

Penning Ion Source Development

Development of Penning ion sources was resumed this year when operation of the polarized-ion source became routine. The hot-filament source (Mark II) now reliably produces 20 μA of $^4\text{He}^{++}$ with a filament lifetime of 24 hours. Problems encountered included optimizing the source geometry for the low operating magnetic field of 1.8 kGauss and protection of power supplies, controls and light link from damage caused by extractor voltage sparking. Similar results have been obtained for $^3\text{He}^{++}$, but regular operation awaits the arrival of a helium recovery system on loan from another laboratory. This will involve a two-part batch process with helium-3 recovered from the vacuum tank, compressed and stored during each run. Purification will take place in a separate system off-line where bottles of clean helium will be prepared for future use.

Fabrication of the cold-cathode source (Mark III) for producing carbon, nitrogen and oxygen ion beams is complete. Initial tests revealed some geometrical problems which have been solved and further tests are imminent. Because of space and power limitations, these tests will employ a low-power igniter supply using capacitive energy storage to initiate the arc and a transistor-bank regulator to stabilize it. If this proves inadequate for routine use, a more elaborate power supply for starting and controlling the arc will be designed. Attempts will be made to obtain small beams of $^6,^7\text{Li}^{++}$ from this source, although plans call for building a separate source with controlled sputtering for lithium, beryllium and boron.

Beam Transport System Development

1. Beamline Hardware. As part of a program to further increase beam intensities by improved beam bunching, a one-half frequency buncher was installed

and tested in the injection Beam Line #1. Based on result of these tests, the extensive beam line modification required for full implementation the multi-buncher system previously described has been defined.

All beam stops and viewers in the beam lines at IUCF use standardized air-driven actuators. These actuators had sliding shaft O-ring seals which resulted in occasional sticking of the actuators due to cold-flow of the O-rings when O-ring compression was high enough to reliably prevent leakage and the period between use was long. Double O-rings with a vacuum pump-out between them were used to allow lower O-ring compression, but sticking still occurred. In addition, a small amount of absorbed air was inevitably carried into the evacuated beam pipe upon shaft insertion. Modification of most actuators, by replacement of sliding shaft O-ring seals with welded metal bellow and static O-ring seals, has been completed. This modification eliminates the mechanical and vacuum problems described above.

Thin ($5\text{--}10\ \mu\text{g}/\text{cm}^2$) carbon foils are used in the inter-cyclotron Beam Line #2 to strip Li^{++} to Li^{+++} before acceleration in the main cyclotron. In order to improve the vacuum in this beam line and help prevent occasional breakage of the stripping foils during rough pumping, installation of an additional diffusion pump station was completed and the roughing/backing system was rebuilt. Automatic slow roughing is provided to protect the stripping foils. Vacuum controls were redesigned and rebuilt to accommodate these hardware modifications.

The low-energy beam polarimeter was temporarily modified for deuteron beam polarization monitoring using the $^3\text{He}(d,p)^4\text{He}$ reaction as previously described. A new design for permanent operation, using more

appropriate small photomultiplier tubes and home-built bases has been completed and parts are on order. New solid-state detector mounts for the left-right counters used for determining the proton beam polarization were designed and fabricated in order to facilitate easier detector installation and more rapid changeover of the polarimeter between proton and deuteron operation.

Routine maintenance on all beam line components is performed on a continuing basis. Beam viewer phosphors and TV cameras, which fail as a result of radiation damage, are replaced. Diffusion, cryogenic and mechanical vacuum pumps are inspected and serviced regularly, as are all freon-cooled diffusion pump baffles. Vacuum leaks in beam line components must be detected and repaired as they become troublesome. Radiation-hardening of rubber O-rings in the high-energy beam lines has been found to lead to leaks requiring O-ring replacement at locations of high neutron flux approximately annually. Water cooling circuits are periodically checked to assure adequate water flow and proper functioning of flow-monitor switches.

In 1980, short entrance and exit beam lines for the new pion spectrograph were installed and the beam line to the polarized neutron beam facility was designed, major components procured, floor layout finalized and installation of shielding penetration blocks completed. Completion of this beam line will be a major effort in early 1981.

2. Ion Optics. The quadrupole currents for the beam line to the new pion spectrograph (QQSP) were recalculated to minimize the vertical beam size in the beam line bending magnets and in the "180° magnet" which provides a small deflection of the proton beam into the beam dump when the spectrograph is set up for scattering in the backward direction. The beam spot at

the target is 1.4 mm wide by 1.0 mm high, total, assuming a 3π mm-mr emittance; the dispersion here is small. A vertical waist just upstream of the 6° bend leading to the QQSP branch of the beam line has been eliminated.

An achromatic beam at the QDDM spectrograph target which minimizes scattering-angle variations has been calculated, giving a width of 3.3 mm and a height of 1.8 mm (for 3π mm-mr) at the target. The vertical waist is at the target position and the horizontal waist is 0.42 m downstream.

The beam optics for a proposed small "stripper ring" in the injector Beam Line #1 was checked for the configuration in which H^- ions are to be injected into the ring and stripped, and protons stored for several RF cycles in order to increase the beam-burst intensity for high-energy, pulse-selected proton beams. The present beam line design immediately following the preinjector terminals will provide beams with the correct phase-space ellipses in both the vertical and horizontal directions without changes or relocation of existing quadrupole lenses.

The quadrupole and bending-magnet configurations for the beam line to the proposed new high-resolution QDD spectrograph system described in a later section of this report has been designed, under the assumption that the dipole magnet from the present QDDM spectrograph will provide the momentum analysis for this beam line.

Computer Controls.

Installation and commissioning of the QQSP pion spectrograph afforded the opportunity to install, in both hardware and software, the first remotely controlled load and polarity switches. These switches are now automatically set by the program used to load previously recorded values into the DAC's of selected

beamlines as part of the normal cyclotron setup procedure. Future retrofitting of existing manual switches will eventually allow complete control of beamline hardware from the control computer.

Micro-processor based controls for the 64-inch scattering chamber were put into operation and used by experimenters. The system allows remote readout and control of two detector arms, the target table and the target-holding wheel while providing protection features against running arms together and running detectors into the beam. Future connection of this system to the control computer will allow an experimenter to record and control device positions from his data acquisition computer over the inter-computer link. Micro-processor based vacuum controls are nearing completion which will allow automatic sequencing of the special, oil-free pumping system on the 64-inch scattering chamber.

It has been realized for some time that the present Xerox Sigma-2 controls computer, while extremely reliable and rather elegant in its own fashion, is limited in its capabilities. The increasing effort required to simply maintain its assembly-level-language-only software and the increasing cost and frequency of hardware maintenance brought about initiation of a search for a replacement computer. A number of 16-bit machines were examined before it was decided to formulate a long-range standardization plan which included the data acquisition computers. We are now awaiting replies from vendors to our specification for a 32-bit machine to be used as the control computer replacement and a prototype data-acquisition computer. We are expecting to purchase a new machine during 1981.

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Shielding Improvements

In 1980, additional concrete shielding elements were purchased to provide a second layer of roof shielding for the main-stage cyclotron vault, add high-density concrete wall blocks at several locations where radiation levels warranted, provide regular and special concrete elements for the polarized neutron beam facility and allow for the addition of a third flight path to the neutron time-of-flight facility.

Twenty-five normal-density (150 lbs/ft³) concrete roof beams were purchased and installed as a second layer on the main-stage cyclotron vault. These T-shaped beams are 50 ft long, 3 ft high and on the average 20 inches wide. Fourteen high-density (220 lbs/ft³) concrete wall blocks of standard size (12 ft high by 4-1/2 ft by 4-1/2 ft) were procured and will be installed in early 1981. Four short wall blocks of ordinary concrete were purchased and installed to allow an opening in the shielding through which neutrons may pass from the swinger facility target location to a detector on a 45-degree flight path. Finally, as part of the shielding required for the polarized neutron beam facility and, in particular, the planned charge-symmetry-breaking experiment, four (two) special upstream blocks of heavy (ordinary) concrete and four downstream blocks of heavy concrete have been designed and a fabrication contract let. Because of their special shape, wooden forms for the high-density concrete blocks are being fabricated at IUUCF. The forms for these blocks will be shipped to the vendor, poured and returned for installation in early 1981.

