Why a particle accelerator framework is the right one for fusion energy machines

Hawkins DeFrance, PharmD
Director of Regulatory Affairs & Safety
Avalanche Energy
OAS – August 2025

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Contents

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Nuclear Experience

<u>About me:</u>

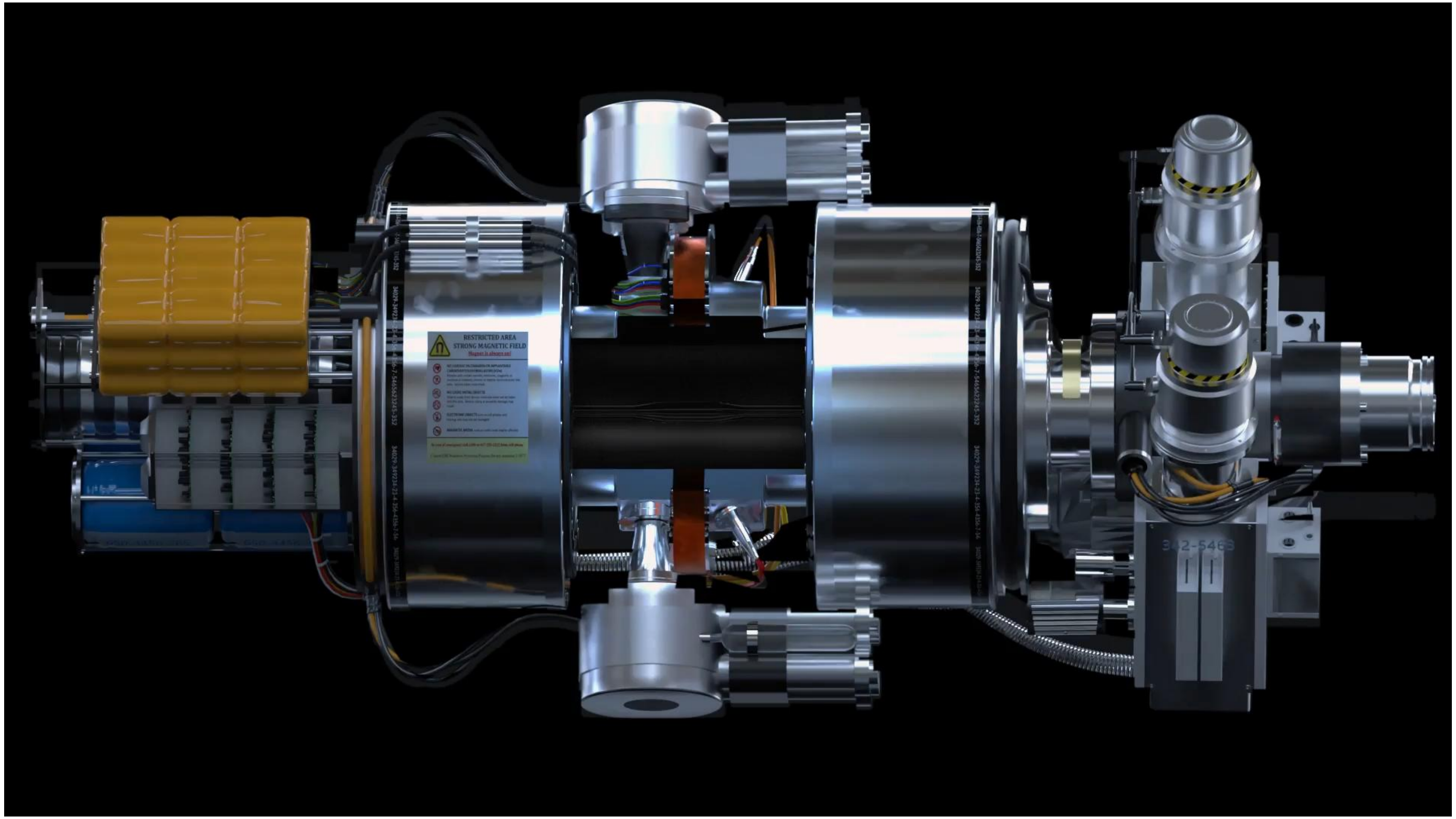
- Nuclear pharmacist
- Director of RA & Safety / RSO at Avalanche
- Chair of WA Pharmacy Commission

<u>Previous experience:</u>

- 17 years at Siemens / PETNET
- Director of Operations; NW
    - Managed 13 cyclotron facilities and staff
    - Radiation Safety Committee member
- Regulatory Affairs Manager

GE PETtrace 800 – Hayward, CA

The Orbitron



- Spin stabilized, electrostatically heated magnetic mirror
- Ions confined in elliptical orbits around a central cathode
- Small, mobile power applications of 1kW to 1MW

