The Significance of Helium-3 Fusion

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Lecture 26
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The Use of Fusion Fuels Will Evolve in the Future

1st Generation

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

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

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

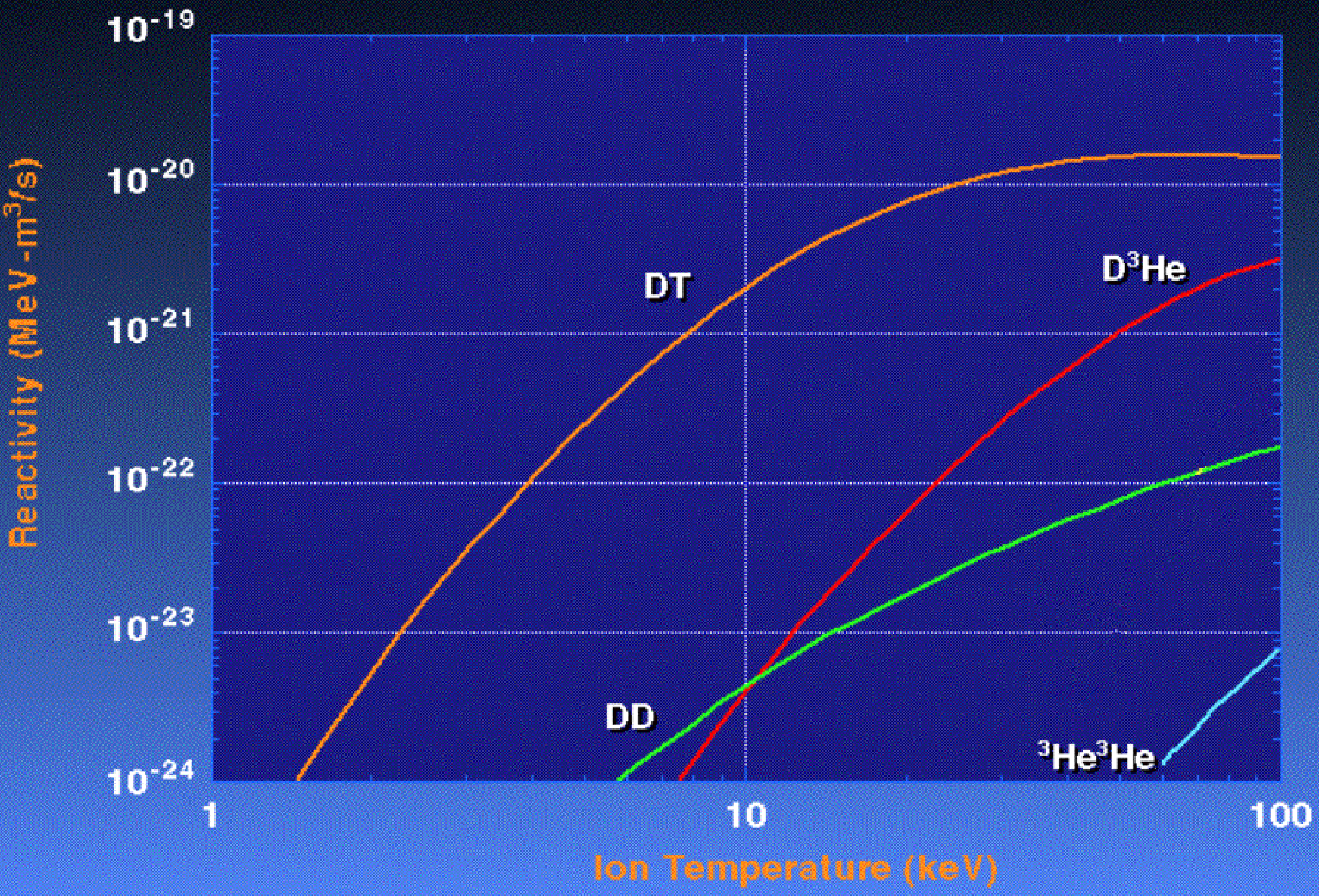
2nd Generation

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

3rd Generation

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

Maxwellian Fusion Reactivities ($\Sigma E_{fus}\sigma v$)



Why Are We Interested in the Advanced Fusion Fuel Cycles 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

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

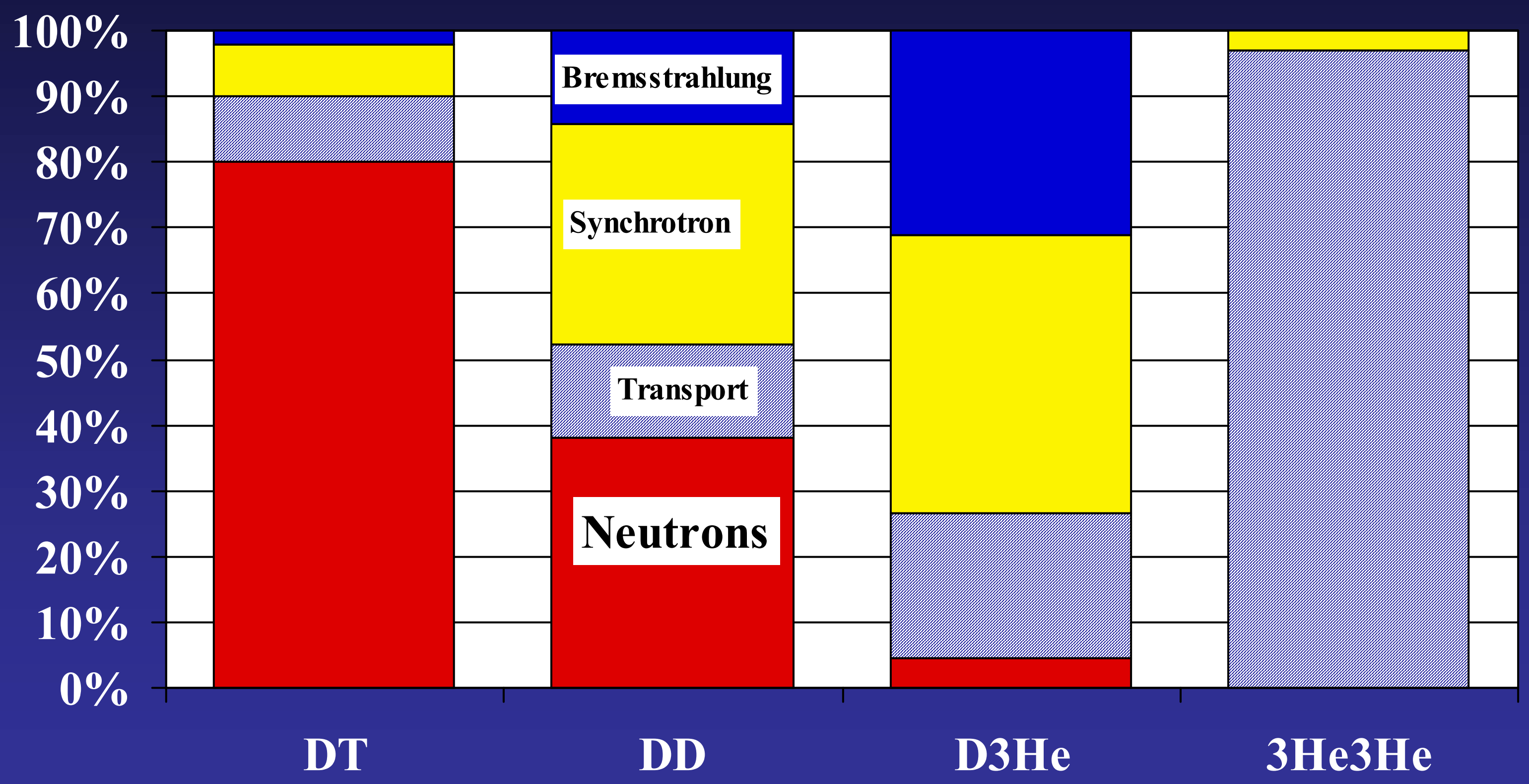
Can the Use of Fusion Fuels Alleviate the Public’s Fear About Radioactivity?

