



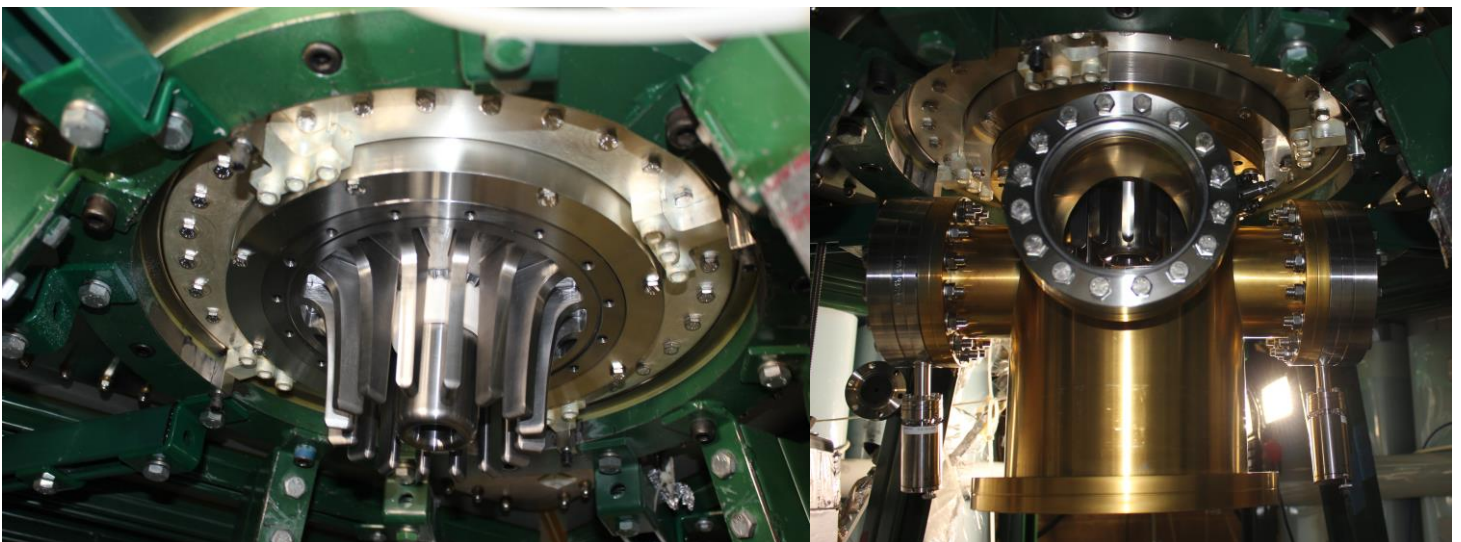
*July 1, 2019 Report*

**Summary:**

- **Beryllium Experiment with FF-2B Starts: Impurities Low, Yield Rising**
- **How We Prepared the New Experiment**
- **Weekly, ongoing, reports on [Facebook](#), free-software [Mastodon](#) in case you don't like FB, and [Twitter](#)—access available without accounts on any platform**

## **Beryllium Experiments Begin with FF-2B: Impurities Low, Yield Rising**

After nearly a year of preparation, on June 4<sup>th</sup> LPPFusion's research team started a new series of experiments using for the first time beryllium electrodes in a plasma focus device (Fig.1). Before starting, we renamed our device Focus Fusion 2B or FF-2B for short. The new name stands for Beryllium electrodes and Boron fuel—which we expect to use late this year—and for “Focus Fusion to be”, the future of Focus Fusion.



