Nuclear Energy Without Radioactive Waste

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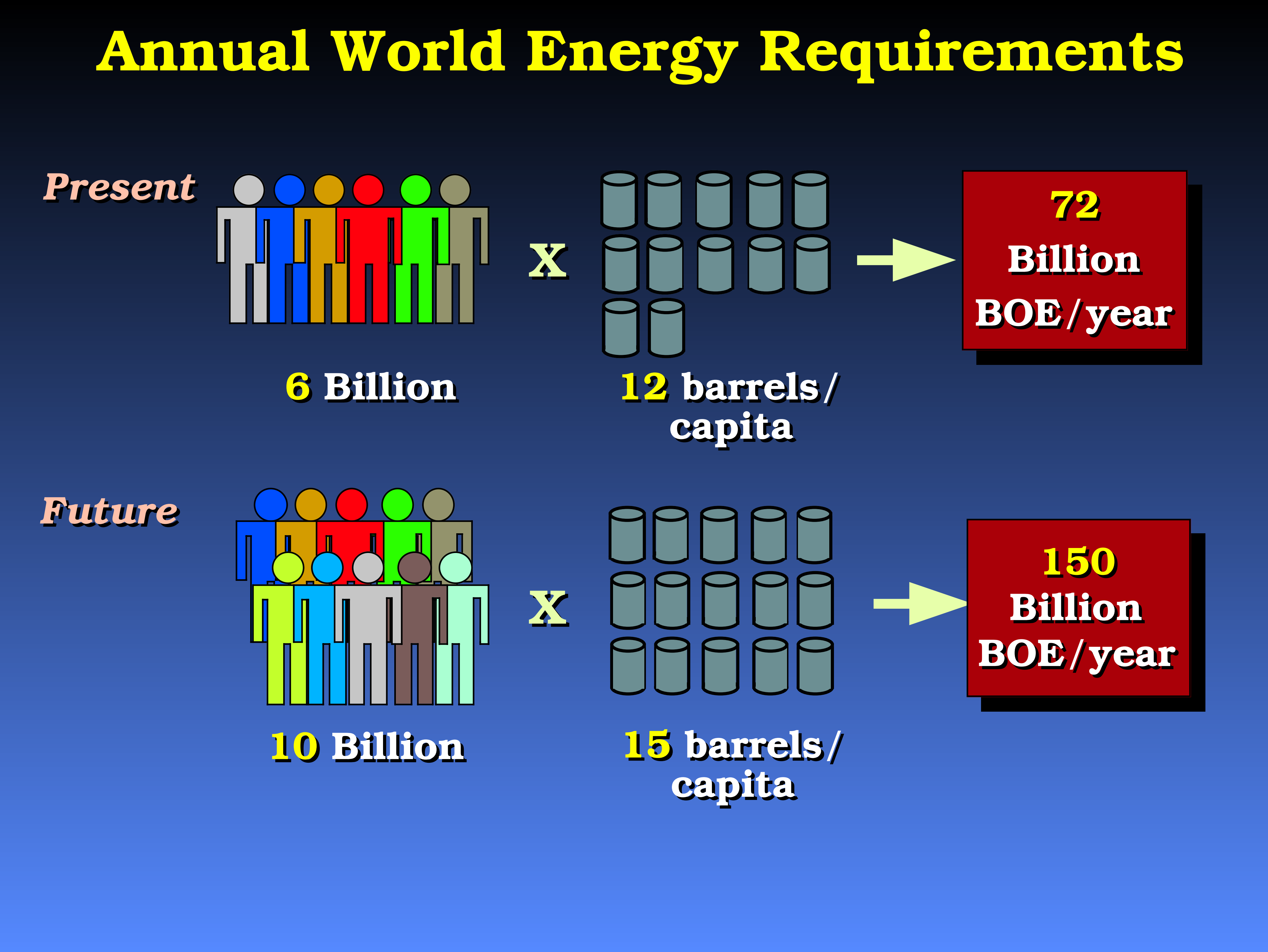
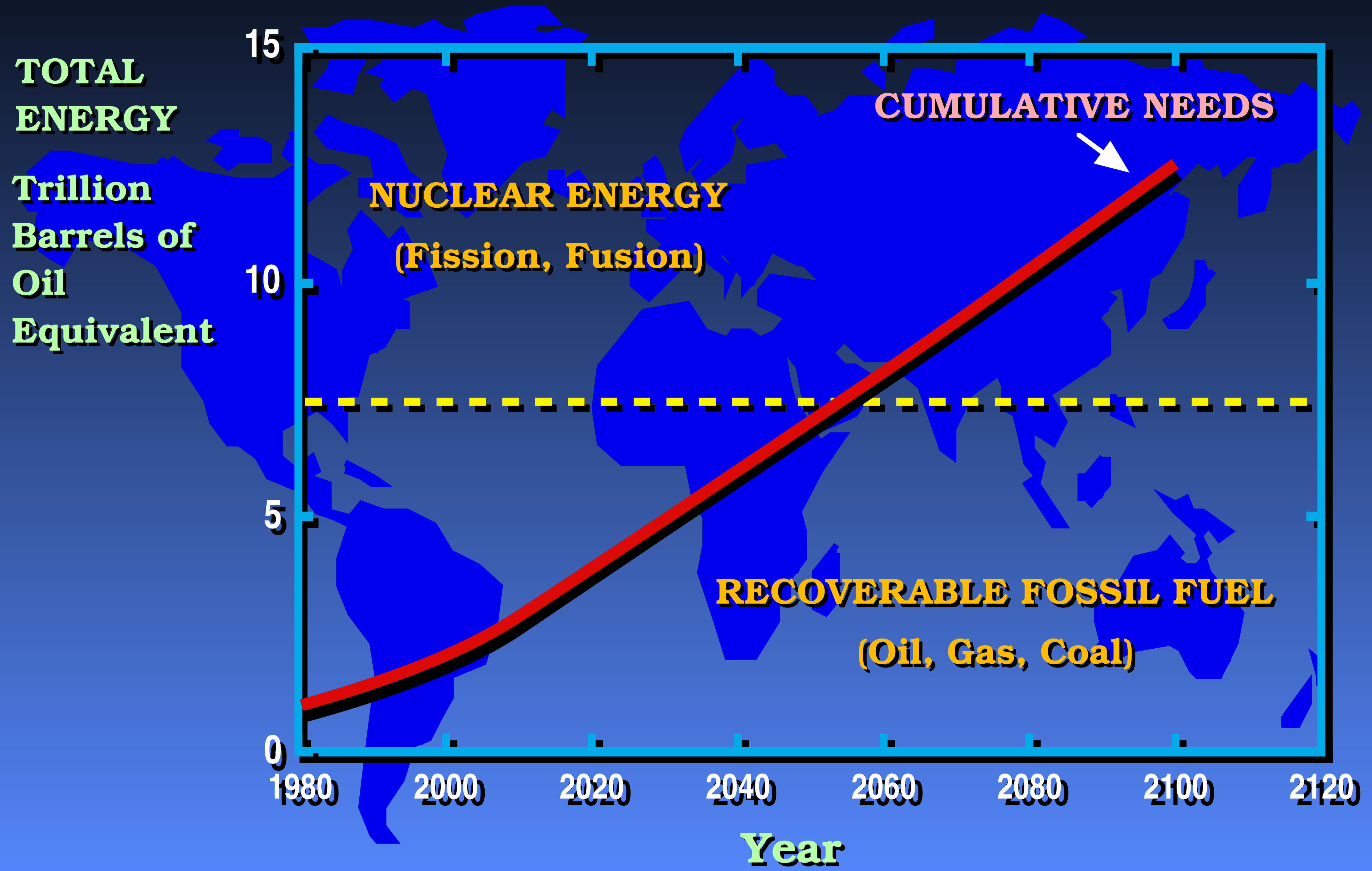

