EXPERIMENTAL FACILITIES DEVELOPMENT

A. Facilities in Operation

1. Polarized Neutron Beam Facility (PNF)

Neutrons were first produced in the PNF on September 2, 1982, with the use of a thick $^7$Li production target, and initial room background measurements were made. Shortly thereafter first use was made in the beam line of a prototype of the 20-cm thick liquid deuterium (LD$_2$) cell that will serve as the neutron production target in the charge symmetry breaking CSB$^2$ experiment. During this run, initial measurements of the neutron beam flux and polarization were made. Subsequently, two more runs in the PNF were made before the year's end: one to measure the neutron energy spectrum with good resolution from the LD$_2$ cell in its final configuration, and one testing out a large fraction of the detectors (MWPC's and large position-sensitive neutron counters) which will comprise the n-p detection system for the CSB experiment. In short, the polarized neutron beam facility has sprung to life, and much progress has been made with initial shakedown runs and tests of the equipment and detector systems to be used in conjunction with this new area.

Although the cryostat for the LD$_2$ cell and much of the gas handling and safety-venting systems were developed and used successfully in an experiment (n-p radiative capture) requiring a liquid hydrogen target, several modifications were needed in order to use the device as a liquid deuterium neutron production target in the primary accelerator beam. A fast acting valve (closing time of order 5 msec) of the type developed at Brookhaven$^4$ for use with the National Synchrotron Light Source was installed in the beam line approximately 9.5 meters upstream from the target position in order to prevent deuterium from getting into the accelerator or other laboratory beam lines in the event of a violent rupture of the target. Because the existing layout of the beam lines forced the fast valve to be at a relatively short distance from the LD$_2$ cell, an "acoustic delay line"$^5$ consisting of a 30-cm diameter beam pipe filled with baffles with a central aperture contoured to the beam shape. Since the fast valve doesn't hold high vacuum, it is backed up by a conventional (slower closing) beam line valve. The signal to fire the valve is derived from a small ion pump$^6$ located on the LD$_2$ target vacuum box. A test of the system, made by rupturing a thin window located on the side of the LD$_2$ target vacuum box showed no observable pressure rise on the upstream side of the fast valve system. The controls for the target and beam line vacuum systems have been modified to insure that target filling cannot begin until the safety-venting system interlocks have been activated. The target vacuum box cannot be opened to the accelerator until the fast valve is cocked and ready to fire.

Because the proton beam is a significant (and variable) heating source for the liquid target a feedback circuit was devised, working off the target pressure, which controls the current to a heating resistor on the target cold head in such a way as to keep the total heat load a constant and thus the target in equilibrium. The target itself is in the form of a cylinder connected by a fill line to the cryostat so that its axis is ten degrees from horizontal. The proton beam, bent also at 10°, passes along the cylinder axis and the neutrons of interest are produced.
parallel to the floor. The target cell is made from a 4.2-cm (o.d.) stainless steel tube turned down to a .0254-cm wall thickness over most of its length. The endcap windows are .0051-cm stainless steel, welded to the tube. The volume of the liquid in the cell is about .25 l. The vacuum pumps which could be exposed to deuterium gas upon failure of the cell have a special vent line going to the outside of the building. The area around the target is enclosed by a hood which is vented with a positive flow to the outside by an explosion-proof fan. The beam line vacuum in this area is sensed by thermocouples operated at low current. High vacuum in the beam line and LD$_2$ target are sensed by the small ion pump and a cold cathode gauge, which are possible ignition sources for deuterium that gets into the vacuum system. Work is in progress to "crowbar" the power supplies for these two devices in a time scale of order 5 msec after loss of vacuum is sensed.

A neutron beam monitor/polarimeter to measure the profiles of the beam intensity and its normal (N) polarization component (with relatively little sensitivity to instrumental asymmetries), and to provide at least crude data on the sideways (S) polarization component, has been constructed and installed in the PNF. It is located about 4 meters from the exit of the neutron collimator, near the beam dump (in the floor) for the primary beam. The polarimeter uses n-p scattering as the analyzer and consists of several NE-102 plastic scintillators viewed at either end by photomultiplier tubes. The target is a .32-cm thick (3x20cm$^2$) scintillator preceded by a thin veto scintillator in order to ensure that the scattering is initiated by neutrons. The recoiling protons produced by n-p scattering in the target are detected at a lab angle of 59.5° by nominally 2.5-cm thick (10x25cm$^2$) scintillators positioned on beam left and right at a distance of 65 cm. Timing between the two ends of the scintillator gives a position resolution of about 3 cm along the scintillator's vertical extent, allowing sufficient definition of the scattering plane for our purposes. A scintillation detector whose center region is plain lucite is positioned behind the veto/target combination for measurements out of the scattering plane (S direction).

Figure 7 shows the time-of-flight spectrum with respect to the cyclotron RF obtained in the October run for neutrons initiating reactions in the scintillator target of the polarimeter. As expected, the spectrum is dominated by the high-energy D(p,n) charge-exchange peak, with a width (FWHM) of ~ 15 MeV. Using calculated values for the polarimeter efficiency and analyzing power for n-p scattering events yielding protons at $\theta_{\text{lab}} = (60\pm5)^\circ$ to the left or right of the beam direction, we deduced from polarimeter measurements in this first run that the beam flux $I_n$ and polarization $P_n$ were consistent (within 10-20%) with the expected values: $I_n = 5\times10^6$ n/cm$^2$-sec at a

![Figure 7. PNF Neutron time-of-flight spectrum](image-url)
position 4 m downstream of the LD$_2$ target when 50 nA of protons are incident on the production target; $P_n = 60\%$ for incident protons with 75% polarization. In the October run we also measured room background singles rates in individual cells of the 12-cell prototype liquid scintillator detector for energetic neutrons under conditions approximating those relevant to the CSB experiment. The observed rates, $\sim 10^4$/l/sec per cell (each cell has a volume of $=4$ liters), should not pose a significant problem in the electronic processing of CSB events.

More detailed measurements of the neutron beam properties have been made in a November run, and will be supplemented in a run scheduled for late January, 1983. The goal of the November run was a measurement of the beam energy spectrum, with good resolution (~2 MeV), as a function of position transverse to the beam direction. The resolution was achieved by measuring the energy (in an intrinsic Ge detector telescope) and scattering angle ($\theta_{\text{lab}}=32^\circ$) of protons resulting from free n-p scattering in a target scintillator of sufficiently large area to intercept the entire neutron beam. The proton angle and projected position of origin of the n-p event in the target were determined with a pair of multi-wire proportional chambers (MWPC's) immediately following the target and a position-sensitive Si detector immediately preceding the Ge stack. The coincident scattered neutrons were detected in the 12-cell prototype liquid scintillator, permitting discrimination against quasi-free scattering n-p events. The data from this run, which are still being reduced, should also provide information on the neutron beam intensity profile and on the efficiency of the prototype neutron detector.

