FACILITY STATUS UPDATE OF IUCF

GARY W. EAST

Indiana University Cyclotron Facility
2401 Milo B. Sampson Lane
Bloomington, IN 47408-0768

The Indiana University Cyclotron Facility (IUCF) consists of three ion source terminals coupled to a separated sector isochronous injector and main stage cyclotron (K=200). The accelerators provide variable energy light ion beams for intermediate energy nuclear physics research. In addition, medical, biological and industrial physics application facilities are available. A new high intensity polarized, ion source provides the capability to produce 4μA, pulsed, 200 MeV protons for injection into the IUCF storage ring with electron cooling. A new medical and radiobiology irradiation facility is now in operation and an area for investigation of single event upsets in IC devices is also in use. An overview of the laboratory status, beams available and examples of applications are presented.

1 Introduction

One of the world's early cyclotrons was constructed at Indiana University and was operational by 1941. The present cyclotron facility is the result of planning which began in the early 1960's and produced the first extracted beam on September 24, 1975. The injector and main stage cyclotrons working in tandem can accelerate protons from 20 to 205 MeV. Other light ions up to $^7Li^{++}$ have been successfully accelerated for intermediate energy nuclear physics experiments.

The electron-cooled storage ring is designed to accelerate protons up to 500 MeV. It can also accelerate light ions up to the 3.6 Tesla-meter rigidity limit of the ring. The first beam was successfully stored in the synchrotron in November 1987 and was first cooled in April 1988.

Table 1: Cyclotron Operating Range

Ion	Charge State	Energy MeV/u
proton	+1	20--205
deuteron	+1	10--50
H_2	+1	10--50
^{3}He	+1 +2	8--95
^{4}He	+1 +2	4--50
^{6}Li	+1 +2 +3	5--25
^{7}Li	+1 +2 +3	8--15

The IUCF Cooler Ring has a circumference of 86.82 m with irregular hexagonal symmetry. Dispersion alternates between 0.0 and 4.1 m in adjacent sides. The transverse acceptance is ~25π mm-mrad. and the longitudinal acceptance is ±0.2% Δp/p. The ramp rate is variable up to 1.0 T-m/sec.

The electron cooling process provides increased luminosity, improved particle beam resolution by reducing the energy spread and beam size, and increased stored beam lifetime. The typical Δp/p of a cooled beam is 0.005%.

2 Polarized Beam Operation

The predominate mode of operation for the cyclotrons have been to produce polarized beams for the experimental investigation of spin dependent interactions. The IUCF High Intensity Polarized Ion Source (HIPIOS) employs cold ~30°K atomic beam technology and an electron cyclotron resonance (ECR) ionizer.[1] The ion source consistently produces 125μA of polarized beam with an average polarization of 70%. Long term stability has been very good with the source in constant operation for periods of 10 days to 2 weeks before maintenance of the cryo vacuum system and cold nozzle is needed.

2.1 Polarized Neutron Facility

The Indiana Polarimeter (INPOL) is a collaboration involving IUCF, Kent State University (KSU) and the Los Alamos Meson Physics Facility (LAMPF). INPOL provides a unique facility to measure the full polarization transfer in charge-exchange reactions up to a momentum transfer q=2.41 fm^{-1} and proton beam energies up to 200 MeV.

The NTOF polarimeter, which is on loan from LAMPF, has been placed in a new building located 150 m on the 0° neutron flight line. A counting trailer also on loan houses the computer and data acquisition system. On the 24° neutron flight line, the KSU polarimeter has been located at 40 m. Another counting trailer provided by IUCF is used to house the data acquisition system from the KSU group.

A new building addition was constructed to house a neutron shutter, dipoles, and solenoids to precess the neutron spin for detection in the two sets of polarimeters. HIPIOS, combined with two super conducting solenoids in the high energy beam line for spin precession, allows the cyclotrons to provide an intense polarized proton beam, pulse selected 1:12 (beam bursts every ~360 ns), on target. Spin transfer observables can be measured simultaneously at two lab angles separated by 24°. Varying the beam swinger magnetic fields and target angles allow measurements in the angular range of 0° to 48°.

3 Radiobiology and Medical Facilities

The beam at IUCF has several key features that make it ideal for radiobiology and medical uses. IUCF has a variable energy acceleration system that can produce beams of protons with energies from 20 to 205 MeV. Most of the scheduled experiments for nuclear research require energies between 150 and 200 MeV that are compatible with cancer treatments.[2]

IUCF routinely delivers proton beams from 5 nA to 2μA within a phase space of 2.5π mm mrad horizontal by 2.0π mm mrad vertical that easily provides dose rates of 200 cGy/min. for a field size up to 20 x 20 cm^2.