*Figure 1. The beryllium electrodes (anode is inner cylinder, cathode, outer vanes) during assembly (left) and inside the new vacuum chamber (right) have now started firing in our new experiment.*



*Figure 2. LPPFusion Director of Communications Ivy Karamitsos officially renaming our device “Focus Fusion 2B” or “FF2B” for short. Traditional renaming of people, such as knighting, used ancestral obsolete weapons (a king’s sword, for example). So our peaceful scientific ceremony used an ancestral obsolete scientific calculator—a slide rule! This slide rule belonged to Melvin Lerner, the father of LPPFusion Chief Scientist Eric Lerner. Melvin Lerner was a leading analytical chemist and scientific administrator, for over 20 years Director of Technical Service for the US Customs Bureau. He was a pioneer in the chemical analysis of marijuana and developed new techniques in statistical analysis and sampling.*

After 44 shots to date, we have achieved our first goal of firing with low impurities. The electrodes are far smoother than the tungsten ones were after a similar number of shots, indicating better erosion resistance, as we expected. Fusion yield has risen 60-fold since the first shot and is now  $1/10^{\text{th}}$  of a joule. This is comparable with the best results achieved with the similar 10-cm long tungsten anode, but not yet above our record of  $1/4$  J, achieved in 2016 with a longer 14-cm anode. We also have not yet observed the long-lived filaments that we hope to produce as a step to

getting much higher fusion yield. That is our next goal.

### ***Achieving low impurities***

Our primary reason for replacing our tungsten electrodes with beryllium ones was to reduce impurities in the plasma. These impurities were, we hypothesized, increasing plasma resistance and causing the filaments to heat up too rapidly, destroying them. Without the initial increase in density caused by the filaments, final density in our plasmoids was too low, limiting fusion yield.

Since it is well known that resistance in plasmas increases with the square of atomic charge, or “z”, of the nuclei in the plasma, we needed a low-z material for the electrodes to reduce the impact of any impurities created by vaporized electrode material. With only four electric charges in its nucleus, beryllium was the best choice for a low-z material.

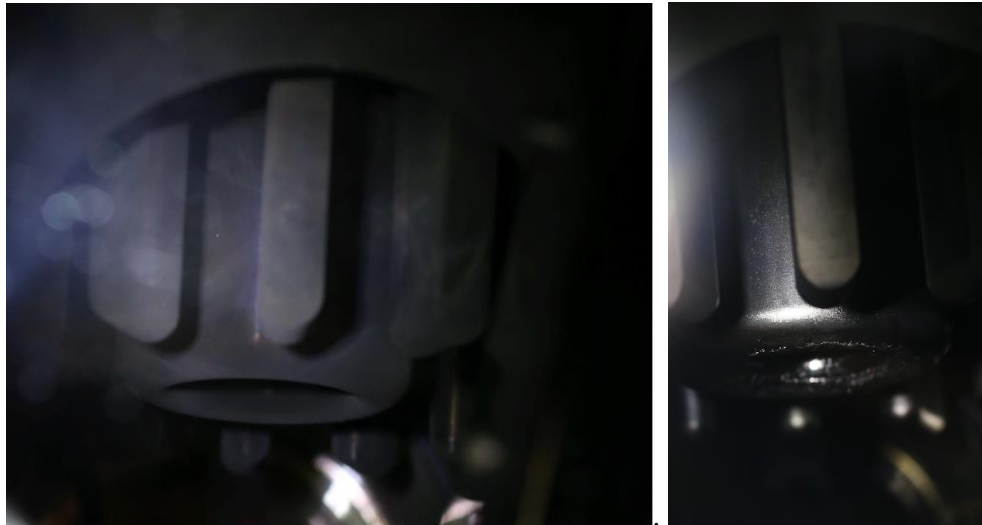
In addition, our tungsten electrode formed a deep, fragile, tungsten oxide outer layer, that was easily vaporized, unlike pure tungsten metal. We expected beryllium would be far better in this respect, and we were right, as it formed a self-limiting oxide layer only 10 nm thick. This could be removed rapidly during firing, we believed, and we made every effort to prevent significant oxygen from entering the chamber after we started firing. (See the section of Preparations, below).

