

**PHY4901 Work Term Report**  
Accelerator Mass Spectrometry at uOttawa

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## **Abstract**

This report describes my COOP term at the A. E. Lalonde Accelerator Mass Spectrometry Lab in the ARC building at uOttawa and gives an overview of the jobs and projects I worked on as well as the skills I learned. Specifically, I give a description of the test stand I built to test vacuum turbines before installation on the new research line, the procedure we followed to test around forty high voltage power supplies, a new target base design I worked on to improve target cooling, and give an overview of some scanning electron microscope observations we made of the surface of the source head ionizer –a hemispherical surface that is heated to strip electrons off of cesium atoms– to understand the causes of ‘target memory’ in the machine.

## Introduction

The AMS lab has a functioning tandem accelerator beam line and ion source that is used for radio-carbon dating and for counting other low abundance isotopes. My job description was primarily to help assemble and test a new beam line that also feeds into the accelerator that employed a new piece of technology called the Isobar Separator for Anions (the ISA line). However very little work was actually done on the assembling of the line as a lot of parts that were required hadn't been completed from the machine shop. Therefore my summer was spent doing work in preparation for the building of the ISA line, as well as some side jobs related the main line of the machine. Now at the end of the summer, the parts have arrived and assembling of the line will begin early September. I decided to ask for an extension of my work term so that I could help get the ISA line finished and will be staying here until December.

The AMS lab during the summer consisted of about 8 individuals who were there daily, including a second-year student volunteering in the lab, two students from France on an internship, a lab technician, a PhD student, a post-doc, an application specialist who managed running the samples, and Professor Kieser. We also worked closely with the people in the earth sciences and radiocarbon labs upstairs who collected and prepared the samples.

## Overview of the Machine

The machine is a tandem accelerator with a cesium sputter ion source and a gas chamber detector (Figure 1). The entire beam line must be under vacuum, and more than a dozen turbomolecular pumps are placed along the line to achieve a pressure on the order of  $10^{-7}$  mbar, or  $10^{10}$  times lower pressure than atmospheric pressure.

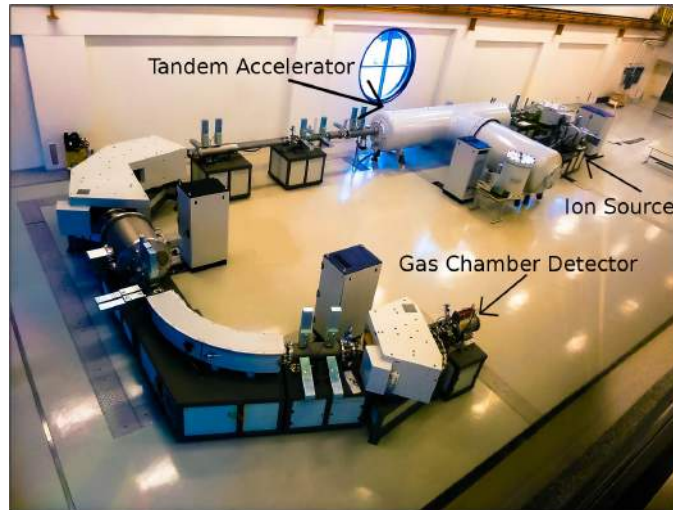


Figure 1: Overview of the machine with ion source, tandem, and detector

“Tandem” refers to the t-shaped tank and works by supplying a potential of 3 million volts between where negative ions enter and the bottom of the ‘T’. Negative ions enter the tank and are passed through a chamber filled with gas at the center of the ‘T’, called the stripper gas. Electrons are stripped from the ions and are attracted away from the beam to the bottom of the ‘T’. The ions, now positively charged and on the far side of the ‘T’ are repelled out of the tank and approach speeds of about 3% the speed of light, or 9000 km/s.

The cesium sputter ion source is a piece of equipment that is capable of generating negative ions from sample material placed in a target that is then entered into the source. The source works by boiling cesium, a highly reactive metal and good donor of electrons, at around 100 degrees celsius. The cesium vapor is then directed towards a hemispherical surface called the ionizer that is heated to 1200 degrees celsius. As the cesium strikes the ionizer it loses an electron and becomes positively charged. Inside the source between the ionizer and the target, a potential of several thousand volts pulls the charged cesium atoms towards the target until they smash into the sample material, ejecting material out of the target. These ejected atoms fly towards the ionizer and pick up electrons, becoming negatively charged. A large potential then draws the negative ions out of the source and through the beam pipe. The targets are small little cups about a quarter the size of a pen cap. Samples are usually prepared as a powder that is pressed into the cup with a ball bearing at high pressure until the powder compacts together as a solid. These targets are then inserted into the source and exposed to the hot ionizer.

The detector is a chamber filled with a gas that ionizes (gives up electrons) easily, usually

isobutane, and is capable of counting individual atoms. It is placed at the end of the beam line, where the ions are at their highest energies. Ions from the beam enter the chamber and collide with isobutane molecules, severing its bonds. The freed electrons are then pulled towards a charged plate and enter a circuit, where the current is measured and amplified. This signal is a 'count'. The higher the energy of the ion, the more bonds are broken and the stronger the current measured. This process happens twice in the chamber, giving two values corresponding to the energy loss of the ion for each ion. The rate the ions enter the chamber is important. If they enter too quickly, signals will be sent faster than the electronics can handle and individual counts are hard to tell apart. The values measured for each ion are plotted on a graph of energy loss vs. final energy. Ions of the same mass and charge state will group together on this chart and different atoms can be told apart (Figure 2).

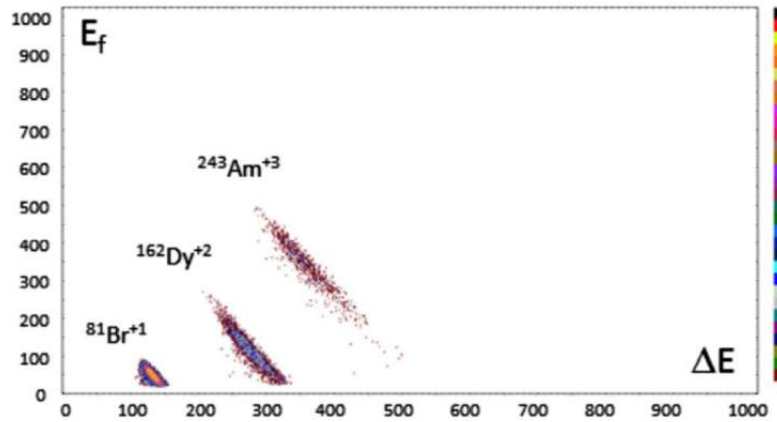


Figure 2: Example of the measurements view from the detector at the AMS. Each cluster of dots represents a different element. [1]

## Beam Control

The machine accelerates ions to high speeds and high energies. It is these high energies that allow for the separation of isotopes of an element with very similar yet different masses, like carbon-12 and carbon-14. Beams of charged particles are controlled and selected using bending magnets, and electrostatic analyzers (ESA). Bending magnets use the Lorentz force to redirect charged moving particles. How do we control the beam using the magnet? Using Newton's laws we get the following expression for the particle's acceleration due to the magnet:

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$

$$\begin{aligned}
m\mathbf{a} &= q\mathbf{v} \times \mathbf{B} \\
\mathbf{a} &= \frac{q}{m} \mathbf{v} \times \mathbf{B} \\
|\mathbf{a}| &= a = \frac{q}{m} vB
\end{aligned}$$

Since the particle moves in a circle with radius  $r$  it experiences centripetal acceleration:

$$\begin{aligned}
a &= \frac{v^2}{r} = \frac{q}{m} vB \\
mv &= qBr = p \quad (\text{momentum})
\end{aligned}$$

The kinetic energy gained by the particle comes from the electric energy it gained from passing through a potential  $V$  at the source. We can use the momentum relation to get relationship between the energy of the ion and the radius of the path the ion will take:

$$\begin{aligned}
mv^2 &= 2E = 2qV = \\
m(mv^2) &= (mv)^2 = q^2 B^2 r^2 \\
\frac{2mE}{q^2} &= B^2 r^2 \\
r^2 &\propto \frac{mE}{q^2}
\end{aligned}$$

That is, the radius of the bend the ion takes is proportional to its mass times its energy divided by the square of its charge.