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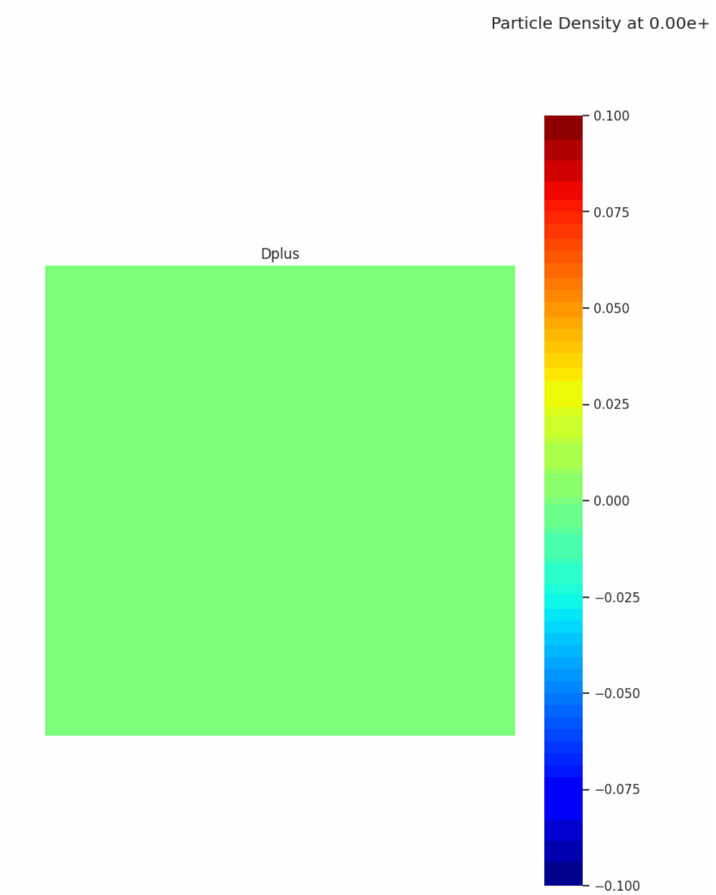
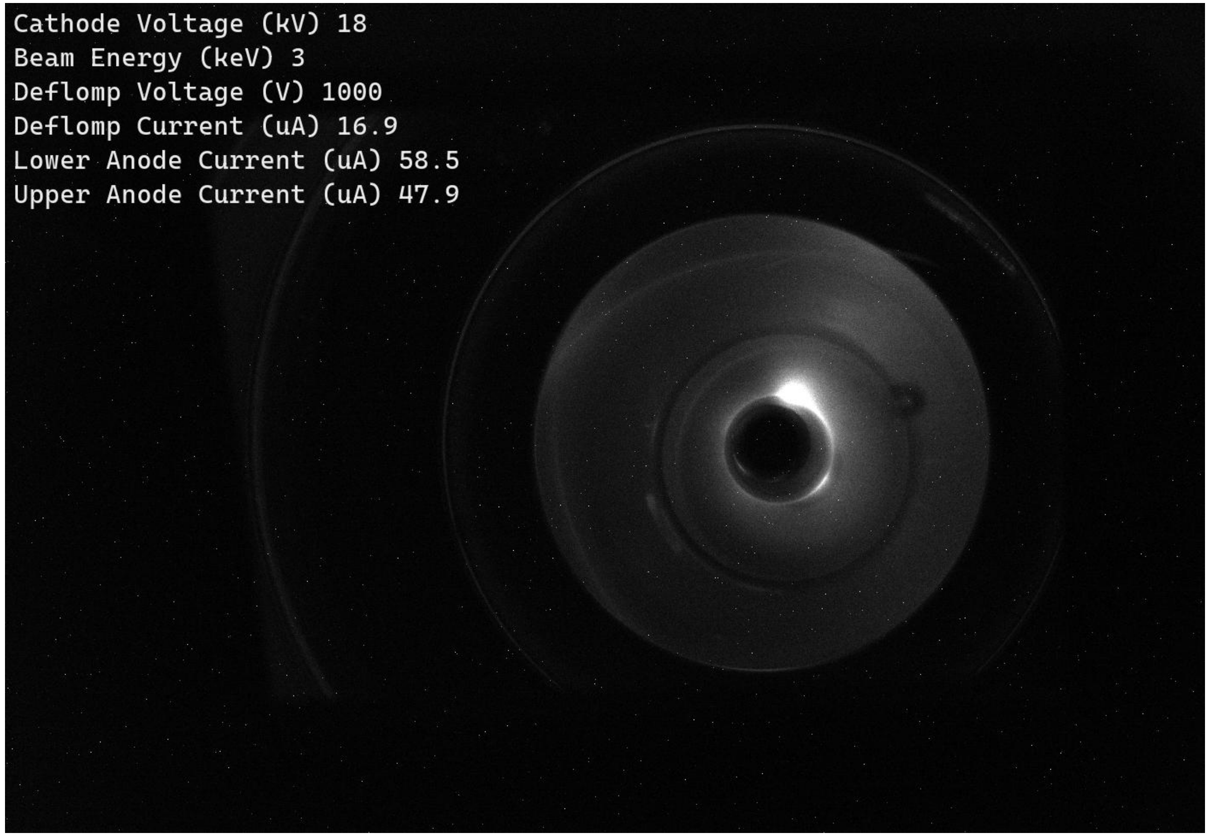
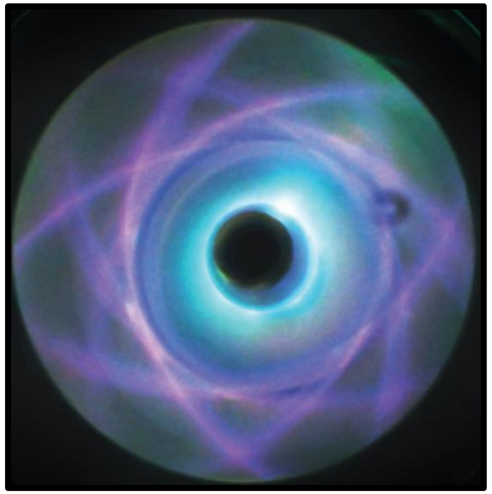
Orbitron plasma beam



WarpX – PIC simulation



Experimental Results



Color Corrected - Experimental Results

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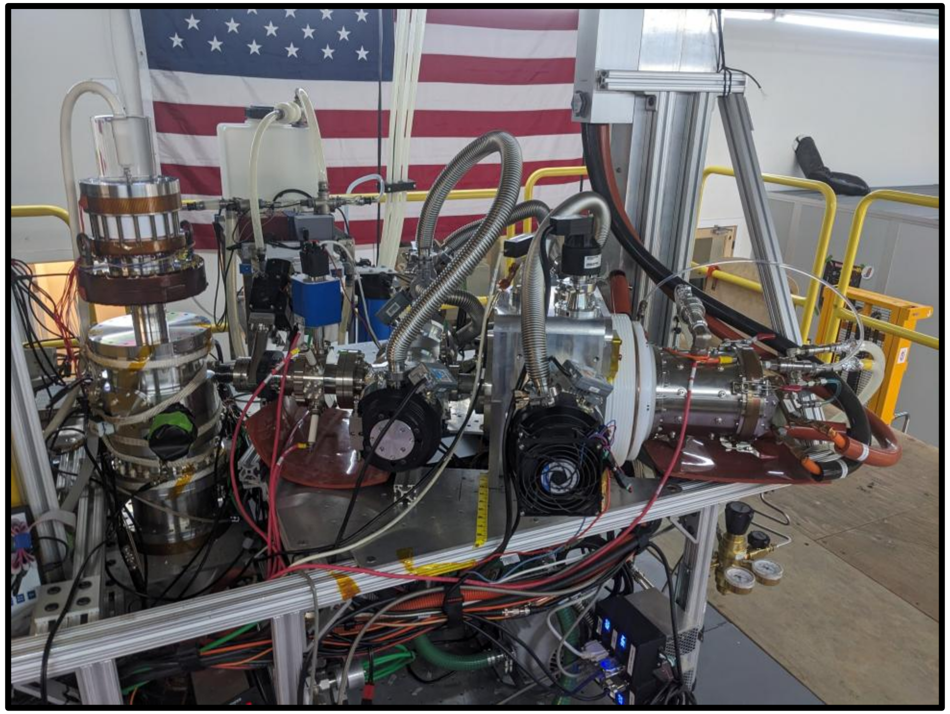
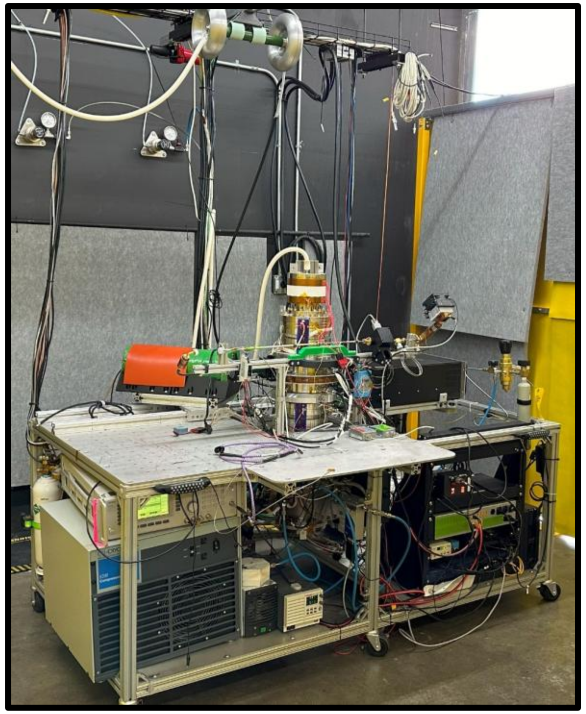
Three Fusion Prototypes Currently in Test at Avalanche