Further measurements of the intensity profile, as well as of the polarization profile, of the beam are planned for the January run. In that run we will also calibrate the neutron polarimeter in the PNF against phase-shift predictions of n-p analyzing powers. The calibration measurements will involve detection (again with the prototype liquid scintillator) of coincident neutrons scattered from the polarimeter target, in addition to the usual detection of recoil protons in the polarimeter scintillators. The neutron detection will substantially improve the definition of scattering angle and the discrimination against quasi-free events, in comparison with normal polarimeter usage. This calibration will be sufficient for our use of the polarimeter in the CSB experiment, although for general purposes it will clearly be desirable to provide at some later date an absolute calibration independent of n-p scattering. We attempted such a calibration this past summer, by comparing analyzing power [$A_y(0)$] and outgoing neutron polarization [$P_n^y(0)$] measurements for $^3\text{H}(p,n)^3\text{He}$ vs. $^3\text{H}(p,n)^3\text{He}$, with the recoil $^3\text{He}$ detected in the QSP magnetic spectrometer. This scheme works in principle because time reversal invariance plus charge symmetry require $A_y(0)=P_n^y(0)$ for $(p,n)$ reactions connecting mirror states. Unfortunately, we were unable to achieve a useful calibration in the allotted time since several factors (especially insufficient tritium content in the tritiated titanium foil used and singles rate limitations in the polarimeter detectors) conspired to make the coincident count rates much lower than expected for the polarization measurement.

2) More details can be found on p. 101 of this report.
4) T. Oversluizen, BNL-29837.
2. Beam Swinger Facility

Several modifications were accomplished to improve performance reliability of the beam swinger target and angle drives. Each hut was fitted with new styrofoam detector windows to reduce weight for easier handling and to minimize neutron attenuation. The dump magnet vacuum chamber exit window was modified to minimize energy losses for a 12° time monitor for (3He,n) studies. Extensive temporary shielding modifications with a neutron collimator were built, installed and removed to accommodate (n,p) feasibility studies. A magnet was modified, installed and used for these studies to bend protons scattered at small angles into hyperpure Germanium telescopes located out of the neutron flux. For (d,n) break-up measurements two small styrofoam huts with temperature regulation were fabricated. In order to support temporary ac power lines to the large TOF huts, new movable powerline supports were designed and fabricated. These supports have concrete bases designed for forklift handling and ropes and pulleys for raising power lines overhead. A vent system to accommodate the safe use of a liquid hydrogen target in the swinger vault was installed for use with a neutron radiative capture experiment.

3. QQSP Pion Spectrometer

Flexible water lines to the QQSP were found to be cumbersome to use in practice. Water swivel connectors were installed above the center of rotation of the spectrometer to alleviate this difficulty. The QQSP was used in its zero degree mode for the first time. To do this a 0-degree Faraday cup-to-spectrometer interface piece was fabricated and installed. The vacuum plumbing was also modified. A small amount of Faraday cup shielding must be restacked appropriately to run the QQSP at zero degrees.

4. QDDM Magnetic Spectrometer

Efforts to run the spectrometer to very forward angles have continued. A special offset internal Faraday cup was installed for this purpose and tested successfully at 6 degrees. In order to perform (p,p'γ) measurements with a large Na(I) gamma detector at 90 degrees to the horizontal reaction plane, defined by the spectrometer, a special hydraulic mount was designed by M. Kovash at M.I.T. and assembled at IUCF. A special lid for the QDDM scattering chamber and a side-port entry target ladder was built for this experiment.

5. 64" Scattering Chamber

This general purpose chamber continues to be adapted for a variety of uses. In addition to the past usage with intrinsic germanium detectors and/or solid state detectors and/or channel plate detectors and/or scintillator detectors used in multidetector arrays in the horizontal plane, the chamber was modified to use multiple scintillator detector arrays out of the horizontal plane with the target at a position near the chamber entrance. This was done for an (α,2p) experiment.

6. Low Intensity Area (γ-cave).

This area continues to support many different experimental setups. The major permanent modification in the last year was to accommodate the new 3-D rotating scattering facility. However, several somewhat extensive special setups were accomplished. For a feasibility study of (p,p'γ) with the large O.S.U.
γ-detector in the horizontal plane and a Ge proton detector telescope in the vertical plane, the out-of-plane chamber used for deuteron polarization measurements was appropriately modified. Protons were detected after passage through a 5 mil Kapton window and several inches of air.

An entirely different new setup was designed and installed for supporting the lead glass detector array for (p,π⁺) angular distribution measurements. The usual (p,γ) setup with the large NaI detector on airpads and the special thin walled scattering chamber continues to be used several times each year.

7. Other Target Area and Support Efforts

As usual there have been many smaller and often unplanned jobs performed this year to support the research of scientific users at IUCF. These together with maintenance and routine reconfiguration of apparatus constitute the bulk of efforts of the research support group. A special effort was required late in 1982 to accommodate the Rice University group's calibration run for the Brookhaven 200-MeV polarimeter. This device was installed at the last intermediate waist position in the swinger beam line upstream of the swinger entrance magnet. A water manifold was moved to provide clearance at this location. Actuators with T.V. viewers were installed just upstream and downstream of the polarimeter to allow instrumental asymmetries to be determined as a function of beam angle. Beam line supports were provided for the polarimeter and copper plates for degrading detected proton energies. A special beam line tune was calculated and executed to provide an essentially parallel beam at the polarimeter target location.
8. 3-D Rotating Scattering Facility

A new scattering facility which allows independent rotation of two semi-circular detector platforms of 30° radius about the beam axis has been constructed. The system was installed in the γ-cave for initial use by two experiments in September. In one of these the detector platforms formed a vertical plane for the measurement of the tensor analyzing power $A_{xx}$ in 80-MeV polarized deuteron scattering from $^{3}$He. The second experiment measured the tensor parameter $A_{yy}$ in 80-MeV deuteron break-up on hydrogen, detecting the two final-state protons in a symmetric but non-coplanar "butterfly" geometry. This arrangement is illustrated in the photographs (Fig. 9).

In both experiments two high-purity Ge detector cryostats were employed, each mounted on a motor-driven arm (designed to cover the range of scattering angles $5°<\theta<175°$) on opposite sides of the beam. As illustrated schematically in Fig. 10a, the target and detector systems were in air, and the incoming and outgoing primary beams were transported to and from the target area via long, tapered vacuum snouts, passing through 25μm Haver foil windows at the vacuum-air interfaces. Since then, a sophisticated, solid-target vacuum chamber with a 4-target cassette, providing sliding-seal vacuum connection to detectors while permitting relative azimuthal (out-of-plane) detector motion through $\pm30°$, has been fabricated and is awaiting final assembly and testing (see schematic arrangement shown in Fig. 10b). Other custom-designed solid-target chambers or large-diameter gas target cells may be readily interfaced with the beam transport snouts, making this scattering facility a versatile and convenient system, adaptable to a variety of experimental configurations. Particularly attractive is the use of this facility for experiments employing Ge-detector cryostats since the detector vacuum housing with its attendant LN cryostat, vacuum and LN transfer lines, and signal/bias cabling is in air and readily accessible for easy installation and servicing.

