Cyclotron Institute upgrade project

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On January 3, 2005 the Cyclotron Institute Upgrade Project (CIUP) began with the approval of the CIUP management plan by the Department of Energy Nuclear Physics Office. The project will extend at least to the second quarter of calendar year 2012. When completed, the upgraded facility will provide high-quality re-accelerated secondary beams in a unique energy range in the world. Funding for the upgrade comes from several sources: the Department of Energy, matching support from TAMU, the Robert A. Welch Foundation and beam time sales for testing electronics components at the Cyclotron Institute.

The CIUP is divided into three major tasks: (1) Re-commission of the existing K150 (88”) cyclotron and refurbish beam lines; (2) Construct light-ion and heavy-ion guides and produce 1+ radioactive ions; (3) Transport and charge boost radioactive ions and accelerate in the K500 cyclotron.

As detailed in the Management Plan, effort made during this year on Task 1 included,

- Construction of equipment for the K150 high vacuum system,
- Development of the negative ion source,
- Development of high intensity proton and deuteron beams, and
- Installation of the radiation monitoring system for the K150 and K500 cyclotron vaults and experimental caves.

Progress was also made on Tasks 2 and 3. This included,

- Procurement and installation of the radiation shielding for the ion guide cave,
- Construction of the Heavy Ion Guide gas cell and transport system, and
- Assembly and installation of the n+ transport system. Below we report on a few of the accomplishments listed above.

K150 Cyclotron Development

In this reporting period, we successfully injected, accelerated, and strip extracted 20 and 30 MeV H^- and 10 AMeV D^- beams from the K150 cyclotron. We then were able to deliver the first K150 beams, namely 30 MeV protons and 10 AMeV deuterons, to three different experiments.

The H^- source was installed in Feb. 2010 as was reported in the last progress report. In addition, a 3.5” einzel lens was installed just below the 90° analyzing magnet in order to make the H^- beam transport consistent with the existing injection scheme from the ECR2 beams into the cyclotron. To accelerate H^- beams, the polarities of the main magnet and all the trim coils were reversed, so that the H^- beams would circulate in the same direction as the normal, positively charged beams. Then to strip extract the H^- beams, a stripper foil system and a corrector dipole were installed as shown in Fig. 1. The stripper system allows the foil to be positioned with range of 2” in radius and 3 degree in azimuth about the nominal stripping point at 38” and 120° (0° being along the dee lip pointing South). Finally, the H^-

corrector dipole bends the stripped beam, which after going through the foil peeled away, by about 15-18 degrees into the exit beam line.

First H^- and D^- beams were developed in May and June of 2010. The very first trial beam was 20 MeV H^-, having accelerated the 20 MeV protons before. After injecting the beam onto the mirror inflector and then finding the beam on the beam probe, the accelerated H^- beam was stripped and extracted onto FC01, a faraday cup located just after the H^- corrector dipole. Finding the proper stripper position and the H^- corrector value took some effort to optimize, but we were able to obtain about 7 μA on FC01.

