Non-Electrical Power, Near Term Applications of Fusion Energy

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Why Are We Concerned About the Timetable for Demonstrating Benefits from Fusion Energy?

- **Commercial electricity from fusion is now perceived as being 50 years or more away**
- **Developing the first fusion reactor is a 20$B+ program**
- **Keeping Americans' attention on a multi-billion, multi-decade project will be difficult**

What Can We Do to Demonstrate Benefits from Fusing Plasmas on a Much Shorter Timeframe (≈5-10 years) and for Much Less Money (<<100 $M)?

Distinction Between "Spinoffs" and "Applications"

- "Spinoffs" generally occur as an unintended consequence of research.

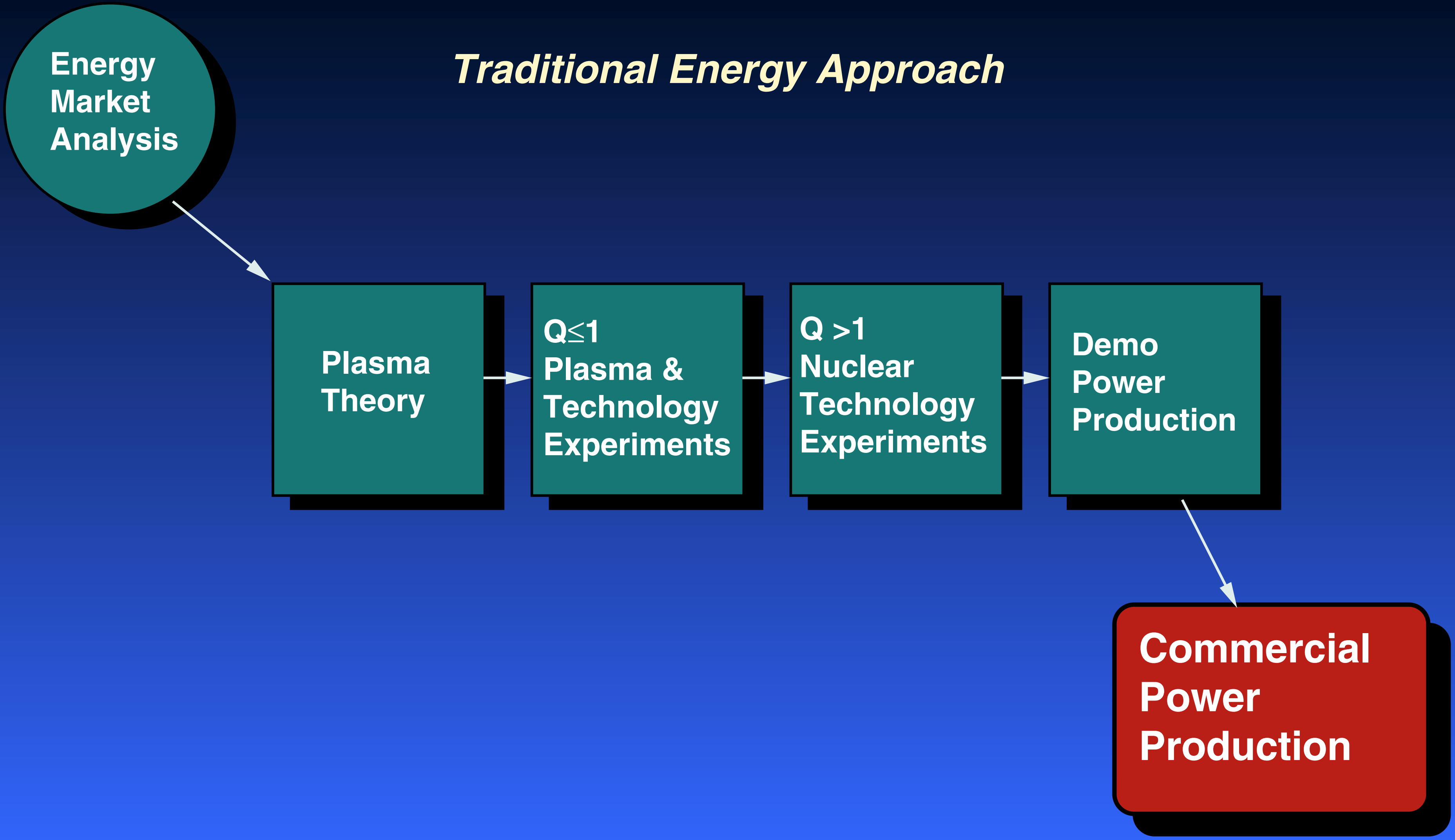
- "Applications" are the uses of a technology to a specific problem which was recognized at the beginning.

- In today's funding climate it is difficult to get Federal research dollars specifically for "spinoffs" (even though the spinoffs can be quite important to society in general, and business in particular).

- "Applications" open up smaller, but perhaps more reliable funding sources from industry.

How Do We Get There From Here?