We’ve achieved our initial goal of getting low impurity, although it did not look like we would, judging by the first shot. As expected, the first shot removed the layer of beryllium oxide, since it is an electrical insulator and the current had to pass through it to get to the beryllium metal below. What we didn’t expect was how much dust this would produce (see Fig. 3). Our electrode looked really dirty as it was totally covered in dark dust. We could roughly measure the amount of dust on the vacuum chamber windows, using our spectrometer. A thicker layer produces systematically more absorption at short wavelengths than at long ones, so by measuring the absorption at various wavelengths we could estimate the thickness at 25 nm. That does not sound like much, but it was 20 times more than we had expected.

However, a literature search showed that beryllium dust forms thin flakes, like snowflakes. Like snow, beryllium dust is very porous. For snow, density is  $1/20^{\text{th}}$  that of water and so snow is 20 times thicker for the same mass. This

is just a geometric property of flakes, so explains why the beryllium flakes create a layer 20 times thicker than a solid layer of beryllium.

Subsequent shots rapidly removed the dust, or melted it into a smooth layer on the electrode and vacuum chamber. As more and more of the dust was removed, the impurities in the plasma decreased.



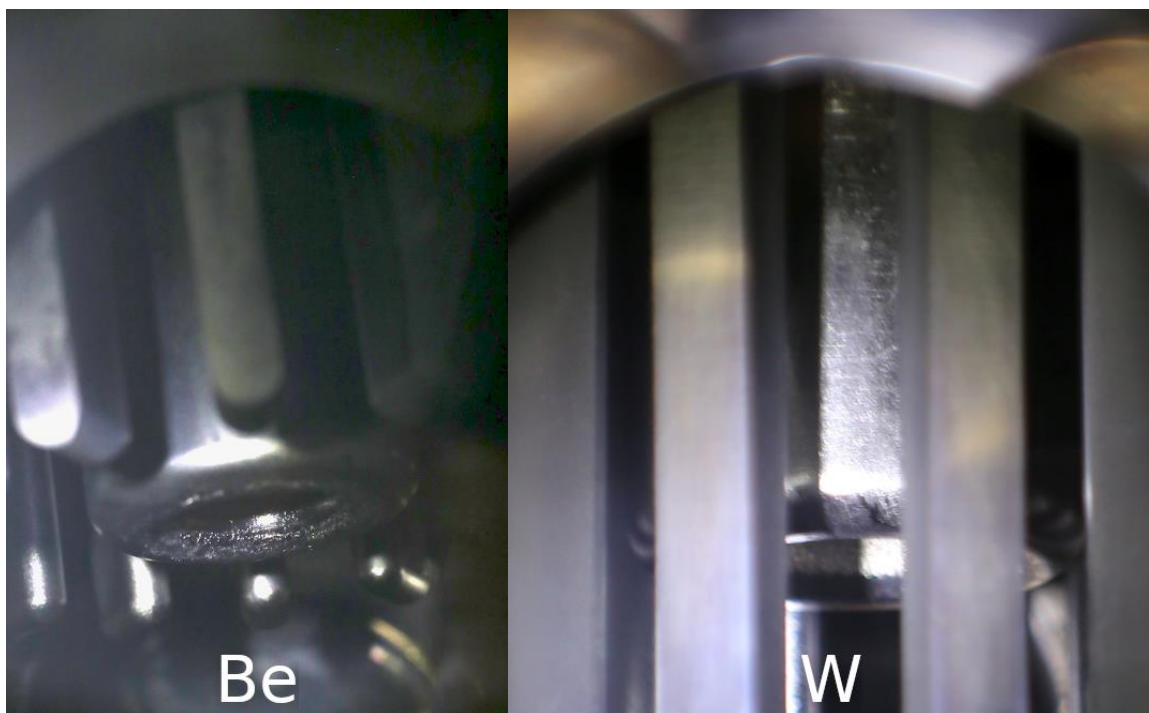
*Figure 3. The initial layer of beryllium oxide turned to beryllium dust after shot 1 (left) but the dust was removed shot by shot, leaving shiny smooth electrodes, (right) after 44 shots.*

We measured the level of impurities three ways, with broadly similar results. First, we continued to monitor the build-up of dust on the windows. This dropped from 25 nm/shot on the first shot to 2.5 nm/shot on shots 2-11 to 0.35 nm/shot on shots 12-38, a rate of decrease of about 10% per shot. We don't really know the porosity of the layers, so we can only use this measurement to set a maximum for beryllium deposition, assuming the layers are now solid metal. That maximum works out to 140 micrograms per shot, or about 5% of the deuterium in the current sheath, by mass. This would only increase resistivity by 10%, which is our current goal.

