New Opportunities for Fusion in the 21st Century – Advanced Fuels

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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 large volumes of radioactive waste
Proliferation	Reactor does not require fissile or fertile material However, excess neutrons can be used to breed ^{239}Pu

Fusion Can Significantly Reduce or Even Eliminate the Public's Fear of Nuclear Power in the 21st Century

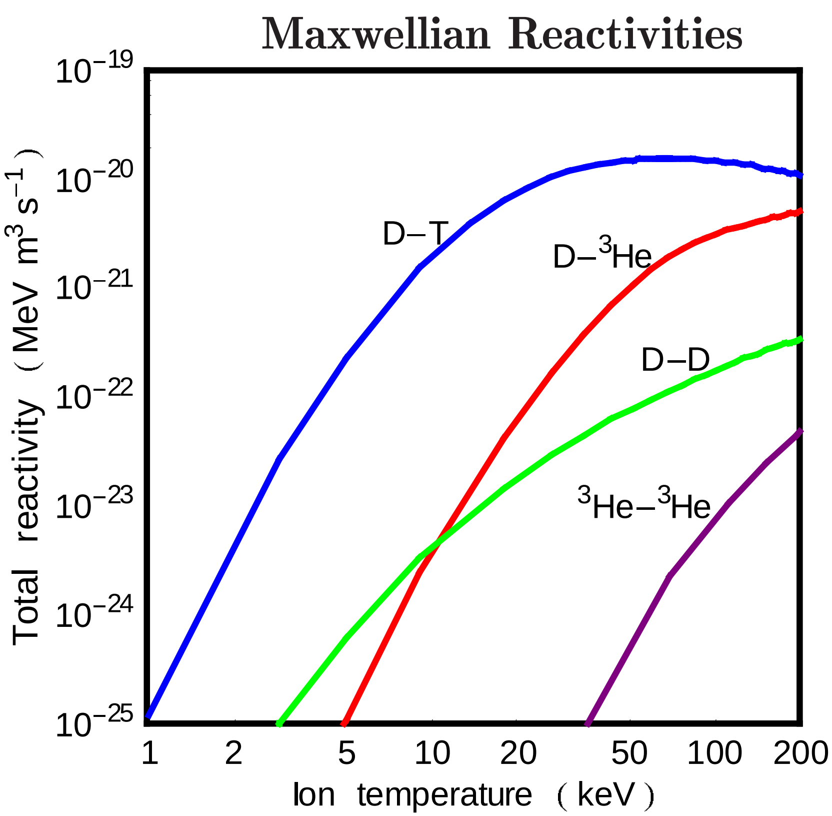
The key to fusion's long-term advantage is that the fuel and reaction products of second and third generation fusion fuels can greatly reduce, or even eliminate radioactivity and potential proliferation concerns.

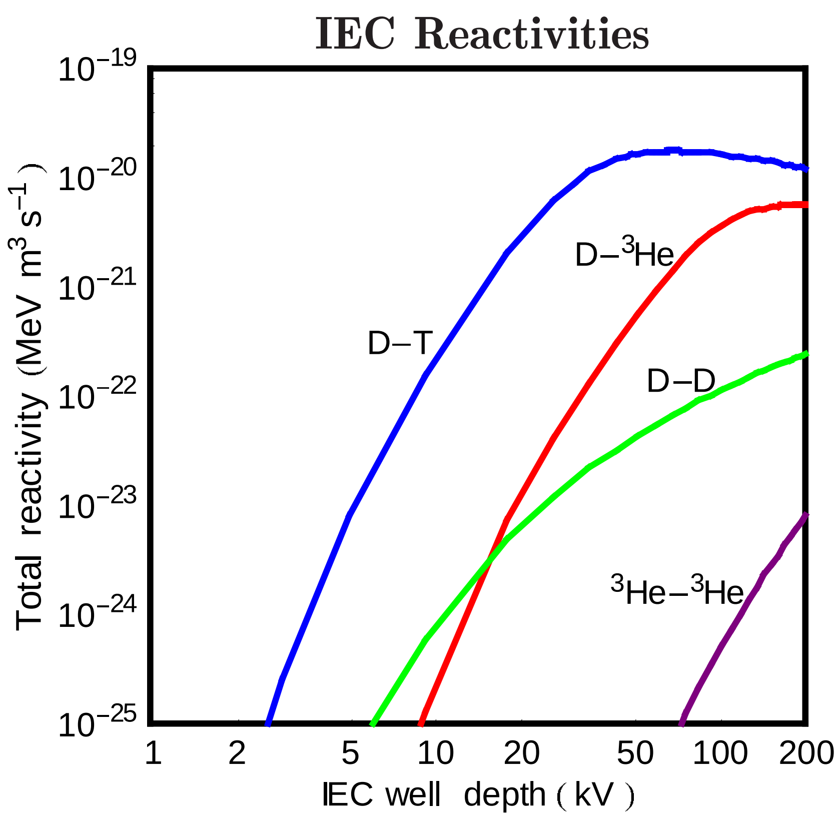
What Do We Mean by Advanced Fuels?

