The Significance of Helium-3 Fusion

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Lecture 25
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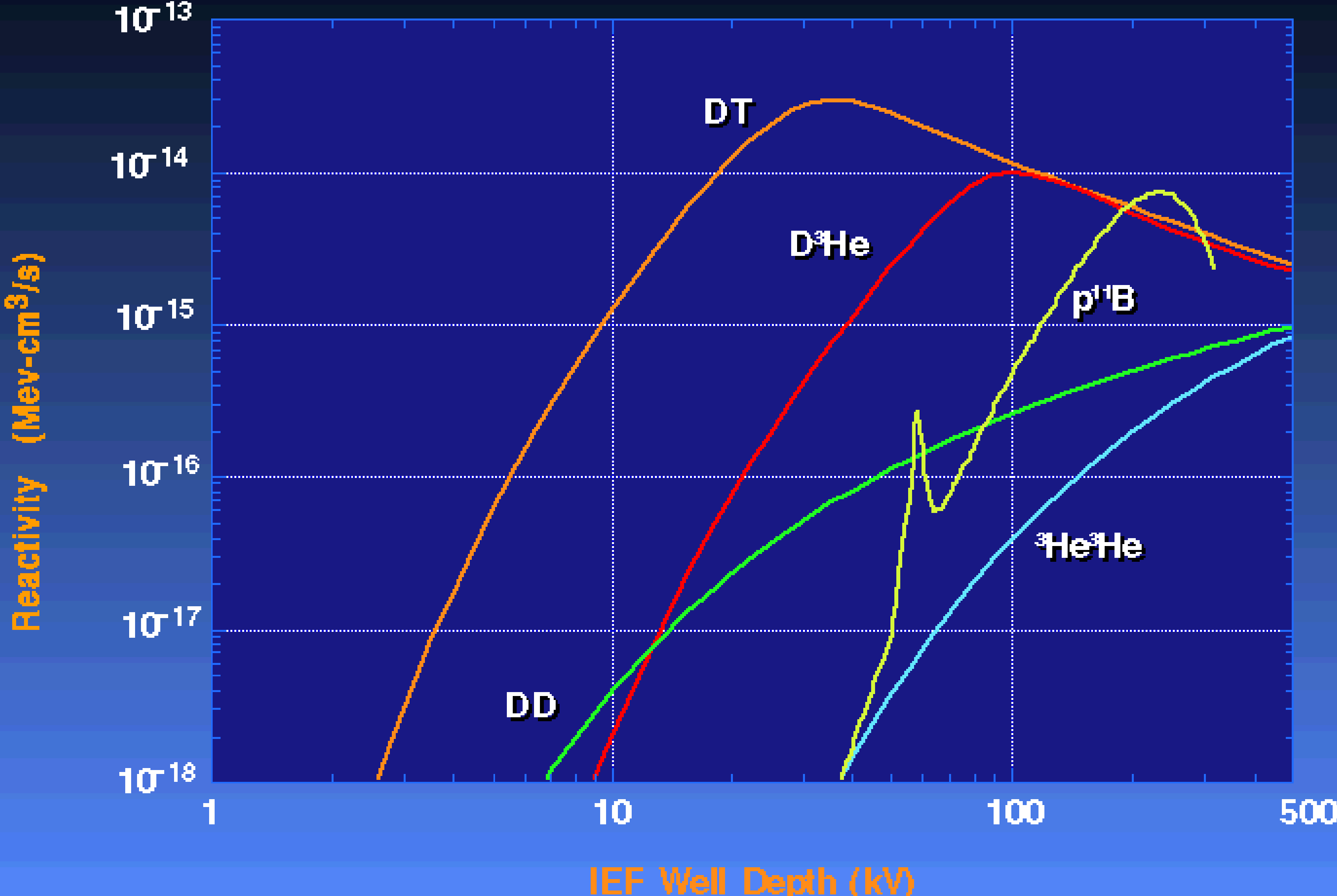
How do We Make Atoms Fuse?

- Placing them under very high pressures at high temperature.
  - Gravity
  - Inertial confinement
- Heating them to very high temperatures (i. e., high velocities) and running them into each other.
  - Containment with high magnetic fields
- Acceleration into each other at high velocities.
  - Electrostatic confinement

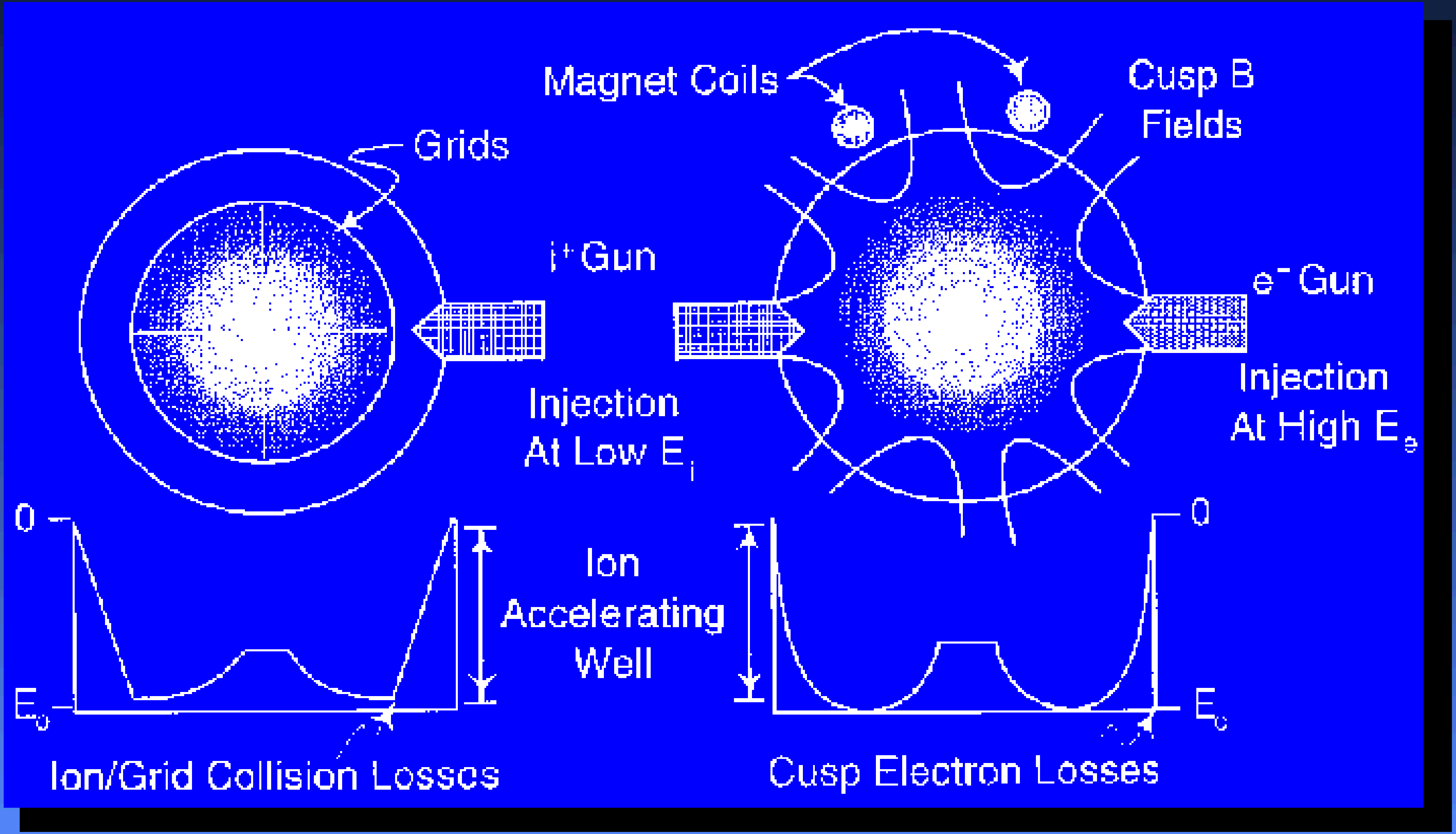
Reactivities ($\Sigma E_{fus}\sigma v$) versus IEF Well Depth



There Are 2 Basic Approaches to IEF

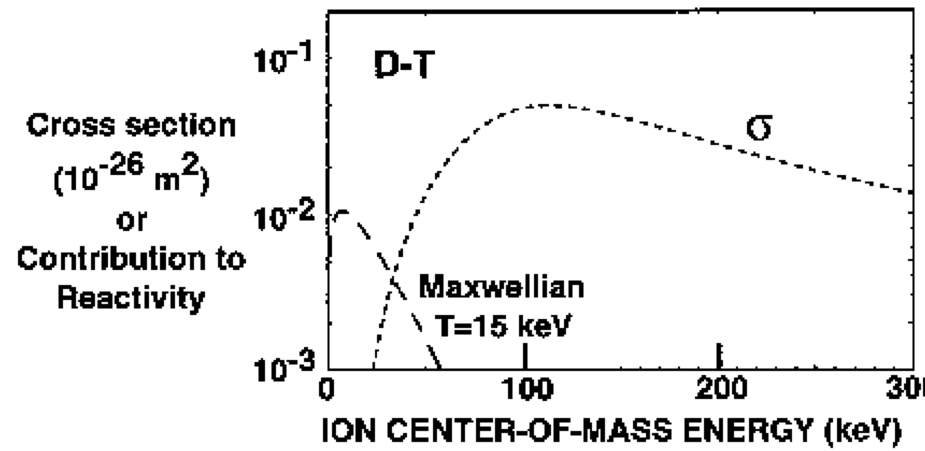
Purely Electrostatic

Virtual Cathodes (Established by Excess Electrons)

