The Development of Lunar ^3He Resources: Near Term Applications and Long Term Prospects

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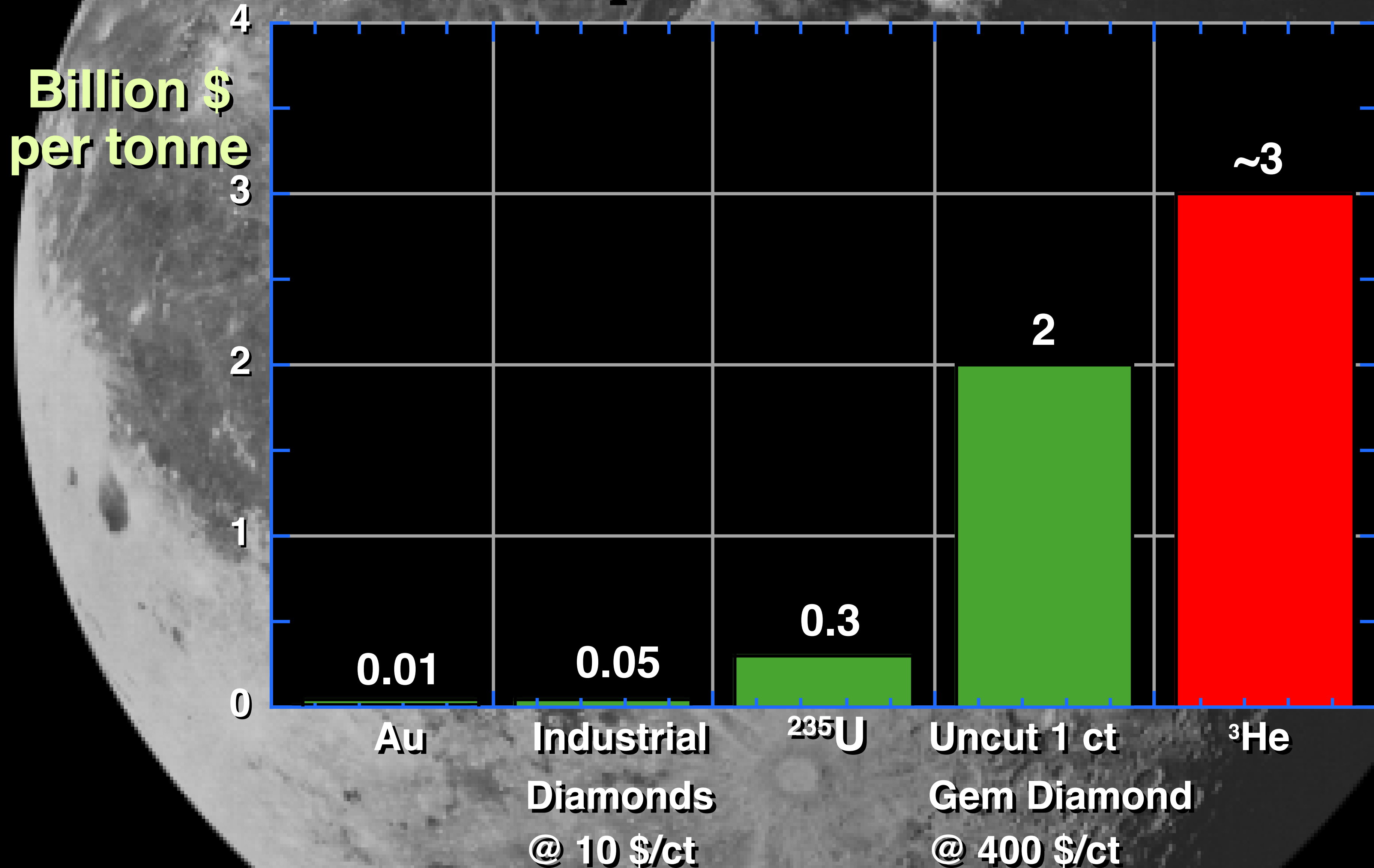
The ^3He Isotope is the Only Known Lunar Resource That Has Enough Economic Value to be Transported to the Earth