- Fusion fuels that emit few or no neutrons
- Not the DT or DD cycle (first generation)
- Most promising fuel cycle (second generation): D^3He
- Future fusion fuel cycles (third generation): $^3He^3He$

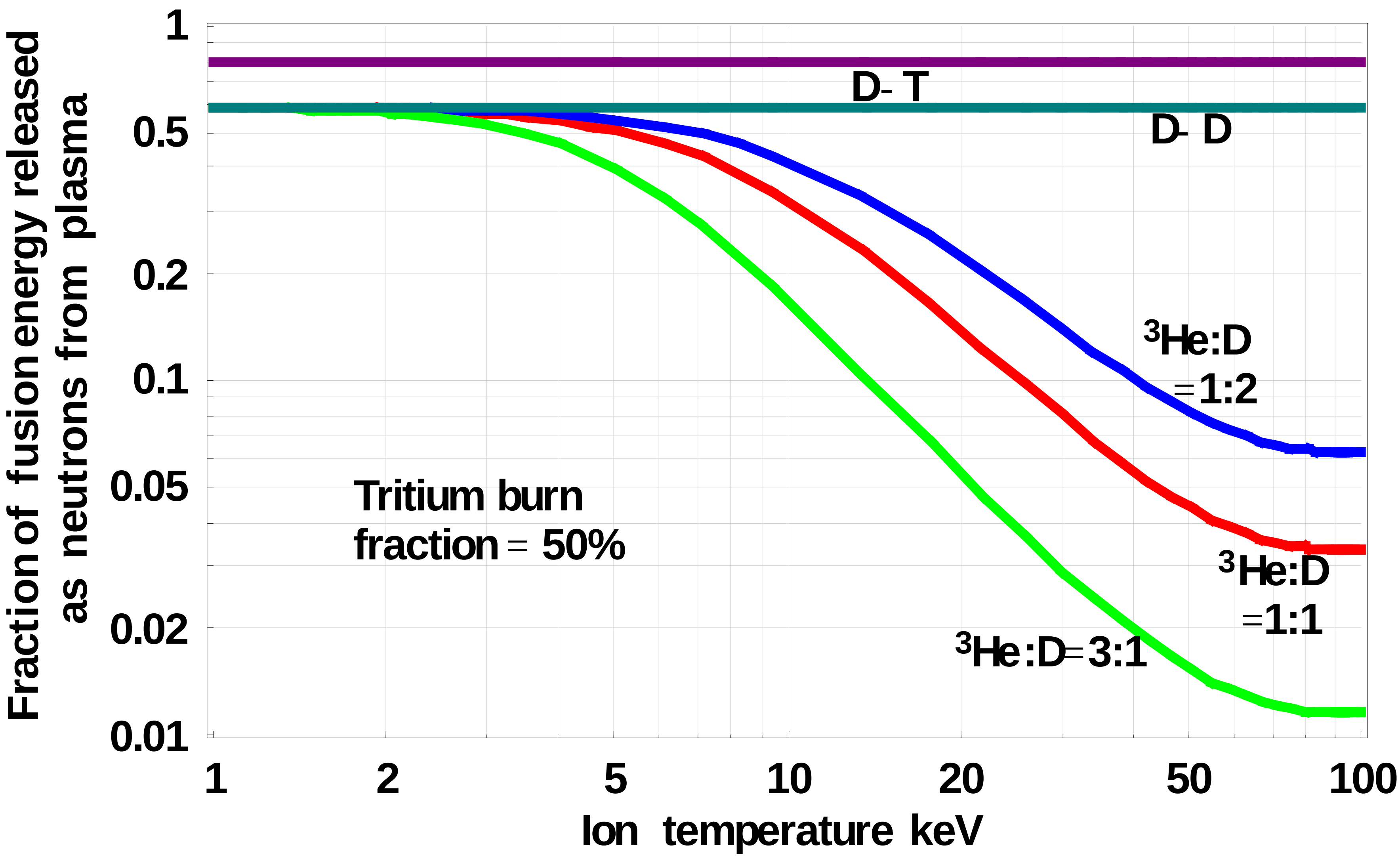
Once the Physics of Fusing Plasmas is Understood, Scientists and Engineers Can Move on to the More Attractive 2nd and 3rd Generation Fusion Fuels

1st Generation	D + T	$\longrightarrow$	n (14.07 MeV) + ^{4}He (3.52 MeV)
	D + D	$\longrightarrow$	n (2.45 MeV) + ^{3}He (0.82 MeV)
	D + D	$\longrightarrow$	p (3.02 MeV) + T (1.01 MeV)
2nd Generation	D + ^{3}He	$\longrightarrow$	p (14.68 MeV)+ ^{4}He (3.67 MeV)
3rd Generation	^{3}He + ^{3}He	$\longrightarrow$	2p + ^{4}He (12.86 MeV)