Annual World Energy Requirements
Present
X
72
Billion
BOE/year
6 Billion
12 barrels/
capita
Future
X
150
Billion
BOE/year
10 Billion
15 barrels/
capita

World Energy Consumption and Resources for the Future



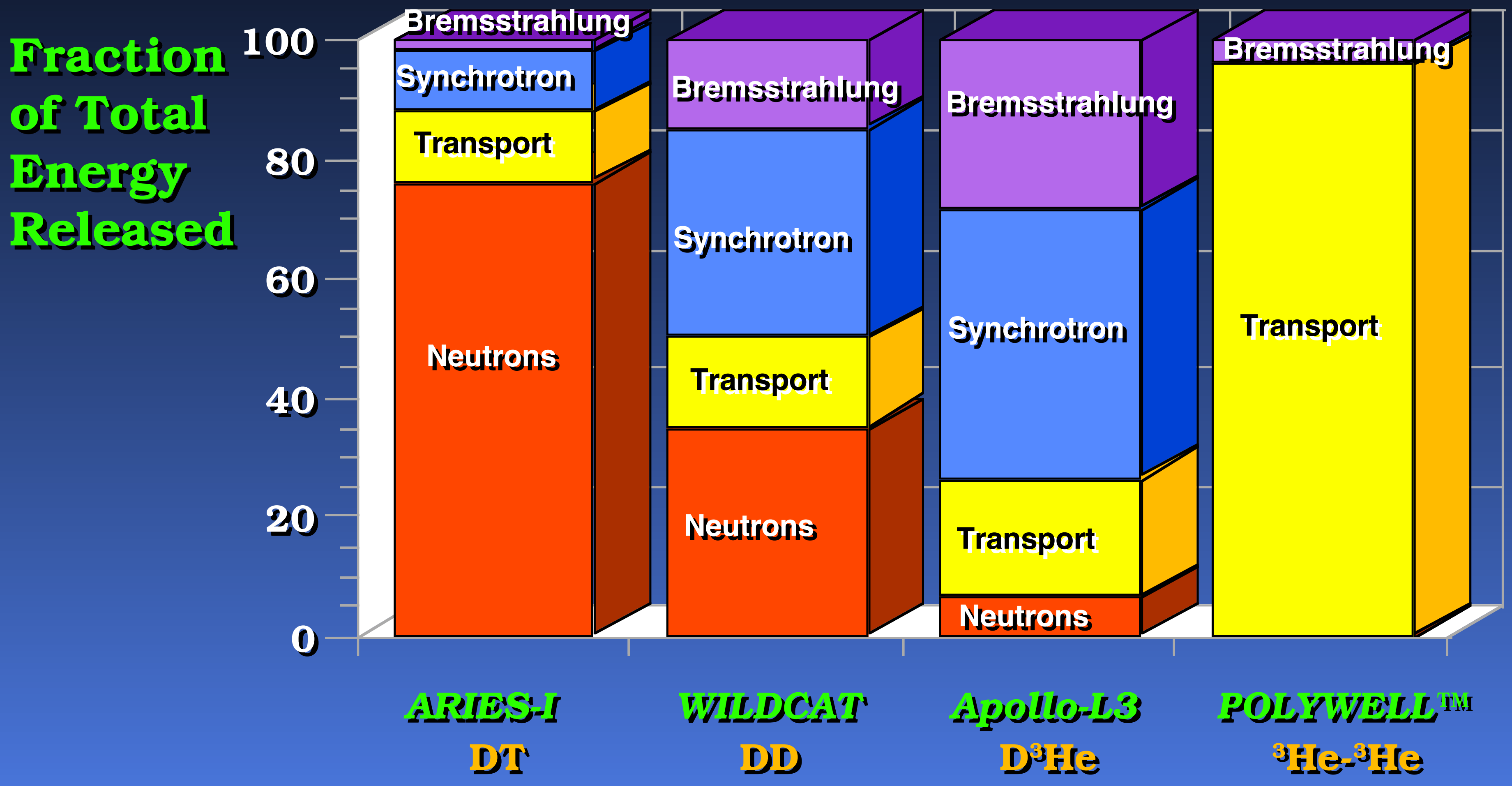
What Do We Mean by Advanced Fuels?