Test Machine 1 - Neo



Test Machine 2 - Marty



Test Machine 3 - Camina

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Fusion’s Current Regulatory Status

US Approach: 10 CFR Part 30 – Byproduct Materials

April 13, 2023

- NRC Commissioners voted unanimously to regulate fusion under the same framework as accelerators

July 9, 2024

- Congress codifies the NRC's decision with the ADVANCE Act

Key reasons:

1. Risk-informed approach
   - No chain reactions or meltdown risk
   - No high-level radioactive waste
   - Radiation footprint is small
   - Accidental releases are not a risk to public safety
2. State-based accelerator licensing
3. Regulatory certainty encourages innovation

International Approaches: Still Developing

June 2025 – IAEA Technical Meeting on Design Safety, Safety Assessment and Regulatory Activities to Facilitate Further Development and Future Deployment of Fusion Facilities

https://www.iaea.org/newscenter/news/fusion-safety-and-regulation-discussed-at-iaea-meeting-in-granada

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France's Approach (NOT Recommended)

French Regulatory Framework

- Fusion facilities are licensed as "Basic Nuclear Installations"
- Fission first approach
- Pre-construction licensing process
- Inspections begin upon issuance

ITER Timeline

- 1985 - ITER conception
- 1988 - Initial Design
- 2010 - Construction began
- 2012 - Nuclear facility license
- 2034? - first D-D reactions
- 2039? - first D-T reactions

↳ *Zero neutrons in 40 years!*

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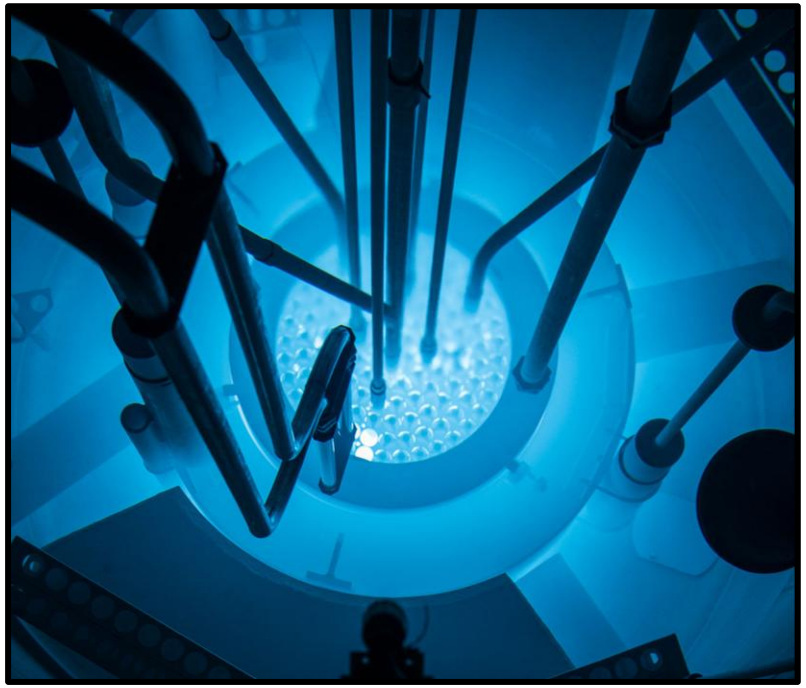
Comparing Fission Reactors, Cyclotrons and Fusion Machines