The spectrometer showed us that the only impurity detectable in the spectrum is beryllium. The strength of the beryllium line relative to the deuterium lines (identical to hydrogen lines) allows us a rough estimate of the abundance of beryllium at 0.16% by number or 0.7% by mass.

A third estimate comes from the dips in current that occur early in the shot. As we learned from the FF-1 tungsten shots, these dips are caused by vaporization and ionization of electrode material. About 7 J of energy is removed from the latest shots, enough to vaporize 70 micrograms of beryllium, or 2.5% of deuterium by mass. **So the impurity level, consisting only of beryllium, is between 15% and 100% of our limit for impurities, meaning that low-impurity functioning has been achieved.**

We have another important indication that beryllium is eroding less than tungsten. With tungsten, the electrodes got rougher and rougher with use. We could see that the initially mirror-smooth surface became a bright white "matte" finish, reflecting light from all angles. But with beryllium, as the initial dust was burned off, the surface has become smoother, as indicated by the mirror reflection of light from a small area. (Fig. 4) Small scale ripples indicate that there has been some melting, but very little of the vaporization-caused roughness of tungsten. This matters, as a rough surface concentrates current in small points, leading to increased vaporization. In contrast, a smooth surface spreads out the current, minimizing further erosion. Of course, once we have filaments concentrating the current, this situation may change.



*Figure 4. Beryllium anode after 44 shots (left) is still fairly smooth in the anode hole as shown by narrow bright reflection, while tungsten electrode after 56 shots in 2017 (right) was rough as shown by broad bright region. In both photos, the gap between the cathode vanes gives the scale of 1 cm.*

### ***Yield rising***

While the beryllium overall has a small impact on the plasma, remaining concentrations of beryllium dust still have a big impact on the symmetry of the current sheath, especially at the start of the shot. This lack of symmetry, we think, is limiting the compression in the pinch and thus the density needed to achieve high fusion yield.

What we have seen, overall, is an irregular, but continuing, rise in fusion yield. Our first measurable fusion yield was on shot 3, with only 1.6 mJ. By shot 7, we were at 20 mJ. On Research Scientist Dr. Syed Hassan's suggestion, we then scanned the fill pressure—changing for each shot the amount of gas we were putting in the machine and thus getting up to 60 mJ by shot 25. We then started altering the axial field coil current, which controls the amount of spin on the plasmoid, reaching 100 mJ on shot 43. By comparison, our record yield with FF-1 was 250 mJ, a quarter-J. Our first fusion yield goal with the beryllium is 1 J and we aim to reach 10 J by 200 shots. Of course, there are downs as well as ups within this overall trend, which can get a bit tense!

Excluding occasional pre-fires, when the whole capacitor bank does not fire together, we are getting about a 5% increase in fusion yield per shot. Some of this is due to our optimizing conditions, but most is probably due to the electrodes becoming progressively smoother and more symmetric after the initial big deposition of dust in the first shot.

We've seen no evidence yet that we have filaments that last until the compression phase, when the plasmoid forms. Once we get to that point, we expect a substantial jump in fusion yield. Until then we expect an incremental rise.

Within the overall pattern of rising yield, there have been as many as seven shots in a row with consistency in yield to within 10%. That is better consistency than we have seen with FF-1, an encouraging observation.