Varying the field strength  $B$  is the main way we can control which particles are bent into the rest of the machine and which particles get bent so that they hit the wall and stop. Electrostatic analyzers (ESAs) are two curved parallel plates with opposite voltages on each plate that also bend the beam and can select ion energies. Only ions with the 'correct' energy will curve enough to pass through the analyzer while ions of other energies are bent and hit the wall of the analyzer.

## Applications

A large benefit to the 3MV accelerator is its sensitivity when detecting very rare isotopes (ten to thousands of atoms). The AMS at uOttawa is commonly used for radiocarbon dating. People around the world pay to send samples of bone, wood, or similar to the lab and have it dated using the machine. The machine dates the samples by counting carbon-12, carbon-13 and carbon-14

atoms and determining abundance ratios. The high sensitivity of the machine allows us to detect 1 carbon-14 atom for every  $10^{14}$  carbon-12 atoms, or a  $C^{14}/C^{12}$  abundance ratio of  $10^{-14}$ . This means that only a couple milligrams of a sample are necessary to perform dating and is a quicker way to date than counting the decays of carbon-14.

The AMS is also used on a weekly basis for iodine-129 counting and uranium-236 counting. Iodine-129 and Uranium-236 are by-products of nuclear fuel processing. Detection of these isotopes in environmental samples (dirt, seawater, air) provide information about the effect of human activities on the environment.

When the machine is not being used for field samples time is spent on finding ways to measure isotopes with the AMS that haven't been used before. The methods involve the way the sample is chemically prepared for the machine, different metal powders that can be mixed with the sample to produce a higher beam current, and finally, the tuning of the machine itself, which involves determining optimal field strengths for the magnets, the voltages applied on ion lenses (called einzel lenses) and the ESA, the pressure of the stripper gas in the tandem tank, and the pressure of the isobutane gas in the detector. For example, over the summer some work was done on measuring the radioactive isotope  $Be^{10}$ , which can be used for dating. This is normally prepared for AMS in the compound  $BeO$ , which also happens to be extremely carcinogenic and is quite a hassle to prepare safely. Finding a safer beryllium containing compound to use in the AMS could shorten preparation times and allow more samples to be processed. In pursuit of a safer compound several experiments were done using the compound  $BaBeF_2$  and a lot of hours were spent tweaking the machine's parameters until finally beryllium-10 was detected.

## Isobar Separator for Anions

The material loaded into the machine plays a large role in getting a stable beam current: how easy it is for the element to form negative ions, whether its compacted strongly enough into the target to not be sucked out by the vacuum, and if there is contamination from other material that can form isobars with the element we are trying to detect.

Two compounds are isobars if they have the same mass. If the two compounds also form the same charge states (-1, -2, etc.), then the isobars have the same charge-to-mass ratio and fly through the machine exactly the same way, making them hard to tell apart. For example in the detection of the rare chlorine-36, sulfur-36 is an isobar that dominates the signal and floods the detector, making it impossible to detect. In the case of sulfur-36, it is everywhere and hard to



avoid contamination before placing the sample into the machine.

The isobar separator for anions (ISA) is a piece of equipment installed on the beam line whose purpose is to separate unwanted isobars from the beam by placing a gas reaction cell in the path of the ions. The cell is a chamber filled with a gas that chemically reacts with the unwanted isobar to remove the negative charge that is allowing it to pass through the beam. For example, in the chlorine-36/sulfur-36 example, nitrous oxide gas is placed in the cell which reacts with the negatively charged sulfur-36. The sulfur-36 atoms lose their negative charge after the reaction and fall out of the beam, no longer being directed by any of the lenses or magnets. Hence the isobar has been separated and the chlorine-36 continues on its way. During the summer we installed vacuum pumps on the ISA and tested that it could hold vacuum (and troubleshooted when it couldn't), as well as installing an entry and exit lens. This happened in the first month or so and assembly work on the ISA stopped for the rest of the summer while we waited for parts to come in from the shop.

The ISA line is separate from the main line and has it's own ion source, electrostatic analyzer, bending magnets, and mini detector that can be bypassed using one of the bending magnets. After the ISA line, ions pass into the tandem on their way to the main detector.

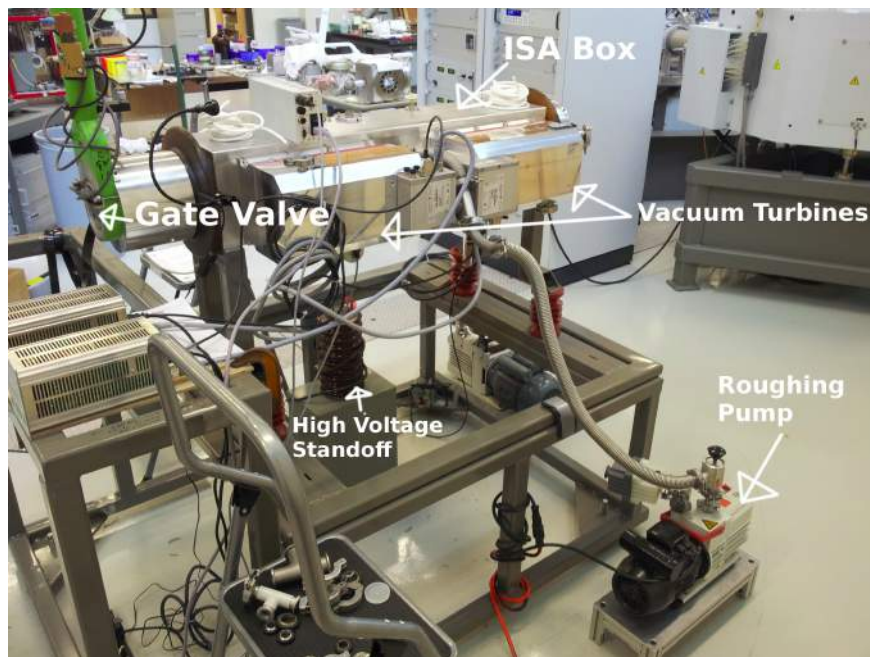


Figure 3: The ISA as it is now. The entire box is raised to 30 thousand volts and when finished will be inside a large plexiglass box for safety. The standoffs are so that arcing doesn't happen between the box and the frame below it.

## Work

This section will give an overview of the work I did during the summer. When I first joined the lab I spent the first two weeks learning about vacuum assembly components. There exist several standards of parts that are used to assemble high vacuum systems. These parts include pipe sections, flanges and O-rings. The standards defined specific sizes and allow for quick construction, modular design, and straightforward reusability. The standards of the parts the lab had are called KF, LF (or NW), Dependex (DPDX), and I sorted and organized hundreds of these parts into shelving so that parts could be found easily during assembly. This also included leak testing the vacuum chamber of the ISA box, where we found several leaks and spent some time sanding down some surfaces so that the O-rings would form a better seal.

