Compact injection line for K150 cyclotron

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A compact injection line has been designed for the K150 Cyclotron, which is being refurbished to provide intense beams for the production of radioactive beams. The ions for the cyclotron will be produced from ECR2, an AECR-U class, two-frequency ion source.[1] The injection line will use a single 90 degree magnet to analyze the beam as well as to bend the beam vertically into the cyclotron, see Fig. 1. The beam focusing will be accomplished with four solenoidal magnets, the last one of which is located inside the yoke of the cyclotron. (The short Berkeley-designed solenoidal magnets are also referred to as Glaser lenses.) Other components in the injection lines are: x-y steering magnets, faraday cups and slits, beam attenuation screens, a beam buncher, and vacuum pumps and valves.

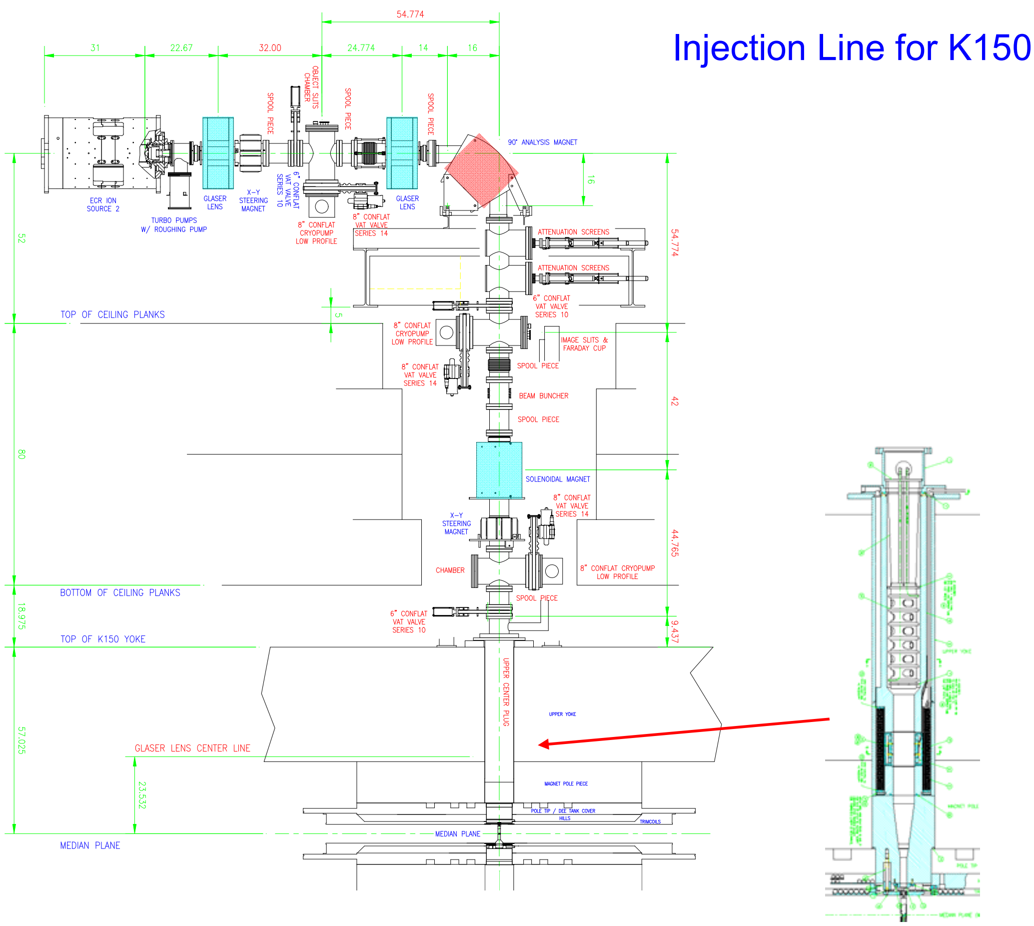

Figure 1. Layout of the injection line for the K150 Cyclotron.

The injection line was designed in a modular fashion using as much as possible existing equipment. The fundamental element in the injection line is the 90 degree analysis magnet. The MSU designed bending magnet has a short 16" (40.64 cm) radius of curvature and with 30 degree entrance and exit edge angles to give a double x and y focusing at about 98 cm object and image distances. The bending magnet section achieves a modest charge-to-mass resolution of 1/70 through ½" object and image slits. The magnet has 4.2" vertical and 6" wide opening. (The beam pipe diameter will be 6" outside of the cyclotron.) Additionally, in order to compensate for space charge effects in this section of the injection line, a Glaser lens will be added just upstream of the 90 degree magnet as shown in Fig. 1. The ECR2 ion source and a Glaser lens are located upstream of the bending magnet section. The first Glaser lens is placed close to the ion source to efficiently collect ions and to refocus them onto the object slit for the bending magnet. The nominal magnification of the Glaser lens from the exit of the ion source to the object slit is 1.4, and this helps to control the divergence of the beam through the rest of the injection line. Vertically downstream of the bending magnet section, a long, MSU designed solenoidal magnet and a short solenoidal magnet in the yoke, located just above the funnel shaped iron plug, are used to focus the beam into the cyclotron. The general scheme of this section is to focus the beam point-to-parallel from the image slit of the bending magnet to the long solenoid, and then run parallel between the two solenoidal magnets, and then focus parallel-to-point with the last solenoidal magnet onto the mirror inflector. Thus, optically the compact 8 m-long injection line naturally divides into three sections.

