Cl ions at 133 Mev. Gamma rays following Coulomb excitation were detected in three large Ge(Li) counters at 10°, 50° and 90° with respect to the beam direction and in coincidence with
backscattered $^{35}$Cl ions. The two gamma vibration bands $K = 3/2$ and $K = 11/2$ (PR-P-86: 2.13, AECL-3668) were excited quite strongly and levels were identified up to spin $13/2$ and $21/2$ respectively; the ground state band ($K = 7/2$) was excited to spin $25/2$.

Lifetimes for the rotational levels were deduced from the Doppler broadened line-shapes observed at $10^\circ$ and $50^\circ$, using the computer code described in PR-P-92: 2.8, AECL-4147. The electronic stopping power for Ho in Ho was taken from Northcliffe and Schilling and scaled by a factor $1.26$ (S.H. Sie et al., Bull. Am. Phys. Soc. 18(1973) 529). Preliminary results are shown in Table 2.10.1.

These data together with the branching ratio measurements should provide a detailed check for both $B(M1)$ and $B(E2)$ values in the ground state band.

<table>
<thead>
<tr>
<th>Level</th>
<th>Gamma Ray Energy (kev)</th>
<th>Mean Lifetime (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K=7/2$</td>
<td>cascade</td>
<td>crossover</td>
</tr>
<tr>
<td>13/2</td>
<td>135.2</td>
<td>250.3</td>
</tr>
<tr>
<td>15/2</td>
<td>154.4</td>
<td>289.6</td>
</tr>
<tr>
<td>17/2</td>
<td>173.7</td>
<td>328.6</td>
</tr>
<tr>
<td>19/2</td>
<td>190.5</td>
<td>364.7</td>
</tr>
<tr>
<td>21/2</td>
<td>209.8</td>
<td>400.3</td>
</tr>
<tr>
<td>23/2</td>
<td>222.6</td>
<td>432.1</td>
</tr>
<tr>
<td>25/2</td>
<td>(241.6)</td>
<td>464.1</td>
</tr>
</tbody>
</table>

*Uncertainties are expected to be ~10-20%*
2.11 A Study of the 14.75 MeV Analogue Resonance in $^{208}$Bi

W.G. Davies, A.J. Ferguson and K. Ramavataram (Université de Laval)

The experiment reported in PR-P-86: 2.10, AECL-3668 and PR-P-91: 2.14, AECL-4068 has been repeated using counter telescopes under more nearly optimum conditions in order to achieve a better peak to background ratio. Two telescopes, the first consisting of a 700 μm ΔE and a 2000 μm E counter and the second consisting of a 1000 μm ΔE and a 2000 μm E counter, were placed on opposite sides of the beam with solid angles of 0.4 and 0.8 msr respectively. The solid angle of telescope 1 was reduced so that it could operate at angles as far forward as 60° with respect to the beam direction.

An excitation function was measured for proton bombarding energies in the region from 14.5 to 14.95 MeV to check the location of the resonances.

Proton angular distributions leading to the ground state and the two excited states at 0.570 and 0.893 MeV in $^{207}$Pb were measured both on resonance (14.75 MeV) and off resonance (14.30 MeV). Measurements were made for 14 distinct angular positions between 60° and 160° with respect to the beam.

Analysis of the data is in progress.

2.12 Lifetimes for Fission by the Blocking Method

J.S. Forster, D. Ward, I.V. Mitchell (Solid State Science Branch), W.M. Gibson (Bell Laboratories), J.U. Andersen (Aarhus University) and E. Laesgaard (Aarhus University)

The blocking studies described in PR-P-98: 2.12, AECL-4596 have been continued under improved experimental conditions. Specifically we have used a smaller beam spot (0.63 mm) than hitherto and have decreased the target-detector distances so that more of the blocking pattern was observed. With $^{16}$O ions in the energy range 84 to 94 MeV on
a single thin Au crystal we observed blocking dips of $\chi \approx 8\%$ for the fission fragments. Preliminary analysis indicates zero lifetime effect with $\Delta \chi (190^\circ-100^\circ) \approx \pm 5\%$.

2.13 Progress on the $QD^3$ Spectrometer
W.G. Davies and G.C. Ball

The new field control system for the $QD^3$ has been thoroughly tested (see PR-P-99:2.19, AECL-4697). A field stability $\Delta B/B_{max}$ of $2 \times 10^{-5}$ of maximum field was obtained over a 2-1/2 day period with stabilities of $5 \times 10^{-6}$ achieved over shorter periods. The limit to the stability appears to be torsional vibrations in the Rawson probes used to measure the fields.

Field cycling tests have been made in order to determine operating procedures for the spectrometer that will ensure the flattest possible magnetic fields in the three dipoles. Measurements of field homogeneity in D1 and D2 for various field cycling procedures have been made with the main power supply under field control. Preliminary results indicate that the field control system automatically provides most of the controlled overshoot and/or undershoot required to achieve flattening. Further understanding of our results awaits detailed analysis of the interrelationship of the eddy currents and the response of the main power supply under field control to the magnetic effects of these currents. Thus it would appear that the use of a well designed field control systems for the trim supplies will produce very homogeneous fields in all three magnets since the rate and degree of overshoot and/or undershoot will then be controlled separately in each magnet.

A "production" model of the rear Charpak counter system has been built and tested. This counter is 1.6 cm thick and has 2 mm wire spacing. The counter works very well using an Ar, CO$_2$, Xe gas mixture; good $\Delta E$ signals were obtained from the cathode as well as digital position signals from the anode
wires. Further tests are in progress. A "production" model of the front counter is currently under construction. This counter is identical, except for length, with the prototype unit reported in PR-P-96: 2.14, AECL-4428.

2.14 Ion Transport with Gas Flow and Electrostatic Focussing
F.K.Y. Wong, H. Schmeing, J.C. Hardy and H.R. Andrews

The ion drift tube (PR-P-96: 2.17, AECL-4428) has been equipped with a focussing element consisting of six concentric coplanar annular electrodes. At the center of the innermost electrode a 0.5 mm diameter hole is drilled, through which transport gas can be allowed to escape from the drift space into a collector chamber. Ions created by an alpha-source can be focussed - with and without gas flow - onto the innermost annular electrode alone. The current density profile was measured in the drift space and at the focussing electrodes. Without gas flow no current passes into the collector chamber; with the help of the gas flow an estimated 20% of the focussed current can indeed be funnelled through the hole in the central electrode into the collector chamber.

Experiments are presently under way to determine which geometrical shape of the central electrode permits the highest fraction of the focussed beam to pass through a given hole size.

2.15 Electronics, Computer and Instrumentation
R.B. Tomlinson, J.P.D. O'Dacre and F.J. Sharp

PDP-10

Three programs have been added to the software package MASTER (PR-P-99: 2.21, AECL-4657) and 21 of the old programs improved. The new features allow the user
to add additional information to the header block and facilitate the retrieval of information about a spectrum and its status. The construction and extensive wiring of the new PDP 10 fast scanner system is essentially complete and bench testing has begun.

**MP Tandem**

The new dynamic vertical steerers (PR-P-99: 2.21, AECL-4657) were tested. Although the results were not conclusive it appears that beam instabilities in the vertical plane are not a serious problem at this time compared to horizontal variations resulting from terminal voltage instabilities. Thus further tests will be postponed until after the installation of the pelletron charging chain.

2.16 **MP Tandem Operation**

J.C.D. Milton

During the first weeks of the strike the MP Tandem lay idle. No experiments were done at any time, but towards the end some routine tests and maintenance were completed: the column and tube insulators were thoroughly inspected, the springs were removed from one side of the high energy tubes and the installation of the copper tube shorting bars (PR-P-94: 2.7, AECL-4257) was completed. In addition, tests were made on the efficacy of the new vertical steerers (see sec. 2.15). Since November 6 the availability of the accelerator has been good, as shown in Table 2.16.1, and the performance high, so that thirteen experiments were performed by CRNL and seven visiting scientists. Non-CRNL scientists were involved in experiments requiring 71% of the available time and their participation was on the average 32%.

The lithium charge exchange (LCE) source, after being rebuilt by General Ionex, has recently returned (slightly
damaged) to CRNL. It is planned to install and test it during the Christmas season.

Table 2.16.1

<table>
<thead>
<tr>
<th></th>
<th>Beam Available</th>
<th>Scheduled shutdown</th>
<th>Unscheduled shutdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>676</td>
<td>0</td>
<td>404</td>
</tr>
<tr>
<td>Percentage</td>
<td>62.6%</td>
<td>0%</td>
<td>37.4%</td>
</tr>
<tr>
<td>Total hours</td>
<td>1080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total percentage</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.17 Intercomparison of 60Co Standards
J.G.V. Taylor and J.S. Merritt

Following the discovery of 19% discrepancies in 137Cs and 241Am standards from a commercial set (PR-P-99, AECL-4697) the 60Co standard from the same set was measured. The measurements agreed with the stated gamma-ray emission rate to 1%, well within the certified accuracy of ± 5%. The supplier is investigating the 137Cs and 241Am discrepancies.

2.18 18F
J.S. Merritt and J.G.V. Taylor

18F produced by 6Li(n,α)t, 16O(t,n)18F in 6Li-enriched Li2CO3 (PR-P-99, AECL-4697) has been purified from 3H and traces of 24Na, 38Cl and 198Au. The 24Na, 198Au and most of the 3H were removed by elution from a hydrous zirconium oxide column, the remaining 3H was eliminated by repeated evaporations, and 38Cl was removed by retaining it on a Dowex-50 column on which Ag+ had been adsorbed.

The purified activity has been followed by 4πβ counting and independently in a "4πγ" ion chamber yielding half-life values of 109.72 ± 0.02 minutes and 109.73 ± 0.02 minutes, respectively, where the uncertainties are standard deviations. The agreement of the results with each other
and with the most precise published half life, 109.72 ± 0.06 minutes, indicates adequate purity has been attained. The only residual activity in the samples observed by Ge(Li) spectrometry was $^{187}_{\text{W}}$ amounting to $< 10^{-5}$ of the initial $^{18}_{\text{F}}$ activity. Further work is planned.

2.19 **Half Life of $^{169}_{\text{Yb}}$**

J.S. Merritt and J.G.V. Taylor

In the course of standardizing 32-day $^{169}_{\text{Yb}}$ for Commercial Products it was noted that no half-life values for this nuclide had been reported since 1960 and that of these, the more recent values were shorter than the older ones. Measurements started after the 4.2-day $^{175}_{\text{Yb}}$ contaminant had decayed to a negligible level, give a preliminary half-life value of 32.015 ± 0.090 (3σ) days, significantly longer than the recently recommended value, 30.7 ± 0.3 days (Nucl. Data Sheets 10 (1973) 359). Measurements are continuing.