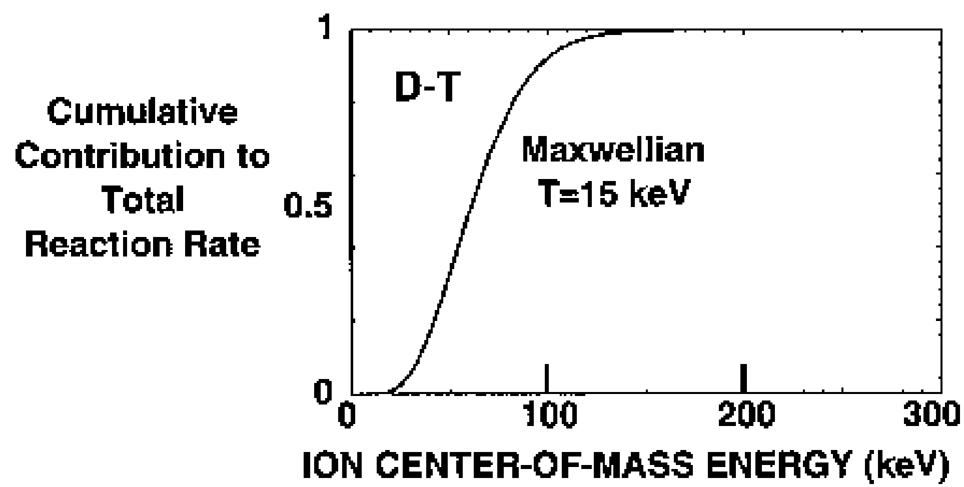


Fusion Power from a Maxwellian Plasma Comes Mainly from the High-Energy Tail in the Distribution

- The reaction cross-section is high only at temperatures above the peak in the distribution function.



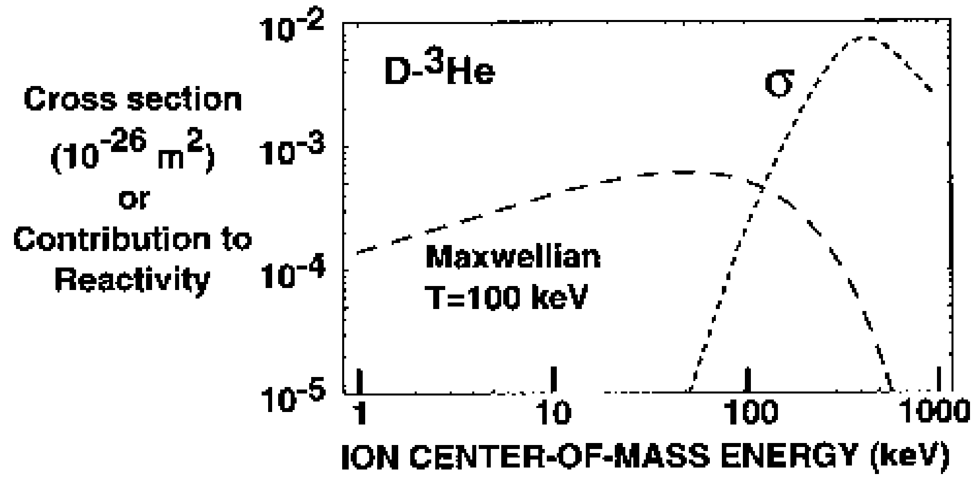
- Considerable energy is invested in filling the Maxwellian with ions which do not contribute to the fusion rate.



Why is IEF Different from Fusion in a Tokamak?

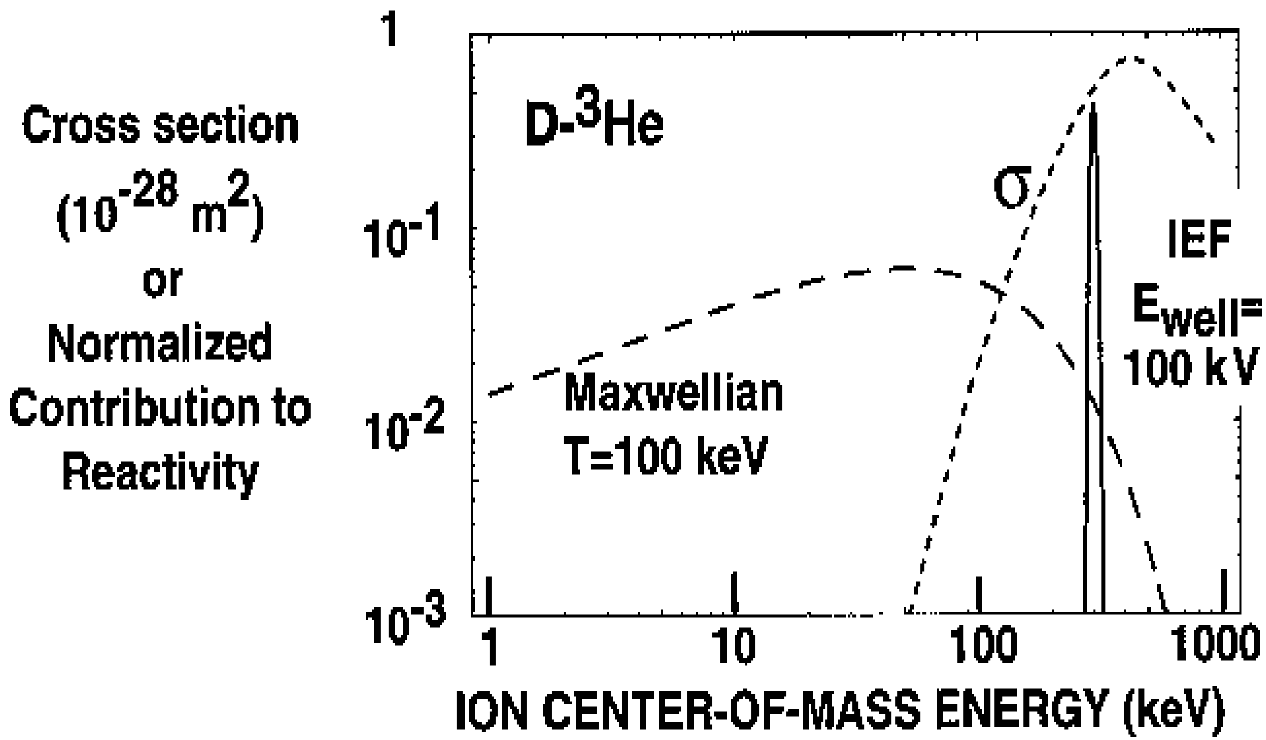
- When containing a collection of plasma particles at high temperatures with a magnetic field, the particles equilibrate in a Maxwellian distribution.

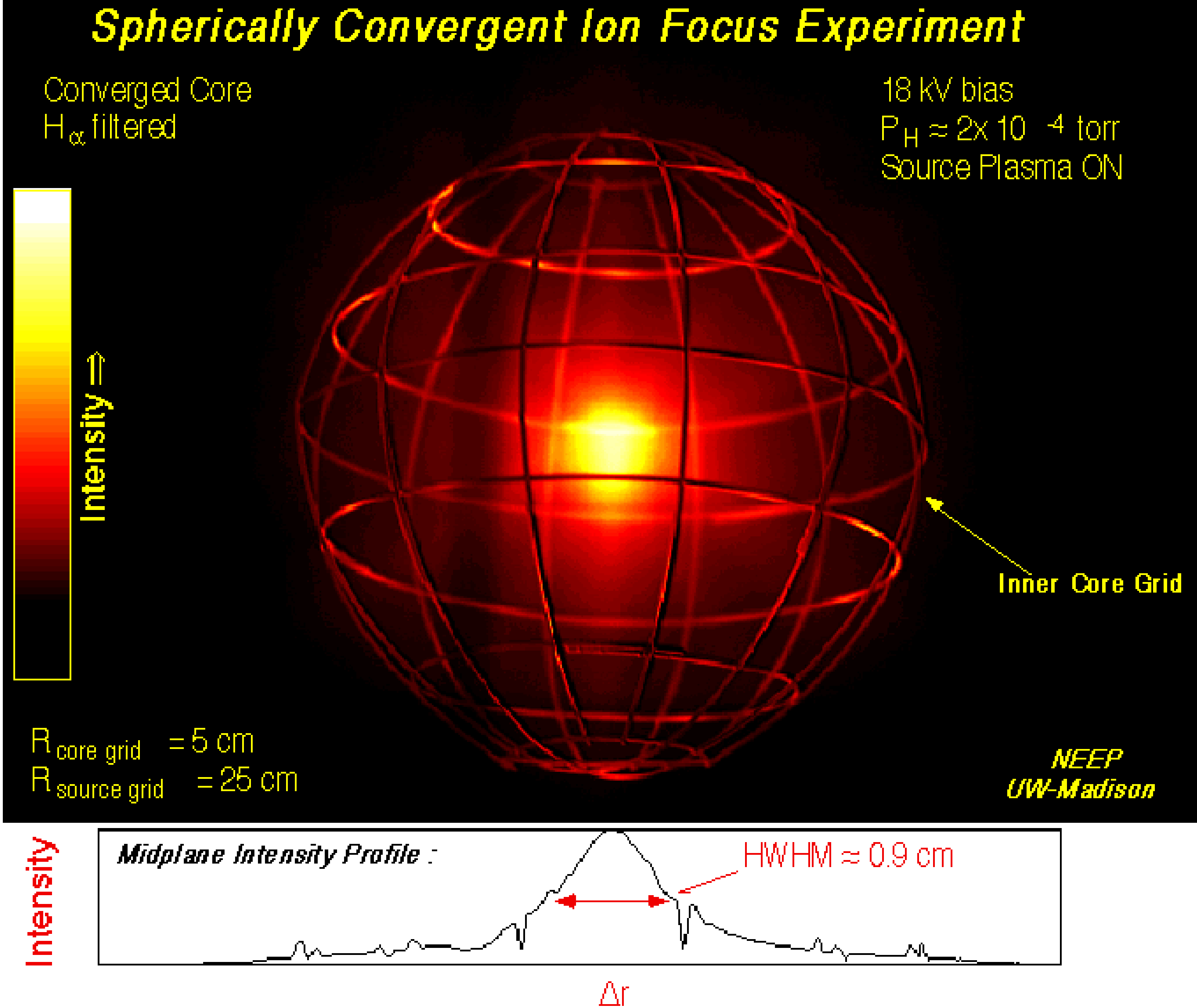
- Considerable energy is invested in filling the Maxwellian with ions which do not contribute much to the fusion rate.