- 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-$p^{11}B$, $^3He^3He$ (third generation)

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

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

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

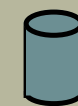
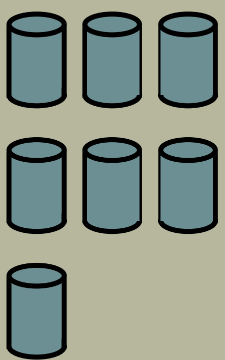
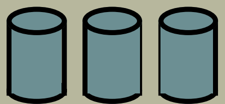


Regulations for the Disposal of Nuclear Waste

Radwaste Class	Period from Decay to Acceptable Level	Meets Minimum Waste Form Requirements	Stability Requirements	Provide an Intruder Barrier	Depth of Burial
A	**<<100 years**	**Yes**	**none**	**No**	**<<5 m**
B	**< 100 years**	**Yes**	**300 y**	**No**	**< 5 m**
C	**< 500 years**	**Yes**	**500 y**	**Yes**	**> 5 m**
Deep Burial	**> 500 years**	**Yes**	**> 500 y**	**Yes**	**Deep Geological Burial**

Source: Nuclear Regulatory Commission 10CFR part 61

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	 55			
Deep Geological (Yucca Mtn.)	≈1000				

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

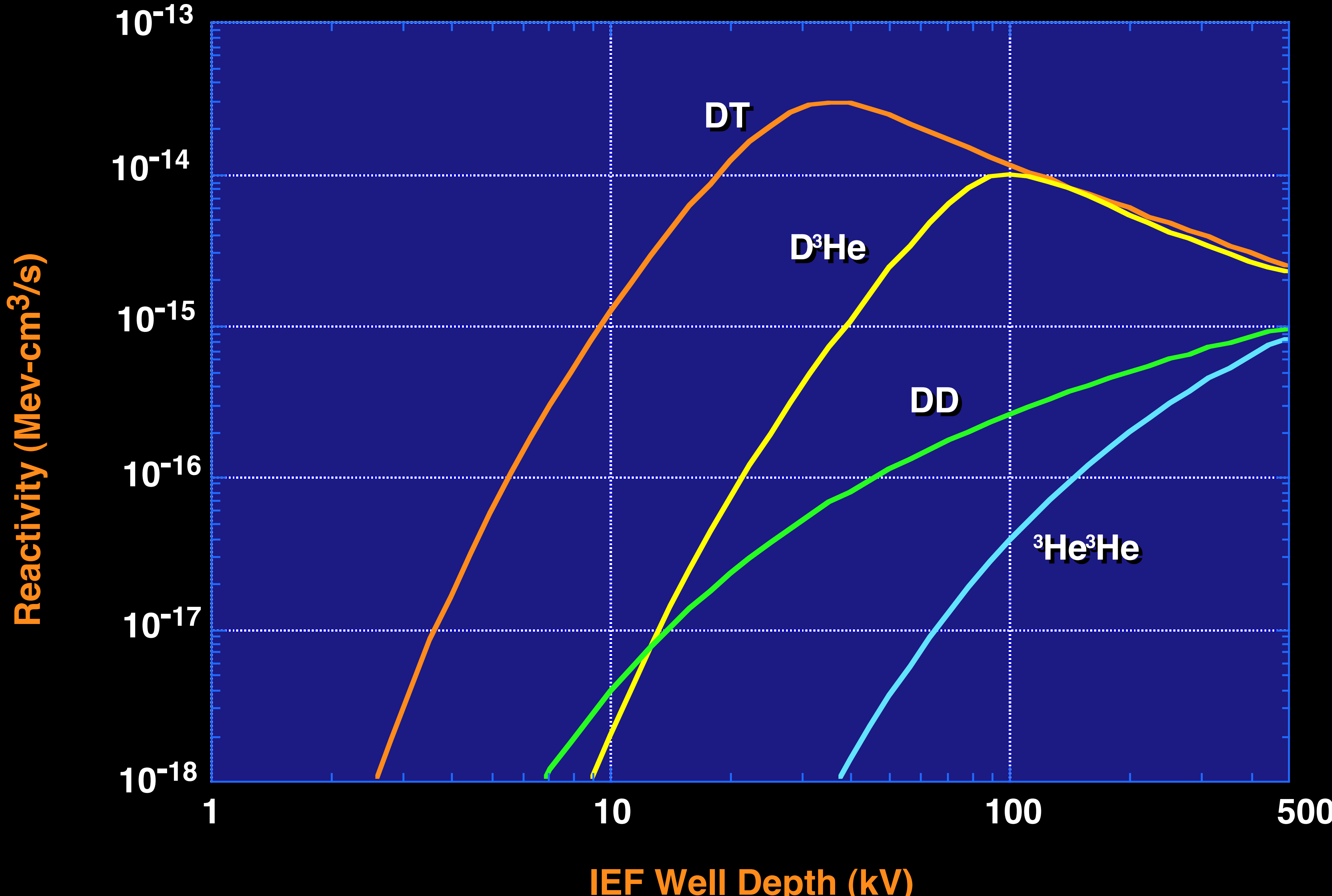
Characteristics of $^3He^3He$ Fusion Power Plants

- 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^3He Fuel Cycle is So Attractive, Why Has it Not Been Pursued More Vigorously?