Some Fusion Fuels Have More Radioactivity Associated With Them Than Others

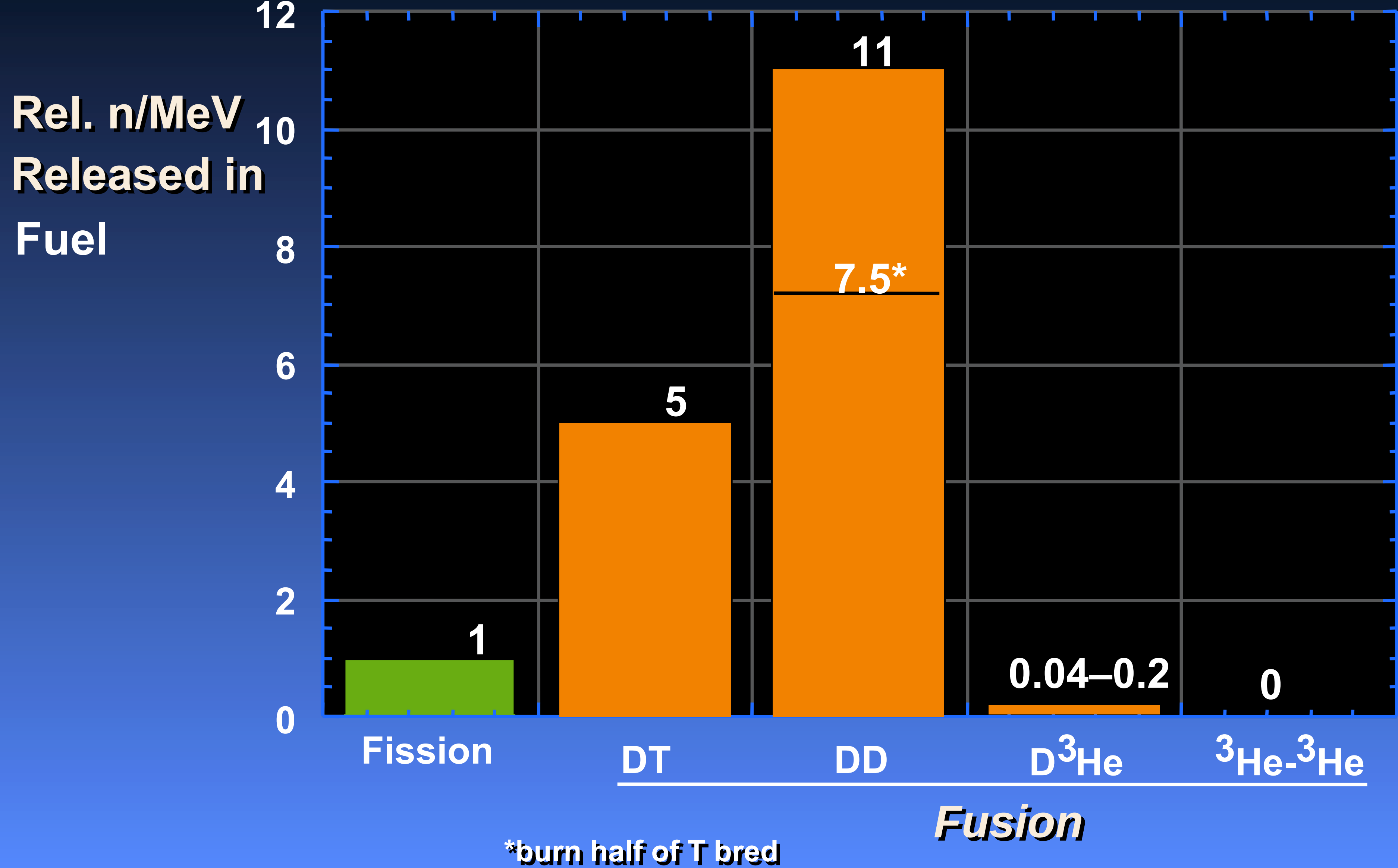
Fuel Cycle	Radioactive Fuel	Direct Radioactivity			Indirect Radioactivity		
DD	--	n	T	--	n		
DT	T	n	--	--	n	T	
D^3He	--	--	--	--	n	T	
$^3He^3He$	--	--	--	--	--		
p^6Li	--	--	--	--	n	T	^7Be ^{11}C
$p^{11}B$	--	--	--	--	n Small		^{14}C small

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

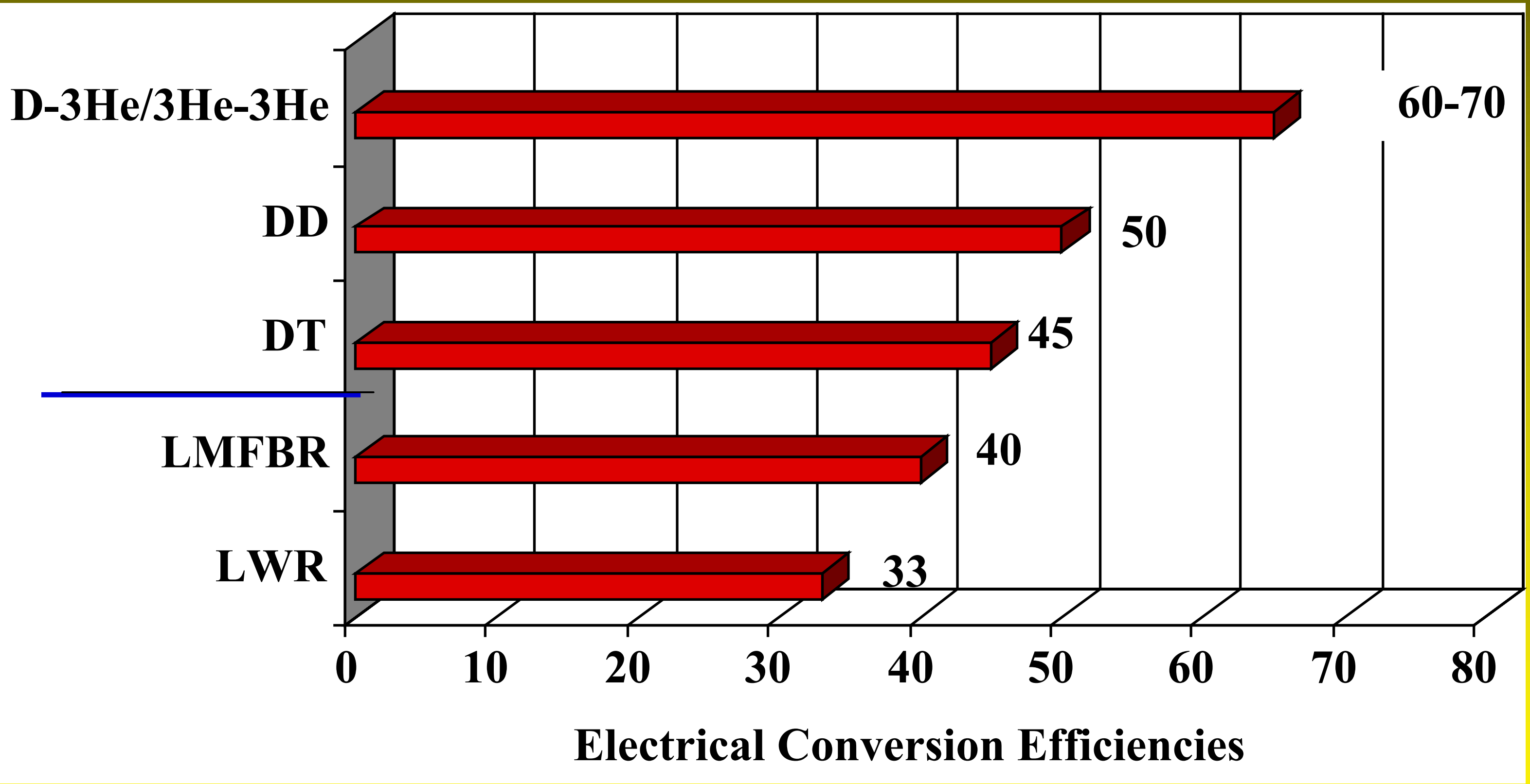
The Form of Energy Released in a Magnetic Fusion Device Depends on the Fuel Cycle