Why is IEF Different from Fusion in a Tokamak?

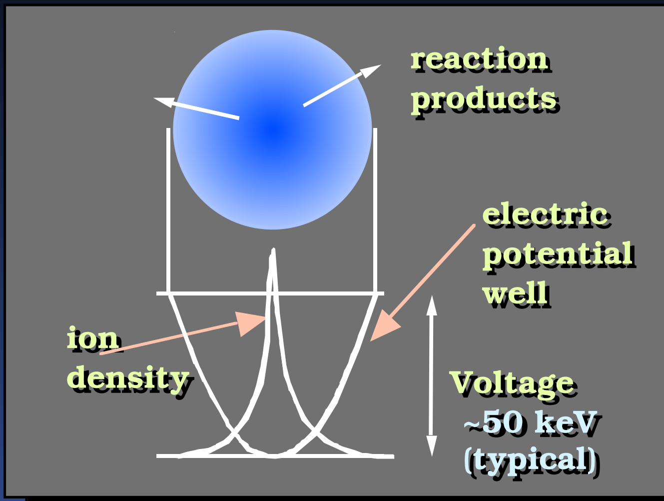
- In IEF, energy can be invested in only those ions which have a high chance of fusion.



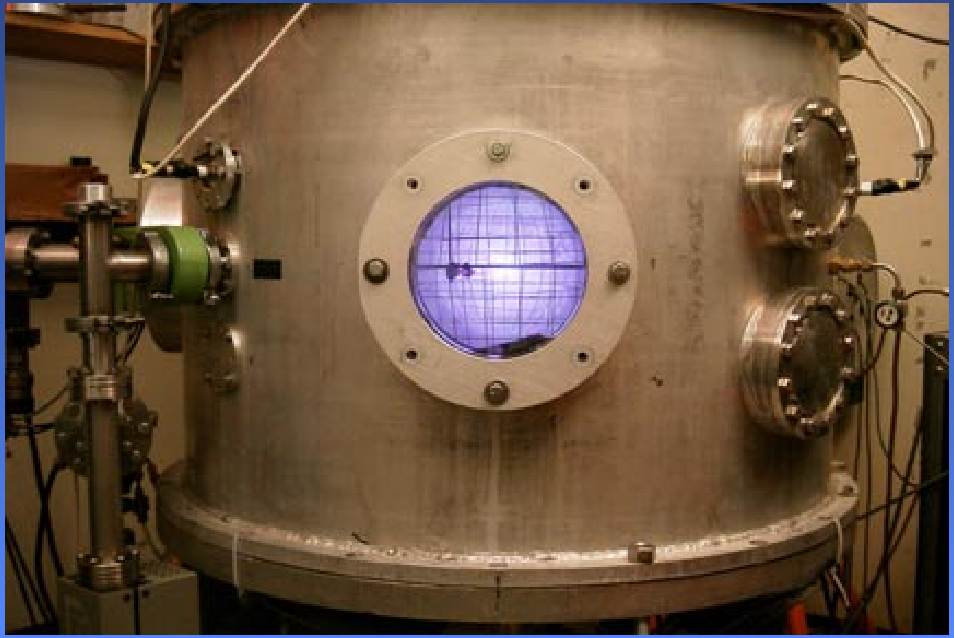


Spherically Convergent Ion Focus Experiment
Converged Core
Hα filtered
18 kV bias
P H ≈ 2x 10 -4 torr
Source Plasma ON
Intensity ⇒
Inner Core Grid
R core grid = 5 cm
R source grid = 25 cm
NEEP
UW-Madison
Intensity
Midplane Intensity Profile :
HWHM ≈ 0.9 cm
Δr

Steady State D^3He Reaction Rate Achieved in Wisconsin IEC Device



cathode voltage=55 kV
cathode current=60 mA
pressure=1 mtorr



Why Are We Interested in ^{3}He Fusion if DT Fusion is Easier?

The Public Developed a Resistance to Nuclear Power in the Late 20th Century

The resistance seems to be largely based on:

1) Fear of radioactivity releases
2) Uneasiness with long-term nuclear waste storage
3) Fear of proliferation of nuclear weapons grade material

All of the above problems stem from the nuclear reaction:

1) Radioactive fuel
2) Radioactive reaction products
3) Neutrons

Can the Use of Fusion Fuels Alleviate the Public’s Fear About Radioactivity?

Fusion Can be Conveniently Divided into Three Eras

1st Generation

$D + T \rightarrow n\ (14.07\ MeV) + {}^4He\ (3.52\ MeV)$

$D + D \rightarrow n\ (2.45\ MeV) + {}^3He\ (0.82\ MeV)$ {50%}

$\rightarrow p\ (3.02\ MeV) + T\ (1.01\ MeV)$ {50%}

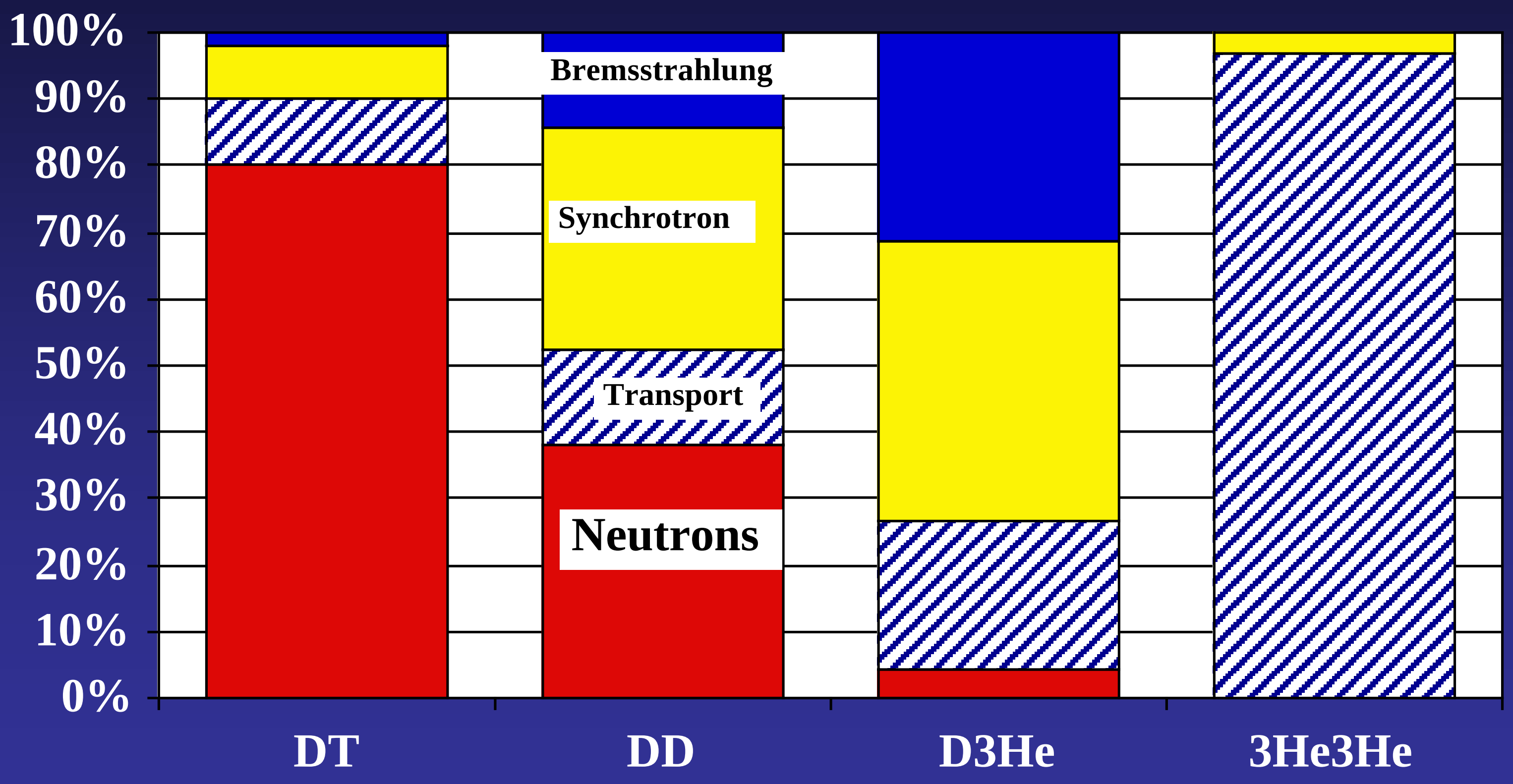
2nd Generation

$D + {}^3He \rightarrow p\ (14.68\ MeV) + {}^4He\ (3.67\ MeV)$

3rd Generation

${}^3He + {}^3He \rightarrow 2p + {}^4He$ (12.9 MeV)