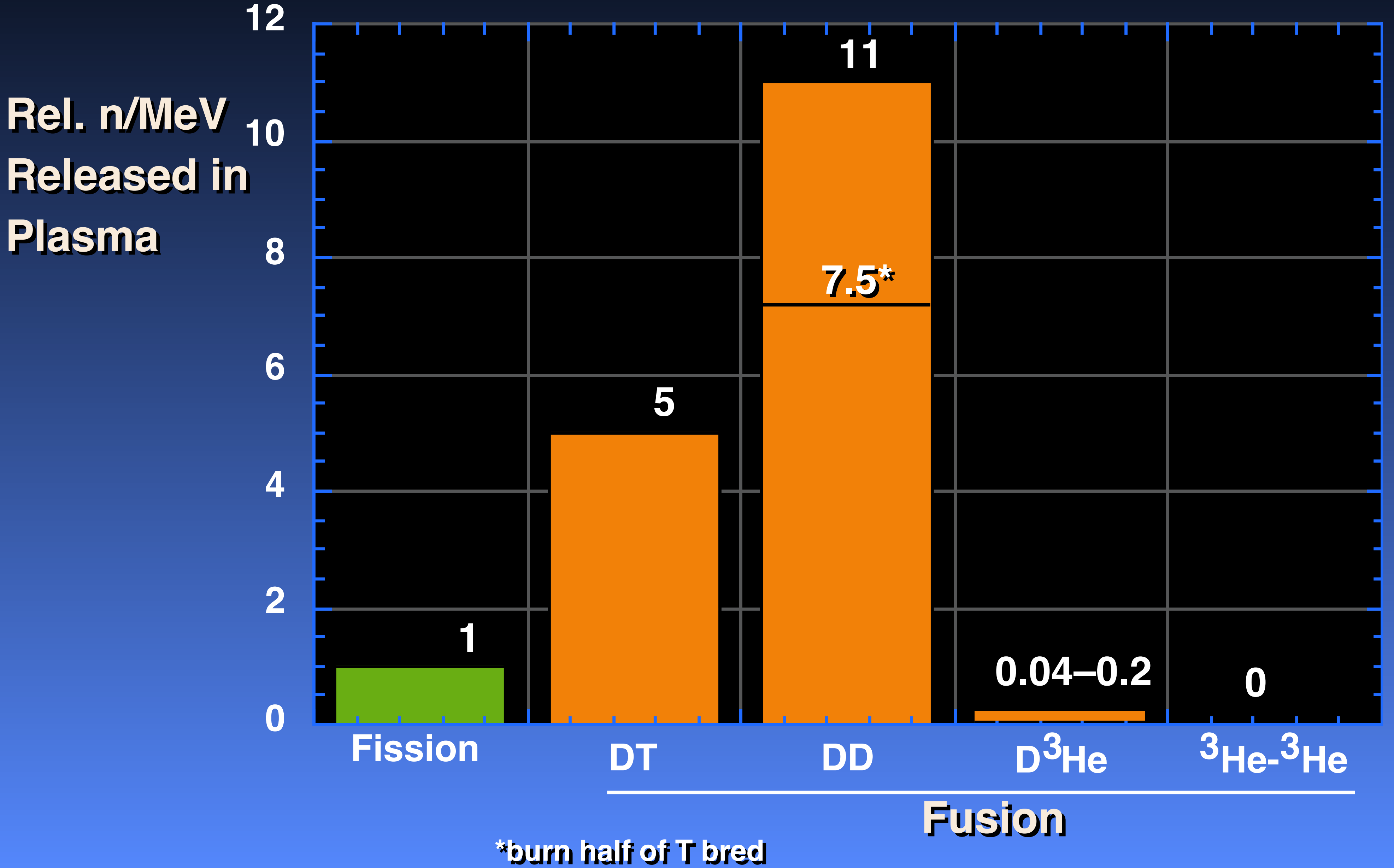




D-^{3}He Fusion Neutron Production Can Be Very Small



The Number of Neutrons Generated by the ^{3}He Based Fusion Fuels is Very Small



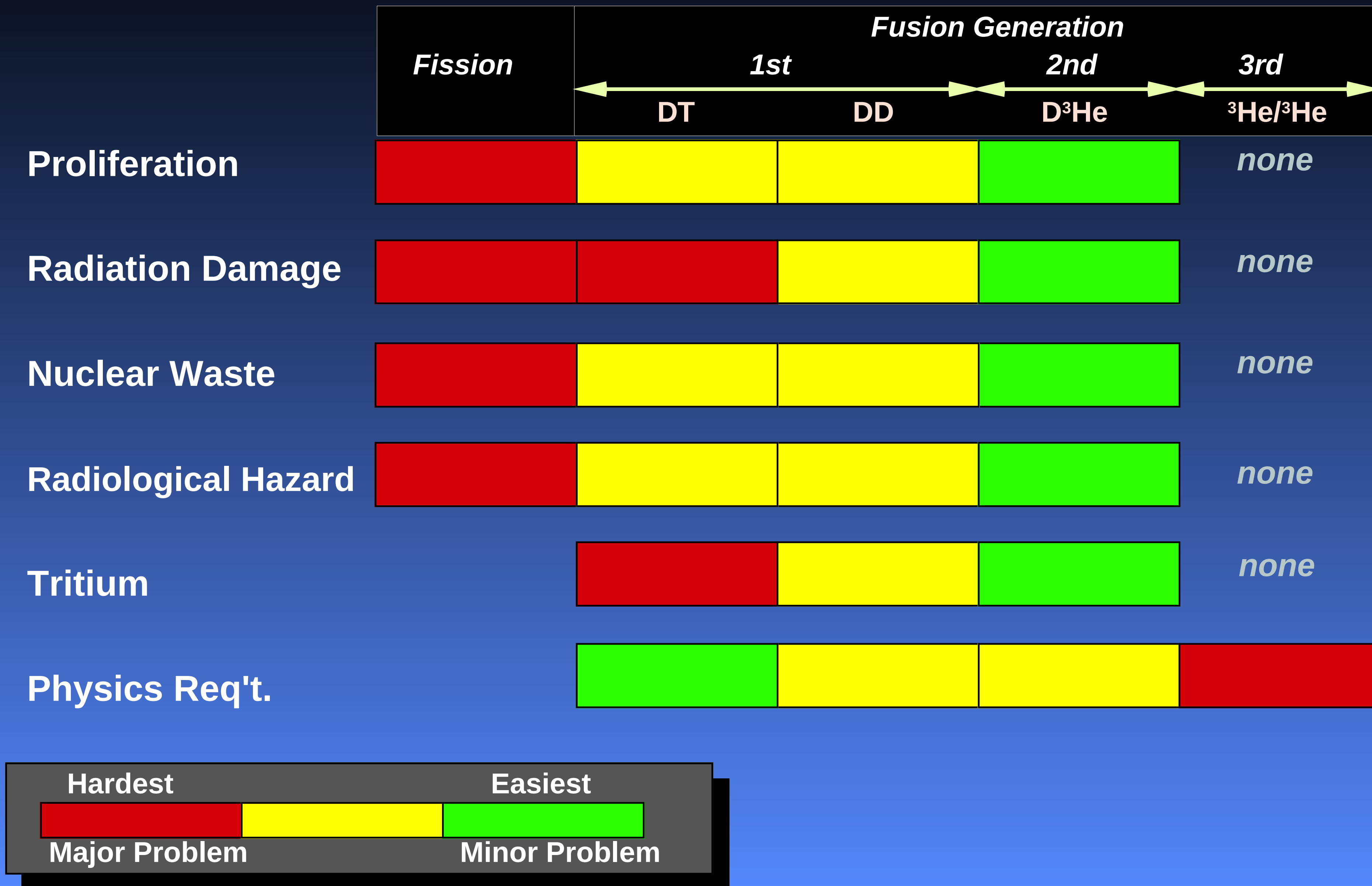
Key Technological Features of Fusion Fuels

	1st Generation DT	2nd Generation D^3He	3rd Generation $^3He^3He$
Physics	Easiest (10 keV)	Harder (50 keV)	Hardest (≥ 200 keV)
First Wall Life (Matls. Dev. Prog.)	3–4 FPY's (extensive)	Full Lifetime (small)	Full Lifetime (off-the-shelf)
Radioactivity (vs. Fission)			
after 1 day	≈ same	3%	'None'
after 100 years	0.1%	0.003%	'None'
Electrical Efficiency (vs. fission)	≈ same	1.5–2 times higher	≈ 1–1.5 times higher

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^{3}He (SiC)	^{3}He^{3}He (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	55			
Deep Geological (Yucca Mtn.)	≈1000				