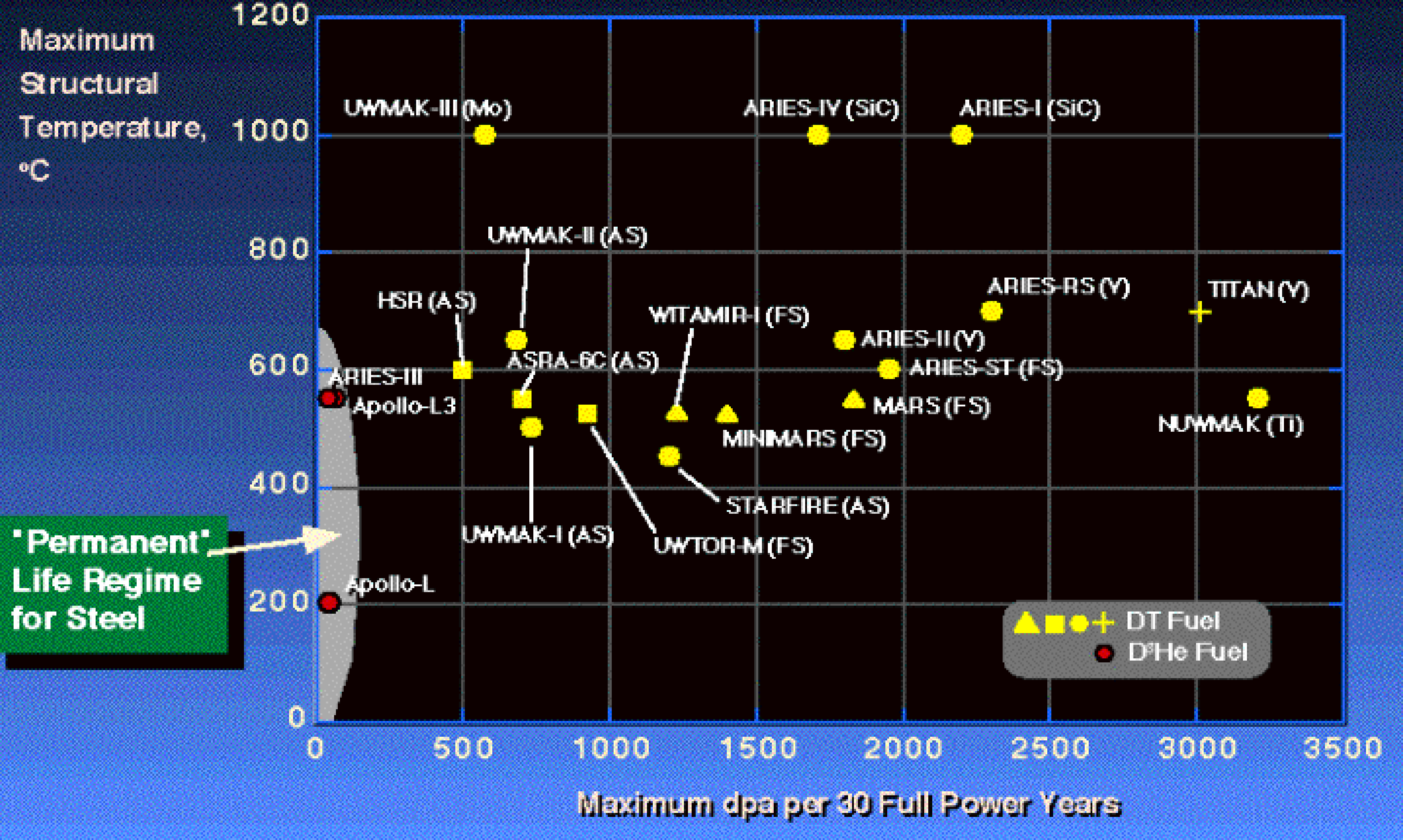
The Number of Neutrons Generated by Helium-3 Fusion Fuels is Very Small



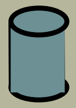
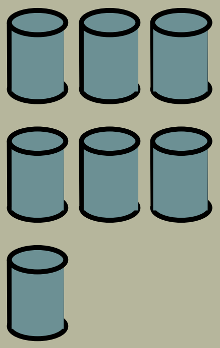
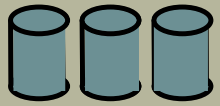
Nuclear Energy Conversion Efficiencies



The Low Radiation Damage in D^3He 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				

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 $^3He\,^3He$ Fusion Power Plants

- No Greenhouse or Acid Gas Emissions During Operation

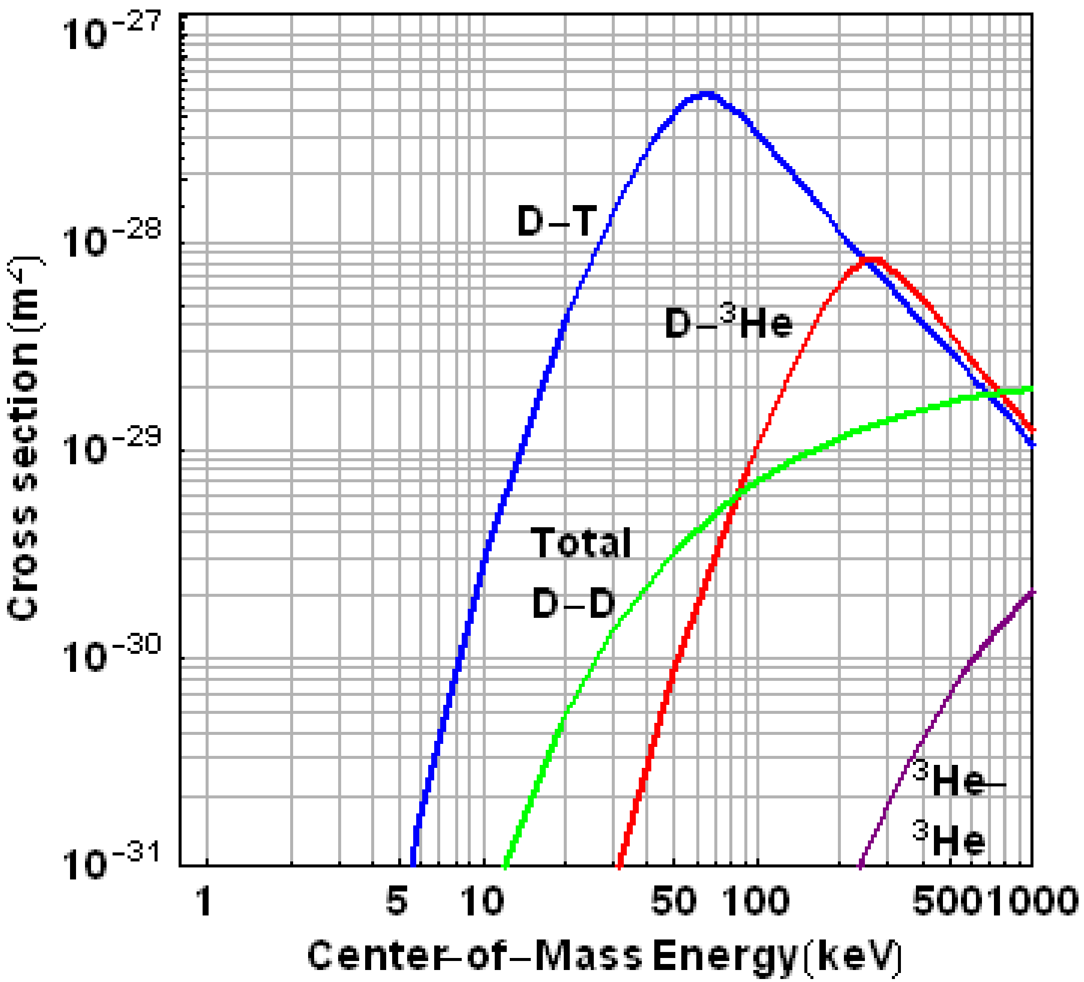
- Very High Efficiencies Possible (>70%)

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

Nuclear Energy Without Nuclear Waste !!