2.20 **Tests of Random Pulse Generator**

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

A series of tests has been carried out on a commercial random pulse generator. It appears to perform as specified after minor adjustments. In particular, (1), the time distributions of output pulses appeared to be random for intervals > 1.4 μs when triggered internally and for intervals > 120 ns (the instrument resolving time) when triggered externally; (2) the pulser peak width measured at low random rates in a Ge(Li) spectrometry system was as narrow as the peak obtained with an Ortec 448 "Research" pulser for short counting times and only 5% ($\approx 0.1$ keV) wider over a 16-hour counting interval.
2.21 Standardizations
J.G.V. Taylor and J.S. Merritt

\( \text{\(^{60}\text{Co}\) - Reactor Control} \)

\( \text{\(^{169}\text{Yb}\) - Commercial Products} \)

2.22 Influence of Coulomb Forces on Superallowed \( \beta \) Decay
I.S. Towner (Theoretical Physics Branch) and J.C. Hardy

See PR-P-100: 4.9

2.23 Publications and Lectures

a) Publications

MEASUREMENT OF THE RELATIVISTIC DOPPLER EFFECT USING 8.6 MEV CAPTURE GAMMA RAYS

EL POLARIZATION IN COULOMB EXCITATION OF \( ^{7}\text{Li} \)
O. Häusser, A.B. McDonald, T.K. Alexander, A.J. Ferguson and R.E. Warner

GAMMA DECAY OF THE LOWEST \( T = 2 \) STATE OF \( ^{24}\text{Mg} \)
J. Szűcs, B.Y. Underwood, T.K. Alexander and N. Anyas Weiss

LIFETIMES IN THE GROUND STATES OF \( ^{184}\text{Hg} \)
Phys. Rev. Lett. 31 (1973) 1421

PRESENT STATUS IN QUANTITATIVE SOURCE PREPARATION
J.S. Merritt
Nucl. Instr. and Meth. 112 (1973) 325

GAMMA-RAY STRENGTH FUNCTIONS
G.A. Bartholomew, E.D. Earle, A.J. Ferguson, J.W. Knowles and M.A. Lone
b) **Lectures**

NUCLEAR BETA DECAY, COUPLING CONSTANTS AND THE WEAK INTERACTION  
J.C. Hardy  
at Université Laval on 26 October 73

BACKBENDING IN THE ROTATIONAL BANDS OF RARE-EARTH NUCLEI  
R.L. Graham  
at the University of Guelph on 13 November 73

CURRENT STATUS OF BACKBENDING PHENOMENA  
D. Ward  
at the Université de Montréal on 23 November 73
3.1 Staff
3.2 Phonons in Tellurium
3.3 Molecular Motions in Solid Nitrogen
3.4 Magnetic Excitations in KMn$_{0.95}$Zn$_{0.05}$F$_2$
3.5 Magnetic Excitations in Ilmenite
3.6 Temperature Dependence of Spin Waves in Pd$_3$Fe
3.7 Temperature Dependence of Magnetic Excitons in Pr$_3$Tl
3.8 Positronium-Surface Interaction in Small Cavities
3.9 Correlation of Thermal Displacements in Crystal Lattices
3.10 Preliminary Testing of the Bremsstrahlung Monochromator at the University of Toronto
3.11 The $^{205}$Tl $\gamma$-Ray Strength Function Below 7.5 MeV
3.12 The 6.82 MeV Background $\gamma$-Radiation in Fast Neutron Capture Experiments
3.13 Non-Statistical Effects in $^{198}$Hg(n,$\gamma$)$^{199}$Hg Reaction
3.14 Measurement of D$_2$O Concentration in Water
3.15 Germanium Quality
3.16 High Purity Germanium Spectrometers
3.17 High Purity Ge Detectors for Reactor Control Branch
3.18 Detector Mounting
3.19 Use of HgI$_2$ and CdTe in Bone Mineral Measurements
3.20 Gas Counters
3.21 Miscellaneous Services
3.22 Publications, Reports and Lectures
3.1 Staff

BRANCH HEAD: A.D.B. Woods

SECTION I  SOLID STATE PHYSICS  TECHNICAL STAFF
A.D.B. Woods(1)  R.S. Campbell
W.J.L. Buyers  H.F. Nieman
G. Dolling  M.M. Potter
T.M. Holden  D.C. Tennant
S.M. Kim
C.P. Martel
B.M. Powell
E.C. Svensson
D. Winfield(2)

SECTION II  NEUTRON NUCLEAR PHYSICS
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E.D. Earle  G.W. Hartsgrove
M.A. Lone  W.M. Inglis
W.F. Mills

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H.I. Malm  H.R. McCrady
Miss M.M.L. Racicot
W.F. Slater
R.J. Toone

GLASSBLOWING  WORKSHOPS
R.C. Bailey  R.R. MacLanders  A.H.W. Hewitt
J.G. Wesanko  H.C. Spenceley

DESIGN  SECRETARIAL STAFF
W. McAlpin  Mrs. Dianne Mitchell
K. Tait(3)

(1) On leave of absence for one year at Institut Max Von Laue-
Paul Langevin, Grenoble, France; left May 23, 1973.
(2) Attached staff from McGill University; left October 12,
(3) Seconded from Design Engineering.
3.2 Phonons in Tellurium
B.M. Powell and P. Martel

Molecular orbital arguments show that a significant electron density exists around the centre of the nearest neighbour bond in tellurium. If the charge distribution of this bond is considered to include the charges on the Te ions at each end of the bond together with the charge near its centre, the distribution closely simulates that of a linear axially symmetric quadrupole. We have attempted to interpret the phonon dispersion curves measured previously (PR-P-96:3.5, AECL-4428) in terms of a quadrupole-quadrupole interaction between the charge distributions of nearest neighbour bonds. The interaction acts effectively between the bond centres, but to utilise standard lattice dynamical treatments it is divided into two parts and considered to act between atoms. The model has only one parameter, the "effective" quadrupole moment of the bond.

Preliminary calculations with interactions to 5th neighbour quadrupoles show that while the model predicts the branches for the $\Delta,\Sigma$ directions to be in the correct order, the upper E mode is too high in frequency while the $A_1,A_2$ and lower E branches are too close together and generally too flat (i.e. independent of wave-vector). The quadrupole-quadrupole interaction does not simulate very effectively the nearest neighbour bond-stretching force, which is known to be a dominant interaction. The addition of this interaction to the model (one additional parameter) results in a significant improvement of the shapes of the dispersion curves for the $\Delta$ direction. In the $\Sigma$ direction however the optical branches remain too flat with little separation between the $\Sigma_1,\Sigma_2''$ branches. The addition of a central interchain force (a further parameter) results in a significant improvement for the branches in the $\Sigma$ direction. The physical justification for
this additional interchain force is not very obvious however.

With the parameters from lattice dynamical models developed previously (PR-P-92:3.5, AECL-4147) we have calculated the phonon frequency distribution $g(v)$ for Te. The distribution shows three distinct regions of structure which correlate with the acoustic, the lower optical and the upper optical branches. A gap in $g(v)$, from about 3.1 to 3.7 THz, exists between the lower and upper optical regions. A minimum in $g(v)$ also occurs at -1.8 THz separating the acoustic and lower optical regions. For some of the models this minimum becomes a definite gap. A further significant feature of $g(v)$ is the presence of a large spike at -4.1 THz which correlates with the upper E mode. The three regions of the calculated $g(v)$ correlate only qualitatively with the distribution measured by Kotov et al. The latter shows none of the detailed structure given by the calculation, and the observed relative magnitudes of the various regions differ substantially from those calculated.

3.3 Molecular Motions in Solid Nitrogen
G. Dolling, with J. Kjems and G. Shirane (Brookhaven National Laboratory)

Coherent inelastic neutron scattering measurements have been made on single crystal specimens of both the $\alpha$ and $\beta$ phases of solid $N_2$, at the High Flux Beam Reactor, Brookhaven National Laboratory. A triple axis spectrometer at the H7 beam facility was employed for most of the experiments; curved and flat pyrolitic graphite crystals were used for the monochromator and analyser respectively. In the high temperature hexagonal close-packed $\beta$ phase, which exists between the melting point (63 K) and 35.6 K, a well-defined dispersion relation for the translational motions of the molecules was observed for modes propagating along the $a^*$
and \( c^* \) axes. The librational motions were not well-defined, and gave rise to broad neutron scattering distributions over a wide range of energy transfers (0-10 meV).

On cooling the \( \beta-N_2 \) single crystal through the phase transition, about one half of the specimen, roughly \( 1.5 \text{ cm}^3 \), transformed successfully to a single crystal of the \( \alpha \) phase (space group \( \text{Pa3} \)). The remaining section, consisting of disoriented fragments, was masked off for the low temperature experiments. A series of measurements at the points \( \Gamma, R \) and \( M \) were made at 15 K in order to obtain sufficient normal mode information for analysis in terms of intermolecular force models. Both librational and translational modes were clearly observable. The \( E_g, T_g \) and \( T_u \) modes at \( \Gamma \) agreed well with those previously observed in Raman and infra-red scattering experiments at or near 15 K. Several modes were also studied as a function of temperature: almost all the modes showed considerable broadening and some decrease in frequency as the temperature approached 35.6 K. The lowest frequency \( T_g \) mode, however, became so broad that at 34.5 K, no distinct peak could be seen. Analysis of the 15 K results in terms of Buckingham-type interatomic potential functions is in progress.

3.4 Magnetic Excitations in KMn\(_{0.95}\)Zn\(_{0.05}\)F\(_2\)

E.C. Svensson, with R. Stedman (AB Atomenergi, Studsvik, Sweden)

Magnetic excitations in a single crystal of antiferromagnetic KMn\(_{0.95}\)Zn\(_{0.05}\)F\(_2\) have been studied by neutron inelastic scattering using a double-monochromator spectrometer at Studsvik. A rather weak resonant perturbation of the spin-waves by the non-magnetic Zn impurities is observed. The impurity-induced widths \( \Delta \Gamma \) are \( \lesssim 0.1 \) THz and the frequency shifts \( \Delta \nu \) are \( \lesssim 0.05 \) THz, and further, the resonance occurs at
rather high frequency where the dispersion curves are relatively flat, so very high resolution and hence long counting times were required. In the [00\zeta] direction, \( \Delta \Gamma \) has a maximum at a reduced wave vector \( \zeta_R \approx 0.275 \) corresponding to a resonance frequency \( \nu_R \approx 1.8 \text{ THz} \). In the [\zeta\zeta0] direction the corresponding values are \( \zeta_R \approx 0.2 \) and \( \nu_R \approx 1.9 \text{ THz} \). Since there are 6 nearest neighbors in the cubic perovskite structure, one would expect, on the basis of simple molecular-field theory, that \( \nu_R = \frac{5}{6} \nu_{\text{max}} = 1.91 \text{ THz} \).