Principal Safety Hazard

Fission Reactors



Radiologic

Cyclotrons

Electrical

Fusion Machines

Electrical

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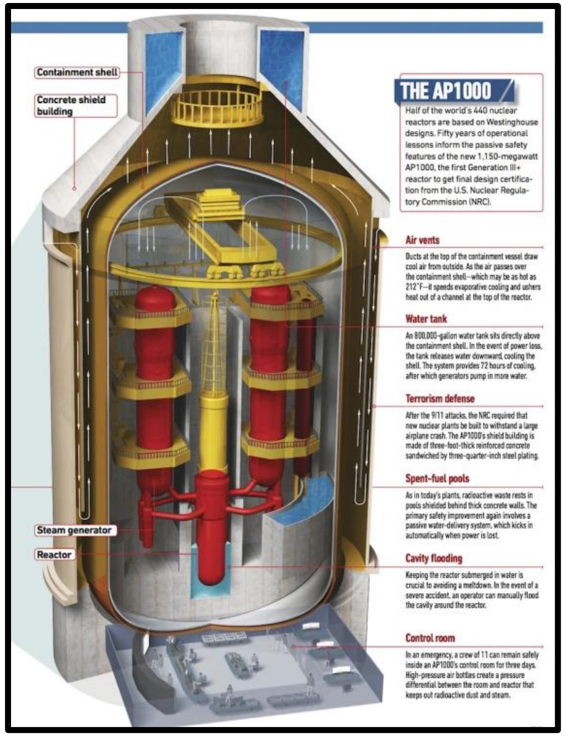
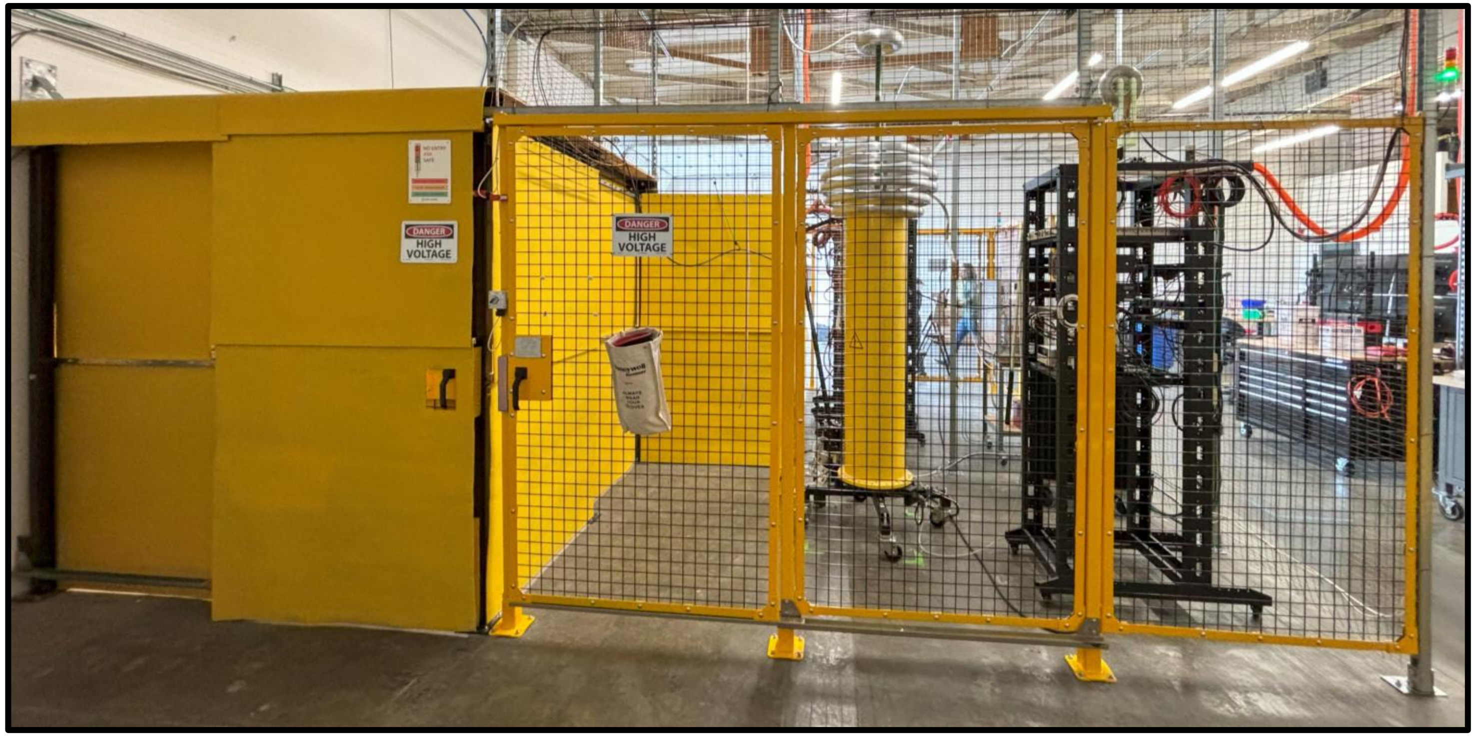
Fission & Fusion Radiation Shielding Examples





<u>Westinghouse AP1000</u>:

- Large facility
- Water tanks and concrete
- Earth
- Pressurized rooms

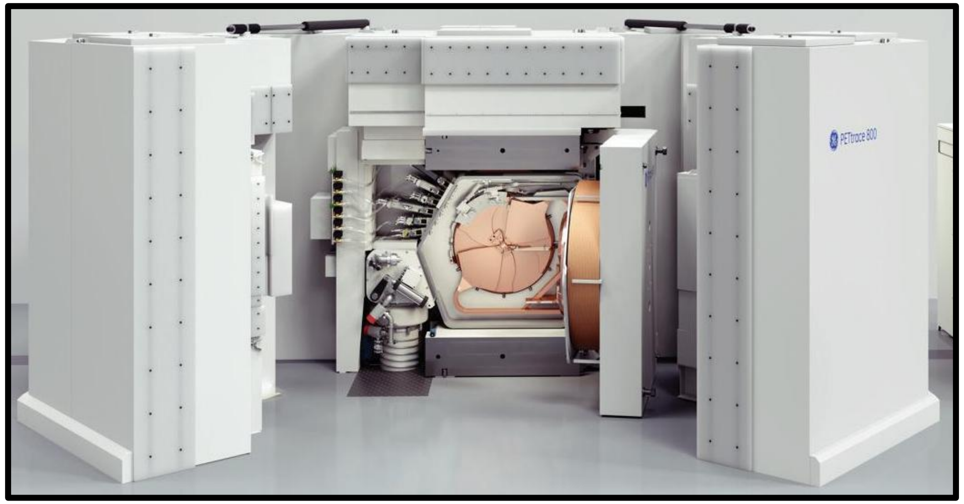
<u>High Voltage Test Cell (Materials Testing)</u>

- 600kV power supply -> 600 keV x-rays
- Safety cage is the Restricted Approach Boundary
- X-ray vault has 3/8” lead lined roof and walls
- CY 2024: 2902 mrem (DDE)

Radiation shielding: concrete, HDPE, & boron

Siemens RDS-111 Eclipse (11 MeV)

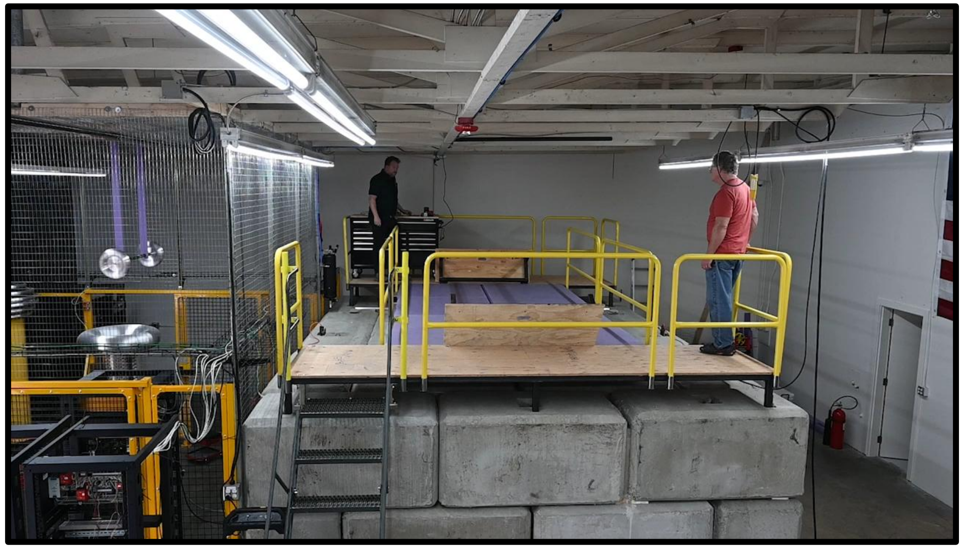
GE PETtrace 800 (17 MeV)