A technique of splitting the beam from the cyclotron to two different experimental areas uses a fast switching magnet and Lambertson septum magnets. The primary user typically receives 90% duty factor while the secondary user receives the remaining 10%. The peak beam intensity delivered to either user can be individually adjusted using a beam intensity modulation system (BIMS)[3] timed in conjunction with the splitter magnet. For a proton therapy or radiobiology irradiation, the initial setup can be completed as a secondary user while the actual protocol can be accomplished with primary beam for short intervals on the order of 1 to 2 minutes.

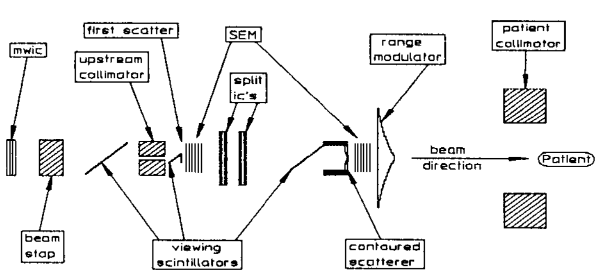

Figure 1: Diagram of the radiobiology and medical beam line (not to scale).

The beam line shown in figure 1 includes a beam spreading system, a range modulator and diagnostics for dose and beam monitoring. The first item shown (upstream, on the left) is a multiwire ion chamber (MWIC), consisting of two wire planes, horizontal and vertical, each with 10 wires. The MWIC measures the incident beam position and profile before and during irradiations to verify that the beam properties do not change. The beam stop immediately after the MWIC prevents exposure until the beam properties are verified. Three 1 mm thick plastic scintillators viewed by television cameras aid the operator in the initial tuning of the beam. The upstream collimator has four segments with a current readout for each segment at the operator's console. The collimator's 1 cm diameter aperture is sufficient to allow 100% beam transmission and still provide protection in case of a gross beam deflection. Once the beam is properly tuned, each segment should read <0.1 nA. After passing through the segmented collimator, the beam is visible on the second viewing scintillator, which is mounted on the support for the first scattering foil. The scattering foil is part of the lateral beam spreading system necessary to provide large, uniform dose distributions.

The first secondary electron emission monitor (SEM)[4] is located immediately after the first scattering foil. The SEM is used to measure total beam current and dose delivered. Initially the SEM is calibrated with a Faraday cup to obtain an absolute beam current measurement. For dose delivery, the SEM is calibrated against a Markus ion chamber manufactured by Nuclear Associates.

After the first SEM are two split ion chambers. Each of these has two planes, one split vertically and one split horizontally. The ion chambers monitor the symmetry of the beam intensity which is sensitive to the incident beam position and trajectory at the first scattering foil. Further downstream is the contoured scattering foil, which is mounted in a collimator with the third viewing scintillator attached on the upstream side. Immediately after the second scattering foil is the second SEM.

Next is an acrylic range modulator used to modulate the range of the Bragg peak. Several range modulators have been constructed, giving modulation from 3 to 18 cm (depth in water) with excellent flatness. For proton therapy, a collimator is used to restrict the field to the treatment region and is mounted just upstream from the patient. Because the beam is fixed horizontally, treatments are limited to the head and neck area. The patient chair has a fixture to immobilize the patient's head and has 5 degrees of freedom. To help in accurate positioning, there are fixed laser beams, a light field and a portable X-ray unit for port verification films.

4 Radiation Effects Research Program

The Radiation Effects Research Program (RERP) at IUCF is designed to provide for an industrial or government user a reliable, efficient and cost-effective facility for a variety of applications. The facility has been used for simulation of the space radiation environment, studies of single event upset and other radiation effects in micro electronic devices, and investigation of radiation effects on optical sensors and opto-electronic devices. Another use of the area has been for the introduction of pinning centers in high critical temperature superconductors to increase maximum permanent fields.

The RERP operates in conjunction with KM Sciences of Beech Grove, Indiana to provide computer control for the delivery of the beam from a beamline stop to the devices irradiated and measures the exposure provided to the users' targets. KM Sciences measures the beam profile using GAFCHROMIC film to ensure proper location of the targets in the beam and calculates the incremental and total accumulated dose.

