D-^{3}He Physics and Fusion Energy Prospects

John F. Santarius and Gerald L. Kulcinski, Fusion Technology Institute, University of Wisconsin

Abstract

The path to attractive fusion power contains strongly interrelated physics, engineering, economic, and environmental obstacles. From a purely physics perspective, D-T fuel seems most attractive. From the viewpoint of the broader issues, D-^{3}He fuel in combination with an innovative confinement concept appears very attractive, stemming from the large fraction of D-^{3}He fusion power produced as charged particles. For a viable D-^{3}He fusion reactor to exist, the key question is how the physics development and ^{3}He supply problem facing D-^{3}He fuel compare to the engineering difficulties faced by D-T fusion, such as the need for tritium-breeding blankets, neutron damage to structural materials, and frequent large-scale maintenance in a highly radioactive environment.

Selected fusion fuels

1st generation fuels:

D + T → n (14.07 MeV) + ^{4}He (3.52 MeV)

D + D → n (2.45 MeV) + ^{3}He (0.82 MeV) {50%}

→ p (3.02 MeV) + T (1.01 MeV) {50%}

2nd generation fuel:

D + ^{3}He → p (14.68 MeV) + ^{4}He (3.67 MeV)

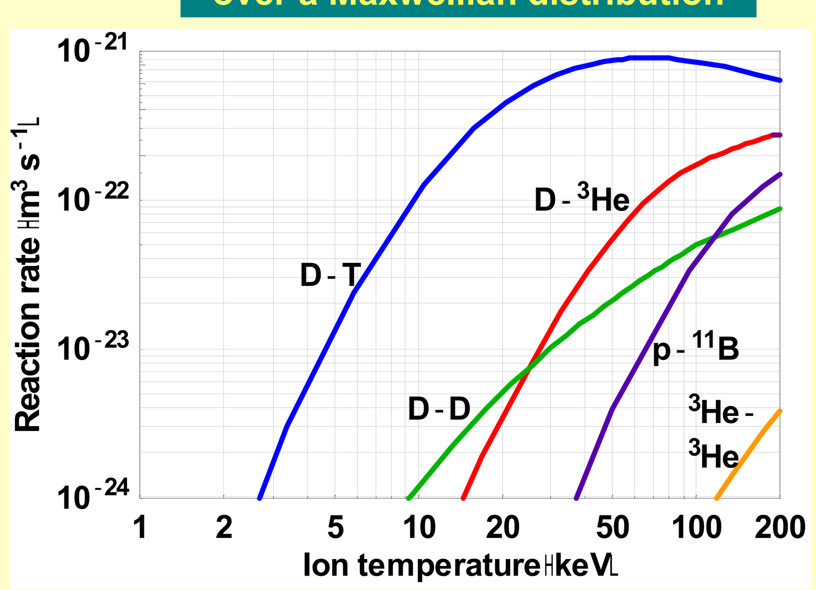
3rd generation fuels:

^{3}He + ^{3}He → 2 p + ^{4}He (12.86 MeV)

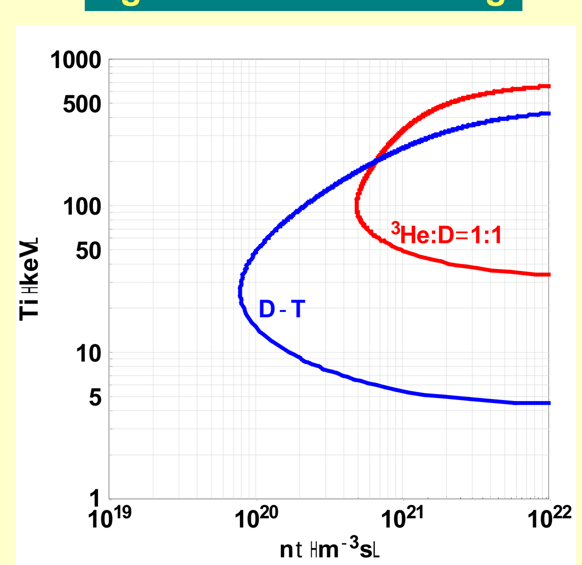
p + ^{11}B → 3 ^{4}He (8.68 MeV)