Annual World Energy Requirements

Present

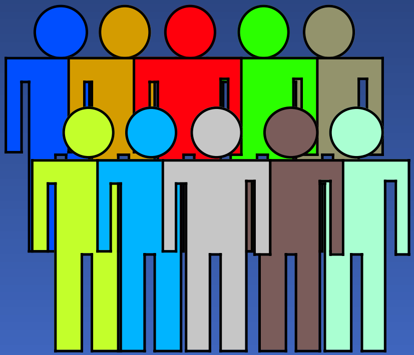
6 Billion

x

12 barrels/capita

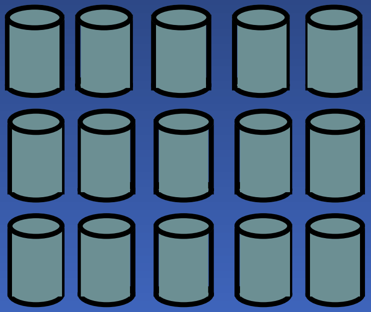
→ **72 Billion BOE/year**

Future



10 Billion

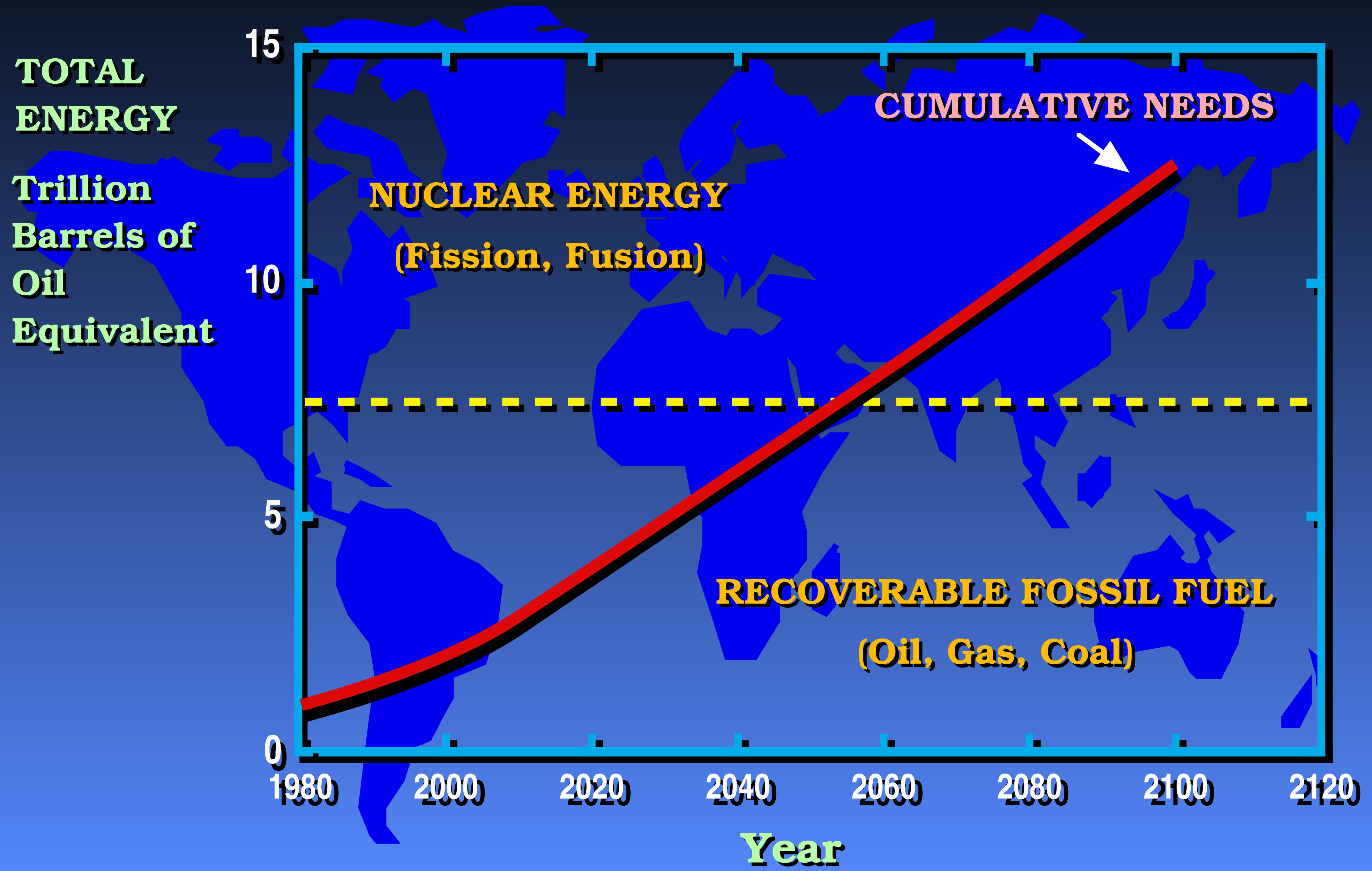
x



15 barrels/capita

→ **150 Billion BOE/year**

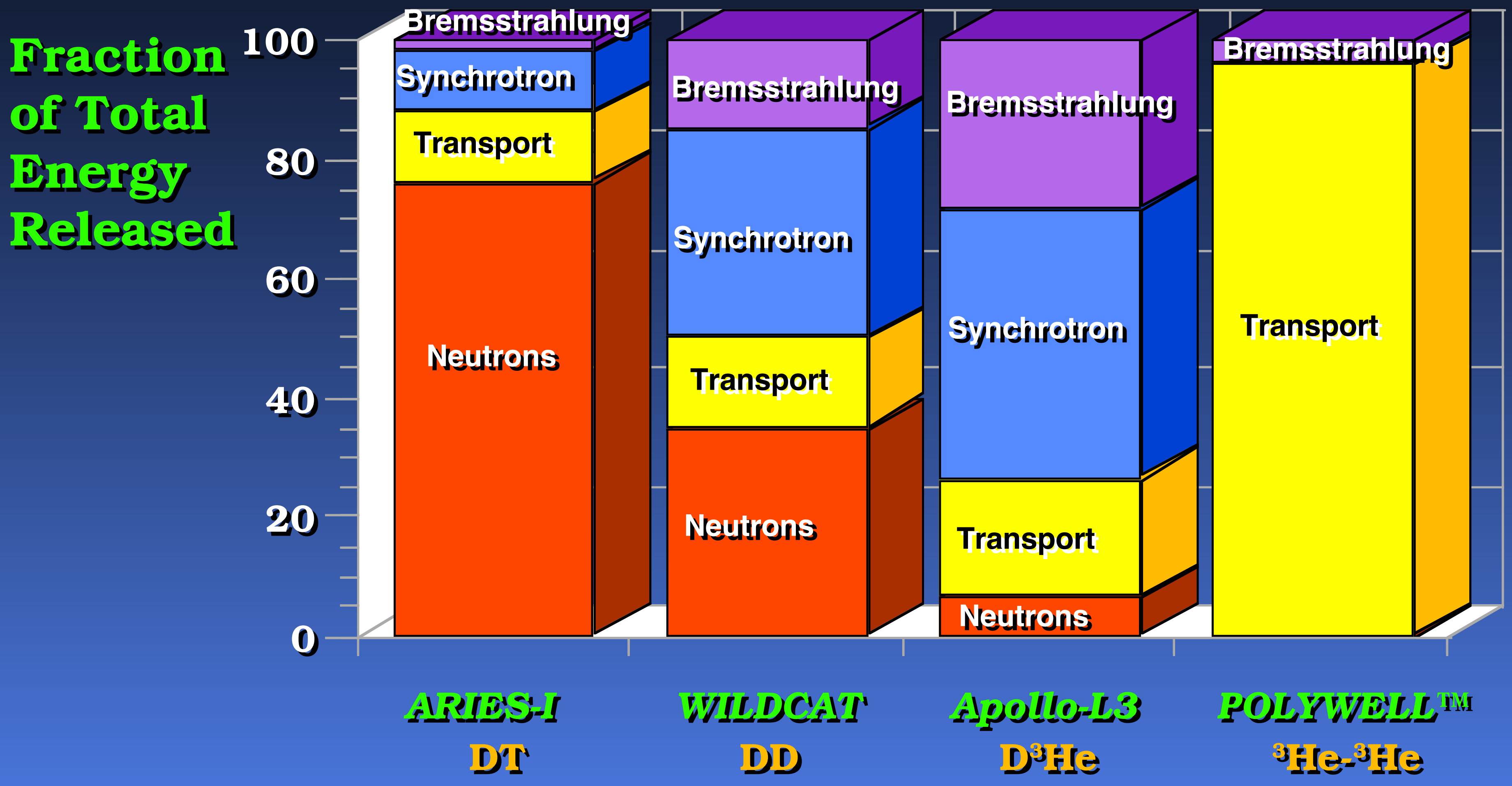
World Energy Consumption and Resources for the Future



Key Fusion Reactions and the Form in Which the Energy is Released

1st Generation	$D + T$	$\longrightarrow$	$n + {}^4He$	**17.6 MeV**