The two detector arms incorporate wedge-shaped (10° wide) detector mounting platforms which are narrower than, but otherwise identical, to those used in the 64" scattering chamber, with the same platform-to-beam distance. Hence, detector systems designed for the 64" chamber may be used with the 3-D scattering facility. The 6-target wheel assembly of the 64" chamber has also been adapted for use with the 3-D facility. Only local arm angle setting and readout (to ±0.1°) is at present available; a digital angle encoder system will be installed shortly, and remote
Figure 9. Top photo: typical experiment setup for the 3-D rotating scattering facility involving Ge detector cryostats. Beam is conducted (from the left) through a vacuum snout to the target wheel. The chain for driving the right detector arm can be seen embedded in the rim of the corresponding semi-circular platform. The worm-gear drive for rotating each platform about the beam axis is visible on the beam entrance hub.

Bottom photo: bottom view of the scattering facility, showing the honeycomb construction of the detector platforms, the rotation hubs for the arms (with target wheel mounted on one of them), beam entrance snout and worm-gear drive.
arm angle control will follow by mid-1983. The azimuthal rotation of the detector tables about the beam is manual (using a self-locking worn gear system) and will not be automated, although eventual installation of a (locally-controlled) motor drive system is contemplated. The honeycomb structure of the detector tables (evident in the photographs, Fig. 9) makes for a fairly light-weight yet very rigid structure with a reasonable load-bearing capacity for detector shielding.

The whole system can be removed (as a unit) fairly quickly and reinstalled without loss of alignment on a set of pillow blocks permanently mounted on the beam-line rails (the conventional low-mass beam pipe/target holder combination for γ-ray work has been adapted to these new mounting blocks).

9. Target and Detector Development

(i) Scintillation Detector Lab

During the past year the scintillator lab has built or repaired 60 detectors. Among the new detectors is an array of general purpose counters with active areas of 4" x 4" and 6" x 6" in thicknesses ranging from 1/16" to 1/2". These are seeing continuous use in various experiments and bench tests. Also, 16 1/2" thick plastic Cerenkov detectors have been built and were recently used in a (p,π⁺) experiment. A previously existing hodoscope was modified with the addition of 10 new elements and successfully used in a ⁴He(p,d)³He experiment.

The hodoscope and Z detectors used in p(n,d)γ were removed from the swinger facility and inspected for damage. They have been exposed to rather extreme temperature changes and it was feared that they might have become crazed. When inspected, the detectors showed no sign of damage. This seems to indicate that annealing detectors immediately after construction greatly lengthens their life. These particular detectors were annealed for 24 hrs per 1/16" thickness at 50°C.

A prototype detector was built to measure accurately low intensity beams and to do beam profiling. The detector consisted of 4 thin strips of scintillator each coupled to an optical fiber of a different length. The fibers were then attached to the same photomultiplier tube. The lengths of the fibers were chosen so that each successive one was 2 ns longer than its neighbor. A test was made with a 0.5 nA, 150 MeV proton beam. A very clean and separate signal was seen from each element.

A new detector has been built using scintillating fibers in place of the scintillator strips and is now ready for an in-beam test. The fibers will allow closer packing so that more elements can be employed.

(ii) Multiwire Proportional Chambers (MWPC)

The designs for both large and small multiwire proportional chambers (MWPC) intended primarily for use with the charge symmetry breaking (CSB) experiment have been finalized. All six of the small chambers (active area = 37.4 x 32.5 cm² and 2 mm wire spacing) have been built. The large chambers are under construction and will be finished this spring.

Prototypes of the large horizontal and the large vertical chambers have been bench tested and used with the beam. Bench tests with a ⁹⁰Sr electron source showed that the graphite coated mylar planes had sufficient rigidity to give a constant efficiency over the entire active area of the MWPC. No extra support was required although this had been anticipated. The horizontal chamber has an active area of 64.8 mm x 85.4 cm² and a wire spacing of 4.36 mm. The vertical chamber has an active area of 69.8 x 88.6 cm² and a
The problems with the LeCroy PCOS II MWPC readout system were found to be caused by two separate phenomena: 1) Design flaws in the chamber boards, 2) inadequate R.F. shielding on the MWPC's. When these problems were diagnosed and fixed the readout system appeared to function adequately. A duplicate of the PCOS II 2700 controller has been fabricated and used during several experiments involving MWPC's. Both units have been modified to permit faster readout.

The first run in 1982 to use these MWPC's with the beam was in the new PNF area in conjunction with an attempt to measure the neutron beam energy spectrum with high resolution. A small horizontal and a small vertical chamber were used to locate the position that the recoiling protons left the scintillator target. The only problem with the MWPC's which developed in this run was a sense wire breaking in the horizontal chamber. The chamber was replaced with a backup chamber which performed well during the rest of the experiment.

The second run in 1982 using MWPC's was intended largely as a test with beam of the performance of the large prototypical MWPC's. In fact, during this run, a large portion of the n-p detection system to be used for the CSB experiment was set up and tested. Two small horizontal, two small vertical chambers, one large vertical and one large horizontal chamber were used during this run. All MWPC's performed well except for a gas leak which occurred in the large horizontal chamber before the run started. The leak was fixed but the gas window will be reinforced to try to prevent this type of failure from occurring in the future.

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Although the wire chamber group has most of its time committed to ongoing projects, it is able and willing to assist any experimental group in the measurement of the $p(n,d)\gamma$ reaction at 190 MeV (Exp. #93) was a large contribution of deuterons produced by $(n,d)$ reactions (into the continuum). This background mainly originated in the two scintillators immediately preceding and following the liquid hydrogen target, i.e. the veto counter and the entrance hodoscope. In order to remove this source of background an extension of the detector set up was required. Low mass, fast response, and the ability to handle high count rates make multi-wire chambers (MWPC) most feasible as diagnostic elements to distinguish between charged particles produced in the target or elsewhere. Therefore, in the new configuration two MWPC's immediately downstream and upstream of the $\text{H}_2$ target were used. They are bolted directly to the vacuum jacket which surrounds the cryogenic target cell.