The injection line design and some of its parameters were initially determined with the first order TRANSPORT code. To study next the space charge effects from intense beams, two other beam transport programs, which include first order space charge effects, were used: Trace3d from Los Alamos [2] and TransOptr from Chalk River, now maintained by Rick Baartman at TRIUMF.[3] Interestingly, initially the results from the two programs did not agree, however later this was traced to the extra factor of 1.5 for the beam current in the Trace3d program. A simple transport test using a 2m drift space using, for example, 0.10 mA beam current for Trace3d and 0.15 mA for TransOptr, confirmed that to get an agreement between the two programs, the input beam current for the Trace3d must be reduced by 1.5 from that for TransOptr. Additionally, the numerical integration of the K-V equations, using 0.15 mA beam current for the present example over the 2 m drift space, also gave the same results as the two programs.

The standard beam emittance used for the transport calculations was 4×30 π-mm-mr, which is adequate for the most beams [4], however, for the light ions a larger 6×75 π-mm-mr was used to test the injection line. The Trace3d calculations with 0.15 mA beam current through the injection line for the two emittance values are shown Fig. 2.

To study the effects of the cyclotron fringe field on the injection line, first the cyclotron fringe field through the 4" hole in the yoke was determined with a Poisson calculation, see Fig. 3. The calculation is compared with a field measurement from Berkeley, reported in the 2000 LBNL Report[5]. The figure shows good agreement between the calculation and the measurement for the rapid falloff of the main field through the yoke hole, however the calculation could not reproduce the small field bumps. One interesting bump in the calculation at 60 cm from the median plane is due to the open structure of the Glaser lens in the yoke hole. Overall, the cyclotron field is well shielded in the yoke hole, away from

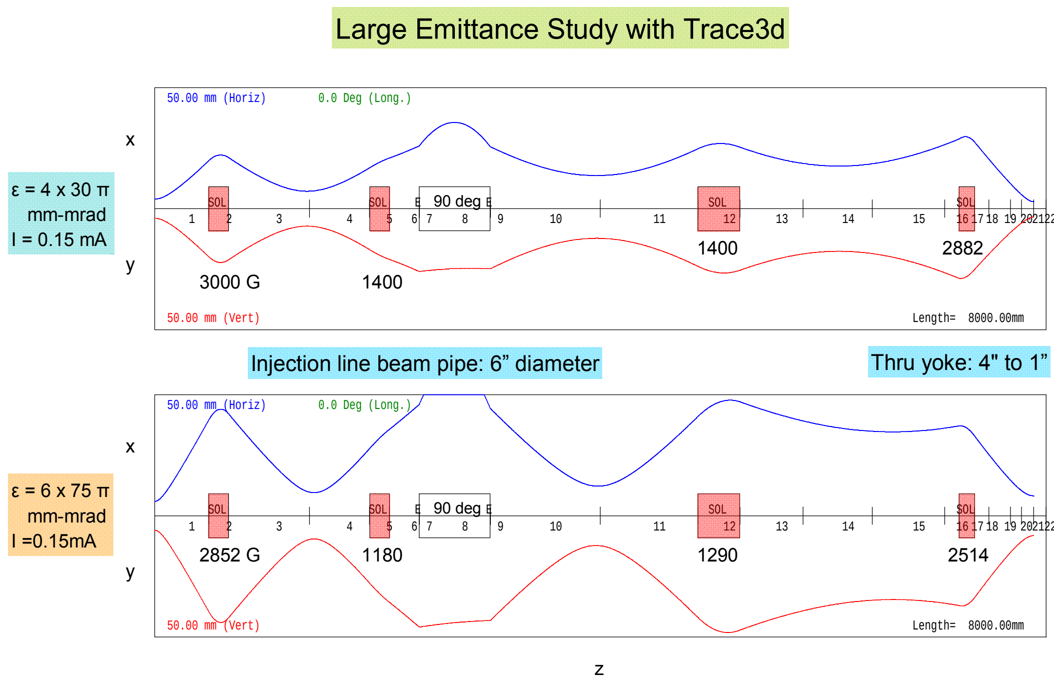

Figure 2. X and Y beam envelopes for transport from the exit of the ion source to the center of cyclotron. The indicated field values for the four solenoidal magnets are possible solutions to keep the beam envelopes under 50 mm half width through the injection line.

the main volume of the cyclotron. The effects of the cyclotron fringe field was studied with TransOptr, which integrates over a user specified external field. Fig. 4 shows the effects of turning on the cyclotron field at 14.4 kG. Clearly the strong cyclotron field provides an extra focusing on the beam, which makes the beam spot smaller and also shifts the waist of the beam slightly upstream as shown on the figure. While playing with the last two solenoidal magnets, it was found that the waist of the beam can be brought back to the center of the cyclotron for this particular cyclotron field (14.4 kG). The effects on the beam at two lower cyclotron field levels of 5 and 10 kG were also studied. The effects were weak at 5 kG and only a small additional focusing was seen. At 10 kG level, similar to the 14.4 kG field effects were observed but less severely. However, more work will need to solve how to properly use the last two solenoidal magnets to focus the beam at the center of the cyclotron. A new central region calculation will be useful to set the beam conditions.