EXPERIMENTAL FACILITIES DEVELOPMENT

A. Facilities in Operation

1. Beam Swinger Facility. A ten-position linear "Geneva" drive target ladder assembly was fabricated and installed at the target position of the beam swinger facility. This target drive is remotely controlled through the Sigma-2 cyclotron controls computer. It has a vacuum interlock so that oxydizable targets may be safely used. Gravel roads were extended to 200 meters on the 0° - 26° flight line and to 150 meters on the 24° - 50° flight line. Shielding modifications were made and a second large detector hut was built to allow measurements on a 45° - 71° flight line. This line is limited to about 90 meter length by the present fence line of the IUCF property.

2. Pion Spectrograph QQSP. The long-awaited delivery of the new pion spectrograph system¹⁾ was made

in May of 1980. After delivery the magnets were set up at the north end of the building for detailed magnetic-field mapping. During this period the 64-inch scattering chamber cave was being prepared for the installation of the spectrograph. The spectrograph beam line branch was installed in early summer and after very intense efforts on the part of the IUCF technical staff during July and August, the spectrograph and its support system were installed (see location 3 on experimental area floor plan, Fig. 5). The spectrograph with its target chamber and focal-plane detectors was prepared for initial tests with beam in late August.

The initial runs with the system used inelastically scattered protons at bombarding energies in the range 12 to 25 MeV. The purpose of these runs

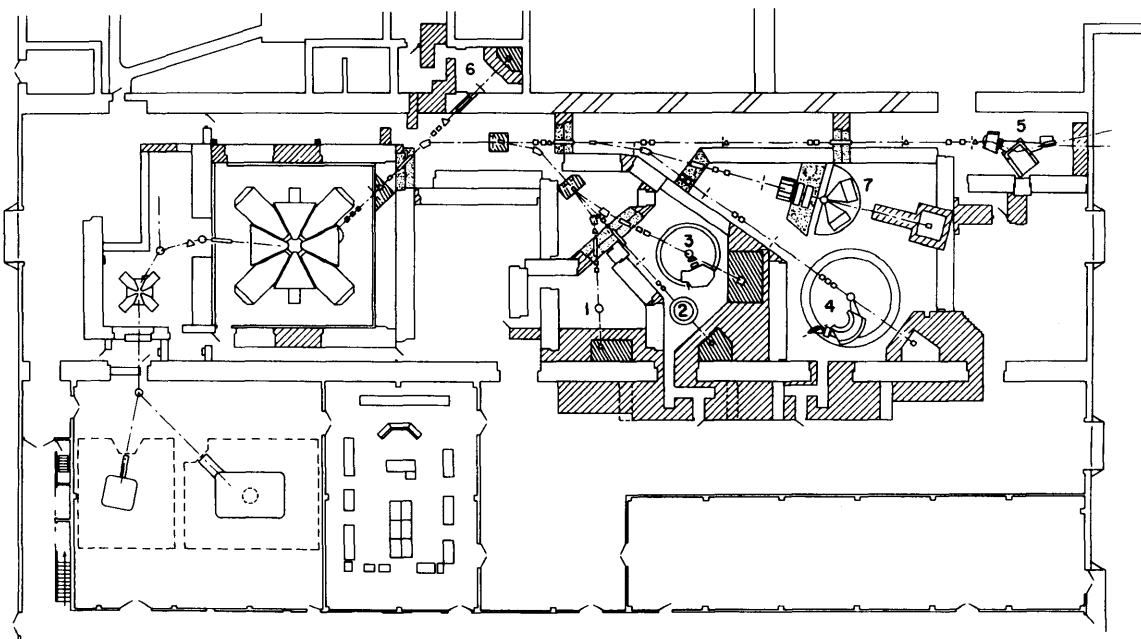


Figure 5. Layout of the accelerator facility and the experimental area at IUCF, showing location of new facilities: the recently installed QQSP pion spectrograph (3) and the polarized neutron beam production and scattering facility (7) under construction. Older experimental facilities shown are the low-intensity γ -cave (1), 64-inch general-purpose scattering chamber (2), QDDM magnetic spectrograph (4), beam-swinger facility (5) for (p,n) reaction studies, and high-intensity irradiation facility (6).

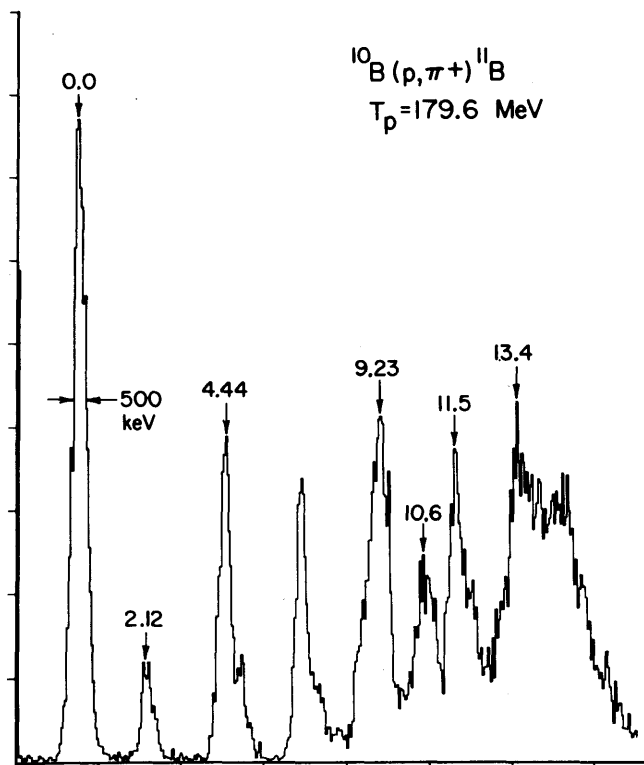


Figure 6. First pion spectrum obtained with the new QQSP spectrograph for the $^{10}\text{B}(p,\pi^+)^{11}\text{B}$ reaction induced by 180 MeV protons, demonstrating the broad momentum acceptance of the instrument.

was to determine the transformation coefficients required to convert position and angle measured at the detector position to a position spectrum at the focal surface and correct for both system aberrations and kinematic effects. In late December, the first measurements of pions scattered through the spectrograph were made. A typical spectrum is shown in Figure 6 which illustrates one of the specific advantages of the QQSP system relative to the QDDM system, namely its broad momentum range. With the QDDM spectrograph, an equivalent spectrum can be obtained only by combining several runs with different field excitations.

One of the significant findings of the magnetic field mapping was that the multipole content of the two entrance quadrupoles deviates from the design values.

The primary effect of this deviation is to cause a reduction in solid angle. The particle ray tracing measurements, however, indicated an even greater loss in solid angle than could be explained by this alone. As a result of this, the magnetic alignment of the quadrupoles relative to each other and to the dipole was checked by a series of magnetic field measurements. These indicated vertical misalignments of approximately 1mm.

As a consequence of these findings, work has been scheduled for early 1981 to correct both the multipole errors and the vertical misalignments. The goal of these improvements is to bring the QQSP operation up to its design aim by the middle of the second quarter of 1981.

1) IUCF Techn. and Scient. Report 1977, p. 23; 1978, p. 158; 1979, p. 154.

3. QDDM Focal-Plane Polarimeter. During the spring of 1980 a polarimeter for use in the focal plane of the QDDM spectrograph was developed¹⁾ which allows one to measure the polarization of secondary protons of 100-200 MeV energy emerging from specific nuclear reactions induced by a primary beam incident on a target in the QDDM scattering chamber. The apparatus is shown schematically in Figure 7; a photograph of the polarimeter installed in the focal plane of the spectrograph is provided in Figure 8.

The polarimeter is primarily intended and was first used for measurements of spin-flip probability (or depolarization) in inelastic polarized-proton scattering at ~150 MeV.²⁾ In this application, the QDDM spectrograph is tuned such that scattered protons corresponding to the desired excitation pass through the usual focal-plane array and then impinge on the thick carbon analyzing target of the focal-plane polarimeter. $\Delta E(\text{Pilot B}) - E(\text{NaI})$ scintillator

telescopes measure the left-right asymmetry from the resulting second scattering from which the final state polarization can be deduced. A valid (\vec{p}, \vec{p}') event consists of a standard focal plane event (SFP = Helix $\cdot [S5 \cdot S6]_L + (S5 \cdot S6)_R$), all gated by protons in S1 vs. S2, protons in S2 vs. S3, elastic protons in S5 vs. S6 and incident beam polarization state. Sorting of prescaled $(S3 \cdot SFP)$ coincidences gated by protons in S1 vs. S2, protons in S2 vs. S3 and incident beam polarization state allows determination of the corresponding differential cross section and analyzing power.