Major Societal and Technical Concerns of Nuclear Energy Options



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

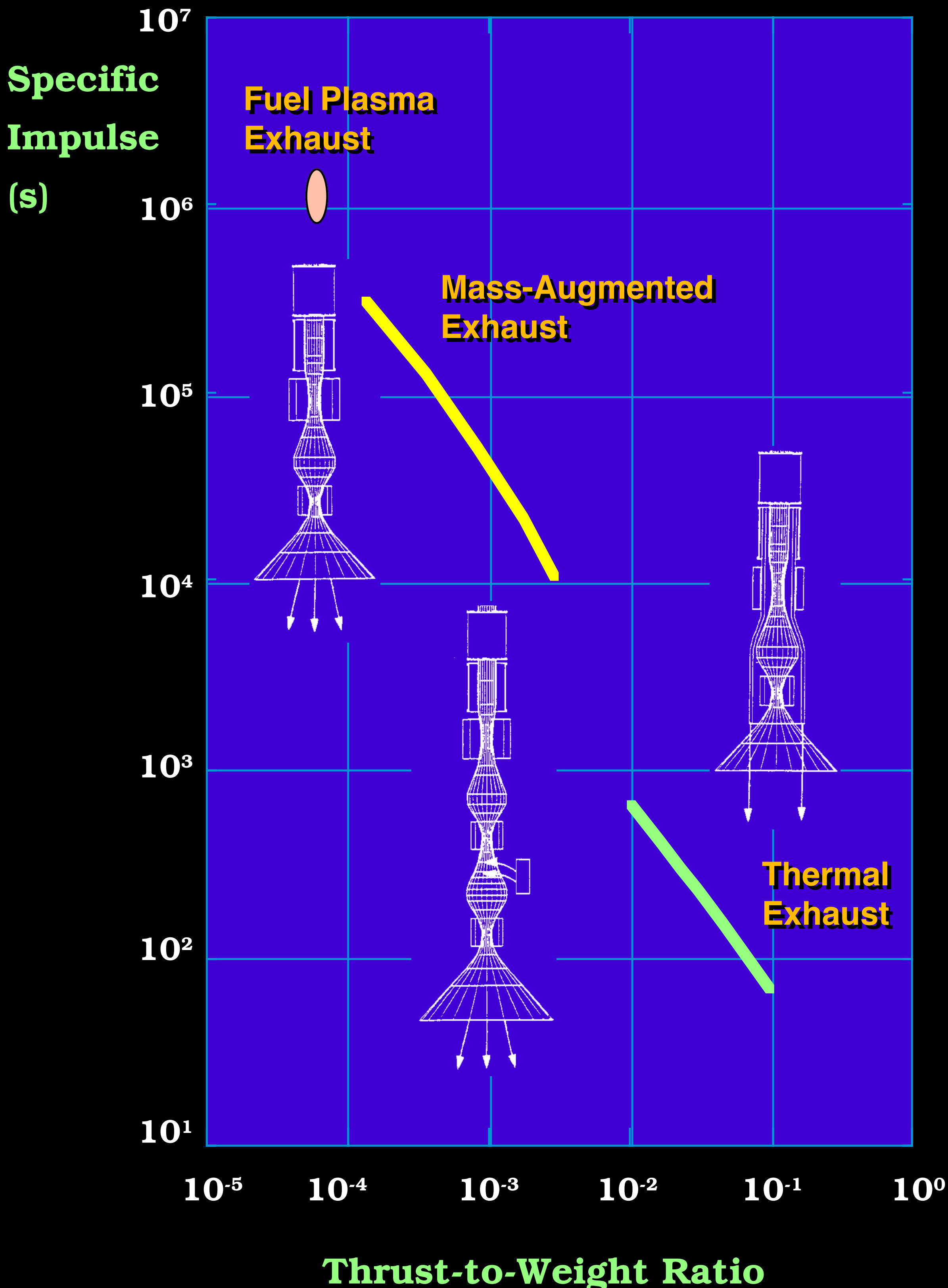
- Medical Treatment
- Civilian Commercial Markets
- Environmental Restoration
- Defense

What Use Can Society Make of Small, Compact (Q<1) Fusion Neutron or Proton Sources?

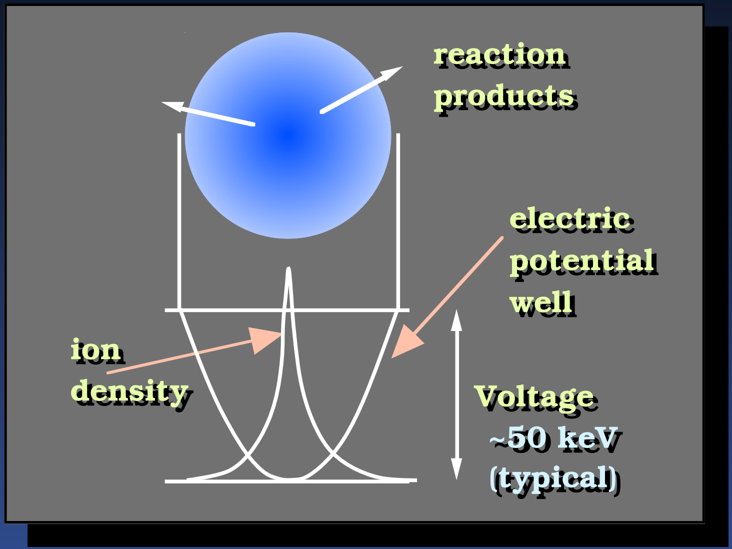
Neutron Applications	•Detection of Clandestine Materials •Trace Elements	PET Isotopes- ^{18}F	Isotopes- ^{99}Mo	•Destruction of Fission Waste •Tritium Production
Proton Applications	PET Isotopes - ^{15}O, ^{11}C, ^{13}N	PET Isotopes- ^{18}F	Isotopes- ^{99m}Tc	•Destruction of Long Lived Radioisotopes
Fusion Power Level	1–10 Watts	10 – 1000 W	1 – 100 kW	10 – 1000 MW

