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

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Outline: D-^{3}He Issues

Physics

Engineering

Safety and Environment

^{3}He Resources

Applications

"Advanced" Fusion Fuels Greatly Reduce Neutron Production

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)

→ p (3.02 MeV) + T (1.01 MeV)

{50% each channel}

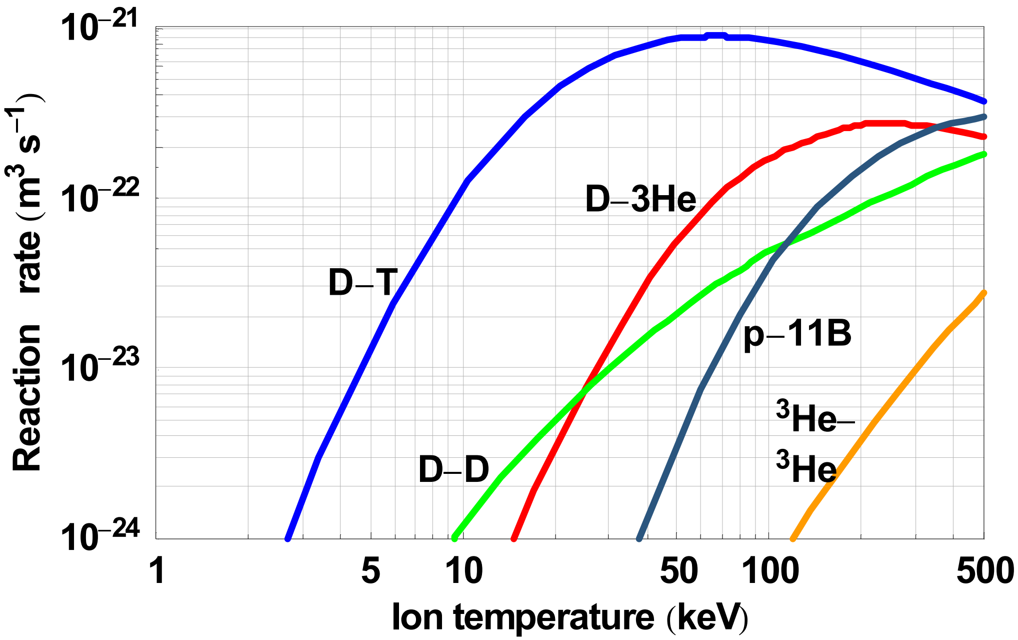
2nd generation fuel:

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

3rd generation fuels:

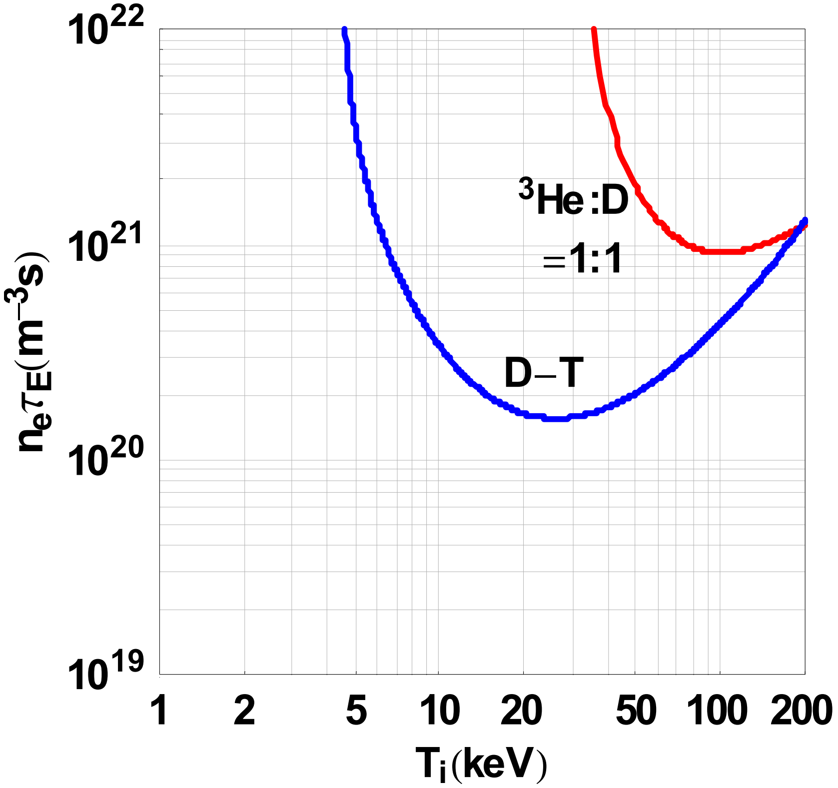
^{3}He + ^{3}He → 2 p + ^{4}He (12.86 MeV)

p + ^{11}B → 3 ^{4}He (8.68 MeV)