Background levels were found to be negligibly small, mainly because of the directionality imposed by the $(S3 \cdot S5 \cdot S6)$ coincidence requirements. The backgrounds were examined by observing the $^{12}\text{C}(p, p')$ spectrum between the ground and 4.44 MeV states. The only processes that produced noticeable rates were scatterings from the S1 and S2 scintillators, and these could be recognized by "incorrect" position signals from the helix. Background rates from other sources were $< 10^{-4}$ of the $(SFP \cdot FPP)$ coincidence event rate from the elastic peak and less than the usual background on the helix from particles scattered upstream.

In order to provide accurate measurements of the outgoing proton polarization, the polarimeter must be carefully aligned and calibrated. While designing the requisite procedures, special attention was devoted to identifying and then determining a consistent scheme of either canceling or correcting for the instrumental asymmetries associated with this system. Briefly, false asymmetries appear when the desired particles at the spectrograph exit have either a lateral (Δx) or an angular ($\Delta\phi$) displacement with respect to the polarimeter axis. If these displacements are due only

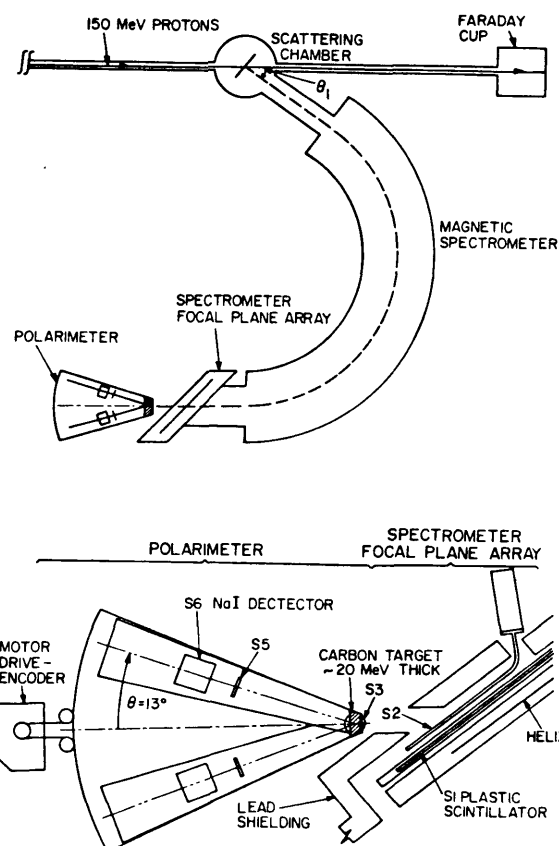


Figure 7. Geometry of the QDDM focal-plane polarimeter.

to a physical mispositioning of the polarimeter relative to the focal plane one can (at least to first order in Δx , $\Delta\phi$) both cancel the associated errors and determine the sensitivity to them. But even with a perfectly aligned polarimeter these effects can still arise when the cross section for scattering from the primary target has a strong angular dependence. This angular variation causes a nonuniform illumination of the spectrograph acceptance, and when the scattered particles are brought to a focus at the helix they subsequently spread out to create an asymmetric intensity distribution on the carbon analyzer. Thus a determination of the dependence of the measured asymmetry on Δx and $\Delta\phi$ for a beam of known polarization

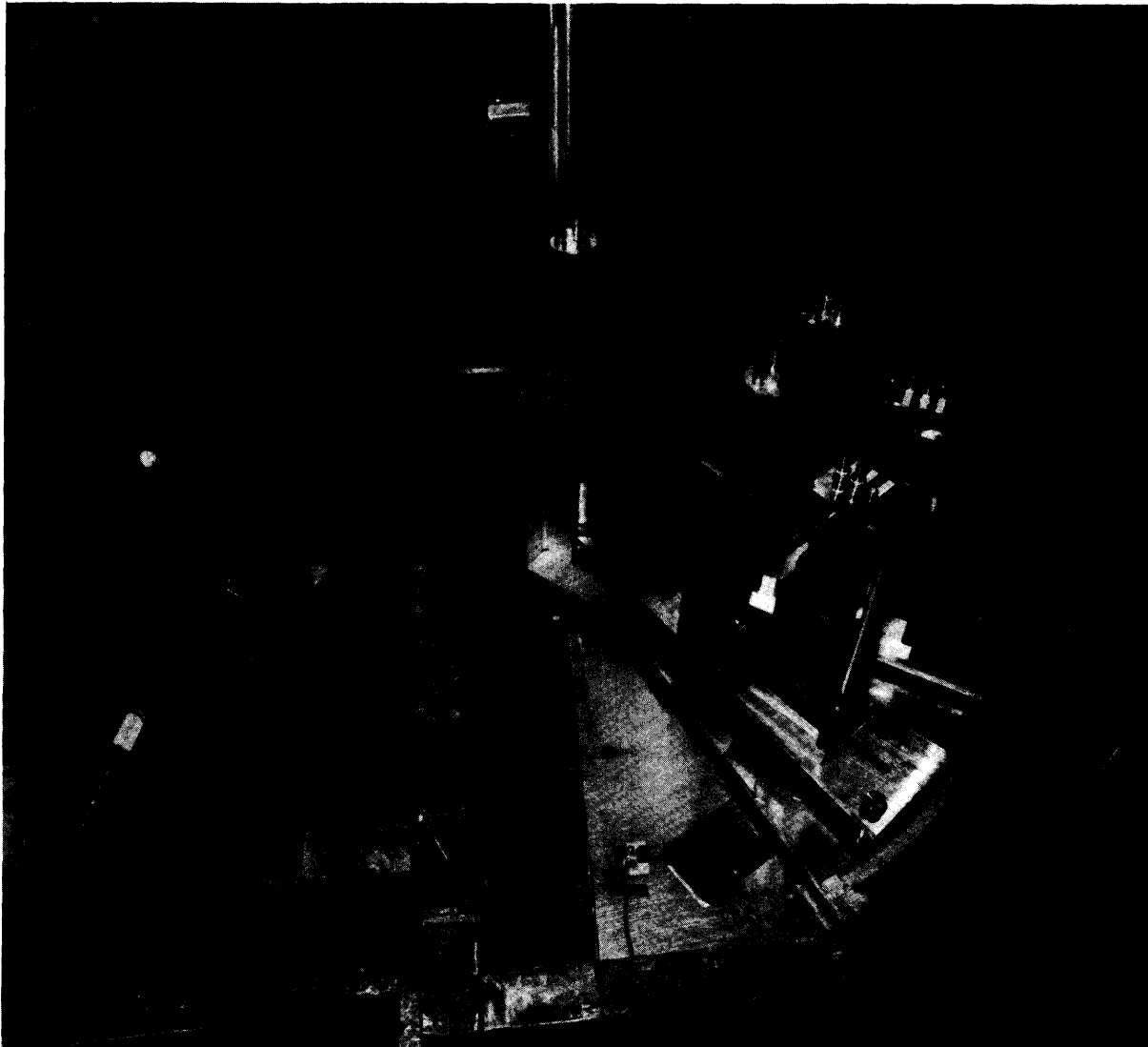


Figure 8. Top view of the focal-plane polarimeter installed on the spectrograph.

incident on the polarimeter forms an integral part of the calibration/alignment procedure. With each spin-flip measurement, the slope of the polarized cross section from the primary target must be measured so that the appropriate correction can be calculated and incorporated in the determination of the outgoing proton polarization (for further details see ref. 3).

The first-order properties of this system are now well understood, and it has been calibrated with 135-150 MeV protons for which it has a scattering efficiency of 0.8-0.6% and an effective analyzing power of 0.26-0.37. Its response has shown no troublesome nonlinearities to date, but an extensive numerical model of the polarimeter to check for the possibility

of such effects is currently being constructed.

- 1) Design and fabrication of the polarimeter hardware was carried out at the Los Alamos Laboratory, Los Alamos, New Mexico 87545, under the supervision of T.A. Carey and J.M. Moss and with the support of P-7 Division.
- 2) See "Polarization and Spin-Flip in Proton Inelastic Scattering", contribution to this annual report.
- 3) IUCF proposal for extension of Expt. 106 (original proposal 79-20: "Measurement of Spin-Flip Probabilities in Proton Inelastic Scattering") presented to June 19-21, 1980 PAC.

4. Other Target Area Improvement and Support Efforts.

Research support in the target areas at IUCF falls into four general categories. These are: maintenance and repair of experimental facilities, reconfiguration of facilities to accommodate different experimental requirements, permanent modification and improvement of existing apparatus and fabrication and installation of new experimental devices. 1980 saw considerable work in each of these categories. An average of 2.5 different experimental setups each week were used this year. Some of these, like setting the QDDM spectrograph up in the desired angle configuration with either external or internal Faraday cup, are quite routine. Others, like that for the $^2\text{H}(p,\pi^0)^3\text{He}$ threshold cross-section and analyzing-power measurements, require substantial but temporary modifications.

