Cyclotron institute upgrade project

H. L. Clark, F. P. Abegglen, G. J. Kim and D. P. May

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 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.

Most of the effort during this reporting period focused on Task 1, restoring the K150 cyclotron major equipment. This included commissioning the K150 RF system and K150 ECR ion source & injection line and accelerating first beams from the K150 cyclotron. Progress was also made on the beam lines with installation of three large dipole magnets and coring the passageway through the K150 vault wall into cave 2. It is anticipated that the K150 beam lines will be completed by the end of summer 2008 with an anticipated first experiment in the fall. Progress was also made on Tasks 2 and included development of a 2m long SPIG to connect the light ion guide to the CB ECR ion source. A radioactive ^{228}Th source has been procured and will be used to further develop the light ion guide system. Development of the heavy ion guide gas cell system with the collaboration of ANL still continues. First pieces of the gas cell are now under construction. Task 3 progress includes the delivery and assembly of the CB-ECR ion source constructed through a DOE SBIR project. All items to complete the CB-ECR ion source have been procured. Construction of the n+ transport system has begun and the power supplies for the magnets and cryogenic vacuum systems have been procured.

In October 2007, first beams of 20 MeV protons were accelerated and extracted from the K150 cyclotron. Values from the cyclotron log book from 1987 were used as the starting values for the RF system, deflector system and cyclotron main, trim and valley coils. After some optimization, the main coil was set to 612 A for a 6.7 kG magnetic filed, the RF system was tuned to 10.1051 MHz with the dee voltage set to 73 kV and the extraction deflector voltage set to 51 kV. Table 2 compares the final operating parameters to those from 1987 and shows excellent agreement with previous operation. In 1987, protons were introduced from an internal filament source; therefore the currents for the first few trim coils are understandably different. Table I shows the beam current values measured by the refurbished beam probe at various extraction radii. The internal beam transmission from 10" to 38" was ~34% and the extraction efficiency was only 10%. Ultimately, 25 nA was extracted and measured on the first Faraday cup (FC-01) outside the cyclotron. This first test showed that the vital components of the cyclotron have been restored. For the production of radioactive ions, much higher intensity is required. However, two key items were not installed for the test: dee inserts and axial Glaser lens in the upper yoke. Due to their absence the shape of the beam in the center region could not be optimized.

Table I. Comparison of K150 cyclotron operating parameters from 1987 to 2007 for 20 MeV protons. All values are in good agreement except for trim coils 1 and 2 which shape the magnet field of the central region of the cyclotron. However in 1987, protons were introduced from an internal filament ion source and in 2007 from ECR2 through the vertical injection line.

K150 Cyclotron Parameters	1987	2007
RF Frequency (MHz)	10.1051	10.1051
Dee Voltage (kVolts)	63	73
Main Coil (Amps)	611.9	612.22
Trim Coil 1 (Amps)	-449	0.22
Trim Coil 2 (Amps)	-335	-110.00
Trim Coil 3 (Amps)	-218	-216.12
Trim Coil 4 (Amps)	-66	-82.64
Trim Coil 5 (Amps)	-33	-33.09
Trim Coil 6 (Amps)	68	68.86
Trim Coil 7,8 (Amps)	0	0
Trim Coil 9 (Amps)	-20	-20.10
Trim Coil 10 (Amps)	94	94.29
Trim Coil 11 (Amps)	48	48.04
Trim Coil 12 (Amps)	191	191.04
Trim Coil 13 (Amps)	257	239.90
Trim Coil 14 (Amps)	-174	-174.23
Trim Coil 15 (Amps)	-4	-4.03
Trim Coil 16 (Amps)	-783	-781.68
Trim Coil 17 (Amps)	612.9	652.86
Deflector Voltage (kV)	46	50.89
Deflector Position 1	50600	50600
Deflector Position 3	50600	50600
Deflector Position 6	49500	49500
Deflector Position 2	48740	48716
Deflector Position 4	52484	52440
Deflector Position 5	50100	50100
Deflector Position 7	50500	50500

Table II. Beam probe current readings for 20 MeV protons at various distances from the center of the K150 cyclotron.

Beam Probe Radius (inches)	Beam Probe Current (nA)
10	650
15	510
20	340
25	270
30	250
35	220
38 (Deflector Entrance)	220

In order to better understand the particle orbits in the central region of the cyclotron, electric field and magnetic field maps are needed. Since no actual mappings exist, theoretical maps may be created from sophisticated software programs. For magnetic field maps, Vector Fields' TOSCA program was purchased. The geometry of the poles, hills and valleys and center plug are entered into the program (as shown in Fig 1). To reduce computation time, whenever possible a simplified geometry is used to describe the actual shapes of the cyclotron (as shown in Fig 2).

