Commonwealth Fusion Systems

CFS Safety Questions

To: Peter Lowitt, Devens Enterprise Commission
From: Kristen Cullen, Commonwealth Fusion Systems

November 20, 2020

Dear Peter,

Please see below for answers to your requested questions related to safety issues at Devens. In order to make this more straightforward, we have consolidated answers to two categories: CFS-1, the manufacturing facility and CFS-2, the research building and fusion device.

Please let me know if you have any follow-up questions.

Best,
Kristen

Kristen Cullen
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Commonwealth Fusion Systems

1. How will you process work? Is it truly an attempt to mimic the sun in some manner, or is it a different process? Please explain. ANSWER:

Scientists have been studying fusion for decades and have been able to safely create fusion in the laboratory using various types of approaches in devices all over the world. The most common and successful approach to fusion is using a device called a tokamak. A tokamak is essentially a magnetic bottle that uses magnets to confine a plasma in which fusion occurs. There have been more than 150 tokamaks built all over the world that use this approach to achieve fusion, including one at MIT in Cambridge. However, there has never been a tokamak or any fusion device that has shown fusion can work as an energy source. This means a device produces more energy out than it takes to start the process – we call this net energy. This is a key element on the path towards a power plant.

CFS is working collaboratively with MIT and leveraging decades of MIT research to build a tokamak, similar to the one in Cambridge, that will produce net energy from fusion for the first time in history. To do this, we are constructing new advanced magnets that will enable a strong magnetic field to confine the fusion process. In the past, this type of magnetic field would require an enormous device, that is very expensive and slow to build to achieve net energy. But with these new magnets, we can build a compact device faster and less costly, and as a result it can achieve net energy from fusion on a timeline that will enable commercialization to combat climate change.

Similar to the process that powers stars like our Sun, fusion occurs when hydrogen fuses together into helium releasing energy in the process. Future commercial fusion systems will harness this energy to use as a source of electricity, but at a much smaller scale than the stars. However, while the stars use gravity to produce fusion in the vacuum of space, CFS will use a tokamak. Inside the tokamak we will create a vacuum and use magnets to confine the fusion process. This confinement is important, if any air gets into the system it will shut off in a fraction of a second and go back to room temperature. This makes fusion difficult to achieve on earth, but also inherently safe. For example, if power to the device went out the machine would turn off and the fusion process would simply stop. If there were a breach in the system, air would get inside and the process would stop. One of the benefits of fusion energy is that we can turn it on an off like a light switch. There are in fact many operating tokamak facilities where you can see this occur.

2. If one "draws a box" around your <u>entire proposed facility</u> what raw materials, natural resources and manmade resources do you plan to go into the facility? Will those change over time? Again, we are looking for a list of chemicals, water, electricity, electromagnetic forces, etc. demands, with very general order of magnitude assessments herein for discussion herein if easily estimated, and not specific quantities. Please explain. ANSWER:

   [Listed below separately]

3. Again, if one "draws a box" around your <u>entire proposed facility,</u> what byproducts, wastes, or emissions will occur? Will those change over time? Again, we are looking for a list of chemicals recreated as future raw materials, waste byproducts, wastewater discharge components, air emissions, different forms of radiation, etc., with very general order of magnitude assessments herein for discussion herein if easily estimated, and not specific quantities. Please explain. ANSWER:

   [Listed below separately]

4. If one "draws a smaller box" around the <u>CFS-1 or the manufacturing facility</u>, what raw materials, natural resources and manmade resources do you plan to go into the process? Will those change over time? Again, we are looking for a list of chemicals, water, electricity, electromagnetic forces, etc. demands, with very general order of magnitude assessments herein for discussion herein if easily estimated, and not specific quantities. Please explain. ANSWER:

The <u>magnet production facility</u>, is known as CFS-1 or the manufacturing facility, will operate as a manufacturing center to create the magnet assemblies used in the SPARC device and operated in the CFS-2 building. While exact quantities are not known at this time, the following materials and services will be utilized in our operations, in quantities normally associated with a manufacturing building of this size:

- Municipal water will be used to service general office areas such as restrooms, our kitchen facility, and the building fire suppression system. Water will also be used, though central chilled water systems, to provide process water to the manufacturing facility.
- Electrical services for the entire building include general building lighting, HVAC and power needs, as well as loads associated with the manufacturing equipment.