For the latter experiment, a copper Faraday cup was placed within the dipole magnet of the QDDM, the 24-inch scattering chamber was removed and replaced with a special target chamber and support plate for massive lead-glass detectors and their shielding. A small piece of thin-walled, 10-cm diameter aluminum tubing served as the target chamber which was attached directly to the QDDM entrance port with a metal

bellows, allowing the spectrograph to move as much as 2 degrees away from the beam direction.

While this temporary reconfiguration may have been the most extensive and labor intensive of the year, many others require significant effort. Each experiment run using the beam swinger time-of-flight facility, for example, requires placement of the detector huts, movement of electronics to the huts and appropriate distribution of power and signal cables. A modification of the QDDM target chamber was made to accommodate a ^3He gas target cell. Special modifications of the 64-inch scattering chamber to use special gas targets and/or special detectors were required by several experiments. The recoil-catcher experimental apparatus was removed from its location at the intermediate focus upstream of the 64-inch scattering chamber.

A modified target chamber in the γ -cave for use in out-of-the-horizontal- plane measurements of tensor analyzing powers in deuteron elastic scattering was installed. Use of the γ -cave frequently requires installation of a different target chamber and the movement of shielding blocks to accommodate large detector assemblies. The necessity of frequent removal and reinstallation of the standard germanium gamma-ray detector support prompted us to construct a light table which can be installed and removed more readily.

At an intermediate focus on the swinger beam line, at a location in the QDDM room, a special target chamber was installed to use a hyper-pure germanium-detector telescope and large neutron detectors to carry out (p,pn) measurements. This effort required lifting roof shielding to install neutron detectors and to stack additional concrete neutron shielding.

A major permanent improvement of the 64-inch scattering chamber system has been the installation of new motors, encoders, and controls to replace the old, unreliable control system. New vacuum controls for this chamber and the new QSSP pion spectrograph were installed. In addition, two roll-around, high-vacuum pumping stations have been built for general purposes and to provide clean pumping in any experimental area for hyper-pure germanium detector telescopes.

A new vacuum-interlocked target chamber for chemically active targets for the QDDM spectrograph was built. A split Faraday cup deep enough to stop 200 MeV protons was fabricated. The vacuum pipe from the exit of the QDDM scattering chamber to the external Faraday cup was rebuilt to allow more convenient handling when changing from external to internal Faraday cup.

Four experimental setup areas near the entrance to the target areas were constructed. These allow storage of parts and provide lighted bench space outside of the radiation-interlocked areas so that assembly of experimental apparatus may be done with beam on target, when needed.

5. Target and Detector Development

(i) Target Preparation Facility. The target lab supplied an estimated 95% of the targets used at IUCF in 1980. Targets prepared, in thicknesses ranging from 100 $\mu\text{g}/\text{cm}^2$ to 150 mg/cm^2 , included:

CD_2 , $^6,^7\text{Li}$, LiCO_3 , Be, BeO , $^{10},^{11}\text{B}$, CH_2 ,
 $^{12},^{13},^{14}\text{C}$, $\text{C}_3\text{H}_6\text{H}_6$, B_2O_3 glass, Si $^{17},^{18}\text{O}_2$,
 $^{24},^{25},^{26}\text{Mg}$, ^{40}Ca , V ^{54}Fe , Co, $^{58},^{60},^{61},^{62},^{64}\text{Ni}$,
 $^{63},^{65}\text{Cu}$, $^{112},^{116},^{120}\text{Sn}$, In, Tb, Tm, ^{176}Yb , ^{180}Hf ,
 $^{206},^{207},^{208}\text{Pb}$.

Most of these are now part of the target inventory pool for users.

We have developed a highly successful airless

spray technique for applying styrene to pressed or settled targets and an evaporation method for producing good Melamine targets up to 13 mg/cm^2 . An electron-gun for material-conservative reductions and evaporations was acquired. The pumping station for evacuation of the target storage jars has been improved to allow more complete pumpout of the jars before sealing. An inert-gas/vacuum target transfer apparatus for the QDDM spectrograph target chamber was fabricated and successfully used. Currently, it mates to a small glove box where rolling of air-sensitive materials is done. A new double-length glovebox with a closed-loop argon purification system was acquired and customizing work on the box interior and a target-ladder port is in progress. The box will allow fabrication and/or storage of targets in an argon atmosphere containing less than 1ppm moisture and oxygen.

In early 1981, the target lab will be moved to a larger room near its present location.

(ii) Drift and Multiwire Proportional Chambers.

Parasitic and in-beam tests with the vertical-wire drift chamber (VWDC) constructed this past year have shown an average intrinsic position resolution of ~ 0.2 mm and an average angular resolution of $\sim 2^\circ$ (these numbers depend somewhat on incidence angle). The measured position resolution is good enough for the new QSSP pion spectrograph (which requires 1mm). The VWDC has been used for QQSP ray tracing (see Figure 9) and pion spectra were successfully acquired.

During the pion run the dark current in the VWDC reached values as high as 30 μA due to evaporation of protons from the target. With this high dark current the chamber broke down electrically after a few hours of use. One possible solution to this problem is to place an absorber plate in front of the drift chamber to keep the evaporation protons from reaching the

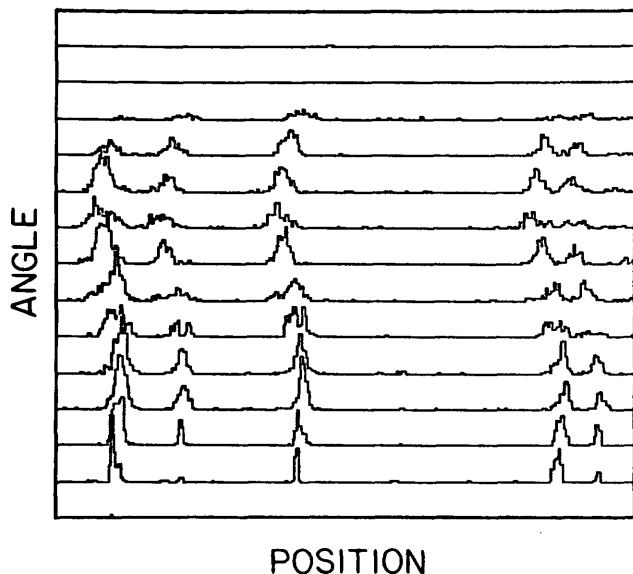


Figure 9. A position vs. angle spectrum of a ray tracing run measured by the VWDC+software system. The distinctive S-shape is characteristic of horizontal aberrations of the QQSP. With such spectra and further software processing the design resolution of the QQSP should be obtainable.

chamber, but this method would degrade the resolution of the spectrograph due to multiple scattering in the absorber. The preferable solution is to use a counter gas which does not break down and contaminate the chamber. One suggested gas mixture, 49-1/2% argon, 49-1/2% ethane, and 1% ethyl alcohol will be tried shortly.

In order to increase the resolution at large angles of incidence the delay-line configuration of Bertozzi¹⁾ was changed from a 3-delay line system to a seven-delay line system. The processing time of an event using the VWDC has not yet been fully evaluated since the data acquisition software has recently been switched to the new RAQUEL program.

A prototype multiwire proportional chamber (MWPC) with active area comparable to the present helical wire chambers used on the QDDM spectrograph has been constructed.²⁾ Various initial design and fabrication faults have been corrected and the MWPC has been successfully bench-tested using a locally modified LeCroy PCOS-II controller to read out the LeCroy 7700 chamber boards. One in-beam test has been conducted by placing the MWPC directly behind the helical counter (followed by standard scintillation counters) in the QDDM focal plane, allowing a direct comparison of the two counters. First use of the new data-acquisition program RAQUEL was necessitated by the variable number of words per event generated by the MWPC readout. No major problems with the readout system of the MWPC were encountered. The data from that test are still being analysed in order to determine the best operating characteristics of the MWPC and associated hardware. Additional chamber boards and components will soon be ordered to read out several new MWPC's soon to be constructed.

A facility has been planned to aid MWPC construction at IUCF, including fabrication of equipment for making printed-circuit (PC) board layouts of modest size (50x100cm), and a large jig-plate gluing table (180x210cm) for laminating PC boards is now nearing completion. First use of this facility in the spring of 1981 will be for the construction of several small, 25-40 cm square active area chambers needed for the Charge-Symmetry-Breaking experiment in conjunction with the Polarized Neutron Beam Facility.³⁾ Later, several larger chambers of up to 100 cm square active area will be constructed for this project.