Traditional Energy Approach



Energy Market Analysis

Plasma Theory

Q≤1 Plasma & Technology Experiments

Q >1 Nuclear Technology Experiments

Demo Power Production

Commercial Power Production

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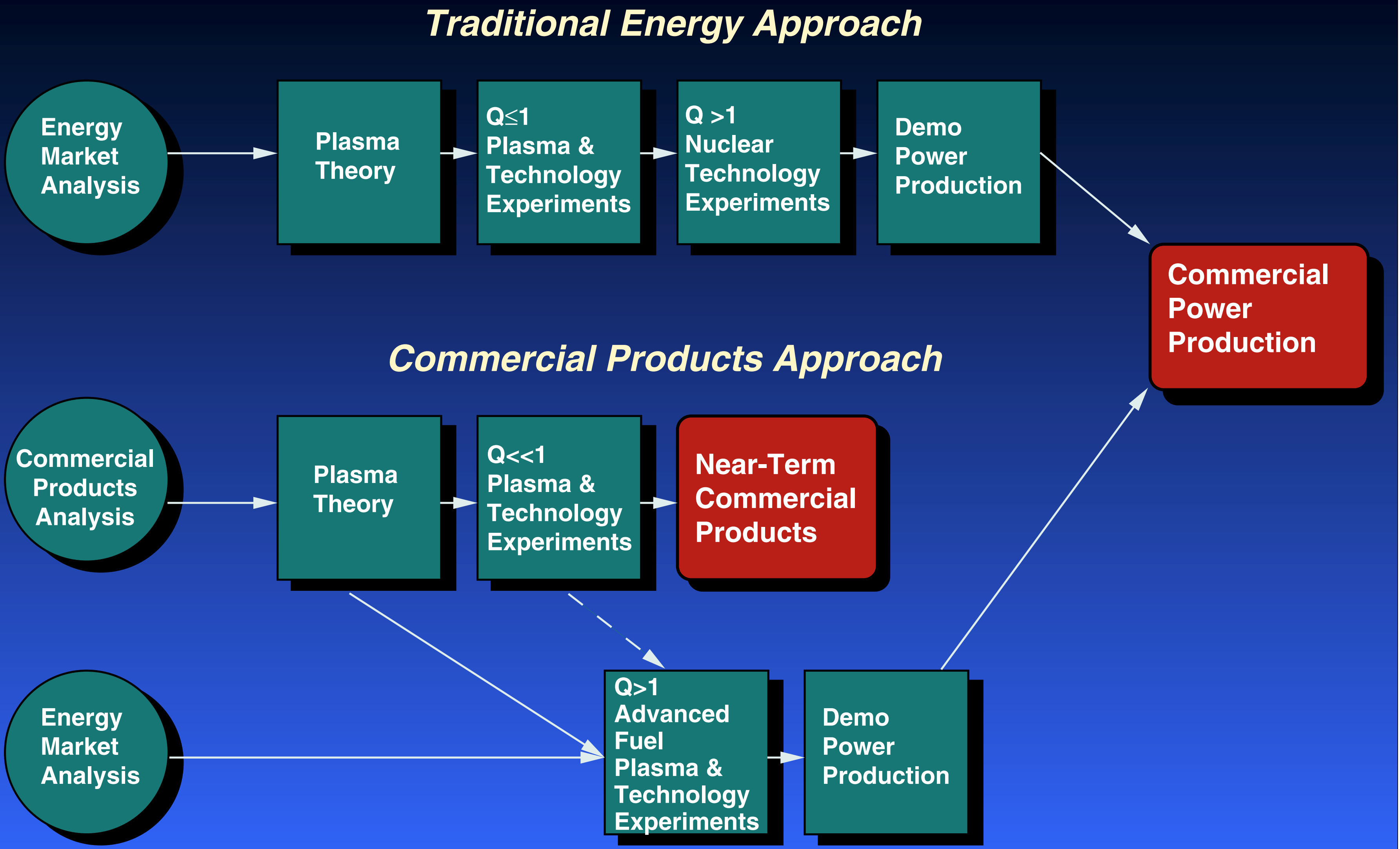

Traditional Energy Approach

Energy Market Analysis

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Demo Power Production

Commercial Power Production

Commercial Products Approach

Commercial Products Analysis

Plasma Theory

Q<<1 Plasma & Technology Experiments

Near-Term Commercial Products

Energy Market Analysis

Q>1 Advanced Fuel Plasma & Technology Experiments

Demo Power Production

In the Near Term (where Q<<1), What Does the Fusion Community Have to Sell That is Unique?

- **Portable Source of Neutrons**

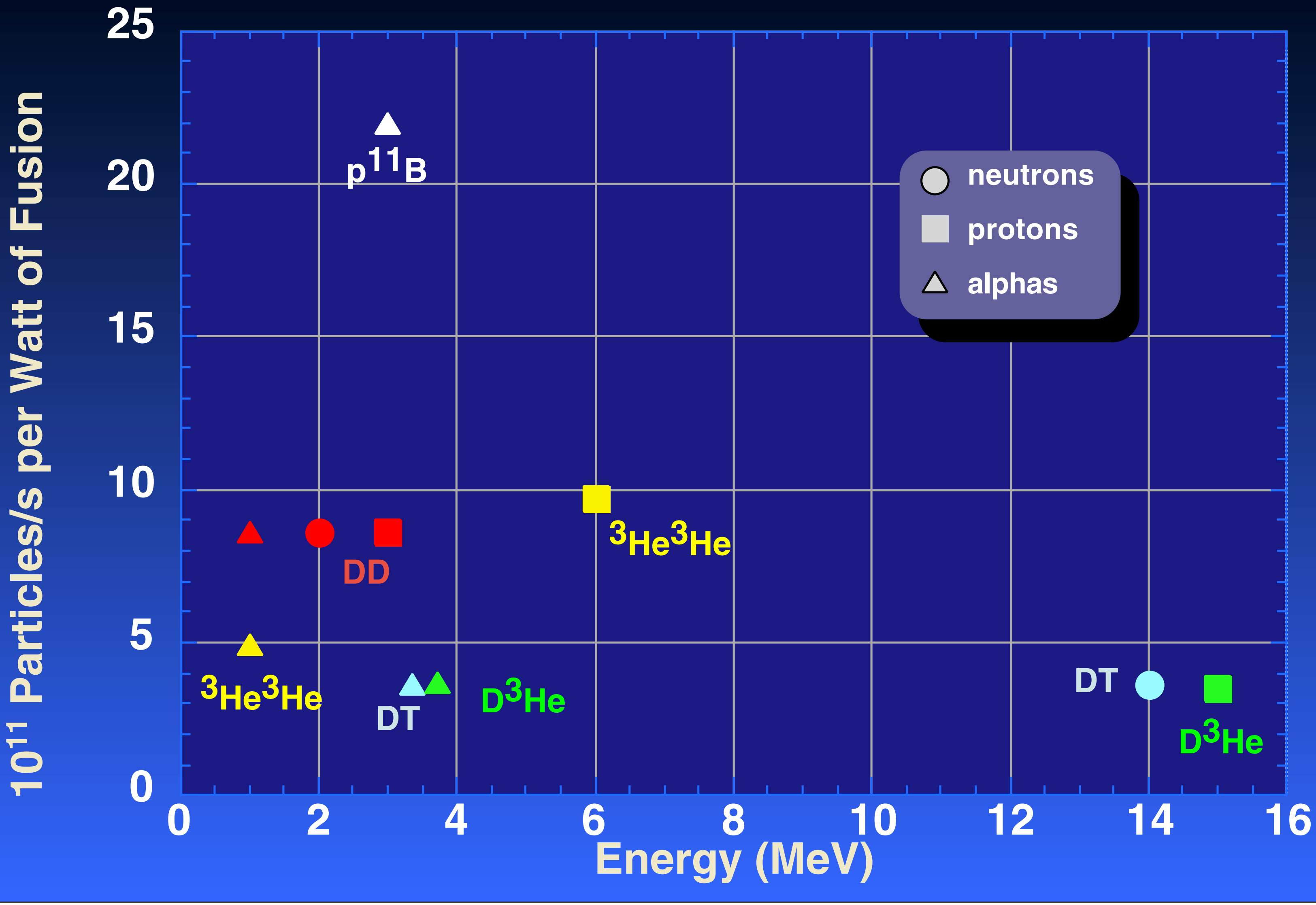
  Non-proliferating technology,
  No fission products,
  Small source possible (few watts fusion power),
  Thermal to 14 MeV Energy