ACS TR-24 (24 MeV)

University of Alberta
(https://youtu.be/XO1EoTvejs0)

Avalanche – Marty Vault (2.4 MeV)



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Control Systems: Fission Reactors

Fission reactor:

- Safety driven
- Complicated
- Operator training takes 18 – 24 months

MIT's Nuclear Reactor Lab

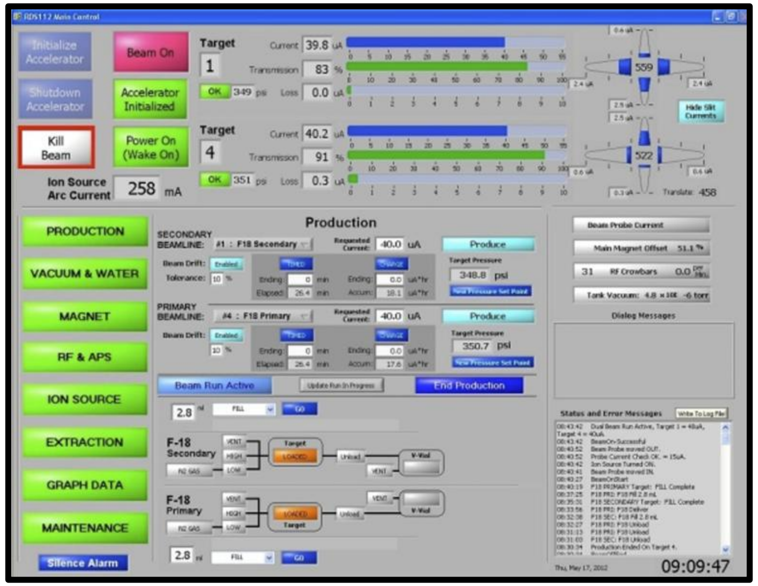
Control Systems: Accelerators

<u>Commonalities</u>:

- Operational efficiency driven
- Simple; typically automated
- 40 hr training for operators