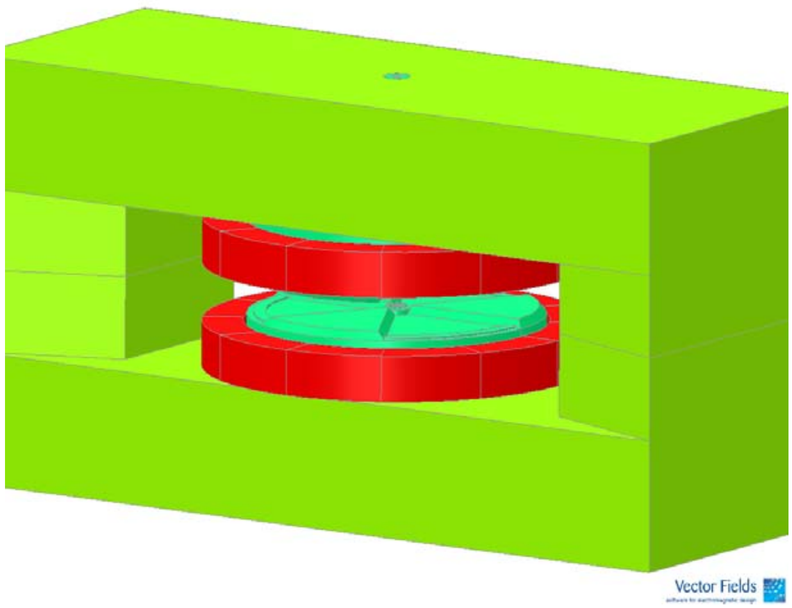

Figure 1. Initial TOSCA modeling of the K150 cyclotron.

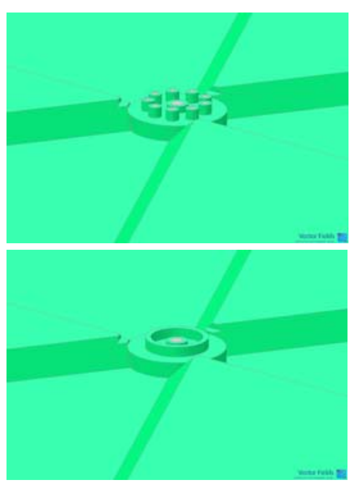

Figure 2. (top) View of the cyclotron center region with nine buttons around the center plug. (bottom) A simplified model with a ring instead of the nine buttons.

First calculations with TOSCA at 1120 A are shown in Fig. 3 along with an equivalent POISSON calculation and the field map data from the Berkeley 88” cyclotron. The TOSCA and POISSON calculations are in agreement. The TOSCA and Berkeley calculations agree to within 10%, however the form of the average B field versus radius is well produced by both programs. At the outer edge of the pole face, the “Rose” shim has been incorporated but does not account for all the rise of the magnetic field. The trim coils, which are series of concentric circular conductors, are modeled well by TOSCA and POISSON and agree well with the Berkeley field maps (shown in Fig. 4).

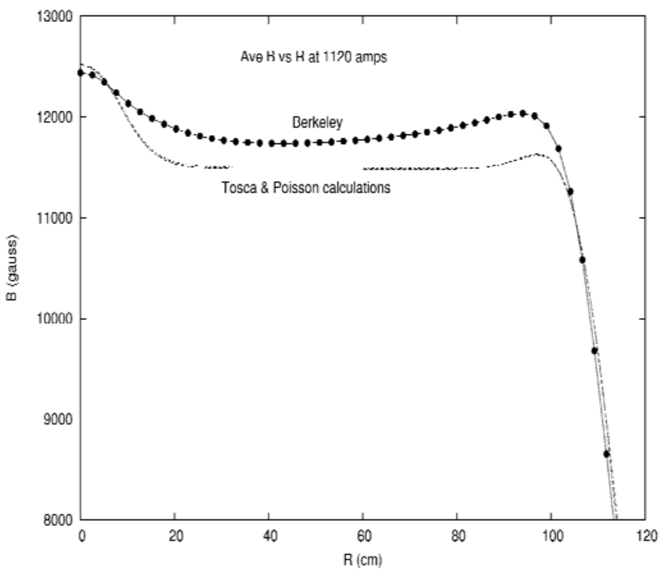

Figure 3. Comparison of the Berkeley field map data with TOSCA and POISSON calculations at 1120 A.

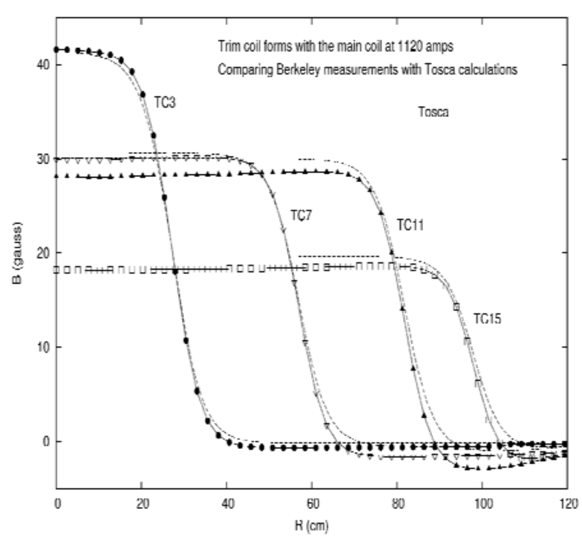

Figure 4. Comparison of the B field forms for 4 of the 15 trim coils at 1120 A on the main coil.