- **Portable Source of Protons**

  Up to 14 MeV Energy
  Little auxiliary radioactivity
  Competes with accelerators or cyclotrons

- **Portable Source of Electromagnetic Radiation**

Fusion Fuels Can Produce Large Numbers of Highly Energetic Particles for Commercial Applications



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*

"Humanity is Losing the War Against Land Mines!"

Johan Molander
U.N. Conference on Land Mines
January, 1995

- Approximately 800 people are killed per month and thousands injured by land mines
- An estimated 100 million land mines now sit in about 60 countries
- 2 million new mines (costing ≈ $5 each) are planted each year and only 100,000 are cleared per year at an average cost of $1,000
- Red Cross estimates that in Cambodia, 1 person in 235 has had a limb amputated, most from mine blasts
- In Afghanistan, nearly 1/4 of mine casualities are children
- In Libya, 27% of arable land remains covered by mine fields dating to World War II

Neutrons Can Be Used to Detect Explosives

- Explosives contain a high concentration of nitrogen and a characteristic ratio of N/O.

- Several Techniques Can Be Used
  - => Nitrogen (quantity)
  - => C, N, O (quantity)
  - => C, N, O (quantity)
  - => C, N, O ratio

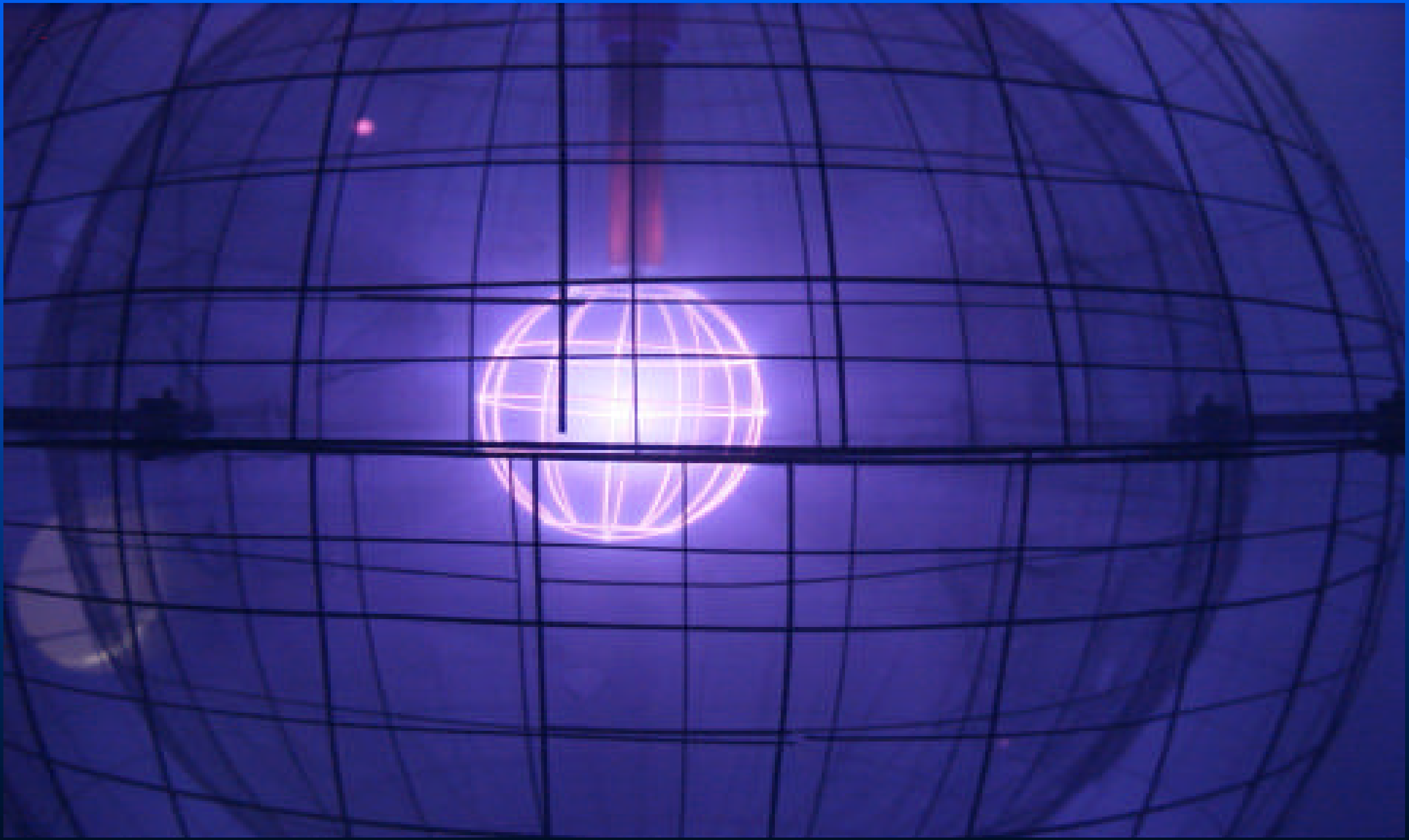
- Thermal Neutron Activation
- Elastic Neutron Scattering
- Pulsed Fast Neutron Activation
- Fast Neutron Associated Particle

- Source Strength

POP – 3x10^{6} n/s (current capability, 2x10^{7} n/s DD)
Goal – 5x10^{10} n/s DD
10^{12} n/s DT

Record Steady State D-D Reaction Rate Achieved in Wisconsin IEC Device

2.2x10^7 neutrons/s (2.45 MeV)



Neutrons Can Be Used to Detect Transuranic Elements

- Major problem in waste at former US (and USSR) weapons facilities.

