

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 to the first quarter of calendar year 2011. 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, the effort made during this year on Task 1 included,

- Procurement and installation of equipment for the K150 high vacuum system,
- Fabrication of the dee inserts for the central region of the cyclotron,
- Development of high intensity 30 MeV Proton beams (design study with H- beams),
- Fabrication and assembly of K150 beam lines, and
- Evaluation of the radiation shielding system of the K150 cyclotron.

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

- Procurement of material for the ion guide beam dump,
- Installation and development of phase 2 of the Light Ion Guide system (connecting the light ion guide to the CB-ECR ion source),
- Development and design of the Heavy Ion Guide system and beam diagnostic systems,
- Installation and testing of the CB-ECR ion source, and
- Procurement, assembly and installation of the n+ transport system. Below we report on a few of the accomplishments listed above.

Central Region Calculations

Following the Berkeley design, a first set of dee inserts (made from titanium) and mounting mechanisms have been constructed and are ready for installation, see Fig 1. From the mirror inflector at the center of cyclotron, the acceleration process starts with the help of the Berkeley designed dee inserts or "batwings". One dee insert is attached to the active dee and the other to the dummy dee. The dee inserts are installed around the inflector housing and provide a well-defined electric field near the center of the cyclotron. The horizontal gap between the two dee inserts is 0.25", and the extent of the dee inserts (along the dee lip) is only a few inches. The nominal gap between the dee and the dummy dee is 2". Center region calculations were undertaken to study the effectiveness of the batwings.

These calculations involve tracking the beam particles through the combined RF electric field and the magnetic field at the center of the cyclotron – along the critical first few turns of the acceleration. The tracking is carried out with the MSU program called Z3Cyclone. Tracking the beam can answer some basic questions such as whether the particles can negotiate all the obstacles in the center, the mirror housing and the dee insert structures. Other important questions such as the RF voltage requirements, the RF phase acceptance, the electrical vertical focusing properties for the first few turns, and the centering of the beam orbits after several turns can also be studied.

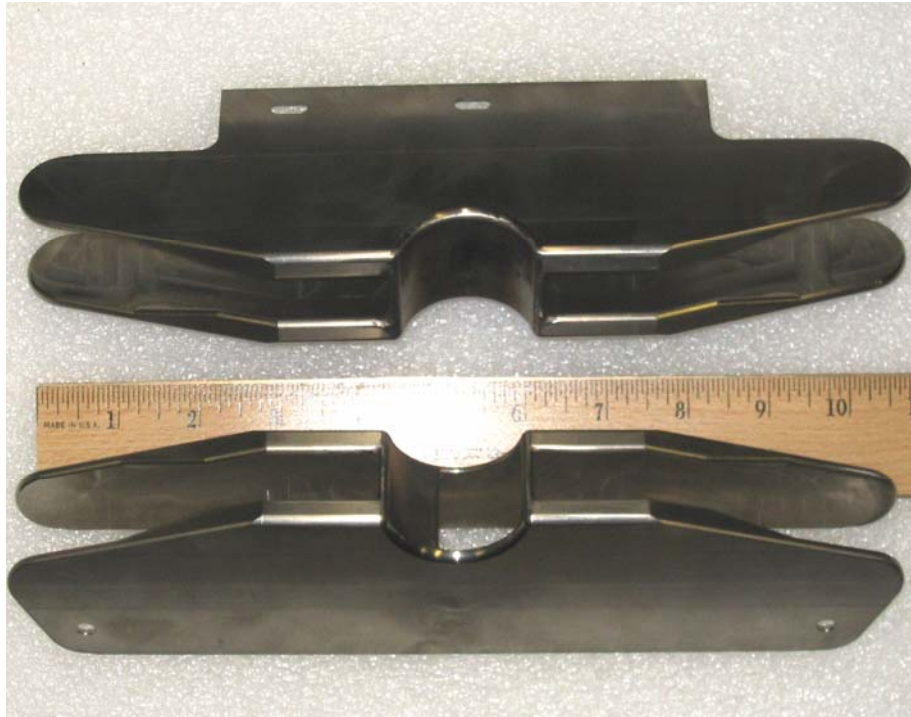


FIG. 1. Berkeley designed dee inserts. They mount onto the dee and dummy dee; the bottom one with an opening for the beam entry attaches to the dummy dee side.