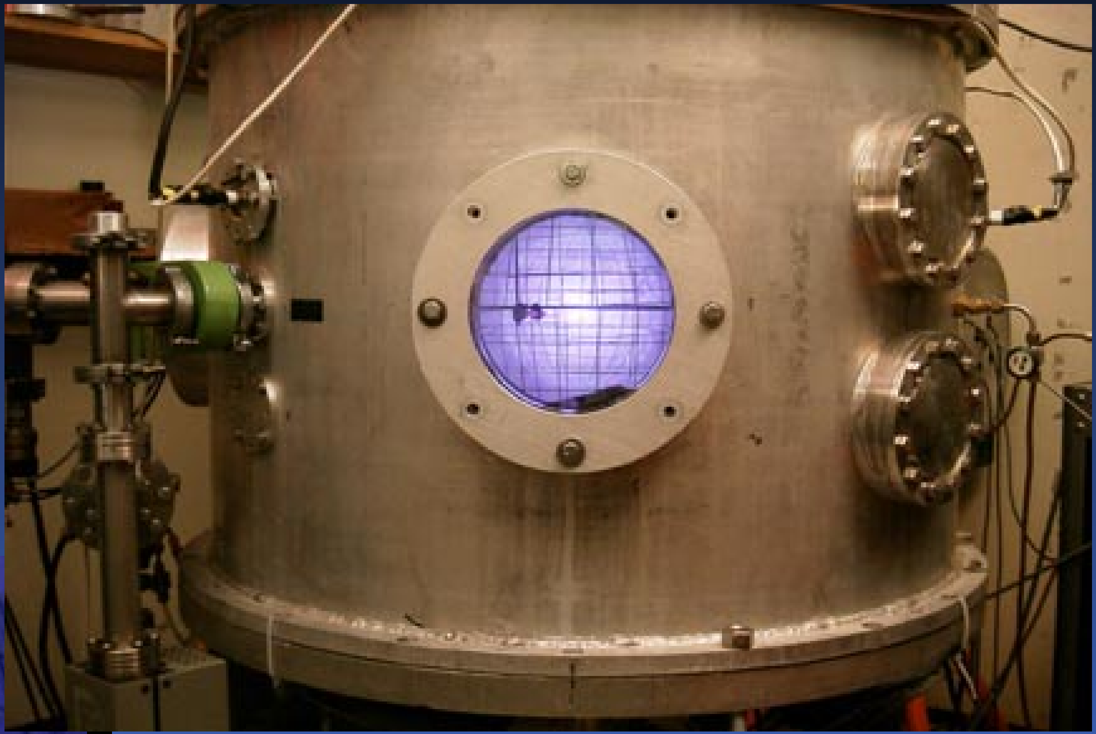
← nearer term

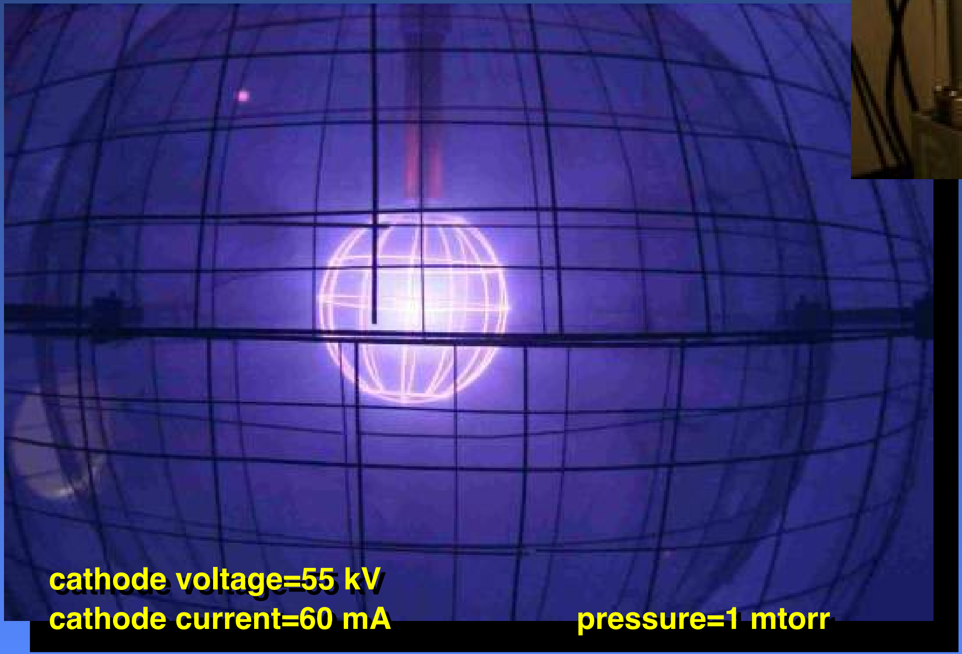
D-^{3}He Fusion Rockets Would Provide Very Flexible Thrust Parameters