- Use neutrons to promote fission and detect delayed neutrons.

- Thermal neutron source desirable
  10^{12} n/s DT => 10^{11} n/s thermalized

- Competition – ^{252}Cf (12 M$/g), 10^{12} n/s per gram

Neutrons Can Be Used to Find Chemical Weapon Agents

Elements of Interest => P or F (nerve agents)
Cl, As, S (mustard gas)

Location =>
- Unexploded Shells
- Buried on Military Sites (~250)
- Smuggled into Sensitive Areas

Technology Required => $>10^{12}$ n/s of 14 MeV n's

Positron Emission Tomography (PET) Has Become a Major Diagnostic of Cancers

- There are now over 60 PET research and 20 PET distribution centers in the U.S.

- When an isotope emits a positron (e^+), it combines with an electron (e^-) to emit two 511 keV gamma rays. The γ rays reveal the location of the isotope.

- PET has detected unsuspected metastases not seen by CT, MRI, and US in 15-30% of patients thus altering surgical procedures and saving an average of $5,000-30,000 per patient.

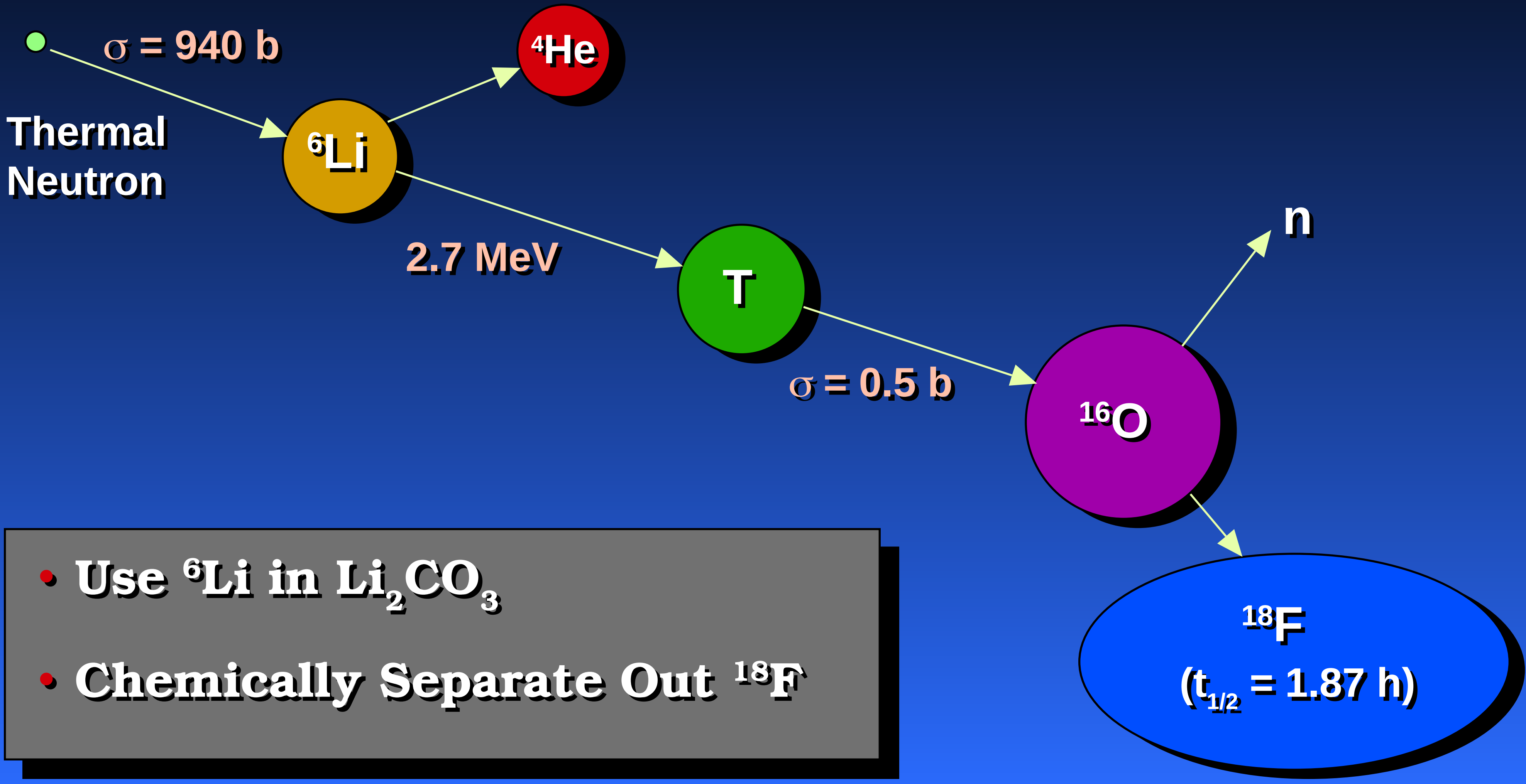
- More than 80% of the PET applications use ^{18}F in fluorodeoxyglucose (FDG).

- On 1/1/98, Medicare started reimbursing medical organizations for certain PET applications ($\approx$ $2,000 total for FDG-PET).

- Cyclotrons (costing 2-2.5 $M each) use 15-20 MeV protons to make the ^{18}F (half-life 1.83 h).