To perform the calculations, a 3-dimensional electric field map in the center region and a 2-dimensional magnetic field map of the cyclotron median plane are needed. A 3-D electric field map can be generated with a number of programs such as Relax3d. However, due to time constraint, a 2-D map has been used to simulate a 3-D field map, which is valid only near the center of the cyclotron. The 2-D electric potential map (looking from above) of the dee inserts together with the circular, grounded inflector housing at the center of the cyclotron is shown in Fig. 2. The beam particles are injected into the cyclotron from the inflector into the dummy dee side, through an opening in the dummy dee insert. The figure shows that the electric field is shielded away in the region between the inflector housing and the dummy dee insert. Another 2-D electric map can be obtained by looking at the dee inserts from the side, see Fig. 3. This 2-D map was used in the tracking calculations, as this map provided a more realistic electric field for the beam particles in crossing the electric gaps. Since this 2-D map completely ignores the inflector at the center of cyclotron, the beam particles had to be transported away from the mirror

inflector before the integration of the particles over the field maps can begin with the Z3Cyclotron program. As for the magnetic field map, a simple flat uniform field was used since we were only interested in the first few turns for this initial center region study.

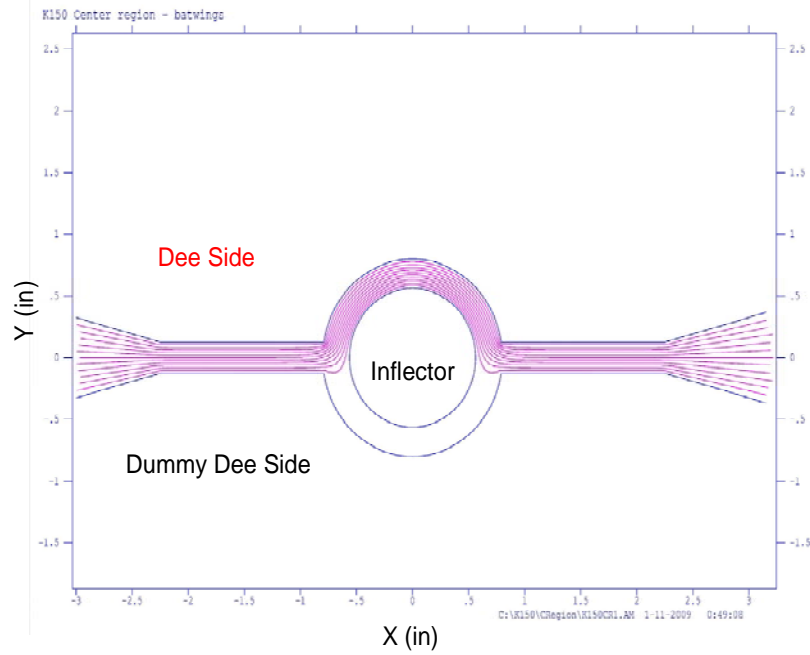


FIG. 2. Two dimensional Poisson calculation of the batwings and the grounded inflector housing looking from the top.