	$D + D$	$\nearrow$	$n + {}^3He$	**3.65 MeV**
		$\searrow$	$p + T$	**(ave.)**
2nd Generation	$D + {}^3He$	$\longrightarrow$	$p + {}^4He$	**18.4 MeV**
3rd Generation	${}^3He + {}^3He$	$\longrightarrow$	$2p + {}^4He$	**12.9 MeV**

The Form of Energy Release is Quite Different in DT, DD, D^3He and ^3He-^3He Fuel Cycles



Characteristics of D^3He 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

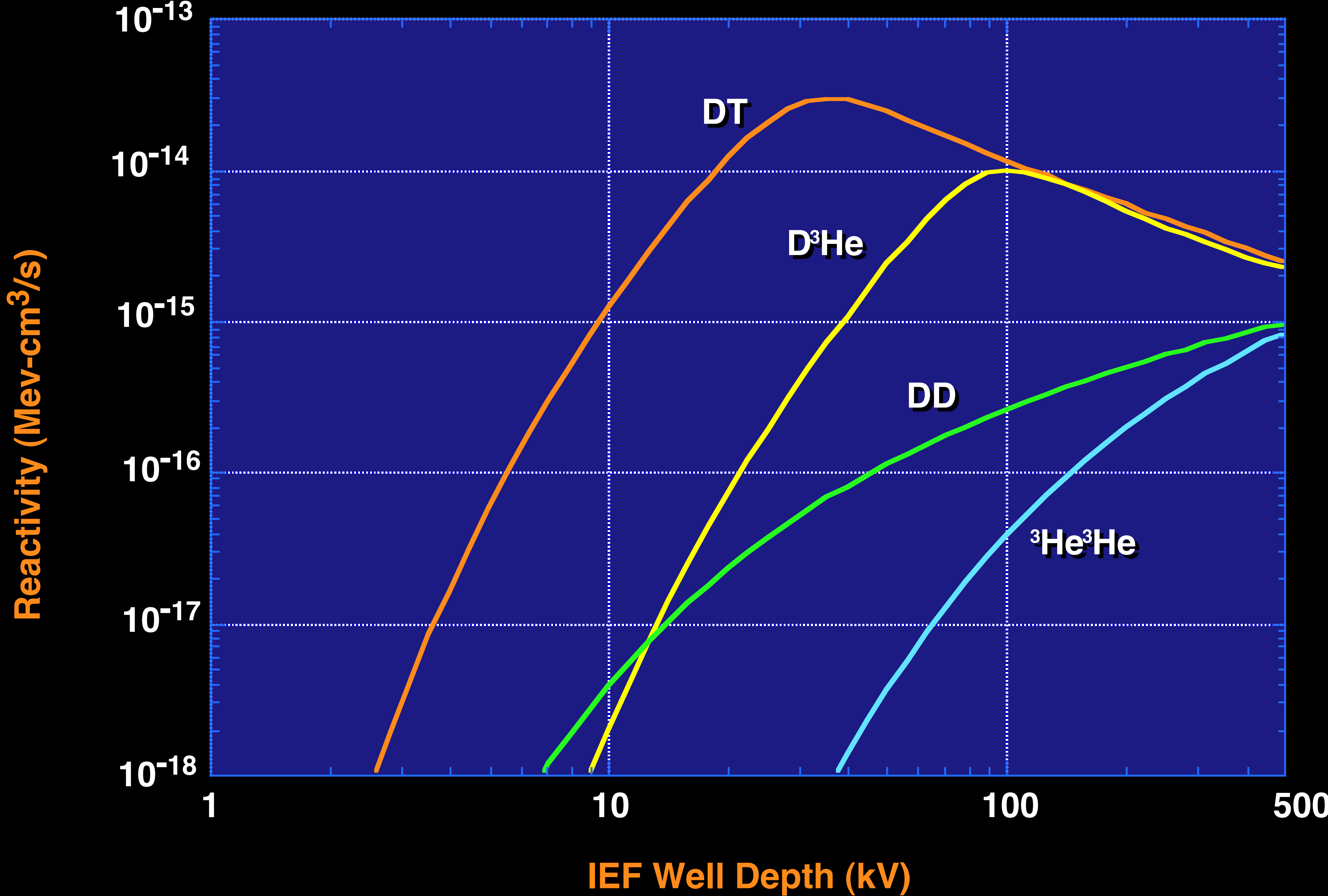
Characteristics of $^3He^3He$ Fusion Power Plants

