K150 operations and development

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We had a busy year operating the K150 cyclotron. For the reporting period we logged over 5600 hours of beam-on-target and 1192 hours for beam developments. Included in the beam-on-target time was 5108 hours (3608 for physics and 1500 for chemistry) for in-house science experiments, and 308 hours for the SEE tests and 184 hours for the LLNL experimentsas shown in Table I.

Table 1. 2021-2022 operational time.

Time	Hours	% Time
Beam on target	5600	64
Beam development	1192	14
Scheduled maintenance	1260	14
Unscheduled maintenance	684	8
Total	8736	100

The active users of the K150 beams were: LIG (ran 8 times and used 10 to 35 MeV proton beams), Folden group (ran six times and used mostly 6.3 AMeV $^{40}Ar^{11+}$ beam), Rogachev and Yennello groups, and the SEE testers, who used proton beams as well as heavy ion beams.

The LLNL group re-mounted their Hyperion setup to the NeutronBall Line, squeezing into the area between downstream of the neutron ball and the beam dump. The final beam focus was provided with the quad doublet 3 m upsteam of their setup, keeping the drift length from the final focal element to the target the same when the experiment was mounted on the Ion Interaction Line. The two quads were already installed previously just downsteam of the neutron ball to quiet the background events on the neutron ball by guiding the outgoing beam particles to the beam dump before hitting the long beam pipe to the beam dump. The effectiveness of the two quads in quieting the background events was not clear, however. The focusing scheme for the Hyperion experiment was to bring the beam point-to-parallel through the long neutron ball section using the two upstream quads, and then use the final two quads to focus the beam onto the Hyperion target. The focusing scheme did deliver the beam clean enough that, in the summer and fall of 2021 the LLNL and the CENTAUR groups were able to complete their experiments using 21 MeV and 27 MeV proton beams.

The usage of the deflector-extracted low-intensity proton beams increased this year. A deflector extracted 2 MeV proton beam was obtained with the main magnet at 186 A, which is the lowest magnetic field for any beam from K150. However the extraction efficiency was poor, and later a slightly higher 3.8 MeV proton beam at 256 A on the main magnet, which had a little better extraction efficiency, was used for an experiment. (Previously the lowest field beam was the 3.4 MeV proton beam produced at 252 A on the main magnet; it used an H^- beam and then strip extracted.) We also extracted 15 and 35 MeV proton beams through the deflector for SEE users, when they also wanted to test with heavy ion beams.

Regarding the heavy ion SEE beams, we wanted to add a few beams heavier than the ^{78}Kr near the 15 AMeV energy. A tiny amount of $^{90}Zr^{31+}$ beam at 15 AMeV was produced for JPL in Feb. 2022, but was deemed too weak, and instead 13 AMeV $^{90}Zr^{29+}$ was extracted and used by the SEE tester. We also worked to accelerate $^{107}Ag^{31+}$ and $^{124}Xe^{36+}$ beams at 11 AMeV, and tiny amounts were extracted and identified using a total energy detector. The search for these very heavy particles was aided by a small improvement from the ECR2 source (discussed elsewhere in this progress report), and as well as vacuum improvement on the cyclotron. With five (two 8" and three 10") cryopumps running on the cyclotron, the vacuum has improved to around 8×10^{-7} torr (without cooling the internal cryopanel). The latest modification to the source has been a 45% increase in the magnetic field with the installation of a slightly bigger and heavier, low carbon (1008) steel plug and a new 1.5" diameter and 0.39" thick bias steel disk at the front of the source. The disk was fabricated from the same low carbon steel used for the steel plug, instead of aluminum that we have used in the past.

Eight times throughout the year we provided intense 7.2 AMeV $^{4}He^{1+}$ beams for the 211 astatine production program (from 209 bismuth targets). The record for the highest beam intensity was 16 μA, and in general 8 to 12 μA was available to the astatine production program throughout the year. With intense beam currents, the frequent deflector sparking has been a problem, but it was getting better as the deflector septum and high voltage electrode positions (and consequently the deflector gap width) were adjusted to find the optimal position to run the deflector.

We wanted to investigate if we could take advantage of the low emittance output from the H^- source to inject $^{4}He^{1+}$ beam more efficiently into the cyclotron. We did verify that the H^- source could produce $^{4}He^{1+}$, and we managed to extract a small amount, less than 0.1 μA, on FC02 in May 2021. After changing the injection geometry and adjusting the permanent magnets internal to the source to convert from the H^- operation to H^+, the extracted current of 5 μA was obtained in Feb. 2022. Obviously much more work is needed to increase the beam intensity, as we can already get up to 16 μA from using the ECR2 ion source. In particular the beam injection into the cyclotron seems to need more work. However as both H^+ and He^{1+} are injected together, the true injection efficiency is unclear. Looking at injecting H^+ beam alone (it was accelerated to 20 AMeV and then extracted through the deflector), the injection was about 29% and the extraction was 42%, for the overall throughput of 12%. Compare to the H^- beams, which at various times showed much higher injection efficiency into the cyclotron, from 50 to 80%, which we assumed is due to the small emittance from the H^- source, the 29% injection efficiency for H^+ must be improved.