- Process gases will be provided, through either central tank farms or small dewars for localized use, and include Helium, Nitrogen and Argon.
- Cleaning solvents, such as isopropyl alcohol, ethanol, and acetone will be used in the manufacturing process, and stored at point of use in appropriate cabinets.
- The manufacturing process shall include various manmade components and raw materials sourced from external vendors and machined, processed and assembled in the facility. Material quantities are not known at this time, but materials will include stainless steel alloys, aluminum plates, copper, various welding consumables, indium paste, silver plating, silicone adhesive, solder, and cryogenic glass epoxy (similar to fiberglass).
- The majority of manufacturing processes in the building consist of mechanical assembly of hardware. Additional processes include machining, precision inspection, vacuum pressure impregnation in an oven at ~400 °F, and welding.
- As a final quality check, each magnet will undergo electrical testing in a sealed cryogenic vessel at temperatures of 77 and 20 K. The worst-case estimate of the magnetic field of these magnets will range from 7 to 24 Tesla (will likely operate at less than half of these fields) and the safety-critical Gauss lines will remain inside the building.

As our operation and manufacturing processes mature, quantities and materials used may change over time, but we expect the range of resources, materials and chemicals used in those processes to remain relatively stable.

5. Again, if one "draws a smaller box" around the <u>CFS-1 or the manufacturing facility</u>, what byproducts, wastes, or emissions will occur? Will those change over time? Again, we are looking for a list of chemicals recreated as future raw materials, waste byproducts, wastewater discharge components, air emissions, different forms of radiation, etc., with very general order of magnitude assessments herein for discussion herein if easily estimated, and not specific quantities. Please explain. ANSWER:

The facility known as CFS-1, will operate as a manufacturing center to create the magnet assemblies used in the fusion device and operated in the CFS-2 building. Additionally, in the future this facility will produce magnets for fusion power systems around the world. While exact quantities are not known at this time, the following waster products, byproducts or emissions can be expected:

- General sewerage discharge from restrooms, kitchen facilities typical for a facility of this size, and process water discharge from operation process. Process water is not expected to require any treatment at this time.
- General trash and recyclable materials associated with an office and manufacturing facility of this size.
- Emissions (hot air) from ovens shall be discharged through appropriate ventilation systems.
- Minor amounts of gas emissions (Helium, Nitrogen and Argon) at localized points in the manufacturing process.
- Scrap material waste from operations, including solder, weld consumables, and packaging materials from material shipments.
- Scrap material waste and cutting fluid from machining which will be contained, stored, and then disposed of accordingly.

- Minor hazardous material waste from cleaning operations (acetone, ethanol, isopropyl alcohol, and associated cleaning supplies), which shall be contained and disposed of accordingly.
- There will be no radiation produced within CFS-1 as part of our manufacturing process.

As our operation and manufacturing process matures, quantities and types of emissions, discharge and waste may change over time, but we expect the range of those byproducts from our process to remain relatively stable.

6. If one "draws a smaller box" around CFS-2 including the research facility and fusion device, what raw materials, natural resources and manmade resources do you plan to go into the process? Will those change over time? Again, we are looking for a list of chemicals, water, electricity, electromagnetic forces, etc. demands, with very general order of magnitude assessments herein for discussion herein if easily estimated, and not specific quantities. Please explain. ANSWER:

The fusion device is located inside CFS-2 which is also known as the research facility.

- The fusion fuels used in the device are isotopes of hydrogen – deuterium and tritium. Tritium consumption is low, and replenishment is not expected. Deuterium replenishment is expected. In addition, the facility will require low amounts of process gasses such as hydrogen, helium, nitrogen, diborane, and neon.
- 94% of the daily domestic water needs are mainly due to cooling tower evaporation. The remainder of the daily domestic water use is attributed to restroom and general usage that may occur.
- The majority of the daily utility electrical demand occurs during operation hours only. Approximately 23 MW of electricity will be needed from the nearby Devens Substation. Of this amount, 3MW will be needed to convert AC power to DC pulsed power to serve the electromagnetic and RF energy conversion generating waste heat throughout the process. We approximate 15MW of dissipated power via the cooling towers. The remaining 5MW of power are expected for typical building facilities and typical transformer losses.
- The primary contributor to EMI has been identified as the magnets in the tokamak and the expected magnetic field strength at the nearest property boundary has been analyzed. The expected magnetic field intensity at the nearest property boundary, west property line perpendicular to the tokamak location, are very low (0.1G or 10uT) and below natural background levels.
- Chemicals commonly found in industrial applications will be used: acetone, alcohol, typical cooling tower water conditioning, lubricating oils.