- No Greenhouse or Acid Gas Emissions During Operation
- Very High Efficiencies (>70%)
- No Residual Radioactivity After 30 Years of Operation (No Radioactive Waste, Radiation Damage, or Safety Hazard).

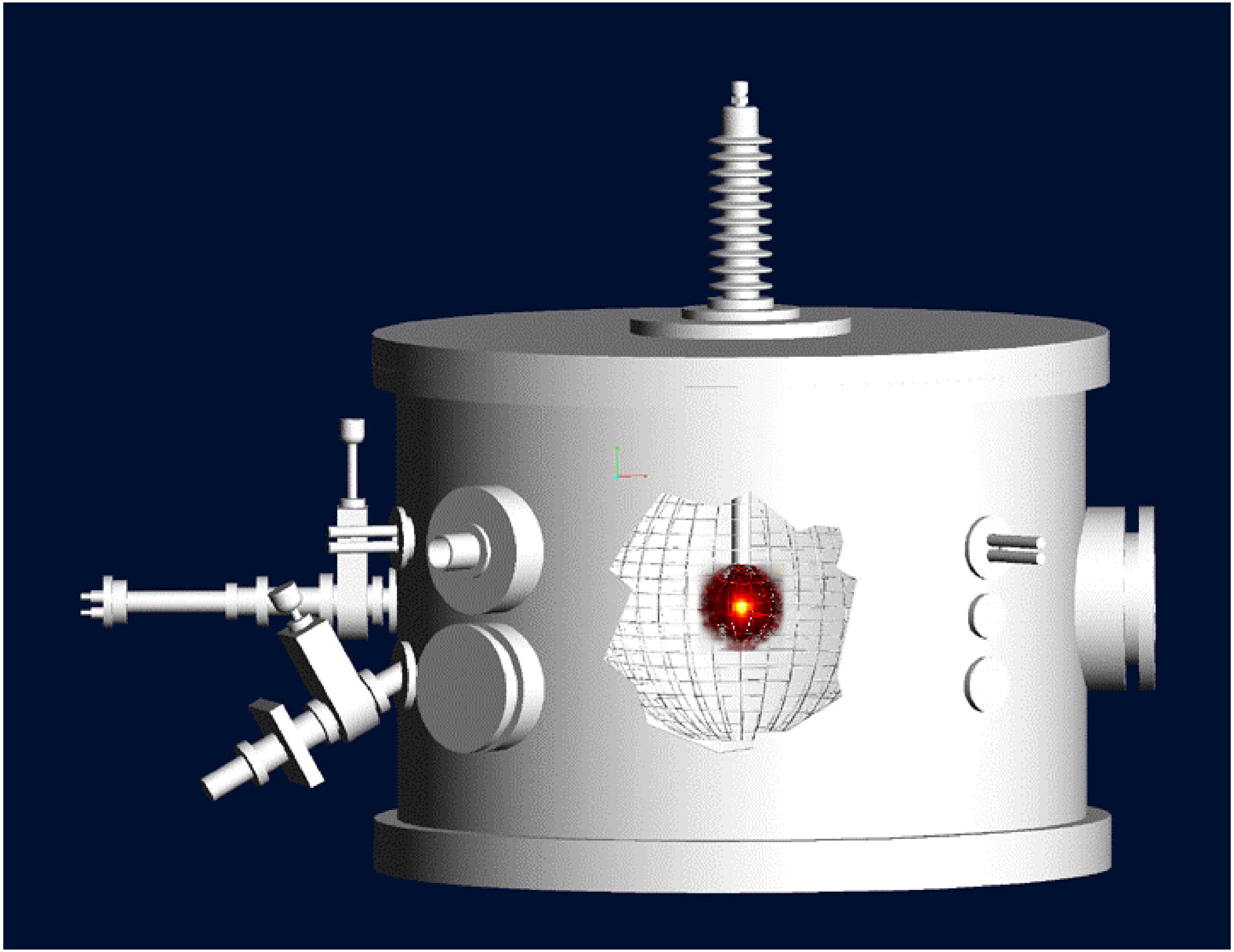
If the Use of the D^{3}He Fuel Cycle is So Attractive, Why Has it Not Been Pursued More Vigorously?