D-^{3}He Fuel Faces Larger Physics Obstacles than D-T

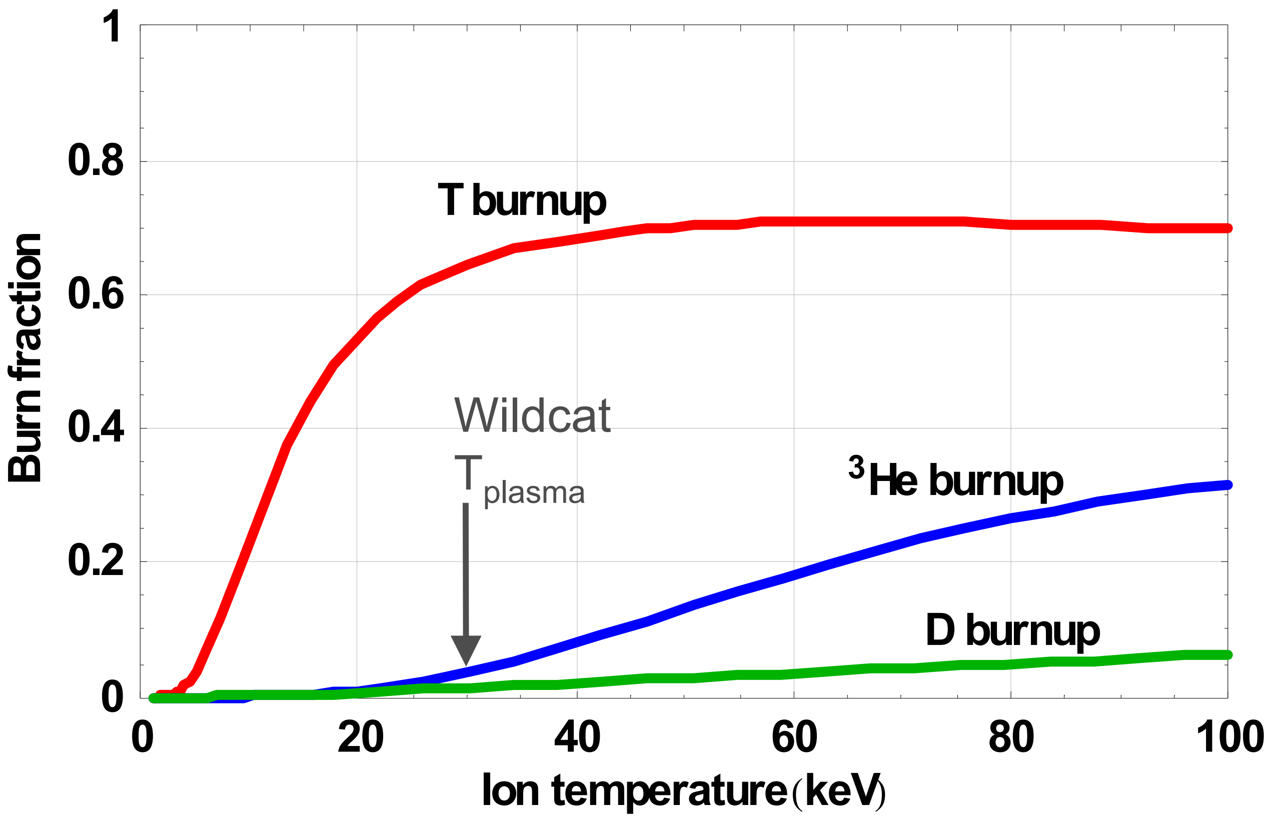
Ignition contours against bremsstrahlung



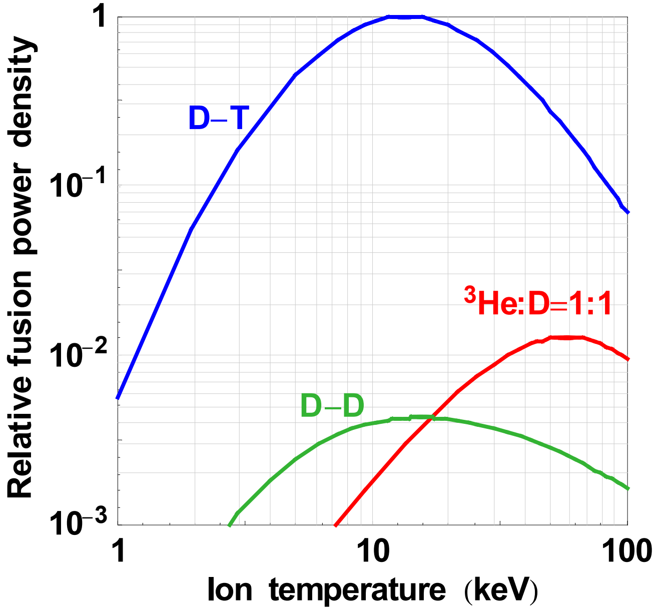
- D-^{3}He, compared to D-T, requires:
  - Minimum factor of ~6 increase in ignition temperature,
  - Minimum factor of ~8 $n_e\tau_E$ increase,
  - Minimum Tnτ increase of ~50 times.
- D-^{3}He fusion relies on significant continued progress in plasma physics.

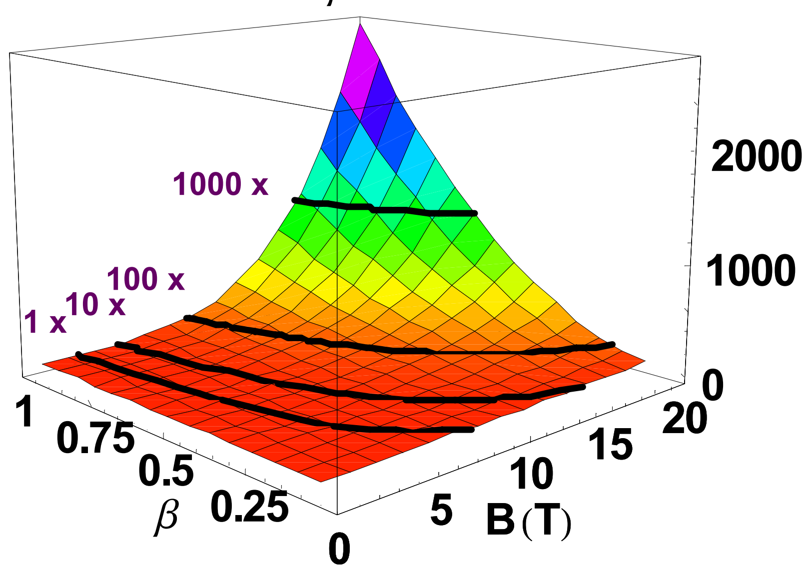
Burning D-D Fuel without Burning the Tritium Produced by D-D Reactions Would Be Difficult

- D-D reaction-product burnup based on Wildcat D-D tokamak reactor parameters.
- If feasible, would greatly reduce D-^{3}He neutron production.