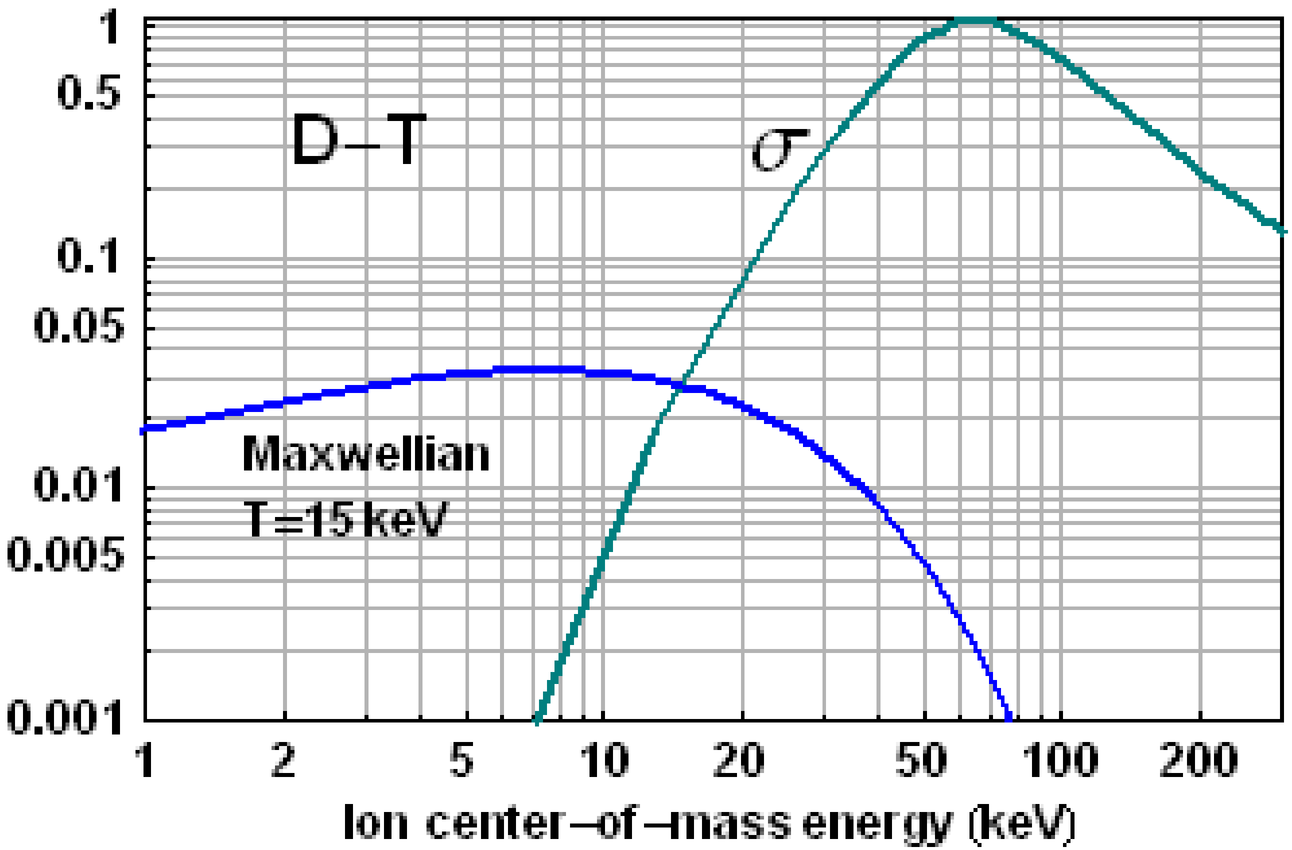
How Can We make the Advanced Fusion Fuel Cycles "Burn" More Efficiently?

Fusion Cross Sections for the First Three Generations



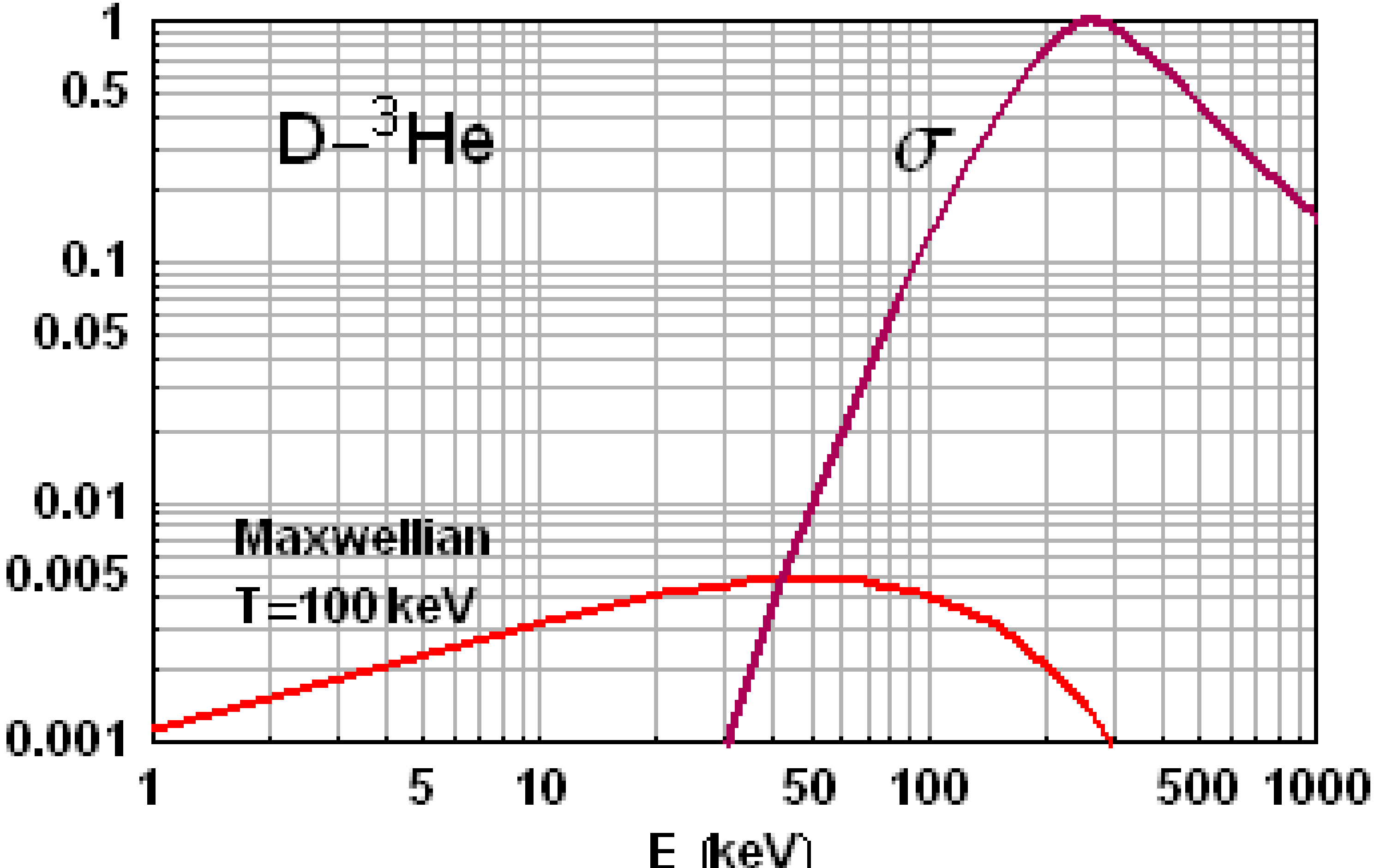
Source: J. F. Santarius

In a Maxwellian plasma, most of the fusions come from the high energy "tail" of the ion distribution



Source J. F. Santarius

In order to generate enough ions in the tail of a maxwellian distribution a D3He plasma would have to be heated to >100 keV



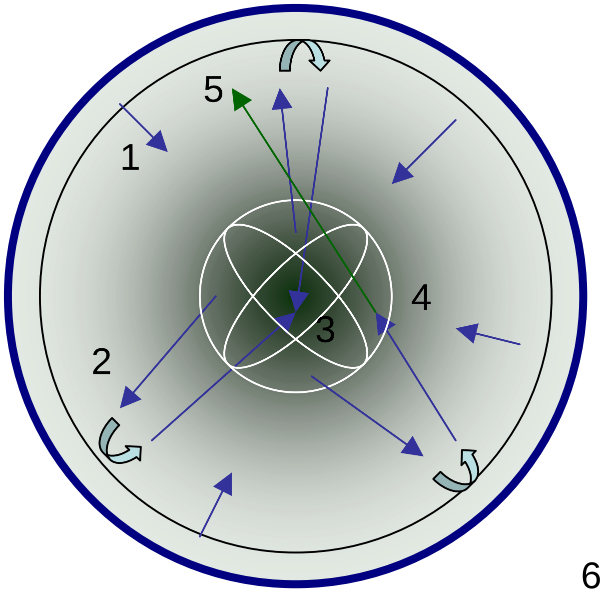
Source-J. F. Santarius

To Avoid the Limitations of Maxwellian Plasmas, Farnsworth Invented the Inertial Electrostatic Concept

1. Positive ions are created from the fuel gas near the outer grid, and are accelerated towards the negativity charged inner grid.