There was also a need to verify equipment that had been brought over from the lab's predecessor IsoTrace in Toronto, which included about forty high voltage power supplies and around twenty turbomolecular vacuum turbines. I along with the volunteer designed and built a test rack with a chamber that the turbines could be attached to and draw a vacuum in, where we then measured the pressure inside to assess how well the turbine is performing.

When a few targets came out of the source melted and bombarded, there was a need for cooling of the target that after some discussion we decided could be better met by redesigning the steel target base. I used Solidworks to create a new target base that would improve cooling by replacing some of the steel parts with copper, which has a higher thermal conductivity. I showed the design to the lab and after a few iterations it was sent to the machine shop to be made.

There was a need to better understand the optics of the ISA line. So I and the volunteer created a simulation using the program Simion which allows one to design ion optics components (like lenses, parallel plates, ESAs, and magnets) and then define charged particles to fly through them. Our simulation helped demonstrate that the design worked and also allowed us to move some components around for the sake of space while still checking that the ions flew through as wanted.

There is an effect in the source where material from one sample contaminates the source and interferes with the next sample's measurements, affecting counts and the calculated abundance ratios. This effect is called source-memory in the literature[2] and during one of the routine source cleanings the post-doc had the idea of taking out the ionizer and examining its surface under a scanning electron microscope. We took some photos and found that material crusts onto the ionizer and I worked on writing up the results for a paper.

## Turbine Test Stand

The turbines used to maintain a vacuum pressure of  $10^{-7}$  mbar spin at around 45000 rotations per minute and are delicately balanced to eliminate vibrations and spin smoothly so as to not generate heat or accumulate wear over running times of hundreds of hours. If a turbine is disturbed while it spins there's a chance a blade hits the side wall, breaks off, and collides with the other blades. At 45000rpm the turbine will violently destroy itself. This disturbance could be someone bumping into it or a sudden flow of air hitting the turbine.

To test the turbines I designed and built a test chamber using standard vacuum parts, shown in Figure 4. I attached two short pieces of 4-inch dependex pipe to a tee-section with a 6-inch dependex opening on either side. I attached two metal bars (spraypainted orange in figure 4) across a steel frame and bolted ring stands to it. The short pieces on either side of the cross acted as arms and hung on the ring stand. I then attached a pressure gauge on one side of the cross and a valve for venting on the other side. The turbine would attach on the bottom of the cross and hang there during operation. The top of the cross was blanked off.

The standard determines how you connect the two parts together. In the case of the dependex connections, it takes an O-ring and sandwiches it between an inner metal ring and an outer metal ring. A thin circular piece of metal called the retaining ring is then slid into a groove formed in the pipe and two flanges are used to squeeze the connection tight, forming a seal that withstands vacuum. The standards come in different sizes. Dependex comes in 2", 4" and 6" sizes.

The turbines are like small jet engines with an opening that can be attached to other pipe sections via one of the vacuum standards. The attachments of the turbines I tested included 6" dependex, 4" dependex, LF-160, and LF-100 standards. LF here refers to the "Large-Flange" standard and the number that follows it is the diameter of the opening in millimeters. The dependex standard is an old and clunky standard compared to the LF standard. The LF standard places an O-ring squeezed between two small aluminum rings in between the flat surfaces of the pipe sections being joined, and clamps are placed that squeeze the o-ring to form a seal. An LF pipe cannot be joined with a dependex pipe because the way they form seals is different, and so an adapter is needed to attach some of the turbines to the 6" dependex cross I had in the stand. The adapter can be a pipe with one standard on opening and a different standard on the other.

We had turbines with LF-160 openings and no adapter for it to 6" dependex; the standard used for the bottom opening on the cross. So I used the software Solidworks to make up drawings for

such an adapter (Appendix A) and it was sent to the machine shop to be made from aluminum. I had never used Solidworks before and it was exciting for me when the part came back and worked as expected.

It is unsafe to turn on the turbines under atmospheric pressure since its more likely the air flow will disturb the blades, so all turbines have an exhaust port that can be connected to a rotary vacuum pump, which is a less delicate kind of pump and can handle the atmospheric pressure. So the process before starting a turbine is to hook it up to the rotary pump, turn it on, let the pressure drop to about  $10^{-2}$ mbar, and then turn on the turbine. A valve is placed between the turbine's exhaust and the rotary pump. To turn off the turbine without disturbing the blades, you close the valve between the turbine and the pump, then turn off the turbine, then listen to the turbine to make sure that the blades have stopped or significantly slowed their spinning before opening the chamber valve and allowing atmospheric pressure to enter the chamber and hit the blades.

After the stand was built it took about three weeks to get through all the turbines, with about 2 turbines tested a day. The most time consuming parts were waiting for the turbine to spin up and spin down (about thirty minutes each way) and cleaning and checking Orings after each disconnection. There were also some rather heavy turbines that needed to be lifted carefully and held in place long enough so that the flange could be bolted. When a turbine seemed to be starting up and running fine but reading an unexpectedly high pressure, we would test for leaks on the vacuum connections to see if the cause is a faulty turbine or a leaky connection. Each turbine costs about \$10000 to replace so any turbine saved meant large savings.

Leak testing is done using a helium leak detector. The detector has a small mass spectrometer tuned to helium. The detector has a vacuum hose that we connect to the chamber, and the detector gives an alarm whenever it detects helium. So using a small hose attached to a helium tank cylinder, we blow helium over the outside of all the flanges and connections. If there is a leak at a specific spot helium is sucked into the enclosure and reaches the detector, which sounds the alarm. This lets us directly locate tiny leaks and lets us fix them.

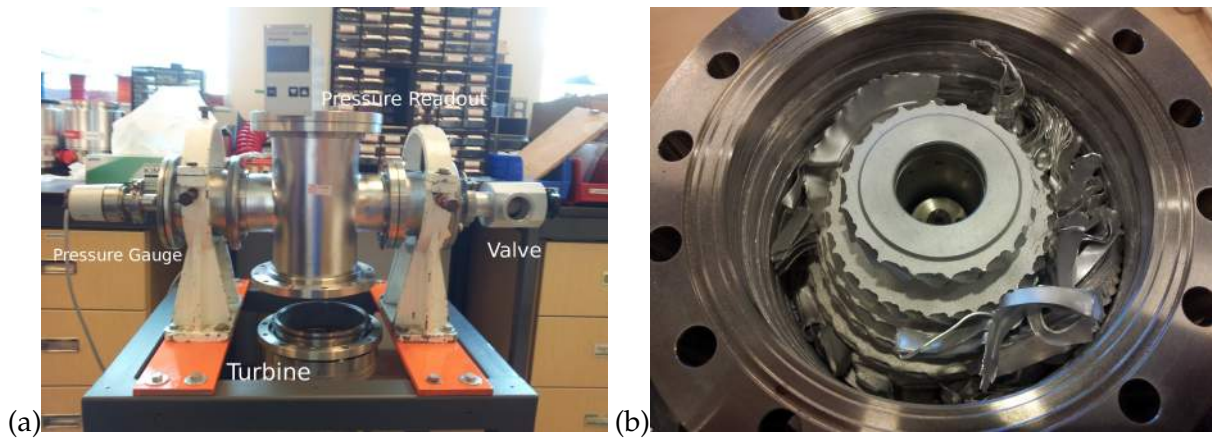
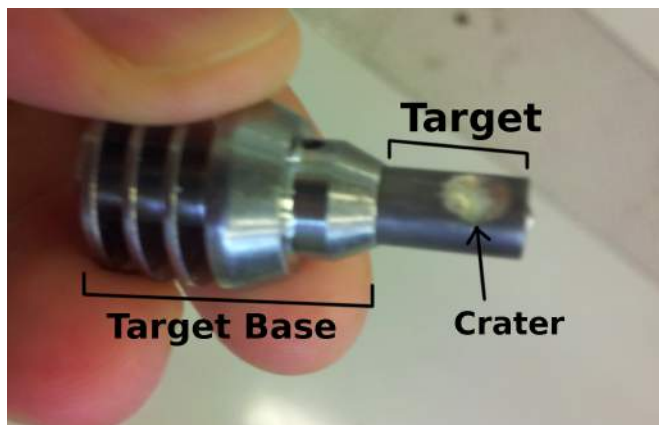


Figure 4: (a) Turbo Test Stand 9000. (b) A seized turbine, blades torn off, twisted and bent.