The case of non-magnetic impurities provides a very stringent test of the theories since there are no adjustable parameters. Although first-order Green-function theory gave an excellent description of the results for \( \text{Mn}_{0.95}\text{Zn}_{0.05}\text{F}_2 \) (PR-P-78:4.5, AECL-3157; PR-P-79:4.9, AECL-3166; PR-P-81:4.8, AECL-3333), its predictions for \( \text{KMn}_{0.95}\text{Zn}_{0.05}\text{F}_2 \) (PR-P-85:4.12, AECL-3667; and R.A. Cowley and W.J.L. Buyers, Rev. Mod. Phys. 44 (1972) 406) are not at all in agreement with the present observations. The theory predicts that the principal resonance should occur at a much lower frequency (\( \nu_R \approx 1.2 \text{ THz} \) and \( \zeta_R \approx 0.15 \) for the [00\zeta] direction) and that the amplitudes of \( \Delta \Gamma \) and \( \Delta \nu \) should be about twice those observed. The reason for the discrepancy is not understood at present. The calculations will be repeated. Calculations based on the coherent-potential approximation are also under way.

3.5 Magnetic Excitations in Ilmenite
C.P. Martel, T.M. Holden and G. Dolling

The measurements described in PR-P-99:3.2, AECL-4657 were continued. The magnetic mode at 1.16 THz was found to broaden and its frequency to decrease as the transition temperature \( T_N \) was approached, thus confirming its magnetic nature.

However, subsequent detailed neutron diffraction studies indicated that the natural crystal specimen might
contain as much as 15% haematite, in the form of veins running throughout the specimen, having a very similar structure and the same crystal orientation as the ilmenite matrix. By means of microprobe analysis, the ilmenite matrix was found to be some 6% deficient in iron (by weight), and was found to contain small iron-rich inclusions in addition to the veins. Such an iron deficiency might account for the unusually low $T_N$ value quoted in PR-P-99:3.2, AECL-4657.

Other specimens from the Bancroft ore deposit were examined and found to have similar haematite content. A specimen of Norwegian ilmenite has been kindly supplied by the Geological Survey of Canada, and this will be studied in the near future. Since the frequency of the observed magnetic mode appears to be independent of wave vector except in the region of a possible magnon-phonon interaction, it is hoped that further information can be obtained from commercially available pure ilmenite powder.

A computer program has been written to analyse the results. The ground state of the Fe$^{2+}$ ion is split firstly by a cubic crystal field into an orbital triplet (lowest) and an orbital doublet. The single ion perturbing Hamiltonian

$$\mathcal{H}_p = -\lambda \hat{R}^2 \hat{S} + R^2 \delta(\ell^2 - 2/3) + \mathcal{H}_{\text{ex}} \hat{S}_z$$

where $\lambda$ is the spin-orbit coupling parameter, $R$ is the orbital reduction factor, $\ell$ is the effective angular momentum describing the lowest orbital triplet, $\hat{S}$ is the spin, $\delta$ describes the trigonal distortion of the cubic crystal field and $\mathcal{H}_{\text{ex}}$ is the molecular field. The observed magnetic mode corresponds to a transition between the ground state of the lowest multiplet and the second excited state; the transition to the first excited state is forbidden.
3.6 Temperature Dependence of Spin Waves in Pd$_3$Fe

T.M. Holden

Pd$_3$Fe is a cubic ferromagnet with a Curie temperature of 493±5K. The average magnetic moment on Fe sites is 1.43 $\mu_B$ and on Pd sites is 0.17 $\mu_B$. Previous magnetic inelastic neutron scattering work on this material has included a study of the low-wave-vector spin-wave excitations by the diffraction method (Antonini et al., S.S. Comm. 9 (1971) 257) and a more comprehensive survey of the excitations in three principal directions at 293K (W.G. Stirling and R.A. Cowley, S.S. Comm. 11 (1972) 271). The present experiments were performed to study the temperature dependence of the spin wave spectrum over a wide range of temperature spanning the Curie point (293;373;423;473;673 K). The experiments were carried out on a triple axis crystal spectrometer at the Dido reactor, Harwell with fixed incident energy $E_0=21.1$ THz. The (220) planes of an Al crystal were used as monochromator and the (111) planes of a squeezed Cu crystal were used as analyser. The temperature of the crystal, mounted within a cylindrical Ta heating element inside a water cooled furnace, was controlled and measured to within about 2° by a chromel-alumel thermocouple.

Measurements were made of the spin wave energies of magnons propagating in the (100) direction between $\xi=0.11$ and 0.40. The groups observed in constant-Q scans at low q were broad, because of the steepness of the dispersion relation and the vertical divergence of the instrument. All the observed width was attributable to instrumental broadening. At intermediate magnon wave vectors ($\xi>0.21$) there was evidence for an intrinsic spin wave lifetime and the slope of the dispersion relation decreased quite rapidly. At $\xi=0.4$ it was impossible to assign an energy unambiguously at 293 K because of the linewidth and the possible presence of phonon
scattering in the same energy range as the magnon.

As the temperature was raised the spin wave energies decreased rapidly and the lifetimes increased. For instance there was a 40% reduction in energy between $0.6 T_N$ and $0.86 T_N$ at $\xi=0.19$. At $0.97 T_N$ the energy distribution of neutron scattering was very broad, and there was appreciable quasi elastic scattering in addition to a weak inelastic peak.

Constant E-scans which were strong at 293 K were absent at 473 K although there was a broad non-peaked contribution to the scattering. This behaviour contrasts with that for nickel (Mook et al., Phys. Rev. Letters 30 (1973) 556) where well-defined intense peaks were observed well above $T_C$ in constant E-scans. Analysis of the results to correct for the effects of instrumental broadening in the temperature dependent spin wave shifts and lifetimes is being carried out.

3.7 Temperature Dependence of Magnetic Excitons in Pr$_3$Tl

W.J.L. Buyers, A. Perreault (Université de Montréal) and T.M. Holden

The predictions of the dynamical susceptibility theory (PR-P-99:3.6, AECL-4657) have been compared with the neutron scattering results for the spectrum of magnetic excitons as observed by R.J. Birgeneau (A.I.P. Conf. Proc. 10 (1973) 1664) in Pr$_3$Tl. Calculations have been made of the temperature dependence of the neutron response observed at a wave vector $Q = 0.6 \AA^{-1}$ in both the ordered ferromagnetic phase and the non-ordered state. This wave vector is in the vicinity of the cross-over of the $\Gamma_1-\Gamma_4$ branch with the $\Gamma_4-\Gamma_3$ branch and it is found that mode-mode interaction plays an important part in determining the shift in frequency of the observed peak as well as its intensity. Because the
experiment was performed at low resolution the peak observed in the neutron experiment is an average over both branches as well as over their individual components. The theory predicts that the frequency of the neutron peak is constant to ±5% between T=0K and T=60K. This is consistent with the experiment which contains 6 data points within this temperature range, each of which is accurate to ±5%. The theory further predicts a nearly constant intensity in the peak below T\textsubscript{C}, and above T\textsubscript{C} a decrease with increasing T as the ground state is depopulated. This is in qualitative agreement with experiment which shows a more rapid decrease with temperature. Recently Birgeneau and Kjems (private communication) have repeated part of the experiment at Brookhaven with higher resolution. They find a two-peaked neutron group in the vicinity of the wave vector of the cross-over supporting our contention that mode-mode interaction is important. In addition they find the growth of a central mode as T→0 in a non-ordered alloy, i.e. scattering at frequency transfers small compared with the instrumental frequency resolution. Part of this we associate with the very low frequency modes within the triplet predicted previously (PR-P-99:3.6, AECL-4657).

3.8 Positronium-Surface Interaction in Small Cavities
S.M. Kim and W.J.L. Buyers

As one step in understanding the annihilation of positronium in vycor glass (PR-P-99:3.7, AECL-4657) the possible states of positronium in a spherical cavity have been studied. The glass host material surrounding the cavity is assumed to attract the positronium atom as a result of polarization forces. The range of this force is expected to be a few angstroms. A model potential has been constructed in which the surface is represented by an infinite potential step at radius r\textsubscript{s} and the attractive surface potential by a
shell of thickness \( t = (r_2 - r_1) \) where the potential is lower than that in the central spherical region, \( r < r_1 \), by an amount \( V_0 \). The positronium wave function \( \psi_{+-}(r) \) and the angular correlation \( \int |\rho(\mathbf{p})| ^2 d\mathbf{p}_x d\mathbf{p}_y \), where

\[
\rho(\mathbf{p}) = \int \psi_{+-}(r) \exp(-ip \cdot \mathbf{r}) \, dr
\]

have been obtained numerically for \( t(\text{Å}) = 2, 4 \) and \( 6 \) and \( V_0(\text{eV}) = 0, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0 \) for all cavity sizes studied in the experiment, \( r_2(\text{Å}) = 22, 28, 37 \) and \( 140 \). The resultant angular correlation shows a narrow central peak and a broader oscillatory tail. The width of the central peak is determined by the value of \( p \) where the front half and back half of the sphere destructively interfere, approximately given by

\[
p \times r_2 = \pi.
\]

The intensity in the broader component and the amplitude of the oscillations depends surprisingly little on whether \( V_0 \) is large enough to bind and localise the positronium in the shell or whether the positronium is free to occupy the whole of the spherical cavity (\( V_0 = 0 \) or \( r_1 = 0 \)). The rate of fall-off at large \( p \) is large for a large shell thickness. For most cavity sizes the width of the central peak is smaller than the effective resolution of the experiments, a combination of 0.5 mr instrumental resolution and 0.75 mr from thermal positronium motion. For example for \( r_2 = 37 \text{Å} \) and \( t = 4 \text{Å} \), the full width at half-height of the central sharp peak is only 0.6-0.7 mr. Since the total positronium peak (narrow plus broad component) is superposed on an even broader component arising from positrons annihilating in the glass or from pick-off processes, a purely experimental separation of the
observed angular correlation into its various components is not unique. Nevertheless the above results should form the basis of any future analysis.

3.9 Correlation of Thermal Displacements in Crystal Lattices

D.P. Jackson (Solid State Science Branch, Chemistry and Materials Division) in collaboration with B.M. Powell and G. Dolling

See PR-CMa-27.