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

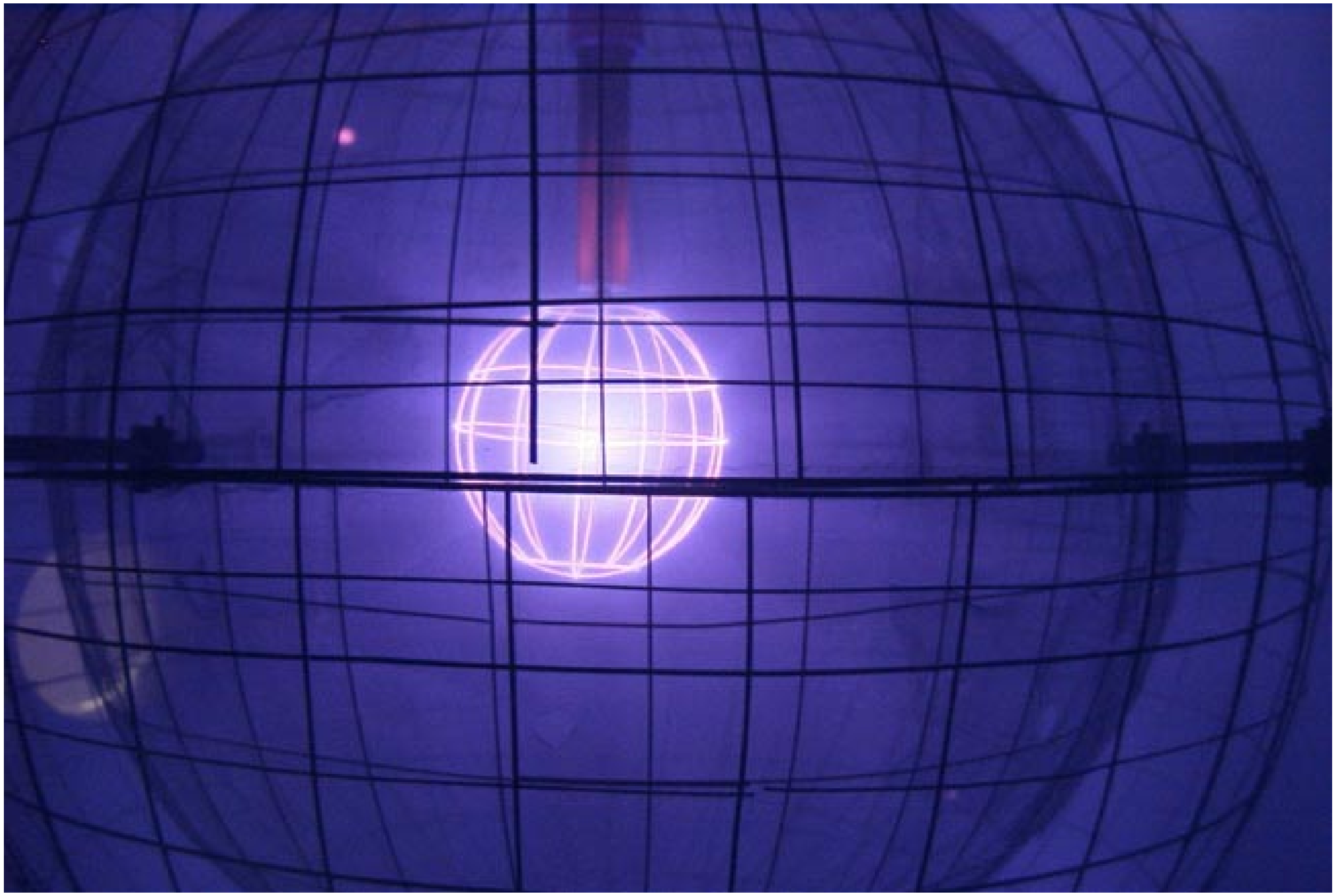






Record Steady State D-^{3}He Reaction Rate Achieved in Wisconsin IEC Device

7 x 10^6 protons/s



Cathode Voltage=70 kV

Cathode Current=30 mA

Pressure= 2 mTorr

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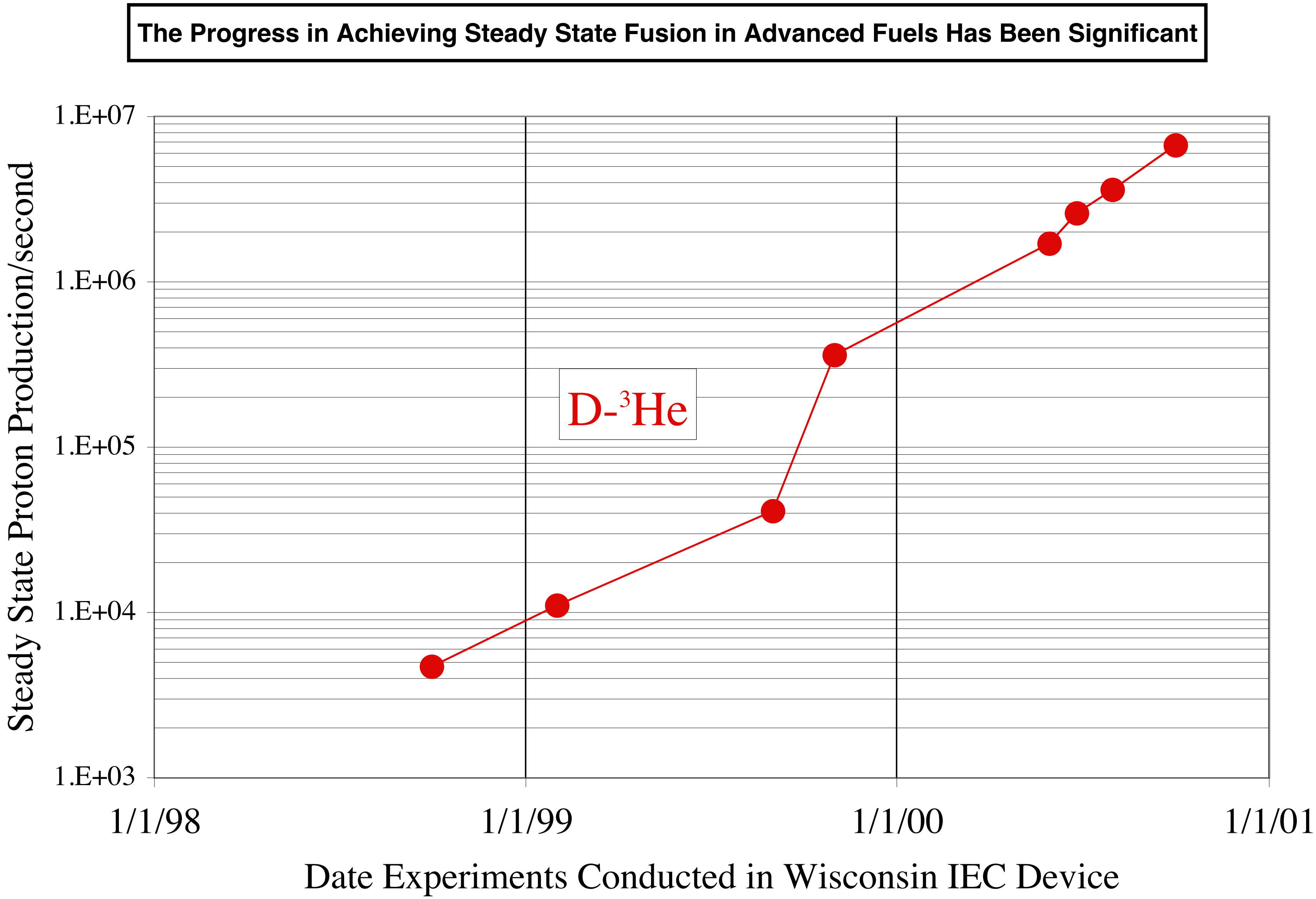

The Progress in Achieving Steady State Fusion in Advanced Fuels Has Been Significant
D-3He
Steady State Proton Production/second
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1/1/98
1/1/99
1/1/00
1/1/01
Date Experiments Conducted in Wisconsin IEC Device

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 material