There Are Currently Over 60 PET Centers in the United States

Neutrons Can Be Used to Produce ^{18}F (after J. Bayless)



- Use ^{6}Li in Li_2CO_3
- Chemically Separate Out ^{18}F

Economics of Producing ^{18}F with Neutrons (after J. Bayless)

Feed Material: 30 g of Li_2CO_3 (95% ^6Li)

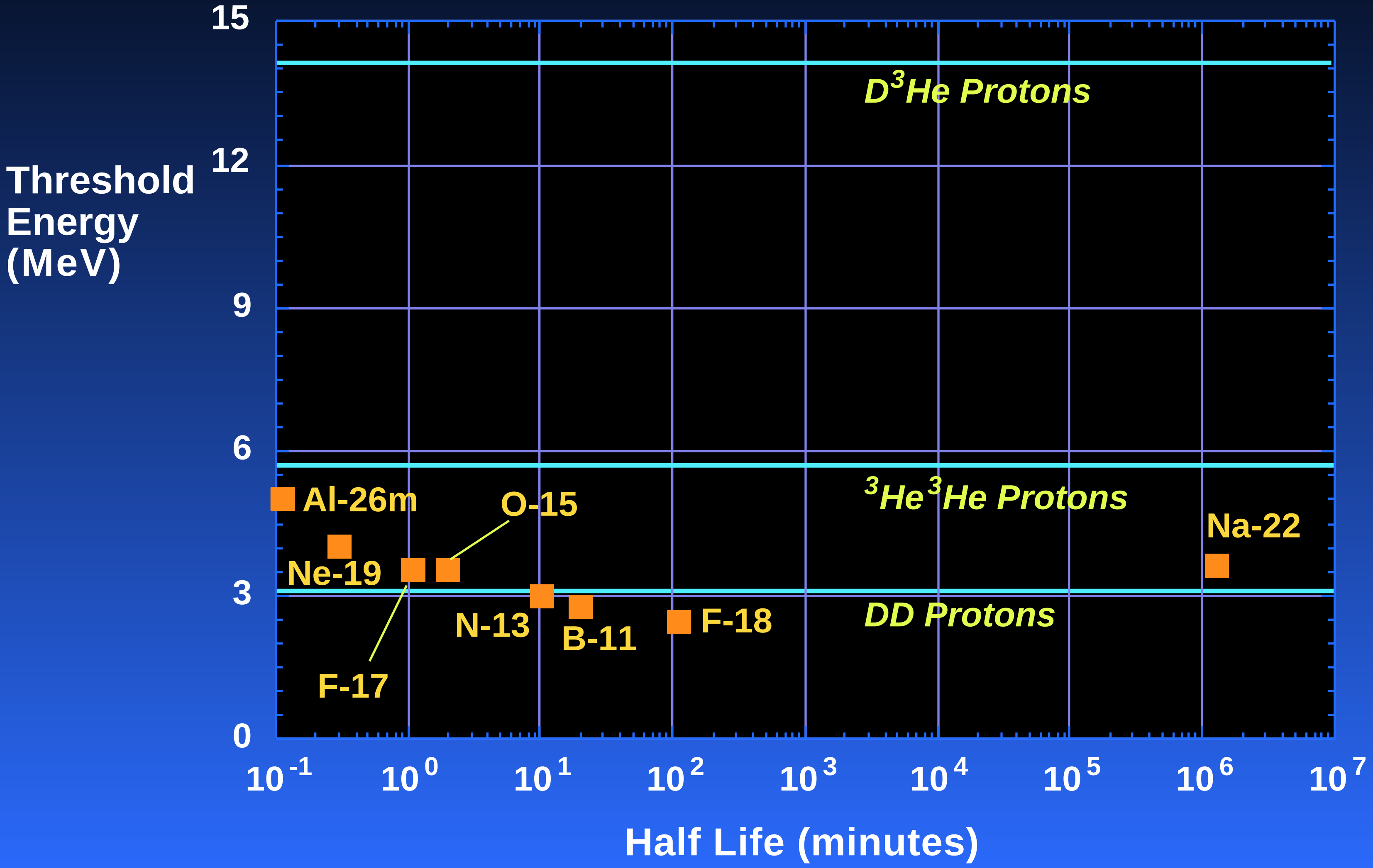
Neutron Source

- $3x10^9$ n/cm^2-s (from a $5x10^{12}$ n/s 14 MeV source with D_2O moderator)
- Production Rate ^{18}F = 5 Ci/hr ($5x10^{11}$ ^{18}F atoms per second)
- Cost Goal (<0.5 M$)

Cyclotron

- 8–10 MeV Protons
- 100 μA/cm^2 ($6x10^{14}$ particles/cm^2-s)
- ~1 Ci/hr
- Cost ~ 2 M$