## Target Base Redesign

When the sourcehead is turned on, the target containing sample material is exposed to  $1200^{\circ}\text{C}$ . The target is a small metal cup that can be made of aluminum, copper, or stainless steel, and is screwed onto a larger stainless steel base. The base is made of a magnetic steel and a magnet pushes the base into and out of the source. The top of the base is cone shaped. When inserted, the cone of the base makes contact with some metal that is cooled using a coolant called Syltherm. Thus heat flows from the target to the target base to the metal to the Syltherm. If the target isn't tightened to the base then the target can heat up. Damage can occur and the target can start sputtering sample material violently, contaminating the sourcehead and skewing the results of the samples that follow. Figure 5a shows a crater melted into the side of a target that wasn't screwed into the base all the way.

The target base is made of stainless steel, and the cone makes contact with another stainless steel part before reaching syltherm coolant. The target makes contact with the base only from its bottom surface, which is a relatively small area. Xiaolei the application specialist suggested that if the cone were to be made of copper, which is much more conductive to heat, the target would cool a lot quicker. Part of the base needs to be magnetic steel however because a magnet pushes the target in and out of the source. I came up with a design and made drawings of a base that used two parts: a steel core that made up the bottom of the base and a copper cone jacket that is screwed onto the core. After a few tweaks suggested by Professor Kieser the drawings were sent to the shop and a handful of the new bases were made for testing. Appendix B shows the drawings and Figure 5b shows the finished base.



(a) Target Damage



(b) New target base, old target base, and a 3d printed prototype of the two parts making up the new base.

Figure 5

## ISA Line Simulation

We needed some evidence that the beam optics of the line would be able to control the ions well enough. A crucial feature of the line is that it needs to be able to slow down the ions before they enter the ISA and then re-accelerate them afterwards. The ions need to react with the gas cell in the ISA and chemical reactions cannot happen at the high speeds the ions are initially travelling at; the ions will just obliterate any gas molecules they come in contact with.

To test out the design a program called Simion was used to simulate each component on the line. These components are the electrostatic analyzers, which 'select' ions based on their kinetic energy, a bending magnet, steerers, and einzel lenses.

The steerers are two parallel plates that bend the path of the ions and are used to tweak the direction of the beam. Normally two steerers are used one after the other and rotated  $90^\circ$  to each other: one steers in the horizontal direction and the other steers in the vertical direction.

The einzel lenses are three cylindrical rings that can each be held at different voltages. The lenses can focus or magnify the ion beam, that is, if the paths of multiple ions are drawn as they fly through the lens, their paths are bent by the lens similar to the way light is bent in a real lens. The einzel lenses are used to change the speed of the ion, so a lens is placed at the entrance and exit of the ISA. The lenses decelerate the ions by magnifying them, which makes the paths of the ions fan outward. The deceleration is analogous to being in a car about to go up a hill and taking your foot off the gas, letting the car's momentum carry itself up the hill, slowing down in the process.

The exit lens reaccelerates them and focuses the paths of the ions. The fanning outward of the paths is difficult and delicate; too much fanning out and the ions collide into the wall but too little and the ions will be moving too quickly to react. There are many arguments about whether the current design works, with one camp insisting with Simion simulations that too much fanning out will occur and a larger box is needed and the other camp insisting it will work and that it needs to get finished as soon as possible, and the conflict hasn't been resolved. As it is, the current ISA design is the one that will be built without modification.

In Simion, you define the shape of electrodes and magnetic poles and it calculates electric and magnetic fields around your electrodes by solving Laplace's equation for the voltage potential  $\phi$  and then calculating the electric field  $\mathbf{E}$ :

$$\nabla^2\phi = 0 \quad \mathbf{E} = -\nabla\phi$$

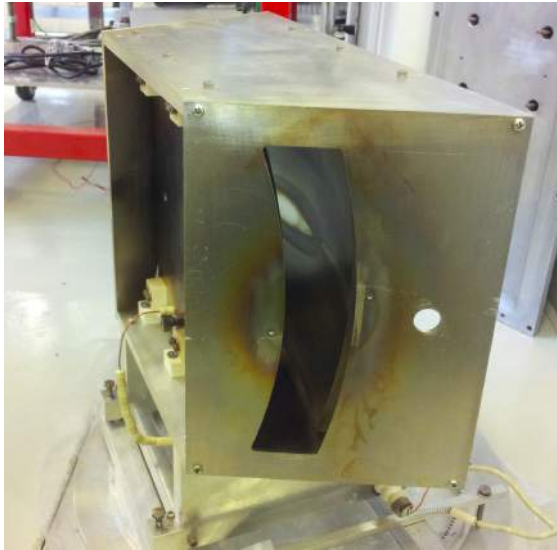
It does the same for magnetic fields using the magnetic potential. Simion does not take into account the effect of a charged particle on a field. For example, in reality if two charged particles are close to each other in the beam they will interact and repel each other. Simion doesn't take this into account; doing so involves solving Poisson's equation

$$\nabla^2\phi = \rho/\epsilon_0$$

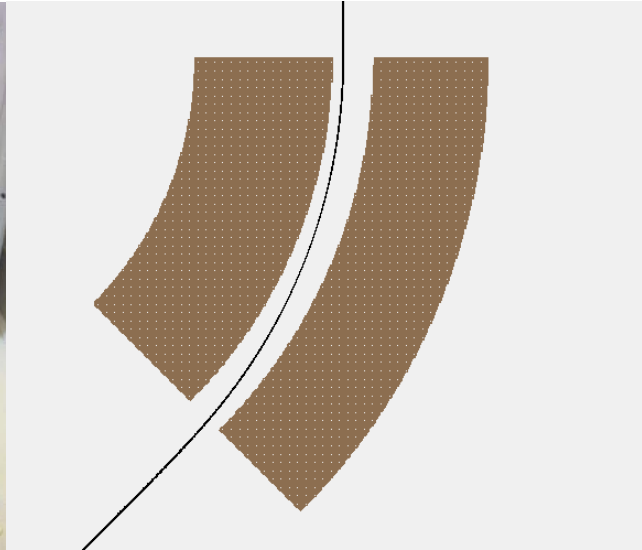
where  $\rho$  is the charge distribution. If we want to believe the simulations we need to assume that particles fly mostly independently and that the fields from the electrodes have a much stronger effect on the net field than the fields of other particles. It seems safe to assume this in most areas of the line; the voltages applied to the electrodes are thousands of volts. Other regions, like the gas reaction cell and the sourcehead, are a lot more violent and complicated and Simion is not a useful tool for these regions.