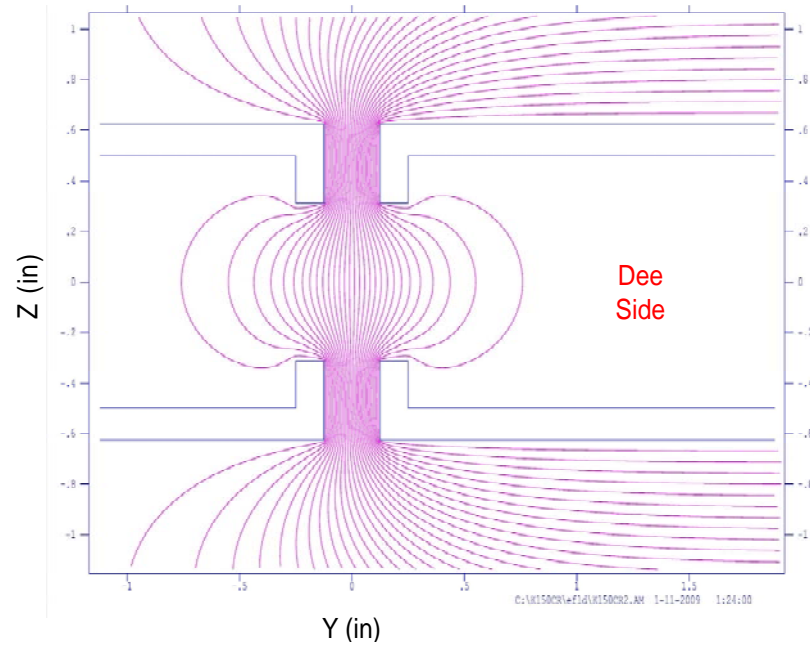


FIG. 3. Two dimensional Poisson calculation of the batwings looking from the side.

The first results of the center region calculations are shown in Fig. 4. The particle tracking started just above the mirror inflector at the center of cyclotron. Using analytical formulas it was tracked through the inflector and then followed into the dummy dee insert. Then, the Z3Cyclone program was used to track through the first few turns of the acceleration. Using 64 kV on the dee, the beam safely negotiated the first turn and led to well-centered orbits, as shown in Fig. 4. With the maximum of 64 kV on the dee, about 500 turns are needed to reach full energy in the cyclotron.

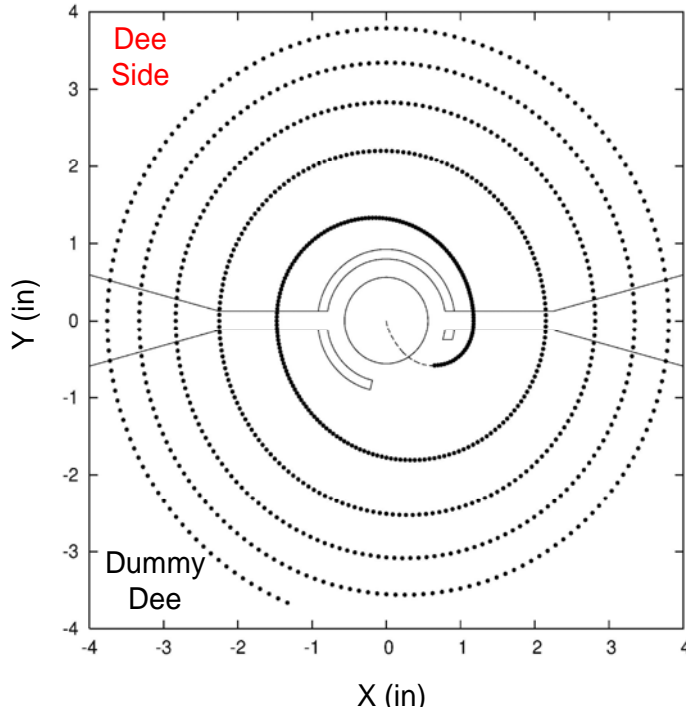


FIG. 4. First few turns of the acceleration in the K150 Cyclotron with a mirror inflector and dee inserts.

Beam Lines

Of the four new beam lines planned for the K150 cyclotron, the lines to the MARS cave and to the Maryland magnet, which in turn connects to the MDM and NIMROD caves, have been installed, and are under vacuum. On Jan 21, 2009, we accelerated and extracted a beam of 20 MeV protons from the K150 cyclotron, and transported the beam around the 160 degree analysis magnet for the first time. In order to complete the beam line installation, we had to move a quadrupole doublet in the BAS line (a K500 beam line) by 13" upstream into the concrete wall. Also, a 2-foot diameter and 10-foot long hole was bored through the concrete wall from the K150 vault to the cave 2 in order to make K150 beams available in the MARS cave. Of course earlier, we replaced the beam switching dipole magnet, located upstream of MARS, with a large 42.5-in circular pole magnet, which we had obtained free from Indiana University several years back. This freed up the Scanditronix dipole magnet, which has been moved to

K150 cyclotron vault and placed between K150 and the analysis magnet, to switch the beams to the Light Ion Guide (LIG) and Heavy Ion Guide (HIG). The two beam lines to LIG and to HIG have been designed, and they will be installed over the next year as we make progress with LIG and HIG installations in the cave north of the cyclotron.

