K150 operations and development

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

We had a busy year operating the K150 cyclotron in the midst of pandemic. For the reporting period we logged over 3767 hours of beam-on-target and 2337 hours for beam developments. Included in the beam-on-target time was 3123 hours (2424 for physics and 699 for chemistry) for in-house science experiments and 644 hours for the SEE tests (see Table I).

. **Table I**. 2020-2021 operational time.

Time	Hours	% Time
Beam on target	3767	43.1
Beam development	2337	26.7
Scheduled maintenance	2416	27.7
Unscheduled maintenance	216	2.5
Total	8736	100

The large beam development hours reflect our time spent on trying to extend the list of 15 and 9.4 MeV/u SEE beams. Other big users of the K150 beams were: the SEE tests using both the proton and heavy ion beams, the Yennello group, and the Rogachev group, which used mainly ^{7}Li and ^{12}C beams from 1.3 to 10.3 MeV/u.

Our beam development work to extend the 15 MeV/u heavy ion beams for the SEE tests continued from last year. This year we were able to add $^{51}V^{18+}$ and $^{78}Kr^{27+}$, to the list of 15 MeV/u beams that we had developed so far: $^{4}He^{2+}$, $^{14}N^{5+}$, $^{20}Ne^{7+}$, $^{40}Ar^{14+}$, and $^{63}Cu^{22+}$. Four separate groups came to use the 15 MeV/u heavy ion beams for their SEE testing in 2020. The $^{78}Kr^{27+}$ beam was difficult to produce, it required lots of power on the source, and high voltages on the RF dee and also on the deflector. Even then the resulting beam intensity was so small that we had to verify the beam with a total energy detector. It also helped to identify two contaminants, namely $^{26}Mg^{9+}$ and $^{52}Cr^{18+}$, and to steer around them to provide over 90% pure krypton beam for the users. In addition, using 0.275 charge-to-mass ions, we have been developing a list of 9.4 MeV/u beams for SEE testing, which includes: $^{22}Ne^{6+}$, $^{40}Ar^{11+}$, $^{51}V^{14+}$, $^{65}Cu^{18+}$, $^{84}Kr^{23+}$, $^{92}Mo^{25+}$, and $^{107}Ag^{29+}$. We are working to add $^{124}Xe^{34+}$ beam to this list.

Since last year we started to develop a few proton beams extracted through the deflector, instead of strip extraction through a foil, and this year we have pushed the energy of the proton beam up to 45 MeV, which required 71 kV on the deflector E1. For those uses which do not need a lot of beam or those that need both proton and heavy ion beams in quick succession, this is a convenient way to produce the proton beams.

The astatine-211 production from bismuth-209 targets requires a very intense 29 MeV ^{4}He beam. We started out accelerating $^{4}He^{2+}$ ions at 710 A on the main magnet, and our best intensity out of the cyclotron was 5 pμA. In the effort to increase the beam intensity, we switched from $^{4}He^{2+}$ to $^{4}He^{1+}$ ions in 2020. The new beam required 1930 A on the main magnet, also higher dee and higher deflector voltages, but it was much easier to produce high currents of $^{4}He^{1+}$ from the source to inject into the cyclotron. Almost immediately we were able to more than double the previous intensity up to 12 pμA and then up to 16 pμA later in 2020. However, using higher dee and deflector voltages meant that they were more prone to sparking, and the beam became was less stable at times. Also, injecting more than 200 μA of light $^{4}He^{1+}$ along with a substantial component of $^{16}O^{4+}$, at the charge-to-mass of 0.25, required more re-tunings of the injection line for each higher current from the source. The internal transmission averaged 70 to 80% with typical cyclotron vacuum of $1x10^{-6}$ torr, and the extraction efficiency was about 50% with 60 to 65 kV on the deflector. However the excessive sparking of the deflector with the beam on has been problems at times. At present, we can produce up to 8 pμA of 7.2 MeV/u $^{4}He^{1+}$ beam reliably, we hope to extend that to 10 pμA and more.