PROGRESS REPORT
PHYSICS DIVISION
January 1 to March 31, 1972

PR-P-93

Chalk River, Ontario
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.
PROGRESS REPORT

1 January/31 March, 1972

PHYSICS DIVISION

Research Director - G.A. Bartholomew
Secretary - Mrs. A.G. Cipriani

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SUMMARY
by
G.A. Bartholomew

1.1 Nuclear Physics Research

Tandem Operation

Prior to the shutdown of the MP Tandem on 16 January, for installation of the high gradient tubes, the availability of the accelerator was

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During the two week period four experiments involving 14 CRNL and 2 university scientists were carried out. The latter collaborated with 3 CRNL scientists in one experiment requiring 40% of the available time.

In preliminary tests prior to installation of the high gradient tubes considerable difficulty has been encountered in running the accelerator column, minus tubes, for prolonged periods at voltages above 13 MV. The voltage breakdowns, which have not been encountered in other HVEC Tandems under similar operating conditions, are localized in one region of the structure but their cause is yet to be clearly established. A remedial program is under way with close collaboration between Operations and Physics Divisions and HVEC advisors.

Findings

Refined measurements of the Doppler effect shown by γ-rays emitted by rapidly recoiling $^{20}$Ne nuclei have verified the predictions of special relativity with good accuracy in a region of velocities significantly different from those of previous tests.

Attempts are being made to detect a strong transient magnetic field (several megagauss, about 1 psec duration) expected when a high velocity ion is stopped in a magnetized ferromagnetic medium. Attempts
to see the effect with $^{120}$Sn ions stopping in iron were not successful; further attempts are planned with $^{130}$Te ions.

Resonance neutron capture $\gamma$-ray studies have shown that $\gamma$-ray intensities in $^{201}$Hg do not conform to expectations from statistical theory. In $^{205}$Tl a 45 eV resonance was shown to be excited by neutrons carrying one unit of orbital angular momentum, not zero as is usually the case for resonances observed at such low energies in heavy elements.

New advances were made in perfecting instruments for nuclear physics.
- the optimum dimensions of a single crystal planar Ge(Li) $\gamma$-ray polarization detector were derived
- the operating characteristics of a multiwire proportional counter for use with the new QB$^3$ spectrometer were tested
- the desirable magnetic field arrangement for a device permitting high resolution experiments with $\gamma$-ray probes is under study. The device (a bremsstrahlung monochromator) is planned for use with the University of Toronto linac.

Precise half-life determinations were made on the following radioactivity standards:
$^{22}$Na, $^{54}$Mn, $^{134}$Cs, $^{139}$Ce and $^{203}$Hg.

1.2 Solid State Studies

Neutron diffraction is being used to study a reorientation of NO$_3$ ions in NaNO$_3$ that occurs near 275°C.

Crystals of "pseudo-DNA", i.e. consisting of ethylguanine and methylcytosine, have been grown and will be used to seed larger crystals for neutron scattering studies relevant to the understanding of DNA.

The effect on magnetic properties of varying the relative concentration of Co and Mn in Co$_{0.9}$Mn$_{0.1}$F$_2$ compounds has been extended to Co$_{0.9}$Mn$_{0.1}$F$_2$. Magnetic excitations are being studied by neutron scattering.

Vibrational excitations were studied in FeS$_2$ and in Co$_{0.92}$Fe$_{0.08}$ and the results compared to theory.
1.3 Solid State Detectors

Efforts are continuing to make reliable robust electrical contacts on high-purity germanium crystals. Some good contacts have been made but the reproducibility of the process must still be improved.

Several high-purity detectors with good operating characteristics have been made. These have been shown to withstand severe adverse handling conditions (temperature cycling, exposure to poor vacuum, and brief forward bias conditions) to a much greater degree than lithium-drifted detectors.

Promising semiconductor detector performance for measuring low-energy \( \gamma \)-rays and \( \alpha \) particles has been achieved with \( \text{HgI}_2 \) crystals. Such detectors are of interest because they may, at least in some applications, serve as well as Si or Ge detectors but with the overall volume of the detector much reduced.

Several large germanium crystals comparable in quality to earlier samples were grown by Ontario Research Foundation. This crystal growing program is now discontinued to make way for a program of growing high-purity germanium crystals.

1.4 Computation

The theoretical study of emergency cooling for reactor fuel elements has continued with the development of an asymptotic solution for the non-linear integral equation encountered in the model for spray cooling.

The buildup of hydrogen in zirconium fuel sheathing has been investigated by a one-dimensional model in which both the diffusion coefficient and the boundary conditions are time-dependent.

A suggested mechanism for the separation of deuterium and hydrogen by differential diffusion through the boundary layer of a fluid in laminar flow over a flat plate has been investigated and found to be unpromising.
Additional experiments have made possible further tests of a model previously described (PR-P-91; AECL-4068) for the oscillations of a fluid in a tube connected to a reservoir at its base.

Computer programs written during the period include:

- a set of programs for the analysis of transmission electron diffraction patterns
- a program for reduction and analysis of data obtained from the underwater profilometer being tested by Fuel Materials Branch.

A program to aid in the search for the best rational approximations to given functions has been developed and used to obtain approximations for the inverse error function and the Bickley functions.

Two methods for handling "stiff" systems of differential equations have been tested extensively, and added to the simulation program FORSIM.

The major changes to computer operating systems have been the implementation of a flexible scheme for the automatic routing of the various types of program output, the development of paper tape input and output facilities for programs run on the CDC 6600 and improvements to plotting routines. Work with the communications controller for the CDC 3300 computer has led to the development of a comprehensive diagnostic system for communications equipment and remote terminals.

During the quarter, the 6600 was used an average of 483 hours per month, and the G-20 an average of 156 hours per month. The total work load of 6600 jobs and G-20 jobs was divided as follows:
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NUCLEAR PHYSICS BRANCH

by

J.C.D. Milton

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2.3 Projectile Reorientation in Light Nuclei
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2.11 Characteristics of a Prototype Charpak Counter
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2.1 **Staff**

Branch Head: J.C.D. Milton

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(1) On leave of absence at the Nuclear Physics Laboratory, University of Oxford, England.

(2) NRC Postdoctoral Fellow.

(3) University of Waterloo student: arrived 4 January.

(4) Attached to Physics Division from Design Engineering.
2.2 Measurement of the Relativistic Doppler Effect Using 8 MeV Capture Gamma Rays

A. Olin, O. Häusser, A.B. McDonald and G.T. Ewan
(Queen's University)

The energies of gamma rays from the 10.26 MeV \( (T = 1, \gamma < 1.8 \text{ kev}) \rightarrow 1.63 \text{ MeV} \ (T = 0) \) transition in \( ^{20}\text{Ne} \) have been measured in an annular Ge(Li) detector at \( 0^\circ \) and \( 180^\circ \) for \(^{16}\text{O} \) capture on \(^{4}\text{He} \) and \(^{4}\text{He} \) capture on \(^{16}\text{O} \) (PR-P-92: 2.2, AECL-4147).

These measurements may be used to test the dependence on recoil velocity of the Doppler shift formula:

\[
E(\theta) = F(\beta) \frac{E_0}{1 - \beta \cos \theta}
\]

where \( E(\theta) \) is the energy of the gamma ray detected at a laboratory angle \( \theta \), \( E_0 \) is the energy of the gamma ray in a coordinate system moving with the recoiling \(^{20}\text{Ne}^* \), and \( \beta = v/c \), where \( v \) is the laboratory velocity of the recoil. Special relativity predicts \( F(\beta) = \sqrt{1 - \beta^2} \).

The value of \( \beta \) can be accurately determined from the data, assuming only that \( F(\beta) \) is not dependent on \( \theta \). Then, from Eq. (1) we derive

\[
\beta |\cos \theta|_{av} = \frac{E(0)-E(180)}{E(0)+E(180)}
\]

where \( |\cos \theta|_{av} \) is averaged over the angle subtended by the photon detector in the laboratory at \( 0^\circ \) and at \( 180^\circ \). From the experimental geometry, we calculate \( |\cos \theta|_{av} = 0.9963 \pm 0.0010 \). The values of \( \beta \) obtained were 0.048731 \( \pm 0.000024 \) for \(^{16}\text{O} \) incident on \(^{4}\text{He} \) and 0.012234 \( \pm 0.000029 \) for \(^{4}\text{He} \) incident on \(^{16}\text{O} \). These agree well with 0.04871 \( \pm 0.00005 \) and 0.012189 \( \pm 0.000013 \) determined from the incident energies.
Eq. (1) may also be used to derive the ratio

\[ R = \frac{F(\beta_0)}{F(\beta_{He})} = \frac{E(0)E(180)}{E(0)+E(180)} \frac{[E(0)+E(180)]_0}{[E(0)+E(180)]_{He}} \]

Special relativity predicts \( R = 0.998885 \pm 0.000001 \) with our values of \( \beta \); direct evaluation of Eq. (3) gives \( R = 0.998905 \pm 0.000052 \). If we parameterize the relativistic effects with \( F(\beta) = \sqrt{1-\alpha \beta^2} \), then \( \alpha = 0.982 \pm 0.030 \).

Eqs. (2) and (3) do not depend on the absolute value of the gamma ray energies, so these ratios can be accurately determined if corrections are made for system nonlinearities and gain variations. The linearity was measured with a Berkeley Nucleonics sliding ramp pulse generator, and the gain variations were monitored by observing the 2.614 MeV gamma rays from a ThB source during the measurements.

Two internal checks are available in the data. Firstly, the observed double to single escape peak separations agree within their statistical accuracies of about 0.6 kev, thus checking the corrections applied for non-linearity and gain variation. Secondly, we find that the ratio of the \(^{20}\)Ne recoil velocities for the two resonant capture reactions equals the ratio of the masses of the incident beams within the statistical accuracy of 0.3\%, as predicted by relativistic particle kinematics.

In conclusion, the present measurements have tested time dilation effects in special relativity with good accuracy at values of \( \beta \) significantly different from any previous measurements (Mandelberg and Witten, J. Opt. Soc. Am. 52 (1961) 529; Greenberg et al., Phys. Rev. Lett. 23 (1969) 1967; Farley, Farley and Picasso, Nature 217 (1968) 17). No deviations were observed from the prediction of special relativity.
2.3 **Projectile Reorientation in Light Nuclei**

O. Häusser and A.J. Ferguson with D.L. Disdier (Laboratoire de Strasbourg-Cronenbourg)

Static quadrupole moments of excited states in light nuclei are most favorably studied by Coulomb excitation of projectiles in the electric field of heavy target nuclei. The feasibility of separating elastically and inelastically scattered ions in an array of seven surface barrier detectors has been studied in more detail (see PR-P-89:2.7, AECL-3912). Complete separation of the peaks was obtained in the scattering of a 90 MeV $^{24}$Mg$^{8+}$ beam (6 nA) from extremely thin (~15 μg/cm$^2$) $^{208}$Pb foils. Analysis of these data gave a B(E2, 0$\rightarrow$2) = 0.044 ± 0.003 e$^2$b$^2$ and a static quadrupole moment $Q_{2+} = 0.16 ± 0.04$ e$^2$b$^2$, a value considerably lower than all previous measurements (for a summary see Vitoux et al., Phys. Rev. C3 (1971) 718) and more compatible with theoretical predictions (H.C. Lee, private communication). The main contribution to the experimental error resulted from poor counting statistics. The new MP Tandem tubes should provide an order of magnitude higher beam currents at the high charge states and this together with the present technique should allow significant improvement in the accuracy of reorientation measurements in light nuclei.

2.4 **Level Structure of $^{55}$Co**

J.S. Forster, with J.R. Leslie, D.J. Martin, W.T. McLatchie and G.F. Millington (Queen's University)

The data from the Lotus goniometer $^{58}$Ni(p,αγ)$^{55}$Co experiment (PR-P-92:2.6, AECL-4147) have been analyzed. Twenty-two excited states of $^{55}$Co have been investigated, four of which have not previously been reported. Decay schemes, branching ratios and multipole mixing ratios have been determined. Spin assignments were made using this (p,α) data, $^{54}$Fe(p,γ)$^{55}$Co data (D.J. Martin, J.R. Leslie
Table 2.4.1

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* Analogue of g.s. of $^{55}\text{Fe}$
† New Level
1 Present $^{58}\text{Ni}(p,\alpha\gamma)^{55}\text{Co}$ results
W. McLatchie, C.F. Monahan and L.E. Carlson, to be published in Nuclear Physics) obtained at Queen's University, and published $l$-values from the ($^3\text{He},d$) reaction (B. Rosner and C.H. Holbrow, Phys. Rev. 154 (1967) 1080). Table 2.4.1 lists spin assignments in $^{55}\text{Co}$. A Doppler-shift attenuation measurement ($^3\text{He},d\gamma$) experiment is being considered to obtain lifetimes of some of these states.

2.5 Search for the Transient Field Effect in $^{120}\text{Sn}$ by DSAM


In a previously reported Doppler-broadened gamma-ray lineshape calculation (PR-P-92.2.8, AECL-4147) it was inherently assumed that no perturbation exists which affects the nucleus. However, when the stopper is a magnetized ferromagnetic medium, the Larmor precession of the magnetic moment about the ambient magnetic field occurs, and in addition the recoil nucleus experiences an aligned, transient magnetic field of several megagauss lasting about 1 picosecond (Herskind et al., Hyperfine Structure and Nuclear Radiations, ed. by E. Matthias and D.A. Shirley, 1968, North Holland, Amsterdam, p. 735). Calculation of the effect of this transient field on the lineshape showed that in favourable cases the time dependence should be observable.