D-^{3}He Could Have a Power Density at Least as High as D-T Power Density

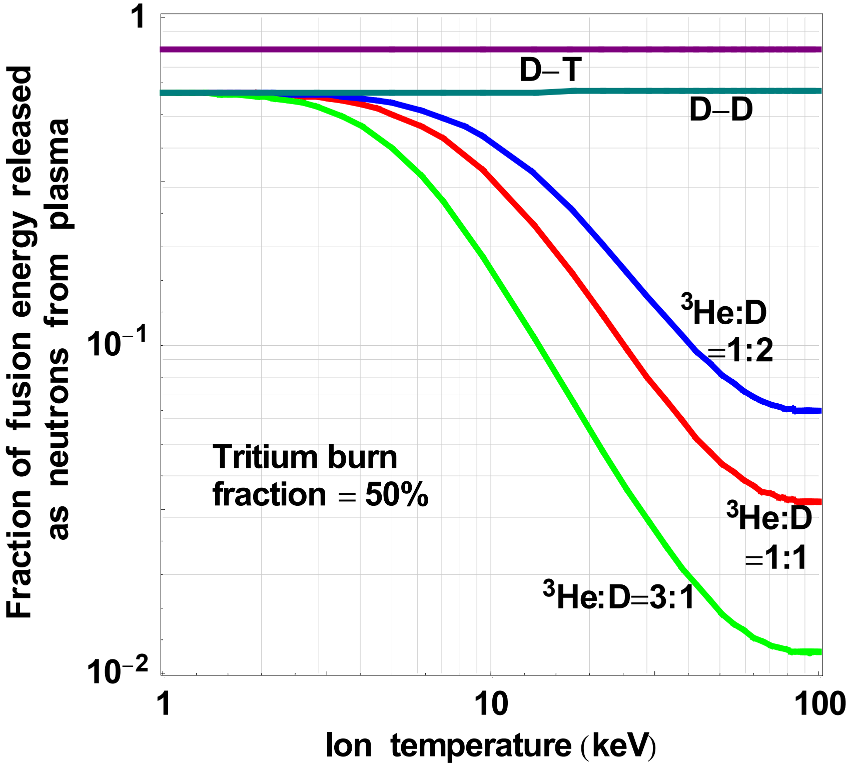




- D-T fueled innovative concepts become limited by neutron wall loads or surface heat loads well before they reach β, B-field, or magnet limits.
- D-T fueled FRC's (β~85%) optimize at B ≤ 3 T.
- Fusion power density scales as $\beta^2 B^4$.
- Superconducting magnets can reach at least 20 T.

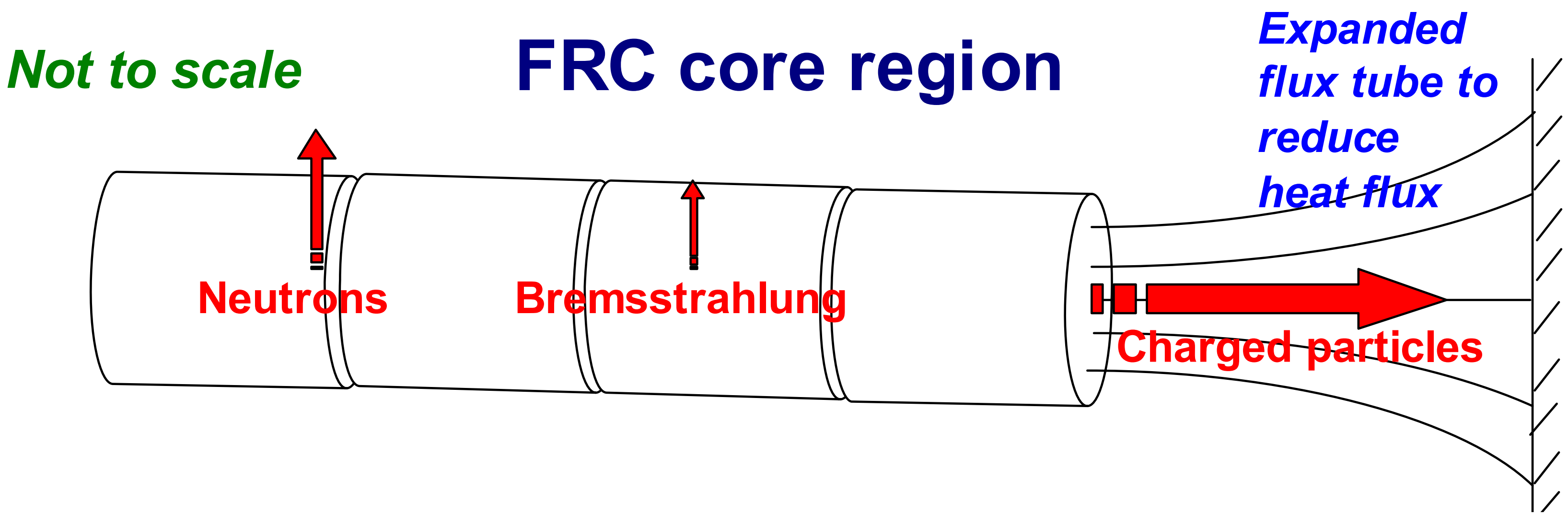
D-^{3}He Fuel Generally Gives Easier Engineering and Safety

- Reduced neutron flux allows
  - Smaller radiation shields
  - Smaller magnets
  - Permanent first wall and shield
  - Easier maintenance
- Increased charged-particle flux allows direct energy conversion
- Unburned tritium will be a proliferation and safety issue



Linear Geometry Provides Solution to Handling Charged-Particle Surface Heat Flux

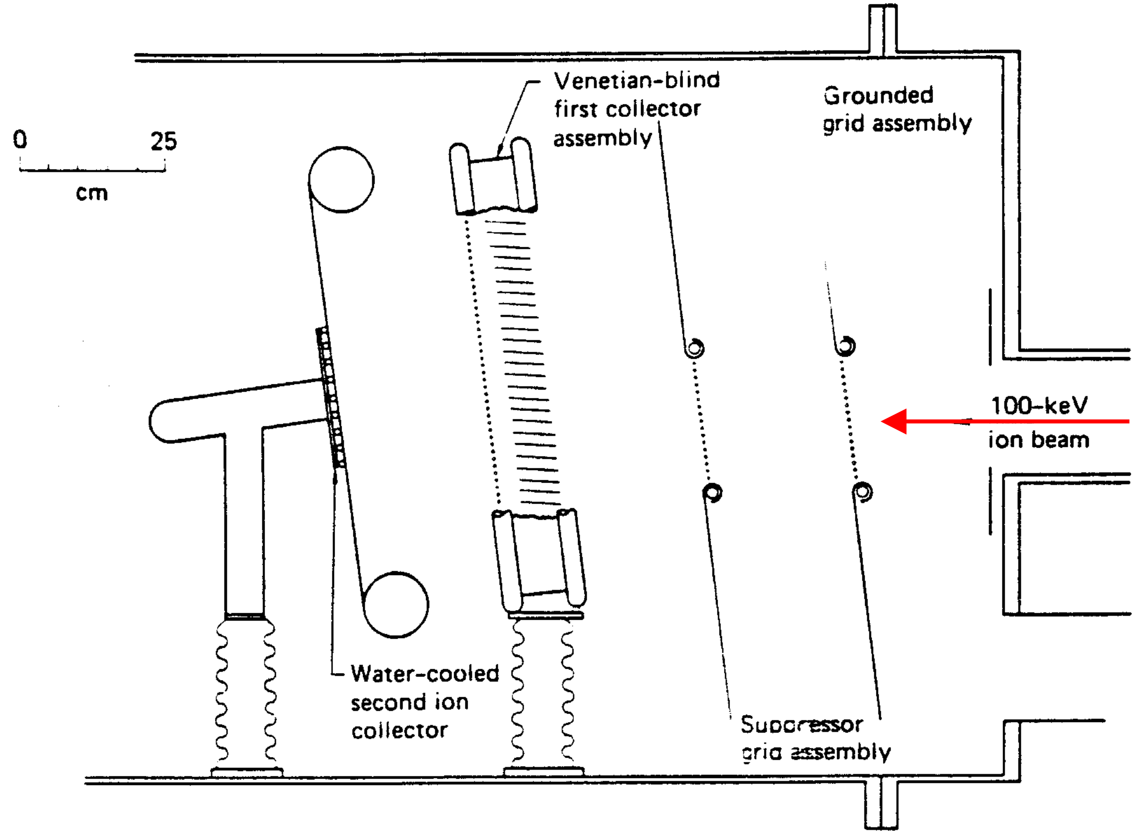
- High power density does not necessarily imply unmanageable first-wall heat flux.
- Charged-particle power transports from internal plasmoid (in an FRC or spheromak) to edge region and then out ends of fusion core.
- Expanded flux tube in end chamber reduces heat and particle fluxes.
- Mainly bremsstrahlung power contributes to first-wall surface heat.
- Relatively small peaking factor along axis for bremsstrahlung and neutrons.