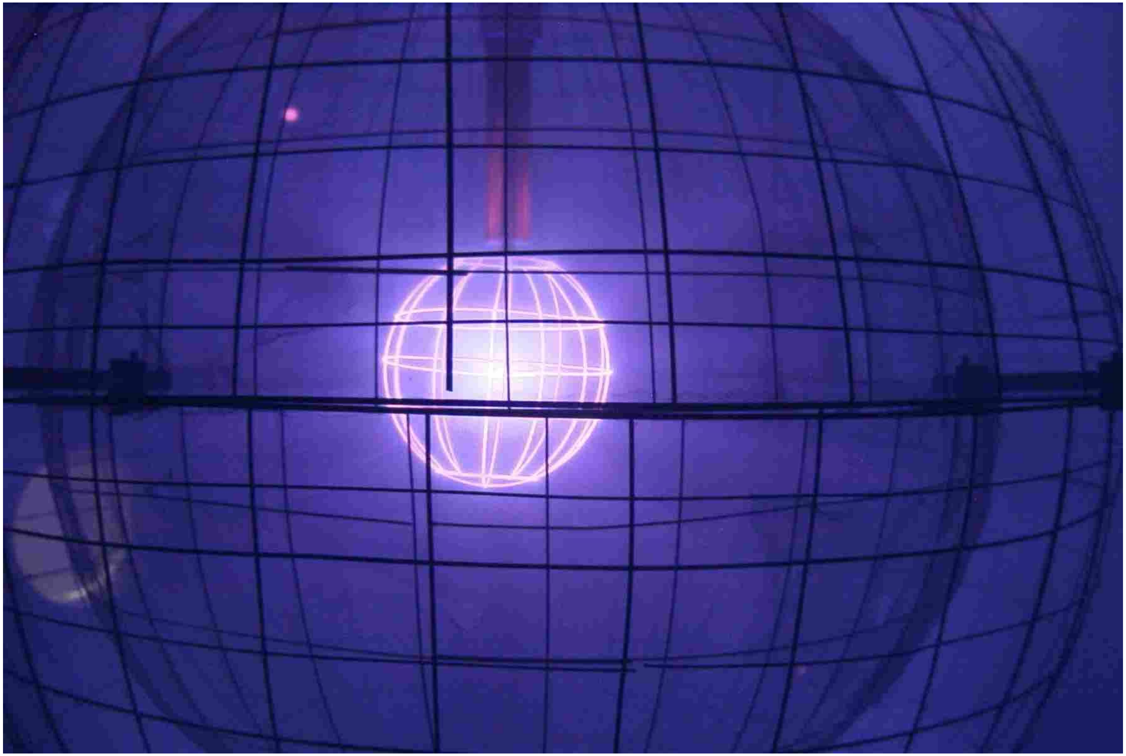
- Physics Demonstration
- ^3He Fuel Supply