We would like to express our thanks to Claude Lyneis and Daniela Wutte of LBNL for their help and providing us with drawings for the components in the cyclotron yoke.

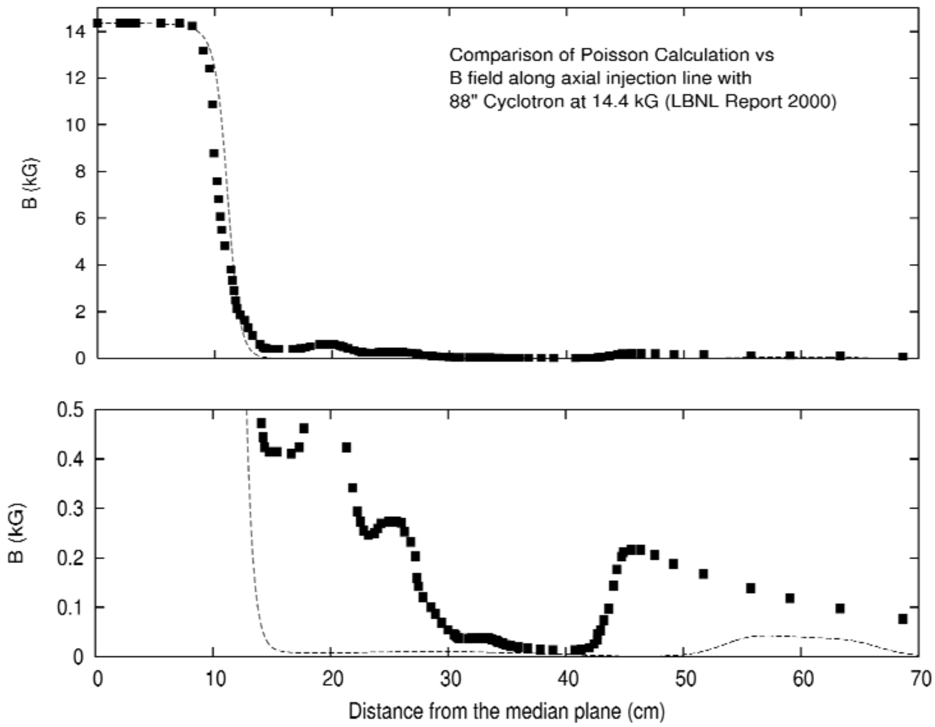

Figure 3. The axial field of the cyclotron through the yoke of the cyclotron.

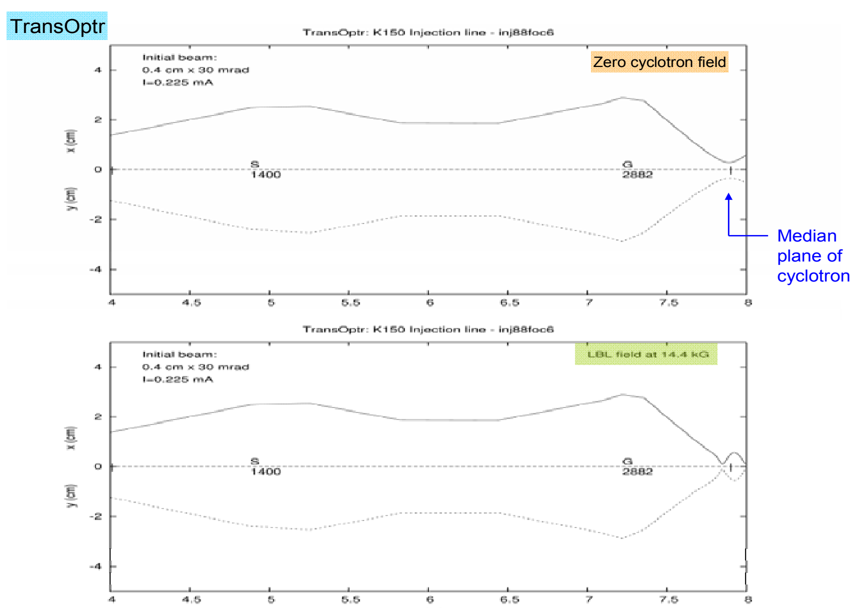

Figure 4. Effects on the beam due to the fringe field of the cyclotron at 14.4 kG.

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[3] E. A. Heighway and M. S. de Jong, "TRANSOPTR," Chalk River Nucl. Lab. Report AECL-6975 (1984).

[4] D. Wutte *et al.*, in Proc. of the 16th International Conference on Cyclotrons and their applications in East Lansing, MI 2001 (2001), p.445.

[5] D. Wutte, "The 88-inch Cyclotron External Injector System," LBNL Report (2000).