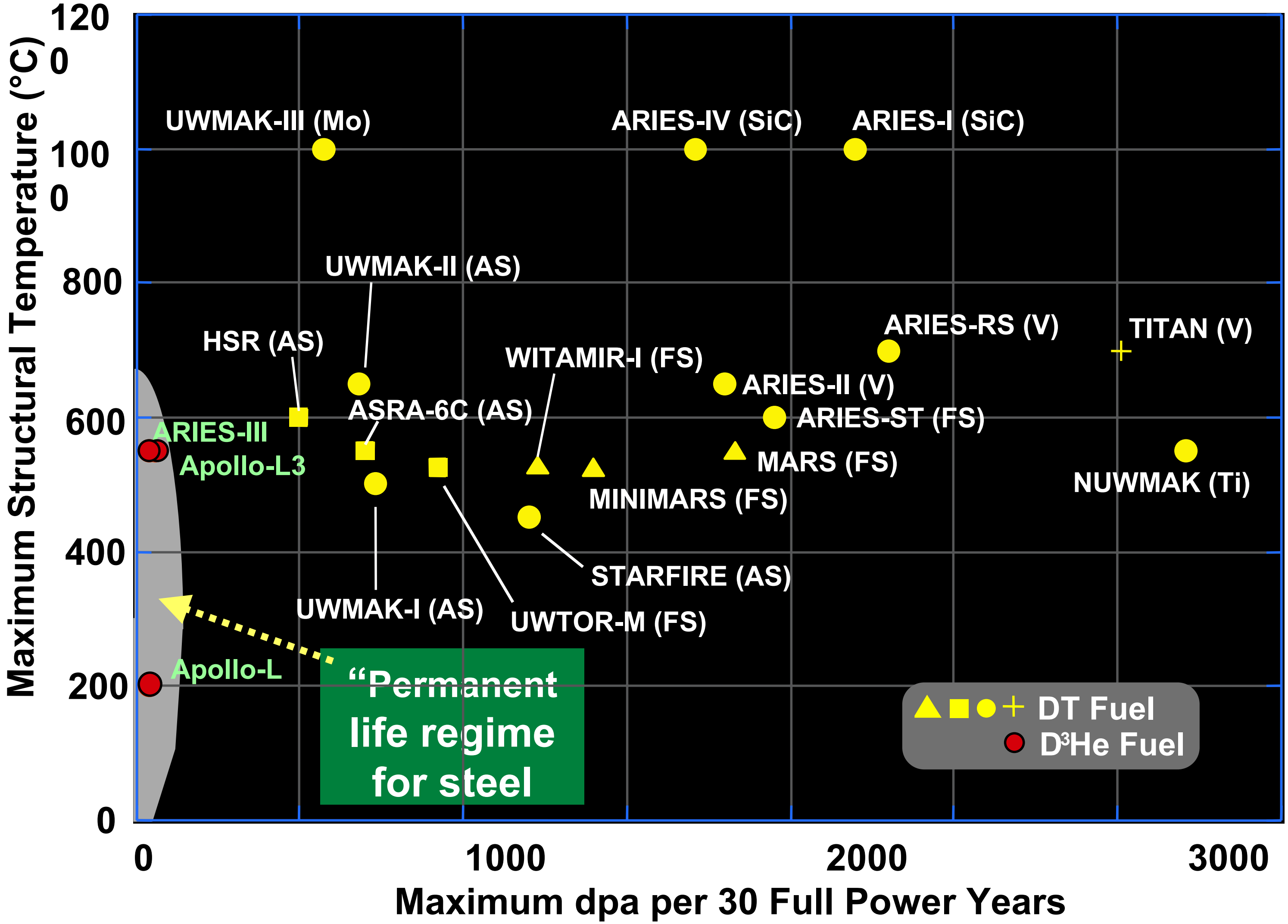
Direct Conversion to Electricity Can Give 60-80% Efficiency

- Experiment and theory agreed within 2%.