D-^{3}He Physics is More Difficult than D-T Physics

Fusion cross sections averaged over a Maxwellian distribution



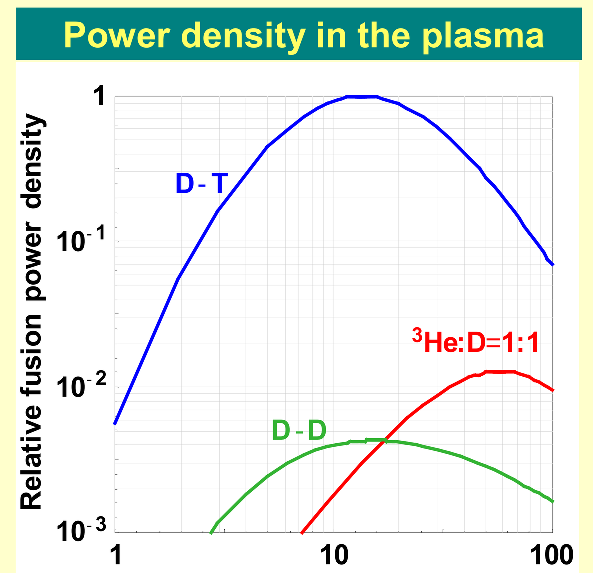
Ignition contours against bremsstrahlung



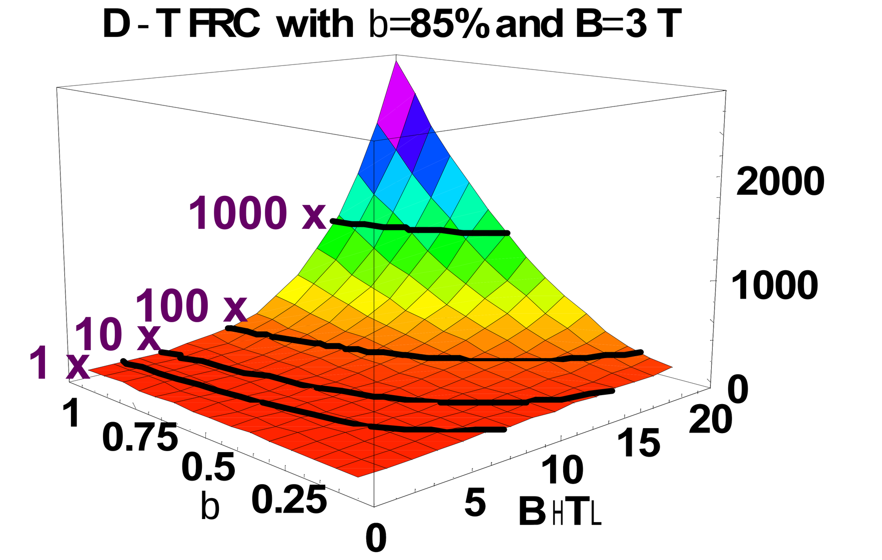
D-^{3}He Fuel Leads to Lower Fusion Power Density, but This Can Be Overcome by Higher Magnetic Fields and Beta

- D-T fueled innovative concepts become limited by neutron wall loads or surface heat loads well before they reach β or B-field limits.
  - β = plasma pressure/ magnetic-field pressure
  - D-T fueled FRC's (β ~85%) optimize at B ≤ 3 T.
- D-^{3}He needs a factor of ~80 above D-T fusion power densities.
  - Superconducting magnets can reach at least 20 T.
  - Fusion power density scales as $\beta^2 B^4$.
  - Potential power-density improvement by increasing β and B-field appears at right.

