K150 operations and development

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We had another very busy year operating the K150 cyclotron. For the reporting period we logged over 4291 hours of beam-on-target and 2313 hours for beam developments. Included in the beam-on-target time was 3110 hours (2451 for physics and 659 for chemistry) for in-house science experiments, 186 hours for the SEE tests, and 995 hours for LLNL-Burke experiments. The K150 operational time is shown in Table I.

Table 1. 2017-2018 operational time.

Time	Hours	% Time
Beam on target	4291	49.1
Beam development	2313	26.5
Scheduled maintenance	724	8.3
Unscheduled maintenance	1408	16.1
Total	8736	100.0

The big users of the K150 beams were the LIG (light ion guide) project, the Rogachev group, and the LLNL-Burke collaboration.

As was in the past years, 10.3, 14.5 and 15 MeV proton beams were produced for the LIG project throughout the year. In November of 2017, the production of the radioactive ^{114}In (1.2 minute half-life) from a ^{114}Cd target and the subsequent charge-breeding and re-acceleration with K500 were investigated. Using the CB-ECR ion source the charge-bred ^{114}In^{19+} ions, along with ^{12}C^{2+} which was used as a pilot beam, were accelerated to 11 AMeV from the K500 cyclotron and were then sent to the MARS spectrometer for analysis. The beam switch from ^{12}C^{2+} to ^{114}In/Cd^{19+} was accomplished by shifting the K500 RF frequency by +9 kHz. The MARS analysis showed that the beam was ^{114}In/Cd mix and that it was indeed produced from the LIG gas cell, although the proportion of indium to cadmium was not determined. This test is described in detail in a separate section.

Last year we accelerated a 6 MeV proton beam at 330 amps on the main magnet which marked the lowest operating cyclotron field to date. However, this year we developed a 3.4 MeV proton beam at an experimenter’s request at 252 amps on the main magnet. This beam has been used twice for an experiment and even once for a SEE testing.

The Rogachev group ran their experiments eight different times using K150 beams to the MDM spectrometer twice and the rest of times to the MARS spectrometer. A low energy, third harmonic, 1.3 AMeV ^{7}Li^{1+} beam was tuned out twice for their MDM runs, once in December 2017 and then in March 2018. The beam transmission to the MDM target was poor due to the poor vacuum (5×10^{-5} torr) through the beam line in the MDM cave in December. For the group’s March 2018 run, with improved vacuum through the MDM cave (~5x10^{-6} torr), the low energy beam transport seemed have improved. However, due to the experimental setup at the time, no beam current was measured at the target position to verify the beam transmission efficiency. The Rogachev group's other six experiments ran in the MARS cave, and these gave us many chances to practice beam transport to MARS cave.

The K150 beam transport to MARS has been challenging from the very beginning, especially the beam line section downstream of the Analyzing Magnet. This section contains a 12 degree and a 26 degree bending magnet, and in addition the vertical beam height changes from the K150 cyclotron side to the K500 beam lines in this area. So, trying to decouple the effects of the two dipoles (and at times also the upstream Analyzing Magnet) and the beam height transition and to steer the beam straight can be difficult. Compounding the problem was that the 26 degree dipole was not correctly installed initially, see Fig. 1. The 26 degree dipole has a narrow pole face and therefore has a limited region of useable