1) W. Bertozzi, M.V. Hynes, C.P. Sargeant, C. Creswell, P.C. Dunn, A. Hirsch, M. Leitz, B. Norum, F.N. Rad and T. Sasanuma, Nucl. Instr. and Meth. 141 (1977) 457.

- 2) IUCF Techn. and Scient. Report 1979, p. 155.
- 3) See later sections of this report.

(iii) Scintillation Detector Laboratory. In February of 1980, a laboratory was set up for the development and fabrication of scintillation detectors. During the past year, techniques for polishing and bending lightpipes have been perfected. Fabrication of fast, stable photomultiplier tube bases is underway. Research into the physical properties of many optical epoxies and studies on the reflective characteristics of various wrapping materials have been carried out. These findings are now being incorporated into the design of IUCF scintillation counters. This has resulted in the production of detectors superior to any previously used at this facility.

To date, approximately 100 scintillation detectors have been produced. These include six large neutron time-of-flight detectors (170cm x 15cm x 15cm), three focal-plane detectors for the QQSP pion spectrograph, and a 14-element hodoscope for the measurement of pion threshold cross sections.

(iv) High-Purity Germanium Detector Telescope Systems. Significant advances in understanding the effects of using high-purity, planar germanium crystals for the detection of light ions at intermediate energies were obtained during 1980. Measurements of the rate and consequences of radiation damage on the operating characteristics of both n-and p-type detectors were made and the effectiveness of our radiation-damage annealing procedures was studied. A total of 9 germanium detectors was used in 11 experiments utilizing over 75 shifts of beam with only one experiment not completed because of a detector failure. This one failure led to the above studies,

which explained for the first time the apparent reliability problems encountered with the new n-type, phosphorous-ion-implanted transmission detectors.

The ΔE -E telescope which failed contained both n-and p-type germanium detectors, where the p-type detector with the thicker lithium-diffused n^+ contact was used as the E detector. After exposure to several shifts of beam, the 10-mm deep n-type transmission detectors would no longer hold a bias equal to the measured depletion bias prior to the run. Several attempts to recover the detectors by annealing failed, and they were sent back to Pehl at LBL. The properties of the p-type detector in this telescope were measured in this lab. It was discovered that the depletion bias of this detector was much larger (by ~1000 volts) than when received from Berkeley. At the same time, Pehl found that the depletion bias of the n-type detectors returned to him were about half of what they were when first sent to us. It turned out that the depletion biases of all of these detectors were considerably changed due to radiation damage, but that annealing of these detectors properly restored them to their original operating characteristics. Details of these phenomena and their effect on detector resolution are discussed below.

Figures 10 and 11 show the depletion bias changes of the p-and n-type detectors, respectively, as a function of annealing time. The detectors were annealed in 8 and 16 hour periods at approximately 140°C, and the depletion bias was obtained by measuring the ratio of the 40 keV and 100 keV X-ray intensities from a ^{153}Gd source as a function of detector bias. When the ratio becomes constant, the detector is fully biased. This technique gives results which agree to within 50 volts with the values obtained by Pehl in his

laboratory by measurement of the detector capacitance as a function of bias.

In Figure 10, the depletion bias of the 15-mm deep lithium-backed p-type detector (#514-8.6) is shown immediately following a run in which the detector was subjected to $> 10^9$ particles/cm² (curve 1). The detector was annealed for 16 hours at 146°C and then for 32 hours at 144°C (curves 2 and 3), which reduced

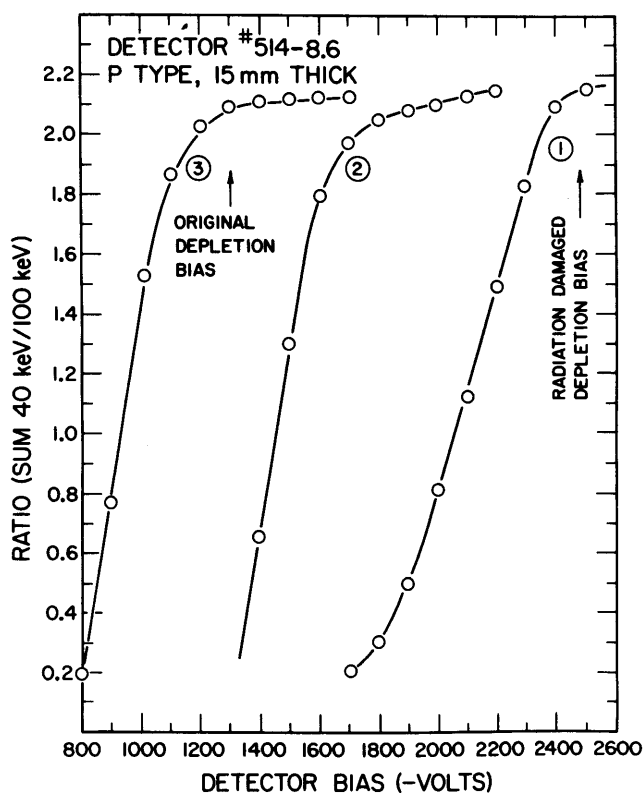


Figure 10. Plot of the ratio of ^{153}Gd 50 keV and 100 keV X-ray intensities as a function of detector bias for a radiation-damaged p-type detector (1), after 16 hours of annealing at 146°C (2), and after 32 more hours of annealing at 144°C. (3).

the depletion bias from the unexpectedly large value of -2400 volts to -1800 volts and then to -1200 volts, which was its original depletion bias prior to beam exposure.

Similar curves for the 10-mm deep n-type transmission detector (#501-6.7) from the same

telescope after annealing for 8, 16, 24, 32, 40, 48, 56 and 68 hours at 140°C are shown in Figure 11 where, in

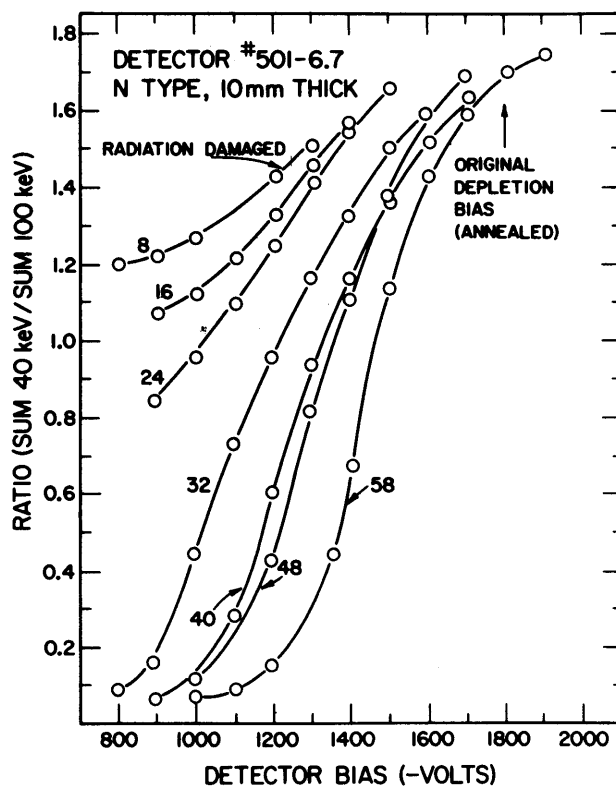


Figure 11. A plot as in Fig. 10, but for an n-type radiation-damaged detector after 8, 16, 24, 32, 40, 48 and 58 hours of annealing at 140°C.

this case, the depletion bias was raised from -1300 volts when radiation damaged to -1800 volts, which was its original value before use. Figure 12 summarises this information by showing the depletion voltage as a function of annealing time. This result, together with those obtained from other detectors similarly radiation damaged, indicates that annealing for approximately 50 hours at 140°C is required to completely repair a radiation-damaged detector. In addition, it appears now that the depletion bias of the detector is the only true measure of its state of damage. The resolution of the Gd^{153} spectrum (of the order of 2-3 keV FWHM) is unchanged throughout all of these annealing stages and

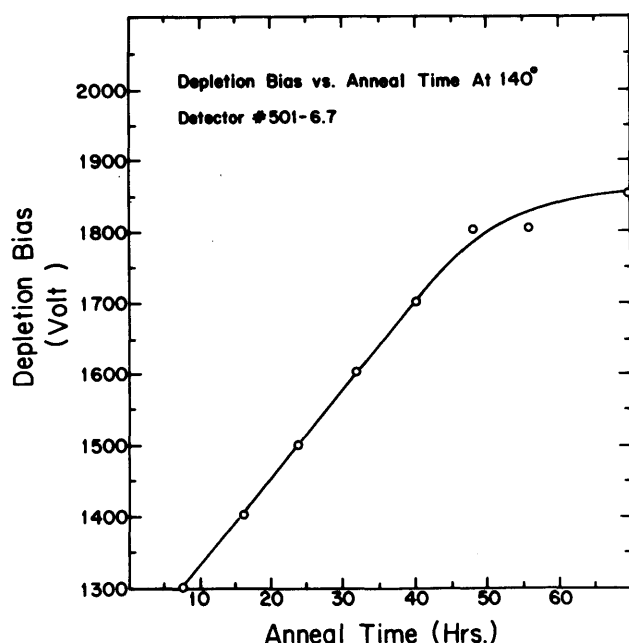


Figure 12. Summary of Fig. 11, showing depletion bias of the n-type detector as a function of annealing time at 140°C. Initial depletion bias of this detector, before radiation damage, was measured to be 1850 volts.

cannot be used as an indication of the detector's condition, as previously thought.