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



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

2.6 x 10^6 protons/s



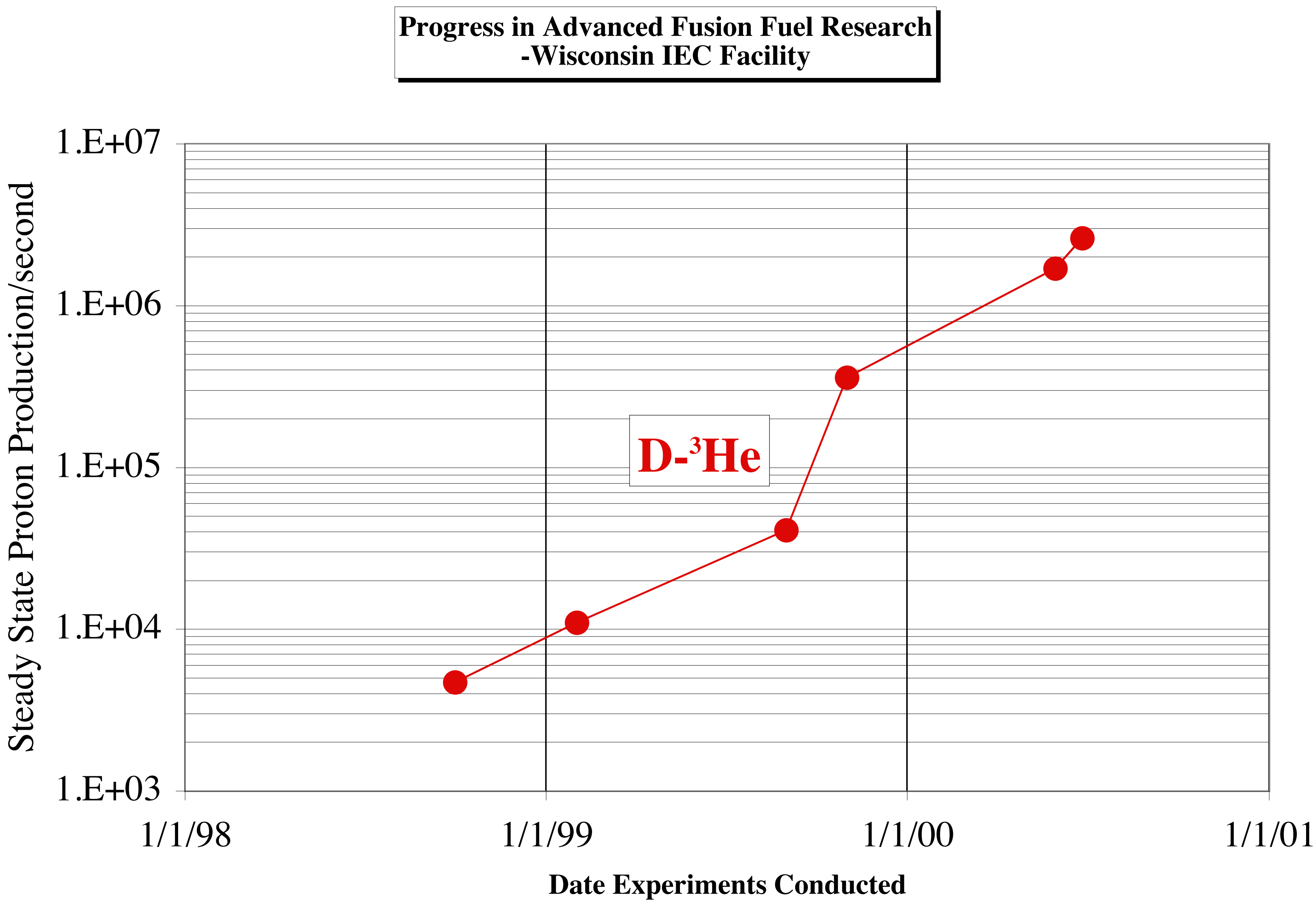
Cathode Voltage=55 kV

Cathode Current=60 mA

Pressure= 1 mTorr

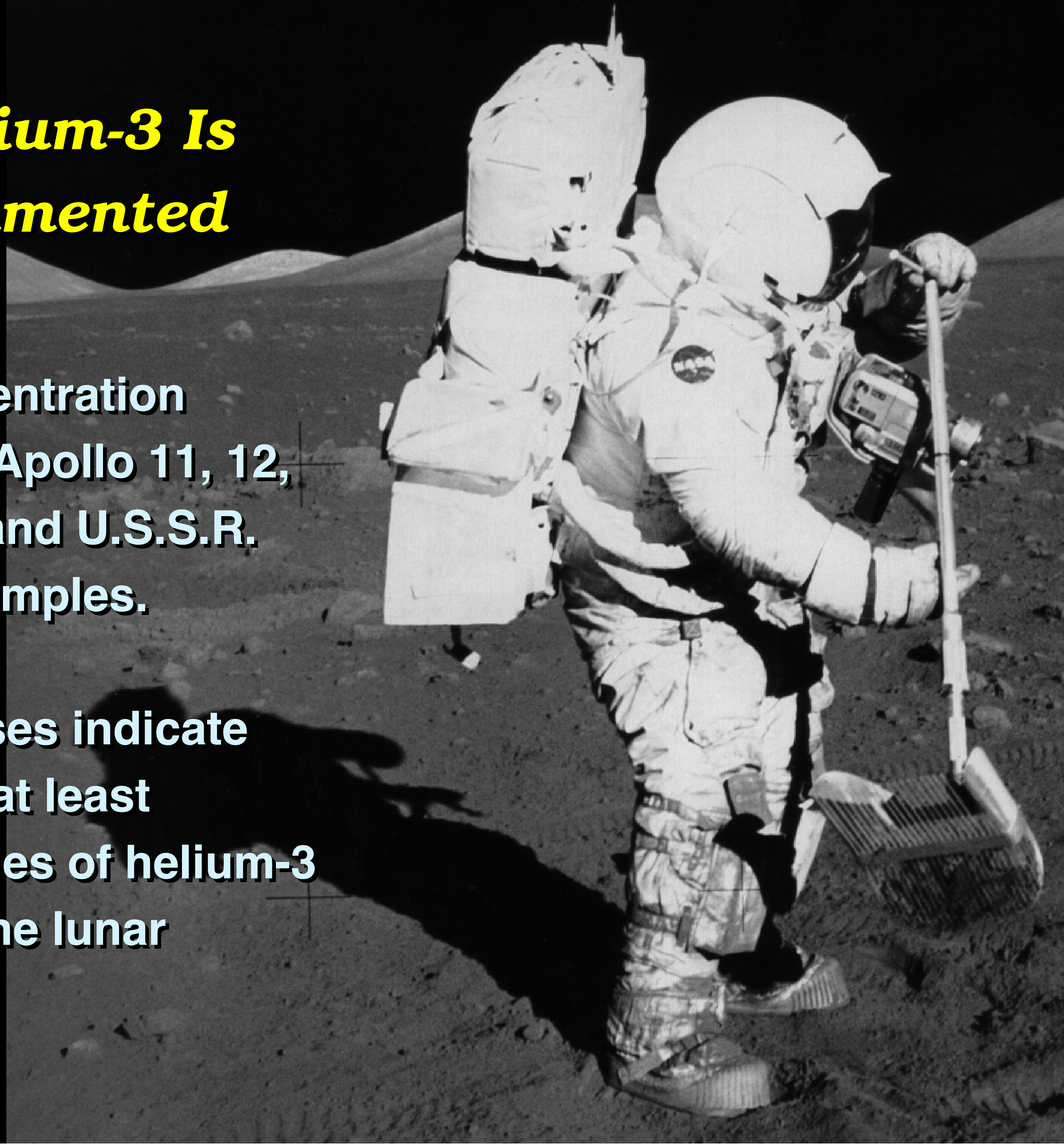
Fusion Technology Institute