2. The ions can oscillate through the inner grid several times, creating a concentration of high temperature ions.

3. The ions can collide, creating a fusion reaction.

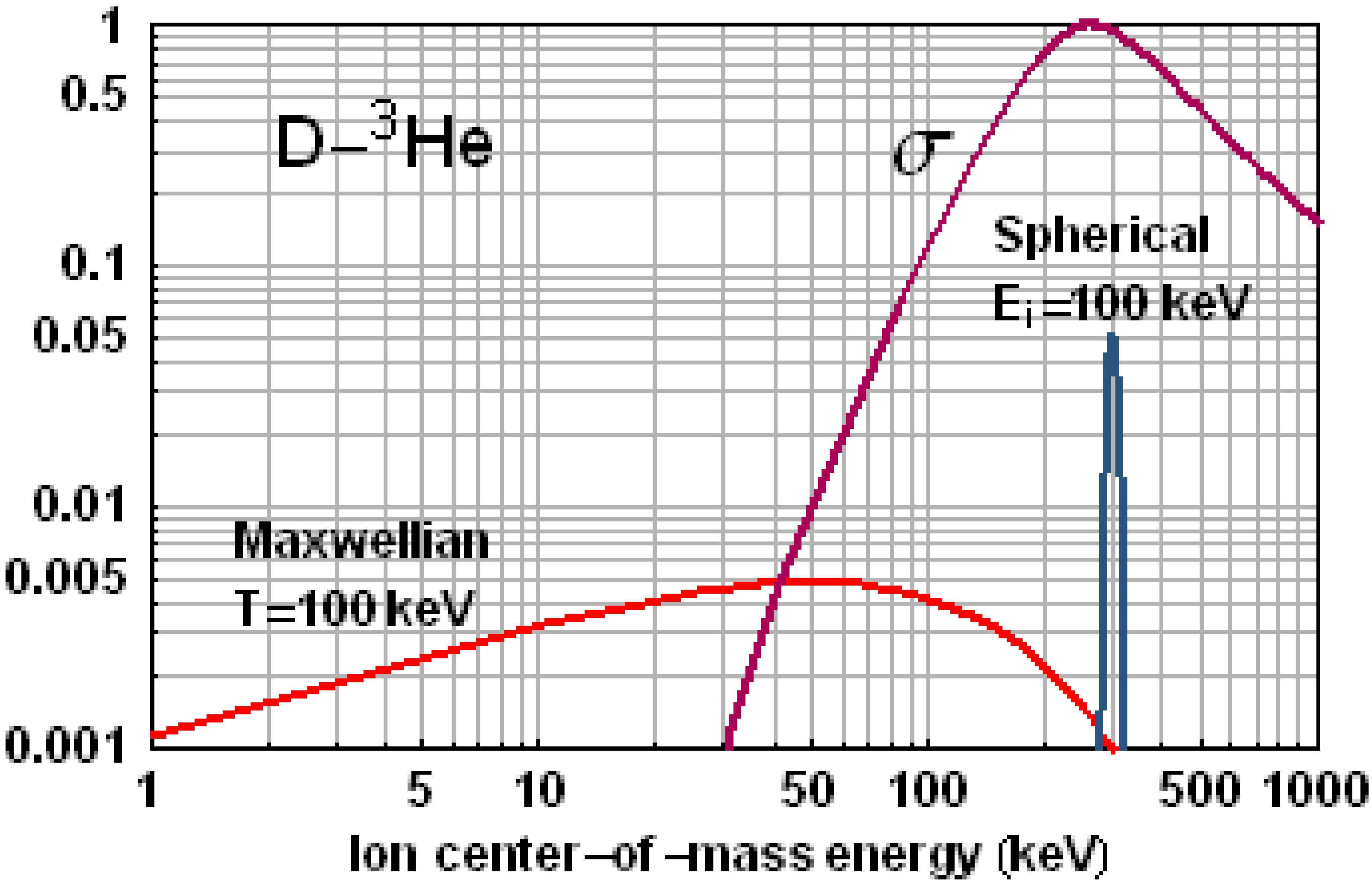


4. The ions can also undergo a charge exchange, creating a fast neutral.

5. Fast neutrals can collide with the neutral gas, also creating fusion reactions.

6. High energy fusion products, such as protons and neutrons, are created and can be used in many different applications.

Using the IEC concept, accelerating ions to 100 keV makes much more efficient use of the input energy



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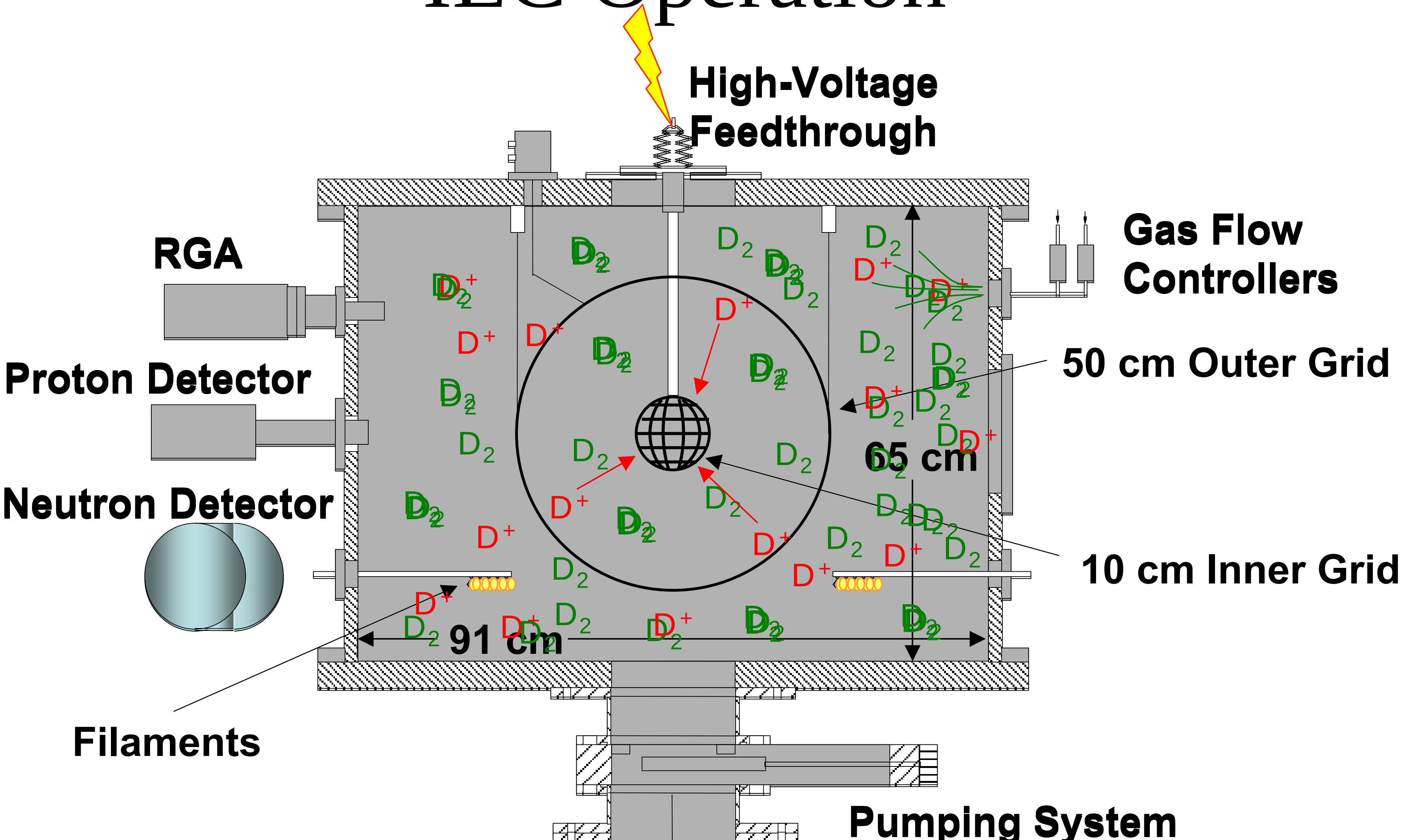
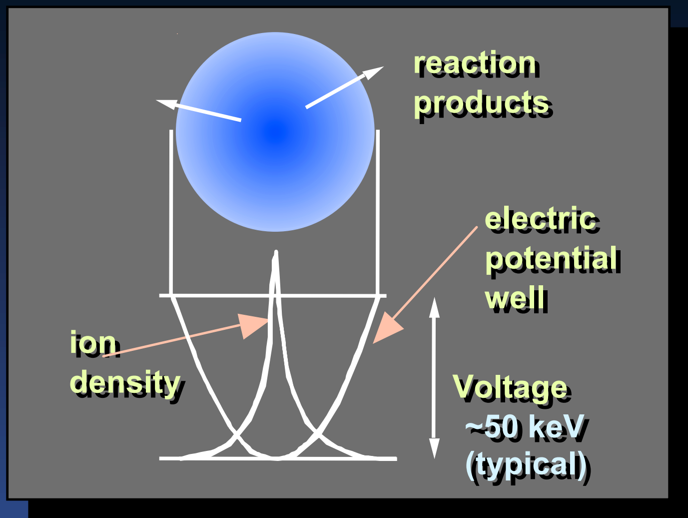
Reactivities ($\Sigma E_{fus}\sigma v$) versus IEF Well Depth