The Form of Energy Released Depends on the Fuel Cycle

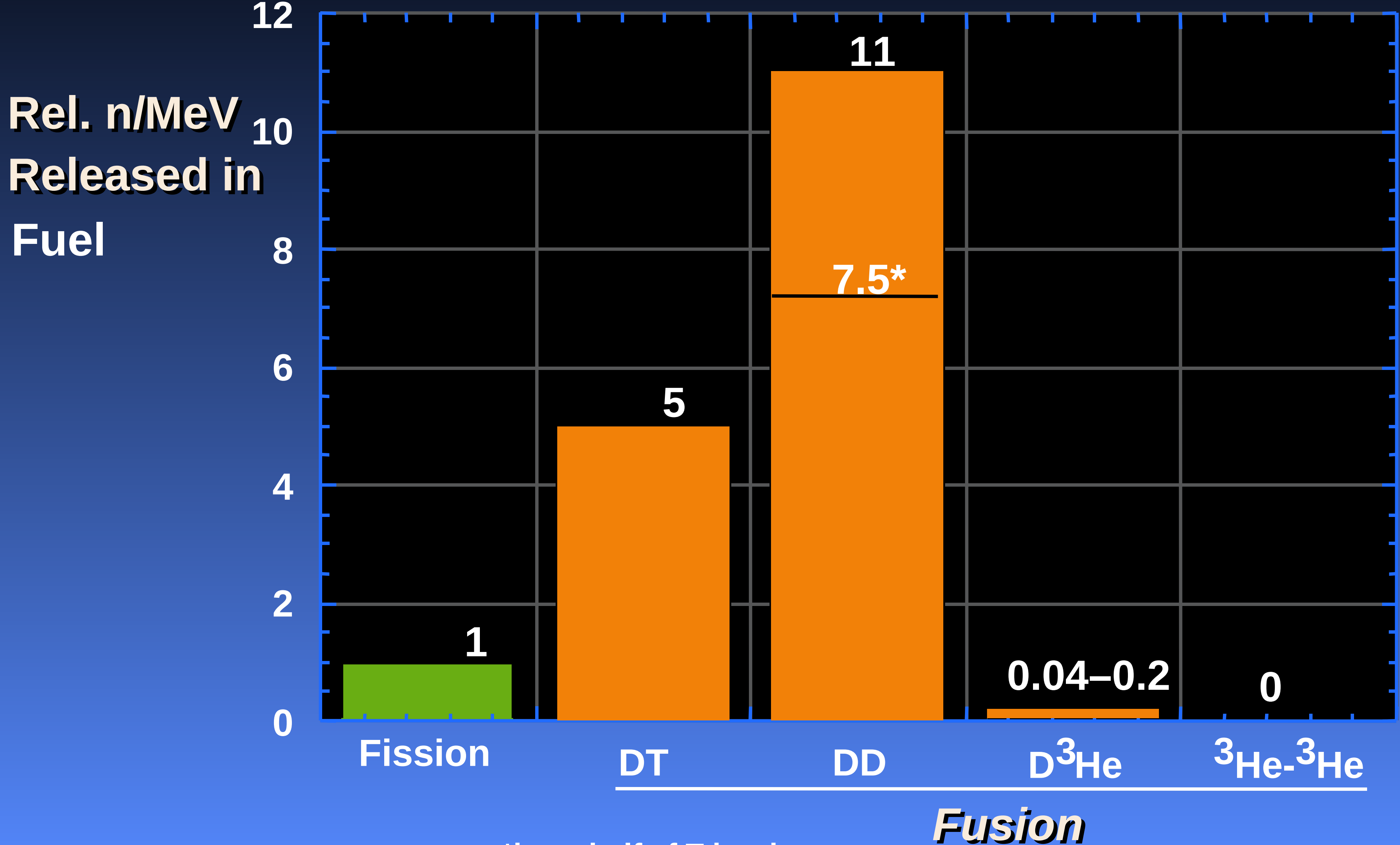


Some Fusion Fuels Have More Radioactivity Associated With Them Than Others

Fuel Cycle	Radioactive Fuel	Direct Radioactivity			Indirect Radioactivity		
DD	**--**	**n**	**T**	**--**	**n**		
DT	**T**	**n**	**--**	**--**	**n**	**T**	
D^3He	**--**	**--**	**--**	**--**	**n**	**T**	
$^3He^3He$	**--**	**--**	**--**	**--**	**--**		
p^6Li	**--**	**--**	**--**	**--**	**n**	**T**	**^7Be** **^{11}C**
$p^{11}B$	**--**	**--**	**--**	**--**	**n** **Small**		**^{14}C** **small**

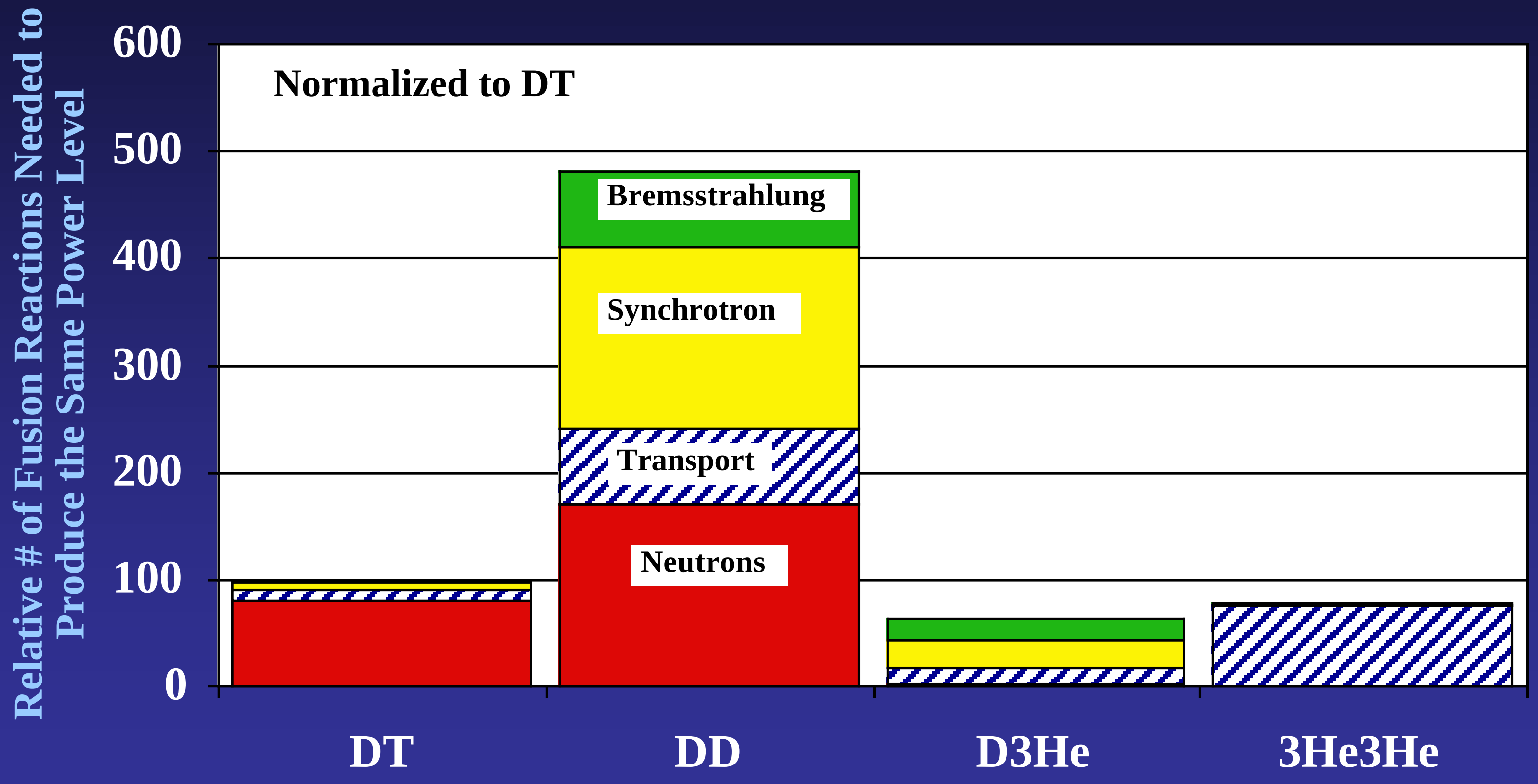
Half Life: T = 12.3 y, ^7Be = 52 d, ^{11}C = 0.33 h, ^{14}C = 5,600 y