3.10 Preliminary Testing of the Bremsstrahlung Monochromator at the University of Toronto

G.C. Dixon, E.D. Earle, G.W. Hartsgrove, W.M. Inglis, A.M. Khan and J.W. Knowles with T.E. Drake and M. Charlesworth (University of Toronto)

Measurements of resolution and efficiency have been made on the bremsstrahlung monochromator, developed at AECL and transferred recently to the Linac Laboratory at the University of Toronto (PR-P-99:3.13, AECL-4657).

For the test of resolution, a beam of 5 MeV electrons was guided through the beam transport system and detected with photographic film. The width of this beam in the focal plane of magnetic spectrometer, described in PR-P-96:3.15, AECL-4428, gives the resolution in the central field of the monochromator if the dispersion of the complete system is made zero. Measurements of beam width under this condition show that the resolution is ≤15 keV, well within the 20-30 keV design specifications.

The efficiency of the monochromator for detecting tagged bremsstrahlung radiation was measured with 1-10 nAmps of 12 MeV electrons incident on the 3 mg/cm² copper radiator of the monochromator. These electrons, slowed down and
scattered in the radiator, produce bremsstrahlung radiation in a narrow cone in the forward direction. The scattered electrons of 5 MeV were detected with a 2" diameter plastic scintillator in the focal plane of the magnetic spectrometer and the bremsstrahlung with a 5" diameter scintillator. The pulses from the detectors were measured singly and in coincidence. It was found that the singles and coincidence rates were in agreement with our predictions.

3.11 The $^{205}$Tl $\gamma$-Ray Strength Function Below 7.5 MeV
E.D. Earle, J.W. Knowles and M.A. Lone

The $^{205}$Tl $\gamma$-ray strength function calculated from the measured photoelastic scattering cross section has been reported previously in PR-P-96:3.13, AECL-4428; and Advances in Nuclear Physics, Vol. 7 (M. Baranger and E. Vogt eds.), Plenum Press, New York (1973) p. 229. We have estimated the sensitivity of the computed strength function, $f(E_\gamma)$, above 3.5 MeV to changes in the nuclear temperature, $T$, and in the assumed value of $f(E_\gamma)$ below 3.5 MeV. These estimates show that large, unrealistic changes in $T$ and $f(E_\gamma)$ are required in order to make a 25% change in the reported strength function.

In the determination of the $^{205}$Tl($\gamma,\gamma$) cross section, from measurements made with the Compton monochromator, it was assumed that no radiation from the nickel ($n,\gamma$) source greater than 8.99 MeV contributes significantly. Gamma-rays at 10.09 and 11.39 MeV, following double neutron capture in $^{58}$Ni, have been reported recently by Moreh and Bar-Noy (Nucl. Inst. and Meth. 105 (1972) 557). The combined intensity of these $\gamma$-rays is only a few percent of the 8.99 MeV $\gamma$-rays of $^{59}$Ni used in the $^{205}$Tl measurement and so does not contribute a significant error to the cross section.
3.12 The 6.82 MeV Background $\gamma$-Radiation in Fast Neutron Capture Experiments
E.D. Earle and M.A. Lone

In heavy nuclei the ratio $\sigma_{\gamma n}/\sigma_{nn'}$ for $E_n > 1$ MeV is often less than $10^{-2}$. Thus in fast neutron capture $\gamma$-ray experiments background radiation from the capture of scattered neutrons can be a serious problem. Pulsed beam and time-of-flight techniques reduce this background appreciably. High energy $\gamma$-radiation at $E_\gamma = 6.82$ MeV was observed in all spectra measured with a 12.5 cm $\times$ 15 cm NaI crystal following fast neutron capture in Tl, Hg, Au and Ta (PR-P-95:3.5, AECL-4314). In a series of tests we have established that this peak is due to the capture of thermal neutrons in I followed by summation of the cascade $\gamma$-rays.

3.13 Non-Statistical Effects in $^{199}$Hg($n,\gamma$)$^{200}$Hg Reaction
M.A. Lone, E.D. Earle and G.A. Bartholomew

In the capture $\gamma$-ray spectrum from the 89.9 eV $1/2^+$ resonance in $^{199}$Hg (PR-P-88:4.15, AECL-3865), El transitions to the final states associated with the 3p neutron quasi-particle orbital are found to be stronger than transitions to other states. Out of a total of 44 transitions observed in the energy range 4.1 to 6.65 MeV, nine carry 62% of the total intensity and all of these are to final states excited in the (d,p) and (d,t) reactions with $l_n = 1$ momentum transfer. This enhancement cannot be interpreted as valency capture since the correlation coefficient between the (d,p) spectroscopic factor and the reduced partial radiation width for these nine transitions is consistent with zero.

One probable explanation of this enhancement is that it is due to the dominance of excited core plus single nucleon configurations in the capturing and final states.
On a weak coupling model one expects large components of the \( |2^+,3d_{3/2}\rangle \) configuration in the \( 1/2^+ \) capturing state at the threshold and of the \( |2^+,3p_{1/2},3/2\rangle \) and \( |2^+,f_{5/2}\rangle \) configurations in the \( 1/2^- \) and \( 3/2^- \) final states. The importance of the excited core plus single particle configurations in this context have been discussed by Bartholomew (verbal report, Bull. Am. Phys. Soc. V13 (1968) 1461) and by Lane (in Proc. Int. Conf. on Photonuclear Reactions and Applications, Asilomar, California (1973), B.L. Berman ed., Lawrence Livermore Laboratory, University of California, 1973, p. 803).

3.14 Measurement of \( \text{D}_2\text{O} \) Concentration in Water

M.A. Lone with J.G. Bayly (Reactor Control Branch) and I.L. Fowler

The design of a prototype apparatus (PR-P-99:3.11, AECL-4657) for the measurement of \( \text{D}_2\text{O} \) concentration in water has been completed and fabrication of various components is in progress.

3.15 Germanium Quality

(a) General

I.L. Fowler

An improved pumping system was put on the crystal furnace at the Ontario Research Foundation (ORF) during August allowing longer bake-out times prior to crystal growth. Four crystals were grown during this period. The first was unsuccessful due to too small a charge being used. The next two were experimental double growth crystals in which, on the first growth, the crystal was necked down after ~90% growth and then expanded again to pull clean; before the second growth, the furnace was opened and the bottom section of the crystal was snapped off. This was an attempt to remove some
remaining segregating impurities before final crystal growth. The last crystal #139 was grown this way from material zone-refined at ORF. This crystal has yet to be evaluated.

Evaluation of recent crystals here, and measurements made on our material by Lawrence Berkeley and Lawrence Livermore Laboratories indicates that there are still impurity problems. Since the identification of phosphorus as a segregating donor, microbiological tests on the charge washing system were carried out and showed evidence of bacteria in the water. The system has been improved, but no evidence is yet available that the number of donors has been reduced. All crystals grown have had a high concentration of aluminum acceptors and a new hypothesis to explain this is being tested. It seems likely that we will always have a copper contamination problem with the present internally-resistance-heated furnace.

Earlier this year we had planned to build a new Czochralski furnace for high-purity germanium. However, an estimate of the likely demand for high-purity Ge spectrometers coupled with the increased size and better quality of the high-purity crystals available commercially suggests that that program should not be emphasized now, and that the time and effort would be better used on other detector problems and other materials. We have thus decided to discontinue all germanium crystal growth work in 1974. However, with the knowledge gained, we expect to be able to grow high-quality crystals following a reasonably short start-up time should the need arise in the future.

(b) Evaluation of ORF Germanium
H.L. Malm, L. Racicot and M. Gulick

One crystal (#139) was received late in the report period and tests on it are just starting, evaluation tests
were completed on a section of crystal #135. In the section of crystal #135 (0.40<x/L<0.64) the net impurity concentration changed from \(N_A - N_D = 5.9 \times 10^{11}/\text{cm}^3\) (p type) at \(x/L = 0.62\). A portion tested near the junction, where the average net ionized impurity concentration was \(8 \times 10^{10}/\text{cm}^3\), showed charge trapping with a mobility-lifetime product (\(\mu\tau\)) for holes of \(5 \times 10^{-3} \text{ cm}^2/V\). The electrons were less severely trapped. The \(\mu\tau\) values for this crystal are 4 times poorer than for crystals #133 and #134.

3.16 High Purity Germanium Spectrometers
H.L. Malm

A number of planar spectrometers made from General Electric germanium with sensitive volumes greater than 10 \(\text{cm}^3\) have been tested. Two diodes fabricated at Electronic Associates of Canada Ltd. with volumes of 13.2 \(\text{cm}^3\) (A=13.2 \(\text{cm}^2\), W=1.0 \(\text{cm}\)) and 13.6 \(\text{cm}^3\) (A=7.5 \(\text{cm}^2\), W=1.8 \(\text{cm}\)) gave resolutions for the 1173 keV \(^{57}\text{Co}\) \(\gamma\)-ray of 2.2 keV (fwhm) and 2.6 keV respectively. These diodes which were brought from Toronto and exposed to air at temperatures between -7°C and +23°C in transit showed a small improvement in the reverse current-voltage characteristics. Two diodes fabricated here with volumes of 10.5 \(\text{cm}^3\) (A=9.5 \(\text{cm}^2\), W=1.1 \(\text{cm}\)) and 16 \(\text{cm}^3\) (A=9.4 \(\text{cm}^2\), W=1.7 \(\text{cm}\)) gave resolutions of 1.9 keV and 2.0 keV respectively for the 1173 keV \(^{57}\text{Co}\) \(\gamma\)-ray. The 1333 keV peak to Compton ratio was 20:1 for the 16 \(\text{cm}^3\) device. It is noteworthy that the 16 \(\text{cm}^3\) diode was made with the p contact on n type material.

A 1 \(\text{cm}^2\) by 0.5 \(\text{cm}\) thick diode from p type Ge was tested using \(^{137}\text{Cs}\) conversion electrons. At voltages above the depletion voltage (200 V) the resolution was 1.55 keV (fwhm) for the 625 keV K line.

Two 1 \(\text{cm}^3\) diodes were made and encapsulated for the Pickering DFP-12 Defect Monitoring system.
3.17 High Purity Ge Detectors for Reactor Control Branch
H.L. Malm, R.J. Toone and I.L. Fowler

(a) Pickering Generating Station DFP-12 Defect Monitoring System

The two cryostats (mentioned in PR-P-99:3.19(a), AECL-4657) containing encapsulated detectors have now been delivered. The small detector was replaced by a 1 cm³ detector before delivery and a spare detector is available.

(b) Detector in Short Vertical Mount - NPD

This unit showed a deterioration in voltage rating after some use. The rating was improved by a brief heat treatment without removal from the cryostat. Detector stability generally is still under investigation.