Each of the two MWPC's consisted of a 10x10 cm wire plane (WP) enclosed at both sides by a cathode...
plane (CP) made of graphite coated 0.006 μm Mylar foil. Gold plated tungsten wire with a diameter of 20 μm has been used and the wire tension was chosen to be 0.5 newton. The wire spacing was 2.0 mm and the distance between the wire plane and both cathodes was 6.4 mm. Separate frames carrying the wire arrangement and cathode planes were made of 1/8 in. G10 printed-circuit board. The plane assembly was mounted on four plastic rods (R) inside a 24 x 25.4 x 6.4 cm³ aluminum housing (H). The outer windows (Wo) were made of 0.006 mil aluminized Mylar. The inner windows (Wi), sealing against vacuum inside the jacket, consisted of 0.025 mm stainless steel foils supported by printed circuit board rings. This housing provided excellent protection of the detectors against environmental high frequency noise.

The MWPC's were operated under atmospheric pressure. Different counting gas mixtures were tested but best results were obtained with Argon (balanced) plus 25% Isobutane and 0.3% 13Bl Freon. The mixture was bubbled through Methylal at 0°C Celsius. The gas flow for each chamber was approximately 4 l/hour.

Since no position information was required, the detector electronics were simple. All wires of a wire plane were electronically connected and carried directly to a nearby Ortec 579 Fast Filter Amplifier for amplification (S). The initial signal out of the chamber for minimum ionizing particles was typically -10 mV. A Kiebler type 5900 dual high voltage power supply provided the negative bias for the cathode planes (HV). The sparking resistance of the chamber was improved drastically by placing a 10 MQ resistor in series. Since long high-voltage cables were used, no additional capacitive filter elements were necessary.

The MWPC's have been operated between -4.0 and -4.6 kV, in the middle of a distinct plateau. Typical currents were 6 μA at counting rates around 300 kHz. The time resolution of the chambers was found to be 16 ns and detection efficiencies were around 98% and varied only slightly.

(iv) A Low-Pressure Multiwire Proportional Counter for Heavy-Ion Detection

A large-area, low-pressure, multiwire proportional chamber for heavy-ion detection has been developed. This detector consists of two wire planes perpendicular to each other and a foil plane between them (Fig. 12). The gap between electrodes is 4 mm. Spacing between wires is 2 mm. We apply a negative potential of 800-850 V to the central foil, grounding both wire planes. We operate with pure isobutane, at a pressure of 8 Torr. Both wire planes are position-sensitive electrodes with a delay-line readout system from both of them (Fig. 13). The time distance between wires is 4 ns/2mm. The sensitive surface of the counter can be

Figure 11. Mechanical assembly of the MWPC. Shown are the detector housing (H), the wire plane (WP) and the two cathode planes (CP), together with the mounting rods (R). Further details are the outer and inner window (Wo, Wi), the high voltage (HV) and signal line connectors (S), as well as gas inlet and outlet (G).
as large as 14 x 14 cm. The total thickness, according to our present technical abilities, can be ~600 µg/cm² of mylar, excluding the exit window. This detector was tested with 5.5-MeV alpha particles from a 241Am source, and with the fission fragments from the p+U and p+Au reactions at 120 MeV and the α + U and α + Au reactions at 190 MeV. Figure 14 shows an example of the position spectrum collected during the p + U experiment. The efficiency measured during the run is greater than 95% for the central foil. Spatial resolution obtained with the present configuration is 2 mm.

![Figure 12. Wire chamber layout for heavy-ion detector.](image)

Figure 12. Wire chamber layout for heavy-ion detector.

![Figure 13. Readout system for heavy-ion detector.](image)

Figure 13. Readout system for heavy-ion detector.

![Figure 14. Position spectrum obtained with the heavy-ion detector.](image)

Figure 14. Position spectrum obtained with the heavy-ion detector.

(v) High-Purity Germanium Detector Telescope Systems

High-purity germanium detector telescopes were used in 14 experiments during 1982 (the same number as last year) with the same reliability and versatility reported since the discovery of the effects of radiation damage on detector operating characteristics. Several new developments have surfaced, however, because of the unusually high radiation environments encountered during two of the experiments. These developments have provided further insight on the properties of these detectors when used in charged particle telescopes.

The first detector to be rendered permanently unusable because of charged particle damage during an experiment at IUCF was detector #550-8.6, a 13.5-mm thick transmission detector fabricated from n-type germanium. This detector was the second detector in a three-element germanium detector telescope used in a 12C(p,p'γ) Spin-Flip measurement. The telescope was at a 21° angle relative to the beam direction and initially subtended a solid angle of 0.7 msr. Five nanoamps of 120 MeV protons were incident on a 20 mg/cm² 12C target, resulting in a count rate of 17 kHz.
in the telescope, which is unacceptably high. The result was that the second detector in the telescope (#550-8.6) began to show an excessively high leakage current, while the first and third detectors behaved normally. In order to complete the run, the solid angle was reduced to 0.3 msr, and the count rate in the telescope was held to 5 kHz. The dominant source of the count rate (and consequent radiation damage) at this angle was the elastic scattering from the thick $^{12}$C target. The interesting question was why the first and third detectors (#475.10.7 and #514-7.0) performed normally throughout the experiment, while detector #550-8.6 did not.

Tests conducted on these detectors following the experiment showed that all had been severely radiation damaged. Detectors #475-10.7 and #514-7.0 annealed normally to their original condition. Detector #550-8.6 was also annealed to its original depletion bias, but was found to have a dead layer approximately 0.08 mm deep on the n+ side of the crystal which was previously not there. The detector was returned to the Lawrence Berkeley Laboratory, where Richard Pehl corroborated our dead layer measurements. The measurement he made indicated that the dead layer was thicker near the center of the n+ surface and tapered off at the edges.

Our explanation for this behavior is that a portion of the detector crystal, which is fabricated from n-type germanium, was changed to p-type germanium by the addition of acceptors produced by charged particle damage. Support for this view is the fact that the leakage current observed on the detector during the experiment was lowered when beam was put on target, which is opposite to what is expected and to what was observed on the other two detectors in the telescope. Perhaps a more convincing argument can be found in a discussion of the impurity concentration $|N_o-N_A|$ of the detectors.

Detector #550-8.6 has an impurity concentration of 0.72 x $10^{10}$ atoms/cm$^3$, while for detector #475-10.7, the first n-type detector in the telescope, it is 3 x $10^{10}$ atoms/cm$^3$. Charged-particle radiation damage creates p-type detectors, and increases the net impurity concentration $|N_A-N_D|$ in p-type detectors. The number of p-type acceptors added to the detectors in the Kovash experiment was determined from the depletion bias changes which occurred during the run. The depletion bias of the n-type detector #475-10.7 decreased from its damage free value of -1700V to -1250V, which corresponds to a change in the net electrical impurity concentration from 3.3 x $10^{10}$ atoms/cm$^3$ to 2.4 x $10^{10}$ atoms/cm$^3$. Therefore 0.9 x $10^{10}$ p-type acceptors were added to this detector during the experiment. In addition, the depletion bias of the p-type detector #514-7.0 was increased from -1600V to -2300V, corresponding to a net electrical impurity increase of 0.82 x $10^{10}$ atoms/cm$^3$. The important thing to notice here is that the number of p-type acceptors added to these two detectors is larger than the net electrical impurity concentration of detector #550-8.6, and is therefore consistent with our belief that at least a portion of this detector changed from n-type to p-type germanium as a result of the radiation damage encountered.