University of Wisconsin–Madison



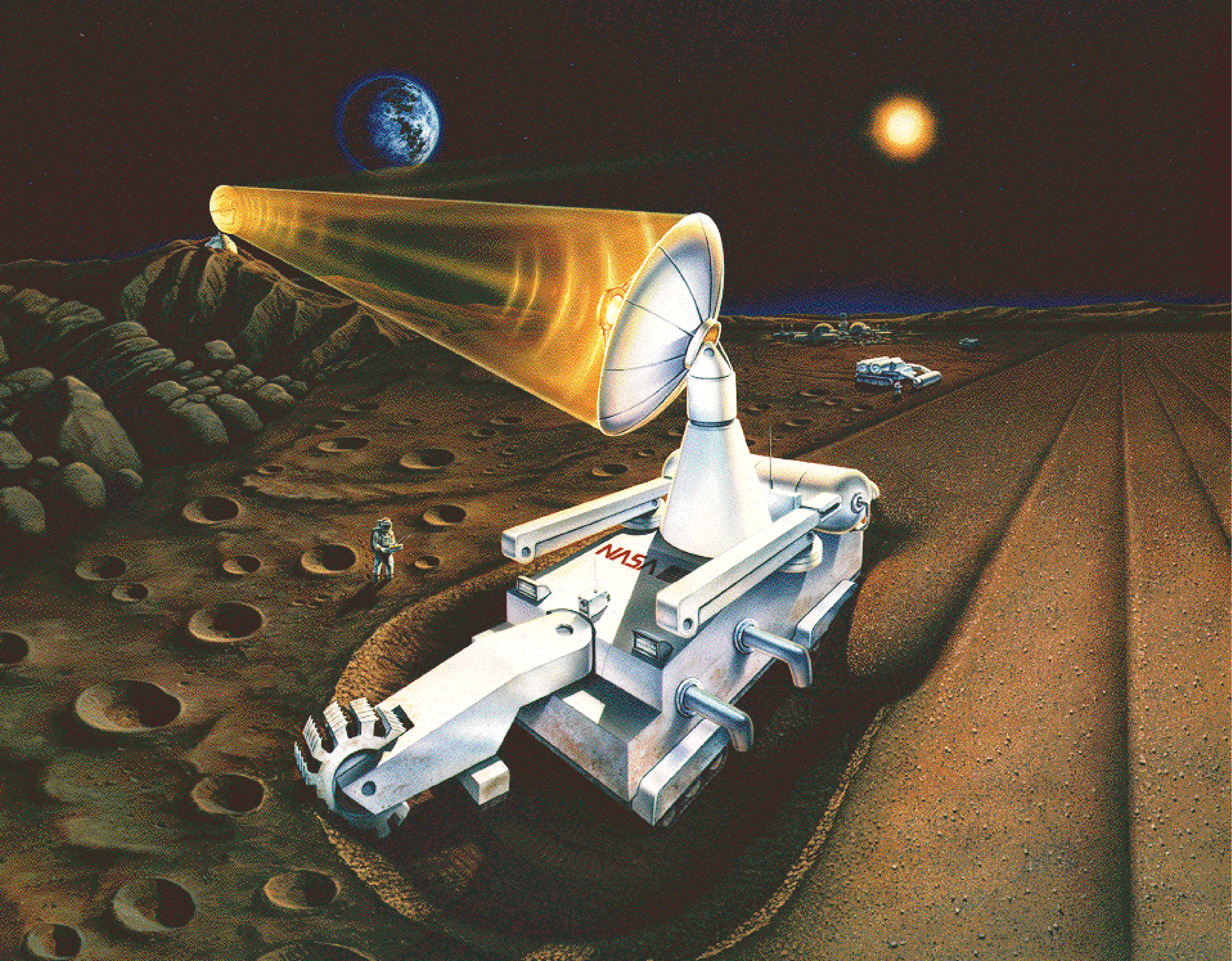
Progress in Advanced Fusion Fuel Research
-Wisconsin IEC Facility
Steady State Proton Production/second
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
D-3He
1/1/98
1/1/99
1/1/00
1/1/01
Date Experiments Conducted