Apparently, not only do the depletion biases change drastically, but the change for n- and p-type detectors are in opposite directions: the n-type detector depletion bias decreases with radiation damage while that of the p-type detector increases with radiation damage. This explains the phenomenon previously reported by Pehl¹⁾ that, after exposure to beam for some period of time, the p-type detector biases could be raised above previously measured V-I curve limits, i.e., as the depletion bias is increased, the maximum operating bias is also increased. More importantly, however, this phenomenon also explains why the n-type transmission detectors apparently failed prematurely during an experiment. As the depletion bias of these detectors was lowered by radiation

damage, so was the maximum operating bias. When the maximum operating bias fell below the original depletion bias, the detector was considered "bad," and the experiment stopped. We will demonstrate here that this was not necessary, and that simply lowering the operating bias as the depletion bias decreases allows the experiment to continue. The fact that the two types of detectors change in opposite directions suggests that the damage is due to interstitial lattice imperfections (so-called Frenkel pairs) produced in the crystal by fast neutrons, which are hole-trapping centers. This is also consistent with the relatively long annealing times required to repair the damage, as reported by Pehl²⁾.

The rate of radiation damage, along with a measure of performance (i.e., resolution) of both n- and p-type detectors was demonstrated in a single experiment. In a (p,pn) coincidence experiment lasting 120 hours, an average of 50 nA of 150 MeV protons were incident on a 35 mg/cm² target. The particle telescope containing a 10-mm n-type ΔE detector and a 15-mm p-type E detector subtended a solid angle of 2 msr and moved over an angular range of 35° to 55° in the laboratory system. The change in the maximum operating bias of the 10-mm transmission detector (#501-6.7) with the total number of particles incident on the telescope is shown in Figure 13. The resolution of the detector was monitored during the run using a ⁶⁰Co source. The resolution remained unchanged at 10 keV FWHM until the run was terminated by an unexpected large drop in the operating bias, at which time the resolution of the ⁶⁰Co spectrum was found to be 30 keV. The 10 keV resolution observed prior to this time was essentially the electronic resolution of the experimental setup, as measured with a pulser. The particle resolution, as measured by the binding-energy spectrum of the

$^{40}\text{Ca}(p,n)^{39}\text{Ca}$ reaction, also remained unchanged throughout the run at 500 keV FWHM, and was mainly

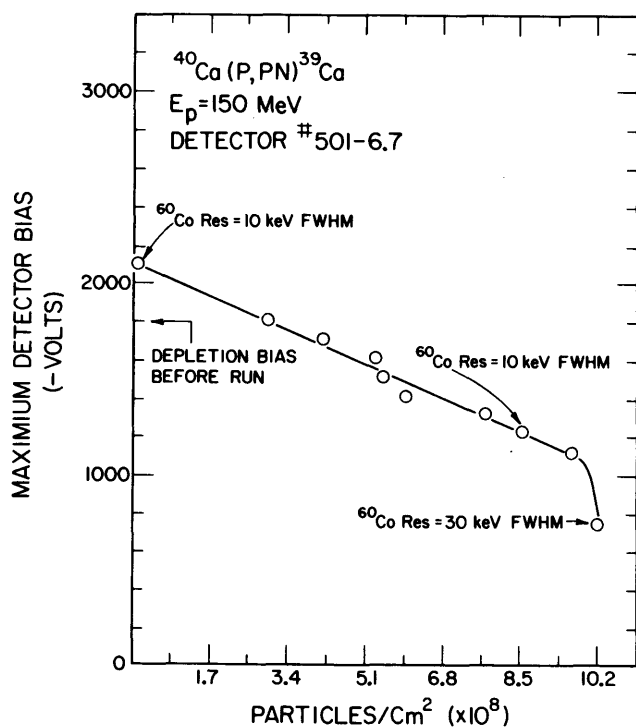


Figure 13. Maximum operating bias of the n-type detector as a function of radiation damage (particle/cm² into detector), showing the decrease in depletion bias. (Experimental conditions: 150 MeV protons incident on a 35 mg/cm² target at 30°, with a 2 msr solid angle).

determined by the neutron flight-path length of 40 meters. While this is not an exact measure of the germanium detector telescope resolution, it indicates that no significant degradation in the performance of these detectors occurs, despite the depletion bias changes, until 10⁹ particles per cm² are intercepted. Since this run, no experiment has radiation-damaged these detectors enough to see these effects. Plans are being made to make a more precise measurement of the particle resolution degradation with radiation damage, but we now believe that this is smaller than other factors affecting the overall resolution of the telescope, such as kinematic broadening. This is also consistent with the experience obtained with these

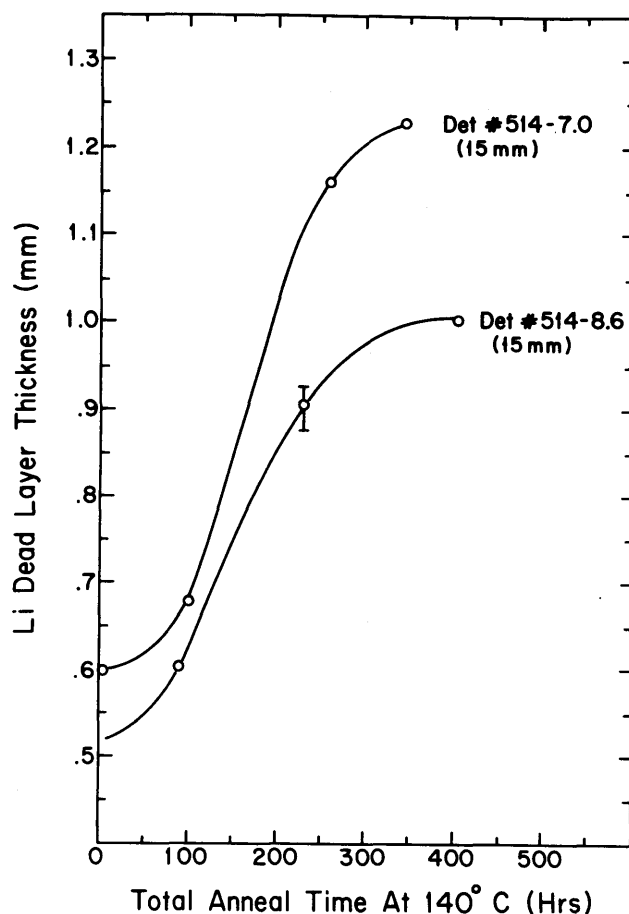


Figure 14. P-type detector dead-layer thickness increase as a function of annealing time at 140°C.

detectors prior to our discovery of these phenomena.

Another area of concern last year was the effect of long annealing times (50 hrs) on the depth of the lithium-diffused surface of the p-type germanium detector. These detectors are delivered with a lithium depth of approximately 0.5 mm. We have kept track of the drift of the dead layers of these detectors as a function of annealing time since their delivery to IUFC. The results for two such 15-mm thick detectors (#514-7.0 and #514-8.6) are shown in Figure 14. The theory put forth last year that the dead layers drift rapidly to about 1 mm and then stop appears to be confirmed by these data. These measurements are continuing.