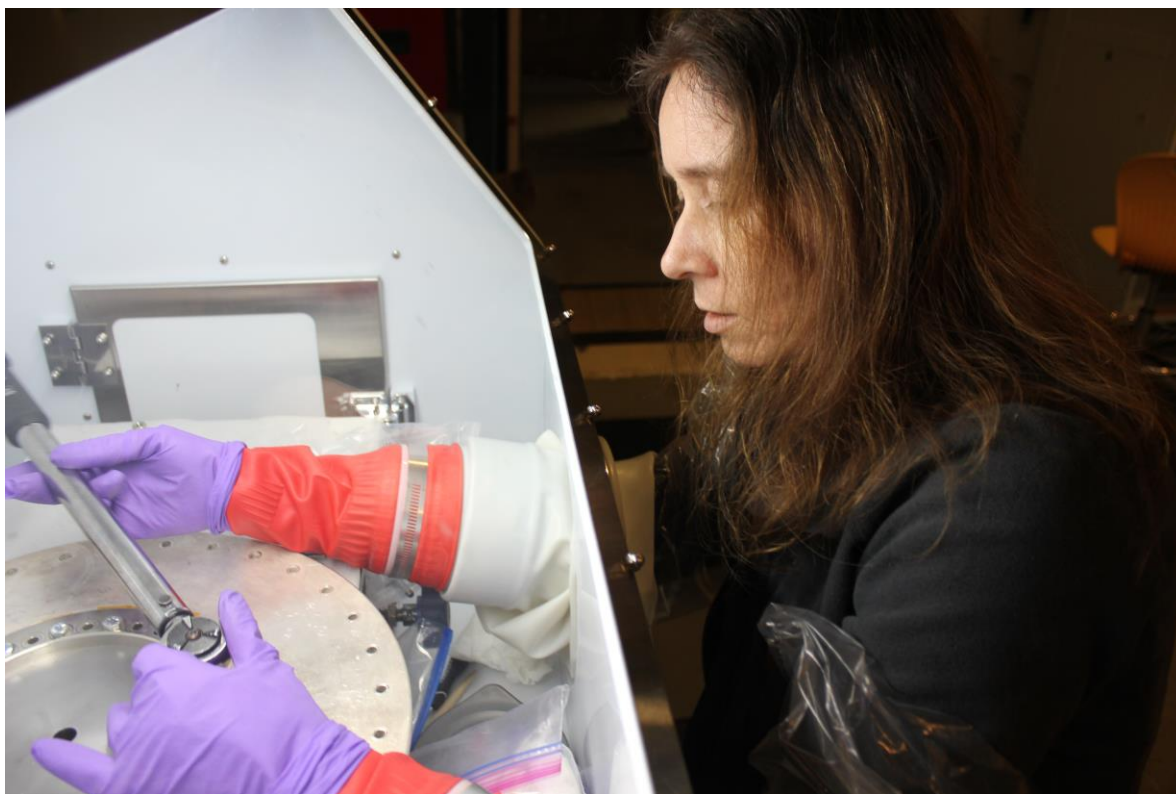
# How We Prepared the New Experiment

It took us five months of intensive work to assemble FF-2B with its new beryllium electrodes. The safety requirements of dealing with beryllium to ensure that none of us were exposed to beryllium dust was one safety concern that slowed us down. But in the process, we have succeeded in greatly upgrading our experimental device. Here's a summary of what we did.