- Physics Demonstration
- ^{3}He Fuel Supply

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

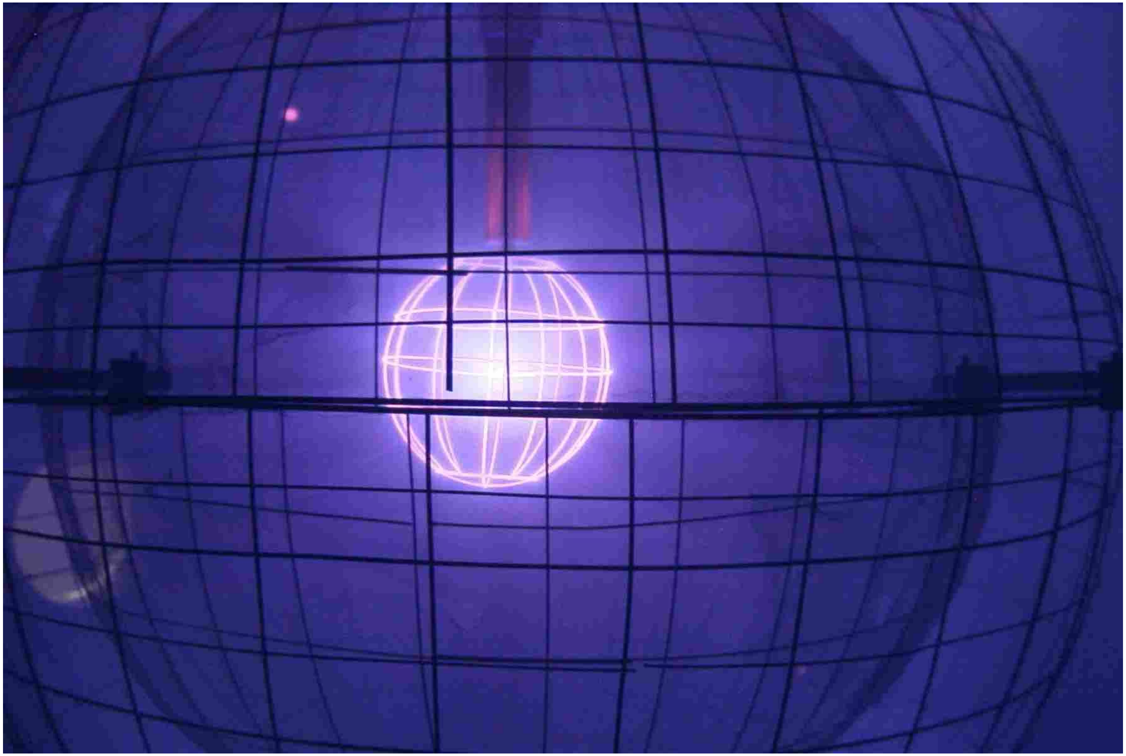


Schematic of Wisconsin IEC Advanced Fusion Device