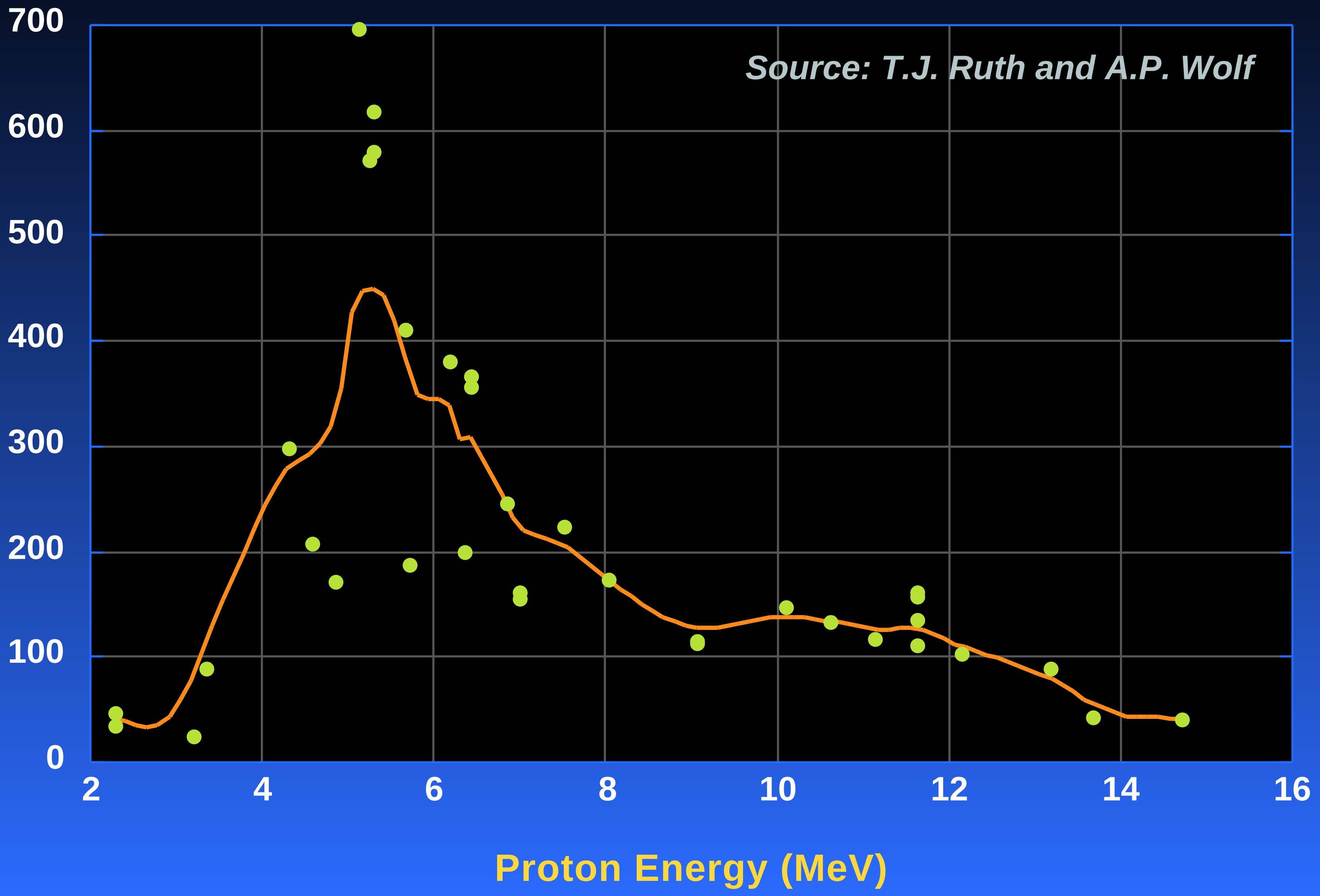
A Wide Variety of Positron Emitters Can Be Made with Protons from Advanced Fusion Fuel Reactions



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

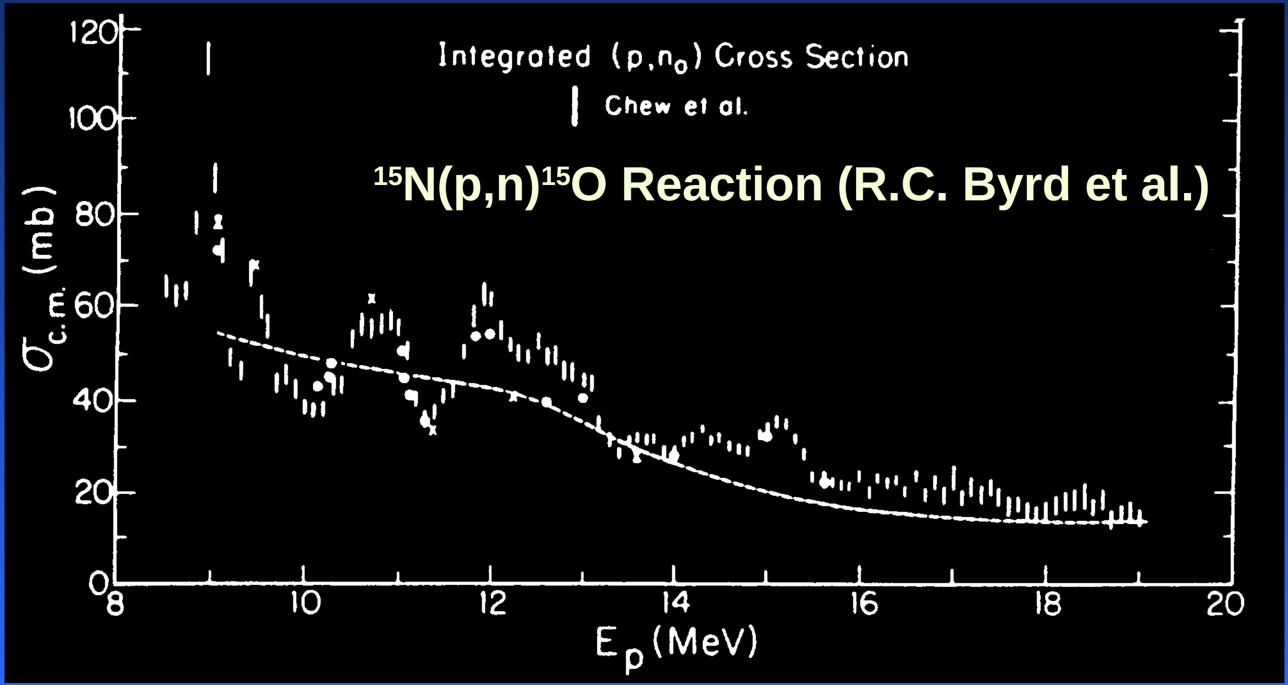
1.5x10^5 protons/s (14.7 MeV)

