Acceleration of H⁻ ions for the Cyclotron Institute Upgrade Project

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Abstract

The Cyclotron Institute at Texas A&M University is undergoing an upgrade that will allow for the production of radioactive ions for nuclear physics experiments. These ions will be produced with one of two ion guides, then collected, charge boosted and reaccelerated in the K500 cyclotron. The first radioactive ion beam for the project will be 27Si (T1/2=4.16s) at 15 MeV/u and will be produced through the reaction 27Al(p,n)27Si with 30 MeV protons. The recently recommissioned K150 cyclotron will accelerate the proton beams to intensity as high as 20 μA in order to produce sufficient amounts of radioactive ions. Rather than using an electrostatic deflector to extract the proton beam from the cyclotron, H^- ions will be introduced into the cyclotron, accelerated to 30 MeV and then stripped to protons with a thin carbon foil at extraction. First tests show the extraction efficiency to be nearly 100% and that the technique greatly reduces interior activation of the cyclotron and problems from secondary radiation. The H^- ion source, injection scheme and results from first tests will be presented.

Overview and RIA

The K150 Cyclotron will be used to accelerate H^- ions and for the production of H^+ ions (protons) at extraction. This is part of a new concept called Rare Isotope Accelerator (RIA) which is a new approach at conducting nuclear physics experiments. The first proposed experiment that will be performed is shown in figure 1; figure 2 shows the layout of the beam lines and several components of interest. The arrows indicate the travel direction of the beam.

$$p + {}^{27}_{13}Al_{14} \rightarrow n + {}^{27}_{14}Si_{13}$$

Figure 1

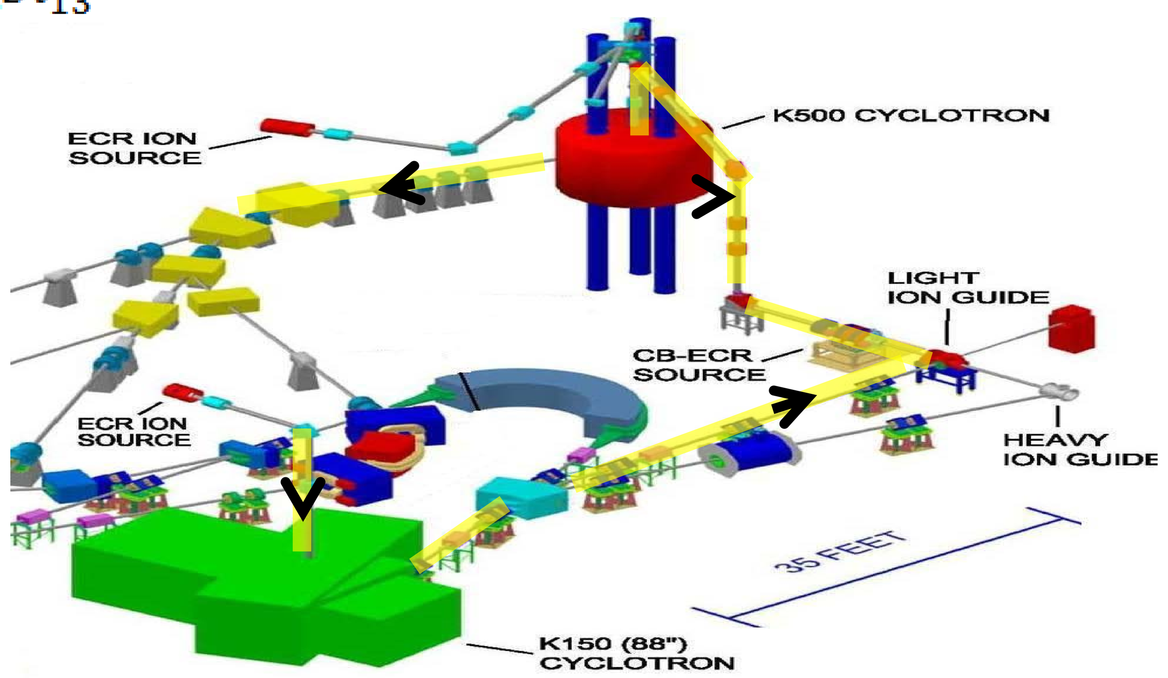


Figure 2

Original Plan for Proton Production and Extraction Problems

The K150 original plan called for the use of Electron Cyclotron Resonance (ECR2) source. The ECR2 source removes electrons, produces H^+ ions (protons) before injection into the cyclotron; these ions are then injected into the cyclotron, accelerated and extracted via a deflector. Figure 3 shows the injection diagram.