Power density in the plasma

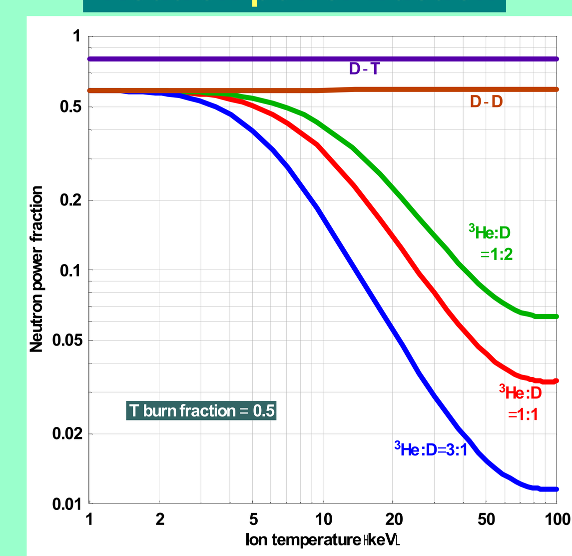


Power Density Relative to a D-T FRC with b=85% and B=3 T



D-^{3}He Fuel Lowers Neutron Production and Eases Engineering Difficulties

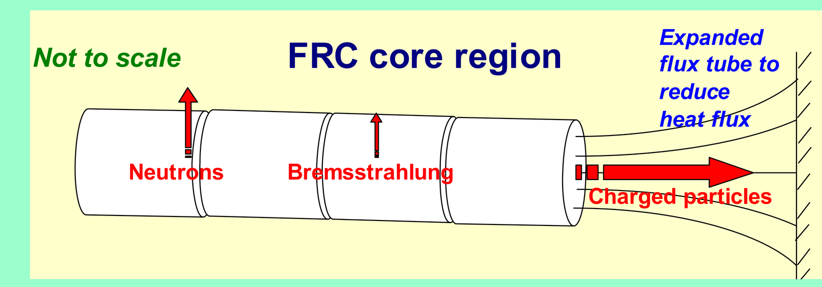
Neutron power fraction

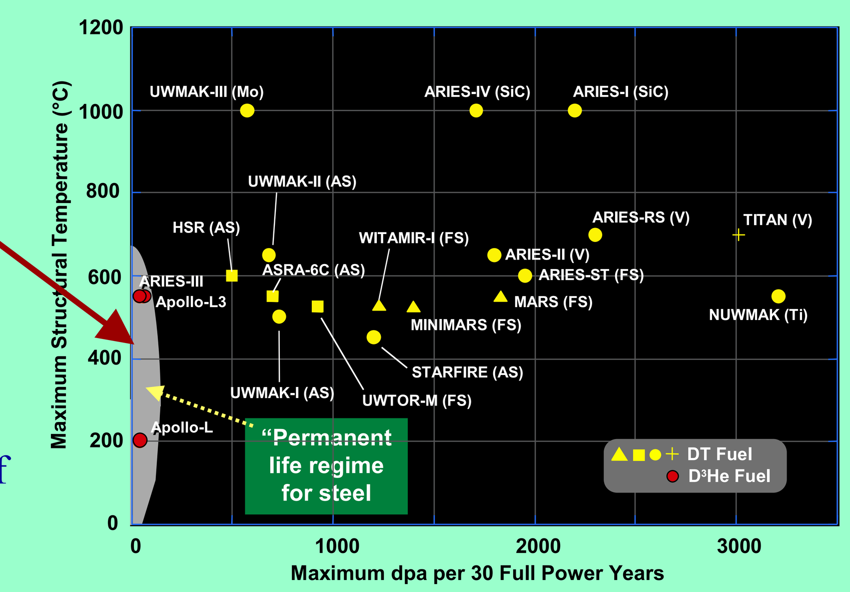


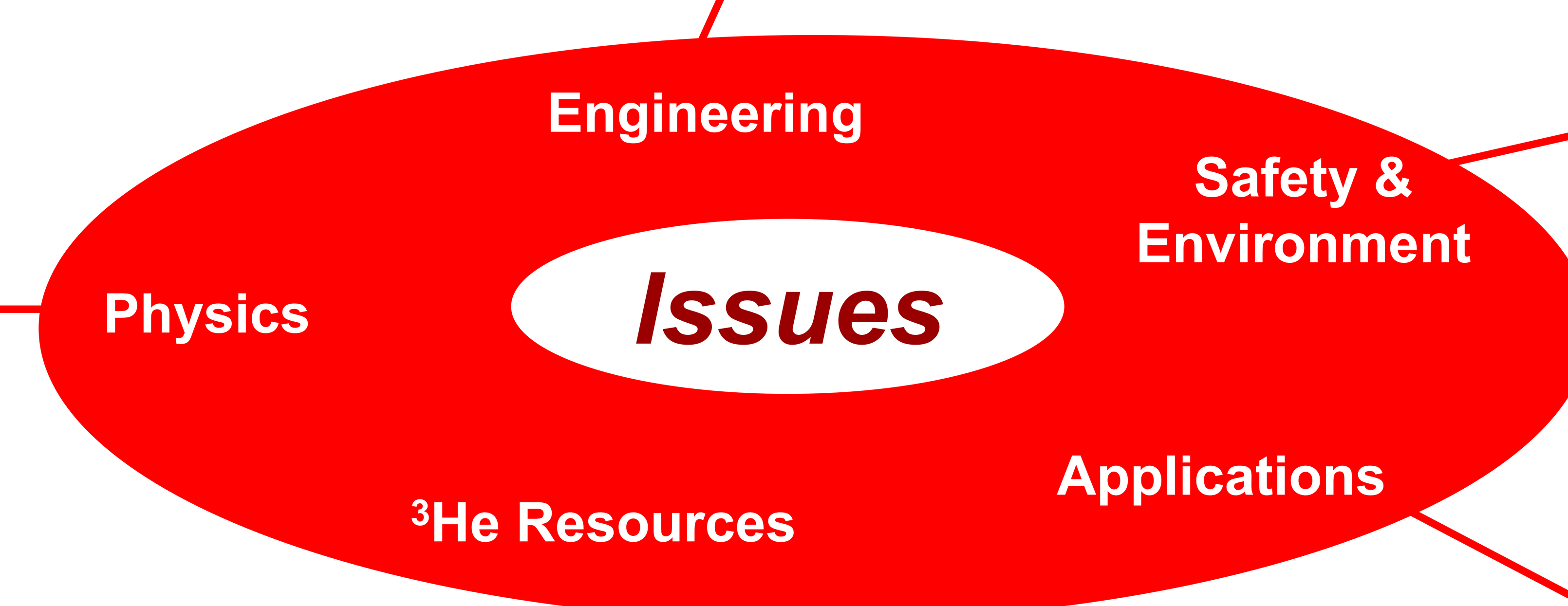
- Reduced neutron flux allows
  - Smaller radiation shields,
  - Smaller magnets,
  - Permanent first wall and shield,
  - Easier maintenance.
- Increased charged-particle flux allows direct energy conversion of fusion energy to electricity.
- Smaller neutron flux reduces activation of materials and radiation damage to them.