The first step in creating the simulation was to create the components, and defining the electrodes, the surfaces that carry voltage. The lenses were modelled as three cylindrical rings. The magnet is modelled as two flat poles separated by some distance, and the particles fly between the two poles. The steerers are two flat plates separated by some distance. The ESA consists of two curved spherical surfaces that form a narrow canal for beams to fly through. A voltage difference is applied across the two surfaces. Figure 6 shows the actual ESA and it's model in Simion.





(a) The inside of the ESA. The discoloration comes from ions hitting the walls.



(b) Simion model of the ESA in cross-section with a particle beam flying through. The path of a particle here is determined by its energy/charge ratio. Only certain ratios have paths that make it through the ESA when it is set to some specific voltage. Since the particles coming out of the source have a wide range of energies, the ESA can be used to select a smaller range.

Figure 6

After creating the components I measured the locations of each component relative to each other based on Autocad drawings that had been made by Professor Kieser. Using these measurements the components are placed on a 'workbench' in Simion to model the entire line as a whole. Once the components are placed I can define the initial positions, energies, and directions of ions and fly them through the model line. While they fly I adjust the voltages on the components one by one until the ions fly all the way through without getting off track or hitting anything (Figure 7).



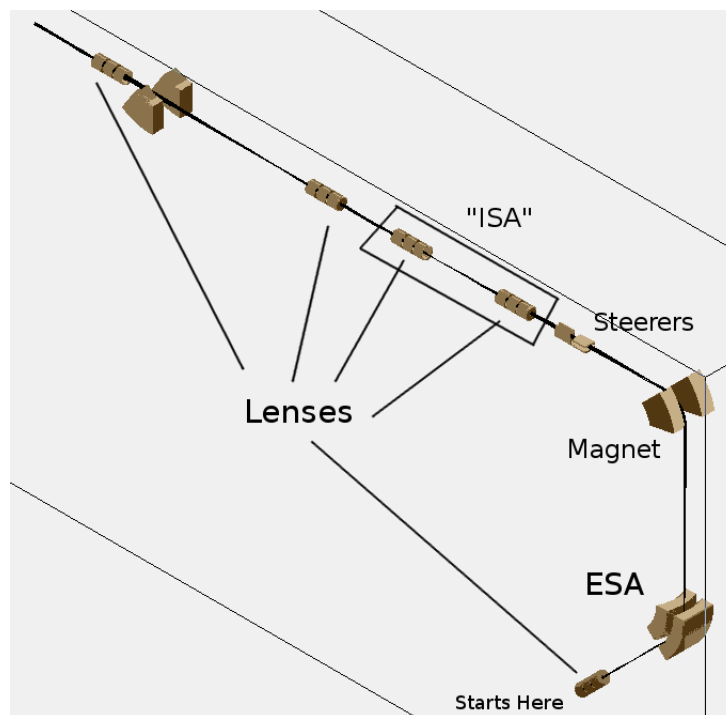


Figure 7: ISA line simulation with a beam flying through. The gas reaction cell is not part of the simulation.

After the ISA is another lens that is meant to focus the beam just before entering the final magnet. The simulations suggested that this lens needs to be moved further down to achieve that focus. Other than that result, creating the simulation has primarily been for learning.

### Source Memory and Ionizer Surface Study

The curse of AMS is contamination in the sourcehead. After a sample is measured, some material can be “remembered” and can remain in the sourcehead for thirty minutes to several hours while other samples are being measured. When measuring samples that only contain a couple thousand atoms of an isotope to begin with even slight contamination from a sample that has a different ratio can skew the measured abundance ratio of the current sample.

There are ways to clear the memory in the source and all are time consuming. After sputtering on a sample, sputtering on a blank target for about twenty to thirty minutes helps reduce the memory. This is observed by watching the current of the isotope in question drop over time. Each sample takes about 10 to 15 minutes to get a good measurement. For some measurements, especially uranium and iodine counting which suffer particularly from source memory, the best way to reduce contamination is to clean take out the sourcehead and clean it. This takes about half

a day; taking out the source involves waiting for it to cool off (if its been on recently), letting the turbines wind down so that the vacuum can be broken, removing the cesium boiler and placing it under an argon atmosphere to prevent explosions, then removing the source and taking it apart. Once it is taken apart, it's cleaned by hand using tissues and methanol and q-tips. It then needs to be reassembled. The lab has two sourceheads so once one is removed the other can be immediately placed in and the startup procedure can begin. Starting up also takes a while. It's about an hour wait for the turbines to start up and the vacuum to reach a low enough level to support a beam, and another half hour for the ionizer and cesium boiler to heat up. A large run has about 150 samples and can take up to three days *without* doing anything to reduce memory. The radiocarbon lab has about 100 samples to go through every two weeks.

Therefore there's a lot of interest in solving the problem once and for all. The approach at AMS labs around the world has been to understand how contamination happens in the sourcehead and to find a new design that will reduce contamination. For example one big improvement that happened in the last few years was redesigning the source to have more space between parts, allowing contaminants to be pulled away by the turbines.

During one of the cleanups of the source we took out the ionizer, the surface that heats to 1200°C and strips the electrons off of cesium, and examined it under a scanning electron microscope. We compared its surface to that of a fresh ionizer that had never been used. We found that material had bombarded the metal of the ionizer and embedded itself inside. On top of this embedding was a crusty layer of sample material that completely covered the ionizer. This material is baked into the ionizer and no amount of scrubbing gets it out. The images made it very clear that there were some long-lasting contamination. It turns out this long-lasting contamination puts a limit on the sensitivity iodine-129 measurements, since no matter how sensitive the rest of the machine is, counts will inevitably come from the ionizer no matter how clean the target is. These results are being written for publication. Appendix C contains the portion of the paper I contributed overiewing the scanning electron microscope images.

## Conclusion

In this report I gave an overview of the accelerator mass spectrometry and its applications and explained the ISA project. I also gave a description of my time in the lab testing turbines and power supplies, designing a new target base, helping with the maintenance of the machine, creating a

simulation of the ISA line and helping with the research in developing the technique of AMS. I learned about vacuum components, how to build high vacuum systems, how to use Solidworks to make drawings for a machine-shop, and how to use Simion to make beam optics simulations. The next few months will be spent building the ISA line and testing it.