Table 5. Inventory of IUCF Hyper-Pure Germanium Detectors

Detector No. (Type)	Transmission Mounting	Thickness (mm)	Dead Layer (mm)	Depletion bias (Volts)
#172-3.1 (p)	No	10.60	1.11	-600
#514-7.0 (p)	No	15.21	1.23	-1700
#514-8.6 (p)	No	14.94	1.09	-1100
#514-12.8 (n)	Yes	1.17	N/A	-40
#551-11.8 (n)	Yes	5.18	N/A	-1100
#477-6.1 (n)	Yes	9.52	N/A	-1750
#501-6.7 (n)	Yes	10.77	N/A	-1800
#475-10.7 (n)	Yes	9.07	N/A	-2100
#550-8.6 (n)	Yes	~13.5	N/A	-700
#517--9.7 (n)	Yes	~15 mm	N/A	-1500

Note: Useful area of all detectors is 450 mm².

Table 5 provides a list of the presently available detectors at IUCF, along with some of their properties which may be useful for planning an experiment. Two each of the 10-mm and 15-mm thick n-type transmission detectors are currently being fabricated for us at LBL, to complete what is hoped to be the final inventory of these detectors here.

- 1) H.W. Kraner, R.H. Pehl and E.E. Haller, IEEE. Trans. Nucl. Sci. NS22, No. 1, 149 (1975).
- 2) R.H. Pehl, L.S. Varnell, and A.E. Merzger, IEEE Trans. Nucl. Sci. NS25, No. 1, (1978).

6. Data Acquisition System

(i) Data Acquisition Hardware. Much of the past year was spent in maintaining the existing equipment. Because one skilled technician position has remained unfilled for six months, maintenance of counter systems and NIM hardware represented a larger-than-anticipated burden.

The slow-speed link communications system has been completed. All three Harris computers and the Xerox control computer are now connected in a star configuration. The microcomputer-controlled CAMAC crate in the center of the star will be able to expand service to new computer systems as they are purchased.

Additional hardware has been constructed or purchased to allow for more than one CAMAC crate per computer system. It is anticipated that the advent of an all-CAMAC based acquisition system will require the use of multiple crates for the first time.

An optically-coupled, differential branch highway extender has been constructed for our CAMAC parallel system. This system provides for ground-loop free operation of our crates at distances exceeding 1000 feet from our computers. This unit will be used for the beam-swinging facility as well as the CSB experiment at the polarized neutron beam facility.

A new joystick CAMAC module is now in operation.

It provides for jitterless operation, variable maximum scale and variable acceleration. In addition to the joystick control, the module contains a date and time-of-day clock for the computers.

Because of diminishing computer availability for testing purposes and the ever increasing number of CAMAC-based acquisition modules, an off-line testing facility has been set up. Using the same microcomputer that controls the link, the off-line CAMAC crate may be down-loaded from the Harris computers. The off-line facility is then used to exercise the TDC or ADC under test. A storage-scope display is also provided for simple diagnostic purposes.

During the latter part of 1980, an increasing amount of effort has gone into design work of the large-scale data acquisition system for the upcoming CSB experiment discussed in a later section of this report.

(11) Data Acquisition and Analysis Software. The increasing difficulty in incorporating required enhancements into the data acquisition program DERIVE led to the decision, early in 1980, to create a new data acquisition system. This system, RAQUEL (ReaL time data AcqUisition and EvaLuation), was completed to the extent that the first version was released on January 1, 1981 for general use.

RAQUEL is a multi-coincident group CAMAC acquisition system which uses dynamic core blocks to hold all parameters and variables. It is written in structured FORTRAN and has no COMMON blocks. This has the advantage of using core for the purposes of each configuration of options, rather than for options for which a particular user has no need. An additional feature of this technique is that there are no software limits on the number of items like arrays, windows, scalars, etc., that a user may define. The only

limitation will be the physical limit of the amount of core available.

A much wider capability in specifying conditions necessary to be satisfied in order that an array be sorted into was also developed. All logical operators, such as .AND., .OR., .XOR., are possible in the construction of a "gate" for an array. Hence, as an example, one may set up the condition that an event be sorted into an array if it is (inside window 1) .OR. (inside window 2).

RAQUEL also uses external sorting programs and external array analysis programs to aid in the development of software uniquely suited for a particular experiment.

RAQUEL has already been used in the tests of a multiwire proportional chamber and of the pion-spectrograph focal-plane drift chamber, and the initial reaction of experimenters is favorable.

In the realm of analysis programs several programs were ordered from the library of "Computer Physics Communications". Implemented and currently functioning are: ABMA, PAKINE, PKPLOT, APLOT, POLARPLOT, EMCASR, KOROBO, SCAT, PIRK2, A-THREE, RCWFN, and EISPACK. Also implemented were CHUCKY from Colorado and RELKMC from CERN.

Further software making use of LINKER, the in-house inter-computer communications link, has been developed. Specifically the ability to send files, or to retrieve files, between computers is now possible and greatly aids housekeeping chores.

The capability now exists in DERIVE (and will soon be implemented in RAQUEL) to control remotely and automatically the polarization states of the beams from the polarized ion source. Under the control of an internal clock, the program cycles through a predetermined set of spin states, acquiring data

separately for each one. For protons, spin up and down are provided automatically. For deuterons, the user is free to choose from among seven states, including positive and negative vector polarization, and positive and negative tensor polarization with either sign for the vector, as well as unpolarized. A complete list is shown in Table 6. Typically, actual beam polarizations are about 75% of maximum for protons and 90% of maximum for deuterons.

Under spin-flip operation, the arrays for each spin state reside temporarily on disc. At the beginning of the time allotted to each spin state, the appropriate set of arrays is read in from disc, and acquisition starts. After a user specified clock time has elapsed, acquisition stops and the arrays are read back to disc. At the same time, a command is issued via LINKER to the control computer to set the polarized-ion source for the next spin state. A positive response is required from the ion source indicating that the action is complete before proceeding. The scaler information is carried with the arrays. Changing the spin state requires about one second. So that this overhead is a small fraction of the beam time, users generally choose run times for each spin state between 15 and 60 seconds. In event-mode tape recording, an extra parameter is added to each event word specifying the spin state currently

in operation.

Use of periodic spin flip has proven to be important for maintaining reproducibility in the measurement of precise analyzing powers. Small changes in the background or detector electronics with time previously made comparisons between the spectra for different spin states imprecise because they averaged over different blocks of time. At present, all of the polarized beam experiments make use of this feature.

(iii) Operating System. A new feature was added to the CAMAC handler which keeps track of the interrupt status of the handler ("held" or "restored"). FORTRAN interface to this feature was also implemented. This makes the handler more general and will be needed when a second CAMAC crate is implemented. Documentation was completed on the CAMSRV program.

The DMS system boot was modified to implement the new clock module on the "C" computer. This new feature will read the clock module if it is present, otherwise it requests the date and time as always. This allows new modules to be added and old ones removed without further software alterations.

The relevant DMS library subroutines and utility programs were modified to utilize the second disc drive where one exists.

An input/output package which uses the upper core map was written for DMS. Some new utility programs implemented on DMS include:

- MTFAST--A fast magnetic tape copy program which uses double buffering for separate input and output channels, and the upper map which enables copying very large files.
- TDUMP --A general-purpose magnetic tape dumping program.
- MTRD --A program which facilitates the reading of source code tapes made on other computers.

Table 6. Maximum values of the beam polarization provided by each spin state in periodic spin-flip operation.

SPIN STATE	PROTON	DEUTERON	
	P_y	P_y	P_{yy}
A		0	0
B	+1	+2/3	0
C	-1	-2/3	0
D		-1/3	+1
E		+1/2	+1
F		-1/3	-1
G		+1/3	-1

MTWRT --A program which facilitates the creation of source code tapes to be read on other computers.

The two IUCF documentation programs DOCLST and DOCMNT were improved and expanded.

Preliminary work has been done on the FORTRAN compiler to enable the use of the upper memory map under DMS.

Some software for the new joystick module is completed; additional work remains to be done.

The VULCAN 8 operating system was installed. New MACROS were written and the utilities were streamlined. Several bugs were discovered in this system and are awaiting corrections from the vendor.

B. Future Facilities

1. Polarized Neutron Beam Facility. The polarized neutron production facility¹⁾ (see location 7 on experimental area floor plan, Fig. 5) is now scheduled for completion in the fall of 1981. All of the commercially fabricated special beam-line magnets, large-aperture quadrupoles, and the proton sweeper magnet are in-house and are being prepared for testing and field measurements. Vacuum enclosures, special beam-line diagnostic devices, and stands for the various beam-line components are presently being fabricated at IUCF. The shielding penetration block has been installed which will contain neutron shutters for both the QDDM and polarized neutron beam lines. The primary radiation shielding wall to isolate the new area from the swinger beam line has been completed. A trench in the concrete floor appropriate for imbedding the primary proton beam dump and associated shielding has been contracted and will be excavated in the spring of 1981. The heavy concrete blocks which will form the

experimental shielding wall and other miscellaneous shielding blocks will soon be poured by the contractor. The cryostat, gas handling, and safety venting system needed for the liquid-deuterium neutron production target will be tested soon with a liquid hydrogen target (to be used in an experiment in radiative n-p capture).