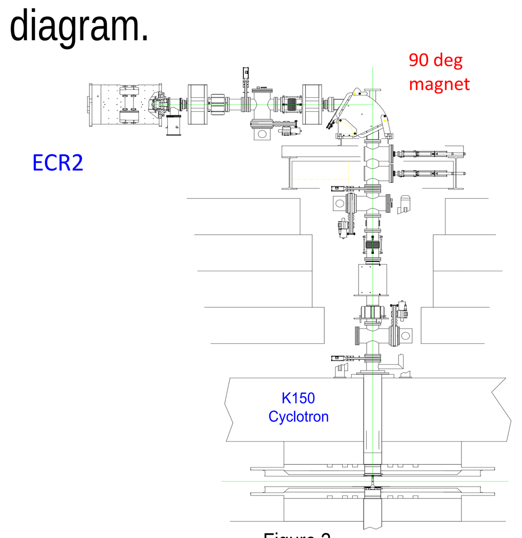


Figure 3

However, problems were observed with the extraction system of the original plan. Among these problems were activation of the deflector causing secondary radiation, loss of run time, and about 50% loss of beam at best. Figure 3 shows the injection line. Figure 4 shows a cross-section of the vault area and the radiation distribution due to this activation, mostly neutrons and gamma rays. Figure 5 shows gamma ray activity and dose rates after irradiation of deflector for 10 days.

Time	Activity(mCi)	Dose Rate(mRem/hr)
10 min	1168.108	52144.3
1 hour	1028.649	45918.9
1 day	686.216	30632.7
3 days	390.27	17421.7
5 days	265.811	11865.8
Na-22 gamma source	0.1	4.5
Rad worker limit: 5000mRem/year		
Distance: .5 meters		

Figure 5

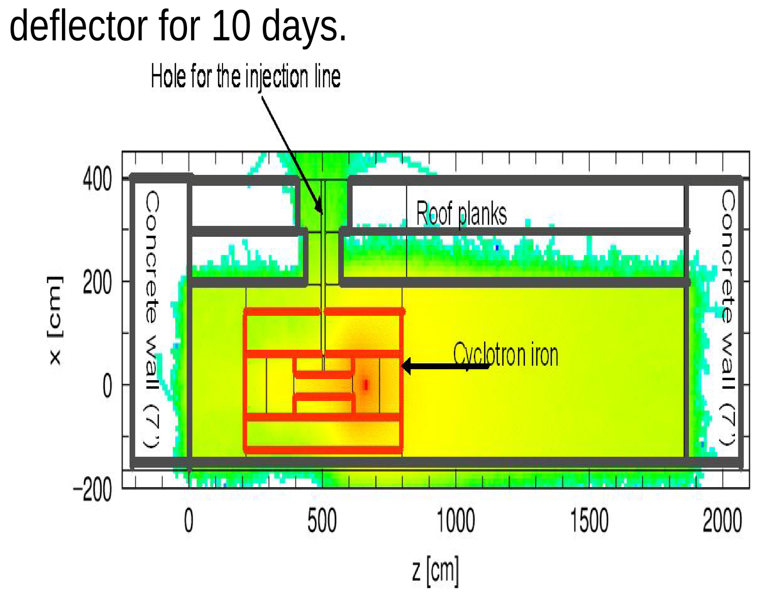


Figure 4

Solutions to Extraction Problem

Several solutions were available to solve this problem. We could build a special deflector for protons, but we would need one for each proton energy, ideally. The deflector needs to be biased at about 80KV, which causes sparking and degrades the surface which means it deflects less. We could also build one out of Aluminum, but it would still be very hot, complicating maintenance. The third, and best option, was to install an H^- ion source. The advantages were 100% extraction efficiency, no need for deflector, no danger of high voltage, and production of high intensity protons and deuteron beams. Figure 6 shows the placement of the H^- source, the current configuration is shown on the right.