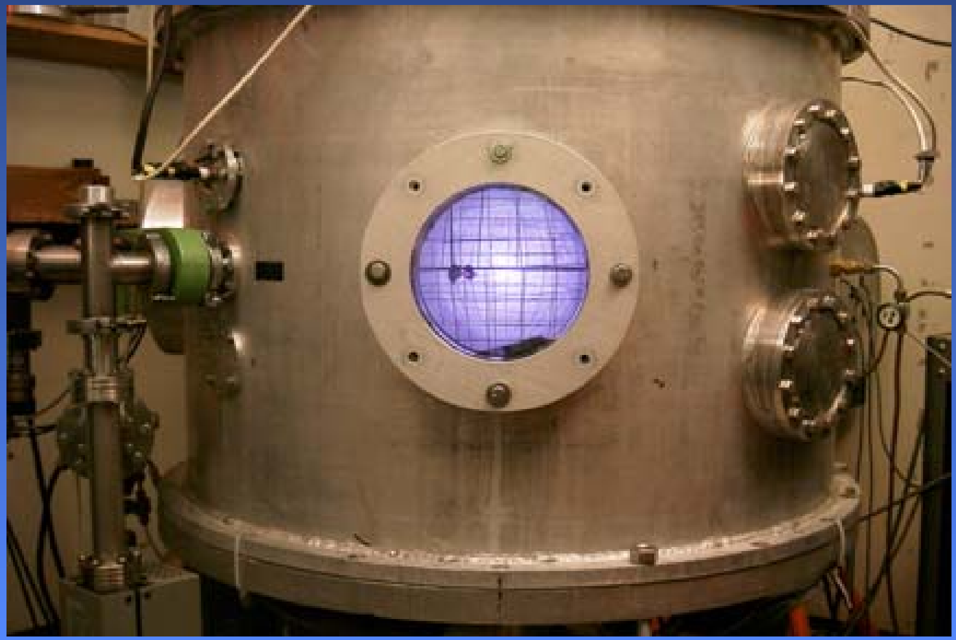
IEC Operation



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

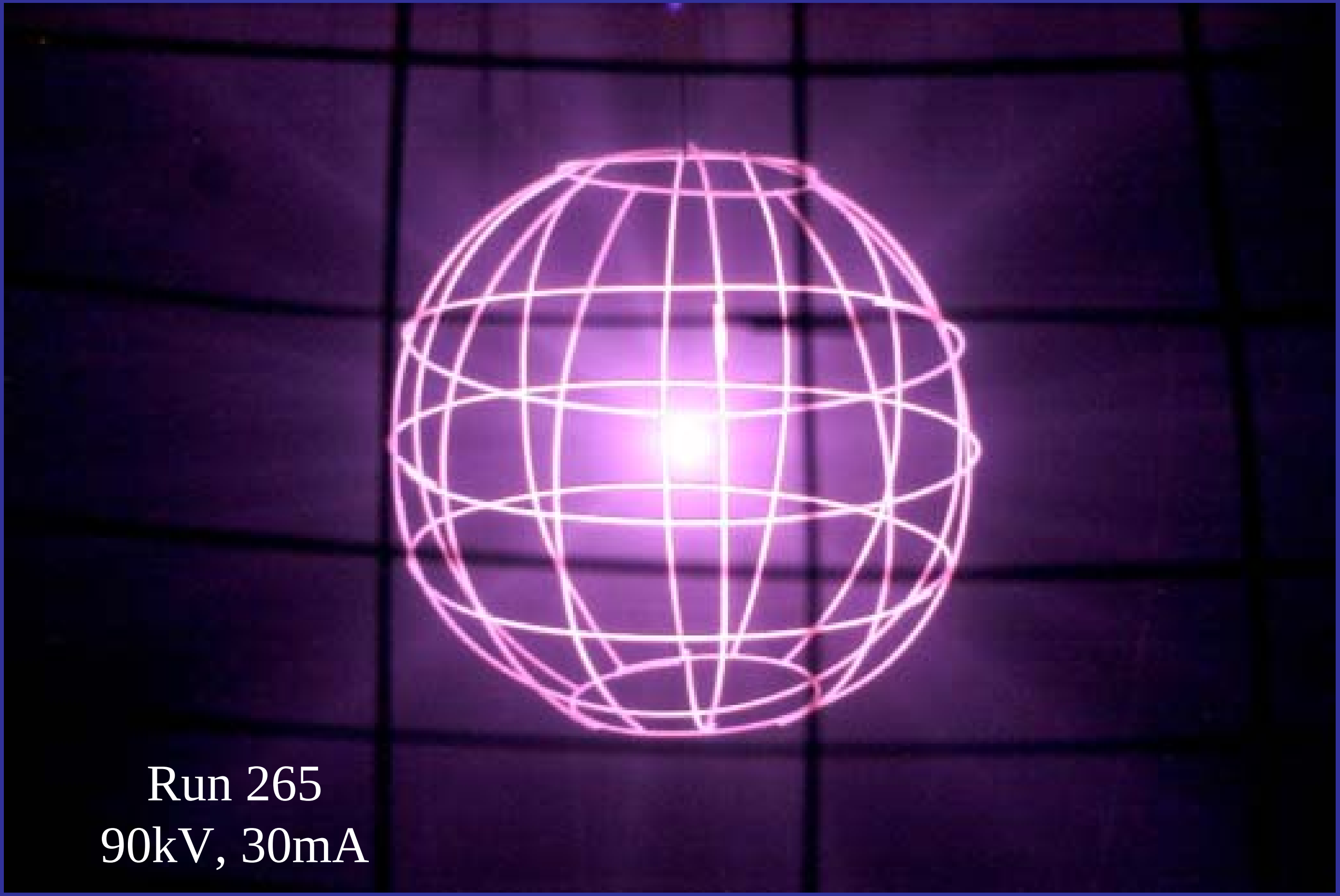


cathode voltage=55 kV
cathode current=60 mA
pressure=1 mtorr

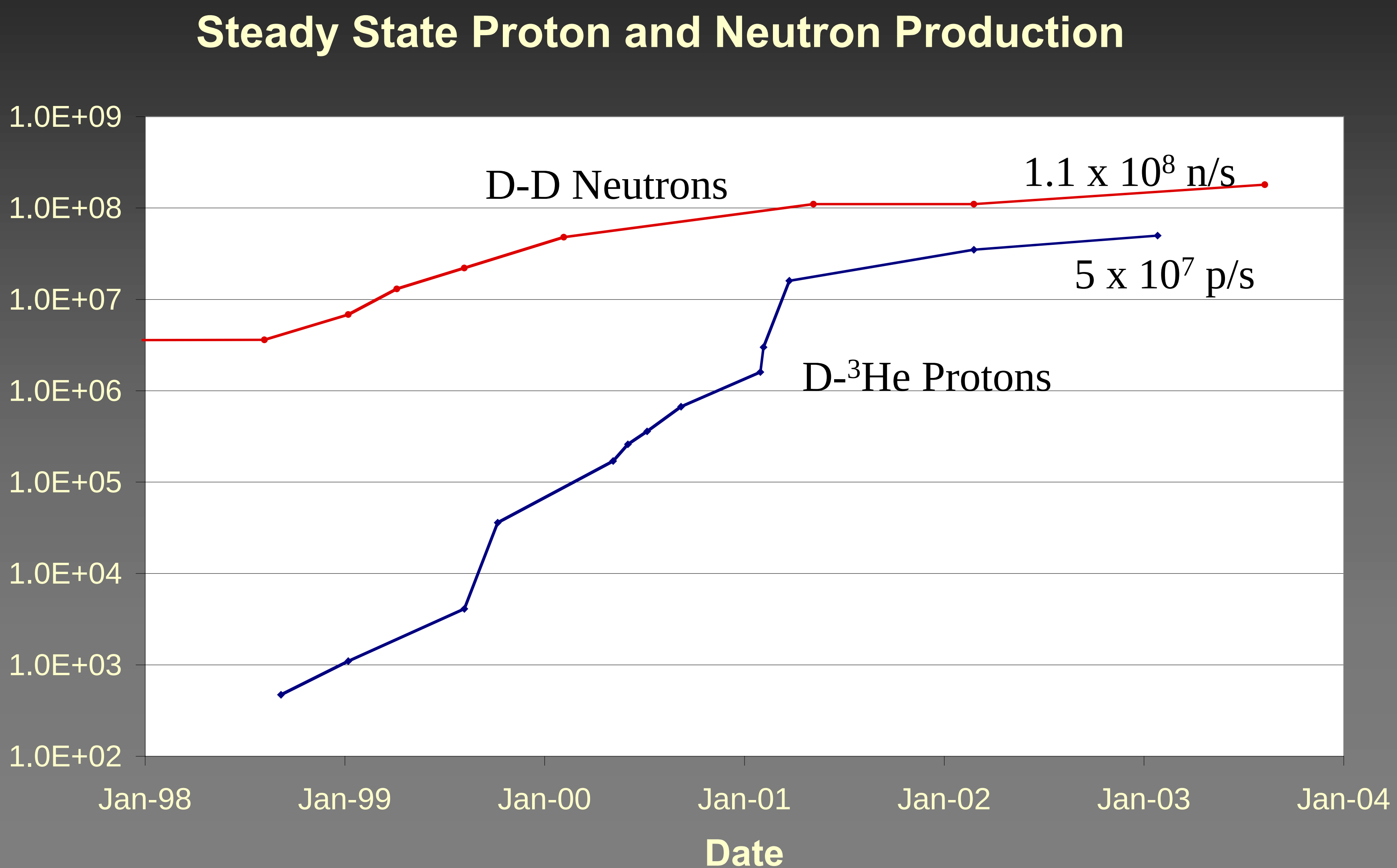