Lunar Helium-3 Is Well Documented



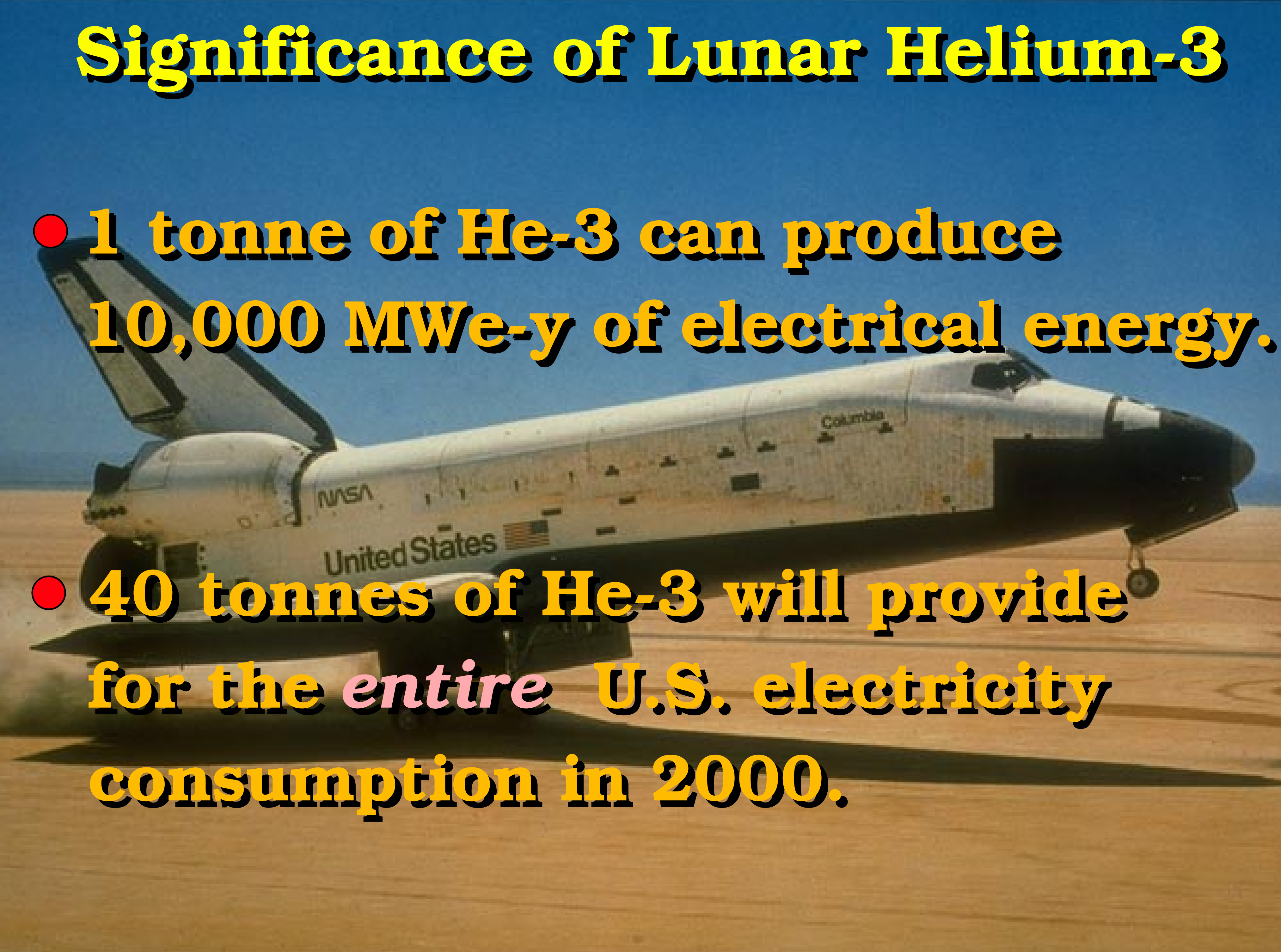
- Helium-3 concentration verified from Apollo 11, 12, 14, 15, 16, 17 and U.S.S.R. Luna 16, 20 samples.

- Current analyses indicate that there are at least 1,000,000 tonnes of helium-3 imbedded in the lunar surface.


NASA

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.