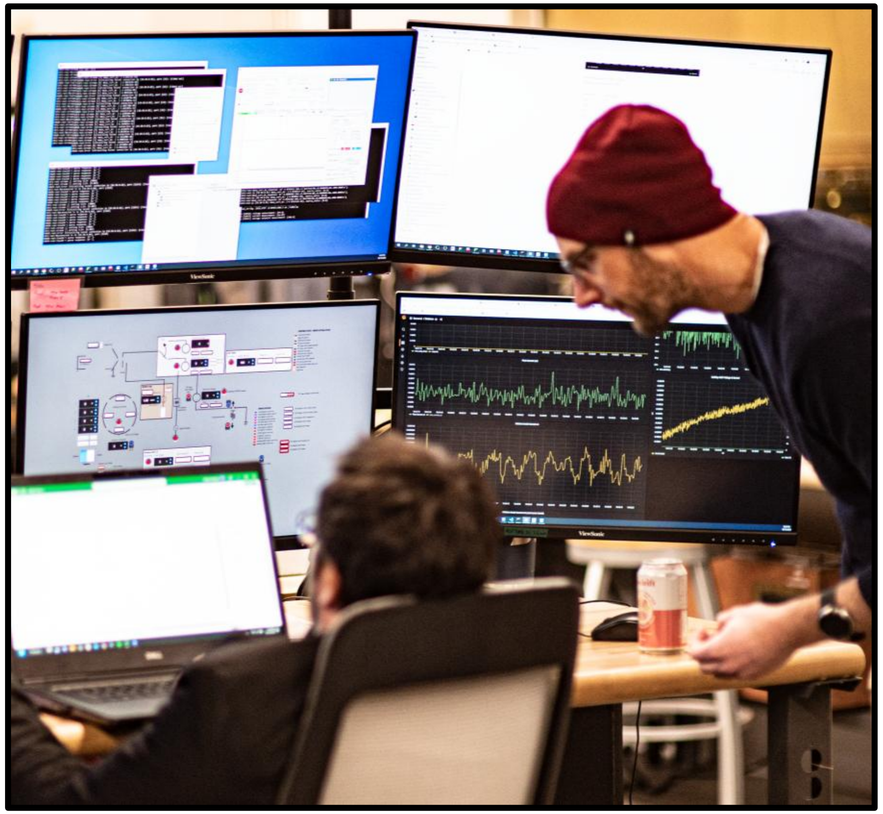
Cyclotrons

PETtrace 800



Siemens RDS-112

Orbitron



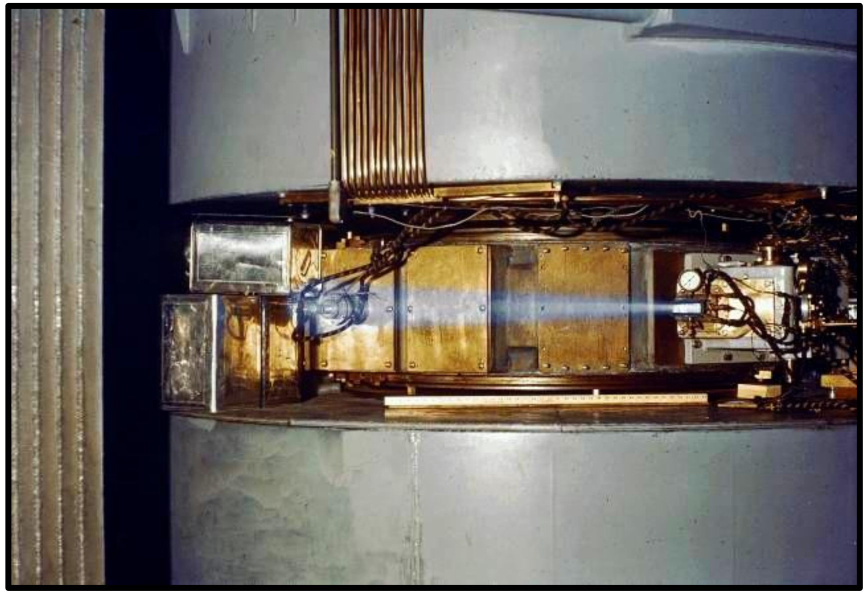
Avalanche

Ion Source

Fission Reactors

None

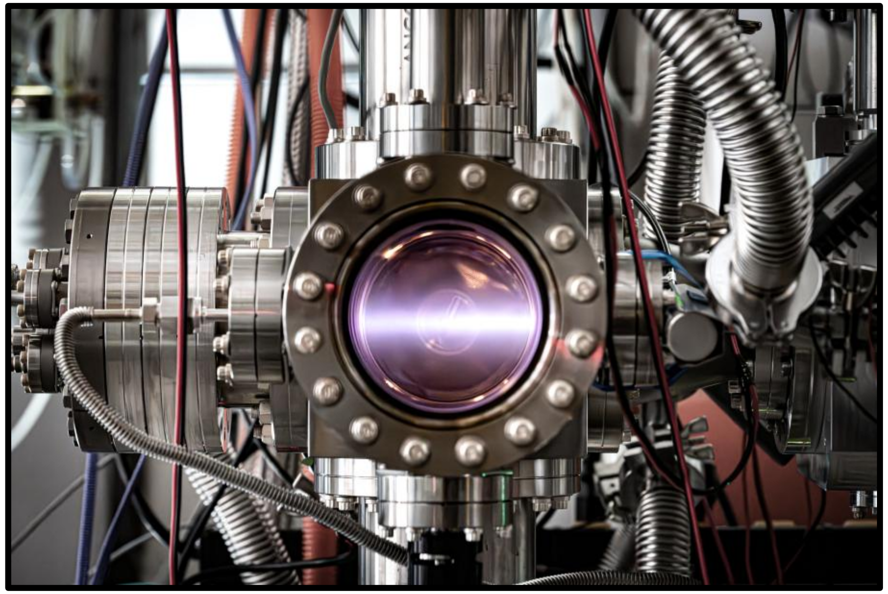
Cyclotrons



Proton Beam

Lawrence cyclotron UC Berkeley (c. 1939)