The layout of the K150 beam lines is shown in Fig. 5. After the beam is extracted and collected with the help of the first pair of the quadrupoles, the beam optics for all the beam lines starts from the object slits located in the first beam box. The biggest challenge for the K150 beam lines is how to handle the much larger beam emittance from the K150 as compared to the K500 beams (about 5π -mm-mrad for K500 beams to 24π -mm-mrad or larger for K150 beams).

In order to control the size of the beam in both x and y transverse directions, using symmetric quadrupole triplets would have been ideal, however that was not possible due to space limitations. Therefore, we used instead closely-spaced quadrupole doublets to function in the point-to-parallel and then parallel-to-point scheme along the beam lines. The spacing between the quadrupoles for a doublet has been shortened in order to control the beam divergences, and at the same time taking advantage of the smaller beam rigidity from the K150 as compared to the K500.

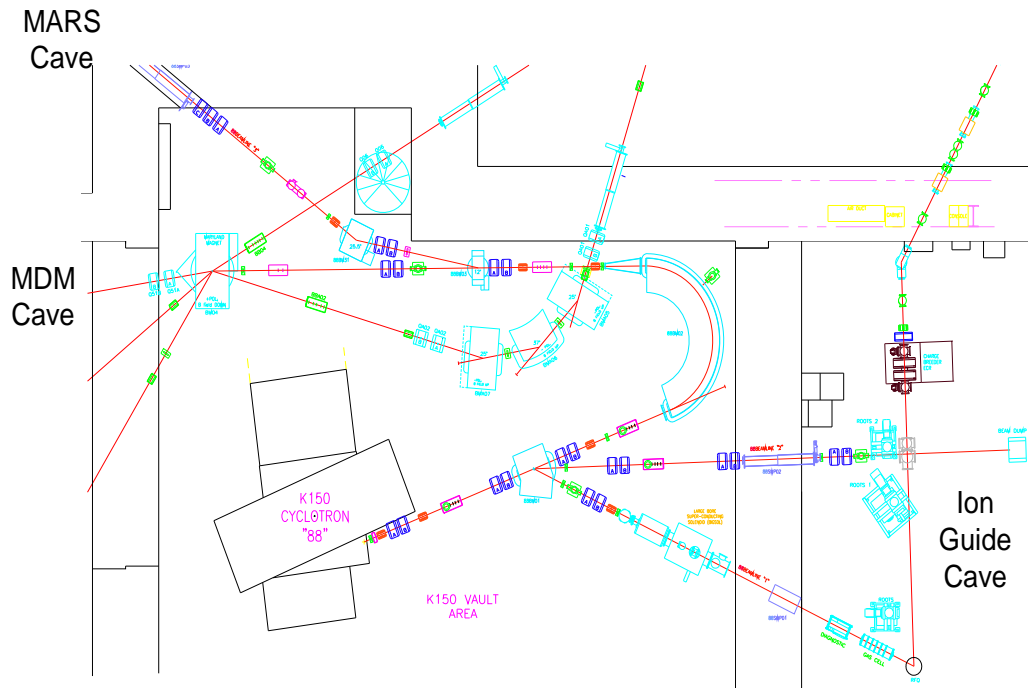


FIG. 5. New K150 beam lines.