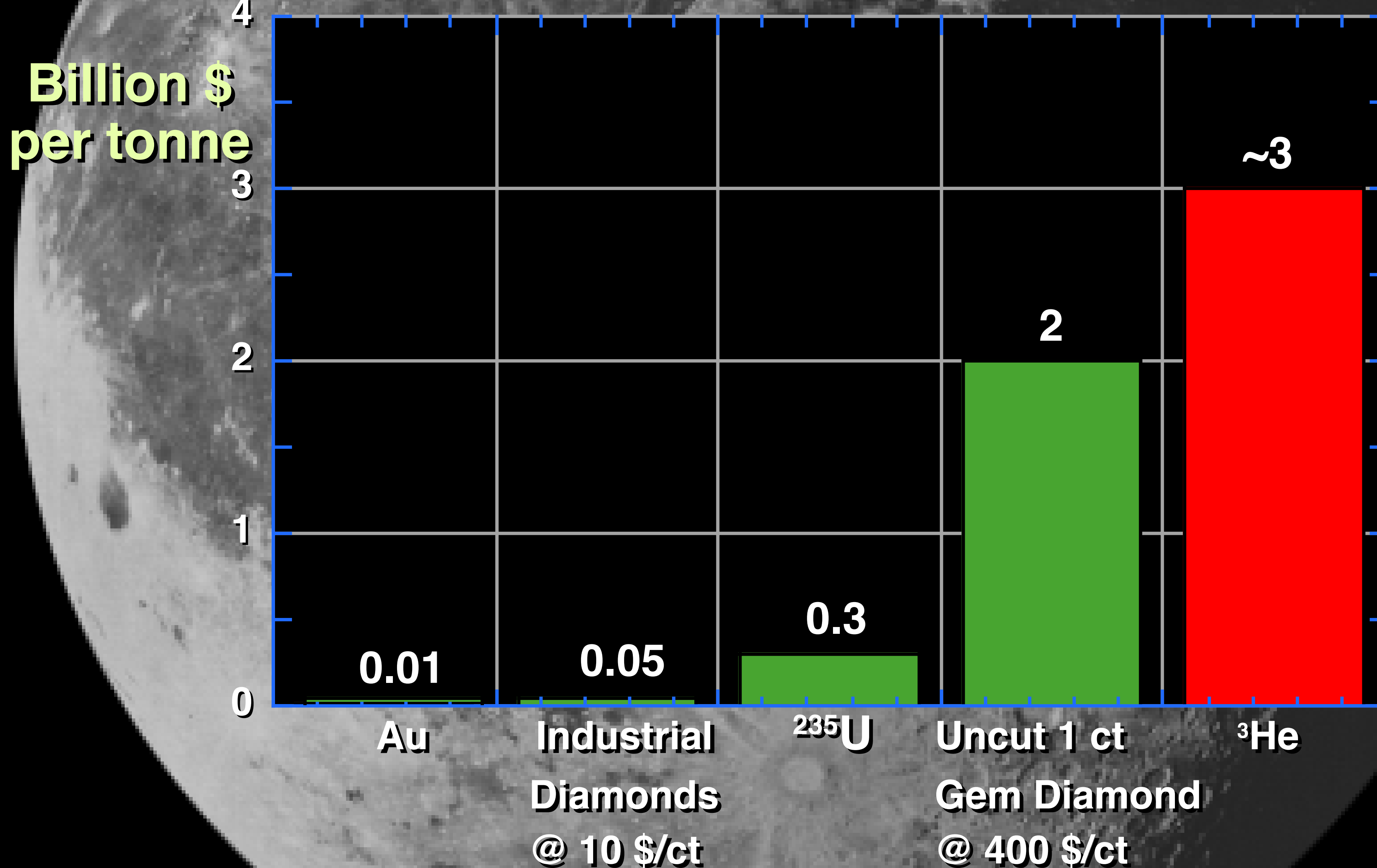
Economic Impact of D-^{3}He

- 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

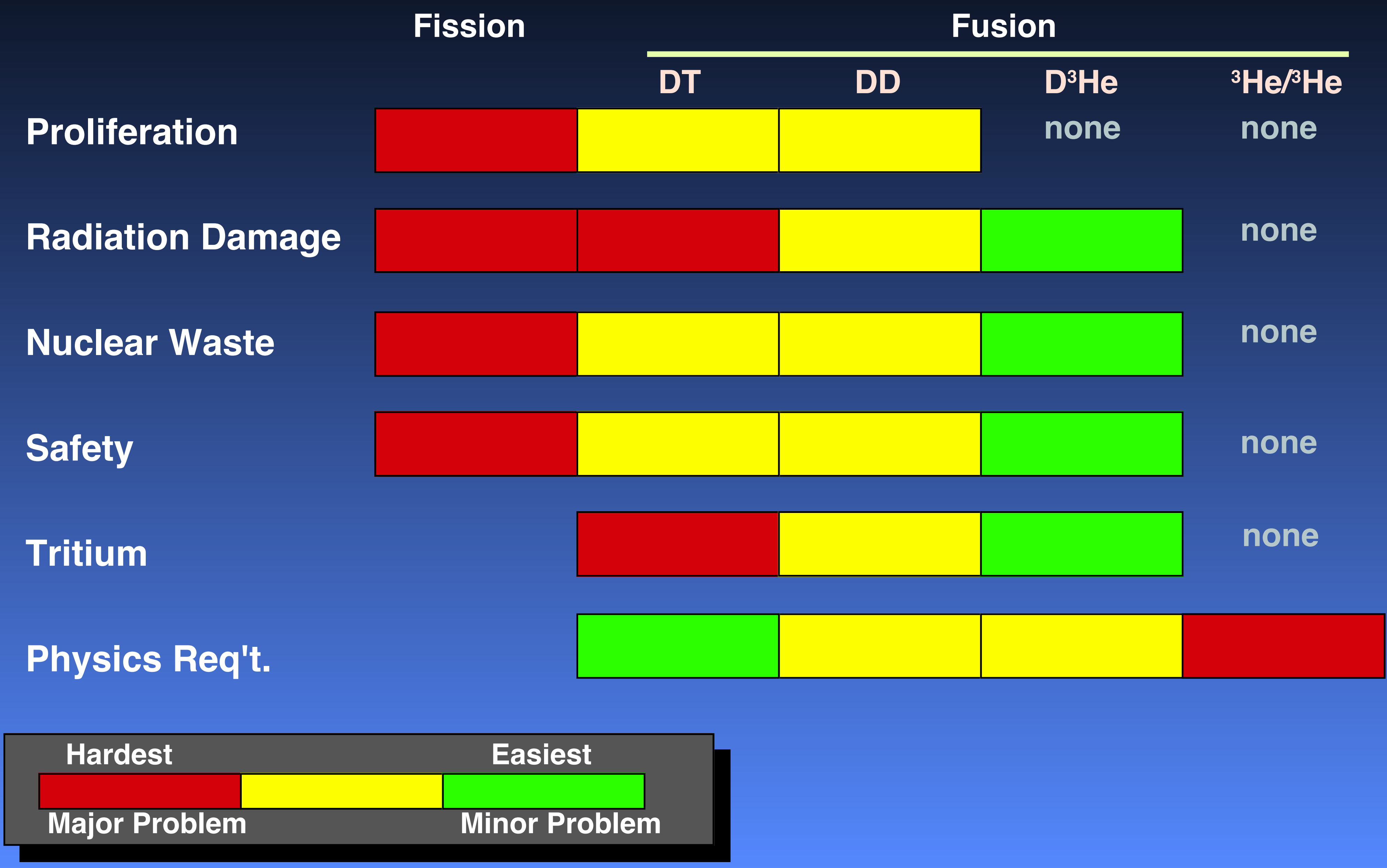
The ^3He Isotope is the Only Known Lunar Resource That Has Enough Economic Value to be Transported to the Earth



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

Major Societal and Technical Concerns of Nuclear Energy Options

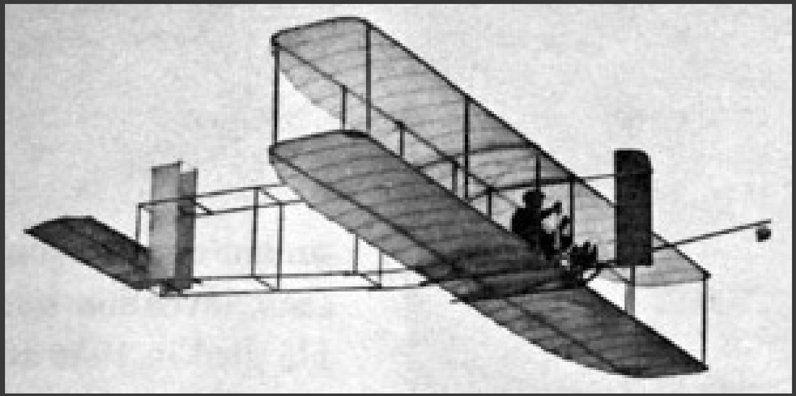


Conclusions

- 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