The lesson learned here is that you do not want to fabricate a high-purity n-type germanium that is "too" pure. Generally, it is preferable for our application to make n-type detectors from germanium with an impurity concentration no less than 2 x $10^{10}$ atoms/cm$^3$. In fact it is desirable to have as large a net electrical impurity concentration as possible, consistent with maintaining a reasonable value for the
depletion bias. The depletion bias varies with impurity concentration as

\[ V_d = \frac{5.66 \times 10^{-8} \omega^2 |N_0-N_A|}{N_0-N_A} \]

where \( \omega \) is the depletion depth of the detector in cm. The impurity concentration for p-type detectors is not as critical, since charged-particle damage makes p-type detectors more p-type. For these detectors, one should opt for the higher purity germanium so as to keep the depletion bias low, since it will increase with radiation damage.

The second new effect observed resulted from the fact that a high-purity germanium detector telescope was severely damaged by neutrons rather than charged particles. A three-element telescope (detectors #475-10.7, 501-6.7 and #514-7.0) was used for a \( ^{12}\nu(n,p) \) feasibility study.\(^2\) A collimated beam of neutrons was incident on a 1.5-MeV thick CH\(_2\) target. The neutrons were produced by a 100nA beam of 120-MeV protons on a 1.5-MeV thick \( ^7\)Li target. The wall between the neutron production target and the CH\(_2\), which housed the neutron beam channel, was not complete, permitting a large background of both fast and thermal neutrons in the area surrounding the detector telescope. Unfortunately, it was not possible to determine this background level precisely, except to say that proton beam intensities greater than 200nA could not be used because the low level count rate in the detectors resulting from this background was excessive. The telescope ran in this configuration for about 60 hours.

At intensities of 200nA and below, the telescope performed well. Two differences between the effects of neutron damage and charged particle damage were observed. First, the resolution of all the detectors (both n- and p-type) were observed to deteriorate before there was a significant change in their depletion bias. This is precisely the opposite of what one observes for charged particle radiation damage. Detector #475-10.7 had a depletion bias decrease of only 300V during the course of the experiment, yet the \(^{60}\)Co gamma ray resolution deteriorated from 18 keV before the experiment to over 40 keV at the end of the run. The detectors were not warmed to room temperature before these resolution measurements were made.

The second and more pronounced effect was that considerably longer annealing times were required to restore the detectors to their original operating parameters than ever experienced previously. The p-type detector required nearly 5 times more annealing time than the n-type detectors, which themselves required 2 times longer to anneal than a detector with equivalent charged particle damage. These results are summarized in Figs. 15 and 16, which show the annealing history both for the neutron damage experienced in this experiment, and for our typical experience with charged particle radiation damage. The damage anneal history for the p-type germanium detector (Fig. 15) is significantly worse than for the n-type detector (Fig. 16), indicating that it is desirable to use only n-type detectors in a high-neutron flux environment.

The 500 hours (~21 days) of annealing required for the p-type detector is too long to consider as a routine consequence of doing an experiment. However, the 100 plus hours required to anneal the n-type detectors in the same telescope is not unreasonable. In addition, the possibility of annealing at higher temperatures (250 - 300°C) is being considered to speed up the recovery process.

Other new developments in 1982 include the fabrication of a new three dimensional scattering table and target chamber\(^3\) specifically for use with the high-purity germanium detector telescopes.
Figure 15. Annealing history for a radiation-damaged p-type germanium detector.

Figure 16. Annealing history for a radiation-damaged n-type germanium detector.

<table>
<thead>
<tr>
<th>Detector No.</th>
<th>Ge type</th>
<th>Thickness (mm)</th>
<th>Depletion Bias (-V)</th>
<th>Delta (V)</th>
<th>Rad. Damage &amp; Anneal Cycles</th>
<th>Thermal Cycles</th>
<th>Total Anneal Time (hrs)</th>
<th>Li Layer Depth (mm)</th>
<th>Delivery Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>#172-3.1</td>
<td>p</td>
<td>10.6</td>
<td>600</td>
<td>&gt;2000</td>
<td>&gt;15</td>
<td>&gt;17</td>
<td>&gt;200</td>
<td>1.13</td>
<td>~1976</td>
</tr>
<tr>
<td>#514-7.0</td>
<td>p</td>
<td>15.21</td>
<td>1700</td>
<td>1300</td>
<td>22</td>
<td>92</td>
<td>2033</td>
<td>2.66</td>
<td>3/21/77</td>
</tr>
<tr>
<td>#514-8.6</td>
<td>p</td>
<td>14.94</td>
<td>1450</td>
<td>1500</td>
<td>34</td>
<td>84</td>
<td>1701</td>
<td>1.17</td>
<td>3/21/77</td>
</tr>
<tr>
<td>#517-9.7</td>
<td>n</td>
<td>~15</td>
<td>1500</td>
<td>200</td>
<td>23</td>
<td>74</td>
<td>1588</td>
<td>NA</td>
<td>8/15/77</td>
</tr>
<tr>
<td>#550-8.6</td>
<td>n</td>
<td>13.5</td>
<td>700</td>
<td>200</td>
<td>8</td>
<td>21</td>
<td>395</td>
<td>NA</td>
<td>11/30/79</td>
</tr>
<tr>
<td>#475-10.7</td>
<td>n</td>
<td>9.07</td>
<td>1700</td>
<td>300</td>
<td>16</td>
<td>51</td>
<td>1172</td>
<td>NA</td>
<td>8/15/77</td>
</tr>
<tr>
<td>#501-6.7</td>
<td>n</td>
<td>10.77</td>
<td>1800</td>
<td>300</td>
<td>18</td>
<td>73</td>
<td>1501</td>
<td>NA</td>
<td>8/15/77</td>
</tr>
<tr>
<td>#477-6.1</td>
<td>n</td>
<td>9.52</td>
<td>1750</td>
<td>150</td>
<td>6</td>
<td>9</td>
<td>271</td>
<td>NA</td>
<td>4/21/80</td>
</tr>
<tr>
<td>#551-11.8</td>
<td>n</td>
<td>5.18</td>
<td>1100</td>
<td>200</td>
<td>4</td>
<td>11</td>
<td>282</td>
<td>NA</td>
<td>4/21/80</td>
</tr>
<tr>
<td>#501-9.3</td>
<td>n</td>
<td>~2</td>
<td>-100</td>
<td>150</td>
<td>1</td>
<td>4</td>
<td>110</td>
<td>NA</td>
<td>4/20/82</td>
</tr>
<tr>
<td>#501-9.6</td>
<td>n</td>
<td>~2</td>
<td>-100</td>
<td>300</td>
<td>1</td>
<td>2</td>
<td>26</td>
<td>NA</td>
<td>4/20/82</td>
</tr>
</tbody>
</table>
new detector cryostats are under construction. This will allow the simultaneous use of up to four detector telescopes for experimentation, as well as allow detector testing and annealing to go on simultaneously with experiments using less than four telescopes. In addition, 5 new n-type germanium detectors, ranging in thickness from 2 mm to 20 mm, have been delivered to IUCF, and two more detectors are expected in 1983. Table I provides a listing of all the high-purity germanium detectors available at IUCF, as well as their operating characteristics. All of these detectors are available to IUCF users for experiment.