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

2.6 x 10^6 protons/s



Cathode Voltage=55 kV

Cathode Current=60 mA

Pressure= 1 mTorr

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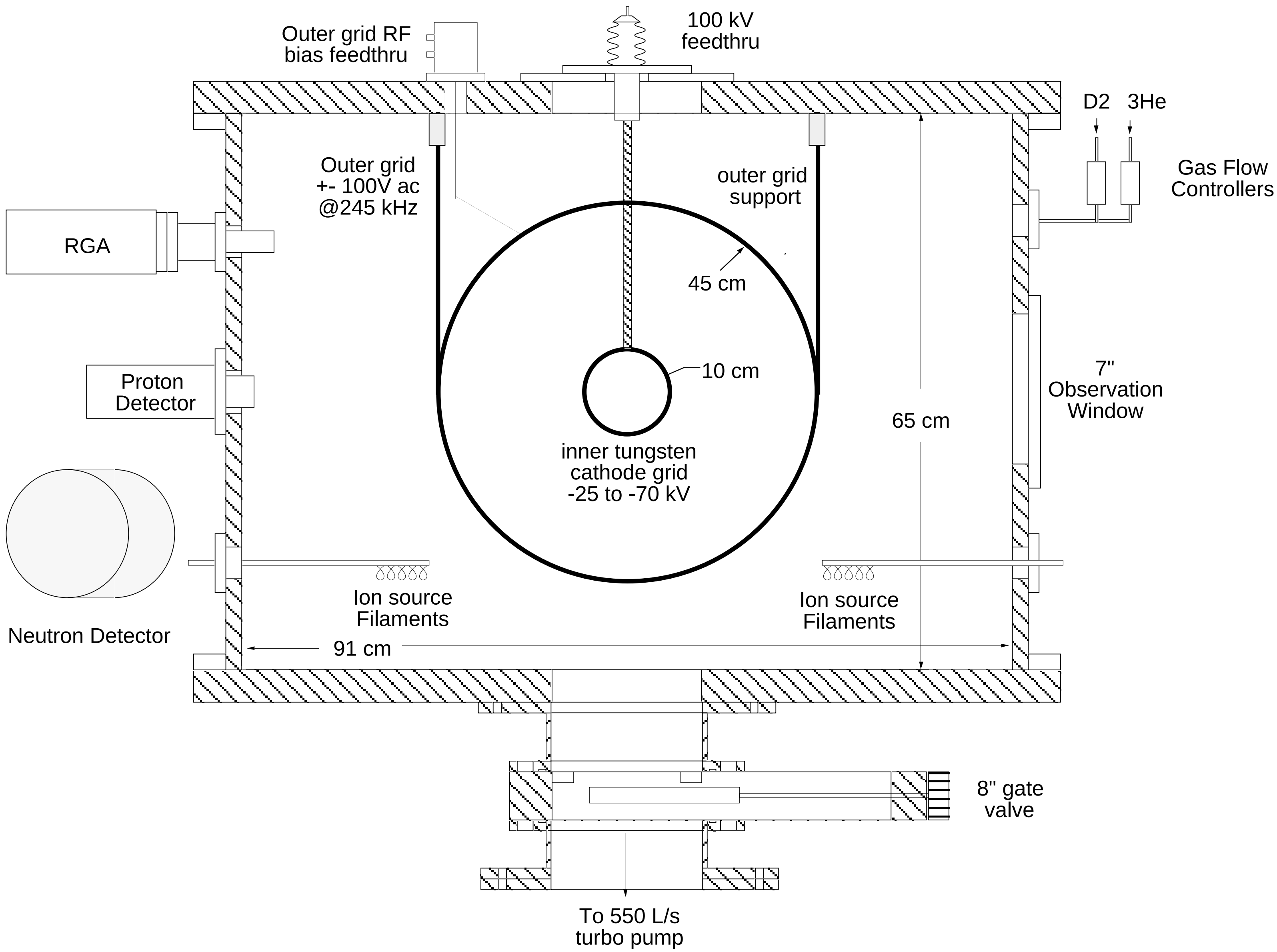
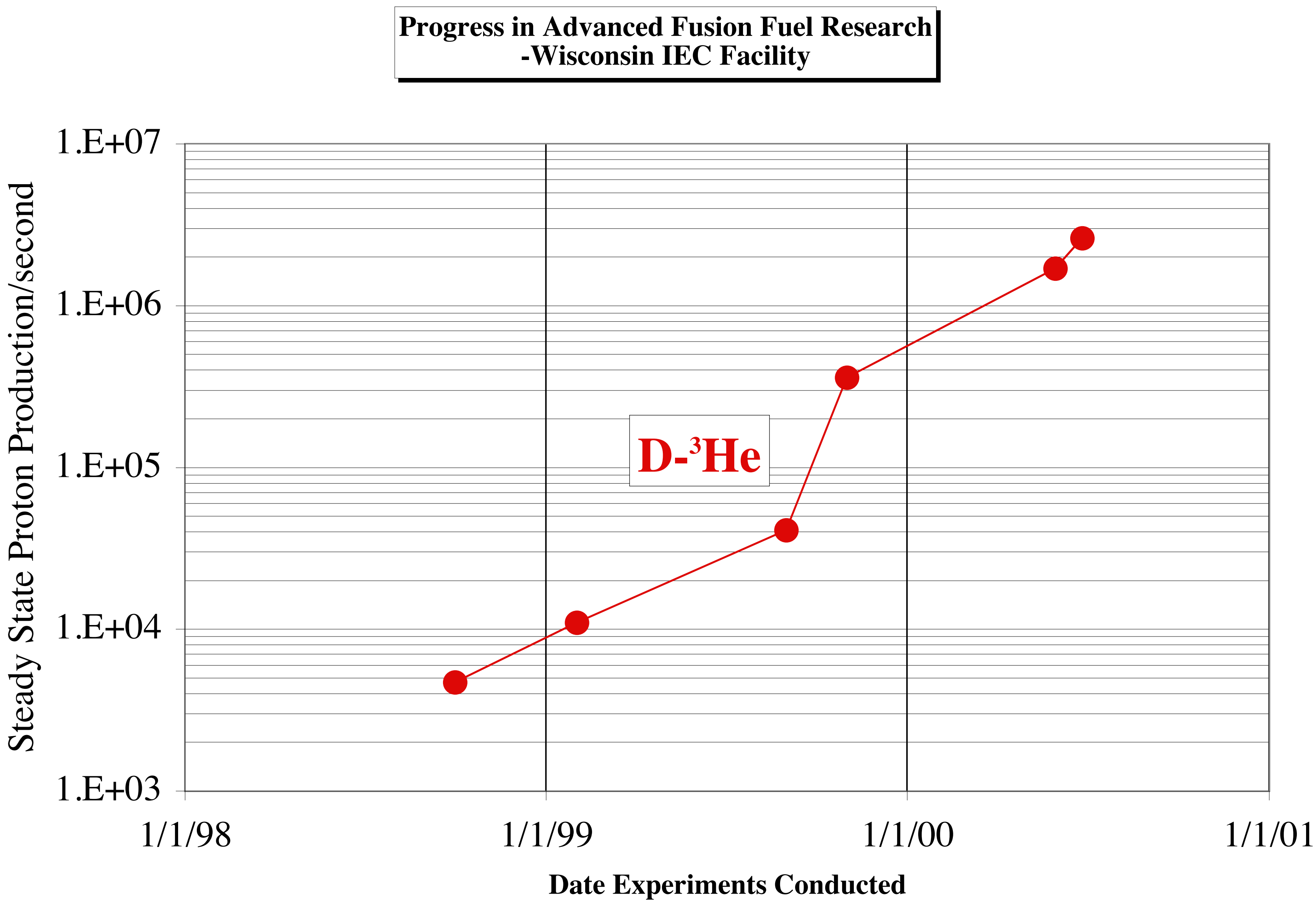
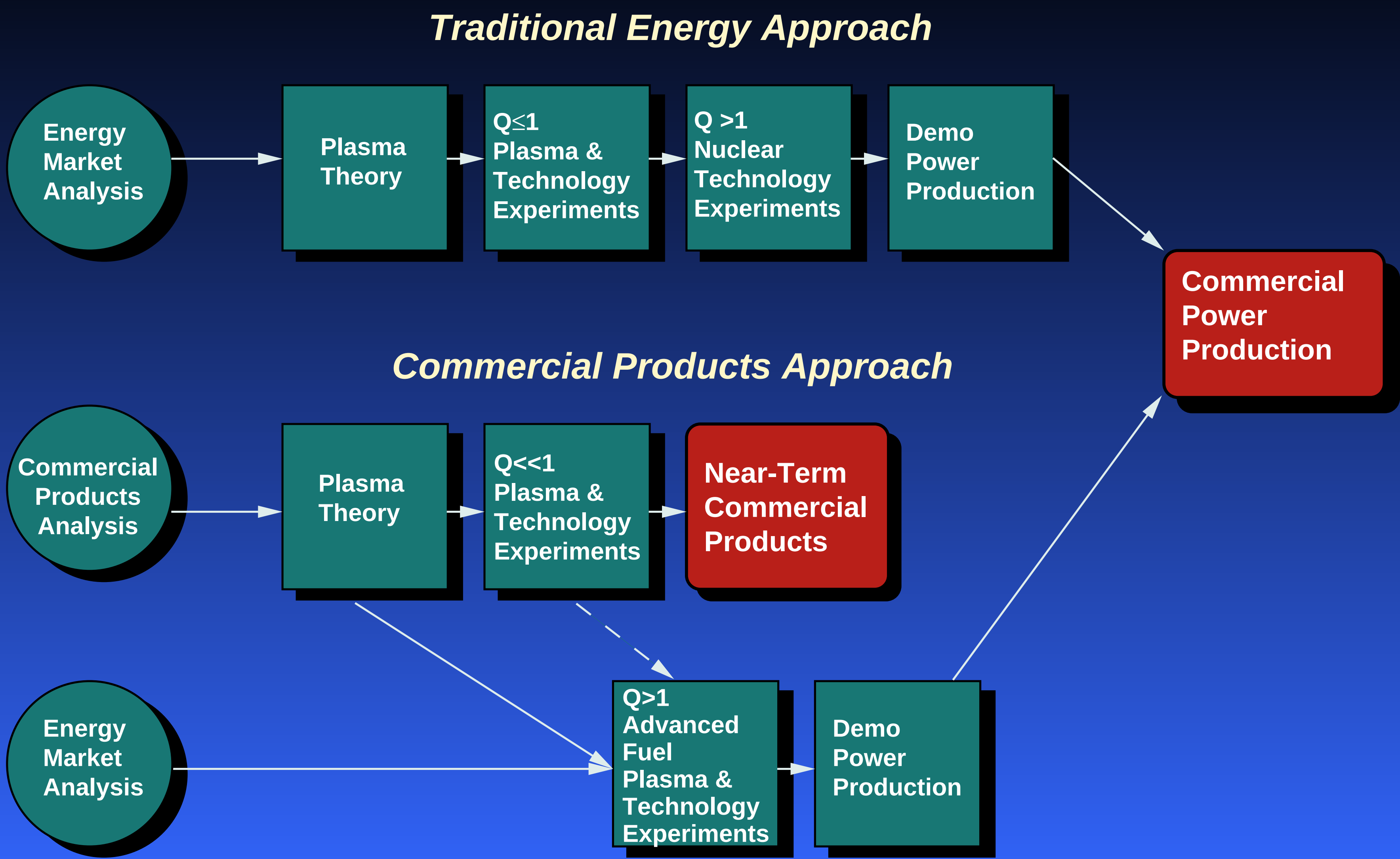
Wisconsin IEC Steady State Fusion Reactor