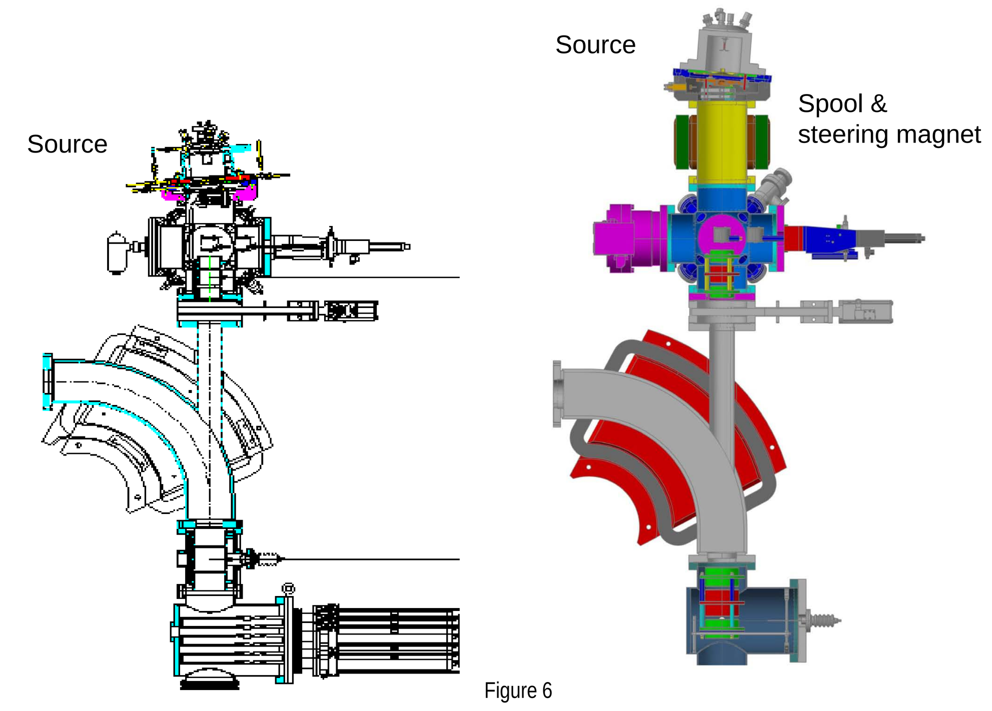


Figure 6

H^- Ion Production, Proton Production and Extraction, and First Results

H^- ions are produced when a "hot" electron excites a Hydrogen molecule, the molecule then moves into a filter field where a "cold" electron attaches itself to one of the Hydrogen atoms creating a negatively charged ion, an H^- ion. This is shown in figure 7, along with the reactions that create the ion. Figure 8 shows the multi-cusp magnetic field that contains the plasma toward the center of the volume. Figure 9 shows the "tilt" suggested for extraction of the beam from the source.