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

3) eliminating T_2 breeding blankets and complicated secondary coolant loops

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

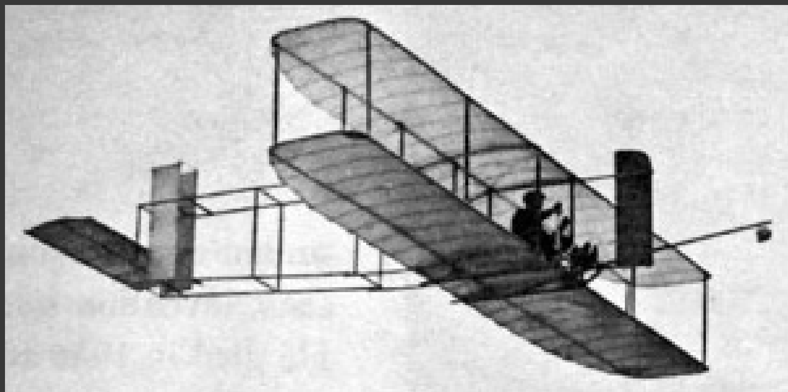
Recommendations

- These compelling attractive features can only be achieved by a vigorous research program on
    - high beta magnetic
    - inertial electrostatic
    - inertial fusion

  concepts specifically suitable for the burning of advanced fusion fuels.

- One of the metrics used to determine the attractiveness of fusion confinement concepts should be the ability to burn the advanced fusion fuels.

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