Orbitron



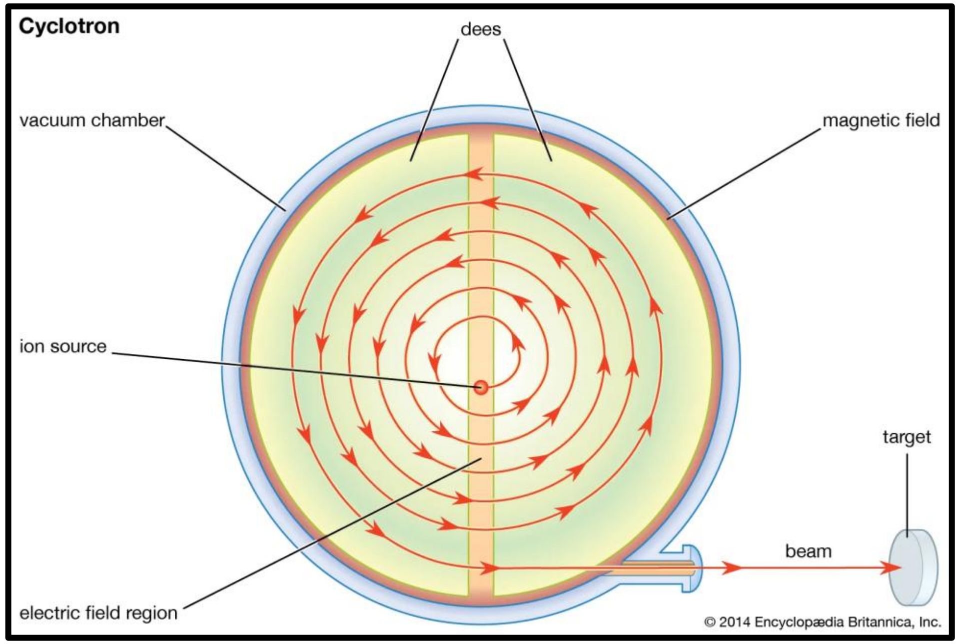
Deuteron or Triton Beam

Targetry

Fission Reactors

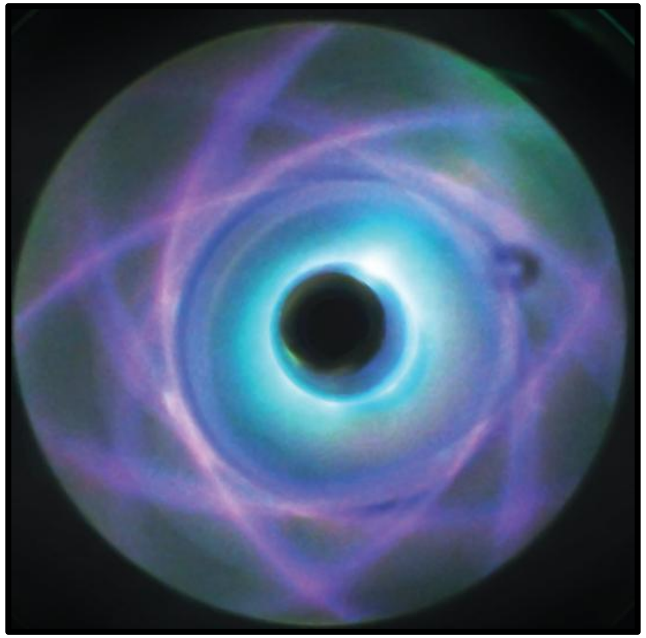
None

Cyclotrons



Beam - Target

Orbitron



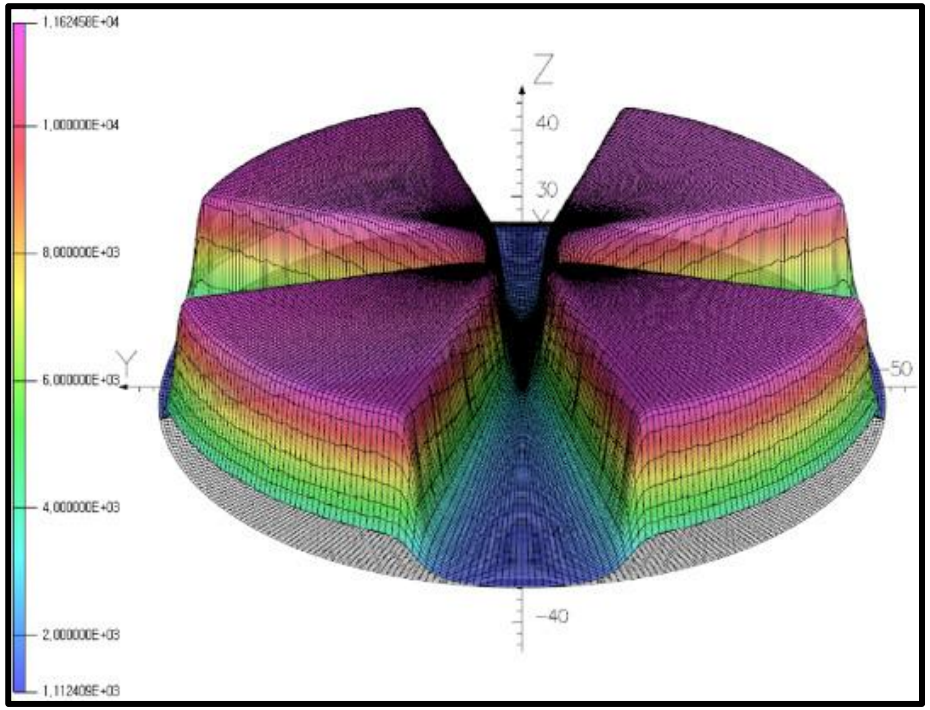
Plasma

Magnets

Fission Reactors

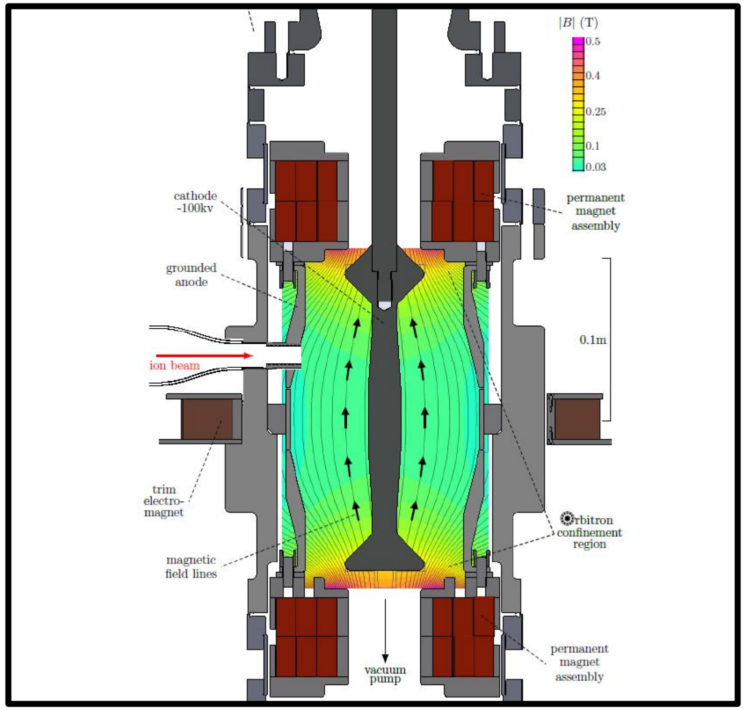
None

Cyclotrons



Strong magnetic field perpendicular to electric field

Orbitron



Strong magnetic field perpendicular to electric field

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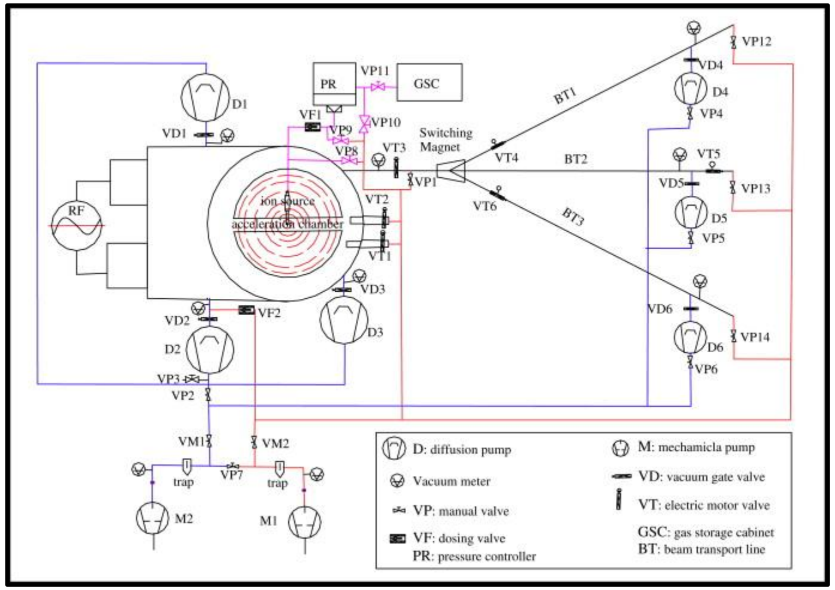
Vacuum Systems