Excited Molecules $e_{hot} + H_2 \rightarrow e + H_2(v'')$

Dissociative Attachment $e_{cold} + H_2(v'') \rightarrow H + H^-$

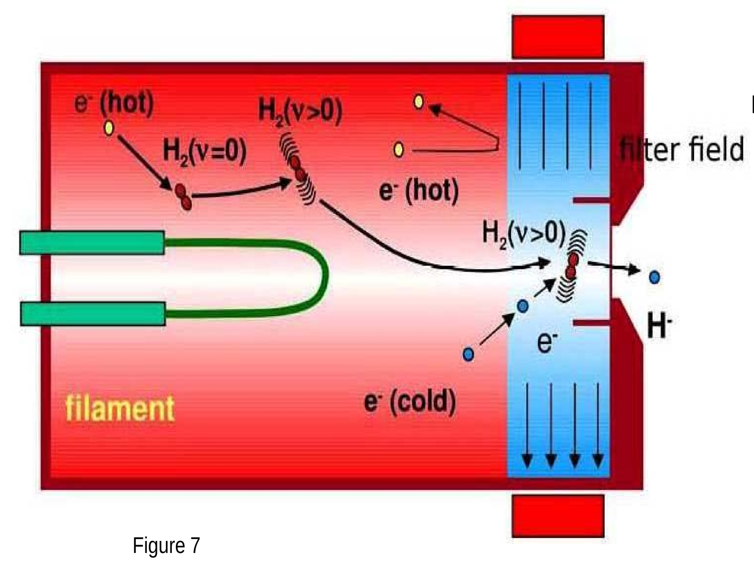


Figure 7

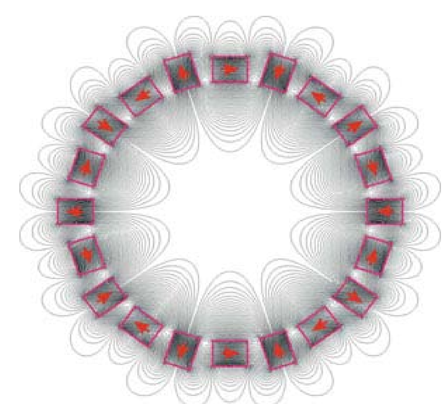


Figure 8

Source "Tilt" suggested by Olli Tarvainen, JYFL

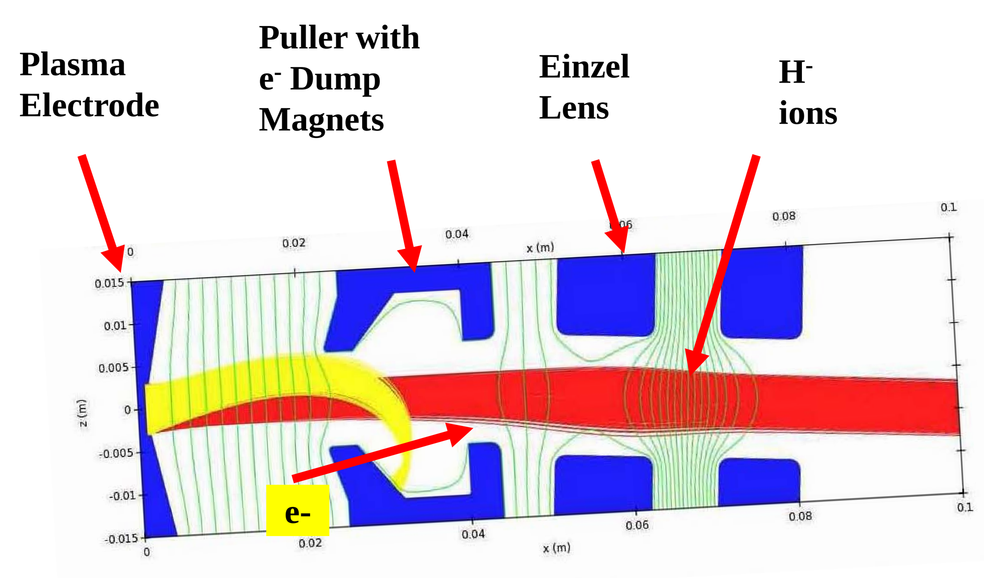


Figure 9

The production of protons occurs when the H^- ions collide with a carbon foil 2 microns thick near the exit of the cyclotron. Upon collision, the 2 electrons are stripped away by the foil and an H^+ (proton) emerges out the other side, this process is depicted in figure 10. Once the protons are produced, the change in charge causes the protons to be deflected out of the cyclotron as shown in figure 11. The highest current achieved from first results was 24.5μA at extraction for a brief moment with a steady current of 10μA at extraction and 60+ hours of filament usage without failure.