The Number of Neutrons Generated by Helium-3 Fusion Fuels is Very Small

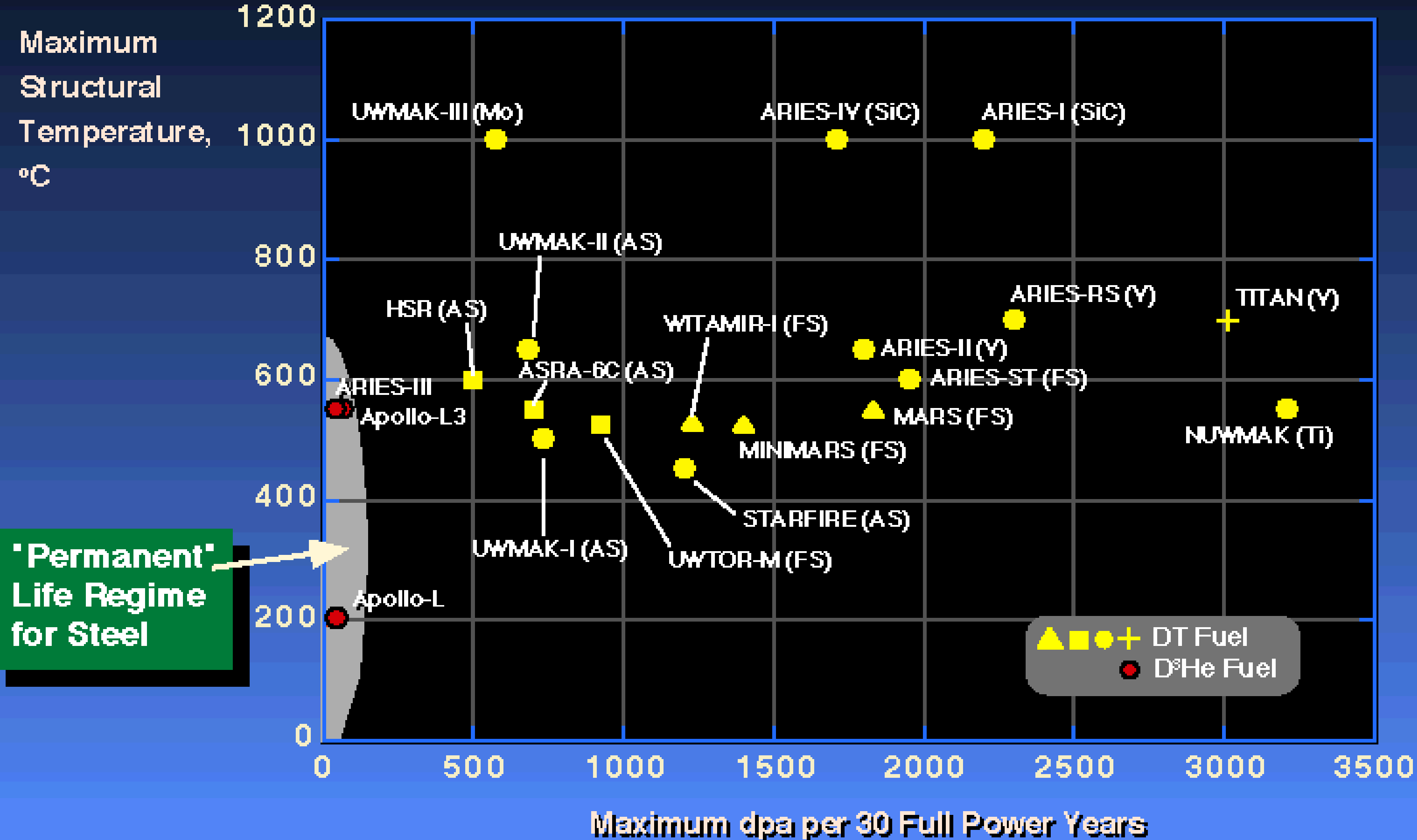


*burn half of T bred

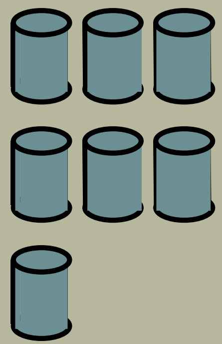
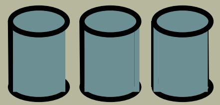
The Amount and Form of Energy Release Depends on the Fusion Fuel Cycle Used



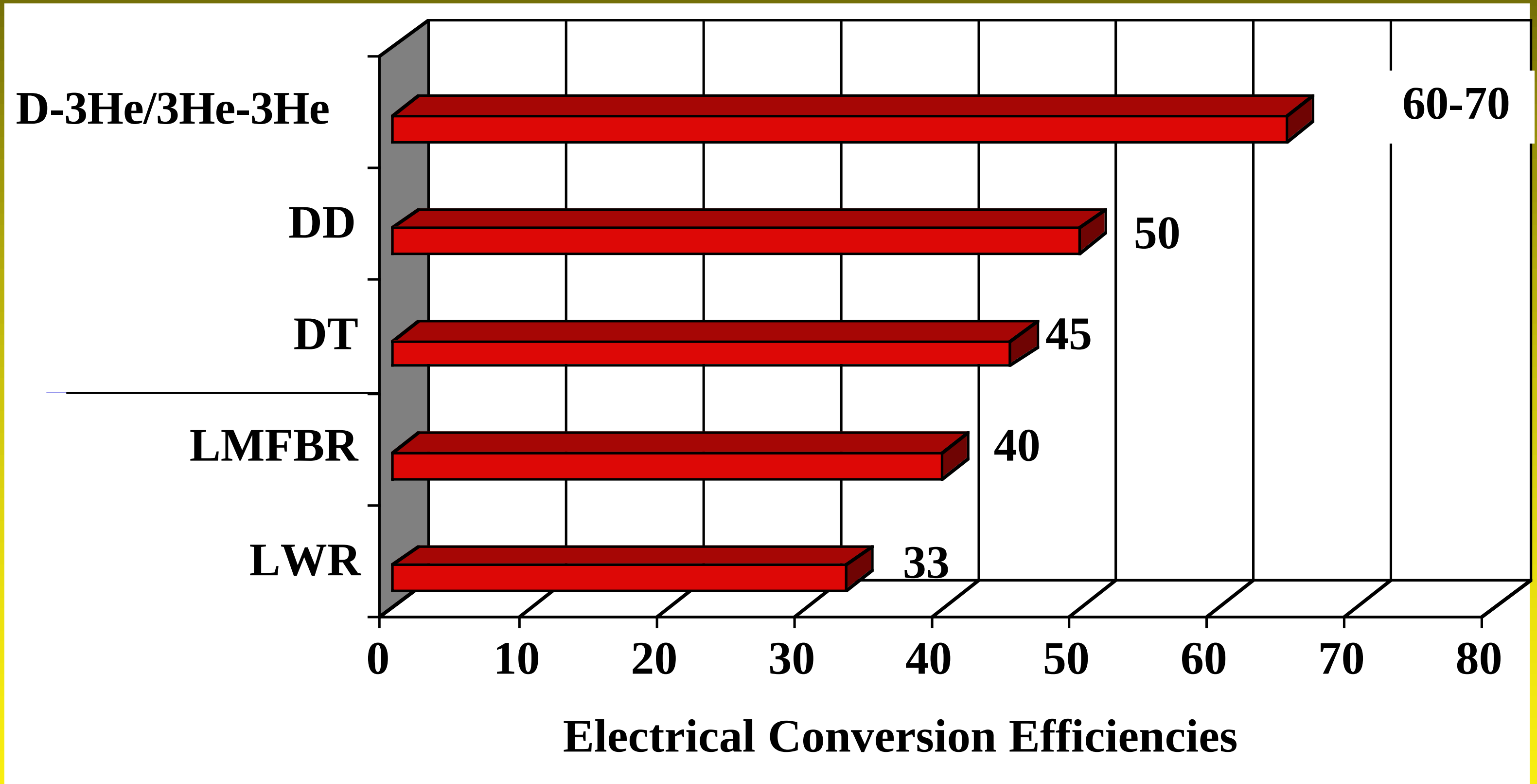
The Low Radiation Damage in D^{3}He Reactors Allows Permanent First Walls to be Designed



The Use of 2nd and 3rd Generation Fusion Fuels Can Greatly Reduce or Even Eliminate Radioactive Waste Storage Problems

Class of Waste	Relative Cost of Disposal	LWR Fission (Once Through)	DT (SiC)	D^3He (SiC)	$^3He^3He$ (any material)
		Relative Volume of Operation Waste/GWe-y			
Class A	1	several times Class C amount	several times Class C amount		
Class C	≈10				
Deep Geological (Yucca Mtn.)	≈1000				

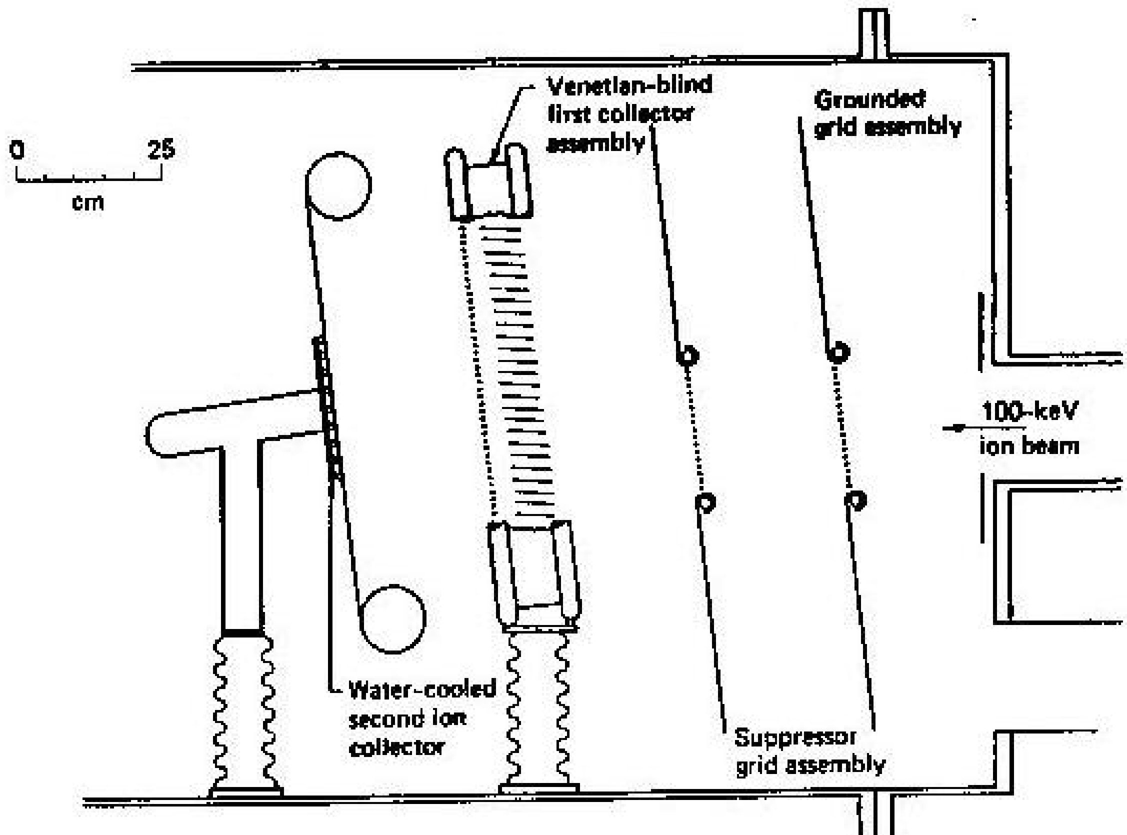
Nuclear Energy Conversion Efficiencies



Direct Conversion of Plasma Energy to Electricity at High Efficiency Has Been Demonstrated

University of Wisconsin

- Experiment and theory agreed to within 2% for the LLNL direct converter experiments.