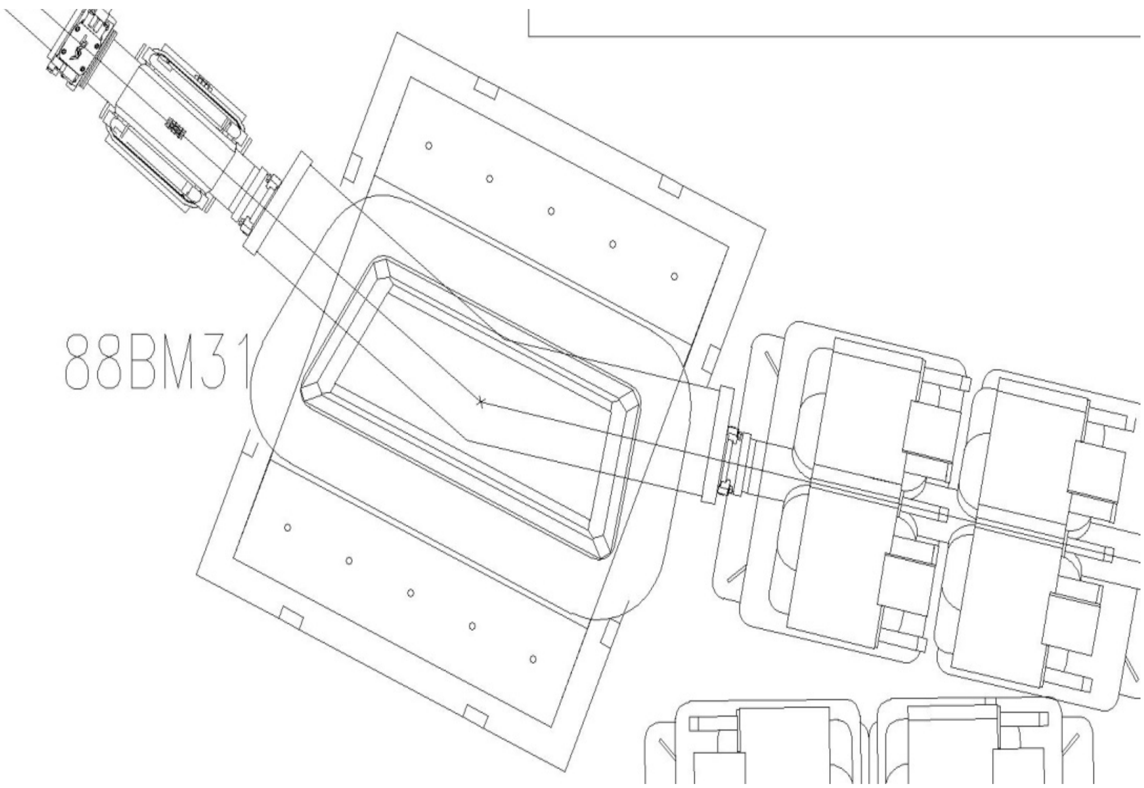

FIG. 1. 26 degree bending magnet BM31, used in the beam line from the K150 cyclotron to the MARS spectrometer. This initial placement of this dipole unfortunately placed parts of the 10 cm wide beam in bad field regions too close to the pole edge of the magnet.

good field of about 12 to 16 cm in width, as can be seen in Fig. 2, whereas the beam envelope would likely occupy 10 cm across. As a consequence the proper alignment of this dipole is very important. After the misalignment of the 26 degree dipole was recognized and corrected (perhaps another 1 cm push might make it even better), the beam transport to MARS has improved. For the Rogachev group's runs in MARS, 6.3 to 15 AMeV, ^{6}Li, ^{7}Li, ^{10}B, and ^{12}C beams were used, and the beam transport efficiency from FC02 to the MARS production target has achieved about 25%, which corresponds to about 50%

transmission through the 160 degree Analyzing Magnet and then another 50% through to the MARS target.

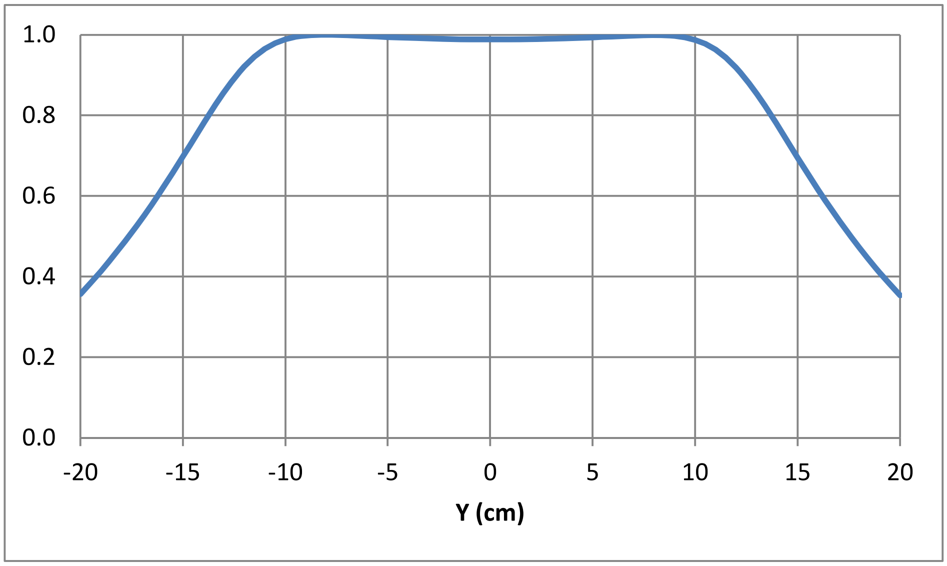

FIG. 2. B field profile across the 26 degree bending maget at the middle of the dipole. The field map was calculated with TOSCA.