The Steady State D-^{3}He Fusion Rate in the UW IEC Device is Now ≈5 x 10^{7} p/s

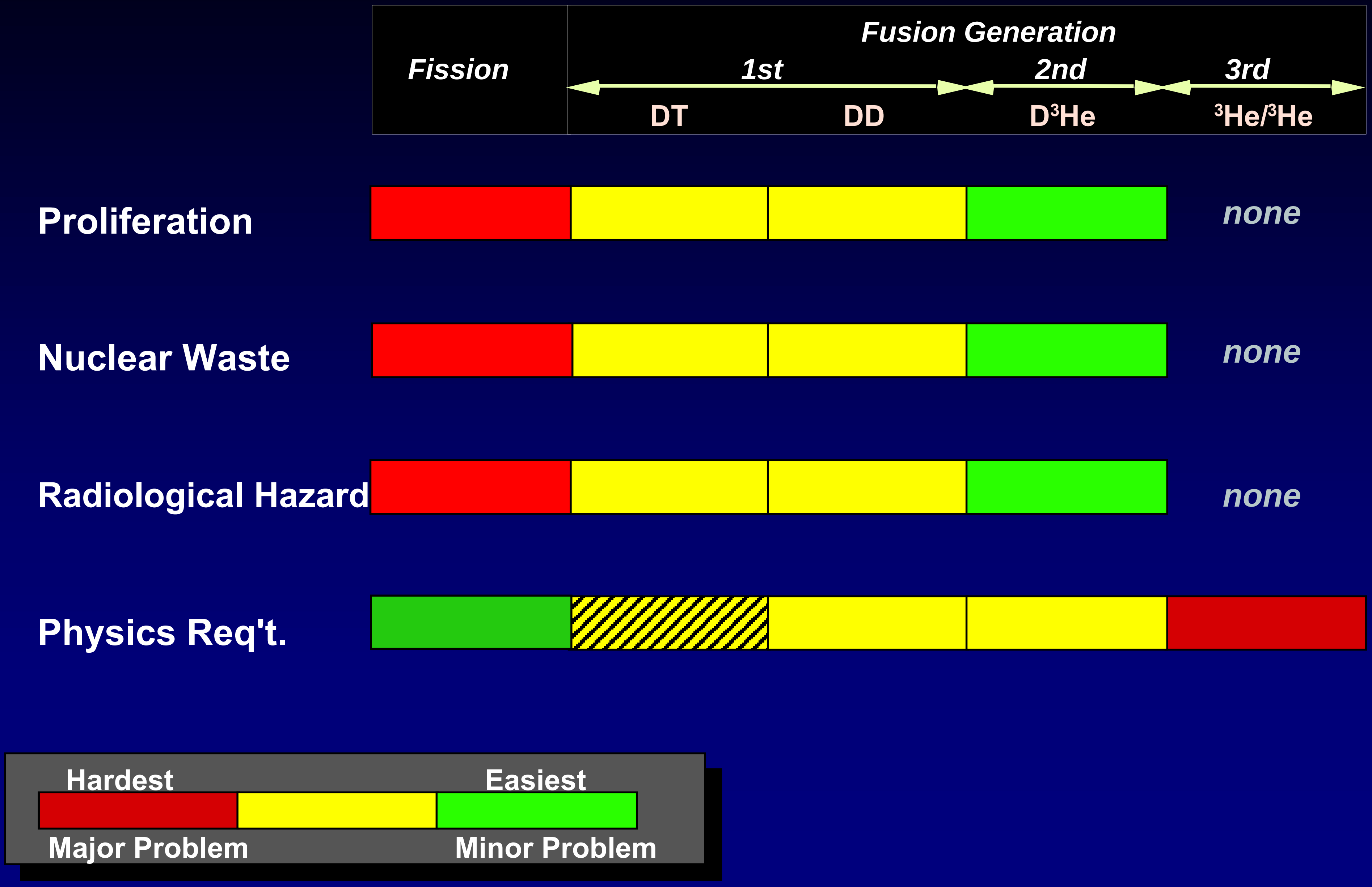
(115 kV, 60 mA)



UW Performance History



Major Societal and Technical Concerns of Nuclear Energy Options



Why Consider the Advanced Fuels for Power Production?