**January:** Dr. Hassan installed the glove box used to isolate all beryllium parts and for work with decaborane fuel.

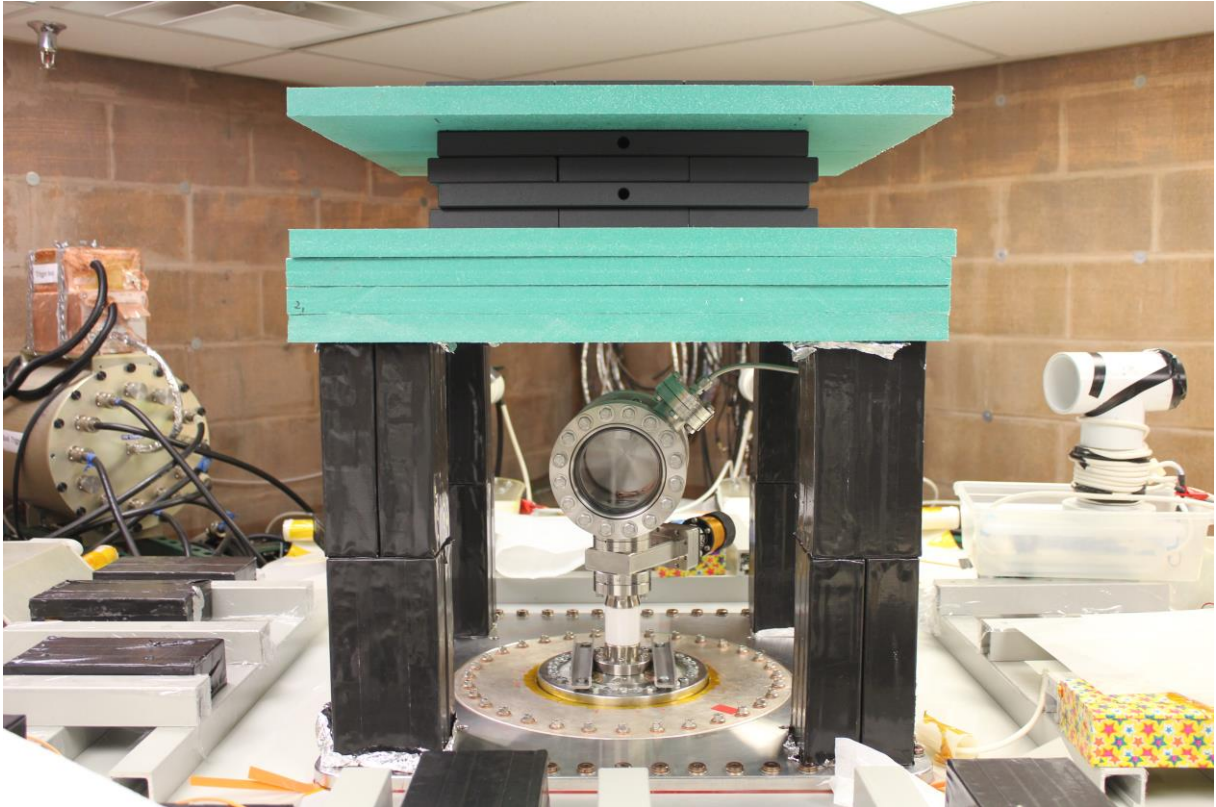
**February:** We did a preliminary bake-out of the silicone gaskets and O-ring and Viton gaskets in a special vacuum oven. This was essential to get rid of volatiles that needed higher temperatures for bake-out, 190 C, than the Mylar insulators on our device could withstand. Also, it allowed us to bake out rapidly with all surfaces exposed.

At the same time, using the glove box, we assembled the beryllium anode onto the steel plate that attached it to the rest of the device. To get high electric conductivity, we use indium, a soft metal, between the silver-coated steel plate and the beryllium. But when we tried to do this, we found that we needed to first remove the very thin layer of beryllium oxide, an insulator that forms on the beryllium when it is in air. For this we needed an ultrasonic welder, which uses ultrasound to break up the oxide layer, trapping the oxide particles under the molten indium. The working surface had to be heated to about 100 C to make sure the indium melted quickly. [It took a while to get the hang of this new technique](#), but once we got it, we were able to successfully merge the anode and its plate. Then we mounted the anode onto the device.