1) IUCF Scient. and Techn. Report 1979, p. 155.

2. Charge Symmetry Experiment. Each of the two identical detector arrays for the $n\text{-}p$ charge symmetry experiment^{1,2)} will consist of a wedge-shaped ΔE plastic scintillator, four multiwire proportional chambers (MWPC), providing horizontal and vertical position information for recoiling protons at two different distances from the target, and a large-volume, position-sensitive liquid scintillation detector for neutrons (and protons). The liquid scintillator (Nuclear Enterprises type NE235H, with mineral oil base) will fill an aluminum vat subdivided into ~100 tapered subcells by thin (0.1 cm), highly polished (83% reflectivity), intersecting aluminum walls. Each such subcell will be viewed from the rear by a 2-inch diameter, 10-stage, fast photomultiplier tube (RCA model 4518), whose output signals are processed by a home-built base incorporating a constant-fraction discriminator circuit. The liquid scintillator is presently in house, the phototubes on order, and the bases being designed and constructed by collaborators at Hope College, Holland, Michigan. A 12-cell prototype of the neutron detector, presently being fabricated at IUCF, will be tested in the spring of 1981 and subsequently used in a measurement of the angular correlation for n-p pairs produced in quasi-free scattering. The latter process should

represent the major source of background contamination in the charge symmetry experiment. Work is in progress on a sophisticated Monte Carlo code to simulate the neutron detector response, including possible systematic effects arising from asymmetries in the interaction of polarized incident neutrons and from multiple interactions of a single neutron.

Construction and testing of the large-area MWPC's will proceed at IUCF in parallel with the neutron detector development. Wire signals will be processed by commercial (LeCroy PCOS-II) MWPC cards and home-modified commercial readout controllers. The signal-processing logic for other detectors will combine commercial electronics (e.g., LeCroy multiple-input TDC's and ADC's) with home-built electronics (e.g., analog summers and coincidence latches). Design of the home-built modules is under way. The electronics will be located in a hut (already constructed) just outside the experimental cave. The readout logic will transfer to the computer (via CAMAC) a variable number (>12) of words per event, to accommodate multiple "hits" in the neutron detectors and MWPC's. We presently envision software processing to employ a modified version of the new general-purpose data acquisition code RAQUEL.

Fabrication of the wedge-shaped ΔE scintillators and of the neutron beam flux and polarization monitors needed for the charge symmetry experiment are planned for late 1981. The cryostat for the "spin refrigerator" polarized proton target has been constructed, leak-tested and cooled to liquid-helium temperatures at the University of Wisconsin, Madison. Superconducting coils to produce the polarizing magnetic field (~ 1 T), in which target samples will be rotated at ~ 20 Hz, and normal conducting Helmholtz coils to produce the much smaller (~ 0.1 T) holding field

required when the target is stationary, will shortly be installed within the cryostat. Target samples consisting of polycrystalline rectangular slabs ($6 \text{ cm} \times 8 \text{ cm} \times 0.75 \text{ gm/cm}^2$) of Yb-doped yttrium ethyl sulfate, will be grown and tested beginning in the summer of 1981. We now envision experimental runs with polarized neutrons on polarized protons beginning in 1982.

- 1) S.E. Vigdor et al., IUCF Technical and Scientific Report, 1978 (p. 15) and 1979 (p. 118).
- 2) S.E. Vigdor et al., Proc. Fifth Intl. Symp. on Polarization Phenomena in Nuclear Physics (Santa Fe, New Mexico, Aug. 11-15, 1980), to be published.

3. Proposal for a New Magnetic Spectrometer System. A design for a pair of magnetic spectrometers was completed in the spring of 1980 and an equipment funding proposal¹⁾ was submitted to the National Science Foundation in August. The spectrometer system consists of a 10 msr, $K=600$ MeV spectrometer designed to give 10 to 15 keV resolution in a 20 MeV excitation range for reaction products of 80 to 200 MeV and a 20 msr, $K=300$ MeV spectrometer of lower resolving power, $p/\Delta p = 2000$, with a broad momentum bite, $p_{\text{max}}/p_{\text{min}} = 1.35$. The project is a joint undertaking of Indiana University ($K=600$) and the University of Maryland ($K=300$). The combined system will permit either high-resolution single-particle measurements (the second magnet serving as monitor) or high-data-rate two-particle correlation measurements.

The $K=600$ spectrometer utilizes position and angle measurements in two planes after the magnet to correct for residual aberrations and can achieve better than 15 keV resolution with an 8 msr solid angle while using the full cyclotron beam energy spread (no energy selection) and 60% to 90% of the full beam emittance (split beam mode). The momentum dispersion in this

design is varied by changing the field ratio in the two dipoles so that a fixed energy dispersion (40 keV/mm along a 60 cm detector) may be maintained over a range of scattered particle energies from 80 to 200 MeV.

Another somewhat unusual features of this magnet is the open-sided entrance quadrupole and a beam deflector magnet which in combination can divert the incident beam to one of three well-shielded external Faraday cups for scattering angles down to 2.5° . From our experience with spectrometer detectors at IUCF energies, the use of an external shielded cup is essential for tolerable background rates with beam currents above about 100 nA. The magnet radius of 2.1 meters which is determined by the resolution goal is large enough to bend nearly all reaction products (except for $(^3\text{He}, t)$ above 200 MeV).

The K-300 spectrometer has a vertical orientation orientation to give (in combination with the K-600 system) the widest possible range of correlation angles. The large momentum acceptance and solid angle for both magnets, in combination with the 100% macroscopic duty factor of the IUCF beam, give a very good performance figure for particle-particle correlation measurements.

The spectrometer system will be installed in the north end of the IUCF crane bay as indicated in Figure 15. The beam analysis system employs the existing QDDM spectrograph magnet as primary analyzer with an adjustable dispersion match at the target.

- 1) "A New Magnetic Spectrometer System for Intermediate-Energy Physics at the Indiana University Cyclotron Facility," A Joint Proposal of IUCF and the University of Maryland to the National Science Foundation, August 1980.

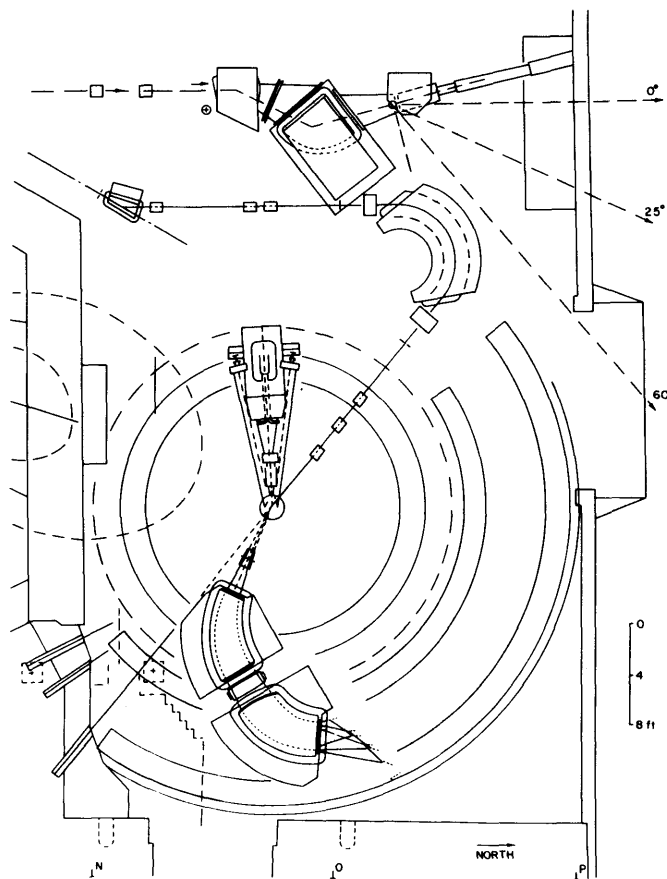


Figure 15. Floor plane showing the north end of the IUCF crane bay with the new beam transport branch incorporating the existing QDDM magnet as analyzer and the K-600 and upright K-300 spectrometers on a common circle. The three external beam dumps are adjacent to the existing QDDM dump to the south. The magnets on the west side are part of the beam swinger system. North is to the right in the figure.