(c) Pickering Generating Station Feeder Scanner

The detector-cryostat system for this application (see PR-P-98:3.17(a), AECL-4595) had to be modified to strengthen the centering support at the detector end. A new tubular support was designed to fit directly onto the Hevimet detector mount. This should not appreciably increase the consumption of liquid nitrogen. The detector was re-mounted without re-processing.

3.18 Detector Mounting
R.J. Toone

Two silicon detectors were mounted in a small portable cryostat for Section II of this Branch. This cryostat is now being modified for another experiment for which a Ge detector is required.
3.19 Use of Hgl$_2$ and CdTe in Bone Mineral Measurements

H.L. Malm with R. Mazess and R.B. Witt (University of Wisconsin)

Preliminary tests were made using Hgl$_2$ and CdTe detectors for measurement of bone mineral mass. In the present technique the bone mass is measured in vivo by means of X-ray absorption using a source and a NaI-photomultiplier combination. A semiconductor detector operated at room temperature has the advantage of less sensitivity to temperature and voltage changes and smaller size. A Hgl$_2$ detector (A = 9 mm$^2$, W = 1.3 mm) was used to measure a standardized bone phantom with a monoenergetic $^{125}$I source (27 keV). The results in terms of bone mineral mass agreed within 1% except for the smallest phantom. Two other Hgl$_2$ detectors showed a deterioration in performance during the trip to the University of Wisconsin. The better energy resolution with the CdTe detector made it possible to do measurements using a $^{153}$Gd source with essentially two energies (41 keV and 97,103 keV). Absorption measurements at these two energies with the CdTe detector made possible a correction for either thickness variations or variations of the fat content of tissue. However, the large number of degraded pulses due to incomplete charge collection and X-ray escape in this particular detector increased the statistical uncertainty of the final result.

These initial results showed that a Hgl$_2$ detector could be used for the monoenergetic absorptiometric measurements if a rugged encapsulation can be devised. Cadmium telluride detectors, with further improvement in leakage current and charge collection, could be used for absorptiometric measurements with one or two photon energies.
3.20 **Gas Counters**  
H.R. McCrady and I.L. Fowler

Two $4\pi$ gas flow counters were supplied to AECL, Commercial Products, Ottawa; the wire was replaced in another flow type counter. Four halogen counters were supplied within CRNL and two fission counters were re-tested and supplied to Pakistan (PINSTECH).

One experimental $^3$He counter has been supplied to Section II of this Branch and work is proceeding on determining an optimum gas filling mixture for this particular application.

3.21 **Miscellaneous Services**  
H.R. McCrady and R.J. Toone

Eighteen copper-glass vacuum seals were supplied to Chemistry and Materials Division in this period. Slabs were cut from a large germanium single crystal for Section I of Neutron and Solid State Physics Branch, a Si crystal was cut for Solid State Science Branch, and other smaller services were performed.

3.22 **Publications, Reports and Lectures**

**Publications**

**NEUTRON SCATTERING MEASUREMENTS OF THE INTERLAYER INTRAFRACTION IN GaSe**  
J.L. Brebner, S. Jandl and B.M. Powell  
Solid State Communications 13 (1973) 1555  
Atomic Energy of Canada Limited publication AECL-4690

**MAGNETIC EXCITATIONS AND MAGNETIC CRITICAL SCATTERING IN COBALT FLUORIDE**  
J. Phys. C 6 (1973) 2997  
Atomic Energy of Canada Limited publication AECL-4564
SPIN-WAVES IN DISORDERED SYSTEMS II. THE DILUTE ANTIFERROMAGNET (Mn,Zn)F$_2$
W.J.L. Buyers, D.E. Pepper and R.J. Elliott
J. Phys. C 6 (1973) 1933

SPIN-WAVES IN DILUTE ANTIFERROMAGNETS: (Mn,Zn)F$_2$
W.J.L. Buyers, D.E. Pepper and R.J. Elliott
AIP Conference Proceedings 10 (1973) 841
Atomic Energy of Canada Limited publication AECL-4691

GAMMA-RAY STRENGTH FUNCTIONS
G.A. Bartholomew, E.D. Earle, A.J. Ferguson, J.W. Knowles and M.A. Lone

POLARIZATION PHENOMENA IN CdTe - PRELIMINARY RESULTS
H.L. Malm and M. Martini
Can. J. Phys. 51 (1973) 2336
Atomic Energy of Canada Limited publication AECL-4692

Lectures

SOFT MODES IN SINGLET-GROUND-STATE SYSTEMS
W.J.L. Buyers and T.M. Holden
19th Meeting on Magnetism and Magnetic Materials, Boston, November 13-16, 1973

POLARIZATION PHENOMENA IN CdTe NUCLEAR RADIATION DETECTORS
H.L. Malm and M. Martini
Paper presented at the 1973 Nuclear Science Symposium, San Francisco
November 14-16, 1973
THEORETICAL PHYSICS BRANCH

by

G.E. Lee-Whiting

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4.2 Neutron Generation and Migration in the D₂O Coolant Circulating in a Pipe
4.3 Solid Helium as a Rare Gas Crystal
4.4 Slow-Neutron Multiple Scattering
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4.12 Reports, Publications, and Lectures
4.1 Staff

Branch Head: G.E. Lee-Whiting

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

Summer Staff
R. Shukla (1)

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(1) Summer Professor; Brock University, terminated December 28, 1973
4.2 Neutron Generation and Migration in the D$_2$O Coolant Circulating in a Pipe

S.A. Kushneriuk

In order to evaluate a proposal for detecting possible ruptures of fuel elements in the reactor by monitoring with a neutron detector the pipes in which the D$_2$O reactor coolant flows, W.J. Edwards of the General Chemistry Branch required more specific information on the fate of the neutrons generated in the coolant. The ruptured fuel elements result in the emission of fission fragments. In principle, because the fission fragments release "delayed" neutrons, the rupture could be detected by detecting the neutrons released by the fragments as the coolant containing the fragments passes the neutron detector.

For such a detector to work, a sufficient flux of neutrons must be available. However, perhaps a more serious consideration is discrimination against the background neutron flux resulting from the "steady" production of neutrons in the D$_2$O coolant via the D(γ,n)H reaction initiated by the γ-rays released in the decay of $^{16}$N present in the coolant. The $^{16}$N is itself produced in the reactor via the $^{16}$O(n,p)$^{16}$N reaction.

Delayed neutrons released by the fission fragments have energies in the 100 keV to 1000 keV energy range. Thus, for purposes of assessing the importance of the background neutrons, the rate of neutron production via the D(γ,n)H reaction in the coolant, the energy spectrum of the neutrons so produced and the fraction of these neutrons that ultimately end up with energies in the keV energy range and still remain in the pipe have been calculated. In order to estimate the neutron flux available for detection, the fraction of the keV energy neutrons that become thermalized in the pipe has also been calculated.
4.3 Solid Helium as a Rare Gas Crystal

H.R. Glyde

The review of the theory and properties of solid helium for the forthcoming book "Rare Gas Crystals" (Academic Press) edited by M.L. Klein and J.A. Venables is now complete (see PR-P-98:4.3 (AECL-4595) and PR-P-99:4.3 (AECL-4657)).

The review is divided into five sections. The first and introductory section relates the distinguishing characteristics of solid helium, such as its large interatomic spacing, the rapid diffusion and tunnelling between atomic sites and the large vibrational amplitudes, to a single distinguishing parameter \( \lambda \), the ratio of the kinetic to potential energy. In solid helium \( \lambda \sim 1 \) while in most solids \( \lambda \) is small. Sections two and three demonstrate why the standard theories for dynamics and defects, which are small \( \lambda \) theories, fail in helium and then review and interrelate the present theories of helium. The predictions of each theory for the ground-state and excitation properties are critically compared with experiment in sections four and five. Here the role of interference terms in explaining the apparently anomalous neutron scattering results and the limits of the Debye theory in explaining the anomalous specific heat in bcc \(^3\)He are emphasized.

4.4 Slow-Neutron Multiple Scattering

V.F. Sears

For a sample whose linear dimensions are vanishingly small in comparison with the slow-neutron mean free path, the scattering cross section is proportional to the Van Hove scattering function \( S(\mathbf{Q},\omega) \). For a sample of finite size there is a non-negligible probability that a neutron will be scattered more than once before leaving the sample so that a

*body-centered cubic
calculation of the resulting scattered neutron distribution requires the solution of an appropriate neutron transport equation. We have shown that the result can be expressed in terms of an effective scattering function which can be expanded in terms of orders of scattering (single scattering, double scattering, etc.). The contribution from single scattering equals \( S(\hat{Q}, \omega) \) times a transmission factor \( H_1 \). The contribution from multiple scattering of order \( j (= 2,3,\ldots) \) is an integral of a function \( H_j \) multiplied by products of \( S(\hat{Q}, \omega) \)'s, one for each collision. The theory has been further developed as follows:

1. Exact upper and lower bounds on the quantities \( H_j \) have been obtained.
2. The quantities \( H_j \) have been calculated exactly for an infinite plane slab. For the quasi-isotropic approximation, in which \( S(\hat{Q}, \omega) = \delta(\omega) \), the double scattering has been calculated for arbitrary directions of the incident and scattered beams.
3. A model expression for \( H_j \) is proposed for arbitrary geometries. This model satisfies the required upper and lower bounds and is asymptotically exact for a thin slab.
4. Using this model, expressions have been obtained for the double scattering in a plane slab, a sphere and a cylinder in the quasi-isotropic approximation.
5. For an arbitrary scattering function \( S(\hat{Q}, \omega) \), the calculation of the double scattering ordinarily involves the evolution of a 7-dimensional integral. By the use of the above-mentioned model, the calculation is reduced to a 3-dimensional (and in some cases 2-dimensional) integral. This greatly simplifies the problem of making multiple scattering corrections in the analysis of slow-neutron scattering data. The method has been applied to recent Chalk River data on liquid neon.
4.5 Penetration of Heavy Ions in Solids
K.B. Winterbon

The preliminary results mentioned under this heading in the preceding progress report (PR-P-99:4.5 (AECL-4657)) have been found to be due to a computational error. The effect of the correlation of electronic and nuclear stopping on the range distribution has been found to be negligible. It is now possible to calculate range distributions with a cross section with 'power' parameter $m$ less than $1/4$. The Bohr and Lenz-Jensen cross sections are examples.

The time evolution of the depth distribution of the collision cascade has been studied (with J.B. Sanders, F.O.M.* Institute, Amsterdam). The time evolution equation is much like the ordinary damage equation, so the techniques developed over the past few years are applicable. The derivation of the equation was made more rigorous than the usual (time-independent) derivation of range or damage equations. It appears to be the only derivation of such equations which holds for the divergent cross sections which are used in essentially all of the computations (other than simulation) done in the field. The work has been written up for publication.