We have attempted to observe the effect in the 1171 keV, $2^+ \rightarrow 0^+$ gamma-ray of $^{120}\text{Sn}$ recoiling in Fe. This nucleus was chosen because a) the static hyperfine field of $^{120}\text{Sn}$ in Fe of 0.33 MG is small compared to the expected transient field, b) the $2^+$ state mean life of 0.9 ps assures ample counts of Doppler-shifted gamma-rays in the time region of interest, and c) our experience with $^{120}\text{Sn}$ targets indicated that they would stand the high beam current necessary to obtain reasonable counting statistics in a practical time period. The $g$ factor of $^{120}\text{Sn}$ is not known, but the hydrodynamic value of \( g = \frac{Z}{A} \approx 0.42 \) suggests
A beam of 100 MeV $^{35}$Cl was used to Coulomb excite $^{120}$Sn, a thin layer (800 $\mu$g/cm$^2$) of which was evaporated onto a 0.005" iron foil. The target was mounted in a 2300 Oersted magnetic field perpendicular to the beam-counter plane. Two coaxial Ge(Li) counters at $\pm 30^\circ$, at which angle the perturbation effect is a maximum, detected gamma rays from recoils into the iron backing as selected by requiring a coincidence with projectiles backscattered into an annular detector. The magnetic field was reversed every hour. There was no discernible difference between the gamma-ray lineshapes observed for the two magnetic field directions.

Analysis of the integrated peak area in the manner conventional to $g$ factor measurements by the perturbed angular correlation technique gives a precession value of $\omega \tau = 0.0025 \pm 0.010$ radians. Extrapolating from known integrated transient field values in the A $\sim$ 100 region, we find $(H\tau)_{\text{transient}} \sim 10$ Megagauss-picosecond for Sn. From this estimate and the $\omega \tau$ value, we conclude that $g_{2+}^{(120}\text{Sn}) = 0.05 \pm 0.20$, which is significantly smaller than the hydrodynamic value of 0.42.

The lineshape fit to the $2^+ \rightarrow 0^+$ gamma-ray peak in the spectrum obtained by summing the spectra of both field directions, yields a mean life of $\tau_{2^+} = 0.89 \pm 0.02$ ps, in excellent agreement with the value derived from $^{120}$Sn recoiling in Sn of $\tau_{2^+} = 0.90 \pm 0.02$ ps reported previously (PR-P-92:2.8, AECL-4147). In both cases the quoted error is the standard deviation of the fitted $\tau$, multiplied by the square root of the minimum chi-square.

We are continuing this transient field study with the search for a more suitable probe. One possibility is $^{130}$Te, for which $g_{2+} = 0.25$ and $\tau_{2+} = 2.9$ ps.
2.6 Accurate Lifetimes for the $4^+$ and $6^+$ Rotational States in $^{156}$Gd

D. Ward, R.L. Graham and J.S. Geiger with N. Rud and A. Christy (Queen's University)

The lifetimes of the $4^+$ and $6^+$ levels of the ground state rotational band in $^{156}$Gd have been remeasured with improved precision. The states were populated by multiple coulomb excitation using an 80 Mev $^{35}$Cl beam, and the lifetimes measured by the Doppler-shift recoil distance method, in which gamma rays were detected in coincidence with backscattered ions (PR-P-90:2.13, AECL-3996). To interpret the decay curves it was necessary to measure the attenuation of the gamma-ray angular distribution for the $4 \rightarrow 2$ transition in $^{156}$Gd implanted in copper. This was done in a separate experiment with the results $G_2 = 0.89 \pm 0.05$ and $G_4 = 0.88 \pm 0.10$. The vacuum deorientation correction was taken from the work mentioned in PR-P-92:2.10, AECL-4147. The results for the lifetimes were $\tau(4^+) = 166.0 \pm 3.0$ ps, $\tau(6^+) = 22.8 \pm 0.6$ ps. These results are consistent with the predictions of the rigid rotor model as shown in Table 2.6.1.

Table 2.6.1

| Transition | $\alpha_{\text{total}}^{a)}$ | $B(E2)$ | (expt-rot)$^{b)}$%
|------------|------------------|---------|------------------|
| 2 $\rightarrow$ 0 | 3.952 | $0.919\pm0.027^{b)}$ | (0.919) | $0.0\pm2.9$
| 4 $\rightarrow$ 2 | 0.229 | $1.276\pm0.023$ | 1.311 | $-2.7\pm1.8$
| 6 $\rightarrow$ 4 | 0.064 | $1.475\pm0.036$ | 1.446 | $+2.0\pm2.4$

2.7 Search for the Decay of $^{64}\text{Ge}$

J.C. Hardy, J.S. Geiger and R.L. Graham with C.N. Davids (University of Texas at Austin) and K.P. Jackson (University of Toronto).

An unsuccessful attempt to produce $^{64}\text{Ge}$ and measure its mass in a heavy-ion transfer reaction has been reported previously (PR-P-91:2.12, AECL-4147). Since that time, some low-lying levels of $^{64}\text{Ga}$ have been established (C.N. Davids et al., Bull. Am. Phys. Soc. II, 17 (1972) 71) through analysis of the $^{64}\text{Zn}(p,\gamma)^{64}\text{Ga}$ reaction. The $\beta^+$ decay of $^{32}\text{Ge}$, which should have a half-life of $< 2$ min, could populate directly or indirectly any of the known states in $^{64}\text{Ga}$, and an attempt was made to observe characteristic gamma rays with the appropriate half-life.

The following reactions were employed:

<table>
<thead>
<tr>
<th>Target</th>
<th>Projectile</th>
<th>Reaction Sought</th>
<th>Bombarding Energy in MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>50$^{\text{Cr}}$</td>
<td>16$^{\text{O}}$</td>
<td>(16$^{\text{O}}$,2$n$)</td>
<td>42,46</td>
</tr>
<tr>
<td>54$^{\text{Fe}}$</td>
<td>12$^{\text{C}}$</td>
<td>(12$^{\text{C}}$,2$n$)</td>
<td>28,32,36,38,46</td>
</tr>
<tr>
<td>54$^{\text{Fe}}$</td>
<td>16$^{\text{O}}$</td>
<td>(16$^{\text{O}}$,2$n$)</td>
<td>55,64</td>
</tr>
<tr>
<td>58$^{\text{Ni}}$</td>
<td>12$^{\text{C}}$</td>
<td>(12$^{\text{C}}$,2$n$)</td>
<td>42,50</td>
</tr>
</tbody>
</table>

No gamma rays attributable to the decay of $^{64}\text{Ge}$ were observed with $1$ sec $< t_{1/2} < 10$ min although nuclei produced from the evaporation of ($pn$), (2$pn$), ($\alpha p$) and ($\alpha pn$) were observed (PR-P-91:2.17, AECL-4068). Furthermore, the known decay of $^{60}\text{Zn}$ was weakly observed following the reactions $^{50}\text{Cr}(12$\text{C},2$n$)$^{60}\text{Zn}$ and $^{46}\text{Ti}(16$\text{O},2$n$)$^{60}\text{Zn}$. Why this decay should be observed while no evidence of $^{64}\text{Ge}$ could be detected from analogous reactions is not understood.

2.8 Calculation of the Polarization Sensitivity of a Planar Ge(Li) Gamma-Ray Detector

A.J. Ferguson and S.T. Lam (University of Virginia)

The CDC-6600 program reported in the previous report (PR-P-92:2.15, AECL-4147) for calculating the
polarization sensitivity of planar Ge(Li) diodes has been used to make comparisons with experimental data and to explore the sensitivity dependence on detector dimensions in order to optimize the latter. Comparison of the absolute efficiency and of the full energy peak/total response ratio are in excellent agreement with measurements made by J.C. Hardy (private communication). Comparisons made with asymmetry measurements made at McMaster University (J.A. Kuehner, private communication) on a group of E2 transitions have also shown excellent agreement. No systematic tendency for the calculated results to lie above the experimental ones was found in contrast to the comparison with the data of Litherland et al. (Can. J. Phys. 48 (1970) 2320).

In exploring the dependence of sensitivity on dimensions, it was found that a maximum is achieved for a depletion depth of 0.15 cm and a length (from front to back) of 2.5 cm, essentially independent of incident gamma-ray energy. The reduction of sensitivity for depletion depths below 0.15 cm is unexpected and the reason for it is being investigated. Sensitivity monotonically increases with width, but relatively slowly beyond a width of 6 cm. For this study, a "standard" counter of 6 cm width x 0.4 cm depletion depth x 2.5 cm length at 15 cm from the target was adopted and the dependence of sensitivity on width, depletion and length was studied for energies ranging from 1 to 5 MeV. The standard counter is an optimum in all but the depletion dimension, where the sensitivity is 86% of the maximum. This may be regarded as a compromise between optimum polarization sensitivity and efficiency. As reported previously, no advantage was found in restricting the illumination to the central part of the counter by means of a collimator.
2.9 Ion Transport with Gas Flow and Electrostatic Focussing
J.C. Hardy, H.R. Andrews and B.K. Hilko with H. Schmeing
(University of Ottawa)

Atoms recoiling from a bombarded target can be thermalized in atmospheric-pressure He gas while remaining in an ionized state. If a constant but small flow of the gas is maintained through an aperture into a low-pressure chamber, it should be possible to focus the ions in the region of the aperture so that they pass through it. Thus, most ions could be transported rapidly to a low-pressure chamber such as the ion-source of a mass separator. Electrostatic focussing conditions are being examined using an electrolytic bath, and a computer program has been written to calculate the path of an ion in combined electrostatic and gas flow fields.

2.10 Beta-Delayed Particle Emission
J.C. Hardy

A survey of β-delayed alpha, proton and neutron precursors has been made, together with a review of that work in the field which relates to nuclear spectroscopy. Those nuclei predicted to be precursors have also been indicated and an explanation offered for the observation in light nuclei of either alpha or proton emission but rarely both. This work will be included as a chapter in the second edition of Nuclear Spectroscopy (edited by J. Cerny, to be published by Academic Press, New York).

2.11 Characteristics of a Prototype Charpak Counter
G.C. Ball, W.G. Davies and J.J. Hill

Measurements of the operating characteristics of a 32 wire prototype of the multiwire proportional counter (MWPC) for the QD^3 spectrometer were made using 12 MeV protons from the Chalk River MP Tandem accelerator. Protons
scattered from a 0.5 mg/cm$^2$ gold foil were detected at 90° by a collimated telescope consisting of the MWPC and a 1 mm thick Si detector outside the vacuum system. Coincidence pulse height distributions, counting efficiencies and time spectra of 3 adjacent wires were measured at normal incidence as a function of cathode voltage, gas mixture, proton energy and position in the unit cell.

A charge sensitive preamplifier and standard cross-over timing circuitry was used and the results were fed to the PDP-1 computer through the FPP interface. All anode wires other than the one being studied were grounded.

The prototype MWPC was as described in PR-P-86:2.2, AECL-3668 but had a 1 mm wire spacing and 1.5 mm anode to cathode distance. The energy resolution, time jitter and mean charge collection times were similar for the 3 adjacent wires studied, nearly independent of counter voltage, and position in the unit cell. The pulse height distributions had the expected Vavilov shapes with widths nearly equal to those predicted theoretically (see S.M. Seltzer and M.J. Berger, Publication 1133, National Academy of Sciences, N.R.C. Washington, D.C. 1964).

With an Ar + 10% CH$_4$ mixture, typical time jitter was 13 ns and the energy resolution $\Delta E/E = 0.65$ FWHM. The gain was an exponential function of the bias voltage ($G = \exp(V/110)$) over the measured region, 1180 to 1330 volts.

Improved operation was observed with a gas mixture of Ar + 34% isobutane. The time jitter was reduced to $\sim 8$ ns and the energy resolution to 0.50. In this case the gain varied as $\exp(V/130)$ from 1380 to 1680 volts.

By gating on protons with energies between 6 and 8 MeV it was found that the signal was proportional to the energy deposited in the counter and that the time jitter decreased to approximately 5 ns.

In all cases for both gas mixtures counting efficiencies $\sim 100\%$ were obtained over the unit cell.
The present results are very encouraging. Development work is continuing on a 160 wire model with 0.5 mm wire spacing.

2.12 Electrical Insulating Properties of SF₆ Insulating Gas Used in the Chalk River MP Tandem
H.R. Andrews

The new tubes of the MP Tandem are guaranteed to operate at 13 MV and warranted to 15 MV. In tests of the column structure prior to tube installation reliable operation in the 12–15 MV range has not been achieved. For this reason comparisons have been made between the electrical insulating properties of gas samples from the accelerator tank and samples of new SF₆ recently received from the manufacturer. The accelerator insulating gas is known to be contaminated with about 15% air and possibly with electrical breakdown products (cf. P.G. Ashbaugh et al., IEEE Transactions on Nuclear Science, NS-12, no.3 (1965) 266). The insulating properties were determined as a function of gas pressure by measuring the breakdown voltage between two 3/4 inch steel balls separated by 0.006 inches. The reproducibility of individual measurements was typically about 1%. Results for selected pressures are shown in Table 2.12.1. The breakdown voltage has been converted to the corresponding field gradient calculated from the separation of the steel balls. Table 2.12.1 shows that at 100 psia the accelerator gas breaks down at a gradient of about 550 kv/cm. This can be compared with approximate gradients calculated for 15 MV operation of the accelerator - 140 kv/cm between the column gaps and a peak field of ~100 kv/cm between the terminal and tank wall. These results show little difference between fresh SF₆ and accelerator tank gas within the limitations of narrow gap measurements, the absence of sources of significant ionization and the absence of particulate impurities.
such as belt dust. Thus with these qualifications, the present measurements do not support the hypothesis of poor gas quality as a cause of the difficulties in operating the accelerator above 10 megavolts. Further measurements are planned to study the variation of breakdown voltage with gas purity, moisture content and possibly with ionizing radiation.