The upstream foil spreads the beam incident upon a collimator with a 7 cm inside diameter. The beam passes through the collimator, a SEM, a thin kapton window, a short air gap, and a second kapton window covering the entrance into an evacuated well-shielded beam stop/Faraday cup. Devices to be irradiated are positioned in the air gap. The energy of particles incident upon test devices can be degraded to known values by insertion of copper plates between the upstream window and the device.

The SEM measures the beam current through the collimator during exposure and is calibrated by insertion of a remotely actuated beam stop/Faraday cup. Beam intensity profiles measured by GAFCHROMIC film are scanned photometrically into digitized profiles. The digitized information along with the SEM currents is used to compute the dose.

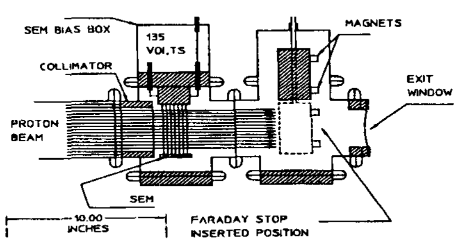

Figure 2 RERP Beamline Schematic (not to scale)

5 Cooler Injector Synchrotron (CIS)

Currently under construction is the Cooler Injector Synchrotron (CIS) that will provide polarized protons and deuterons with much greater peak intensity than is currently available from the cyclotrons for injection into the Cooler Ring.[5] CIS will improve the duty factor for polarized beam operation in the Cooler Ring, reduce overhead and maintenance costs, and eliminate the Cooler/cyclotrons energy matching requirements.

CIS is designed as a small rapid cycling synchrotron. Polarized H^- and d^- will be provided by an ECR ion source similar to HIPIOS. Initial acceleration will be provided by a PL-7 RFQ/DTL linac purchased from AccSys Technology, Inc., Pleasanton, CA. The 7 MeV H^- beam from the linac will be strip injected into CIS using a 4μgm./cm^2 carbon foil and ramped to 200 MeV for injection into the Cooler.

The CIS ring will have 4 dipoles 2.0 m in length with the dipole magnet radius 1.273 m. The circumference of the ring will be 17.364 m, which is 1/5 of the Cooler ring circumference. CIS is designed to provide 9.5 x 10^{10} polarized protons for Cooler experiments and operate up to a 5 Hz repetition rate for Cooler ring fills. Initially CIS will be operated and tested at 1 Hz.

Focusing will be primarily provided from the dipole edge angle of 12°. Four trim quads will supply additional focusing in the ring. The horizontal betatron tune (Q_X) is 1.463 and the vertical tune (Q_Y) is 0.779.

Single turn extraction will use a fast electrostatic horizontal kicker in the first straight section followed 90° later by a vertical Lambertson magnet. Beam extracted from CIS will be injected into the Cooler Ring using the same injection path in use by the cyclotrons. This will preserve the capability of injecting other light ions into the ring.

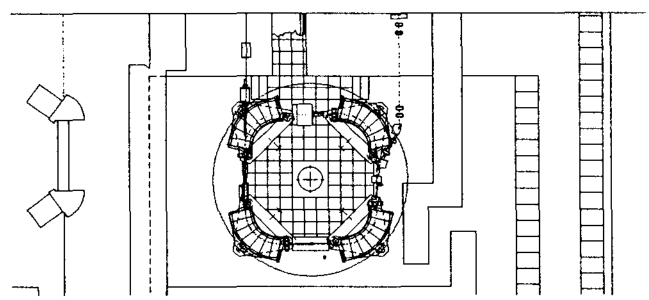

Figure 3 Cooler Injector Synchrotron (CIS)

Acknowledgments

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References

1. V. Derenchuk, R. Brown and H. Petri "Polarized Ion Source Development at IUCF" in *Proc. of the Int. Workshop on Polarized Beams and Polarized Gas Targets*, Köln, 1995 (to be published).
2. C. Bloch et al "The Indiana University Proton Radiation Therapy Project" in *Nuclear Instruments and Methods in Physics Research*, 890 (1993).
3. T. Ellison et al in *IUCF Scientific and Technical Report* 204 (1993).
4. G. W. Tautfest and N. R. Fechter in *Rev. Sci. Inst.*26, 229 (1955).
5. D. L. Friesel and S. Y. Lee, "CIS a Low Energy Injector for the IUCF Cooler" in *Proc. of the 1995 Particle Accelerator Conference and International Conference on High Energy Accelerators* Dalas, TX(to be published)