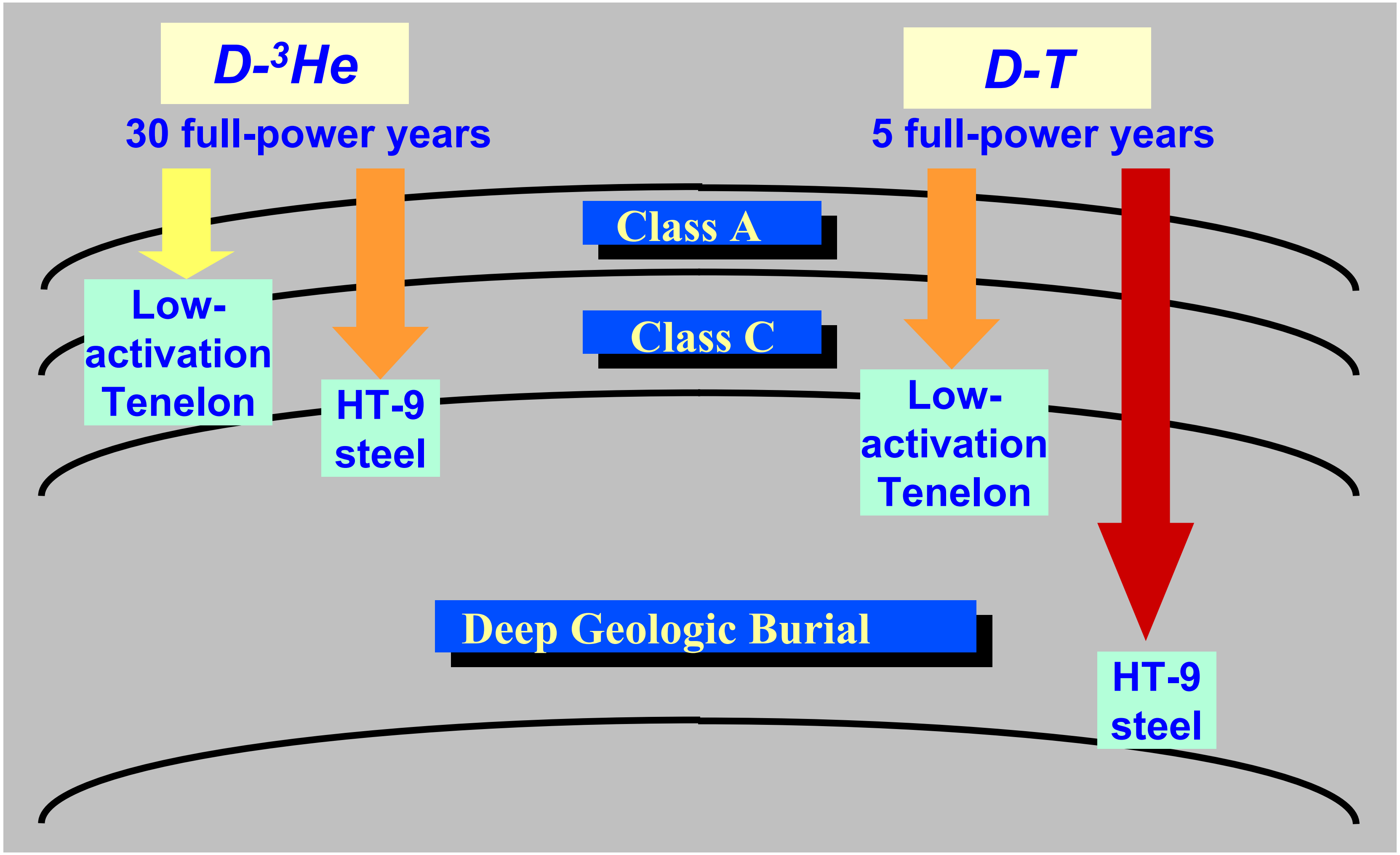
Barr-Moir experiment, LLNL
(*Fusion Technology*, 1973)



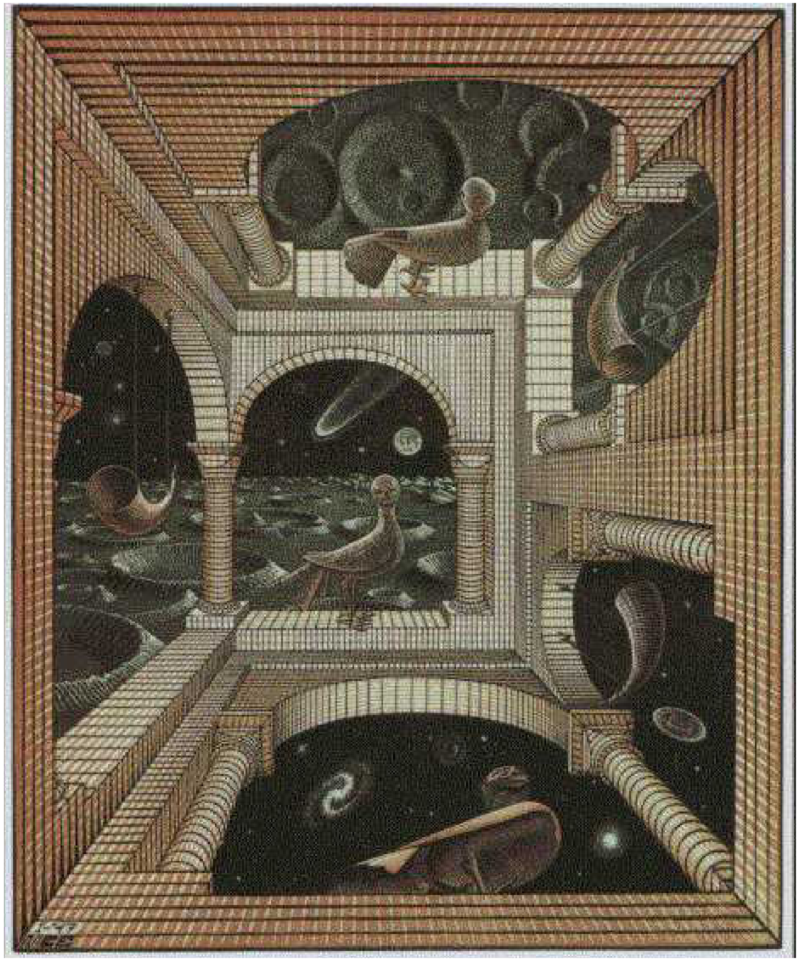
The Low Radiation Damage in D-^{3}He Reactors Allows Permanent First Walls and Shields to be Designed