Table 2.12.1
Comparison of Insulating Properties of Tandem Accelerator Tank Gas and Fresh SF$_6$

<table>
<thead>
<tr>
<th>Pressure (psia)</th>
<th>Fresh SF$_6$</th>
<th>Tandem Tank Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>240</td>
<td>175</td>
</tr>
<tr>
<td>50</td>
<td>350</td>
<td>300</td>
</tr>
<tr>
<td>75</td>
<td>460</td>
<td>425</td>
</tr>
<tr>
<td>100</td>
<td>590</td>
<td>550</td>
</tr>
<tr>
<td>125</td>
<td>740</td>
<td>675</td>
</tr>
<tr>
<td>150</td>
<td>905</td>
<td>800</td>
</tr>
</tbody>
</table>

*Relative accuracy (reproducibility) = 1%; absolute calibration = 15%.

2.1.2 MP Tandem Operation
J.C.D. Milton

The MP Tandem was shut down on January 16 to prepare for the installation of the new high gradient tubes. Up to that time the operating record was:

- Beam available: 253 hrs, 65.9%
- Scheduled shutdown: 88, 22.9
- Unscheduled shutdown: 43, 11.2

384, 100.0

During this period 4 experiments involving 14 CRNL and two university scientists were carried out. The latter collaborated with three CRNL scientists in one experiment requiring 40% of the available time.
On January 17 work began on removing the old tubes and resistors and installing the new resistors. This work was completed on schedule and voltage holding tests of the column structure began January 26. Initially it proved difficult to condition above ~11 MV and this was attributed to a fibre optics light pipe recently installed from the terminal to the low energy end. Although no damage to the fibre optics could be detected, the light source at ground potential had been blown on two separate occasions so the light pipe was removed. Since that time a large number of tests have been run and several changes made in the accelerator (the old resistors were replaced on February 22, the paint removed from the tank floor and the underlying iron polished on March 16). To date it has been possible to operate the terminal above 14 MeV for ~15 minutes and above 13 MV for ~1 day, however these conditions are reached only a few days after cleaning the inside of the tank and then rapidly deteriorate. Other MP's using SF₆ are known to show significantly better performance than this but HVEC has been unable to suggest reasons for the difference. The majority of electrical breakdowns take the form of sparks to the floor of the tank concentrated at the point where the diameter of the tank begins to increase on the high energy (or belt) side of the terminal. This suggests a connection with belt dust. One other factor, SF₆ purity, is discussed in Sec. 2.12. We have not yet successfully purified the gas to test this factor in the accelerator environment.

2.14  

Half-lives of $^{22}_{\text{Na}}$, $^{54}_{\text{Mn}}$, $^{134}_{\text{Cs}}$, $^{139}_{\text{Ce}}$ and $^{203}_{\text{Hg}}$

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

The decays of several radioactivity standards produced in this laboratory have been followed and half-life values computed from the data are summarized in Table
2.14.1. Except for $^{134}$Cs$^m$, which was counted in a $4\pi \beta$ proportional counter, all activity measurements were made in the $4\pi \gamma$ ion chamber relative to a radium reference source. The indicated errors except for $^{134}$Cs$^m$ are 3 times the statistical errors obtained from the least squares fits. For the $^{22}$Na, $^{54}$Mn and $^{139}$Ce samples no evidence of impurities has yet been found by gamma-ray spectrometry or a search for trends in the fits to the data, and the measurements of these 3 will be continued. After the decay of the $^{203}$Hg had been followed for about 5 half-lives small impurities of $^{60}$Co and $^{110}$Ag$^m$ were detectable by Ge(Li) spectrometry. Corrections were estimated from the gamma-ray spectrum and applied to the individual data points; initially this was negligible (0.004%) and for the last data point it was 3.6%, when the ratio, signal/background, was 3.5. Because the error in applying the correction was smaller than the statistical error assigned to the individual data points, the error in the final half-life value from these impurities is negligible ($< 0.01$ days). For $^{134}$Cs$^m$, however, larger corrections for impurities of $^{24}$Na and $^{134}$Cs were necessary ($\approx 0.5\%$ of the initial counting rate) and were determined by following the decay of the sample for a time equal to about 18 $^{134}$Cs$^m$ half-lives, although data for only the first 8 were used to compute the half-life values. For 2 sources made from neutron irradiated CsCl and CsCO$_3$ samples, the values differed by 0.003 hours which is sufficiently larger than the statistical error of an individual run ($\leq 0.001$ hours) to suggest that the difference may come from an error in correcting for impurities or some other systematic effect. This difference has been used as the error of the mean value given in Table 2.14.1.

These results are in good agreement with accepted values.
Table 2.14.1

<table>
<thead>
<tr>
<th>Radio-nuclide</th>
<th>No. of half-lives followed</th>
<th>Half-life</th>
<th>This work</th>
<th>Accepted value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{22}_{Na}$</td>
<td>0.9</td>
<td>951.7 ± 2.7 days</td>
<td>949.7 ± 3.7 days (1)</td>
<td></td>
</tr>
<tr>
<td>$^{54}_{Mn}$</td>
<td>3.1</td>
<td>312.2 ± 0.2 days</td>
<td>312.5 ± 0.5 days (1)</td>
<td></td>
</tr>
<tr>
<td>$^{134}_{Cs}^m$</td>
<td>8.5</td>
<td>2.91 ± 0.003 hours</td>
<td>2.91 hours (4)</td>
<td></td>
</tr>
<tr>
<td>$^{139}_{Ce}$</td>
<td>1.4</td>
<td>137.5 ± 0.3 days</td>
<td>137.5 ± 0.3 days (5)</td>
<td></td>
</tr>
<tr>
<td>$^{203}_{Hg}(3)$</td>
<td>9.0</td>
<td>46.60 ± 0.02 days</td>
<td>46.59 ± 0.05 days (1)</td>
<td></td>
</tr>
</tbody>
</table>

(2) PR-P-89:3.4.3, AECL-3912, and
(3) PR-P-90:3.4.2, AECL-3996 give results for the earlier parts of these data.
(4) 2.91 ± 0.01 hours by A.P. Baerg, R.M. Bartholomew and R.H. Betts (Can. J. Chem. 38 (1960) 2147) and 2.895 ± 0.005 and 2.913 ± 0.005 hours by B. Keisch (J. Inorg. Nucl. Chem. 17 (1961) 180).

2.15

$^{203}_{Hg}$ Intercomparison

J.G.V. Taylor

A final analysis still awaits data from two of the seven participating laboratories (see PR-P-90:3.4.1, AECL-3996 and PR-P-92:2.19, AECL-4147).

2.16

Sample Activation in the NRU-NRX Rabbit Facilities

J.S. Merritt and F.H. Gibson

Because of an incident in which an excessive sample activity was inadvertently produced in an NRU-rabbit irradiation, an internal report was prepared tabulating the activities and gamma-radiation fields to be expected following rabbit irradiations of 1-mg samples of most elements.
2.17  

**60**Co Comparison  
J.S. Merritt and J.G.V. Taylor

At the request of the Taiwan Reactor project, two **60**Co gamma-ray point source standards from the National Bureau of Standards, Washington, were assayed by relative Ge(Li) spectrometry against similar CRNL standards. The CRNL assay was 1.0% higher than the NBS certified value, the agreement being well within the overall errors of 1.3% (NBS) and 0.5% (CRNL). The standard error of the comparison measurements was about 0.1%.

2.18  

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

- **60**Co - Taiwan Research Reactor
- **60**Co - Solid State Science
- **137**Cs - Taiwan Research Reactor
- **137**Cs - Medical Research
- **137**Cs - Solid State Science

2.19  

**Miscellaneous Services**  
J.S. Merritt

Sources (or solutions) prepared:
- Nuclear Physics: **125**I, **241**Am
- Neutron and Solid State Physics: **57**Co, **241**Am
- Health Physics: **63**Ni (samples of solution).

2.20  

**Publications, Reports and Lectures**

(a) **Publications**

A MEASUREMENT OF THE RADIATIVE WIDTH OF THE 8_{11}^+ 11.948 MeV LEVEL OF **20**Ne  
T.K. Alexander, O. Häusser, A.B. McDonald and A.J. Ferguson  

HIGH SPIN STATES IN **20**Ne FROM **16**O(α,α) SCATTERING  
LEVELS EXCITED IN THE $^{70}{\text{Ge}}(p,d)^{69}{\text{Ge}}$ AND $^{70}{\text{Ge}}(p,t)^{68}{\text{Ge}}$ REACTIONS
T.H. Hsu, R. Fournier, B. Hird, J. Kroon, G.C. Ball and F. Ingebretsen

THE $K^\pi = 1/2^+$ ROTATIONAL BAND IN $^{43}{\text{Sc}}$
G.C. Ball, J.S. Forster, D. Ward and C.F. Monahan

LIFETIMES IN $^{43}{\text{Sc}}$
G.C. Ball, J.S. Forster, F. Ingebretsen and C.F. Monahan

LIFETIMES OF LEVELS IN $^{38}{\text{Ar}}$
G.C. Ball, W.G. Davies, J.S. Forster, A.N. James, D. Ward

THE AUTOMATIC MEASUREMENT OF YIELD FUNCTIONS WITH AN ELECTROSTATIC ACCELERATOR
S.T. Lam and A.J. Ferguson
Nucl. Instr. and Meth. 99 (1972) 151.

FIRST FORBIDDEN NON UNIQUE BETA TRANSITIONS AND MIRROR COMPARISONS IN LIGHT NUCLEI
I.S. Towner and J.C. Hardy

MEASUREMENT OF ELECTROMAGNETIC TRANSITION PROBABILITIES WITH THE COULOMB EXCITATION METHOD
D. Ward
Proceedings of the International Conference at Mont Tremblant on Dynamic Structure of Nuclear States (1972). University of Toronto Press.

GAMMA SPECTROSCOPY WITH HEAVY IONS
O. Häusser
Proceedings of the International Conference at Mont Tremblant on Dynamic Structure of Nuclear States (1972). University of Toronto Press.

COULOMB REORIENTATION OF $2^+$ STATES IN $^{32}{\text{S}}$ AND $^{112}{\text{Cd}}$
O. Häusser, T.K. Alexander, A.B. McDonald and W.T. Diamond

A HIGH-RESOLUTION DETECTION SYSTEM FOR SHORT-LIVED GASEOUS ACTIVITIES
J.E. Esterl, R.G. Sextro, J.C. Hardy, G.J. Ehrhardt and J. Cerny
Nucl. Instr. and Meth. 97 (1971) 229.
Lectures

ACCELERATOR-BASED NUCLEAR PHYSICS EXPERIMENTS: PRESENT AND FUTURE
J.C. Hardy
at McMaster University on 26 January 1972.

METHODS OF ESTIMATING ERRORS AND CONFIDENCE LIMITS IN A NON-LINEAR LEAST SQUARES ANALYSIS OF EXPERIMENTAL DATA
W.G. Davies
at the University of Oslo, Norway on 11 February 1972.

PHYSICS OF THREE BODY FINAL STATES FROM $^3$He+d AT 27 MeV
W.G. Davies
at the University of Oslo, Norway on 14 February 1972.

COULOMB BREAKUP OF $^6$Li
G.C. Ball
Invited seminar at State University of New York on 15 February 1972.

ISOSPIN FORBIDDEN PARTICLE DECAYS OF T = 3/2 LEVELS IN LIGHT NUCLEI
A.B. McDonald
at McGill University on 29 February 1972.

TWO-NUCLEON TRANSFER REACTIONS IN LIGHT NUCLEI
J.C. Hardy
Invited talk at symposium on Two Nucleon Transfer and Pairing Excitations at Argonne National Laboratory on 20-21 March 1972.

THREE BODY FINAL STATES FROM THE $^3$He+d REACTION AT 27 MeV
W.G. Davies
at Laval University on 27 March 1972.
NEUTRON AND SOLID STATE PHYSICS BRANCH

by

A.D.B. Woods

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3.2 Normal Modes of Iron Pyrites
3.3 Phonons in fcc Co$_{0.92}$Fe$_{0.08}$
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3.5 Single Crystal Growth of a DNA Complex
3.6 Soft Spin-Wave Mode in Holmium
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3.9 Resonance Neutron Capture $\gamma$-Ray Studies
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3.19 Equipment and Systems
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3.21 Publications, Reports and Lectures
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BRANCH HEAD: A.D.B. Woods

SECTION I  SOLID STATE PHYSICS  TECHNICAL STAFF

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T.M. Holden (2)  M.M. Potter
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B.M. Powell (5)
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J.G. Wesanko  H.C. Spenceley

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W. McAlpin  Mrs. Dianne Mitchell
R. Milks (8)
K. Tait (8)

(1) On leave of absence for one year; left August 31, 1971.
(2) Attached to University of Guelph for eight months; left September 30, 1971.
(3) NRC Postdoctoral Fellow.
(4) NRC Postdoctoral Fellow from Istituto di Chimica delle Macromolecole del C.N.R., Milan, Italy.
(5) On leave of absence for one year at Research Establishment Risø, Roskilde, Denmark; departed February 29, 1972.
(6) On attachment from McGill University; arrived February 21, 1972.
(7) On attachment from University of Toronto.
(8) Seconded from Design Engineering.
3.2 Normal Modes of Iron Pyrites
G. Dolling

The triple axis crystal spectrometer at the C4 facility, NRU, has been employed to measure normal modes of vibration in iron pyrites, FeS$_2$, at room temperature. Cu(220) and Cu(002) planes were employed as monochromator and analyser respectively, and the spectrometer was operated throughout in the constant-$Q$ mode, with a fixed incident neutron energy of 61 meV. Most of the measurements were made at the high symmetry points $R(0.5,0.5,0.5)$ and $M(0.5,0.5,0)$, and along the $\Lambda$ or [111] direction. The acoustic modes are roughly consistent with the known elastic constants. At the $R$ point, only one mode was observed, with a frequency (units THz) of $6.99 \pm 0.04$. It is possible that this is really an unresolved doublet. At $M$, peaks were observed at $5.52 \pm 0.09$, $5.82 \pm 0.06$, $5.99 \pm 0.06$, $6.20 \pm 0.07$ and $6.90 \pm 0.05$. Theoretically one expects 9 distinct modes at both $R$ and $M$, within a frequency range 4-16 THz.