The $^{18}O(p,n)^{18}F$ Cross Section Peaks Between 5–6 MeV



Small Mobile PET Generators Could Reduce Radiation Exposure to Patients

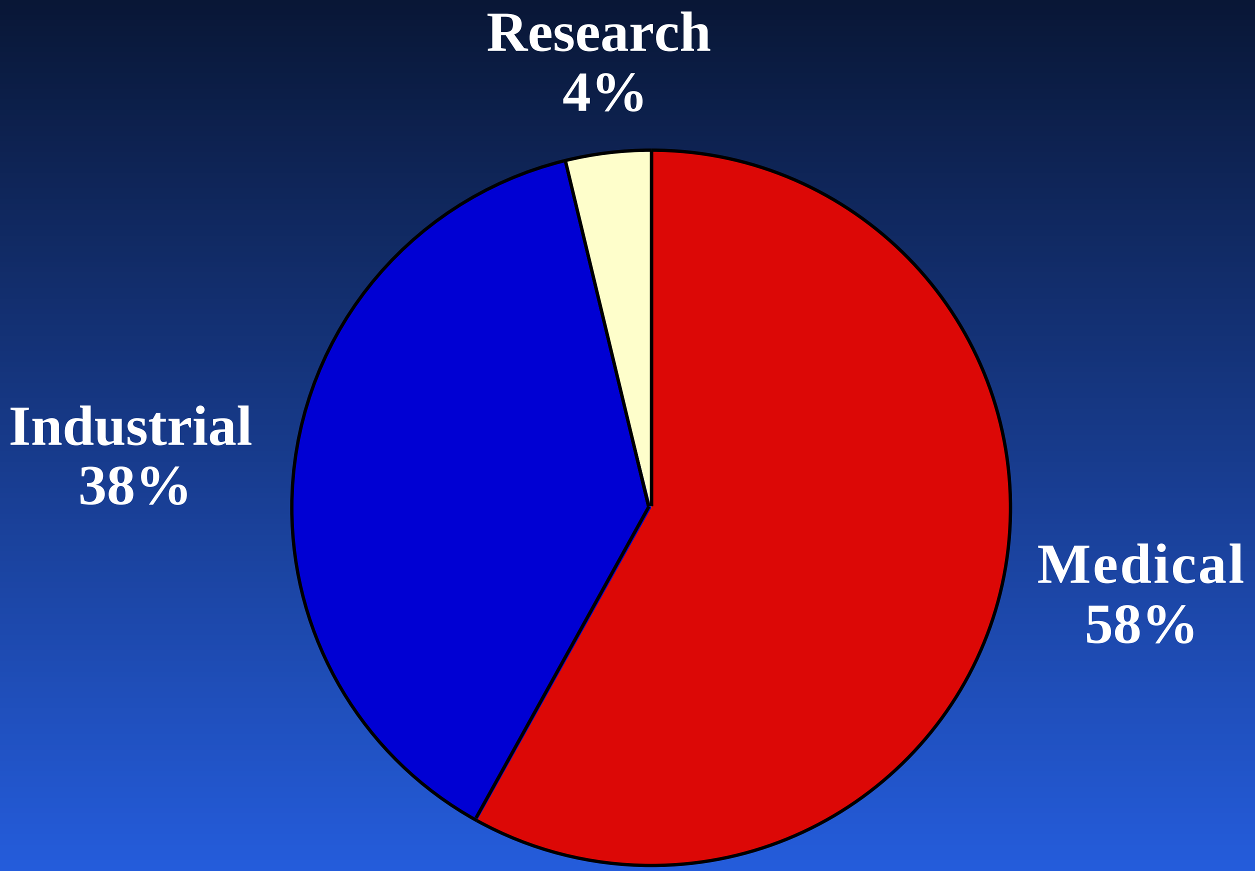
- Presently ^{18}F ($t_{1/2}$ = 1.83 h) is used extensively for brain scans
- Current regulations preclude the repeated use of ^{18}F on young children and pregnant women
- An ideal PET isotope would be ^{15}O ($t_{1/2}$ = 2.03 min)
- 1 Watt of D^3He fusion could produce ≈8 mCi of ^{15}O (steady state)



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

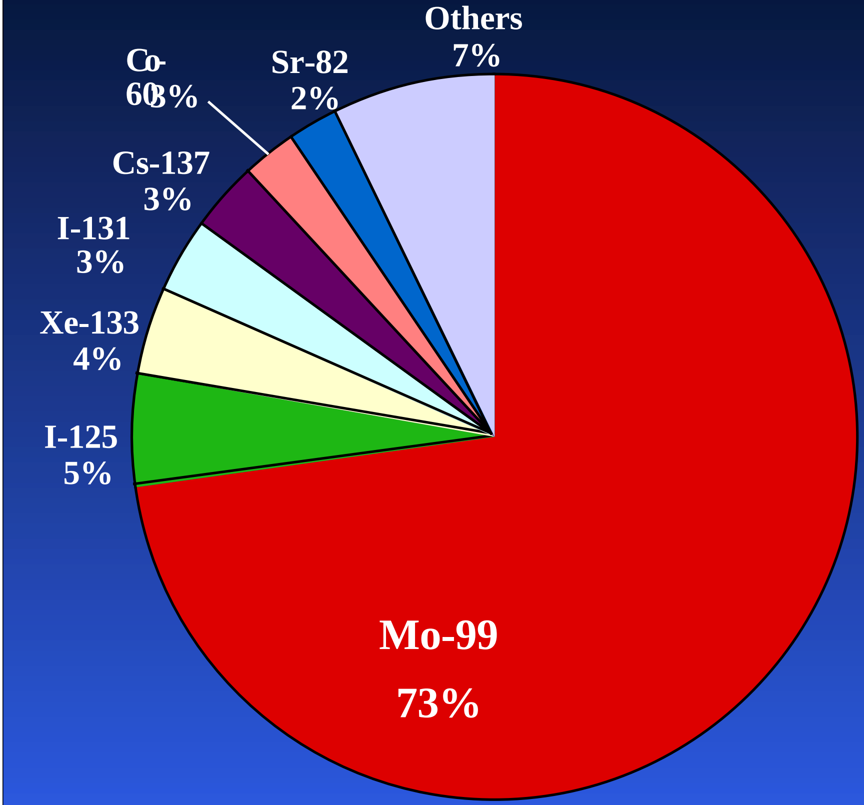
The World Demand for Radioisotopes was Dominated by Medical Applications in 1994