2) J. Rapaport, et al., this report, p. 170.

(vi) Target Lab Technical Status

The target lab supplied an estimated 95% of the targets used at IUCF in 1982. Targets prepared, in thicknesses ranging upward from 50 \( \mu \text{g/cm}^2 \), included:

- \( \text{CD}_2 \)
- \( 6,7\text{Li} \)
- \( 7\text{LiCl} \)
- \( 11\text{B} \)
- \( 12,13\text{C} \)
- \( ^{14}\text{N} \)(Melamine)
- \( 24,25\text{Mg} \)
- \( 27\text{Al} \)
- \( 28,29\text{Si} \)
- \( 29\text{S} \)(Ozone)
- \( 40,48\text{Ca} \)
- \( 51\text{V} \)
- \( 54\text{Fe} \)
- \( 58,60,62,64\text{Ni} \)
- \( 59\text{Co} \)
- \( 76\text{Ge} \)
- \( 81\text{Br} \)
- \( 115\text{In} \)
- \( 116,117\text{Sn} \)
- \( 121,123\text{Sb} \)
- \( 128,130\text{Te} \)
- \( 140\text{Ce} \)(Ozone)
- \( 192\text{Os} \)
- \( 208\text{Pb} \)
- \( 209\text{Bi} \)
- \( \text{UF}_4 \).

Most noteworthy, we have developed a new technique of binding pressed powder targets with polyethylene (\( \text{CH}_2 \)). Heretofore styrene was usually the binder of choice. The new \( \text{CH}_2 \) bound targets are stronger and more shock resistant. As little as 1\% (by weight) of \( \text{CH}_2 \) is required.

The most intensive development work centered on developing a highly efficient and reproducible technique for producing a self supporting 300 \( \mu \text{g/cm}^2 \) \( ^{48}\text{Ca} \) target. With valuable information provided by Terry Nolan (Michigan State) and much experimentation to find a suitable substrate, parting agent, etc., we were successful. The target was clean, 1/2" in diameter and required only three mg of \( ^{48}\text{Ca} \).

Three new compacting dies made of tungsten carbide in a 6\% nickel matrix were purchased. They have greatly improved our ability to produce pressed targets with low contamination levels. The four column 30 ton press platens have been reground to take full advantage of the new dies.

10. Data Acquisition

(i) Data Acquisition Computers—Hardware

A large effort during the year was spent on planning for and acquiring the first VAX-11/750 data acquisition computer upgrade. As part of a four year plan to phase out the use of the Harris Computers, the first VAX will be used initially for development and implementation of data acquisition hardware and software.

Approval from the NSF for the first computer was received in March 1982; delivery and acceptance was completed in August 1982. The computer selected was a VAX-11/750 configured as follows:

- 124 Mbytes RM80 disk
- 2 Mbytes memory
- 1600/800 TU77 tape drive
- 1 floating point accelerator
- 1 user control store
- A Trilog T-100 printer/plotter
- A Tektronix 4112 graphics terminal
- A Kinetic Systems KSC-2053 CAMAC branch driver

A Racal-Vadic communications controller was added to the initial purchase. Because of a very attractive price, a pair of used TU77 tape drives with controller was subsequently purchased from the high-energy physics group on campus. An Able Computer UME/32 communications controller was added to provide for 19.2 kilobaud, DMA graphics terminal support with a minimum of system overhead. Racal-Vadic modems with auto-answer capability were purchased to
provide for dial-up support for the computers. Finally, five additional terminals were obtained under a Digital Equipment Corporation external grant.

Initial installation of the computer was trouble-free. After three minor problems in the first two weeks (a disk failure, a ram chip failure, and a failure in the time-of-day clock), the computer has performed flawlessly. A basic hardware maintenance contract has been purchased for the first year of operation.

Because of our experience with smoke contamination of the computers from the ion source fire, it was decided to provide a safer environment for the new systems. The CPU's and disk units will be located in small limited access room adjacent to the existing computer rooms. Magtape drives, printers, terminals, and other user oriented devices will be located in the main areas. This plan allows for the use of a small automatic HALON fire protection system along with a stand-alone air conditioning system. The room modification work has almost been completed in the upstairs area; the lower control room work will be scheduled for later completion.

The second VAX system purchase was begun in the month of December. Because of availability of new products, more processing power was purchased for essentially the same base system price. The system now on order from DEC is a VAX-11/750 with:

- 456 Mbytes RUA81 disk
- 5 Mbytes of memory
- 1 1600/800 bpi TU77 tape drive
- 1 floating point accelerator
- 1 user control store
- 1 Unibus expansion
- 1 DECnet hardware/software support

Current plans call for moving the upstairs Harris batch computer downstairs to provide for a third on-line computer. As soon as the second VAX arrives, one VAX will be devoted to software development and the other one will be available for interactive and batch usage.

(iii) Data Acquisition Software

The 1981 Annual Report noted that the FORTRAN compiler running under DMS on the Harris computers had been modified to allow use of memory above 192K. The largest change to the data acquisition system RAQUEL this last year was to take advantage of this new feature to store histograms in "upper memory". This makes it possible simultaneously to use all the physical memory available on the computer, add more features to RAQUEL and provide the user with more histograms. Minor changes were also made related to projecting 2-D onto 1-D histograms, more easily modifying sorting conditions, and handling overflow conditions.

(iii) VAX Software

The new VAX-750 computer has seen very heavy use from the day users were allowed access to it. A number of codes were imported and first tested on the IU campus VAX-780 so that users were ready and waiting before the VAX-750 was installed. The usage has been great enough already to fill 90% of the available disc space, cause grumblings about lack of terminals, and permit the elimination of support for the VULCAN operating system on the Harris computers.