3.3 Phonons in fcc Co$_{0.92}$Fe$_{0.08}$
E.C. Svensson, B.M. Powell and A.D.B. Woods

The study (PR-P-90:4.5, AECL-3996) of the lattice dynamics of fcc Co$_{0.92}$Fe$_{0.08}$ has been continued using the triple-axis crystal spectrometer at the C5 experimental hole of the NRU reactor. The absorption and incoherent-scattering cross sections, which are respectively about 25 and 4 times the coherent-scattering cross section, make the measurements very difficult, and so far they have only been extended to the zone boundary for the $\langle \zeta \zeta \zeta \rangle_T$ and $\langle 00\zeta \rangle_T$ branches. For the other branches we have not yet been able to obtain reliable results at frequencies $\geq 6$ THz because the scattering in this region is dominated by the peaks in the density of
states seen via the large incoherent-scattering cross section.

Near the zone centre, the results for all branches lie very close to those for nickel (Birgeneau et al., Phys. Rev. 136 (1964) A1359). At higher wave vectors the frequencies fall below those for nickel and the difference appears to increase rapidly as the zone boundary is approached. The \([\zeta\zeta\zeta]T\) and \([00\zeta]T\) zone-boundary frequencies are respectively 3.87 ± 0.05 THz and 5.83 ± 0.10 THz as compared with 4.24 ± 0.06 THz and 6.27 ± 0.10 THz for nickel.

3.4 Neutron Diffraction from \textit{NaNO}_3 Powder

B.M. Powell and P. Martel

Previous attempts to determine the reoriented configuration of oxygen atoms in \textit{NaNO}_3 by X-ray diffraction have proven unsuccessful because of insufficient instrumental sensitivity for X-rays scattered above 200°C (Cherin et al., Acta. Cryst. 23 (1967) 455). Using a well-filtered beam (12" of SiO₂) and 2.07 Å neutrons from a (110) Be monochromator at the outer L3 spectrometer we have carried out neutron scattering measurements which show that certain pure oxygen reflections (e.g. (012), (012), (124)) virtually disappear at 275°C, while other composite reflections ((222), (323), (011)) decrease slightly or not at all.

Typical relative intensities of the (012) peak at 27, 58, 112, 257, 264, 268, 272 and 277°C are 2500, 2520, 1920, 1120, 620, 580, 330 and 30. Energy analysis with a (220) germanium analyzer indicated that there was very little change in width of the quasielastic peak near 275°C.

Preliminary structure factor calculations support either of two possibilities:

1. At 275°C the two \textit{NO}_3 radicals have rotated to positions ±30° about the triad axis.
2. At 275°C the \textit{NO}_3 radicals are freely rotating.
3.5 Single Crystal Growth of a DNA Complex

P. Martel

Naturally occurring nucleic acids are very complicated long chain molecules containing sugar and phosphate groups. Two chains are often bound together by hydrogen bonds between four relatively small protruding bases called guanine, cytosine, adenine and thymine. Large single crystals do not exist.

The long nucleic acid strands can be broken down and the bases recovered and recrystallized into ethylated and methylated single crystals having the same hydrogen bonding between bases as exists in the natural state of DNA. The bonds are now precisely directed and located in a 3-dimensional lattice and there is also a large increase in the fraction of hydrogen in the bonds relative to all the hydrogen in the structure.

Normally the incoherent scattering of neutrons by hydrogen masks most of the interesting effects in such experiments. However if there is proton tunneling in certain specific directions there can be directional neutron scattering (D.K. Steinman and G.C. Summerfield, J. Phys. Chem. Solids 30 (1969) 449). According to Löwdin (Rev. Mod. Phys. 35 (1963) 724) there is proton tunneling between bases along the bonds in DNA and this tunneling may even account for mutations, cancer and aging.

With a view to obtaining specimens for neutron scattering studies we have tried to grow what we call a pseudo-DNA crystal made up of ethylguanine and methylcytosine (E.J. O'Brien, J. Mol. Biol. 7 (1963) 107). With materials obtained from Cyclo Chemical Co. of Los Angeles, we have succeeded in growing three crystals having ten times the dimensions of those of O'Brien but with a maximum dimension still no greater than 3 mm. The crystals were
grown from dimethyl sulphoxide solvent in a test tube surrounded by sand, the whole being contained in a 1-liter dewar which itself was placed in an oven. The oven was lowered in temperature in six equal stages from 90°C to ambient over a period of about a week. The crystals appeared single upon observation of specular reflections from different facets observed with an optical microscope. Their consistency and appearance is not unlike crystallites of ordinary salt. They will be used as seeds in a more elaborate apparatus designed to produce larger crystals.

3.6 Soft Spin-Wave Mode in Holmium
A.D.B. Woods and B.M. Powell

Studies of the $\vec{q} = \vec{k}_0$ spin wave mode as a function of temperature have been continued (PR-P-92:3.9, AECL-4147) at the inner L3 spectrometer. Measurements were made at momentum transfers corresponding to $\vec{q} = (0,0,2)2\pi/c$ at temperatures of 4.2K, 10K, 15K, 20K, 30K, 40K, and 78K. The transition temperature for this specimen is 22.5K. At 4.2K the peak is well defined and corresponds to a frequency of 0.28 THz. As the temperature is increased the frequency decreases in a manner consistent with soft mode behaviour and also exhibits an apparent increase in width. At the same time the tail of the elastic scattering shows a marked increase in width and intensity. At 20K and above no distinct spin wave peak is observable and, if it exists, it is lost in the tail of the quasi-elastic distribution. It is possible that at the higher temperatures the mode is overdamped. Analysis of these results is continuing.

3.7 Magnetic Excitations in $\text{Co}_{0.9}\text{Mn}_{0.1}^F_2$
E.C. Svensson and S.M. Kim

Magnetic excitations in antiferromagnetic $\text{Co}_{0.9}\text{Mn}_{0.1}^F_2$ have been studied with the triple-axis crystal spectrometer at
the C5 experimental hole of the NRU reactor. Measurements were carried out at 4.2K for excitations propagating along the a and c directions in the Brillouin zones containing the (001), (100) and (101) reciprocal-lattice points. Two branches of well-defined magnetic excitations were observed having minimum frequencies (in THz) of $0.67 \pm 0.04$ and $1.46 \pm 0.05$ and maximum frequencies of $1.1 \pm 0.1$ and $2.15 \pm 0.08$. The lower branch is believed to be associated mainly with manganese ions, and the observed frequency variation indicates propagating character in contrast to the manganese local mode predicted (PR-P-85:4.12, AECL-3667) by low-concentration Green-function theory. The total frequency variation for the lower branch and the perturbation of the upper branch of "cobalt-like" excitations are, as expected, much smaller than for $\text{Co}_{0.7}\text{Mn}_{0.3}\text{F}_2$ (PR-P-86:4.6, AECL-3668). At $q = 0$, the intensity for the lower mode is greater than for the upper, but it then decreases very rapidly with increasing $\vec{q}$ and the lower mode is barely visible at the zone boundary. In contrast, the scattering by the upper-branch excitations is strong throughout the region studied. The measurements are continuing.

3.8 Positron Annihilation Measurements
S.M. Kim and P. Martel

The angular correlation of positrons annihilating in molybdenum has been measured along the [110] axis using the standard long slit geometry. The slits subtended at the sample an angle of 0.4 milliradians. The angular distribution of annihilation photons resembled a gaussian distribution with a full width at half maximum of 0.55 reciprocal lattice units. This result was compared with the theoretical calculation based on the pseudopotential interpolation scheme, which includes the relative s- and d-enhancement empirically. Good agreement between the measurement and calculation was
obtained by enhancing the s-part by a factor of 4 more than the d-part. A similar enhancement was required in comparing the crossed slit results with the theoretical calculations (PR-P-91:4.9, AECL-4068).

3.9 Resonance Neutron Capture \(\gamma\)-Ray Studies
M.A. Lone, E.D. Earle and W.M. Inglis

The intensities of the individual \(\gamma\)-ray transitions from a neutron resonance exhibit Porter-Thomas fluctuations. However because many transitions are involved, the total radiation width is expected to be the same for all resonances of any given isotope. Among the heavier elements a significant departure is found in the \(^{201}\text{Hg}\) isotope where the total radiation width of the 70.9 ev resonance is 460 \(\pm\) 30 meV whereas the weighted average of the radiation width of 7 known resonances below 700 ev is 325 \(\pm\) 20 meV (BNL 325, supplement 2, 1966). The measurements of the \(\gamma\)-ray spectra following resonance neutron capture in the 43 ev, 70.9 ev and 210 ev resonances in \(^{201}\text{Hg}\) (PR-P-89:4.11, AECL-3912) show that the enhancement in the radiation width of the 70.9 ev resonance is due mostly to a single transition of 7316.3 keV to the \(2^+\) first excited state in \(^{202}\text{Hg}\). The intensity of this transition is \(I_\gamma=24\%\) (\(\Gamma^{\gamma}f=110\) meV). The average \(\gamma\)-ray intensity per neutron capture of the 136 \(\gamma\)-rays between 4150 keV and 7755 keV observed in the \(J=1\) resonances at 70.9 ev and 210 ev is \(\bar{x} = \frac{\langle I_\gamma/E_\gamma^3 \rangle}{E_\gamma^3} = 6.3 \times 10^{-5} \text{ (MeV)}^{-3}\). The value of \(x\) for the 7316.3 keV transition from the 70.9 ev resonance is \(6.1 \times 10^{-4} \text{ (MeV)}^{-3}\). The probability of this enhancement occurring as a Porter-Thomas fluctuation is \(<1.6 \times 10^{-3}\). Because of the small reduced neutron width of the 70.9 ev resonance, the enhancement of this transition cannot be explained on the valence capture model as has been possible in the medium weight nuclei near \(^{92}\text{Mo}\) and \(^{98}\text{Mo}\)
3.10 The 45 eV p-wave Resonance in $^{205}_{\text{Tl}}(n,\gamma)^{206}_{\text{Tl}}$

E.D. Earle, M.A. Lone and G.C. Dixon

The gamma ray intensity distribution following neutron capture in the 45 eV $^{205}_{\text{Tl}}$ resonance is significantly different from the distribution from known s-wave resonances (PR-P-91:4.13, AECL-4068) in that the 5.5 MeV anomaly is absent. The symmetric shape of the neutron transmission dip for this resonance and an intense $\gamma$-ray transition to a $J^\pi=3^-$ level at 804 keV in $^{206}_{\text{Tl}}$ suggest that the resonance may be due to p-wave neutron capture.

The angular distributions of several high energy $\gamma$-rays following neutron capture in this resonance have been studied and indicate that this level is formed by the capture of p-wave neutrons and has $J^\pi=2^-$. Two independent measurements were made. The ratio of gamma ray intensity, $I$, at 150° to the intensity at 90° was measured with a 39 cm$^3$ Ge(Li) detector and $I(135°)/I(90°)$ was measured with a 55 cm$^3$ detector. In each measurement the intensity ratios for seven $\gamma$-rays from the two s-wave resonances at 2.8 and 3.0 keV in $^{205}_{\text{Tl}}(n,\gamma)^{206}_{\text{Tl}}$ were compared and found to be constant. Since these $\gamma$-rays have isotropic distributions the mean intensity ratio was used as a normalizing factor for the ratios of the four observed $\gamma$-rays from the 45 eV resonance. It was found that the transitions from the 45 eV resonance to the 804 keV $3^-$, 307 keV $1^-$ and 266 keV $2^-$ states are anisotropic while the transition to the 637 keV $2^-$ state is isotropic. The angular distributions are consistent with the predicted values for a $2^-$ resonance if one assumes appropriate values for the E2/M1 mixture for each transition but the angular distribution for the transition to the 804 keV $3^-$ state is not consistent with capture in a $1^-$ resonance. Since these are the only
reasonable alternatives for the resonance spin it is concluded that the resonance is $2^-$.