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



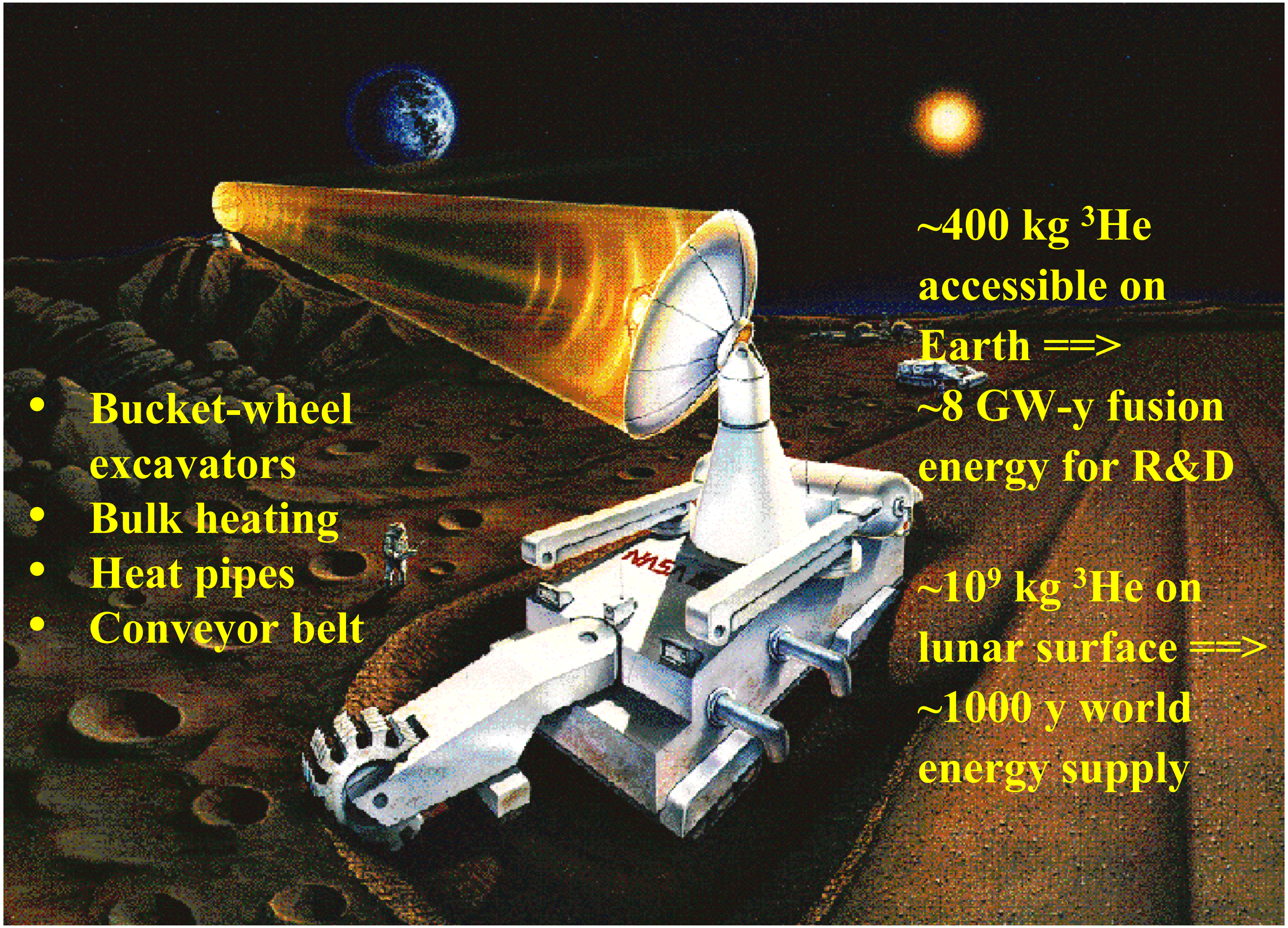
The ^{3}He Fuel Source is an Issue —So Think Outside the Box



Escher, Other World, 1947

- ~400 kg ^{3}He accessible on Earth (~8 GW-a fusion energy for R&D)
- ~10^9 kg ^{3}He on lunar surface for 21st century
- ~10^{23} kg ^{3}He in gas-giant planets for indefinite future