H- Acceleration

One of the concerns for the project is the extraction efficiency of high intensity light ions from the cyclotron. Poor extraction efficiency may cause radiation damage to and high activation of the

cyclotron deflector. One solution is to accelerate H^- ions and then strip to H^+ near extraction. At other cyclotron labs this technique has shown to have extraction efficiencies of nearly 100% and greatly diminishes interior activation problems. Simple ray tracing calculations show that such a system could physically fit into and operate within the vacuum space of the K150 cyclotron. With the deflector pulled back from the extraction channel (but not removed from the cyclotron), H^- ions could be accelerated to 38-40" and then stripped to H^+ . Upon exit, the trajectory of the H^+ ions would then be steered along the normal beam line with a dipole magnet (see Fig 6).

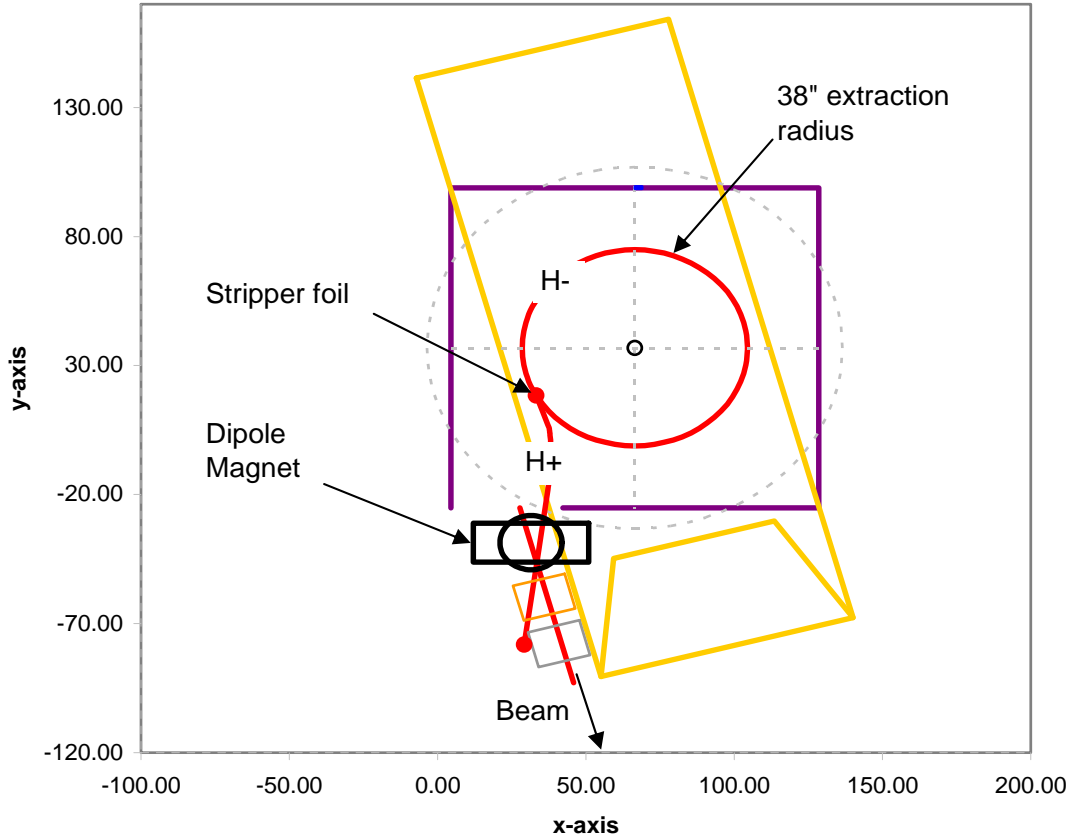


FIG. 6. Raytracing calculations for H^- stripping at the exit of the K150 cyclotron.