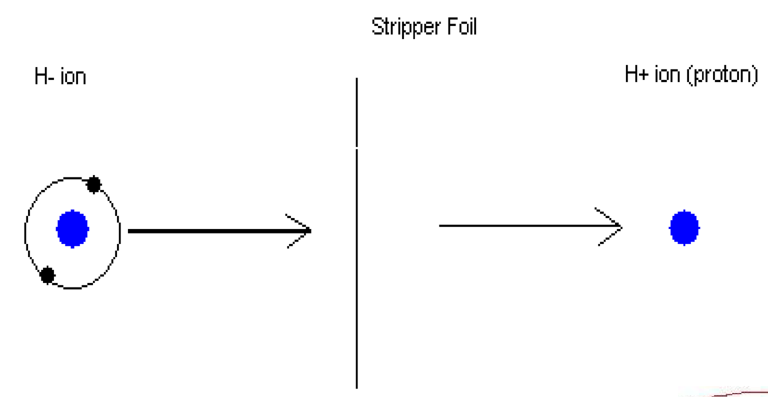


Figure 10

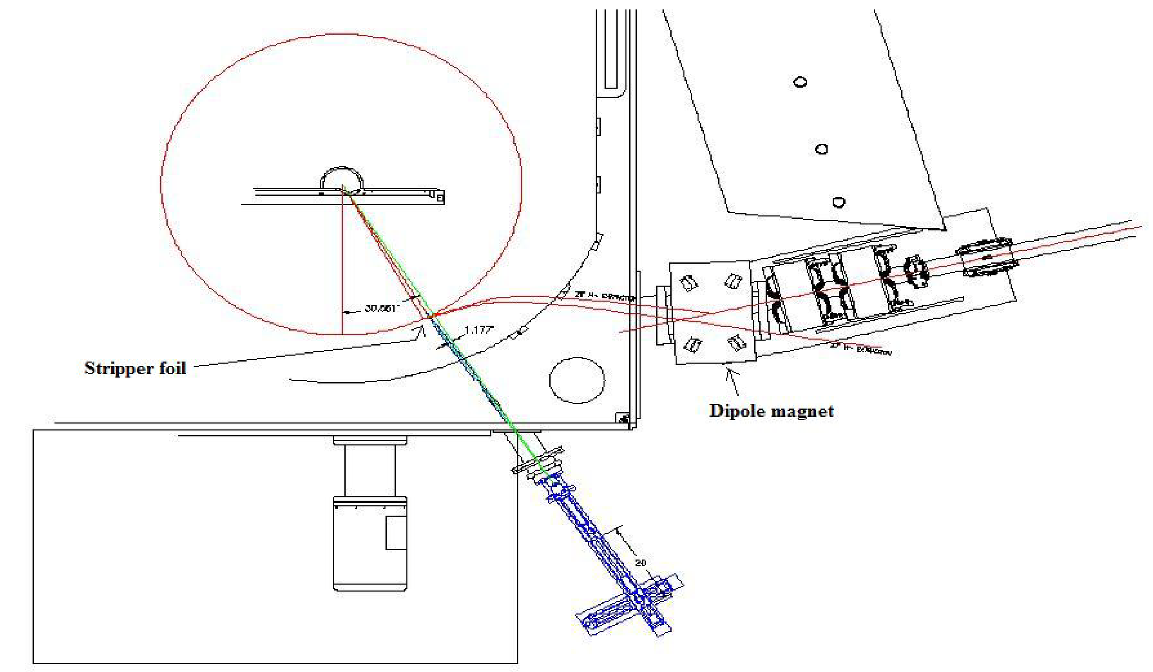
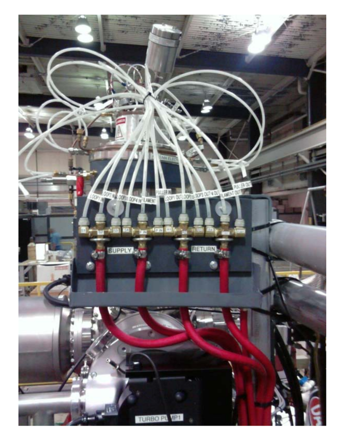


Figure 11

Other Upgrades to the K150 Cyclotron

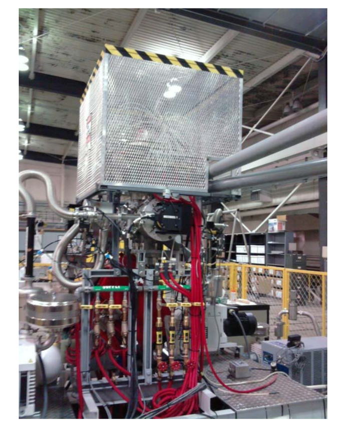
Raised water cooling system – reduced clutter. (Picture 1)
Installed door switches in HV cage – safety precaution. (Picture 2)
Installed safety cage to isolate HV near source. (Picture 3)
Installed spool, steering magnet, and platform. (Picture 4)
Installed gas lines, air lines, electrode covers, wired some interlock lines.

Picture 4



Picture 1

Picture 2



Picture 3

Future Work

Test beam focusing, throughput down the beam line
Joe Brinkley will develop program to optimize beam from source
Improve ion source – filament is limiting factor
    Inductively coupled rf-discharge, eliminates filament
Inductively heated thermionic emission cathode
    Extends the lifetime of the filament – further development needed

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