4.6 Doppler Shift Attenuation Calculations
K.B. Winterbon

A program has been written to calculate moments of the Doppler-shifted spectrum by the iterative method developed for range and damage distribution moments (PR-P-94:4.7 (AECL-4257)).

It has been observed that the spectrum can be calculated directly, i.e. without first calculating moments. A program written to do this is now being tested.

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*Fundamenteel Onderzoek der Materie
4.7 Perturbative Analysis of Deformations in Nuclei

M. Harvey

Continuing the study of how deformation effects manifest themselves in the spherical shell model of nuclei (PR-P-99:4.8, AECL-4657) we have made a perturbative analysis of the energy of the deformed Hartree-Fock state from the Hamiltonian \( H_A = T + \hbar \omega_Q [\gamma M.M + x Q.Q]x \) exchange. We have identified the perturbation diagrams in first and second order in \( x \) but have so far failed to identify the set of diagrams to all orders that would be needed to describe the total deformation energy. An analysis of the energy in terms of two- and three-body operators and a study of the energy surface on the complete \( \beta \gamma \)-plane has also been made.

4.8 Single-Particle States of the Spherical Shell Model

M. Harvey and H.C. Lee

The definition of single-particle wave functions and energies in the spherical shell model (PR-P-98:4.13, AECL-4595) has been analysed further. A computer error and lack of convergence in solving the Hartree-Fock equations was the main cause of the large mass-dependence of the single-particle energies previously reported. Corrected results show a slight decrease in the spin-orbit strength throughout the (ls,0d)-shell. The s-d splitting is constant throughout most of the shell but decreases towards the end; this latter property may be a result of the finite basis used in the Evalin Hartree-Fock programme.

4.9 Influence of Coulomb Forces on Superallowed Beta Decay

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

For a closed-shell-plus-two system, a particular case of the more general \( 4n+2 \) species involved in superallowed Fermi \( \beta \)-decays, we are estimating the influence of Coulomb
forces on the renormalisation of the $\beta$-decay operator using
the Bloch-Horowitz procedure. We use Brandow's version of
the theory in which a perturbation series is developed for
the renormalised operator in terms of fully linked Feynman
diagrams. For our problem there are 25 such diagrams to be
considered in second-order, 10 of which are the so-called
'folded' diagrams. The calculation is complicated by the
presence of the Coulomb force, which in an isospin formalism
manifests itself in terms of spherical tensors of rank zero,
one and two. To date we are still working through the Racah
algebra necessary for the evaluation of these 25 diagrams.

4.10 Pion-Nucleus Reactions
H.C. Lee

This work, described previously (PR-P-99:4.10,
AECL-4657), is being continued. A program package for the
computation of Green's function for particles with negative
energies has been completed.

4.11 Nuclear Convection- and Magnetisation-Currents
H.C. Lee

The distribution of charge and electromagnetic-
currents within a nucleus determines its response to external
electromagnetic probes. In general one may write the current
as

$$\mathbf{J} = \mathbf{J}_C + \mathbf{v} \times \mathbf{A}, \quad (1)$$

where $\mathbf{J}_C$ is irrotational. The leading contribution to $\mathbf{J}_C$ is
the convection current $-i\hbar \mathbf{v}$; the most important part of the
magnetisation current is obtained when we replace $\mathbf{A}$ by $\mathbf{\mu}$, the
density of magnetisation. Some information about the structures
of $\mathbf{J}_C$ may be obtained by applying the equation of continuity to
measured charge distributions. To relate experimental data to nuclear structure, however, a microscopic calculation of the current densities is necessary.

There now exists an abundance of (e,e') scattering data for nuclear magnetic dipole excitations, most of which are analysed in terms of phenomenological current densities. These data could be exploited more profitably if they were to be analysed with nuclear currents calculated from first principles. Working toward this goal we have constructed a program package to calculate single-particle current densities. From these the current density between any two nuclear states can be computed, if the single-particle density matrix between the two states is known.
4.12 Reports, Publications, and Lectures

Reports

RELATIONSHIP BETWEEN THE SPHERICAL SHELL MODEL AND THE
DEFORMED HARTREE-FOCK MODEL FOR NUCLEI
M. Harvey
AECL-4602

Publications

ANHARMONIC LATTICE DYNAMICS IN POTASSIUM
M.S. Duesbery, Roger Taylor and H.R. Glyde
Physical Review B8(1973)1372

CANADA AS A DEVELOPING COUNTRY
H.R. Glyde
Science Forum 35(1973)26

ORIGIN OF ELECTRIC QUADRUPOLE ENHANCEMENTS IN A=17 NUCLEI
M. Harvey & F.C. Khanna

NUCLEAR STRUCTURE STUDIES OF ^{20}Ne AND ^{24}Mg IN THE
VARIATION-AFTER-PROJECTION HARTREE-FOCK METHOD
R.Y. Cusson and H.C. Lee
Nucl. Phys. A24(1973)429

REFLECTION OF LIGHT IONS FROM SOLID SURFACES
J. Böttiger and K.B. Winterbon
Rad. Effects 20(1973)65

Lectures

INTERACTION OF RADIATION WITH MATTER AND ITS RELEVANCE
TO FUSION
F.C. Khanna
to University of Manitoba, December 6, 1973

1. HOW CAN A SPHERICAL SHELL MODEL DESCRIBE A DEFORMED NUCLEUS?
2. THE ROLE OF THE GROUP SU_3 IN NUCLEAR THEORY
M. Harvey
to the University of Toronto, November 29, 1973
THE ORIGIN OF THE SPHERICAL SHELL MODEL
M. Harvey
to Université Laval, November 9, 1973

DEFORMATION RENORMALISATIONS IN THE SPHERICAL NUCLEAR SHELL MODEL
M. Harvey
to the University of Rochester, October 18, 1973

INELASTIC ELECTRON SCATTERING FROM EVEN TIN ISOTOPES
H.C. Lee
to the C.A.P. Theoretical Physics Division Eastern Regional Annual Meeting, November 2, 1973

AN ANALYTIC THEORY OF DOPPLER-SHIFT ATTENUATION
K.B. Winterbon
to Queen's University, October 5, 1973

EXCITATIONS IN SOLID HELIUM
H.R. Glyde
to University of Alberta, September 25, 1973 and
to McMaster University, October 24, 1973
MATHEMATICS AND COMPUTATION BRANCH
by
D. McPherson

5.1 Staff
5.2 Operating Systems and Programming Languages
5.3 Solution of Poisson's Equation Between a Set of Circles Surrounded by an Outer Circle
5.4 CANDU Fuel Modelling - Program MESSIAH
5.5 Analytical Study of Rewetting in Emergency Cooling
5.6 Minimax Approximations of Mathematical Functions
5.7 Simulation Programs
5.8 Heat Transfer Programs
5.9 Data Reduction Programs
5.10 Information Handling Programs
5.11 MAC/RAN III
5.12 Miscellaneous Programs and Subroutines
5.13 Operations
5.14 Publications, Reports and Lectures
5.1 Staff

Branch Head: D. McPherson

Section I: Systems

Head:
D. McPherson

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

Programmers:
D.B. Goulding
Mrs. E.A. Okazaki

Computer Operator:
Miss M.D. Howard

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 N.L. Armstrong
Mrs. L.L. Blimkie
Mrs. L.P.L. Cybulski
Mrs. B.M. Davidson
Miss K.M. Farnsworth (1)
Mrs. L.M. Gray
Mrs. C.M. Hepburn
Miss M.A. Lamb (2)
Mrs. A.A. Laroche
Miss K.E. Lynn
Mrs. J.A. Mullin

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:
Miss S. Bérubé
Miss C.A. Edwards (3)
E.G. Long
D.G. Stewart
Mrs. L. Yamazaki

Secretarial Staff
Mrs. K.F. Barnard

(1) Joined Branch 3 July 1973 from Finance Division.
(2) Terminated 31 October 1973.
5.2 Operating Systems and Programming Languages

i) CDC 6600 System

(a) SCOPE 3.4 Operating System

L.D. Hansen and C.J. Tanner with W.J. Irving, CDC

Adaptation of CDC's SCOPE 3.4 operating system to the CRNL configuration is proceeding. Most of CRNL's subroutine library has been incorporated into the system. A number of currently used programs are being modified to run with SCOPE 3.4 to evaluate the new operating system, to identify areas of incompatibility with the current operating system and compilers, and to determine what modifications can be made to minimize conversion problems. It is expected that the transition to SCOPE 3.4 will take place in February or March, 1974.

(b) Revised Format for Program Listings

L.D. Hansen, D. McPherson and C.J. Tanner

The formats for the output of the COBOL and FORTRAN compilers, the COMPASS assembler and several utility programs were revised to eliminate unnecessary page skips and to take advantage of the eight lines per inch option of the Computing Centre printers. In addition an option has been added to the COBOL compiler to generate 80-column program listings suitable for handling by keyboard terminals.

(c) FORTRAN Library

(1) Logarithm of the Gamma Function

L. Yamazaki with J.H. Schmidt (Control Data Canada, Ltd., Ottawa)

An extension was made to CGAMMA, a routine for evaluating the gamma function for complex arguments, to permit, optionally, the calculation of \( \ln(\Gamma(z)) \).
(2) **POLSAW**

L. Yamazaki

A system of subroutines for calculating the properties of light water and steam, originally developed by Advance Engineering Branch, is currently being adapted for inclusion in the FORTRAN library.

(3) **Harwell Subroutine Library**

L. Yamazaki and J.M. Blair

A copy of the Harwell subroutine library has been purchased from AERE, Harwell. This library contains a number of FORTRAN subroutines, particularly in the areas of linear algebra and function optimization, which will be incorporated into the CRNL library.

ii) **CDC 3300 System**

(a) **Remote Job Entry Terminals**

D.B. Goulding and J.F. Steljes

Improvements and additions to the system for handling remote job entry terminals (i.e. CDC 200 user Terminals or simulators, and generalized 200 U.T. simulators such as the PDP-10, PDP-8 and CDC 1700) include:

1. Detection of card reader errors at the time they occur so that the terminal operator can be notified to take immediate action.
2. Program to process coded output files for the generalized terminals, and to handle two modes of binary output files for these terminals.
3. Dial-up ports have been added to support intermittent use of a terminal.

Testing of the latter two features is not yet complete.
(b) **Keyboard Terminals**

D.B. Goulding and J.F. Steljes

Six terminals of various types are installed and in regular use for "conversational" job entry, examination of output files or CRT generation of plot files. Additional features to improve the usefulness of the terminals, especially with regard to file editing, are being developed.