The 20th Century Approach to Fusion Only Partly Alleviates Public Concerns About Nuclear Power

Public Concern	How DT Fusion Addresses Concern
Radioactive Releases	Avoid runaway reactions and "meltdown" scenarios However, still have gigacuries in reactor in the event of an accident
Long Term Radioactive Waste Storage	Choice of fuel and structural material can reduce effective half life to < 100's years However, radiation damage and replacement of components can produce large volumes of radioactive waste
Proliferation	Reactor does not require fissile or fertile material However, excess neutrons can be used to breed fissile fuel

Characteristics of D ^{3}He Fusion Power Plants

- No Greenhouse or Acid Gas Emissions During Operation
- Very High Efficiencies (>70%)
- Greatly Reduced Radiological Hazard Potential Compared to Fission Reactors (<1/10,000)
- Low Level Waste Disposal After 30 y
- No Possible Offsite Nuclear Fatalities in the Event of Worst Possible Accident

Characteristics of ^{3}He Fusion Power Plants

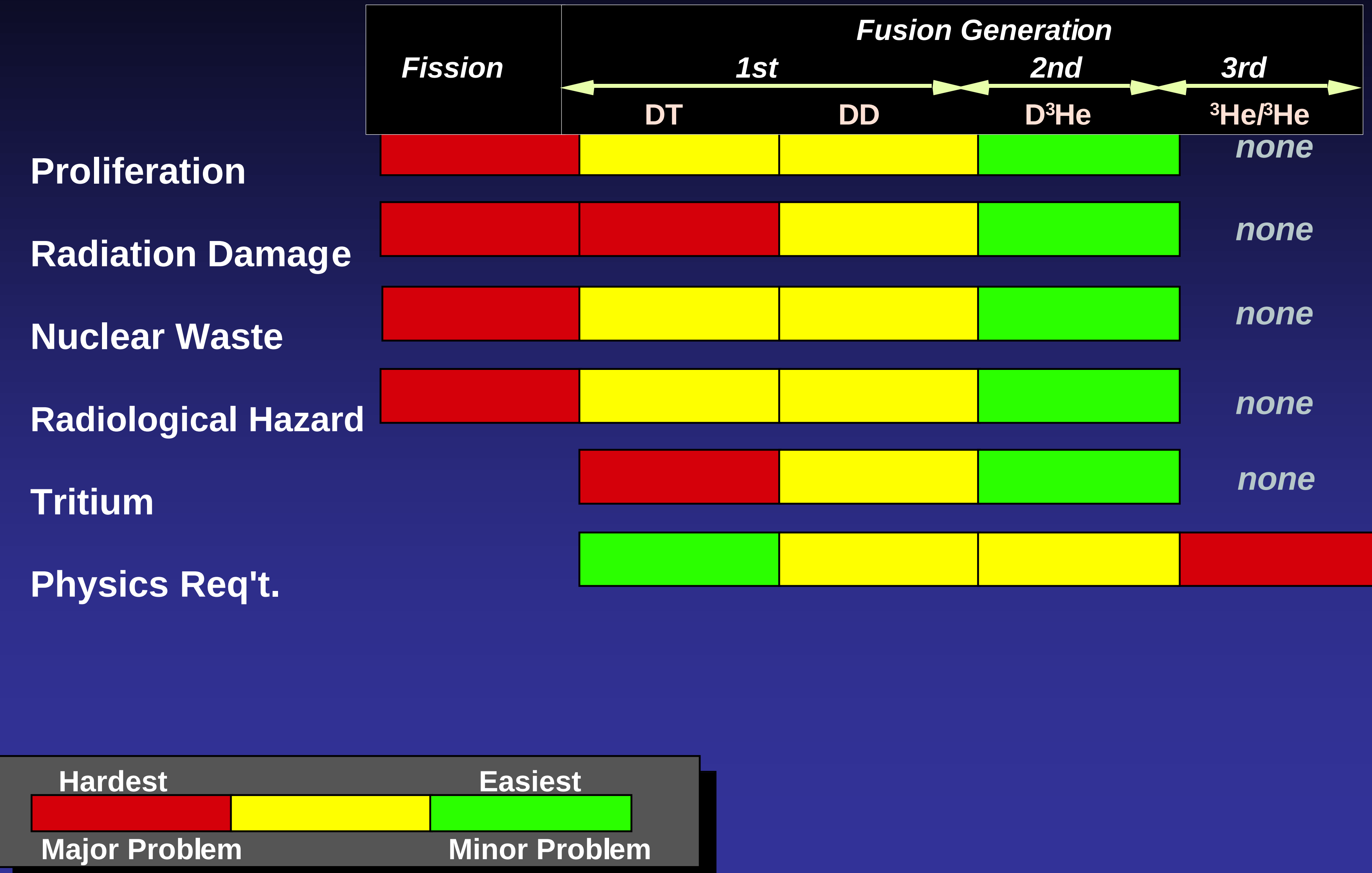
- No Greenhouse or Acid Gas Emissions During Operation

- Very High Efficiencies Possible (>70%)

- No Residual Radioactivity After 30 Years of Operation (No Radioactive Waste or Nuclear Safety Hazard).

Nuclear Energy Without Nuclear Waste !!

Major Societal and Technical Concerns of Nuclear Energy Options

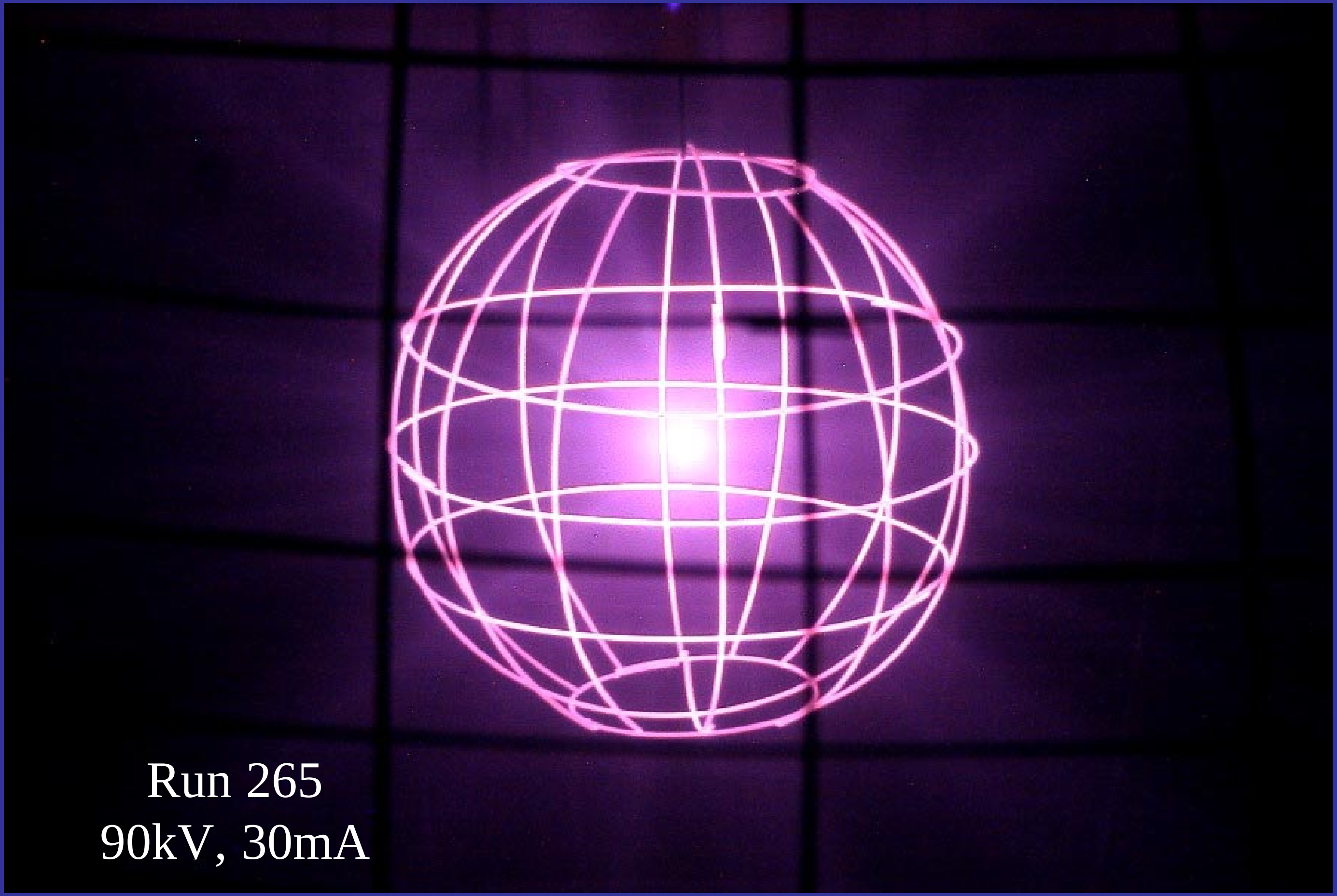


Why Consider the Advanced Fuels for Power Production?