3.11 Photoneutron Measurements near the Photofission Threshold of $^{238}\text{U}$

J.W. Knowles

Measurements of the total photoneutron cross section $\sigma(\gamma,\text{n})$ of $^{238}\text{U}$ (PR-P-92:3.15, AECL-4147) have been continued. The measurements show a pronounced narrow peak at 6.2 MeV similar to that observed previously by Khan and Knowles (Nuclear Physics A179 (1972) 333, AECL-4050) in $\sigma(\gamma,f)$ measurements. Photoneutron cross sections $\sigma(\gamma,n)$ for $^{238}\text{U}$ obtained from the $\sigma(\gamma,N)$ measurements after subtraction of the $\sigma(\gamma,f)$ contribution, assuming the average number of neutrons emitted per photofission to be 2.5, show little or no evidence, within a 30 per cent limit of error, of a corresponding narrow peak at 6.2 MeV in contrast with previous indications (PR-P-92:3.15, AECL-4147). The measured values of $\sigma(\gamma,n)$ for $^{238}\text{U}$ between 6.05 MeV (the neutron separation energy) and 7.5 MeV are 2 to 3 times smaller than those obtained by Khan and Knowles using compound nucleus statistical theory to extrapolate from neutron transmission measurements for the neighbouring $^{239}\text{U}$ nucleus.

3.12 An Improved Bremsstrahlung Monochromator for use with the University of Toronto Linac

J.W. Knowles and J.C. Kim

Previous studies of the bremsstrahlung monochromator (CRNL-511 (1971) unpublished internal report) have shown that a factor of five improvement in resolution over earlier designs (J.S. O'Connell, Rev. Sci. Instr. 32 (1961) 1314) is possible if the effect of fringing fields of the 180° magnetic spectrometer, required to measure the momentum of the scattered electrons, is negligible. Further studies show that a considerable reduction of the
effect of fringing fields on the resolution can be made by adding a single quadrupole lens to the electron beam transport system. This lens, positioned between the bremsstrahlung radiator foil and the magnetic spectrometer, confines the scattered electrons at the entrance of the spectrometer, to a few degrees in the vertical plane, thereby keeping them clear of the intense fringing fields close to the pole pieces. With this arrangement we anticipate a resolution of about 20 keV for the tagged photons of the bremsstrahlung monochromator.

3.13 Reactor Beam Hole Use
A.D.B. Woods

Reactor beam hole experiments were somewhat hampered by the large amount of NRU shutdown time during the quarter. Advantage was taken of the shutdowns to effect changes to the PDP-8 L3 spectrometer control program. These improvements have removed many irritating inconveniences in the original version of the program and, through better utilization of the disc, allow the possibility of the use of other programs. Shutdown time was also utilized to clear up gradually worsening noise problems at the C5 spectrometer and to carry out repairs to the C2 chopper.

During the period 9 experiments were carried out by 9 scientists at 5 beam hole locations. In addition 2 McMaster University students carried out experiments at their own spectrometer at hole E2 and J.M. Robson and D.J. Winfield from McGill University carried out experiments with very long wavelength neutrons (~ 500 Å) at hole T3. These beam hole experiments utilized more than 90% of the available reactor operating time.

3.14 Contacts on High-purity Germanium
T.A. McMath

Work has continued on the problem of making electrically satisfactory and mechanically robust contacts to
high-purity germanium. A reliable and reproducible process for making \( p^+ \) contacts has so far not been developed.

Mechanically strong and stable \( n^+ \)-contacts can be made by diffusing lithium (from a painted on lithium in oil suspension) at temperatures as low as 280°C for \( \sim \) 5 minutes. These are 0.2 to 0.5 mm thick but, until the need arises for both thin \( p^+ \) and \( n^+ \) contacts, the Li-contact will be used.

Good, high-voltage, \( p^+ \)-contacts have been made by evaporating films of gold, chromium, and palladium-gold alloy. If such a detector, after initial satisfactory operation in a test cryostat, remains good after the first remounting it is likely to remain a good diode. However, the yield of good diodes from any batch of apparently identically processed samples is still small, and surface treatment of poor diodes has not been generally successful in improving the performance. So far, we have not been able to identify with certainty any factor or response during processing which correlates with the performance of the finished detector. Studies, for example, of the effects of different surface treatments prior to evaporation are very time consuming and not always conclusive because other variables, hard to control, are involved.

On the other hand, the successful detectors have shown very good spectrometer performance and they have remained stable; our best detector has survived about five temperature cycles from room temperature to \( \sim \) 80K and back, two cryostat vacuum failures and an accidental brief forward bias with no deterioration in spectrometer performance. This detector was stored at room temperature, in vacuum, in a cryostat for weeks at a time between tests.

Operating bias is usually limited to about twice the depletion voltage, insufficient for optimum resolution. This is likely to be associated with processing and we may see a general overall improvement shortly when our rebuilt 'clean'
vacuum evaporator system is put into service.

We have just put into service a new test cryostat much better suited to the evaluation of small high-purity Ge detectors.

3.15 Lithium Precipitation in Germanium
H.L. Malm and H.R. McCrady

After a slice of germanium has been saturated with lithium at an elevated temperature, the lithium precipitates at room temperature and becomes electrically inactive. Consequently, the Li precipitation process can be monitored by the slice resistivity. It has been found, in agreement with some previous investigators, that reducing the degree of Li supersaturation (by reducing the saturation temperature from 400°C to 300°C) reduces the rate of Li precipitation by a factor of about 250. This result has been applied to extend the time that a Ge(Li) diode may be drifted before a reheat or rediffusion process is necessary to correct the deterioration of diode properties resulting from Li precipitation. Other precipitation tests involving Ge with and without dislocations indicate that there is an incubation time before precipitation begins in material with dislocations. Measurements are continuing on a number of different crystal samples saturated with Li at different temperatures.

3.16 Mercuric Iodide
H.L. Malm and H.R. McCrady

This rather unlikely material has been operated as a semiconductor conduction spectrometer for low energy γ-rays and α particles. HgI₂ with atomic numbers of 80 for mercury and 53 for iodine and a density of 6.4 g/cm³ has the highest linear attenuation coefficient for γ-rays of any crystal now used for γ-spectroscopy. The band-gap of 2.1 ev and consequent high resistivity (> 10¹³ Ω cm) allows operation as
an efficient γ-ray spectrometer at room temperature.

Crystals of good optical quality up to 4 mm x 4 mm x 4 mm have been grown from which smaller portions were cleaved for testing. Contacts were made by painting on a suspension of carbon in alcohol. Spectrometer performance was achieved using crystals ~ 4 mm² area and up to 1 mm thick. Using an $^{241}$Am source resolutions of 10 keV (FWHM) for the 18 keV X-rays and 20 keV for the 59.5 keV γ-ray were observed. Irradiation with the $^{241}$Am α particles showed that the mobility-lifetime products, $\mu_T$, were $10^{-5}$ to $10^{-4}$ cm²/V for electrons and $10^{-6}$ to $10^{-5}$ cm²/V for holes. At room temperature the electron mobility was found to be 70 cm²/V sec while the more severe trapping for holes prevented a reliable measurement of their mobility. Work is continuing on further improving this material for spectrometer use and also towards the practical applications of these spectrometers.

3.17 Germanium Quality
I.L. Fowler and R.A. Birdseye

Tests have been carried out on detectors made from Ontario Research Foundation crystals 88, 89, and 91 (mentioned in PR-P-92, AECL-4147). Small detectors showed good drift characteristics and fair to good spectrometer performance. Characteristics so far measured of coaxial detectors from these crystals have not been as good as those made from earlier crystals.

Crystals 94, 95, 97, 99 and 101 (2.1 to 3 kg each and all grown under similar conditions) have been received, but so far no spectrometer tests have been made. (Tests of these crystals have been given lower priority than the work on high-purity germanium.)

As of now, growth of large crystals for Ge(Li) spectrometers has ceased. The crystal furnace and charge
handling procedures are being modified and it is planned to grow a series of small undoped crystals during the next period; the object is to determine the feasibility of growing high-purity Ge either in the existing furnace or in one of modified design.

No further high-purity germanium samples have yet been obtained pending information on material quality from the manufacturer.

3.18 Testing, Supply, Mounting and Servicing of Ge Detectors
I.L. Fowler and R.J. Toone

One large planar detector was mounted in a horizontal cryostat for preliminary analysis measurements in NRU Reactor building by Chemical Engineering Branch. Help with installation was given.

Two detectors, one coaxial and one planar were put back into operation by re-processing and clean-up following cryostat warm-ups.

3.19 Equipment and Systems
T.A. McMath and R.J. Toone

The new test cryostat for high-purity Ge detectors (mentioned in 3.14 above) was assembled, leak-tested and fitted with a good low-noise preamplifier. This assembly is arranged to fit into a framework carrying a collimated beam source so that γ-ray scanning can be carried out in a readily repeatable geometry.

Our vacuum evaporator for clean materials (i.e. not Li) has been completely redesigned and rebuilt as a much more convenient and 'cleaner' system for evaporating metal layers onto high-purity Ge detectors. Re-assembly is almost complete and vacuum tests are being carried out.
3.20 Miscellaneous Services
R.C. Bailey and H.R. McCrady

Much of the glassblowing service during this period was what we regard as 'normal'. A good deal of work was done on apparatus for heavy-water process research for the Chemistry Branches and a large deuterium reactor apparatus was constructed for Materials Science Branch. A 7 ft. fractionating column tapering from ~ 6" to 1½" in diameter was made for Fuel Materials Branch; this required jig design, as did the sealing of 4" dia. fitted discs into 5" dia. tubing for another apparatus. Repairs were made to gas analysis apparatus at NPD on several occasions during this period.

Several pieces of glass apparatus were inside silvered, copper-glass vacuum seals were supplied to Materials Science Branch and four gas counters were supplied – 3 halogen type and one BF₃ proportional type.

3.21 Publications, Reports and Lectures

Publications

LATTICE DYNAMICS OF TRANSITION METALS
A.D.B. Woods
Atomic Energy of Canada Limited publication AECL-4121

A SEARCH FOR DEEP TRAP LEVELS IN Ge(Li) DETECTORS
T.A. McMath and Eiji Sakai
IEEE Trans. NS-19 (1972) 289
Atomic Energy of Canada Limited publication AECL-4201

LARGE HOLLOW-CORE COAXIAL Ge(Li) DETECTORS
I.L. Fowler and R.J. Toone
Nucl. Instr. and Methods 98 (1972) 193
Atomic Energy of Canada Limited publication AECL-4202

THE 5.5 MeV ANOMALOUS RADIATION IN $^{205}_{\text{Tl}}(n,\gamma)^{206}_{\text{Tl}}$
E.D. Earle, M.A. Lone, G.A. Bartholomew, B.J. Allen, G.G. Slaughter, and J.A. Harvey
Atomic Energy of Canada Limited publication AECL-4082
PHOTOFISSION OF $^{232}$Th, $^{238}$U AND $^{235}$U NEAR THRESHOLD USING A VARIABLE ENERGY BEAM OF $\gamma$-RAYS
A.M. Khan and J.W. Knowles
Nucl. Phys. A179 (1972) 333
Atomic Energy of Canada Limited publication AECL-4050

Lectures

THE 5.5 MeV $\gamma$-RAY ANOMALY IN THE MASS REGION 190<A<208
E.D. Earle
At Rensselaer Polytechnic Institute, Troy, New York, January 17, 1972

NEUTRON SCATTERING AND THE LATTICE DYNAMICS OF MOLECULES
B.M. Powell
At the Université de Montréal, Montreal, P.Q., February 1, 1972

SPIN WAVES IN RARE EARTH METALS
A.D.B. Woods
At Institut für Festkörperforschung, Kernforschungsanlage, Jülich, Germany, March 3, 1972

The following papers were presented at the 9th Annual Solid State Physics conference, Manchester, England, January 4-6, 1972:

MAGNETIC EXCITATIONS IN THE INDUCED MOMENT ANTIFERROMAGNET TbSb

MAGNETIC EXCITATIONS IN RANDOMLY DISORDERED ANTIFERROMAGNETS
D. Pepper, R.J. Elliott and W.J.L. Buyers

A MERCURIC IODIDE GAMMA-RAY SPECTROMETER
H.L. Malm
At the 13th Scintillation & Semiconductor Counter Symposium, Washington, D.C., March 1-3, 1972

The following papers were presented at the IAEA Symposium on Neutron Inelastic Scattering, Grenoble, France, March 6-10, 1972:

DISPERSION RELATIONS FOR MAGNETIC EXCITONS IN TERBIUM ANTIMONIDE
TEMPERATURE DEPENDENCE OF THE NORMAL MODES OF NIOBIUM
B.M. Powell, A.D.B. Woods and P. Martel

NORMAL MODES OF SOLID CARBON DIOXIDE
B.M. Powell, G. Dolling, L. Piseri and P. Martel

LOW-MOMENTUM-TRANSFER NEUTRON SCATTERING IN LIQUID HELIUM

MAGNETIC IMPURITIES ASSOCIATED WITH IMPURITIES IN INSULATORS

SOFT MODES AND LANDAU TRANSITIONS IN Pb\textsubscript{1-x}Sn\textsubscript{x}Te ALLOYS
G. Dolling and W.J.L. Buyers
At the APS Conference on the Physics of IV-VI Compounds and Alloys, Philadelphia, Pa., March 24-25, 1972

LATTICE DYNAMICS OF CARBON DIOXIDE
G. Dolling, B.M. Powell, L. Piseri and P. Martel
At the APS Meeting in Atlantic City, N.J., March 27-30, 1972
THEORETICAL PHYSICS BRANCH

G.E. Lee-Whiting

4.1 Staff
4.2 Electron Spectrometer for Bremsstrahlung Monochromator
4.3 Dispersion of Radioactivity in Open-Ended Flow Systems
4.4 Neutron Scattering at Large Momentum Transfer
4.5 Penetration of Heavy Ions in Solids
4.6 Doppler-Shift Attenuation Calculations
4.7 Effect of Core Polarisation on the Spherical Shell-Model Potential
4.8 Coulomb Mixing in Superallowed Fermi Beta Decays
4.9 Electromagnetic Effects on Nuclear Beta-Decay in the Hartree-Fock Approximation
4.10 Heavy-Water Studies Group

Publications, Reports & Lectures
4.1 Staff

Branch Head: G.E. Lee-Whiting

H.R. Glyde (1)
M. Harvey
F.C. Khanna
S.A. Kushneriuk
H.C. Lee
V.F. Sears
I.S. Towner
K.B. Winterbon

Secretarial Staff

Mrs. M.E. Carey

(1) On one year's leave of absence with the International Development Research Centre - September 16, 1971.
4.2 Electron Spectrometer for Bremsstrahlung Monochromator

G.E. Lee-Whiting

The calculations described in PR-P-92;4.2 (AECL-4147) have been continued. The effect of placing a magnetic screen (a vertical ferromagnetic slab with small holes for the beam) just in front of the poles has been studied. In the preliminary calculations the holes for the beam have been ignored. The screen is assumed to be at the same potential as the plane of symmetry lying between the poles. It was found that a desirable field distribution could be produced, but only at the cost of a prohibitively large leakage flux.