## Appendix A: LF160 to 6" Dependex Adapter Drawing

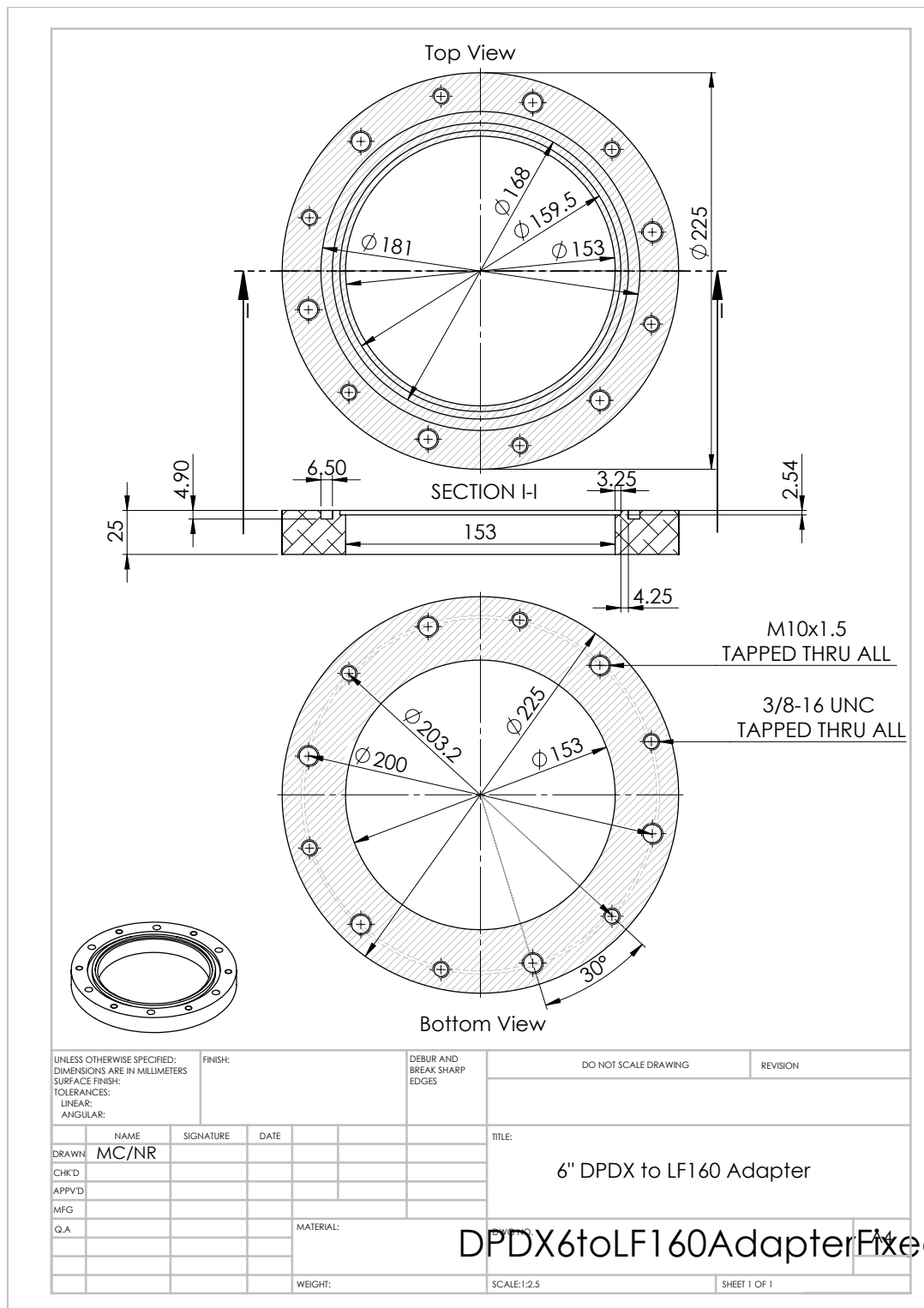


Figure 8: Drawing of an adapter made in Solidworks

Appendix B: Target Base Drawings

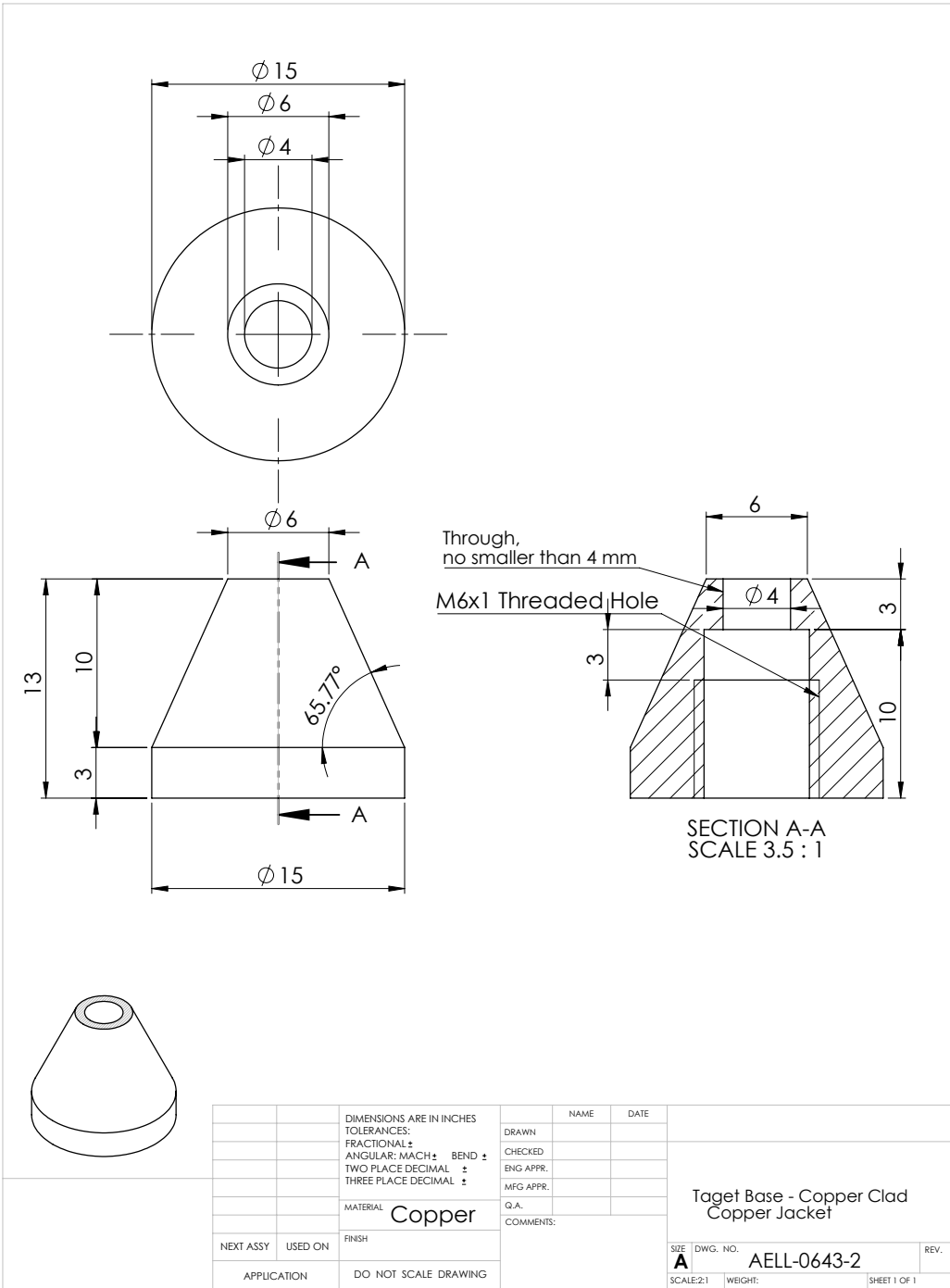


Figure 9: Copper Jacket

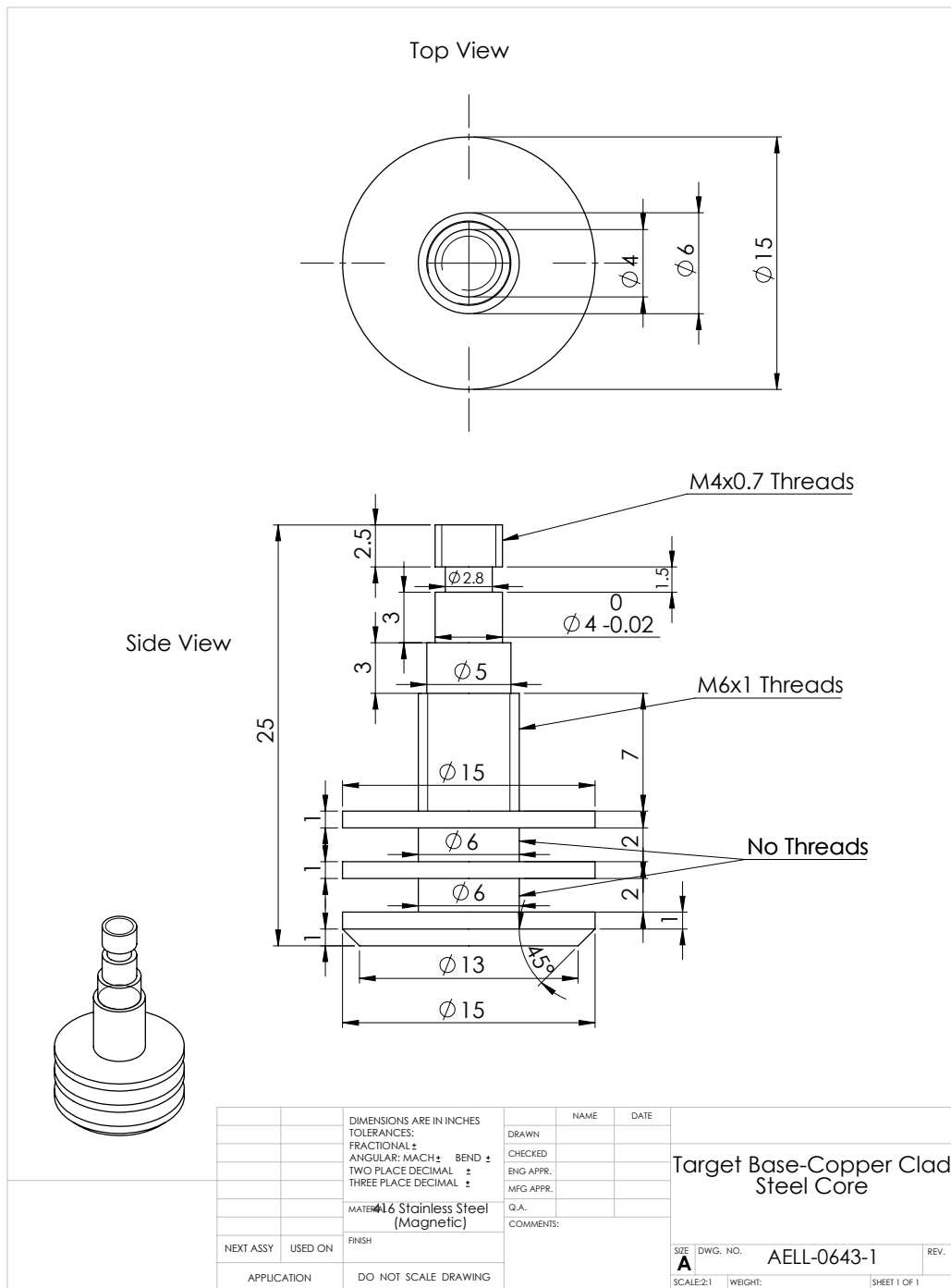


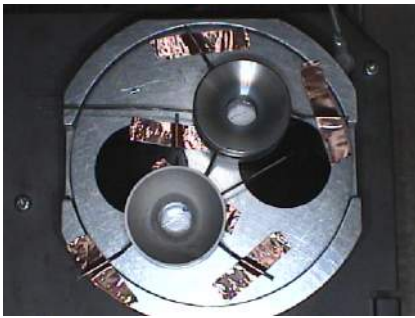
Figure 10: Steel Core

## Appendix C: Surface Examination of Spherical Ionizer used in Accelerator Mass Spectrometry

A used spherical ionizer from a cesium source head was taken out and its surface was examined under a scanning electron microscope. The surface of the used ionizer is compared to the surface of a new, unused ionizer. Images and qualitative observations are reported as well as spectra of surface composition.

### Ionizer

The ionizer is a spherical surface made of molybdenum and has four tungsten legs attached to its sides that are used for heating. The ionizer is used in the source head of an accelerator mass spectrometer. It is heated to 1200°C and cesium is boiled onto its surface. Cesium that hits the surface of the ionizer becomes positively charged and is attracted to a target holding some sample material by a potential applied across the ionizer and the target. When cesium strikes the sample material, material is ejected (called sputtering) and negative ions are formed which are accelerated towards the ionizer. Some of this material passes through an aperture in the middle of the ionizer, but material can also strike the ionizer, shaping its surface and depositing material on it.



Ionizers placed on the SEM platform. Used ionizer in the bottom left, new ionizer in the top right.

Figure 1: Ionizers

### Method

The source head was dismantled and the ionizer was removed and placed next to a fresh ionizer on the scanning electron microscope's platform. The tungsten legs were taped to the platform using copper tape. Secondary electron images and backscattered images were taken.