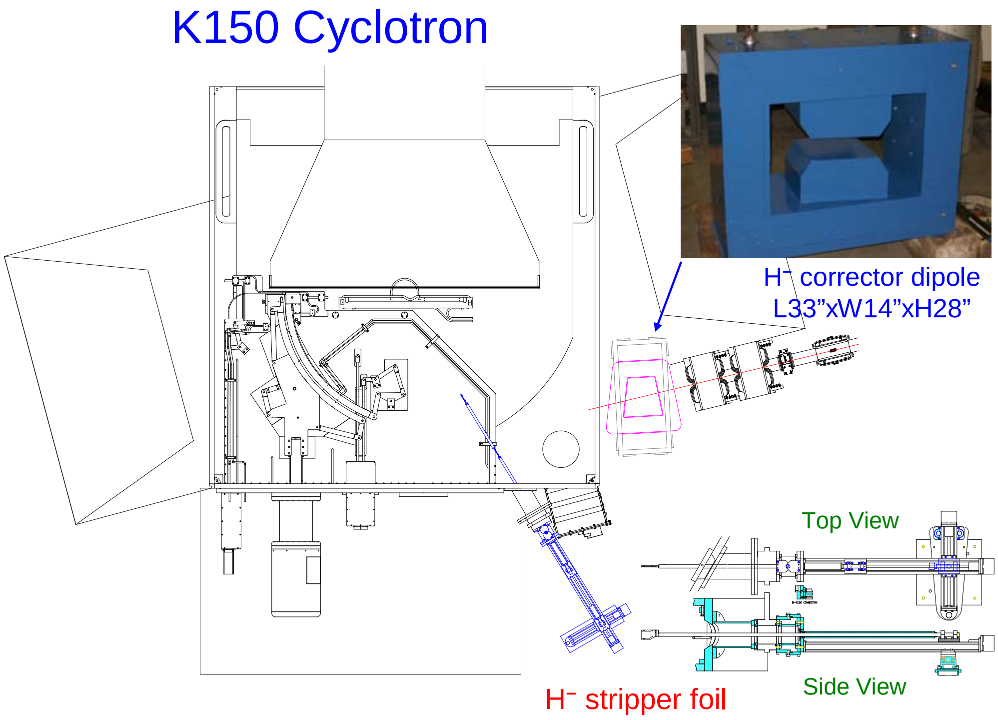

FIG. 1. Strip extraction for H^- beams. A stripper foil system and a small dipole were added to produce very efficient strip extraction for the H^- beams.

The next beam was 30 MeV H^-. And after a few days of tuning the beam, including the source and the beam buncher, we were able to achieve 17 μA of extracted beam on FC01, meeting another milestone for the K150 cyclotron. We actually topped 24 μA on FC01; however, the beam current declined over time due to deteriorating vacuum in the cyclotron due to beam and RF heating. The fleeting 24 μA was obtained just after unblocking the beam with an injection line cup, which was blocked to cool the cyclotron vacuum over several minutes. We believe that this vacuum problem would slowly improve as the cyclotron becomes conditioned over time.

We also worked on two deuterium beams, at 10 and 20 AMeV, using the same H^- source with deuterium gas instead of hydrogen gas. We were able to accelerate and extract 1.2 μA of 10 AMeV deuterons on FC01. However, for the 20 AMeV D^-, we were able to accelerate, but were unable to find the extracted beam on FC01. Next time, we plan to take smaller energy steps in developing higher energy beams.

The developed H^- and D^- beams were used in actual experiments by three separate groups in Nov. and Dec. 2010. The 30 MeV proton beam was used by Sobotka (Washington Univ. in St. Louis) and Youngblood in the MDM cave, and the 10 AMeV deuteron beam by Natowitz in the K150 vault at the end of Heavy Ion Guide line. The first K150 beam transport to the experimental areas was difficult, just because the beamlines were new and unfamiliar. More detailed accounts of the first beam transport of the K150 beams are given below. After the beams were delivered to the experimenters, each group used the beam for about 10 hours per day for a few days; the source and the beam ran very stably during the runs.

In developing the 30 MeV H^- beam and also in trying to meet the 14 µA extraction milestone, the following numbers have been collected from May 2010.

1) The H^- source provided up to 800 µA at ILC02.
2) Injection efficiencies from ILC02 to inflector cup were 30-50%.
3) Beam acceptance into cyclotron is defined as the ratio of the beam current on the beam probe at 10", BP(10") to the beam current on ILC02. Since only a small area of the mirror inflector properly inflects the beam into cyclotron, whereas the entire mirror electrode can collect the beam, the ratio of the beam current from the inflector to BP(10") is not a direct measure of the beam acceptance. The above definition of the beam acceptance into the cyclotron obviously includes beam injection efficiencies. The beam acceptance ranged from 2-3% (without bunching). The bunching was not very effective for intense beams, it enhanced by only about 30%, whereas for 10% of the full beam, the bunching factor was 370%. The space charge effects on the buncher and the inflector seem dramatic; the mirror inflector operates by slowing the beam down and speeding it up on the way out, and a slow beam is more susceptible to space charge effects, and so having a spiral inflector would help here.
4) The internal transmission from 10" to 38" was 80-90%.
5) Strip extraction efficiencies, as measured as the ratio of the beam current on FC01 over BP(38"), ranged from 70-80%.
6) Recall that we topped 24 µA on FC01 (however briefly), which we summarize as: 24 µA = 800 µA x 1.3 x 0.034 x 0.80 x 0.85 This translates into the throughput for the intense beam production, from ILC02 to FC01, at only 3%.