4.3 Dispersion of Radioactivity in Open-Ended Flow Systems

S.A. Kushneriuk

As described previously (PR-P-73,5.6 - AECL-2687; PR-P-88,5.5 - AECL-3865), model calculations have been made of the dispersion of radioactive matter in open-ended and closed fluid flow systems. In these calculations it had been assumed that the flow-speed of the fluid transporting the radioactive material in the system was constant and that in the dispersion the nucleate sorption-desorption process on the system walls took place at constant rates. The dispersion is now being examined specifically to see how the temporal behaviour of the concentration of radioactive matter deposited on the system walls is affected by changes in the flow-speed of the fluid and/or changes in the nucleate sorption-desorption rates. The system being studied is an open-ended pipe. Fluid flow is single-pass and changes are of a step-function type.

4.4 Neutron Scattering at Large Momentum Transfer

V.F. Sears

In the limit of large momentum transfer \( k \) the
scattering of thermal neutrons by a macroscopic system can be described in terms of the impulse approximation, in which the scattered atom recoils as if it were free, and the energy distribution of the scattered neutrons is the Doppler profile characteristic of the velocity distribution of the atoms in the initial state. The effect of final-state interactions, which are ignored in the impulse approximation, is to produce at finite $\kappa$ a narrowing of the energy distribution of the scattered neutrons. In a recent article (Sears, Phys. Rev. A5(1972)452) we have discussed such narrowing effects for incoherent neutron scattering by simple classical fluids by deriving an asymptotically exact expansion of the scattering function and its FWHM in inverse powers of $\kappa$. The results were compared with molecular dynamics data for liquid argon.

Egelstaff et al. have recently observed the narrowing in liquid rubidium at 200°C which, however, they analysed in terms of an incorrect expression for the narrowing. We have analysed their data using the exact expansion (Sears, ibid) and find a value $<F^2> = 5.6 \times 10^{-10}$ dyne$^2$ for the mean square force on an atom in liquid Rb. This corresponds to an effective Debye temperature of 44°K which is only slightly less than the value 52°K for the solid at T=0 and adds support to the view that the liquid alkali metals (unlike the rare-gas liquids) are rather solid-like.

Narrowing effects were also reported by Lefevre et al. at the IAEA meeting in Grenoble (March 6-10) in the scattering of hydrogen gas at 85°C and were analysed in terms of an approximate kinetic theory of the scattering. We have re-analysed this data in terms of the statistical mechanic expression for the narrowing in a hard-sphere gas (Sears, ibid) in a way which demonstrates the narrowing more clearly and shows that the narrowing is a universal function of the single variable $\kappa l$ where $l$ is the mean free path.
The theory of the narrowing effects has been generalized (within the Gaussian approximation) to include quantum effects. Quantum effects are especially important in liquid neon where it is found that one must take into account both the first and second quantum corrections. With the inclusion of the second quantum correction a substantial improvement in the agreement of the theory with the recent data of Buyers et al. is obtained.

4.5 Penetration of Heavy Ions in Solids

K.B. Winterbon

Calculation of the net recoil density (PR-P-92,4.5 - AECL-4147) from its moments is proving difficult. Several weight functions for orthogonal polynomial expansions have been tried, with no great success. The method of "function fitting" described by Fano, Spencer, & Berger (Hand. d. Phys. 38 II 660) has also been tried, but it too is not completely satisfactory.

Part of the problem is that the net recoil density has a singularity at zero depth. A method has been devised for determining the nature and size of this singularity; it involves considering the recursion relation for the moments as a functional equation. The net recoil density turns out to have an $X^{-\frac{1}{2}}$ singularity at zero depth ($X=0$).

Previous calculations (PR-P-82,5.7 - AECL-3417) of the large-depth asymptotic behaviour of power cross-section range and damage profiles have been sharpened and made more rigorous. The results have been used to estimate the asymptotic behaviour for cases for which the power cross section approximation is not valid. A description of this work has been submitted to Radiation Effects.
4.6 Doppler-Shift Attenuation Calculations

K.B. Winterbon

The integral equation for the doppler-shifted $\gamma$ spectrum from a decelerating ion described in PR-P-92,4.5 - AECL-4147, has been used to calculate the mean shift $F(\tau)$ in the power cross-section approximation for a range of mass ratios. A brief description of this work has been submitted to Physical Review Letters.

4.7 Effect of Core Polarisation on the Spherical Shell-Model Potential

M. Harvey

The self-consistent deformed harmonic oscillator has been examined in detail. The single-particle potential can be considered to arise from the Hartree self-consistent procedure on a quadrupole-quadrupole (Q.Q) potential. Using the Bloch-Horowitz method we have shown that the corresponding, effective potential in the restricted space of a single spherical oscillator shell is again a Q.Q potential but with roughly twice the strength. The doubling of strength is consistent with the (effective) charge on a nucleon increasing by about $\frac{1}{2}$ on restricting the particle to orbitals of a spherical potential. This simple analysis provides a plausible explanation of why the energy scale for spectra from "restricted" Hartree-Fock (H.F.) calculations needs to be increased to get agreement with the spectra from unrestricted Hartree-Fock calculations.

The eigensolutions of the Q.Q potential in the spherical shell model can be found using $SU_3$-group techniques. The spectra are in better quantitative agreement with those from H.F. calculations (and experiment) at the beginning of the sd-shell than at the end. The nuclei at the end of the shell exhibit vibrational features which are entirely missed.
by the simple model, and largely missed by H.F. The analysis has suggested a better method for including core polarisation effects into the spherical shell model potential; it is anticipated therefore that vibrational effects are best discussed within the framework of the spherical shell model.

4.8 Coulomb Mixing in Superallowed Fermi Beta Decays

I.S. Towner

The Fermi matrix element between $0^+$ states of a T=1 isotriplet has the value: $<M_F>^2 = 2(1-\delta)$, where $\delta$ is a small positive quantity characterising the effect of Coulomb mixing in the beta decay. Calculations of $\delta$ have been made using the following models: (a) Assume the Coulomb force configuration mixes the wavefunction of the $0^+$ state of the isotriplet with the next $0^+$ state in the spectrum of this nucleus. There is more mixing in the proton-rich nucleus than in the other two. Calculations using first-order perturbation theory typically predict $\delta$ of order $10^{-3}$ to $10^{-4}$. (b) Extend the above idea, and allow configuration mixing with a large number of other $0^+$ states. Matrix diagonalisations are carried out using the Oak Ridge shell model program, and the resulting values of $\delta$ are still of order $10^{-3}$ to $10^{-4}$. (c) Use a single particle model to calculate the matrix element $<M_F>$ recognizing that the radial shape of a proton wave function differs slightly from that of a neutron. Calculating these wavefunctions using a Saxon-Woods potential and including a one-body Coulomb potential for the proton, results in a value for $\delta$ typically of order $3 \times 10^{-3}$.

In a few cases it is possible to compare two mirror decays within a given isotriplet. Defining an asymmetry $\Delta$ from

$$\frac{(ft)_+}{(ft)_-} = \frac{1-\delta}{1-\delta} \equiv 1 + \Delta$$
with \( \Delta \theta (\delta_+ - \delta_-) \), we find that \( \delta_+ \) and \( \delta_- \) calculated in the above models are both positive and close in magnitude; thus the asymmetry is much smaller and of undetermined sign.

4.9 Electromagnetic Effects on Nuclear Beta-Decay in the Hartree-Fock Approximation

H.C. Lee

If good isospin is assumed for nuclear states, the nuclear matrix elements for the superallowed Fermi positron or electron decay are given by

\[
M_{\pm} = \langle T, T_Z^\pm 1 | T, T_Z^\pm | T, T_Z^\pm \rangle = \sqrt{(T^+ T_Z^\pm)} (T^+ T_Z^\pm + 1).
\]

For isospin triplets, or \( T=1 \) states, \( M_{\pm} = \sqrt{2} \). The actual value for \( M_{\pm} \) may be different from \( \sqrt{2} \) because electromagnetic interactions will break the isospin symmetry in nuclear structure. For isospin triplet the deviation of \( M_{\pm} \) from the standard value is expressed in terms of the quantity

\[
\delta_{\pm} = \frac{1}{2} (2 - |M_{\pm}|^2),
\]

which is defined exactly as in Sec. 4.8.

Both theoretical deduction and experimental evidence suggest that \( \delta_\pm \) is small in most cases. A precise knowledge of the value of \( \delta_\pm \) is desirable, however, since it may serve as a test of our understanding of the weak interaction and as a means to determine the weak coupling constant more precisely.

Calculations of \( \delta_\pm \) for some light nuclei are currently being made in the Hartree-Fock approximation (HFA). Three sources of isospin symmetry breaking mechanism are included in the calculations: (i) The Coulomb interaction; (ii) the electromagnetic spin-orbit interaction; and (iii) the proton-neutron mass difference. The Coulomb interaction is by far the most important mechanism. Because this interaction has a very long range, it is expected that the HFA
will account for the bulk of the electromagnetic effect on isospin symmetry breaking. The departure of \(|M^+|^2\) from 2 results from differences in the single-particle wave-functions in the two nuclear states connected by the beta decay. In the complementary work of Sec. 4.8 the single-particle wave-functions are identical in the two nuclei, but mixtures of excited states are included; such mixtures are essentially excluded in the HFA.

Preliminary results in the HFA show that both \(\delta_+\) and \(\delta_-\) are of the order of \(1.5 \times 10^{-2}\) for superallowed Fermi decays between \(T=1\) states. This causes a 0.75\% correction to the weak coupling constant which is quite significant.

Electromagnetic effects on the Gamow-Teller decays are also being studied. Here one is interested in asymmetry in mirror decays instead of in absolute decay rates.

4.10 Heavy-Water Studies Group

G.E. Lee-Whiting

The Group's (see PR-P-92,4.10 - AECL-4147 for composition, etc.) current activities have been stimulated by a paper by Mayer, Kwok, Gross & Spencer (Appl. Phys. Lett. 17(1970)516) on "Isotope Separation with the CW Hydrogen Fluoride Laser". These authors irradiated a mixture of comparable amounts of CD\(_3\)OD, CH\(_3\)OH and Br\(_2\) vapours with laser infrared radiation of a frequency corresponding to a vibrational mode of the CH\(_3\)OH molecule; during an irradiation of about 1 min. the CH\(_3\)OH was observed to disappear, presumably as a result of the reaction of excited CH\(_3\)OH molecules with bromine. The group has been considering whether this idea could be adapted to the economic production of heavy water. It is examining three questions: i) Whether cheaper photons from a hot source with filters might be used; ii) Could methanol be conveniently enriched in deuterium by exchange with HDO, so that water might be used as a primary source;
iii) Is there some reaction of methane (abundant in natural gas) which might be used instead. The symmetric methane molecule also has many advantages from the spectroscopic point of view.

Publications, Reports & Lectures

Publications

ANHARMONIC LATTICE DYNAMICS IN Na
H.R. Glyde & R. Taylor
Phys. Rev. B5(1972)1206

INCOHERENT NEUTRON SCATTERING BY SIMPLE CLASSICAL LIQUIDS FOR LARGE MOMENTUM TRANSFER
V.F. Sears
Phys. Rev. A5(1972)452
Atomic Energy of Canada Limited publication AECL-4017

ON THE REFLECTION COEFFICIENT OF keV HEAVY-ION BEAMS FROM SOLID TARGETS
J. Böttiger, J.A. Davies, P. Sigmund, & K.B. Winterbon
Rad. Effects 11(1971)69

REFLECTION OF keV HEAVY-ION BEAMS FROM SOLID TARGETS: DEPENDENCE ON ENERGY & ANGLE OF INCIDENCE
J. Böttiger, H.W. Jørgensen, & K.B. Winterbon
Rad. Effects 11(1971)133

THE STRUCTURE OF $^8$Be & ITS RELEVANCE TO THE FISSION PROBLEM
M. Harvey & A.S. Jensen
Nucl. Phys. 179(1972)33
Atomic Energy of Canada Limited Publication AECL-4041

FIRST-FORBIDDEN NON-UNIQUE BETA TRANSITIONS & MIRROR COMPARISONS IN LIGHT NUCLEI
I.S. Towner & J.C. Hardy
Nucl. Phys. A179(1972)489
Atomic Energy of Canada Limited Publication AECL-4044

ROUNDING CORNERS ON POLES OF POLYGONAL PROFILE
G.E. Lee-Whiting
Nucl. Inst. & Meth. 95(1971)433
Atomic Energy of Canada Limited Publication AECL-4033
Reports

THE DEPENDENCE OF THE INTEGRATED INTENSITY OF A SCATTERED NEUTRON GROUP ON THE EXPERIMENTAL CONDITIONS
V.F. Sears & G. Dolling
AECL-4133 (January 1972)

Lectures

COLLECTIVE & SINGLE-PARTICLE EXCITATIONS IN LIQUID NEON
W.J.L. Buyers, V.F. Sears, P.A. Lonngi & D.A. Lonngi
presented at the Symposium on Neutron Inelastic Scattering
Grenoble, France, March 6-10, 1972.

