K150 operations and development

G.J. Kim, B.T. Roeder, F. Abegglen, H. Clark, L. Gathings, D.P. May, H.I. Park, and H. Peeler

We had a busy year operating the K150 cyclotron. For the reporting period 4/22-3/23 we logged over 3912 hours of beam-on-target and 2296 hours for beam developments as shown in Table I. Included in the beam-on-target time was 3360 hours for in-house science experiments, and 552 hours for the SEE tests.

Table I. 2022-2023 operational time for K150 cyclotron.

Time	Hours	% Time
Beam on target	3912	45
Beam development	2296	26
Scheduled maintenance	1960	22
Unscheduled maintenance	568	7
Total	8736	100

The active users of the K150 beams were: LIG, Yennello, Rogachev and Folden groups, and the SEE testers, who used proton beams as well as heavy ion beams.

The LIG ran more than a dozen times using from 9.0 to 27 MeV proton beams, using intensities from 2 to 10 μA for their radioactive ion production and then charge breeding with CBECR for injection into K500. Getting the proton beam intensity up to 10 μA is relatively easy with the H^- source and the strip extraction. The source output is regulated with the H^- arc current, and with a few amps on the arc current there is enough to get to 10 μA on FC02. The injection efficiency into cyclotron is good and the extraction efficiency is very high, around 80%. But not all the extracted beam can be transported to the experimental cave as the beam spot at the object slit is a little wide. As for the beam transmission to the LIG gas cell, we averaged about 80 to 90%, (from FC02 to FC23) as the beam current was optimized onto the faraday cup (FC23) just downstream of the gas cell.

The astatine 211 production program continues to run regularly, once a month usually, and uses 8 to 12 μA of the 7.2 MeV/u $^{4}He^{1+}$ beam for 12 to 16 hour irradiation on a water-cooled bismuth target. We have extracted up to 18 μA on FC02 thus far, but the RF and the deflector run more stably near the 10 μA level. The deflector extraction efficiency has improved to about 50%, and the throughput from ILC02 to FC02 is about 10%. Typical beam intensity numbers are: starting with about 200 μA on ILC02, with 50% $^{4}He^{1+}$ and the rest $^{16}O^{4+}$, 10 μA of $^{4}He^{1+}$ is extracted on FC02.

We tuned out 6.6 and 6.9 MeV/u $^{48}Ti^{13+}$ beams for the Folden group, and we used a high temp oven and also a Ti-MIVOC method to feed the ion source. To run the high temp oven, it required 157 W (109 A at 1.44 V) to produce metal vapor into the source, and this gave us more than 800 nA out of the cyclotron. Unfortunately this much beam current ate up the source material too fast and just after one day of running it needed to be loaded again. Running at a lower oven power at about 130 W and hence a lower beam current of about 200 nA to stretch the run without reloading the Ti metal into the source did work, but running the high temp oven was not entirely trouble free for the run. In the Fall of 2022, we tried a MIVOC method, whereby Ti-MIVOC (Titanocene) powder in a bottle was leaked into the ion source. This method is much easier to run than setting up the high temp oven, however for this first go around the beam current was insufficient, as less than 100nA was extracted from the cyclotron and deemed inadequate for the experiment. For the next time, because the larger conductance is important, a larger diameter tube between the MIVOC bottle to the source will be used. Since our usual gas inlet tube is ¼" diameter, a larger inlet will need be connected to the side port on the source, where the sputter fixture or the low temp oven gets installed.

The SEE testing continues to run regularly and both proton and heavy ion beams are used for the testing. Since last year beams heavier than ^{78}Kr have been used in testing, such as ^{90}Zr and ^{107}Ag at 13 and 11 MeV/u, respectively. This year 9.4 MeV/u ^{124}Xe^{34+} beam has been added. However, our established 15 MeV/u beams are requested more often, and in order to save time tuning one beam to another, we have tried switching the beams by changing the RF frequency while keeping the magnetic field the same. For example, after tuning out the ^{40}Ar^{14+} (z/A=0.3504) beam at 8.6988 MHz for 15.3 MeV/u, to change to similar charge-to-mass (z/A) beam near 0.35, the RF frequency is scaled with the charge-to-mass. So to switch to ^{78}Kr^{27+} (z/A=0.3466), the new RF frequency of 8.6037 MHz would be used. However the energy of the new beam goes as the square of the frequency, thus the energy would be 15.0 MeV/u for the ^{78}Kr^{27+} beam.

The effectiveness of the internal cryopanel on the cyclotron vacuum and beam vacuum attenuation were studied during the summer and fall of 2022. The cyopanel has two cooling plates and each is separately cooled by flowing LN2 or LHe. The refrigerant consumption rate and cyclotron vacuum values are evaluated. The typical cyclotron vacuum, without the cooled cryopanel, is around 1x10^{-6} torr and is referred to as the base vacuum. With LN2 on flowing on the larger of the cooling plates and the other cooled by the LHe the vacuum improved to 7x10^{-7} torr. A better vacuum was obtained with LHe cooling both the plates, and it got to 1x10^{-7} torr. The vacuum improvement should help especially with heavy ion beams and we tested that with 6.3 MeV/u ^{129}Xe^{31+} and 3.0 MeV/u ^{197}Au 37+ and 38+ beams. For the Xe beam the extracted current improved from ~1 nA at the base vacuum to ~2 nA at 1x10^{-7} torr. However, for the gold beams the improvements were much more dramatic. Tuning up 3.0 MeV/u ^{197}Au^{37+} beam, we saw tiny 4 pA on FC02 with the base vacuum, and as the cryopanel cooled and the vacuum dropped to 1.1x10^{-7} torr the beam current increased to 170 pA. We even saw 50 pA of 3.0 MeV/u ^{197}Au^{38+} at 1.1x10^{-7} torr, and then as cryopanel warmed up only 1.5 pA remained as the cyclotron vacuum return to the base value.