The K150 cyclotron and its beamlines are shown in Fig. 2. As was mentioned previously that first K150 beams were delivered to three separate experiments in late 2010; beams have been transported to the MDM cave and to the Heavy Ion Guide line (inside the K150 vault).

For the K150 beamlines, a big challenge was how to control the beam divergence in transporting large emittance beams from the K150 cyclotron. Using TRANSPORT, the beamlines were designed to transport 24 π mm-mrad emittance beams, utilizing two sets of quadrupole doublets configured for point-to-parallel and then parallel-to-point focusing scheme. By dividing the usual two large angular kicks

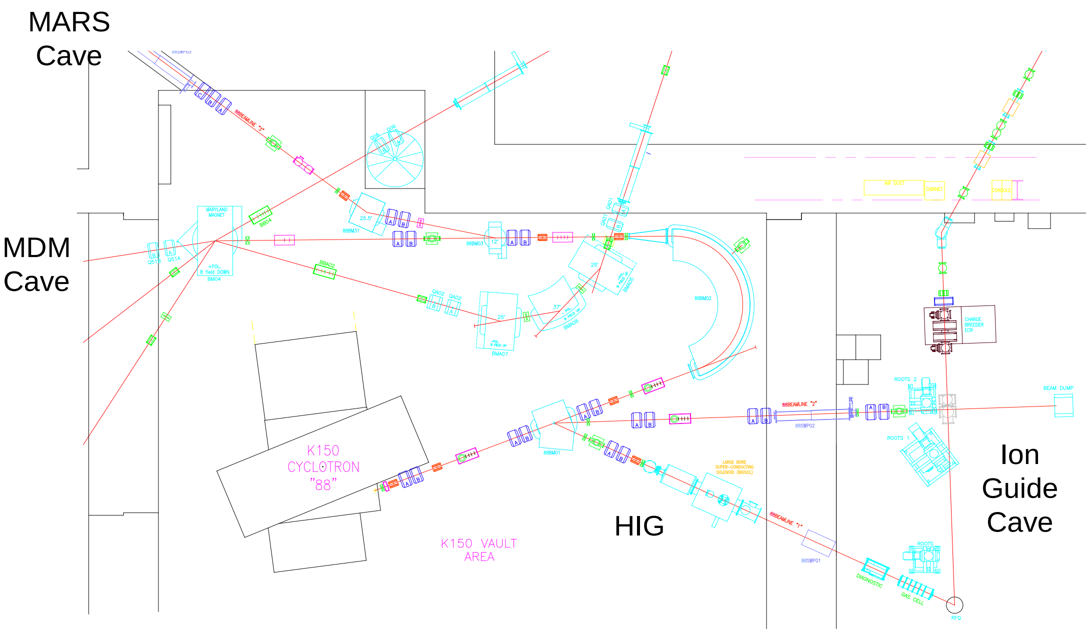

FIG. 2. New K150 beam lines.

from a quadrupole doublets into four gentle kicks using two pairs of doublets, we wanted to control the beam divergence through the beamlines. However in practice, this scheme became complicated due to couplings of four quadrupoles from two doublets.

Having a field calibration for the quadrupoles (we used a TOSCA calculation) has helped to get close to the proper values on the quadrupoles, however, we need more experience with the K150 beamlines as well as working with the larger emittance K150 beams.

Ion Guide Cave Radiation Shielding System

The design for the beam dump and shielding structure was approved by a review panel in March 2007. Following the guidance of the review panel, the shielding system of the Ion Guide cave (see Fig 3.) was studied with additional concrete shielding around and above the beam dump. The extra beam dump shielding and an extra layer of 18” thick roof planks were found to reduce the secondary radiation inside and outside the cave by two orders of magnitude. The cost for the additional shielding is within the budget of the project and has been implemented.

The beam dump (to stop the intense proton beams from the light ion guide) will be made from pure aluminum (to stop the beam) surrounded by thick concrete walls (to retain secondary radiation produced by the aluminum). Heat from the beam will be removed by water cooling the aluminum with a purchased cooling unit. Aluminum quoted to be 99.98% pure was cast into one solid block and then machined into shape. A second aluminum beam dump has been machined as well.