One argument for obtaining a VAX computer was that it would give us access to a large body of developed software. We have implemented some widely used calculation programs in the field of nuclear physics, including a wide variety of DWBA programs. A few codes have also been obtained to perform beam transport and magnet design calculations.

The CERN scientific subroutine library has been installed, along with software packages to use the
graphic plotting capabilities of our TRILOG printer and to drive a modem so as to make a user's terminal appear to be hosted by a remote computer instead of the local VAX. For medium resolution color graphics, a GIGI terminal is available with all the standard GIGI/ReGIS software from Digital Equipment Corp. For high resolution graphics, PLOT10 is being installed for our Tektronix 4112 terminal. SPEAKEASY is available for interactive computation and data analysis and a set of RAQUEL data tape utility programs exists to facilitate supplying experimental data to the VAX.

Work on generating data acquisition software for the VAX itself is in its very early stages. We have imported a CAMAC driver from E. Blair at Oak Ridge National Lab and are suitably modifying it for our hardware and making preliminary timing measurements for later reference. When PLOT10 is running we will begin to evaluate methods of driving histogram displays.

B. Future Facilities

1. The IUCF-Maryland Double Spectrometer System

The new dual magnetic spectrometer facility for IUCF, consisting of a 6 mAR, K=600 spectrometer [where K=(A/Q)E (MeV)] designed to give 15 keV overall resolution in a 20 MeV excitation energy range for reaction products of 80-200 MeV and a 14 mAR, K=300 spectrometer of moderate resolving power but a broad momentum acceptance, $p_{\text{max}}/p_{\text{min}}=1.35$, is now fully funded (the final installment of funding was obtained from the NSF in September of 1982), and the final magnet design was completed by mid-1982. The project is a joint undertaking of Indiana University and the University of Maryland, with P. Schwandt (IU) serving as overall project coordinator and P. Roos (UM) managing the Maryland contribution.

The combined spectrometer system will make possible either high-resolution single-particle measurements (with the second magnet serving as an effective monitor of luminosity and beam spot size and position) or high-data-rate, two-particle correlation measurements. The design parameters and general technical specifications of the two spectrometers have been described previously. The principal parameters are summarized in Table 1.

The high-resolution, moderate-solid-angle K=600 magnet system, which is the responsibility of the Indiana group, is illustrated schematically in the plan view shown in Fig. 17. The $(x,0)$ bend plane of the two-dipole system $D_1,D_2$ is horizontal. The independent-dipole design allows the momentum dispersion to be varied by changing the field ratio in the two dipoles so that a nearly constant energy dispersion may be maintained over a broad range of scattered particle energies. The entrance quadrupole $Q$, which is open-sided to permit diversion of the incident beam to an external beam dump even at small scattering angles ($\theta_{\text{min}}=5^\circ$), contains hexapole and octupole components to reduce $(x|\delta^2)$ and $(x|\delta^4)$ aberrations. The pole-face correction coil $H$ sets the $(x|\delta^2)$ aberration to zero in the center of the focal surface for each of the three dispersion modes, while the triangular pole-face winding $K$ allows kinematic correction up to $dp/d\theta=+0.05p$ at maximum field.

The moderate-resolution, large-solid-angle K=300 spectrometer, which is the responsibility of the Maryland group, is shown in elevation in Fig. 18. The bend plane of the $D_1/D_2$ split-dipole configuration with a common yoke is vertical to allow, in combination with the K=600 magnet, the widest possible range of correlation angles. The entrance quadrupole $Q$ is of the same design for both spectrometers. The beam
Table I. Parameters of the IUCF Dual Spectrometer System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>K=600 (3 dispersion modes)</th>
<th>K=300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum momentum (MeV/c)</td>
<td>860</td>
<td>760</td>
</tr>
<tr>
<td>Maximum proton energy (MeV)</td>
<td>334</td>
<td>269</td>
</tr>
<tr>
<td>Maximum magnetic rigidity (T-m)</td>
<td>3.00</td>
<td>2.55</td>
</tr>
<tr>
<td>Maximum dipole fields (T), D1/D2</td>
<td>1.23/1.64</td>
<td>1.70/1.70</td>
</tr>
<tr>
<td>Nominal bend radius (m)</td>
<td>2.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Nominal bend angle</td>
<td>115°</td>
<td>70°</td>
</tr>
<tr>
<td>Maximum solid angle ΔθAϕ (msr)</td>
<td>6.2</td>
<td>14</td>
</tr>
<tr>
<td>Maximum radial acceptance Δθ (mrad)</td>
<td>±45</td>
<td>±66</td>
</tr>
<tr>
<td>Maximum axial acceptance Δϕ (mrad)</td>
<td>±44</td>
<td>±68</td>
</tr>
<tr>
<td>Momentum range Pmax/Pmin</td>
<td>~35,000</td>
<td>~2,000</td>
</tr>
<tr>
<td>Resolving power p/δp</td>
<td>6.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Momentum dispersion (cm/%)</td>
<td>65</td>
<td>170</td>
</tr>
<tr>
<td>Energy dispersion (keV/mm), 200 MeV protons</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>Horizontal magnification at Pmax</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Vertical magnification at Pmax</td>
<td>81</td>
<td>85</td>
</tr>
<tr>
<td>Focal plane length (cm)</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Focal plane width (cm)</td>
<td>54-60°</td>
<td>45-55°</td>
</tr>
<tr>
<td>Focal plane inclination, extreme rays</td>
<td>5-120°</td>
<td>20-160°</td>
</tr>
<tr>
<td>Range of scattering angles θ</td>
<td>10/8</td>
<td>10/10</td>
</tr>
<tr>
<td>Dipole gaps (cm), D1/D2</td>
<td>125</td>
<td>40</td>
</tr>
<tr>
<td>Dipole total weight (tons)</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Total power consumption (kW), 200 MeV protons</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Entrance and exit faces on all dipoles are easily-machined straight cuts or circular arcs. Allowance for magnetic shimming of edge profiles during field mapping has been made.

The detailed mechanical design of the dipole steel cores (yokes and pole-piece assemblies), dipole coils, and vacuum chambers for both spectrometers was completed by late summer of 1982. Engineering drawing and written specifications were prepared and submitted to prospective vendors for bids on the complete dipole packages in mid-September. Review of the dozen bids received in early November for the complete magnet system or its components showed that significant cost savings could be realized by soliciting separate bids for the dipole steel assemblies, the coils, and the vacuum chambers. A second round of bidding was
initiated in December for the dipole steel cores (the item with longest fabrication time), and several bids with acceptable quotations of cost and delivery time were received in January of 1983; they are being reviewed as of this writing. Separate bid specifications for the dipole coils and vacuum chambers are being prepared and quotations on these items will be requested shortly.