### Observations

#### A. New Ionizer

To have something to compare with, we took pictures of a new ionizer that had never been used for sputtering.

Figure 2 shows regular and jagged lines of material all flowing in the same direction at x3500 magnification and a spectrum with a large peak that matches the peaks expected from molybdenum. Overall we find a uniform and machined surface.

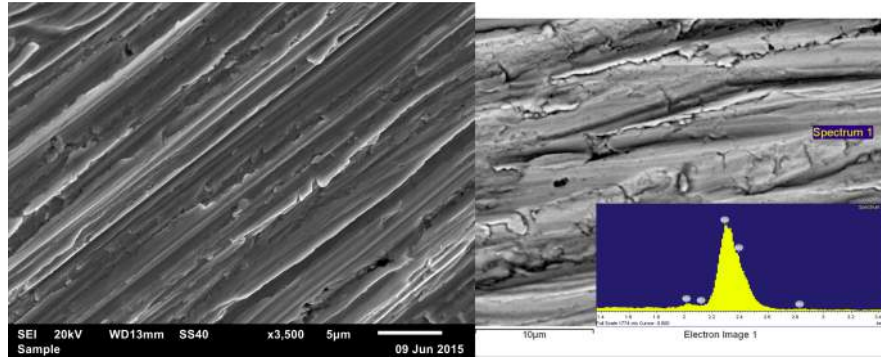
#### B. Used Ionizer

The used ionizer's surface is characterized by a crusty layer of material.

Figure 3 shows images taken midway between the center of the ionizer and its outer rim. We observe a patchwork of crusty material with smaller flecks of a different material embedded in the patchwork. In the center of the image is a fleck larger than the others and seemingly unique in the image. Spectra were taken at 3 different points of the surface: the crusty material, one of the small white specks embedded in the crust, and the large speck in the center of the image. The spectra was then compared with markers showing known peaks for different elements. All spectra showed the same large low energy peak which we believe is interference from carbon present in the SEM. The spectrum of the crust showed a large peak and a smaller peak matching known peaks of niobium. The spectrum of the small speck also showed a large peak and a small peak, but more closely matching known peaks of molybdenum, the material the surface of the ionizer is made of. The spectrum of the large speck showed multiple peaks. In addition to a large peak matching niobium, we observed three peaks matching calcium and a peak matching oxygen. We concluded that the large fleck is a piece of calcium oxide.