High Heat Fluxes in D-^{3}He Reactors Are Manageable

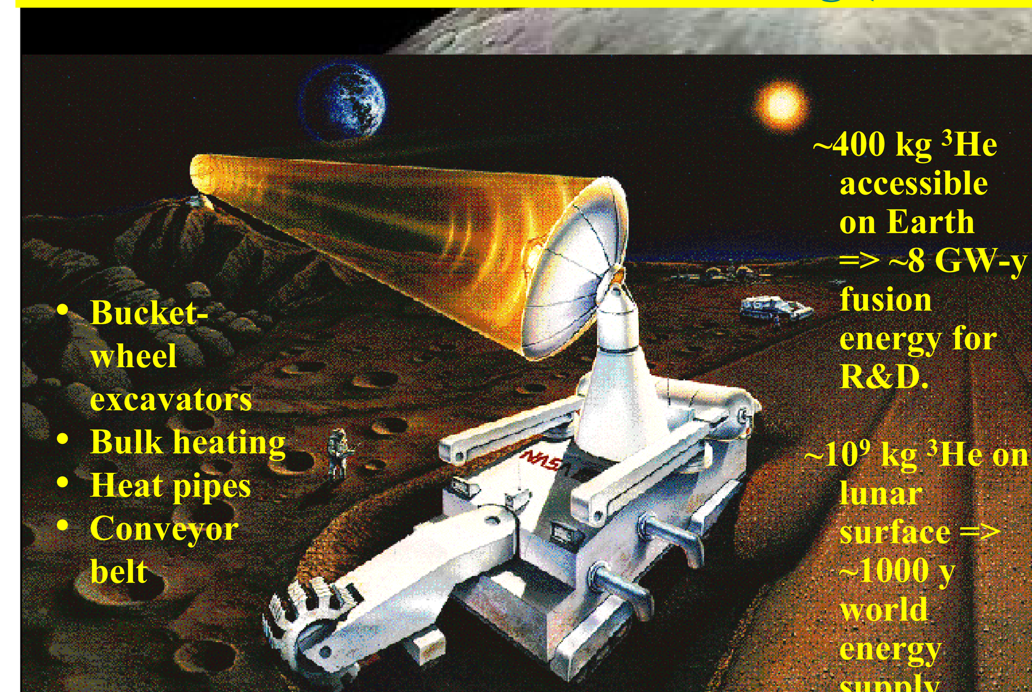
- Charged-particle power transports from internal plasmoid (in an FRC or spheromak) to edge and then out ends.
- Expanded flux tube in end chamber reduces heat and particle fluxes.
- Mainly bremsstrahlung power contributes to first-wall surface heat, giving a relatively small peaking factor along the axis.



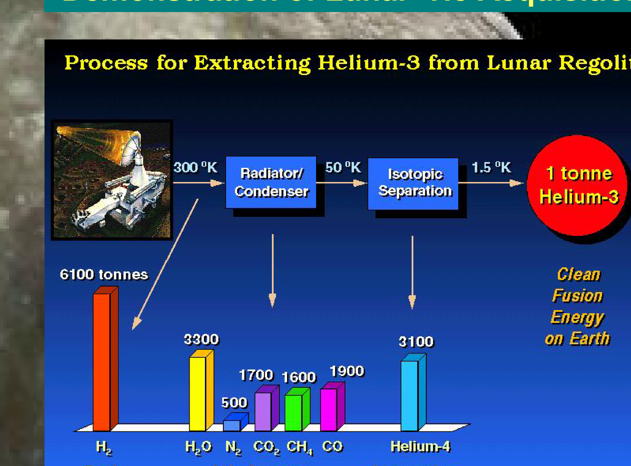




^{3}He Resources Are an Issue: Earth Contains ^{3}He Sufficient for an Engineering Test Program. Moon Contains ~10^9 kg (~10^{10} MWe-years) of ^{3}He.