Lunar ^{3}He Mining Would Use Well-Developed Terrestrial Technology

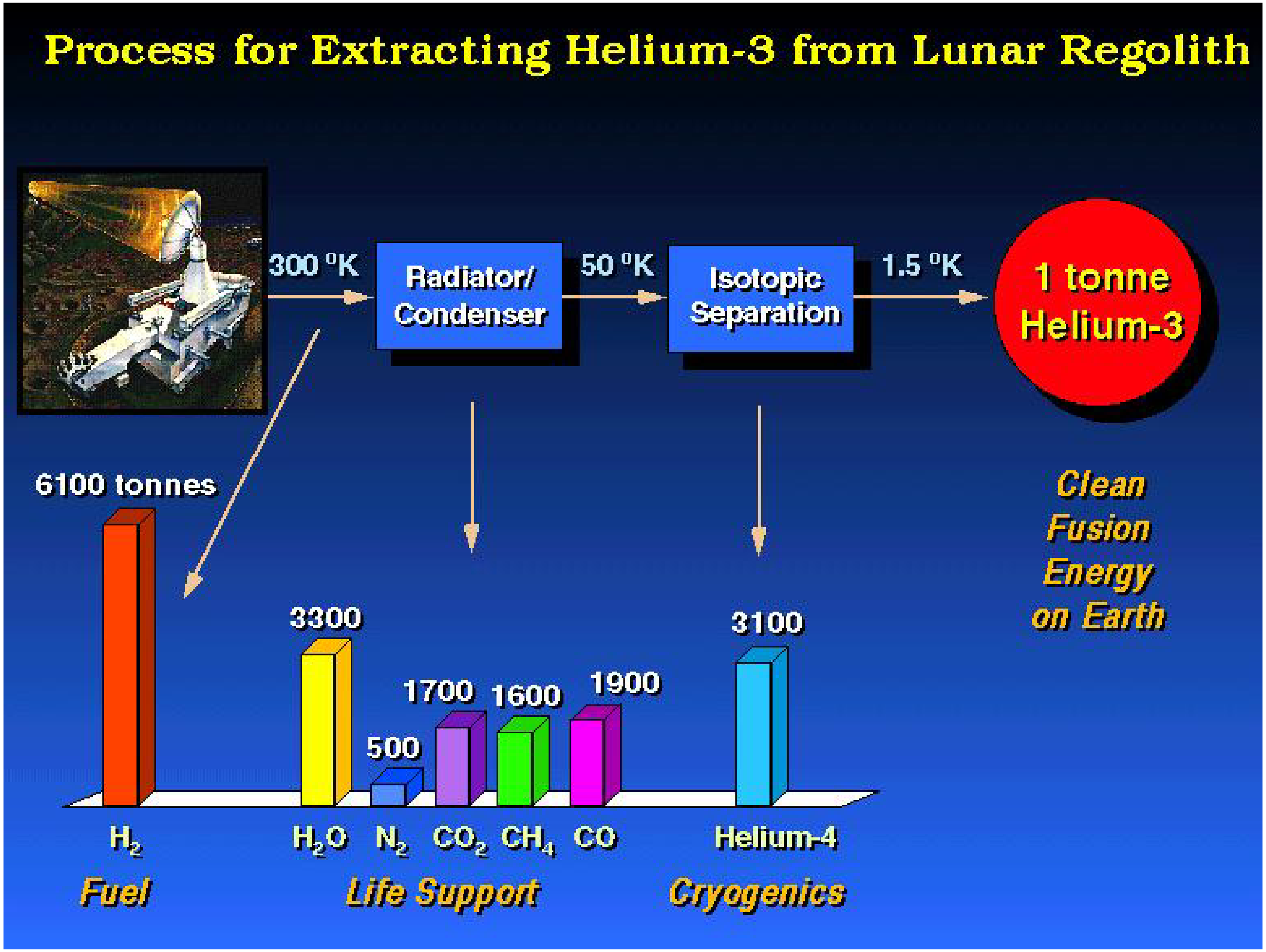


- Bucket-wheel excavators
- Bulk heating
- Heat pipes
- Conveyor belt

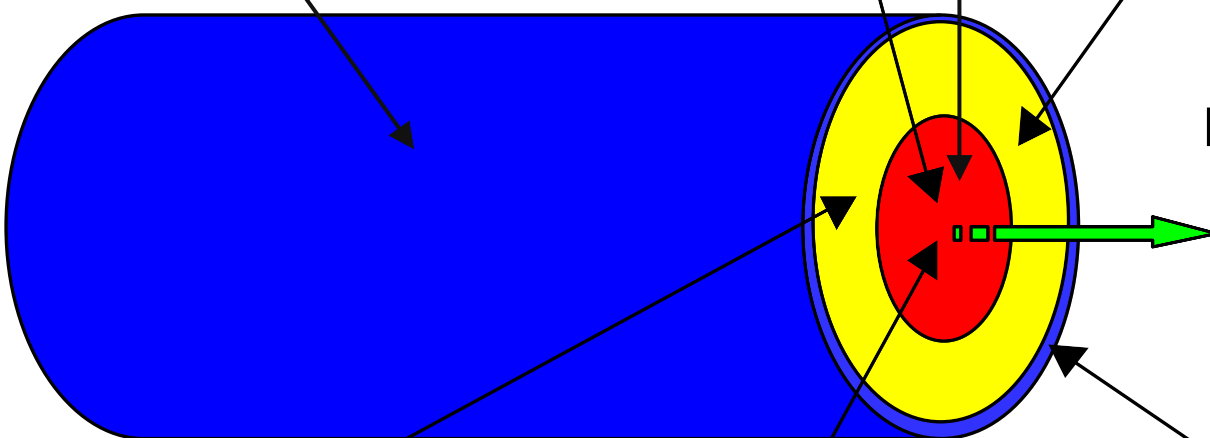
~400 kg ^{3}He accessible on Earth ==> ~8 GW-y fusion energy for R&D

~10^9 kg ^{3}He on lunar surface ==> ~1000 y world energy supply

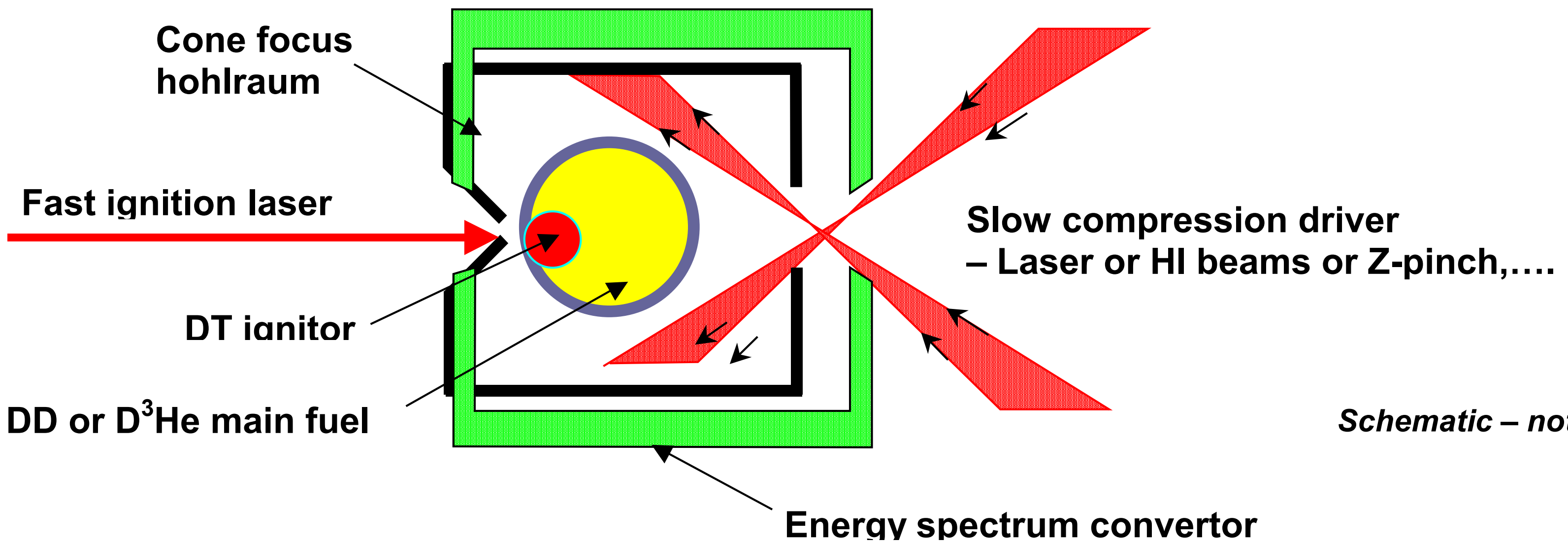
Mining Other Volatiles Would Support a Lunar Initiative, Allowing a Symbiotic Demonstration of Lunar ^{3}He Acquisition



Proliferation-Resistant D-^{3}He Power Plant May Be Possible



It May be Possible to Efficiently Burn DD or D^3He Fuels in Fast-Ignited ICF Targets



Schematic – not to scale

Four unique aspects of ICF for advanced fuels:

(1) The required high ignition/burn temperatures (~30/150keV) can be obtained via a precursor DT ignitor region (~10/50keV).