The cyclotron laboratory in Jyväskylä, Finland (JYFL) has had great success with a multi-cusp source that was built by them with help from the TRIUMF lab in Vancouver, Canada. The experience of JYFL is that their source LIISA (Light-Ion Ion Source Apparatus) produces over 5 mA of H^- at the 5.9 kV extraction voltage suitable for their fixed center region geometry for 30 MeV. This results in a proton beam out of the cyclotron of 60 μA . JYFL has offered to loan their prototype negative ion source to us in an MOU for 8 years. This ion source has a shorter plasma chamber than LIISA, but is capable of producing at least 1 mA of H^- which is suitable for our project (14 μA extracted from the K150 cyclotron). To become fully functional, the source requires new power supplies, a gas system and beam line elements. Our plan is to attach the H^- source assembly to the existing vertical flange of the 90°

magnet on the ECR2 injection line. The layout of the H-source of the ECR2 injection line is shown below in Fig. 7.

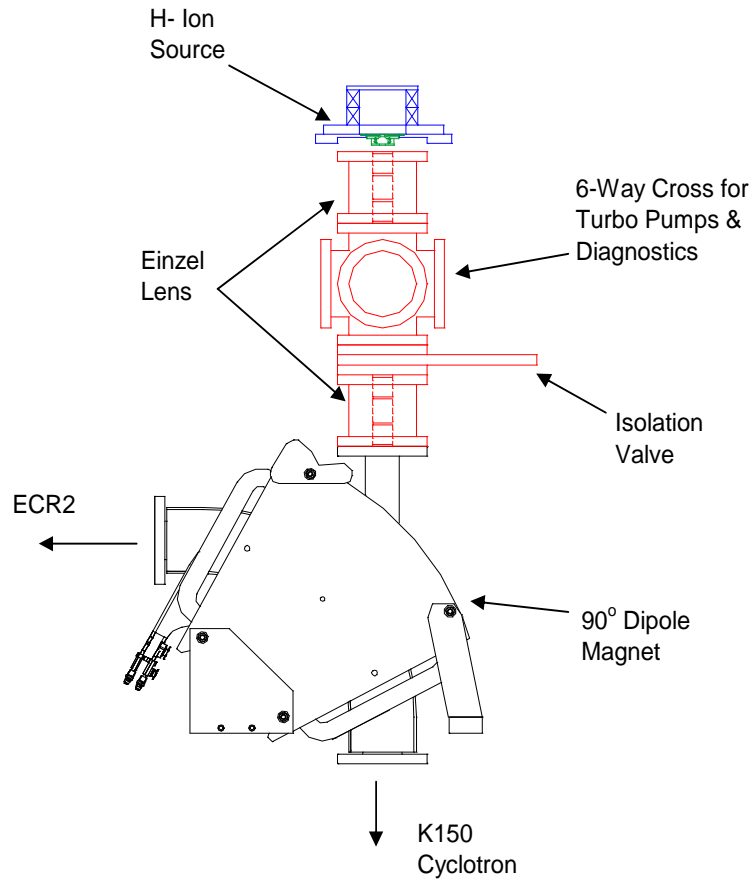


FIG. 7. Layout of the H- LIISA ion source on the ECR2 injection line of the K150 cyclotron.

Radiation Shielding Evaluation of the K150 Cyclotron Vault

The radiation shielding system of the K150 cyclotron vault was studied with the same computer codes/models (PHITS, MORTIZ and MCNPX) that were used to study the ion guide beam dump and radiation shielding system. Prompt radiation created by protons at 50 MeV, deuterons at 50 MeV and alpha particles at 127 MeV on thick targets of Pb, Cu, C and Ta placed at various locations inside the K150 vault was studied (see Fig 8).

The calculations show that the thick concrete walls and double-layered roof system provide adequate protection by showing zero dose levels outside the vault. One area of concern is region above the center of the cyclotron where the roof planks are arranged to allow a hole through the shielding for the vertical injection line equipment. At 1 meter from the hole, the calculated neutron dose is ~200 mrem/hour however the dose decreases rapidly to ~10 mrem/hour at a distance of 2 meters. It is clear that

this area will need additional shielding and an interlock safety system similar to the system used for region above the K500 cyclotron. Additional calculations for the estimates for “sky-shine” radiation above the opening are now underway.