Mining Other Volatiles Would Support a Lunar Initiative, Allowing a Symbiotic Demonstration of Lunar ^{3}He Acquisition

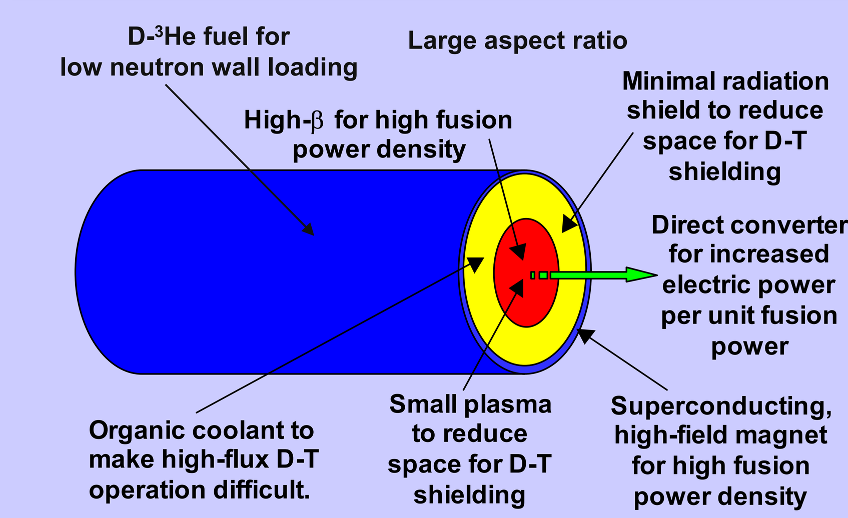


Conclusions

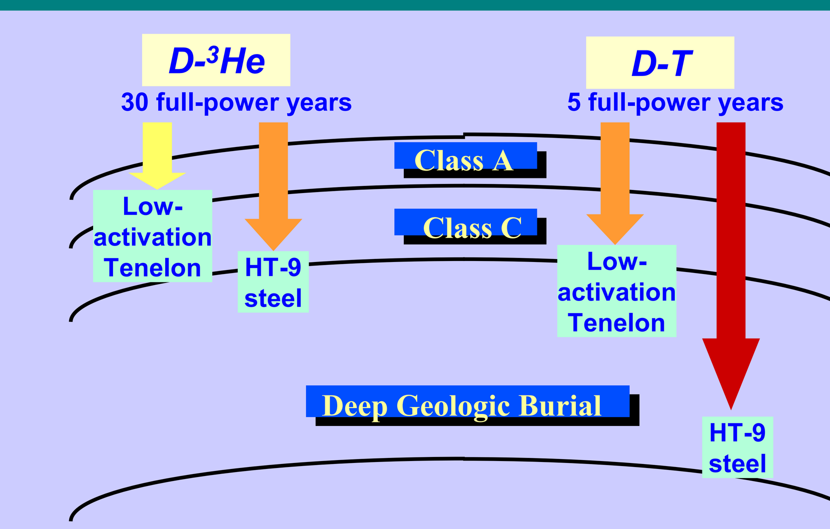
Burning an advanced fusion fuel would require substantial, continued progress in plasma physics, including better plasma energy confinement and development of the FRC or another suitable innovative confinement concept. The attractiveness of D-^{3}He fusion's engineering, safety, and environmental characteristics, however, makes this a potentially important research area.