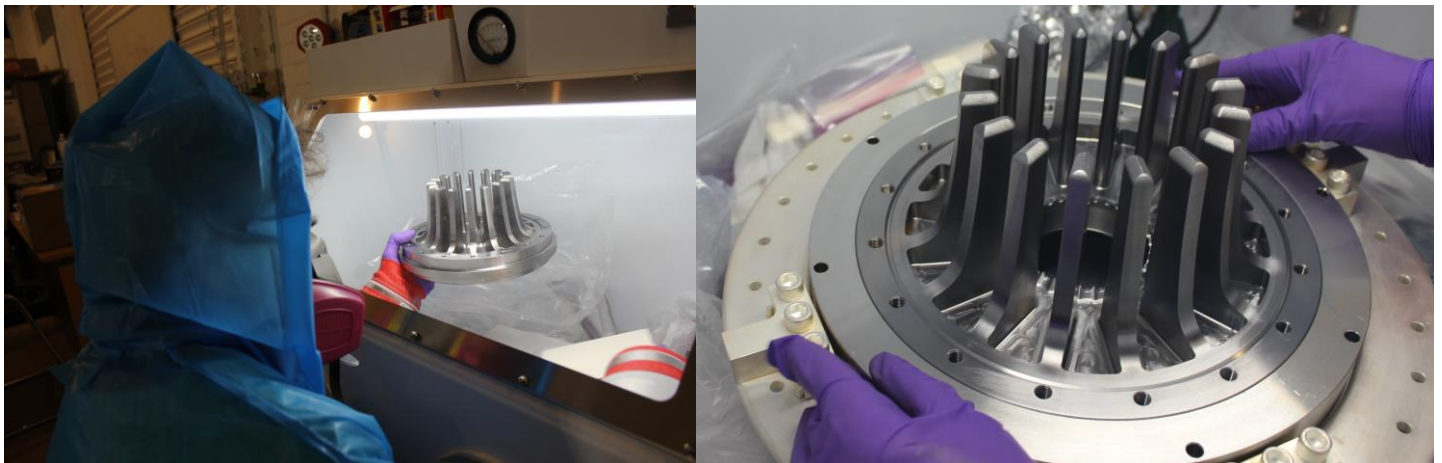


*Figure 5. Ivy Karamitsos tightens the bolts connecting the bottom of the beryllium anode (grey disk) to its connecting steel plate. She's protected from any potential contact with beryllium dust by the sealed glove box. The Plexiglass window to the box, barely visible in this photo, is at the border of the white area. Four layers of gloves—of which three are visible—protect against any possible tears. We did not actually believe that we produced any beryllium dust in these operations, but have used the highest possible protections in any case.*

**March:** Dr. Hassan added a new upper vacuum chamber on top of the anode. This chamber is designed to observe the electron beam, which is generated by the plasmoid and exits through a hole in the new beryllium anode. Next, we used a steel brace to bolt the cathode onto its steel plate. That went faster, with our experience from the anode. But then we had to carefully center the cathode onto the anode. This is always a difficult operation, as we are aiming to get centering within about 50 microns. This is needed, because the gap between the cathode and the insulator, which lies between the anode and cathode, is only 500 microns, a half-millimeter, and we want the gap to be even within about 10%. Our IT team, systems administrator Jose Varela and CIO Karamitsos completed custom software, FetchScopes, that fetches the data from our old, used, oscilloscopes to our data computer without having to rely on no longer supported drivers or on ancient Windows software. Also, [putting on the space \(bunny\) suit](#) proved to be somewhat challenging for some of us.



*Figure 6. The new upper vacuum chamber installed on top of the anode. The chamber is being used to measure the electron beam, exiting through a hole in the anode.*