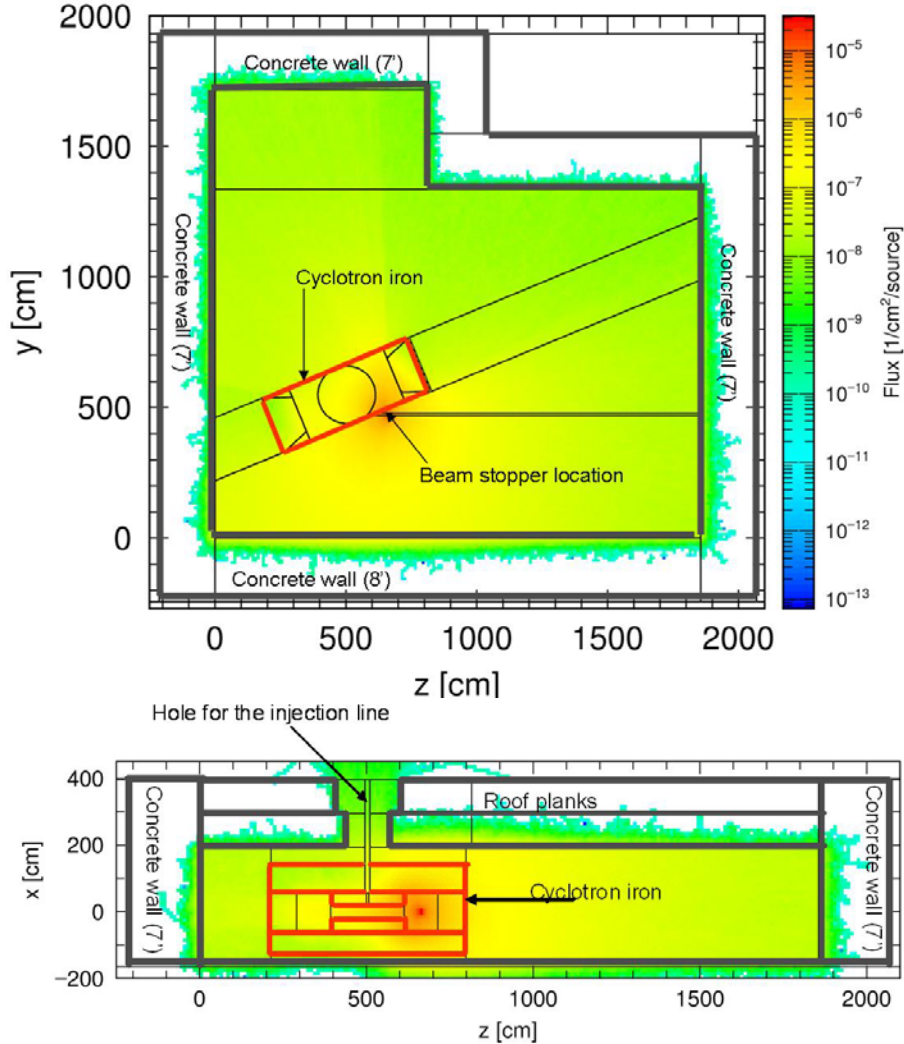


FIG. 8. Top (above) and side (bottom) views of the cyclotron iron, vault walls, roof system and beam target location. All neutrons and gamma rays produced by the 20 μ A, 50 MeV proton beam are contained by the shielding system except for the opening above the cyclotron.

Charge Breeding ECR Ion Source

The CB-ECR ion source was delivered in September 2007 and assembled by Wayne Cornelius in October 2007. All of the equipment needed to complete the CB-ECR ion source has been procured and installed including both coil power supplies, the turbo pumping systems, microwave transmitters and control equipment. The analyzing magnet for the CB-ECR ion source has been constructed and is currently being installed.

The CB-ECR ion source was turned on for a short period of time. The TWT transmitter was turned on and plasma was created successfully. The extraction plate was removed and the star shape carbon coating by the hexapole field (see Fig 9) was observed. An extraction current of about 300 μA at 50 V extraction voltage was collected on a Faraday cup.



FIG. 9. The extraction plate of the CB ECR ion source after initial testing with the TWT transmitter. Note the star shape carbon coating by the hexapole field is observed.