Fission Reactors

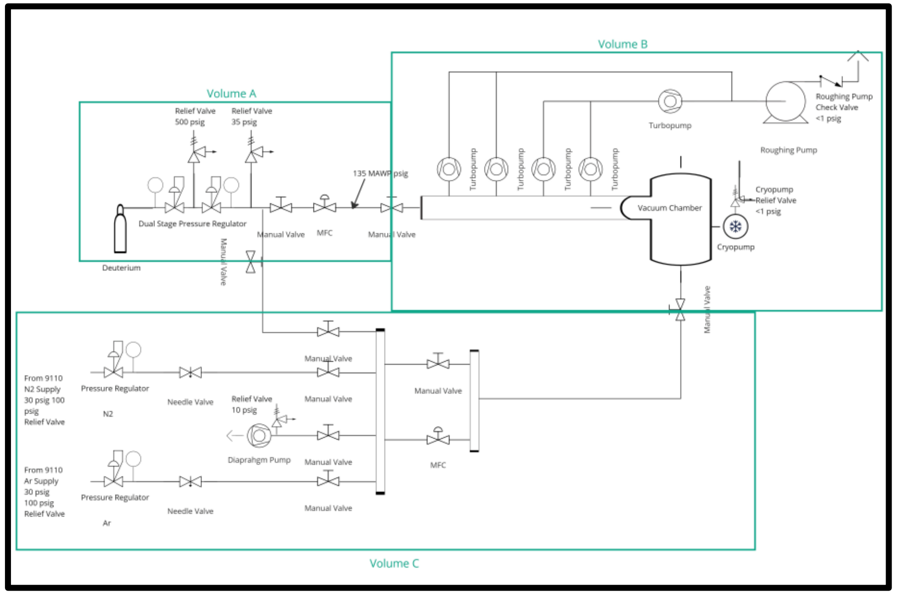
None

Cyclotrons



Ultra High Vacuum

Orbitron



Ultra High Vacuum

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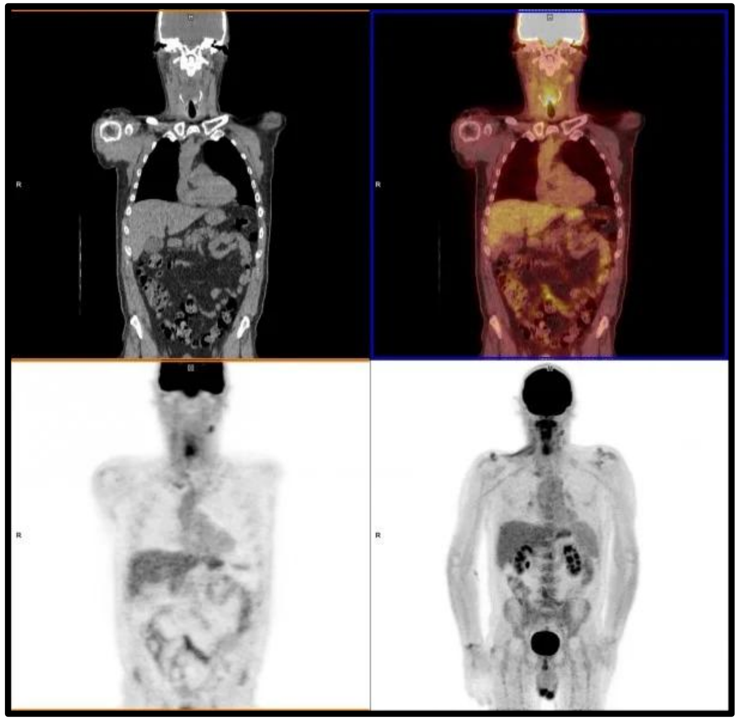
Worst Case Scenarios – Human Error Outcomes

Fission Reactors

Meltdown - Chernobyl

Cyclotrons



Patient Care Impact

Fusion Machines

Power Outage

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Greatest Radiologic Risk Waste Streams

Fission Reactors

HLW

Cyclotrons

LLW/NARM

Orbitron

LLW/NARM

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Decommissioning

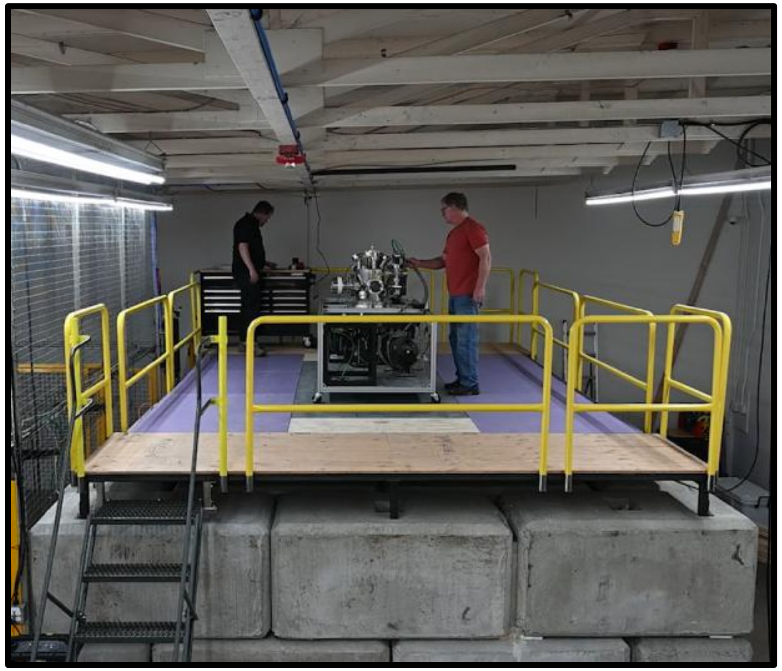
Fission Reactors

Massive project

Cyclotrons

Vault & Machine

Orbitron



Vault & Machine

Particle Accelerator Size Matters

Cyclotron size

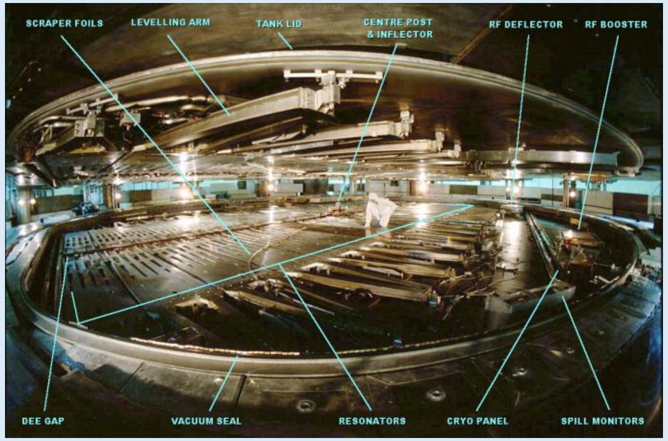
IONETIX – 12 MeV

17 MeV

24 MeV

33 MeV

235 MeV

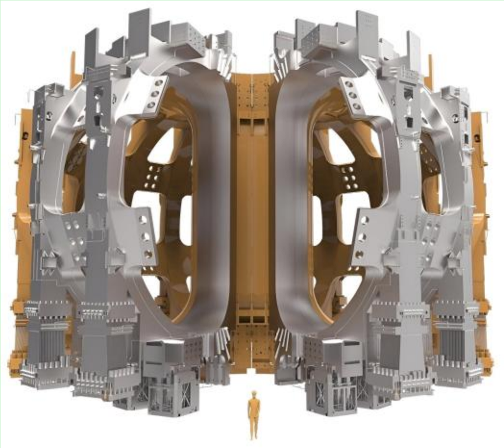


TRIUMF – 520 MeV

Fusion machine size

6 – 100cm radius

Tokamaks
Stellarators
Reverse Field Confinement
Inertial Confinement
Z-Pinch



ITER – 30m radius

Smallest -› Largest

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Summary

Fusion Machines

- Same subsystems as cyclotrons
- Same shielding strategies as cyclotrons
- Radiologic risks are commensurate with cyclotrons
- Radiologic waste streams are the same as cyclotrons
- Off-normal events cause them to shut off (no risk of core melt down)

Call to Action

1. Fusion companies need regulatory flexibility for fast innovation and integration.
2. NRC's framework is risk informed and appropriate. States should continue to lead efforts.
3. We need US Regulators to help drive IAEA to choose a particle accelerator regulatory framework

Hawkins DeFrance (hdefrance@avalanche.energy)
https://www.linkedin.com/in/hawkinsdefrance
http://avalanchefusion.com