D-^{3}He Greatly Enhances Safety and Environment

Proliferation-Proof Fusion Electric Power Features

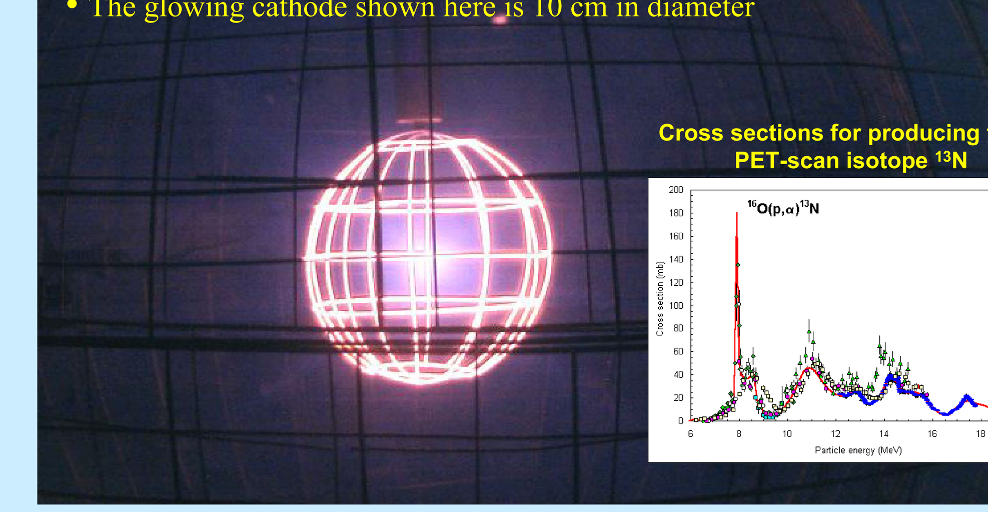


Radioactive Waste Disposal is Much Easier for D-^{3}He Reactors than for D-T Reactors

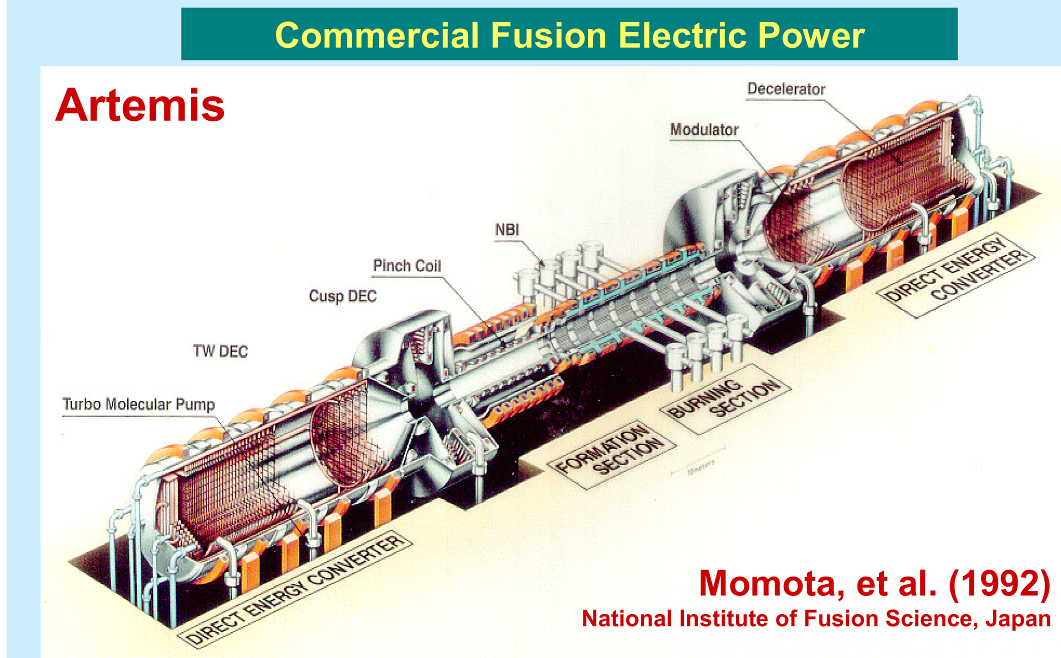


Radioisotope Production

- In inertial-electrostatic confinement (IEC) fusion, high voltages on spherically symmetric, semi-transparent grids radially accelerate ions.
- UW IEC experiments have achieved 180 kV accelerating potentials, steady-state D-^{3}He fusion, and proof-of-principle ^{13}N production.
- The glowing cathode shown here is 10 cm in diameter



Commercial Fusion Electric Power



Innovative Confinement Concepts Workshop, Madison, Wisconsin, 25-28 May 2004

Contact info: 608-233-2685; santarius@engr.wisc.edu