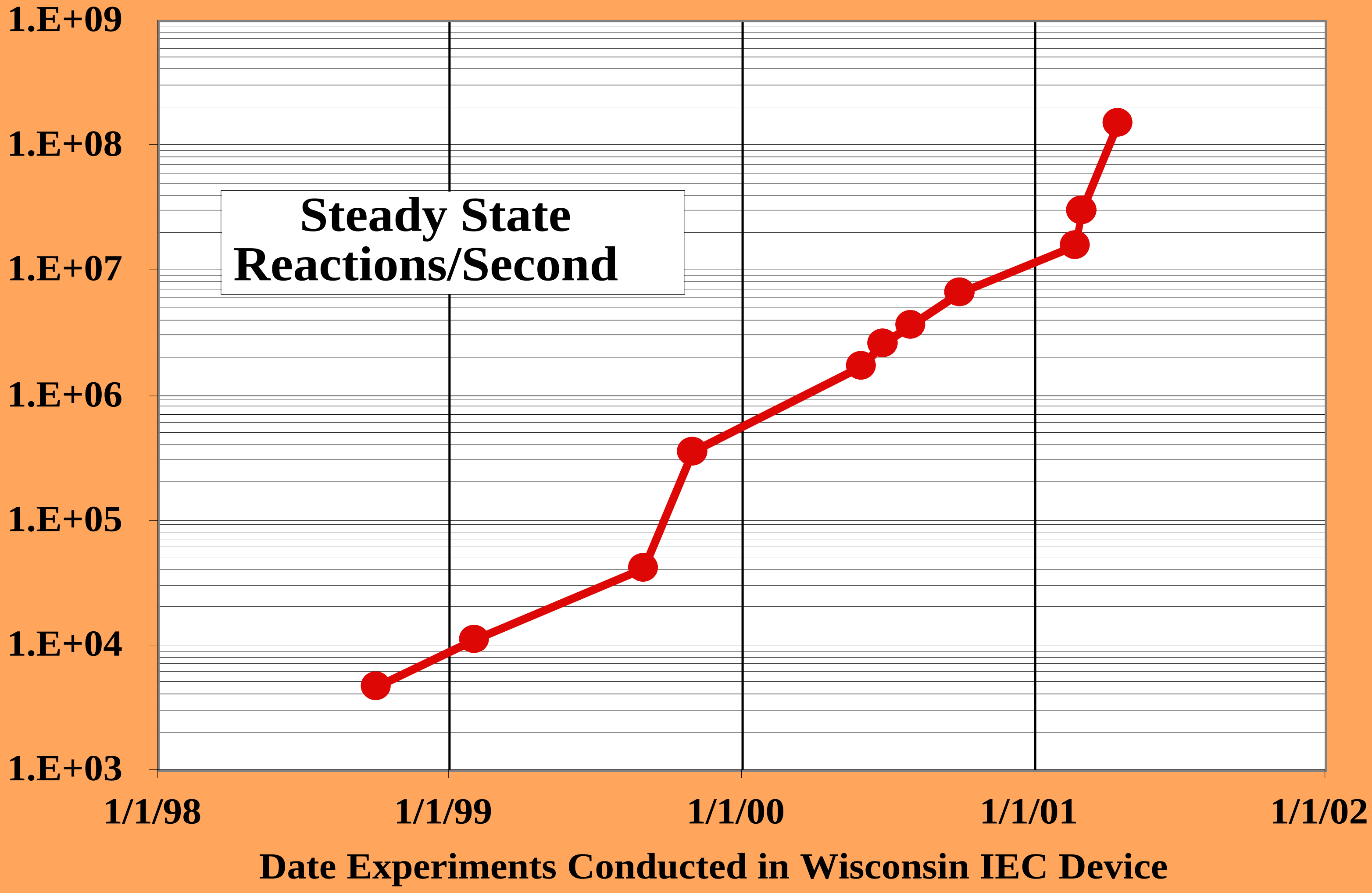
Major Advantages	Major Disadvantages
• Significant Reduction in Radiation Damage – (permanent 1st wall) • Greatly reduced (or no) radioactivity • Potential for Direct Conversion – (higher efficiency & lower waste heat)	• Higher operating temperature – (higher $n\tau$ values) • Lower plasma power density or yield – (requires higher beta or ρr) • Fuel source-^{3}He – (requires NASA collaboration)

The Steady State D-^{3}He Fusion Rate in the UW IEC Device is Now 1.5 x 10^8 p/s

(115 kV, 60 mA)

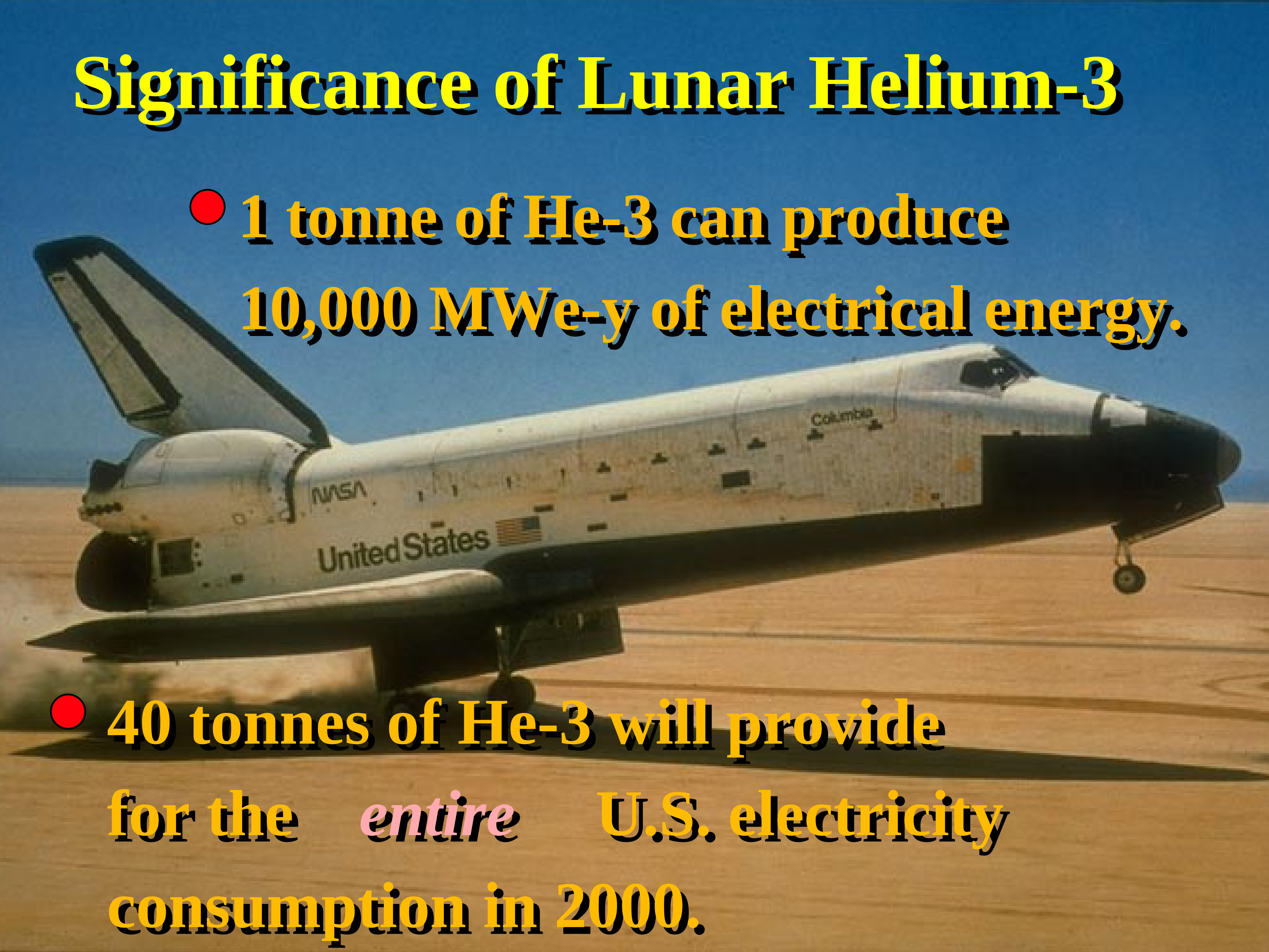


Significant Progress Has Been Made in Producing High Energy Protons from the D^3He Reaction