Reconditioning of several dipole power supplies obtained from the University of Maryland is underway, and procurement of additional power supplies has been initiated. On the basis of a 10-12 months delivery time for the dipole magnets, the assembly, field mapping and installation of both spectrometer magnet systems is expected to occur during the first half of 1984. The dual spectrometer facility will be installed and operated at the north end of the IUCF crane bay area until its relocation in the IUCF cooler ring projected for early 1987. Since the beam transport to the new spectrometer system in its initial location will employ the existing QDEM spectrometer magnet as a
primary momentum-analysis and variable-dispersion-matching magnet, operation of the QDDM system as a spectrometer is expected to cease by mid-1984.

Design work has begun on the position-sensing focal-plane detector systems for both spectrometers. The rather different focal-plane characteristics and resolution requirements of the two spectrometers entail somewhat different approaches. For the K=300 spectrometer two x-y wire chambers, each 100 cm long by 20 cm high, will be used. The modest requirements on the precision of position and angle determinations for this magnet (\( \pm 1\) mm, \( \pm 1^\circ \)) can be met by delay-line wire chambers with 1 mm cathode (x) spacing and 2 mm anode (y) wire spacing. The choice of delay-line readout entails the obvious advantage of great simplicity of the associated readout electronics. A prototype delay-line wire chamber is being designed and constructed. This chamber is expected to provide position resolutions of the order of 0.5 mm in the bend plane (x) and 2 mm in the transverse plane (y). In order to minimize the event processing time, segmentation of the 1 m long delay line is being considered and investigated.

In order to reach the design resolution of the K=600 spectrometer, position and angle determinations in two planes are required to correct for residual aberrations. In the bend plane, x and y measurements to a precision of 0.2 mm and 3 mrad fwhm, respectively, are required. The orthogonal (y) position needs to be determined with relatively low precision (5 mm), and then only as a guide to setting the entrance quadrupole field; y-determination should not normally be required for aberration corrections to meet the resolution goal. Hence, the initial design calls for the first detector to be a vertical drift chamber and the second to be a delay-line wire chamber similar to those for the K=300 spectrometer. The length of the K=600 spectrometer focal surface depends on the dispersion mode chosen and varies by about 30%. The prototype chambers under consideration will be 95 cm long (the maximum length needed for the low-dispersion mode) by 5 cm high.

Construction of the prototype wire chambers will commence in early 1983 and testing of these chambers, along with further studies of alternative designs, position readout schemes and fabrication methods, will be carried out over the summer of 1983.

*P. Roos is presently spending a sabbatical leave at IUCF to assist in the spectrometer design work.


2. The IUCF Cooler Ring

A storage ring with electron cooling (the IUCF "Cooler") is a planned future addition to IUCF. The ring will be filled by beam from the cyclotron. After manipulations in phase space, the stored beam will impinge on internal, thin targets to exploit the advantages of a cooled, stored beam for specific nuclear science experiments in the IUCF energy region.

The Cooler has received significant funding in 1982 from the National Science Foundation as a research and development project and is scheduled to begin construction in 1983 with a target date for completion in 1987. Beginning with 1982 and continuing through the construction phase, the Cooler project will issue a separate Annual Report which will be available on request for those who would like to keep in touch with technical details of the project. (We will set up a separate mailing list, based on requests received, which will be cumulative over the life of the construction project).

Among the significant changes in the design in the past year, we mention the incorporation of a second
injection path for non-fully-stripped beams which can more easily build a large stored intensity by stripping onto the stored beam stack at the injection point. We visualize two basic operating modes, one for high resolution, and a second for high luminosity. In the high resolution mode, the beam is cooled to such a low emittance that the space-charge tune shift limits the stored current to <1 mA. This current can be reached by stacking a few hundred turns. In this mode the beam is shared with other cyclotron users, being diverted to the Cooler on a pulse-by-pulse basis during the fill cycle. In the high luminosity mode, the interactions of the beam with a thicker target establishes the thermal equilibrium between target heating and electron cooling at a larger emittance which is compatible with larger stored currents. These will be achieved by stripping injection of beams such as H$_2^+$, D$_2^+$, He$^+$, Li$^+$, which are now available, and perhaps later of H$^+$ and other ion species. It will be possible to stack 10 to 100 mA in this injection mode and to obtain luminosities in the range $10^{32}$ to $10^{33}$/S.cm$^2$. The maximum energies of non-fully-stripped beams from the cyclotron (e.g. 100 MeV H$_2^+$ + 50 MeV protons) are below the energy range of interest for most IUCF users, so provision is made in the ring design to ramp the stored beam to any final energy of rigidity less than 3.6 Tesla-meters. This energy adjustment will also be useful in the high resolution mode to allow an independent energy choice by the ring user.

A second conceptual development in the Cooler design arises from the realization that the strict upper bound on target thickness for an internal target, which is set by the need to establish thermal equilibrium, is actually a constraint on the thickness averaged over a cooling time constant. It will be possible to use thicker targets which intercept only a portion of the beam on any one passage, such as single-crystal whiskers and coated fibers. Vapor jets must still be employed to obtain access to recoiling nuclei of low energy, but are not necessary for all experiments. This concept simplifies the preparation of beam for the dual spectrograph target station in particular because the spatial localization of a fibre target relaxes the stringency of the dispersion-matching requirements and the contribution to the resolution which could arise from the finite thickness in the beam direction of a jet target. A solid target is also free from the instability limit to luminosity initiated by the time delay in the reaction force of the ion cloud produced by the beams in a vapor target on the beam position which drives a coherent amplitude growth. For our geometry this limit occurs at 4$\times$10$^{33}$/S.cm$^2$.

Technical developments in 1982 include the construction of a high vacuum bakable test assembly which has achieved the base vacuum of a few nanoTorr needed for the Cooler. The test stand will be used to evaluate pumps, gauges, and other components and to explore baking and pumpdown cycles. The Cooler project has taken over the construction of the "stripper loop" which is aimed at low energy beam accumulation to increase the single pulse intensity, and the design and construction of the first elements of the beam splitting hardware which will divert pulses to the Cooler. This device also includes prototypes of Lambertson septum magnets of the type to be used in ring injection, and of a resonant ferrite RF buncher which will operate at one-third of the cyclotron RF frequency. The latter make available the longer interval between cyclotron pulses which is needed by the long-path neutron facility.
Magnet design activities include the ramping and transient analysis of a laminated dipole kindly loaned to us by the FNAL Cooler project. This entailed development of a microprocessor-based prototype of the cyclic control system which will manage the Cooler operation. The solenoids to be used to maintain polarization transverse to the ring bend plane have been mapped as part of the preparation for correction of the very homogenous field needed to maintain a low electron beam temperature in the cooling region. The vacuum test stand data has helped establish the gap allowance for ring lattice magnets for thermal insulation, heaters, and vacuum walls.