(c) **Graphic Terminals**

J.F. Steljes and D. McPherson

Two of the terminals mentioned in (b) above use a storage CRT and can accept graphical output as well as alphanumeric information. To establish the design parameters for a system to provide an interactive graphic capability, a 6600 program has been written to "translate" for the display terminals files produced for Calcomp plotters by the 6600 plotting routines. The DISPLAY program provides for the addition of grid lines to the plot and allows all, or only a portion of, the plot to be displayed, provides manipulation of scale factors and positioning of the display on the screen. The next step, now under development, is to provide for "conversational" entry of the parameters which select the above features, the translation program then being submitted automatically to the 6600. Ultimately the system will be truly interactive, with the translation program being part of the 3300 plotter handling system.

(d) **Disk Access Programs for the CDC 3300**

G.N. Williams

Testing of a 3300 program to provide access to the 841 disks is under way. Direct access to the disks will enable the 3300 to handle input and output files with a minimum of attention from the 6600, and will also provide the 3300 with adequate storage for the keyboard access file handling system.
iii) **PDP-10 System**

J.A. Edgecombe

Modifications of and additions to the PDP-10 system include:

1. Installation of version 506A1 of the DEC monitor.
2. Implementation of the file backup system FRS, modified to conform to our needs.
3. Improvement of a number of DEC utilities to utilize the availability of eight lines per inch on the printers.
4. Modification of the drivers for the local devices to accommodate changes in the FORTRAN compiler and operating system.

In addition work has begun on diagnostic routines for the local devices, and specifications for a communications protocol for the link to the PDP-1 were developed.

5.3 **Solution of Poisson's Equation Between a Set of Circles Surrounded by an Outer Circle**

W.N. Selander, S. Bérubé, and S.R. MacEwen (Material Science Branch)

This problem has been solved successfully in the lowest-order approximation (PR-P-99: 5.3, AECL-4657); agreement with a previous solution is to about five figures. This approximation appears to be adequate for the current application, where the inner circles are of small diameter. In this problem an explicit upper bound for the error can be found from the output, since the error takes its maximum value on the boundary. For larger inner circles, the distribution of error on the circle is found to be strongly dipolar, as expected.
5.4 **CANDU Fuel Modelling - Program MESSIAH**

W.N. Selander and E.G. Long

An oral and written presentation describing program objectives and recent subroutine modifications was prepared and submitted to the second meeting of the Fuel Modelling Advisory Committee. The purpose of this presentation was to allow committee members to assess the advantages and disadvantages of the program and to decide on its future development.

5.5 **Analytical Study of Rewetting in Emergency Cooling**

J.M. Blair

The purpose of this investigation is to be able to predict the rewetting time, and hence the maximum temperature, in a fuel element after a loss-of-coolant accident.

Further study has shown that the formula in PR-P-99: 5.5, AECL-4657, is applicable to the parameter range $\beta/\alpha < 1$ and $\alpha > 1$. In a practical reactor situation this corresponds to the conditions existing when the emergency cooling is by bottom flooding, but not to the case of spray cooling, for which $\beta/\alpha$ can range up to 10. Attempts to extend the formula to the latter range have not been successful so far.

The analysis, which has been carried out for a solid rod, is being repeated for slab geometry, so that the formula will be directly applicable to a thin fuel sheath. The work is continuing.

5.6 **Minimax Approximations of Mathematical Functions**

J.M. Blair and C.A. Edwards

A number of approximations generated previously, (PR-P-95: 5.11(vii), AECL-4314; and PR-P-94: 5.3(ii), AECL-4257) are subject to an unacceptable amount of cancellation of significant digits, and have had to be discarded in favour of less efficient approximations. A method of overcoming the
cancellation problem, by expressing the approximation in "Minimal Newton Form" (MNF) (C. Mesztenyi and C. Witzgall: Stable Evaluation of Polynomials: Jour. Res. Nat. Bur. Stand. B Vol. 71B(1) 1967, 11-17) has been programmed and applied to the approximations to $I_0(x)$ and $I_1(x)$. We have found that for the best approximations of a given degree in the Walsh arrays the conversion to MNF involves a simple origin shift, but for other approximations the MNF is more complicated.

The results will be issued in report form.

5.7 Simulation Programs

i) Extension to FORSIM to Permit the Automated Solution of Systems of Implicitly Coupled Partial Differential Equations

M.B. Carver and S.Y. Ahmad (Advance Engineering Branch)

Extensions have been made to the FORSIM system for solving sets of implicitly coupled partial differential equations with linear or nonlinear boundary conditions (PR-P-99: 5.5(i), AECL-4657). Solution is by the "method of lines", in which the equations are discretized in space and then integrated as coupled ordinary differential equations. Approximations to the spatial derivatives may be quadratic, quartic or sixth order and the spatial grid may be chosen to be non-uniform if required. Seven integration algorithms are provided. The program has proved to be more accurate than the classical method of characteristics solution of coupled hyperbolic equations, and is considerably easier to use.

Default values of all parameters are implicit so that the program can run with minimum instructions from the user, but elaborate controls and input/output options are available if required.
ii) Use of FORSIM to Analyze Two-Phase Flow Loss-of-Coolant Problems in Reactor Circuits

M.B. Carver and S.Y. Ahmad (Advance Engineering)

The loss of coolant accident, in which a rupture in the reactor circuit causes rapid draining of coolant from the reactor core, has long been a problem of great concern to the safety analyst. The resultant transients in the coolant are extremely fast, and the decompression usually generates choked flow. Because the conservation equations of compressible two-phase flow must be solved in a manner compatible with the speed of the transient, the analysis can be extremely time consuming. Several codes have been developed to perform this analysis. Explicit methods, and implicit methods, including the method of characteristics have been tried, but codes to date have been slow, and inconvenient to use. Many of the codes also suffer from their heritage, in that they have undergone a process of evolution over many years with significant increase in scope but very little improvement of method.

A completely new approach to the problem has been taken. Instead of tailoring the mathematics of the code to the particular problem, a proven simulation system is being used, thus giving access to several methods of various degrees of sophistication within the same program. The variable step integration algorithms in FORSIM automatically take care of the sonic flow problem, so no artificial criterion for maximum step size is required. In particular, Gear’s algorithm has been shown to be ideally suited for this type of problem, as its ability to increase step size after the initial transient has decayed permits the solution to be followed for long periods of time.

The code has been run in successful comparison with experimental data, and the results will be reported.
iii) Dynamic Simulation of Bruce Heavy Water Hydraulics  
M.B. Carver and J.G. Melvin (Mechanical Equipment Development Branch)  

The dynamic simulation of the model of Bruce Heavy Water Plant Hydraulics proposed by Melvin (BHWP Model Data Package, Technical Memorandum, April 1973) is complete and has undergone a complete test program. The model consists of three stage one towers connected in parallel to a stage 2 tower. New operating conditions following large perturbations of all independent variables were obtained, and the model was stable in every case.

The model was run on the FORSIM system, and all the integration algorithms available were tried. These include fixed and Runge-Kutta, Euler, and trapezoidal routines and variable-step Runge-Kutta, Adam-Moulten, Gear, and Fowler-Warten routines. For this problem, which required iteration within the time step to maintain constant flow, the simple fixed-step Euler was found to be the most efficient method. With 280 differential equations, this gave a CP time to problem time ratio of about 1:1.

The model was based on perfect flow controllers which maintained flow constant at all times. Differential flow controllers which merely apply corrections when the flow deviates from design conditions, will now be inserted in the model and the behaviour of this softer system will be studied. This will eliminate the need for iteration within the time step and considerably improve execution speed.

iv) Provision of Calcomp Plots for FORSIM  
M.B. Carver and D.G. Stewart  

The printer plot routine in FORSIM has been considerably improved, decreasing storage and increasing efficiency. An additional option has been added to provide printer plots, Calcomp plots or both. Up to five curves per graph are allowed.
iv) **MIMIC**  
M.B. Carver and D.G. Stewart  
A fixed-step Euler integration algorithm has been added to MIMIC as a simple alternative to the Runge-Kutta and Fowler-Warten routines previously available.

At the request of J.T. MacLean of Process Systems Design Branch, a new option has been added to MIMIC to permit cases to be executed in two or more computer runs. The necessary restart data is saved on a file which is catalogued at the end of each run.

v) **Solution of Nonlinear Partial Differential Equations Using FORSIM**  
W.N. Selander and M.B. Carver  
The discontinuity in the spatial derivatives mentioned in PR-P-99: 5.6(ii), AECL-4657, is being further investigated to determine its sensitivity to case parameters. In connection with this, the program for heat transfer in a molten rod was solved using a seven-point difference formula. As expected, this offered improved accuracy over the five-point formula but showed the same discontinuity in spatial derivatives.

vi) **The BHWP Dynamic Simulation**  
P.Y. Wong  
The first phase of developing a cold tower model has now been completed and the second phase of simulating a complete tower has begun. In the cold tower model, solutions of the dynamic equations have shown that the time constant for the gas flow is much smaller than that for the water flow and that the coupling effect between the gas and water is not large enough to be of significance. These results indicate that the counter-current flow problem in the cold tower can be treated as de-coupled during a given perturbation.
Based on the dynamic solutions and the technique of transfer function, an approximated analytical solution for the cold tower dynamics has been determined. In the case of a step perturbation, the solution can be approximated by:

\[ Q_i = Q^* - (Q^*-Q_0)e^{-\alpha t}(1 + \alpha t + \frac{(\alpha t)^2}{2!} + \cdots + \frac{(\alpha t)^{i-1}}{(i-1)!}), \quad i=1, \ldots, n \]

where \( Q_i \) is the water flow out of the \( i^{th} \) tray. The time constant \( \tau(1/\alpha) \) depends on tray geometry and flow conditions, that is, clear liquid or froth-like mixture. In addition to clear liquid, two froth mixtures, represented by the Wolfe's and Treybal's correlations, have been investigated. Both mixtures showed approximately the same hydraulic characteristics, with Wolfe's correlation giving a slightly larger time constant than Treybal's. In the absence of foaming, it is concluded that a water perturbation, within 30% of Bruce design, should not cause any upset of the cold tower operation.

vii) Steady-State Simulation of the Bruce Heavy Water Plant

L.E. Evans

Attempts are being made to improve the efficiency of the programs used by Chemical Engineering Branch for the steady state simulation of D_2O plants. One version of the simulation program for a GS process plant was analyzed in detail. Sections were reorganized and recoded to improve efficiency, particularly in the tower model and physical property subroutine. The time saving thus achieved averaged about 35%. Since even the improved programs use a large portion of the available 6600 time, a study was started with J.M. Blair to consider methods other than direct iteration.

One approach is to represent the plant by a large system of nonlinear equations and to use sparse matrix techniques to solve a linearization of the system. Such a
algorithm has been implemented at Harwell using the Marquardt algorithm and this set of programs is being modified for our library. No practical assessment of this method for GS simulation is yet available.