Major Advantages

- Significant Reduction in Radiation Damage
  - (permanent 1st wall)
- Greatly reduced (or no) radioactivity
- Potential for Direct Conversion
  - (higher efficiency & lower waste heat)

Major Disadvantages

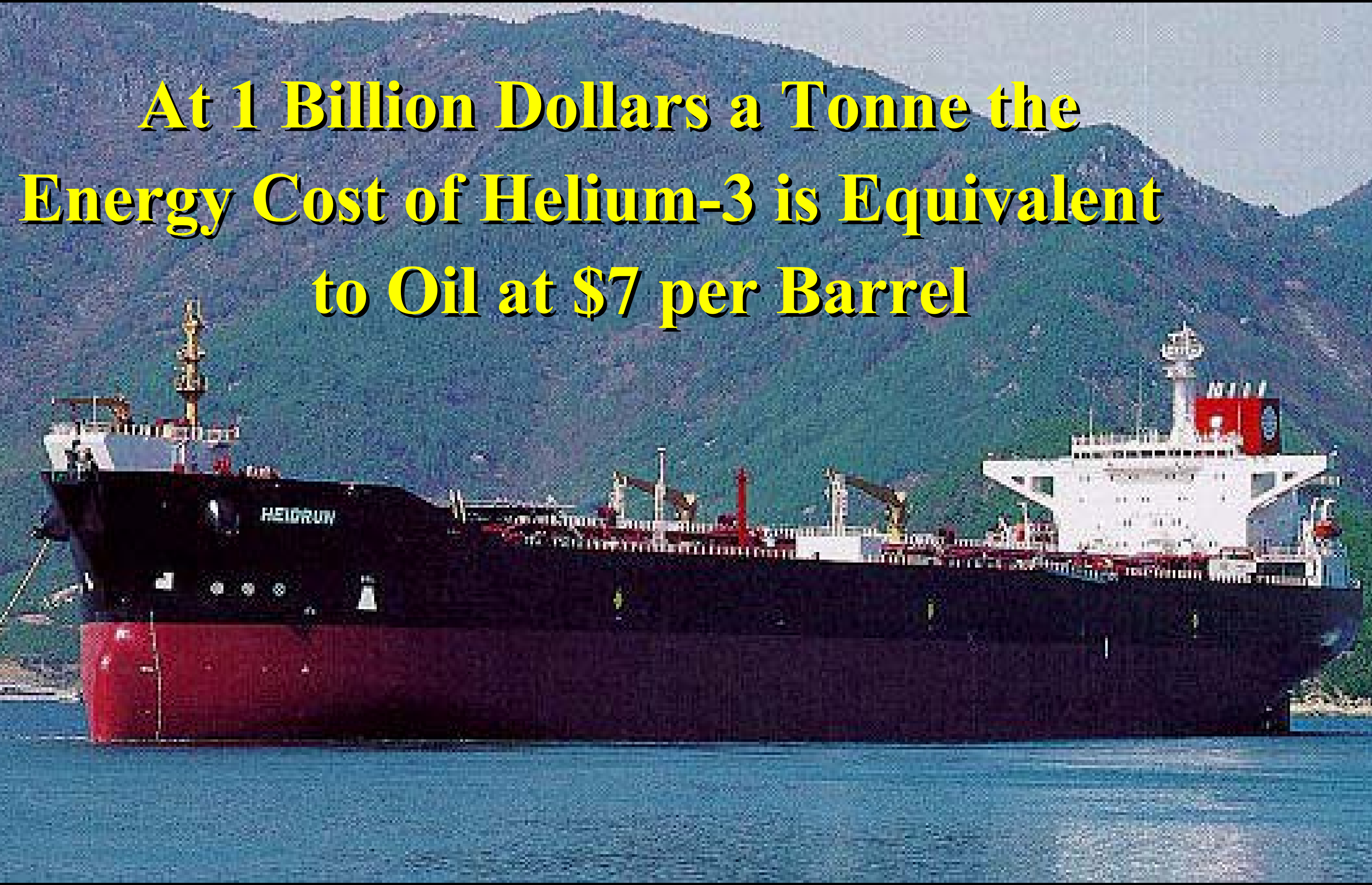
- Higher operating temperature
  - (higher $n\tau$ values)
- Lower plasma power density or yield
  - (requires higher beta or ρr)
- Fuel source-^{3}He
  - (requires NASA collaboration)

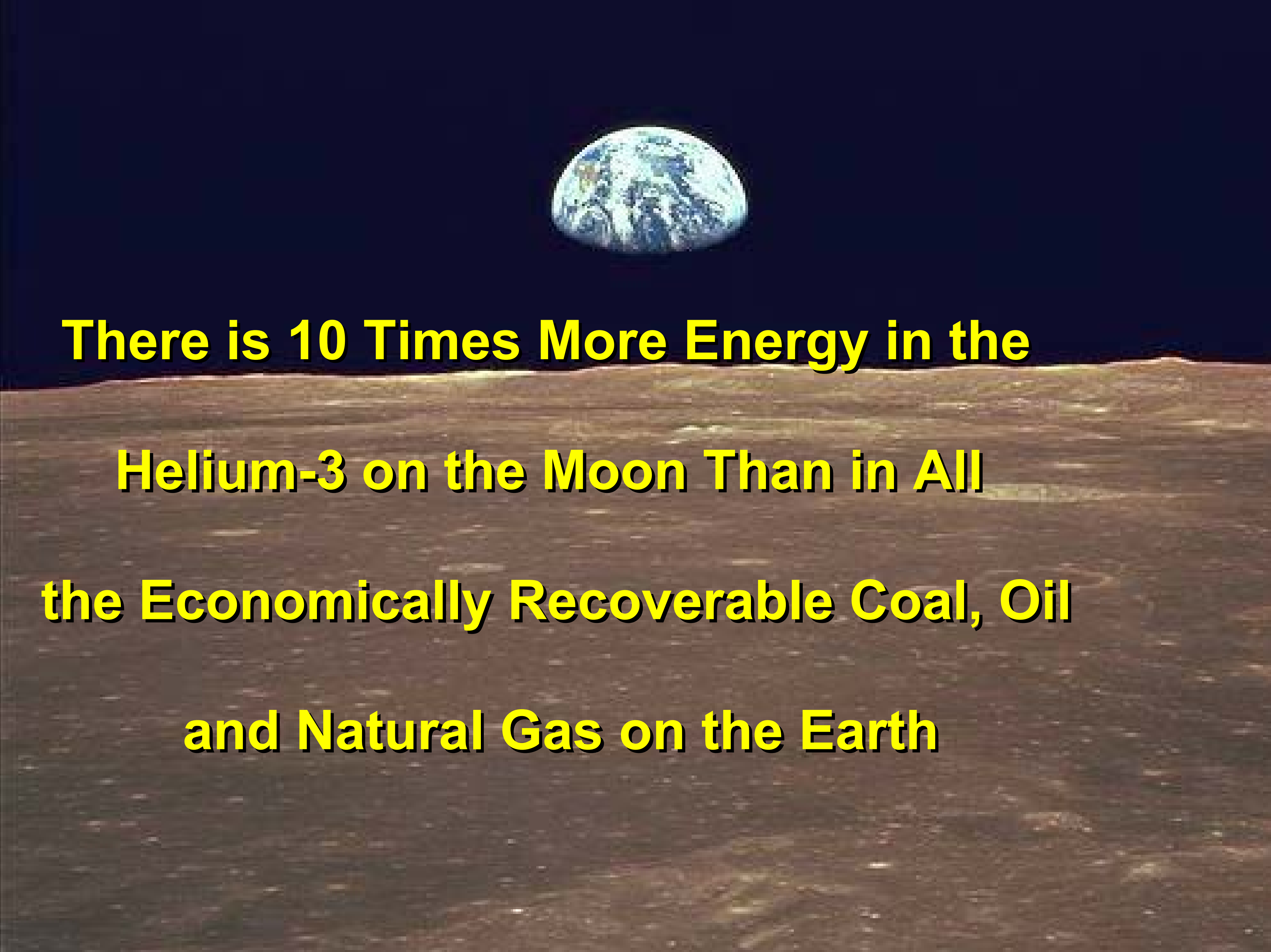
Significance of Lunar Helium-3

- 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 2004.

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

Conclusions

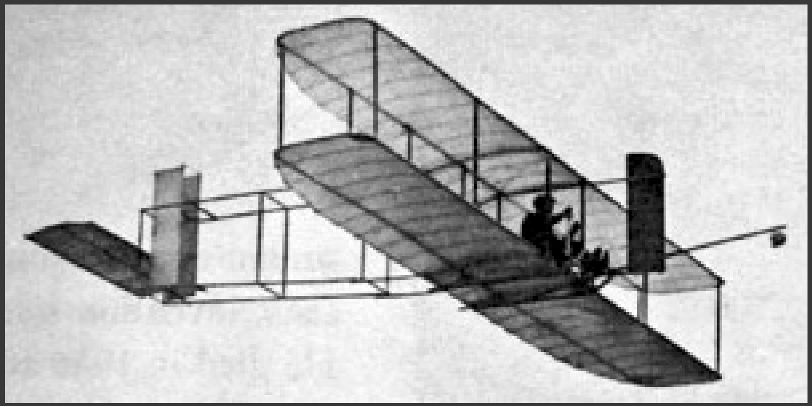
The use of second and third generation fusion fuels could revolutionize the Public's view of fusion power by:

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**