7. Again, if one "draws a smaller box" around the CFS-2 including the research facility and fusion device, what byproducts, wastes, or emissions will occur? Will those change over time? Again, we are looking for a list of chemicals recreated as future raw materials, waste byproducts, wastewater discharge components, air emissions, different forms of radiation, etc., with very general order of magnitude assessments herein for discussion herein if easily estimated, and not specific quantities. Please explain. ANSWER:

- Emissions anticipated are from typical facility equipment such as boilers, humidifiers, cooling towers, and standby generators. An analysis was conducted to determine if an air quality permit would be needed for the facility and deemed not necessary. The conclusion was based on thresholds being below all limits as indicated in 310 CMR stated exemptions.
- During operations of the fusion device, very small amounts of tritium will be released out of the exhaust stack. Our fusion device will also produce neutrons and as a result will be fully shielded with concrete to protect from radiation. Combined this is a factor of 10 below the yearly limit allow by the Massachusetts Radiation Control Program and not harmful to the public. This increase at the site boundary would be extremely small and nearly indistinguishable from background radiation.
- Wastewater is expected to be standard domestic water grade quality with minimal amounts attributed to restroom and general usage that may occur. Typical cooling tower emissions are expected. Any non-sanitary discharge that could occur in the facility will be contained and disposed of properly and not via the site sanitary system.
- The produced gas from the fusion process will be small amounts of helium. This is less than a few grams over the life of the system.
- Process Gases (put in and then taken out) will be hydrogen, helium, nitrogen, diborane, and neon.
- Electrical power from the fusion process will be returned to the motor generator. Standby generators will create exhaust, when used during loss of power.
- Heat from the fusion process will be extracted through cryogenics and cooling water.

8. What is the preferred chemical, nuclear, and energy reaction, for the fusion device including intermediate steps and byproduct reactions? Again, these reactions need not be properly balanced or perfectly inclusive of all modified alternatives, but simply the initial approach? And how, generally, will theses reactions be modified during the research. Please explain. ANSWER:

- The main fusion reaction is deuterium and tritium that results in helium 4 and a neutron.
- We will start in deuterium/deuterium operations, with very few total reactions, then move to deuterium/tritium. The reactions themselves won't change in time, just which type of gas we put into the machine.

9. We have tried to put ourselves in our neighbors' and/or the general public's "shoes" to anticipate their concerns to streamline this review and approval process. We could use your help as well. We understand the traditional concerns, and think we understand some of the specific concerns with this type of facility, but we also know that we cannot fully understand the potential before we get fully into the review and approval. So knowing what you know about the proposed process, what do you anticipate as the public concerns that must be addressed that are specific to your planned facility? Again, each item does not need to be detailed, but should be of a list form, with a brief explanation as possible. Please explain. ANSWER:

- Fusion fuel – Deuterium and Tritium
  Our fusion device will use two isotopes of hydrogen as its fuel. The first, deuterium, is extracted from water. The other, tritium, is a radioactive form of hydrogen with a short half life that is produced in the atmosphere. It is found in small amounts in groundwater throughout the world. Tritium is also found in everyday objects that are self-luminous such as exits signs, watch dials and navigational compasses. Tritium makes these devices glow without the need for electric power.

  When operational, CFS will have a small inventory of tritium on site - 10 grams. This is about the mass of 2 quarters. Our device will only use approximately half a gram at any time to run. Tritium requires special handling on site and a license from the Massachusetts Radiation Control Program who also regulate the safe operations of the fusion device and its decommissioning and the end of its operations.

  All of the tritium on site will be stored using proven safety methods and best practices from the various sites around the world that include national laboratories, medical research facilities and hospitals. CFS will also have systems in place to monitor the tritium to ensure it stays contained. Our plans are significantly more robust than what's required by regulation, with built-in redundancies and layers of protection.

- Distinguishing fusion from "nuclear" fission
  It's important to clarify that fusion and fission are two fundamentally different processes. Fission or what is commonly referred to as "nuclear" power is what takes place in the nuclear power reactors that generate electricity today. Fission has two basic properties that create risk. First, it works via a chain reaction in the fuel, uranium, and the chain reaction has the potential to go unstable. Second, when the uranium fuel 'fissions', it produces highly-radioactive byproducts which in the short run generate lots of heat that can melt the fuel and in the long run is the source of long-lived nuclear waste. Fusion has neither of these problems. It does not work via a chain reaction, and therefore cannot go unstable. And the byproduct of the fusion reaction is helium, a stable element that is used to inflate balloons.

- History of fusion research
  Fusion research has been conducted for decades all over the world. Many other tokamaks, similar to the fusion device we are proposing at Devens, have been built and safely operated around the world in the same way. For example:
  - The tokamak "TFTR" at Princeton operated safely for 15 years. TFTR also used deuterium/tritium as its fuel. It operated successfully, did not impact the environment, and is now decommissioned.
  - MIT has had tokamaks operating safely in Cambridge, MA for decades. Our team at MIT still conducts tours at this facility and we would extend an open invite for a tour if it would be helpful information surrounding the permitting process.
  - General Atomics has operated a tokamak called DIII-D in San Diego since the late 80s.
  - JET in the UK is using Deuterium/Tritium fuel for its tokamak operations.