NUCLEON CLUSTERING & FISSION
M. Harvey
University of Michigan, March 23/72

HARTREE-FOCK-PROJECTION CALCULATIONS FOR LIGHT NUCLEI
H.C. Lee & R.Y. Cusson
MATHEMATICS & COMPUTATION BRANCH

D. McPherson

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5.3 Emergency Cooling Studies
5.4 Diffusion of Hydrogen in Fuel Sheathing
5.5 Thermal Diffusion in a Flat Plate Boundary Layer
5.6 Oscillations of a Column of Fluid
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5.13 Data Reduction Programs
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5.16 Publications, Reports and Lectures
5.1 **Staff**

**Branch Head:** D. McPherson

**Section I: Systems**

**Head:**
D. McPherson

**Programmer/Analysts:**
J.A. Edgecombe
L.D.J. Hansen
D.C. Knowles

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

**Section II: Operations**

**Head:**
G.N. Williams

**Programmer:**
C.D. Price

**Operator Supervisor:**
Mrs. V.L. Tomlinson

**Computer Operators:**
Miss N.L. Armstrong
Mrs. M.D.P. Denault
Mrs. S.F. Erven
Mrs. C.M. Hepburn
Miss M. Howard
Mrs. A.A. Laroche
Miss K.E. Lynn
Miss J.A. Roche
Mrs. L.J. Sutton
Miss D.E. Wright
Miss W.M. Wright

**Section III: Mathematical Services and Applications**

**Head:**
J.M. Blair

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

**Programmer/Analysts:**
Miss J.L. Barton (1)
M.B. Carver
P.Y. Wong

**Programmers:**
Mrs. N.R. Burnham
Mrs. E. Ironside
J.H. Johnson (2)
J.H. Schmidt
Mrs. L. Yamazaki

**Section IV: Cosmic Ray Monitoring**

J.F. Steljes

**Secretarial Staff**

Miss K.F. Suttill

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(1) Terminated 29 February 1972
(2) Waterloo student; joined branch 5 January 1972
5.2 Operating Systems

i) Compilers and Programming Facilities

(a) FORTRAN

M.B. Carver and W.J. Irving (CDC)

Postponement of an update of the FORTRAN Extended compiler planned for early March has been forced because of several uncorrected errors in the CDC release. Additional corrections are being incorporated and the next update of FORTRAN Extended is planned for late April.

(b) RAHAB Precompiler

G.H. Keech

The SNOBOL precompiler for the Savannah River reactor physics code RAHAB has been revised to incorporate new FORTRAN features in the CRNL version and to speed up precompiler processing. The latter was achieved by improving some of the scanning algorithms. Execution of the translated program has also been improved by having the precompiler insert in-line functions for the routines which access 6600 half-words.

(c) Paper-Tape Facilities for the 6600 Programs

D.B. Goulding, J.F. Steljes and G.N. Williams

A paper-tape input parameter has been added to the 6600 job card. The occurrence of this parameter initiates paper-tape reading and the conversion of the data to a SCOPE-format disk file accessible to the 6600 program. Job execution is inhibited until the disk file has been constructed.

The FORTRAN-callable subroutines for reading and punching paper tape have been written and are currently being tested. Tape can be read either as a stream of binary data or as coded and formatted information; for the latter there are extensive facilities for checking the validity of data and for recovery from errors in the data.
(d) **MTSCAN Version D**

D.B. Goulding

MTSCAN, a utility program for examining magnetic tapes and producing a directory of tape contents and location and type of errors, has been modified to generate better and more complete reports. A novel feature incorporated in this latest version is the ability to obtain a printout of records "as read" in spite of tape parity errors.

(e) **CHECKPOINT and REPRIEVE**

L.D. Hansen

For jobs which require very long execution times it is important to be able to take periodically "snap shots" of current values of all variables and positions and contents of files so that if execution is terminated prematurely, the job can be resumed from the last snapshot. Similarly, in the event of an abnormal job termination, it is often necessary to obtain a moment's grace from the system in order to properly close files and produce useful diagnostic information. CDC's SCOPE operating system contains CHECKPOINT and REPRIEVE routines to provide these functions, but errors in coding and deficiencies in design limit their usefulness. Errors in CHECKPOINT have been corrected, and methods of overcoming deficiencies and making these functions more useful are being investigated.

(f) **Submission of G-20 Jobs from Remote Terminals**

D.B. Goulding and D. McPherson

The 6600/3300 communications system was extended and the 6600 job card processing routine modified so that G-20 job decks can be processed by remote card-readers.
ii) Miscellaneous Systems Routines

(a) Plotting Routines

J.F. Steljes

A change to the 3300 plotting program has been made to deal with the plotting of points outside the allowed area. The pen now travels in a straight line towards the position of the required point until it reaches the limit and then travels along the limit until the intercept of the point is reached. The appearance of the plot inside the allowed area is always correct. Previously, a point lying outside the allowed area was replaced by a point on the limit.

Modifications have been made to the plot routines to use fully the instruction repertoire of the Calcomp 600 series plotters. The revisions have been tested and will be installed when necessary modifications to the plotter interfaces have been completed by CDC.

(b) 3300 Print Routines

G.N. Williams

The 3300 printer routine was revised to drive the CDC 512 line printers which were installed during the period. Provisions for backspacing or rewinding and restarting a print job in response to console type-ins were added to simplify recovery of output after paper jams or other printer malfunctions.

(c) File Dump and Restore Routines

M.B. Carver

The file queue rescue routines have been modified to permit a specified number of or all the files to be extracted from any or all of the input, output, plot, punch, export or individual terminal queues. An exclusive feature has also been added whereby all queues but those associated with a specified terminal or with all terminals may be dumped.
iii) Generalized Remote Job Entry Scheme

D.C. Knowles

As a first stage in this scheme a stand-alone program has been written for the CDC 3300 computer which uses many features of the 3316 multiplexor controller in order to transmit messages to terminals and examine the replies.

The program can be used:

(a) to check the behaviour of the 3316;
(b) to check the quality of the transmission lines to any one terminal;
(c) to check the responses of 200 User Terminals and 200 user terminal simulators;
(d) to assist in the programming of remote terminal computers.

The program has been tested and used extensively. A long-standing problem with the medium-speed transmission line to WNRE was at least partially solved with the aid of this program. Although the cause of the problem is still not known, recognition of the symptoms enabled a correction to be made to EXPORT/IMPORT 200, so that the fault no longer interferes with the normal running of the 200 User Terminal at WNRE.

The 200 User Terminal simulator for the CDC 1700 computer has been modified to include a diagnostic capability when selected by the central site computer. It has also been modified to maintain counts of all good and bad messages received from the central site and to type these out on the teletype when requested by the operator. These modifications will further assist the development of the remote job entry programs on the CDC 3300 computer.
iv) **PDP-10**

J.A. Edgecombe

The system monitor was updated to 5.03C version and systems programs maintained at latest DEC-released levels, with all reported patch releases installed.

Coding has been started on the Computing Centre communications project. Modifications to DEC standard spooling programs, which will be used for queuing jobs waiting for files to be transferred between the PDP10 and the 6600, are essentially complete.

v) **FORTRAN Library**

J.H. Schmidt

A new FORTRAN subroutine has been written to evaluate the Bessel functions $I_n(x)$, $J_n(x)$, $K_n(x)$ and $Y_n(x)$ for $x \geq 0$ and integer $n \geq 2$.

5.3 **Emergency Cooling Studies**

J.M. Blair and J.L. Barton

For the case of spray cooling, the thermal analysis of the rewetting process leads to a nonlinear integral equation on the half line $x \leq 0$, as noted in PR-P-91; 6.6; AECL-4068. An asymptotic solution has been developed, enabling us to reduce the domain to a finite interval. A numerical solution is constructed by discretizing the integral equation and solving the resulting system of simultaneous nonlinear algebraic equations by the Gauss-Seidel-Newton method.

The accuracy of the resulting solutions has still to be assessed for the cases of practical interest. The work is continuing.
5.4 Diffusion of Hydrogen in Fuel Sheathing

J.M. Blair and L. Yamazaki

Solutions of the one-dimensional diffusion equation when the diffusion coefficient and the boundary conditions are functions of time have been computed. The solutions were calculated numerically using the Crank-Nicolson finite difference scheme. The integrated flux describes the growth of hydrogen in zirconium fuel sheathing.

The calculations were done for C.E. Ells, Applied Materials Research Branch.

5.5 Thermal Diffusion in a Flat Plate Boundary Layer

W.N. Selander

The steady-state mass transport equation for the solute species in a binary mixture of temperature $T$ flowing at velocity $\bar{q}$ is

$$\bar{q}.\text{grad } c - D[\text{div}(\text{grad } c) + \alpha \text{ div}(c \text{ grad}(\log T))] = 0$$

where $D$ is the ordinary diffusion coefficient, $\alpha$ is the thermal diffusion ratio and $c$ is the solute concentration. The first two terms represent "conventional" mass transport, and the term multiplying $\alpha$ represents diffusion induced by a thermal gradient. This equation has been solved for laminar flow past a heated flat plate in order to assess the practicability of such an arrangement for deuterium separation. The usual boundary layer assumptions were made and a similarity solution obtained.

An approximate analysis of the resulting ordinary differential equation shows that the greatest separation obtainable is only a few percent for typical engineering parameters. Computed solutions of the equation agree with this estimate. It is concluded that this type of thermal diffusion is unattractive as a separating mechanism for deuterium. Since the simple case treated above is typical, it appears
unlikely that any improvement could result from variations of the geometry or flow conditions.

5.6 Oscillations of a Column of Fluid

W.N. Selander

Oscillations of a fluid between a reservoir and a tube having an immersed length of 90 cm have been observed. This experimental work, done in cooperation with J.I. Veeder of Reactor Physics Branch, is now complete (PR-P-91, 6.3, AECL-4068). Preliminary comparison of the results with the theoretical model are satisfactory; however, the mechanism of damping is being further investigated.

5.7 Transmission Electron Diffraction (TED) Analysis by Computer

J.L. Barton (see also PR-CMA-20, 4.2.5, AECL-4204)

Three programs have been written to select the best solution set of Miller indices for a particular crystal system for a given camera constant and ring radii. The programs differ in the analyses of the errors in the observed d-spacings, which is the basis for choosing the best set of solutions (i.e. the solutions with the most consistent errors). The best method would be an analysis of the variance of the errors in the observed d-spacings of all possible sets of solutions. One program uses this method but this is not always feasible, due to excessive computation time. The second program examines the moduli of the residuals and the third and most useful uses a combination of the first two methods.

5.8 Rational Function Approximations

J.H. Johnson

i) REMES2

A program called REMES2 has been developed as a useful tool for obtaining best rational function approximations to continuous functions of one variable. The best approximation \( P_m(x)/Q_k(x) \) for given \( m,k \) is that rational function minimizing
where \( f(x) \) is the function to be approximated and \( w(x) \) is a weighting function. The program is a double precision (up to 29S for CDC 6600) implementation in FORTRAN IV of the second algorithm of Remes using an inductive method suggested by Werner to obtain starting values. The Walsh array may be traversed in any of several different directions since the nearest successful approximation is used in the starting value calculation.

**ii) Approximation of the Inverse Error Function**

The REMES2 program is being used to obtain best rational approximations to the inverse error function, \( y = \text{inerf}(x) \) defined by

\[
x = \sqrt{\frac{2}{\pi}} \int_0^y e^{-t^2} dt
\]

This function enters into many statistical applications; for example, normally distributed random numbers may be obtained easily from uniformly distributed numbers with one evaluation of this function. It also enters into the solution of a one-dimensional concentration-dependent diffusion equation. In the range \( 0 \leq x \leq 1 - 10^{-10000} \) approximations up to 20S have been obtained. The tentative results may be briefly summarized in tabular form:

<table>
<thead>
<tr>
<th>Range</th>
<th>Form of Approximation</th>
<th>Smallest ( m+k ) for 10S</th>
<th>Smallest ( m+k ) for 15S</th>
<th>Smallest ( m+k ) for 20S</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-10^{-100} &lt; x \leq 1 \cdot 10^{-10000})</td>
<td></td>
<td>8</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>(-10^{-100} &lt; x &lt; 1 \cdot 10^{-10000})</td>
<td>( P_m(\xi)/(\xi Q_k(\xi)) )</td>
<td>10</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>(-10^{-10} \leq x &lt; 1 \cdot 10^{-10})</td>
<td>( x P_m(x)/Q_k(x) )</td>
<td>11</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>(-10^{-16} \leq x &lt; 1 \cdot 10^{-15})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-10^{-15} \leq x &lt; 1 \cdot 10^{-16})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
These approximations have not yet been tested for conditioning problems so that the above data may not be final.

iii) **Approximation of the Bickley Functions**

The Bickley functions may be represented as repeated integrals of $K_0(x)$, a modified Bessel function of the second kind. Thus

$$K_n(x) = \int_x^\infty K_{n-1}(t) \, dt$$

with $K_0(x)$ defined as $K_0(x)$. An efficient algorithm for calculating these functions is important since they are used extensively in several reactor programs. At the present time a double precision subroutine (accurate to 27S) to calculate $K_1(x)$, $K_2(x)$ ($\equiv K_0(x)$), and $K_{-1}(x)$ ($\equiv K_1(x)$) has been written and partially tested. Using these three values and a recurrence relation, higher order $K_n(x)$ may be obtained. When a problem with loss of precision in some ranges is solved, approximations to the Bickley function will be determined using the REMES2 program.