5.8 Heat Transfer Programs

M.B. Carver

i) TRUMP: General Heat Transfer Program

Modifications were made to TRUMP to permit individual cards within data blocks to be changed between cases, thus avoiding the necessity for re-reading large almost identical data blocks for successive cases.

ii) DECAY

D. Kuhnke (Ontario Hydro, attached to Fuels Engineering Branch) is using the DECAY-TRUMP system, reported in AECL-4018, to predict temperature transients which occur when fuel bundles are removed from storage bays. Several changes have been made to DECAY to provide an interface with an Ontario Hydro code which produces the irradiation history of the bundle.

5.9 Data Reduction Programs

i) Heavy Water Plant Data

C.D. Price

(a) Bruce Heavy Water Plant

Conversion to a sequential file system for Bruce Heavy Water data has been completed. Data for a one-month period is accumulated in a random access file, then transferred to a sequential tape file.

The files are complete up to 30 November 1973. A program used previously to reproduce Operating Data sheet images from the random access file has been converted to list data from the sequential tape.
Currently a manual is being written for the preparation of data and the use of available retrieval programs. The personnel at the Bruce Heavy Water Plant will be able to operate the system from their plant via a proposed terminal connected to the CDC 6600 at CRNL.

(b) Port Hawksbury Heavy Water

A request to have computer accessible data and plotting programs, similar to those for Bruce Heavy Water, was made by Eric Winter, Chemical Engineering Branch, CRNL. Since the Port Hawksbury Plant has a tower arrangement similar to the Bruce Plant, conversion of existing programs for Bruce data was possible. Data for August 1972 currently have been put into the random access form for testing, and key-punching of data up to April 1973 is proceeding.

ii) Spectrum Input Routines

E.G. Long

Routines to read and format data suitable for use with JAGSPOT, PEKIN, etc., have been written for magnetic tapes, produced by the SUCCESS1 system and the ND3300 and ND4420 pulse height analyzers.

iii) Reactor Loop Data

L. Yamazaki

A FORTRAN program was developed for the calculation of burnups and linear powers of the elements involved in the X2 and X5 loops in NRX. The program uses the compressed data from the Vidar recorder as input and stores the current element burnups as well as a brief element history on magnetic tape for each reactor cycle. The program includes a subroutine to plot element burnups and/or linear powers against time in the reactor.
A storage problem developed when an attempt was made to calculate and store intermediate results for the total length of an experiment (approximately 18 months). More efficient methods of data storage are currently being investigated.

iv) JAGSPOT

G.H. Keech

New features have been added to the spectrum fitting program JAGSPOT:

(1) The full-width at half-maximum for each peak.
(2) An "isolation" ratio. This parameter, between 0 and 1, indicates how isolated the peak is from the background and neighbouring peaks. It is defined by

\[ \frac{\sum_{i=1}^{NP} y_i(xp)}{B(xp) + \sum_{i=1}^{NP} y_i(xp)} \]

(3) Printing the normalized peak areas in the summary table.
(4) Giving the user control over the rejection of poor fits from further analysis. For example, one default option rejects peaks where \( \chi^2 \) is greater than 100.

v) TUBE

S. Bérubé

The program reads paper tapes containing fuel sheath thickness and diameter data, and produces printouts and plots of these quantities. The program will be used by C.E.L. Hunt, Fuel Engineering Branch, in developing a mathematical model of fuel sheath collapse and ridge formation.
5.10 Information Handling Programs

i) A general Information Retrieval System

C.J. Tanner

A generalized information retrieval system is being set up. This system will allow the user to define the record structure, create a file, add records to the file, delete records from the file, modify records in the file and list selected records in the file. All input will be in free format.

ii) Personnel File System

C.J. Tanner

Work has continued on the establishing of a personnel data base. Sub-files for location (building, station number and telephone number) and home address have been set up, and programs involved in the leave system are being tested.

iii) Salary Tabulation Program

S. Bérubé

Some minor modifications have been made to the tables and plots for SALTAB, a program which deals with AECL salaries (PR-P-98: 5.10(iii), AECL-4595). In addition a spline fitting routine has been incorporated for smoothing and interpolation.

5.11 MAC/RAN III

D.G. Stewart

An improved version of the FORTRAN program MAC/RAN III for the analysis of time series data was installed in October by University Software Systems. This new version contains added processors and more options than the old MAC/RAN. Modifications were made by U.S.S. to accommodate local plotting programs and dynamic field length allocation.
In the testing of MAC/RAN three errors were found. Two of these problems have been reported to University Software for investigation; a correction for the third has been developed and installed.

Modifications made to MAC/RAN III since installation include:

1. The option of dividing the power spectral densities by the variance of plotting and printing, following a suggestion by T. Heidrick, WNRE*
2. An EXEC RELEASE data card by which a file or files can be released when no longer required by the job.
3. A printout of a summary of the channel statistics for each input channel of the power spectral densities processor was added.

Several other modifications are now being planned.

5.12 Miscellaneous Programs and Subroutines

i) GNLS: A FORTRAN Program for Generalized Nonlinear Least Squares Curve Fitting
   L. Yamazaki and J.M. Blair

"Generalized" least squares curve fitting refers to the case where the independent as well as the dependent variable is subject to error, with an error variance which is known or can be estimated. This program, which was acquired from Texas Instruments Inc. and is alleged to be able to solve the above problem efficiently, is being adapted for the CDC 6600 and tested.

ii) NRU Crystal Spectrometer Control Program
   E.G. Long and G.H. Keech

A translation has been made of the APEX code L3MODES into FORTRAN. This program produces paper tapes for the computer control of the crystal spectrometers at NRU used by the Neutron and Solid State Physics Branch. The translated program is now being tested.

*Whiteshell Nuclear Research Establishment
iii) **LOOPLOAD**  
L. Yamazaki

LOOPLOAD is a FORTRAN-coded program used to produce loading diagrams for NRX reactor startup. The program has recently been modified to output more detailed documentation concerning the loop loading. Work is currently being done on a subprogram to calculate the critical power ratio. This subroutine will be incorporated into LOOPLOAD.

iv) **Thermal Analysis of Hybrid Microcircuits**  
L. Yamazaki

A FORTRAN program, developed by Hughes Aircraft Company, California, to predict the temperature distribution within hybrid microcircuit modules has been modified for the CDC 6600. The program accounts for the effects of arrangement of circuit elements on the substrate as well as for variation of package characteristics and external conditions. The program is currently being applied to local cases from the Electronics Branch to determine critical temperatures and temperature differences on the substrate.

v) **PAL8 Assembler**  
D.B. Goulding

The PAL8 assembler was upgraded to allow the selection of operation code sets at the same time the operation codes necessary to assembler PDP-8/E code were added to the system.

5.13 **Operations**

i) **Equipment Changes**  
G.N. Williams

In October a 32,768 word increment was added to the CDC 6600 central memory to bring it to its full size of 131,074 words.
During November, two drives were added to the 841 disk sub-system; total storage capacity of the 6-disk system is now 215,040,000 6-bit characters.

Two input/output channels were added to the CDC 3300 in November to make up the full complement of eight. One channel will be used to give the 3300 access to the 841 disk sub-system, the other will be used with the Computek graphic terminal.

ii) Computer Use by Division

The following table is an analysis of 53,367 jobs representing 921.1 hours of the 6600 central processor time.

<table>
<thead>
<tr>
<th>Number of Jobs</th>
<th>CP Time, hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computing Centre</td>
<td>8,542 (16.0%) 51.4 (5.6%)</td>
</tr>
<tr>
<td>Commercial Products</td>
<td>10 (0.0%) 0.0 (0.0%)</td>
</tr>
<tr>
<td>Power Projects</td>
<td>5,994 (11.2%) 85.3 (9.3%)</td>
</tr>
<tr>
<td>WNRE</td>
<td>3,226 (6.0%) 61.6 (6.7%)</td>
</tr>
<tr>
<td>Technical Information &amp; University Relations</td>
<td>289 (0.5%) 2.0 (0.2%)</td>
</tr>
<tr>
<td>Biology &amp; Health Physics</td>
<td>871 (1.6%) 17.1 (1.9%)</td>
</tr>
<tr>
<td>Chemistry &amp; Materials</td>
<td>1,601 (3.0%) 75.5 (8.2%)</td>
</tr>
<tr>
<td>Physics</td>
<td>2,966 (5.6%) 57.3 (6.2%)</td>
</tr>
<tr>
<td>Applied Physics</td>
<td>2,541 (4.8%) 29.8 (3.2%)</td>
</tr>
<tr>
<td>Advanced Projects &amp; Reactor Physics</td>
<td>12,111 (22.7%) 313.4 (34.0%)</td>
</tr>
<tr>
<td>Fuels &amp; Materials</td>
<td>7,983 (15.0%) 201.9 (21.9%)</td>
</tr>
<tr>
<td>Administration</td>
<td>170 (0.3%) 0.4 (0.0%)</td>
</tr>
<tr>
<td>Medical</td>
<td>71 (0.1%) 0.0 (0.0%)</td>
</tr>
<tr>
<td>Finance</td>
<td>1,568 (2.9%) 4.8 (0.5%)</td>
</tr>
<tr>
<td>Operations</td>
<td>1,825 (3.4%) 6.0 (0.6%)</td>
</tr>
<tr>
<td>General Services</td>
<td>42 (0.1%) 0.0 (0.0%)</td>
</tr>
<tr>
<td>Plant Design</td>
<td>1,055 (2.0%) 5.4 (0.6%)</td>
</tr>
<tr>
<td>Special Projects</td>
<td>2,424 (4.5%) 8.4 (0.9%)</td>
</tr>
<tr>
<td>Others</td>
<td>78 (0.1%) 0.9 (0.1%)</td>
</tr>
</tbody>
</table>
5.14 Publications, Reports and Lectures

Reports

FORSIM: A FORTRAN-ORIENTED SIMULATION PACKAGE FOR THE SOLUTION OF PARTIAL AND ORDINARY DIFFERENTIAL EQUATION SYSTEMS
M.B. Carver
Atomic Energy of Canada Limited Report, AECL-4608

CPS33: AN ASSEMBLER FOR CDC 3000 COMPASS
P.H. Green and J.H. Johnson
Atomic Energy of Canada Limited Report, AECL-4656

Lectures

FORTRAN IV FOR THE CDC 6600
J.M. Blair
Algonquin College Continuing Adult Education Course
October 1973 to February 1974, CRNL

INTRODUCTION TO THE 6600 AND SCOPE OPERATING SYSTEM
D. McPherson

THE USE OF PROGRAMMING LANGUAGES
M.B. Carver
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