Progress in Advanced Fusion Fuel Research
-Wisconsin IEC Facility
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
Steady State Proton Production/second
D-³He
1/1/98
1/1/99
1/1/00
1/1/01
Date Experiments Conducted

How Do We Get There From Here?



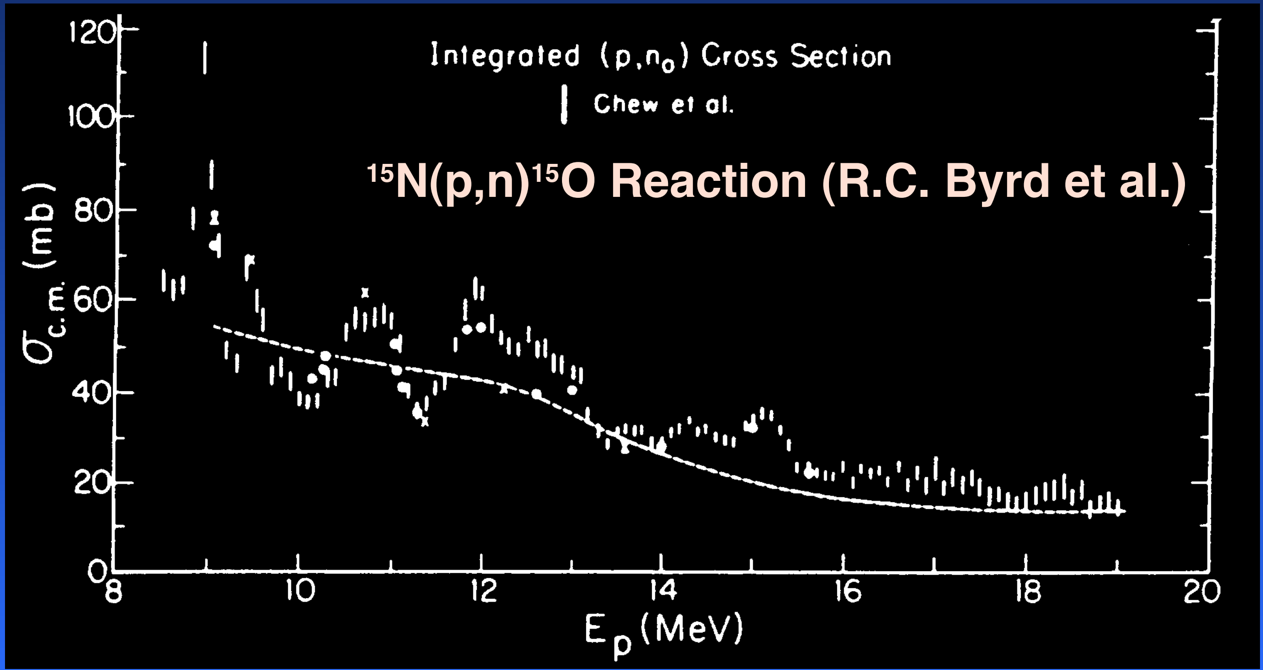
What Use Can Society Make of Small, Compact (Q<1) Fusion Neutron or Proton Sources?

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

Small Mobile PET Generators Could Reduce Radiation Exposure to Patients

- Presently ^{18}F ($t_{1/2}$ = 1.83 h) is used extensively for brain scans
- Current regulations preclude the repeated use of ^{18}F on young children and pregnant women
- An ideal PET isotope would be ^{15}O ($t_{1/2}$ = 2.03 min)
- 1 Watt of D^3He fusion could produce ≈8 mCi of ^{15}O (steady state)



Radioisotopes Particularly Suited For Production With Protons From D-^{3}He Fusion

Isotope	$t_{1/2}$	Parent Isotope	Maximum Steady State Production at Equilibrium (mCi/watt D-^{3}He)	Useful Dose (mCi)
^{15}O	2.03 m	^{15}N	8	~ 1
^{18}F	1.83 h	^{18}O	14	1 – 10
^{99m}Tc	6.01 h	^{100}Mo	4	1 – 25

The Development of the Right Fusion Concept Should Lead to Near Term, as Well as Long-Term Benefits to Society

Phase 3

Long Range Benefits of a Q>10 Device

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

Phase 2

Intermediate Term Application from a Q = 1–5 Device

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

Phase 1

Near Term Application from a Q < 1 Device

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

Economic Impact of D-^{3}He

- One tonne of ^{3}He burned with 0.67 tonne of D can produce ≈ 10,000 MW_e-y
- If that much electricity were produced from oil, it would require ≈130,000,000 barrels of oil
- At 20 $/barrel of oil, this would cost $2.6 B

====> Therefore, the energy content in 1 tonne of ^{3}He is worth ≈ $2.6 B

- In 1999 the United States produced ≈ 420,000 MW_e-y of electrical energy
- This amount of electricity could be produced by 42 tonnes of ^{3}He
- The value of 42 tonnes of ^{3}He is ≈ $100 B at $20/barrel of oil

What Resources From Moon Can Have a Major Impact on Future Generations?

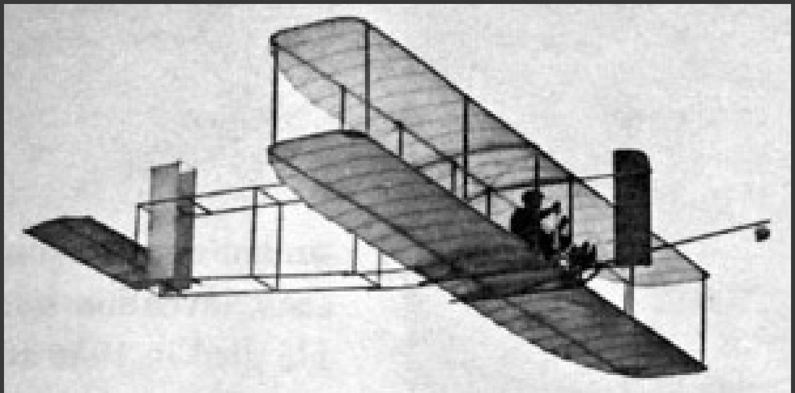
	Energy	Volatiles, Metals, and Minerals
On Earth	• ^3He • Microwaves from Solar Power	Probably None
In Space	• ^3He • Microwaves from Solar Power • H_2-O_2, fuel cells	• Volatiles (H_2, N_2, O_2, CO_2, H_2O) • Al, Fe, Ti, etc. • Regolith
On the Moon	• ^3He • Solar Energy • H_2-O_2, fuel cells	• Volatiles (H_2, N_2, O_2, CO_2, H_2O) • Al, Fe, Ti, etc. • Regolith

Conclusions

- The use of the D^3He fusion fuel cycle can reduce the volume of radioactive waste by more than a factor of 100 when compared to a fission reactor.

- The use of the $^3He^3He$ fusion fuel cycle can eliminate the need for radioactive waste storage.

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