5.9 **Integration of Systems of Ordinary Differential Equations with Widely Separated Eigenvalues**

M.B. Carver

The solution of this type of 'stiff' equation system by standard methods is extremely time consuming because the maximum permissible integration step size is limited to a magnitude suitable for handling the fastest transient in the system even after the effect of that transient should have become negligible.

Two integration algorithms which attempt to bypass this difficulty have been tested in the simulation program FORSIM.
For stiff equation systems Gear's algorithm proved extremely efficient, reducing solution time by a factor of over 1000 compared to standard methods. The Fowler-Warten routine also gave a marked time reduction, a factor of about 100, and although slower than Gear's method, it requires considerably less storage.

Gear's method is already available as a library subroutine, and after further tests, the Fowler-Warten routine will also be released.

5.10 Simulation Programs

M.B. Carver

i) MIMIC

Several new features have been added to the MIMIC program to give the user better control of the integration routine and also more rigorous specification of the output he requires. Two new reserved variables CPTIME and ERRLIM have been added to permit the user to access elapsed CP time and convergence error within the compiled program. The integration routine now automatically records all convergence problems and summarizes these and the variables responsible after every run.

MIMIC has undergone considerable modification since it was first obtained from CDC and is now much improved. A report containing a complete description of the new facilities is being written as a supplement to the existing CDC manual.

ii) FORSIM

Three new integration routines have been added to the FORSIM simulation program giving the user a choice of five integration algorithms in all. Once the subroutine containing the differential equations has been written, the user may select the appropriate integration algorithm by means of a simple control variable, so several integration
algorithms may be tested on the same set of equations by merely changing one data card. The available routines are:

**Fixed Step:**
1. Runge-Kutta-Gill

**Variable Step Error Controlled:**
2. Runge-Kutta-Gill
3. Adams Predictor Corrector
4. Fowler-Warten Predictor Corrector
5. Gear's Predictor Corrector

The latter two routines are designed for the solution of stiff equation systems (see Section 5.9).

5.11 Cosmic Ray Monitoring

J.F. Steljes

Data processing of the results from the four Canadian stations is continuing.

Publication of the IGY results (1958-1962) in report form has commenced. Previously the data for these years were available only in loose-leaf form or upon request to NOAA, where it is stored on a magnetic tape.

Assistance is being given to the firm of Electronics Associates Ltd. of Toronto in fabricating cosmic ray readouts for sale. A study is being made to determine the best way for the firm to build and test reliable systems.

5.12 Information Handling Programs

i) PROD Program

C.D. Price

Additional features now incorporated in the PROD program (PR-P-92, 5.11(i), AECL-4147) include:
(1) Multi-interrogation of up to ten drawings on a single interrogate or update pass (only parts for these drawings will comprise output in all or any of the reports generated).

(2) Any operations that have been performed on a record (add, delete, correct, revise, key) may be displayed at any time during issues of the reports, and these status codes made to disappear after issue.

(3) Data in key fields may be changed or altered and this change would be made on all similar parts.

Physical changes made to the PROD file were:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Old</th>
<th>New</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>File Size</td>
<td>454 PRU</td>
<td>283 PRU</td>
<td>38% reduction in size</td>
</tr>
<tr>
<td>Record Size</td>
<td>161 ch</td>
<td>133 ch</td>
<td>18% reduction in record size</td>
</tr>
<tr>
<td>Major Key Size</td>
<td>26 ch</td>
<td>23 ch</td>
<td>12% reduction in key size</td>
</tr>
</tbody>
</table>

ii) Evaluated Nuclear Data Files

P.Y. Wong

Three data tapes, ENDF/B-III 303, 305 and 306, from the National Neutron Cross Section Center, have been added to the CRNL ENDF data library. A new version of the processing code RIGEL from NNCSC has been received and is now under testing.

5.13 Data Reduction Programs

i) Analysis of Magnetic Tapes from the Underwater Profilometer Facility

N.R. Burnham and J.M. Blair

Laboratory tests of the underwater profilometer are presently being carried out in Fuel Materials Branch before the facility is transferred to the Reactor Fuel Bays
for production work. The magnetic tapes containing profile-meter scans of dummy fuel elements have been analyzed with the TAPESCAN program and a subroutine developed earlier for VIDAR tapes (PR-P-92, 5.7(i), AECL-4147). Analyses obtained from the tape scan have prompted minor modifications to the data acquisition system.

ii) **JAGSPOT**

N.R. Burnham and G.H. Keech

The G-20 APEX version of the spectrum analysis program JAGSPOT is being translated into FORTRAN for use on the 6600 system. The rough translation is now complete.

Advantage is being taken of this opportunity to consider various improvements for the 6600 version, most of which would not have been possible with the G-20 version due to lack of core memory.

### 5.14 Miscellaneous Programs

i) **Shell-Model Codes**

G.H. Keech

The shell-model codes MULTISHELL and TENSOR have been supplied to outside users at Oxford, England; Firenze, Italy; Lyon, France; Utrecht, Netherlands; and Tallahassee, Florida.

An error in MULTISHELL (CRNL version of Oak Ridge Shell-Model Code) involving the case of a "large" matrix in a multi-case computer run has been corrected. A FORTRAN routine to extract certain information from the SSME data tape has been written to facilitate the preparation of some of the option-selection cards required for input to the program.
ii) **ISOSHLD: A General Purpose Isotope Shielding Analysis Code**

P.Y. Wong

Developed at Battelle Memorial Institute, ISOSHLD (RSIC Code Package CCC-79, Pacific Northwest Laboratory, Richland, Washington, January 1968) is designed to calculate the decay gamma-ray and bremsstrahlung dose at the exterior of a shielded radiation source. The code has been tested and debugged, and a working version for the CDC 6600 is now available.

iii) **Bruce Pump Vibration Analysis**

P.Y. Wong

A vibration analysis was performed of the coolant circulating pump designed for the Bruce reactor. Several cases were analyzed by the ROTOR code (PR-P-92, 5.6, AECL-4147), giving the performance characteristics of the pump under various operating conditions.

iv) **MESH3: A Triangular Mesh Generation Program**

P.Y. Wong

Designed to provide geometry data for the face seal analysis program (R. Metcalfe, Mechanical Equipment Development Branch), MESH3 generates a triangular mesh for a face seal of an arbitrary geometry.

5.15 **Operations**

i) **Job Identification and Routing**

D.C. Knowles, D. McPherson, E.A. Okazaki, and G.N. Williams

Jobs can be submitted to the Computing Centre through remote card-readers and by a pick-up service as well as at the Computing Centre. It is often necessary to distribute output by a different mechanism or to a different location than implied by the point of origin and the method
of submission. Each terminal or delivery location is assigned a unique identification; modifications to the operating system have been made so that the routing of all job output is unambiguously identified both to the system and to computer operators. Appropriate control cards give users the ability to specify routing for all job output or for selected output items.

ii) **Status Routine**

D.B. Goulding

The routine to list the status of the files in the 6600 was rewritten so that when its execution is requested from a remote job entry station, it produces a detailed report only of files associated with that station and an abbreviated summary of other files in the system.

iii) **Equipment Changes**

G.N. Williams

During the period two CDC 501 line printers were replaced by a single CDC 512 printer; the Computing Centre now operates with two 512 printers, a reduction made possible by the extensive use of terminals for input/output. In addition, a channel switch was added to the system so that, for normal operation, all unit record equipment can be operated by the 3300 but at least one each of card reader, card punch and printer can be made separately available to the 6600 and 3300 when required.
### iv) Use of the Computers

#### Hours of use of

<table>
<thead>
<tr>
<th>System</th>
<th>January</th>
<th>February</th>
<th>March</th>
</tr>
</thead>
<tbody>
<tr>
<td>6600 System</td>
<td>389.7</td>
<td>536.2</td>
<td>523.8</td>
</tr>
<tr>
<td>G-20/3300 System</td>
<td>154.9</td>
<td>160.0</td>
<td>152.5</td>
</tr>
</tbody>
</table>

#### Use by Division

**6600 System**

The following table is an analysis of 42,978 jobs representing 974 hours of 6600 central processor time.

<table>
<thead>
<tr>
<th>Division</th>
<th>Number of Jobs</th>
<th>CP Time, Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computing Centre</td>
<td>7223 (16.8%)</td>
<td>38.3 (4.0%)</td>
</tr>
<tr>
<td>Head Office</td>
<td>271 (0.6%)</td>
<td>2.0 (0.2%)</td>
</tr>
<tr>
<td>Biology &amp; Health Physics</td>
<td>166 (0.4%)</td>
<td>12.3 (1.3%)</td>
</tr>
<tr>
<td>Chemistry &amp; Materials</td>
<td>752 (1.7%)</td>
<td>63.7 (6.5%)</td>
</tr>
<tr>
<td>Physics</td>
<td>2176 (5.1%)</td>
<td>106.8 (11.0%)</td>
</tr>
<tr>
<td>Applied Physics</td>
<td>1511 (3.5%)</td>
<td>17.6 (1.8%)</td>
</tr>
<tr>
<td>Advanced Projects &amp; Reactor Physics</td>
<td>8863 (20.6%)</td>
<td>180.4 (18.5%)</td>
</tr>
<tr>
<td>Fuels &amp; Materials</td>
<td>5821 (13.5%)</td>
<td>213.5 (21.9%)</td>
</tr>
<tr>
<td>Administration</td>
<td>513 (1.2%)</td>
<td>0.5 (0.1%)</td>
</tr>
<tr>
<td>Finance</td>
<td>1175 (2.7%)</td>
<td>3.9 (0.4%)</td>
</tr>
<tr>
<td>Operations</td>
<td>3974 (9.2%)</td>
<td>14.4 (1.5%)</td>
</tr>
<tr>
<td>Plant Design</td>
<td>641 (1.5%)</td>
<td>3.6 (0.4%)</td>
</tr>
<tr>
<td>Special Projects</td>
<td>2369 (5.5%)</td>
<td>9.2 (0.9%)</td>
</tr>
<tr>
<td>Power Projects</td>
<td>3952 (9.2%)</td>
<td>34.5 (3.5%)</td>
</tr>
<tr>
<td>WNRE</td>
<td>3537 (8.2%)</td>
<td>271.6 (27.9%)</td>
</tr>
<tr>
<td>Others</td>
<td>34 (0.1%)</td>
<td>1.1 (0.1%)</td>
</tr>
</tbody>
</table>
G-20/3300 System

The following table is an analysis of 4,843 jobs, representing 467.3 hours of G-20 time.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Jobs</th>
<th>G-20 Time, Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computing Centre</td>
<td>29</td>
<td>0.6</td>
</tr>
<tr>
<td>Head Office</td>
<td>171</td>
<td>22.4</td>
</tr>
<tr>
<td>Biology &amp; Health Physics</td>
<td>768</td>
<td>186.0</td>
</tr>
<tr>
<td>Chemistry &amp; Materials Physics</td>
<td>245</td>
<td>9.5</td>
</tr>
<tr>
<td>Physics</td>
<td>1765</td>
<td>102.7</td>
</tr>
<tr>
<td>Applied Physics</td>
<td>223</td>
<td>30.7</td>
</tr>
<tr>
<td>Advanced Projects &amp; Reactor Physics</td>
<td>645</td>
<td>39.4</td>
</tr>
<tr>
<td>Fuels &amp; Materials Operations</td>
<td>610</td>
<td>56.6</td>
</tr>
<tr>
<td>Plant Design</td>
<td>236</td>
<td>11.8</td>
</tr>
<tr>
<td>Others</td>
<td>150</td>
<td>7.6</td>
</tr>
</tbody>
</table>

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5.16 Publications, Reports and Lectures

Publications

ESTIMATING ERRORS IN EXPERIMENTAL DATA
(Condensed Version of AECL-3781)
J.M. Blair
Instruments & Control Systems, January 1972

Reports

TEMPERATURE TRANSIENTS IN A CYLINDER DUE TO A TIME VARYING
HEAT TRANSFER COEFFICIENT
J.M. Blair and W.N. Selander
AECL-4126, January 1972

ROTOR: A CDC 6600 COMPUTER CODE FOR THE ANALYSIS OF PUMP
PERFORMANCE
P.Y. Wong
AECL-4076, January 1972

COSMIC RAY MT-64 MUON MONITOR DATA - V
J.F. Steljes
AECL-4077, January 1972

COSMIC RAY MN-64 NEUTRON MONITOR DATA - XX
J.F. Steljes
AECL-4148, March 1972

COSMIC RAY IGY NEUTRON MONITOR DATA - II
J.F. Steljes
AECL-4149, March 1972

COSMIC RAY NM-64 NEUTRON MONITOR DATA FROM KULA, HAWAII
J.F. Steljes
AECL-4161; March 1972

Lectures

INTRODUCTION TO COBOL PROGRAMMING
E. Ironside
Delivered at CRNL during February 1972
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