(2) The larger driver energies (required by the larger rho-R's for efficient advanced fuel burn-up) can be offset through fast ignition.

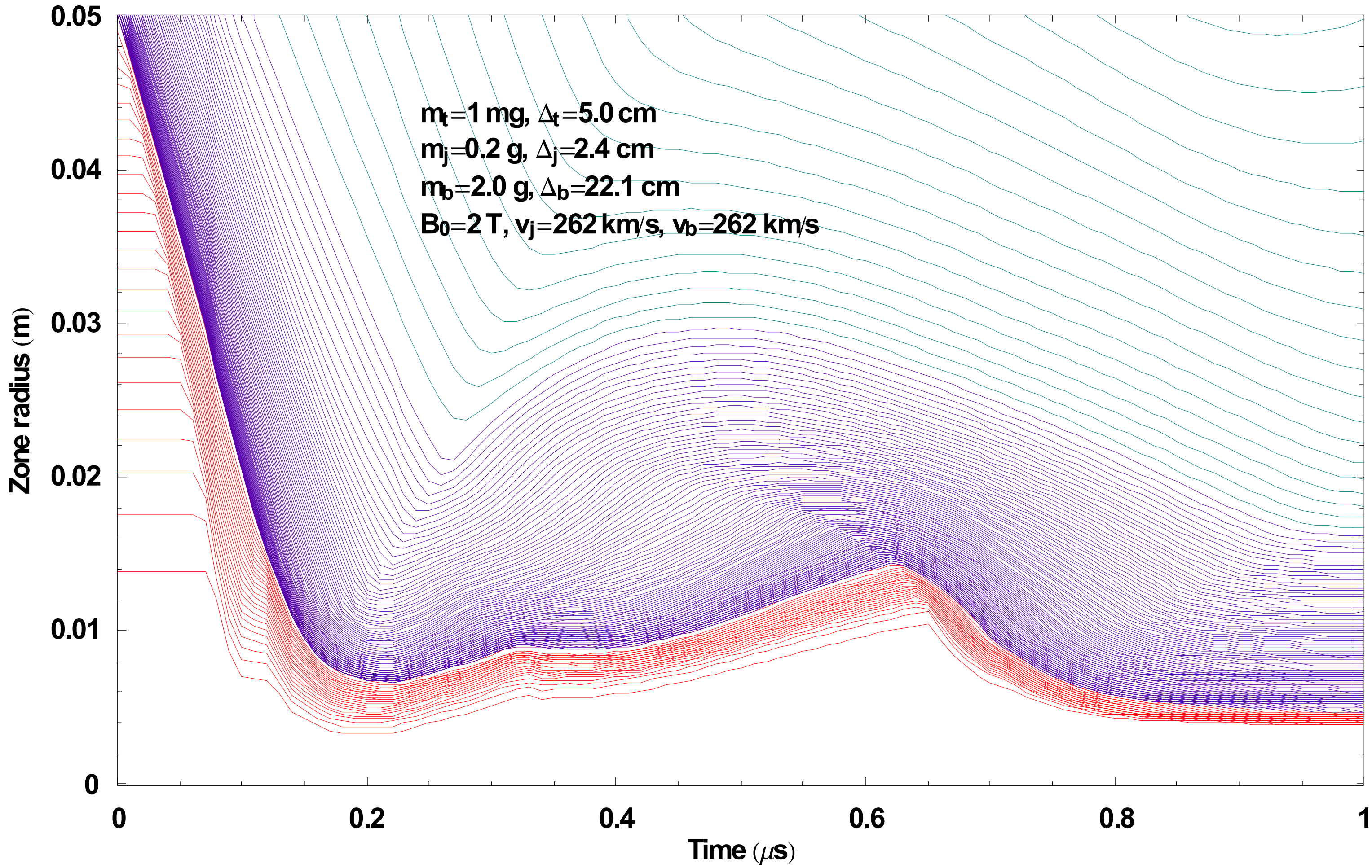
(3) Bremsstrahlung is self-trapped in the compressed fuel

(4) Tritium for the DT ignitor (~1% inventory) is self-bred as the main fuel burns

- Viewgraph contributed by John Perkins, LLNL.

Could D-^{3}He Be Used in Magnetized-Target Fusion?

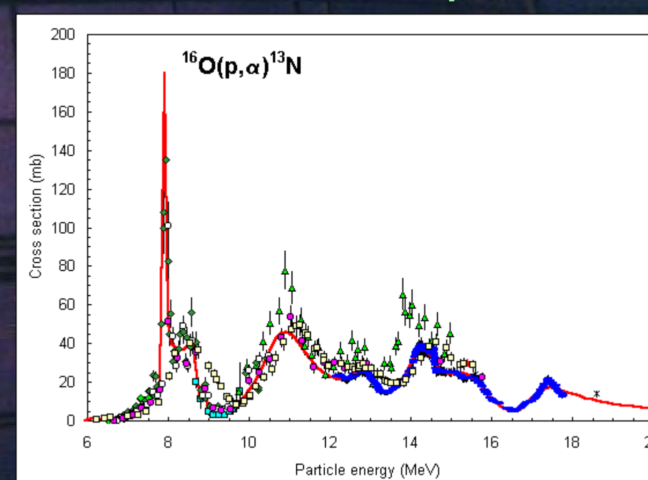
- Investigation in progress.



D-^{3}He Fusion Protons Can Produce Useful Radioisotopes

- In inertial-electrostatic confinement (IEC) fusion, high voltages on spherically symmetric, semi-transparent grids radially accelerate and focus 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

Cross sections for producing the PET-scan isotope ^{13}N



Conclusions

- Burning D-^{3}He fuel requires substantial, continued progress in plasma physics and high-β concepts.
- ^{3}He fuel for this century must come from the Moon, but long-term ^{3}He resources are essentially inexhaustible.
- Potential ICF and MTF D-^{3}He options should be explored.
- Near-term D-^{3}He applications are already being developed.
- The attractiveness of D-^{3}He fusion's engineering, safety, and environmental characteristics makes this a potentially important research area.