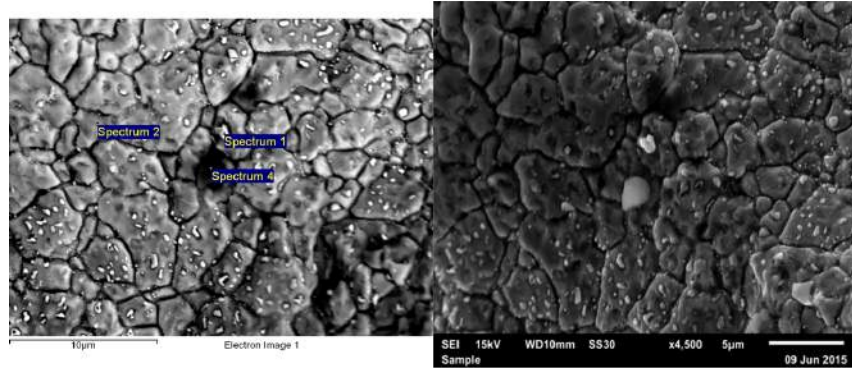
Looking more closely at the small specks embedded in the crust we see spectra that suggest a varied composition. Figure 4 shows a close up of two specks and their spectra. The largest peak in both spectra matches a niobium peak. Both also have a much smaller peak to the left of the niobium, almost like a shoulder. The shoulder peak of one of the spectra most closely matches a known peak of lead, while the shoulder peak for the other matches more with tungsten. There are multiple higher energy markers for lead and tungsten that either have very little measured signal or no signal at all.

Towards the center of the ionizer, near the edge of the



On the left an SEI image of the new ionizer surface. On the right a BEC image and its measured spectrum.

Figure 2: New Ionizer Surface



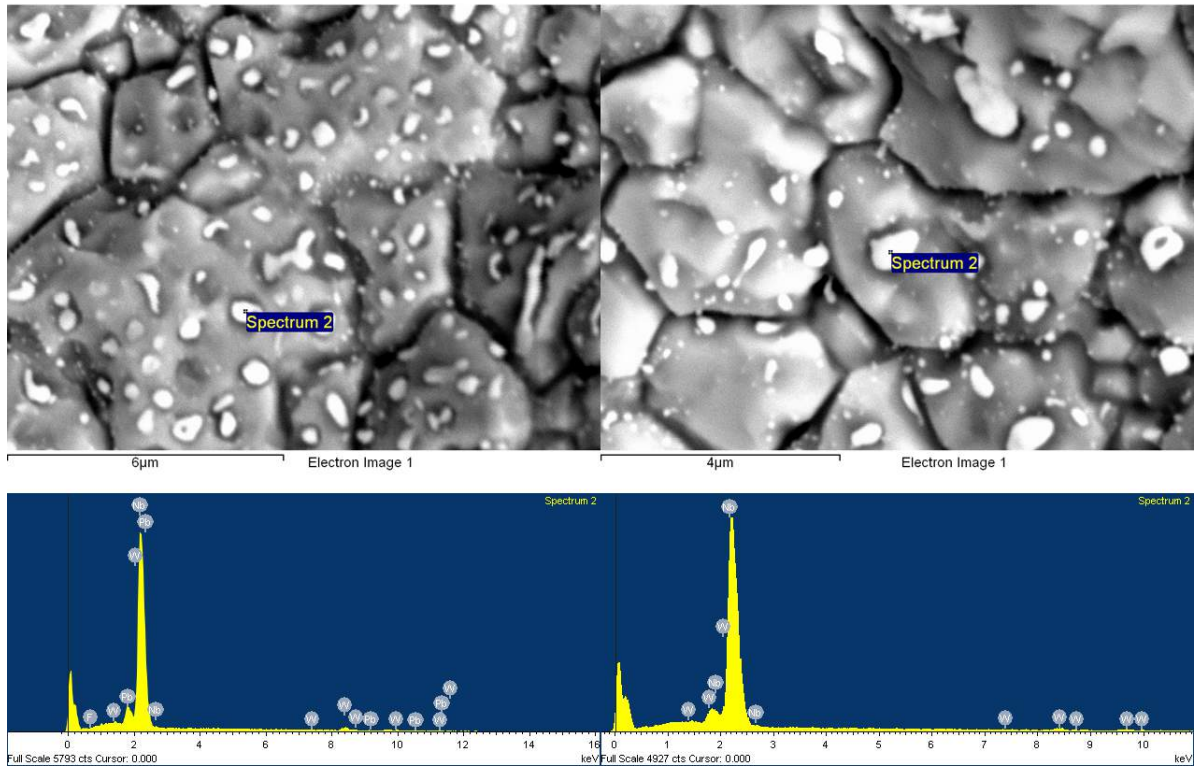
On the left a BEC image showing the three locations where the spectrum was measured. The surface was not flat so differences in brightness do not necessarily indicate a composition difference and could be shadowing. On the right an SEI image of the same location.

Figure 3: Used Ionizer Surface

shade change seen in Figure 1, we can see a sharp transition between cratered regions of molybdenum and of the crusty and speckled niobium region (Figure 5a). Moving out towards the edge of the ionizer, we see only

crust and the specks are absent (Figure 5b).





BEC images of the surface with corresponding spectra below each image.

Figure 4: Spectra of Small Specks

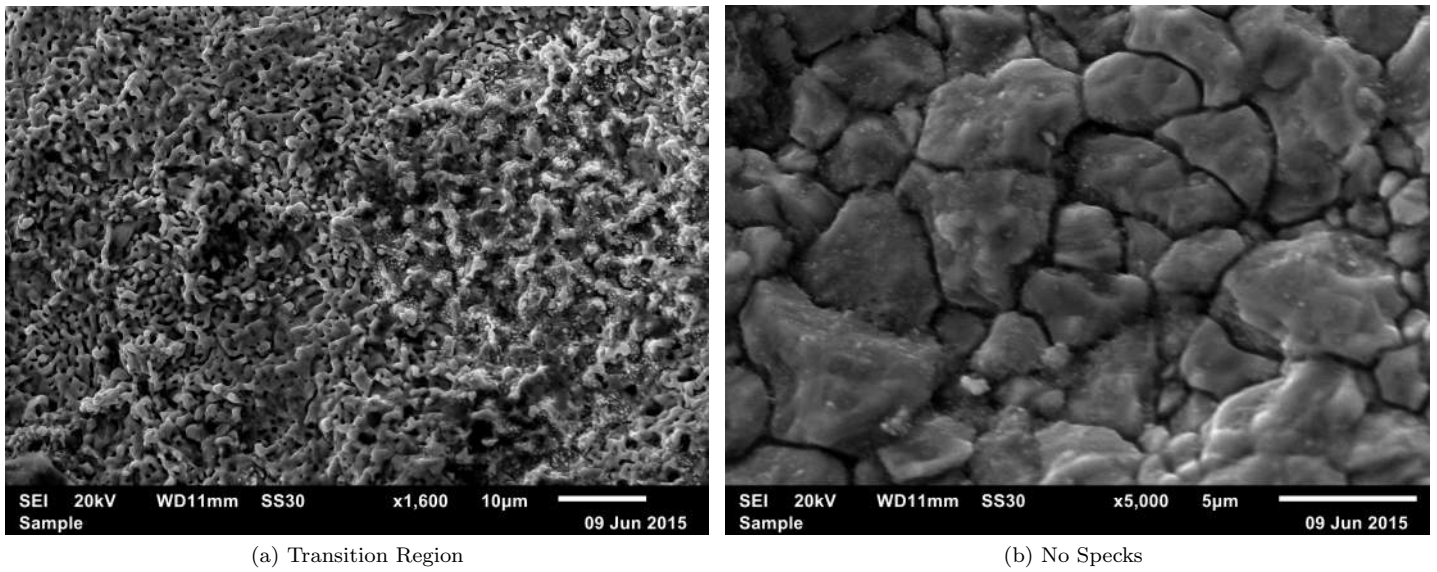


Figure 5

# Bibliography

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- [2] S. Pavetich et al., Interlaboratory study of the ion source memory effect in  $^{36}\text{Cl}$  accelerator mass spectrometry, Nucl. Instr. Meth. B (2014), <http://dx.doi.org/10.1016/j.nimb.2014.02.130>