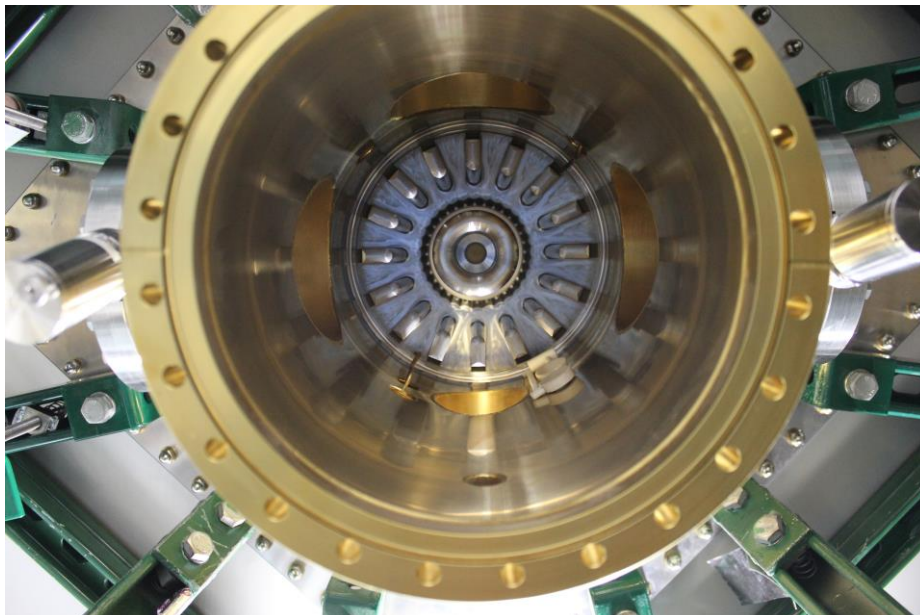


*Figure 7. Karamitsos (top) holds the beryllium cathode in one hand inside the glove box, demonstrating its light 3-kilogram weight. The tungsten cathode it replaces weighed 30 kg. Lerner (bottom) completes lowering the cathode and its steel brace onto the silver-coated steel connecting plate.*

We then added the new main vacuum chamber, which has enlarged windows, and sealed it up. In the process, we made a disturbing discovery. Despite many checks of the drawings, the beryllium cathode had 8 fewer bolt-holes than the vacuum chamber that bolted on to it. Fortunately this did not really matter, as the bolts in the holes they had in common applied enough pressure to seal the Viton gaskets. But the fact that a potentially serious error had gone unnoticed had our CIO Karamitsos insisting on generating a complete 3D assembly drawing for the whole device, a task undertaken by LPPFusion Mechanical Engineer Rudy Fritsch. Once the drawing is complete, in the near future, new drawings can automatically be checked by Solid Works software (\$10K+ additional module not purchased yet.)



*Figure 8. Dr. Hassan, in full protective dress, prepares to install the new vacuum chamber onto the beryllium electrodes, which are already attached to the device. The gold color of the chamber is from its titanium nitride coating, which prevents oxygen from escaping the underlying stainless steel.*



*Figure 9. The beryllium electrodes, with the anode (with hole in center), white insulator, and cathode all centered to within 50 microns, viewed from below.*

**April:** This month was devoted to upgrading the vacuum system to have all remote-operated valves. This would be important in the event of any break in the vacuum, but also is essential when we start firing with decaborane. We expect a side reaction will produce small amounts of radioactive carbon-11, with a half-life of 20 minutes. We will have to stay out of the experimental room while firing, but the C-11 will decay to background levels overnight. We had to take a lot of time to get rid of all leaks, including replacing outdated valves.

**May:** During this month we baked out the entire chamber at 100C. We needed to add insulation, surrounded by aluminum foil to get everything hot enough to eliminate as much water, remaining volatiles and especially any trapped air as possible. Only oxygen reacts with beryllium at room temperature, so that is what we wanted most to get rid of. We succeeded in meeting our goal of less than 0.2 microtorr of oxygen per minute entering the chamber.



*Figure 10. The vacuum chamber and drift tube (thin tube below) get copper sheet cladding to spread the heat out evenly during bake-out.*



While all these preparations were going on, we also used the glove box to take a 2-gm sample of our new decaborane fuel for testing. The tests went very well with only 0.068% B-10 and 0.0007 % iron present. This means we will be able to use the fuel late in the year without worrying about the production of radioactive Beryllium-7 from B-10 or any significant chemical impurities.

Outside of the lab the team [produced a video regarding Lerner's take on "black hole" M87](#). Lerner was invited by NJ senator Joe Pennacchio to present the latest on fusion energy R&D with other fusion researchers at a Fusion Symposium in Trenton NJ. Lerner also [presented at NYC MENSA](#) why fusion energy is the missing link necessary for the Green New Deal.



*Figure 11. The FF-2B vacuum chamber with insulation and outer aluminum foil. Now it looks like a baked potato, but getting the bake-out done is more important than looks!*