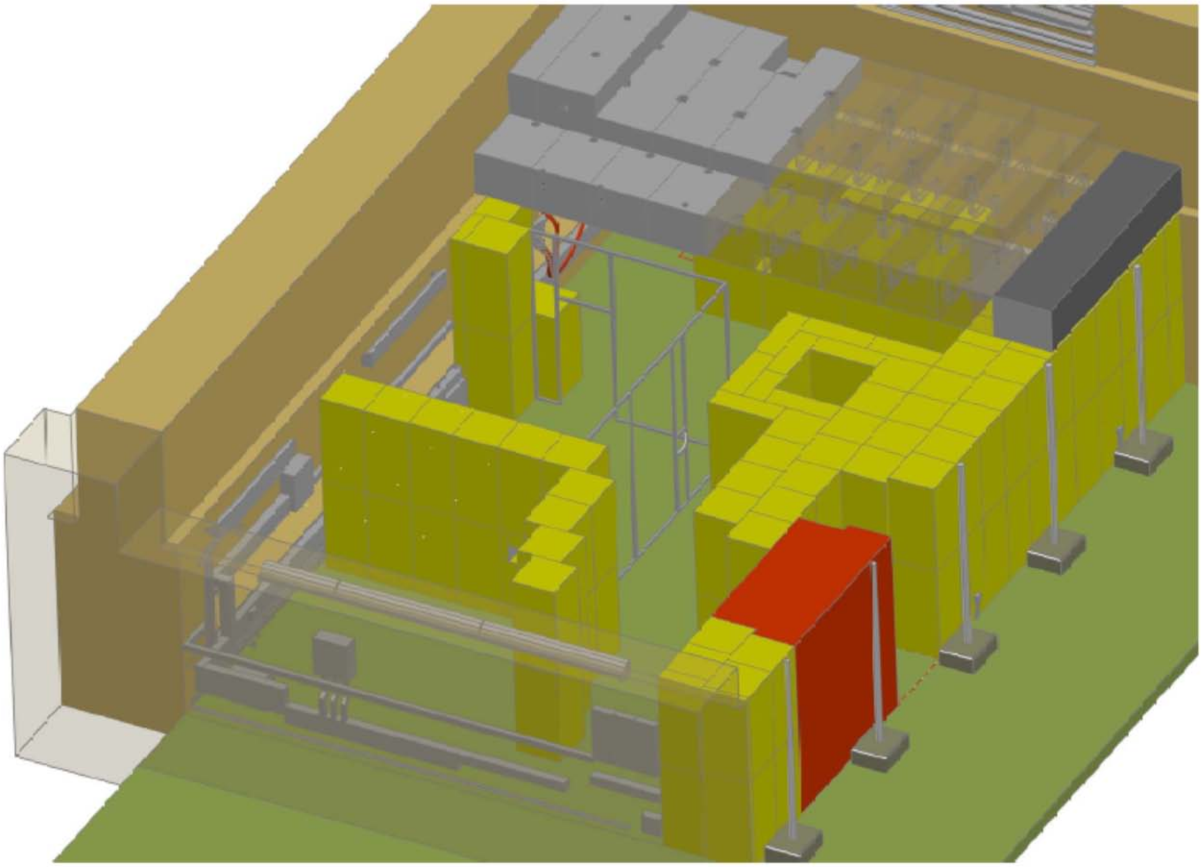

FIG. 3. Ion Guide Cave Radiation Shielding system was completed in February 2011 and tested in March 2011.

Preparation of the Ion Guide cave was completed in September 2010 and included the complete removal of the office building on top of the roof planks. The CB-ECR ion source and Light Ion Guide were dismantled and/or covered to protect them during the installation of the Radiation Shielding system. The majority of the shielding system (wall block, wall panels and roof planks) arrived as scheduled and was installed in November and December 2010. The four remaining wall blocks were installed and the end walls poured in early March 2011.

In late March 2011, the beam dump and radiation shielding system were tested and were found to perform as according to design. Beams of 30 MeV protons at intensities of 10 μA were stopped on the beam dump in the ion guide hall. The leakage of secondary radiation from the cracks and passageways in the radiation shielding system were carefully measured and documented. No major leakage points were discovered. The results of the test will be reported in another progress report.