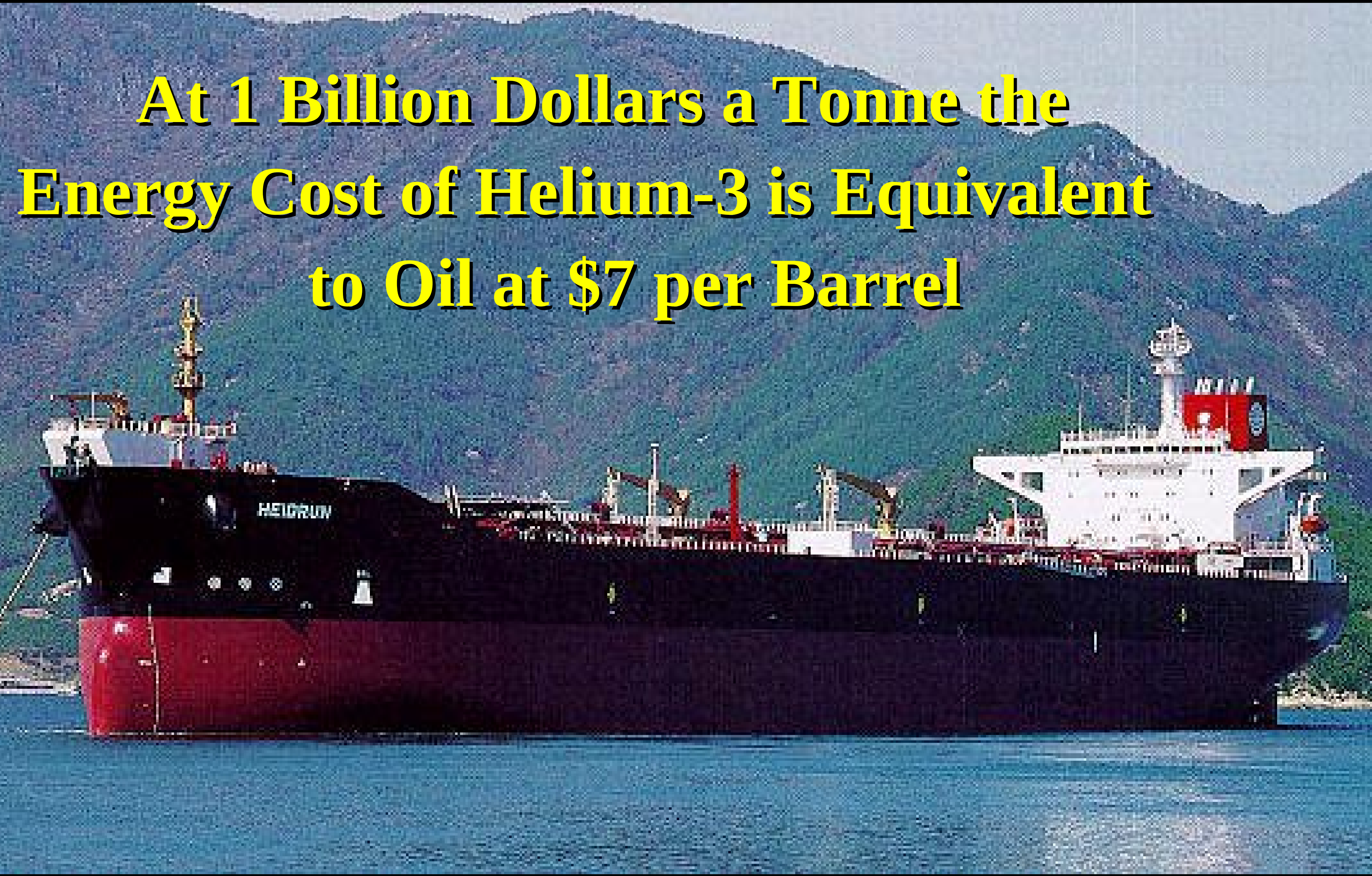


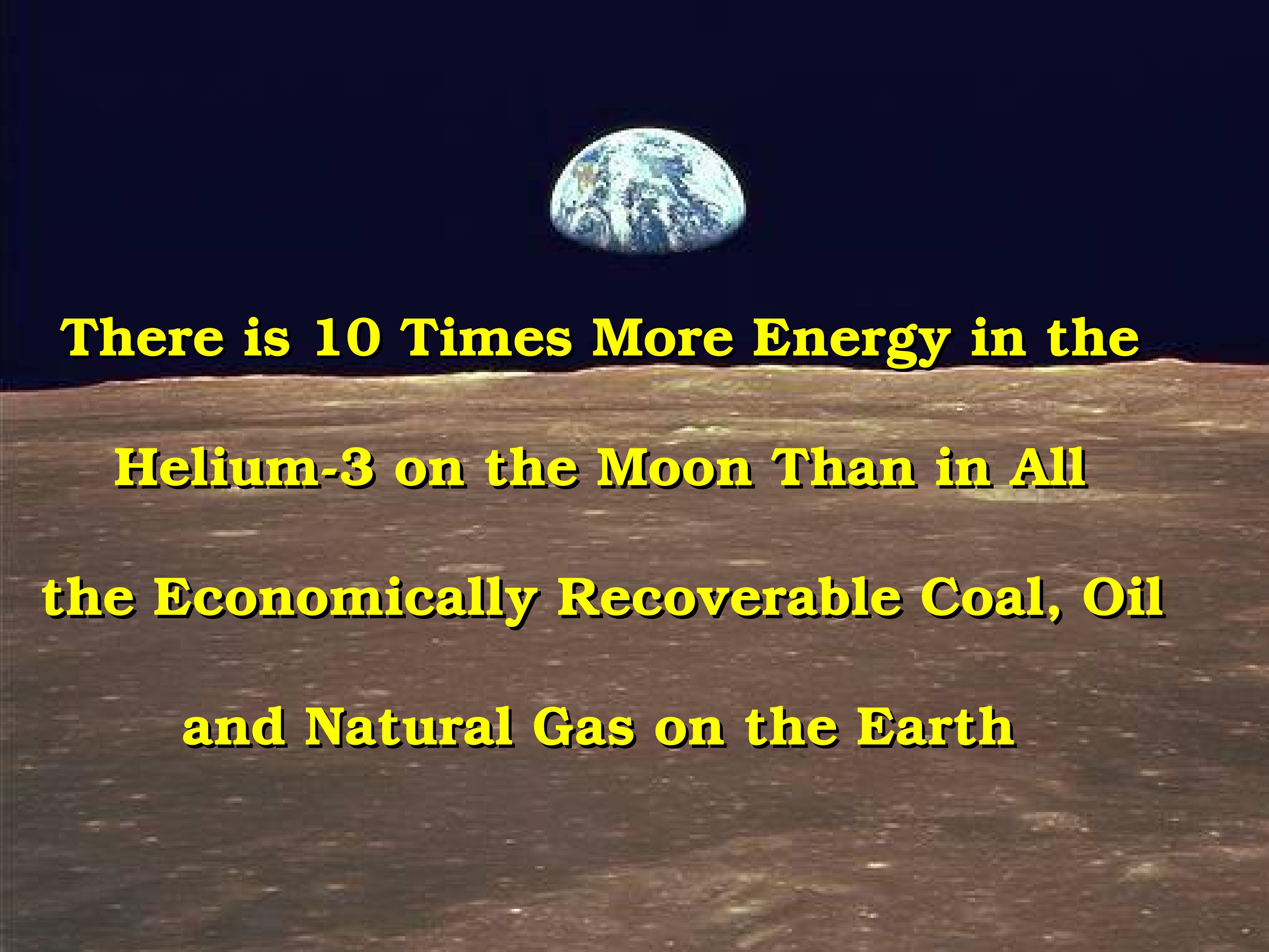
Significance of Lunar Helium-3

- 1 tonne of He-3 can produce 10,000 MWe-y of electrical energy.
- 40 tonnes of He-3 will provide for the *entire* U.S. electricity consumption in 2000.



At 1 Billion Dollars a Tonne the Energy Cost of Helium-3 is Equivalent to Oil at $7 per Barrel




There is 10 Times More Energy in the
Helium-3 on the Moon Than in All
the Economically Recoverable Coal, Oil
and Natural Gas on the Earth

The Development of the 2nd and 3rd Generation Fusion Fuels in the 21st Century Could Lead to Near Term, as Well as Long-Term Benefits to Society

Phase 3

Long Range Benefits of a Q>10 IEC Device

- All of Phase 1
- All of Phase 2
- Small, Safe, Clean and Economical Electrical Power Plants

Phase 2

Intermediate Term Spinoff from a Q = 1–5 Device

- All of Phase 1
- Destruction of Toxic Materials
- Space Power
- Propulsion Technologies
- Remote Electricity Stations

Phase 1

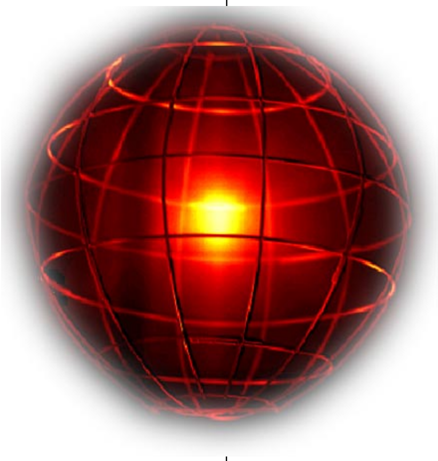
Near Term Spinoff from a Q < 1 Device

- Medical Treatment
- Civilian Commercial Markets
- Environmental Restoration
- Defense

Applications

Near Term

- Medical Isotope Production
- Cancer Therapy
- Detection of Explosives
- Detection of Chemical Wastes



Mid-Term

- Destruction of Fissile Material
- Destruction of Radioactive Wastes

Long Range

- Small (50-100 MWe) Electrical Power Plants
- Use of Advanced Fuels (Helium-3)
- Space Propulsion
- Base Load Electrical Power Plants
- Hydrogen Production
- Synthetic Fuel Production

Conclusions

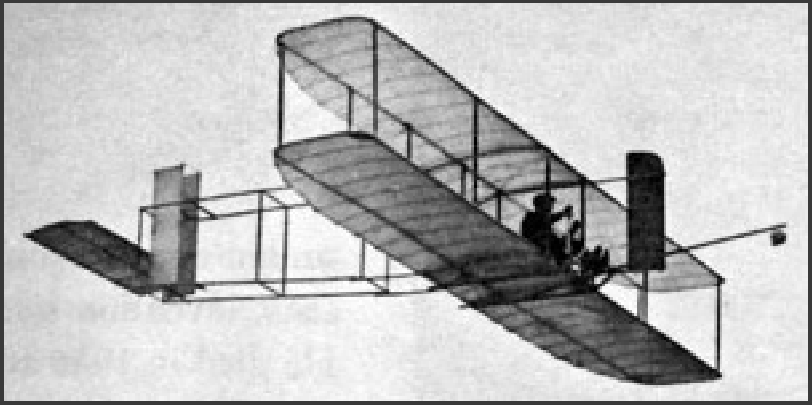
The use of second and third generation fusion fuels could revolutionize the Public's view of fusion power by:

1) **eliminating one of the greatest barriers to public acceptance of nuclear power – the concern over radioactive waste, radioactivity releases, and proliferation of weapons grade**

2) **allowing off-the-shelf structural materials to be used, thus eliminating expensive neutron test facilities & long development times.**

3) **allowing high efficiency operation and in-city siting of electrical power plants**

They Said It Couldn't Be Done



"Man will not fly for fifty years." –Wilbur Wright, 1901

"Heavier-than-air flying machines are impossible." –Lord Kelvin, president, Royal Society, 1895

"There is not the slightest indication that [nuclear energy] will ever be obtainable. It would mean that the atom would have to be shattered at will." –Albert Einstein, 1932

"Anyone who looks for a source of power in the transformation of the [nucleus of the] atom is talking moonshine." –Ernest Rutherford, 1933

"Airplanes are interesting toys but of no military value." –Marshall Foch, future WWI French commander-in-chief, 1911

"Space travel is utter bilge." –Dr. Richard Wooley, Astronomer Royal, space advisor to the British government, 1956