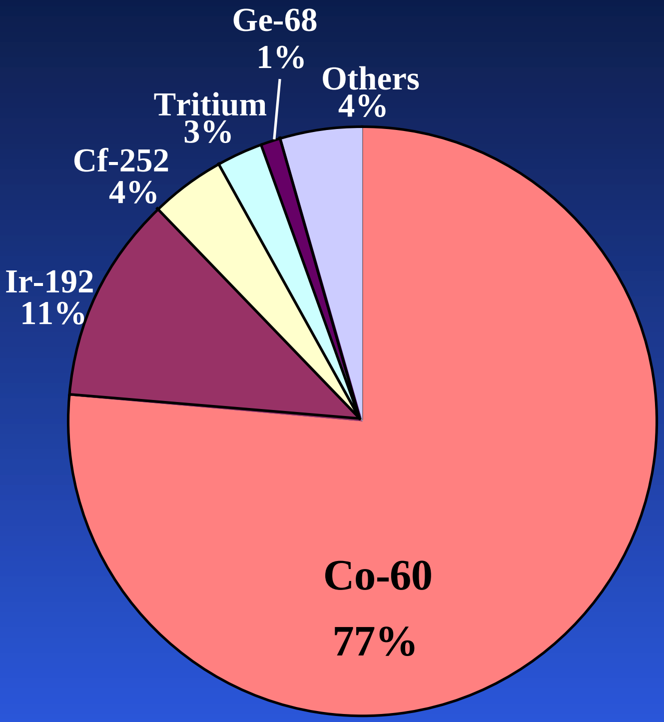
Source: A. Andersen

Total Demand-102 $M in 1994

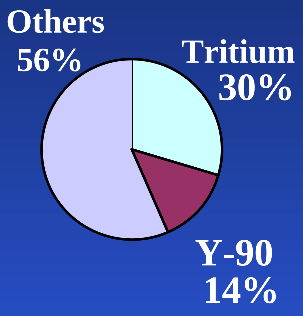
The World Demand for Radioisotopes was Over 100 $M in 1994



Medical – 59 $M



Industrial – 39 $M



Research – 3.7 $M

Why is ^{99}Mo ($t_{1/2}$=66 hr) Important?

- Its daughter, ^{99m}Tc, has a half life of 6.04 hr and is used in over 10,000,000 clinically administered procedures in the U.S. annually (80% of all radioisotope procedures).

- ^{99m}Tc is used for:
  - bone scans
  - lung scans
  - heart scans
  - liver/spleen scans
  - biliary scans
  - gastrointestinal scans
  - Meckel's (stomach) scans
  - renal (kidney) scans
  - thyroid scans
  - brain scans
  - white blood cell scans

- Roughly 40% of hospitalized patients in the U.S. have at least 1 nuclear medicine study during their stay.

How is ^{99}Mo Produced?

- *Fission Product of ^{235}U*

10,000 Ci ^{99}Mo per gram Mo fission product

- *Fission neutron absorption by ^{98}Mo (24% of elemental Mo)*

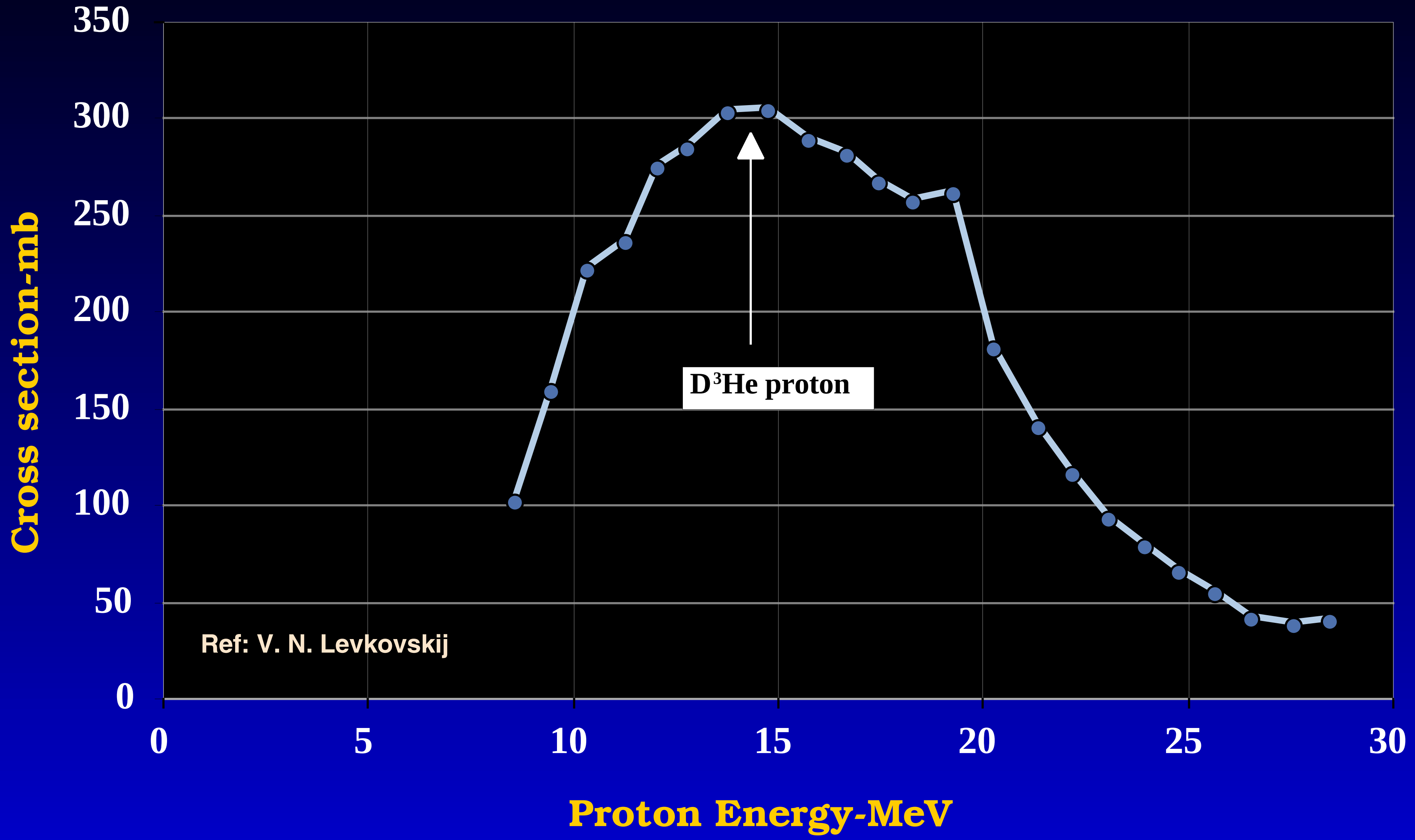
^{98}Mo (n,γ) ^{99}Mo 1 Ci/g of Mo

- *Fusion neutron irradiation of Mo*

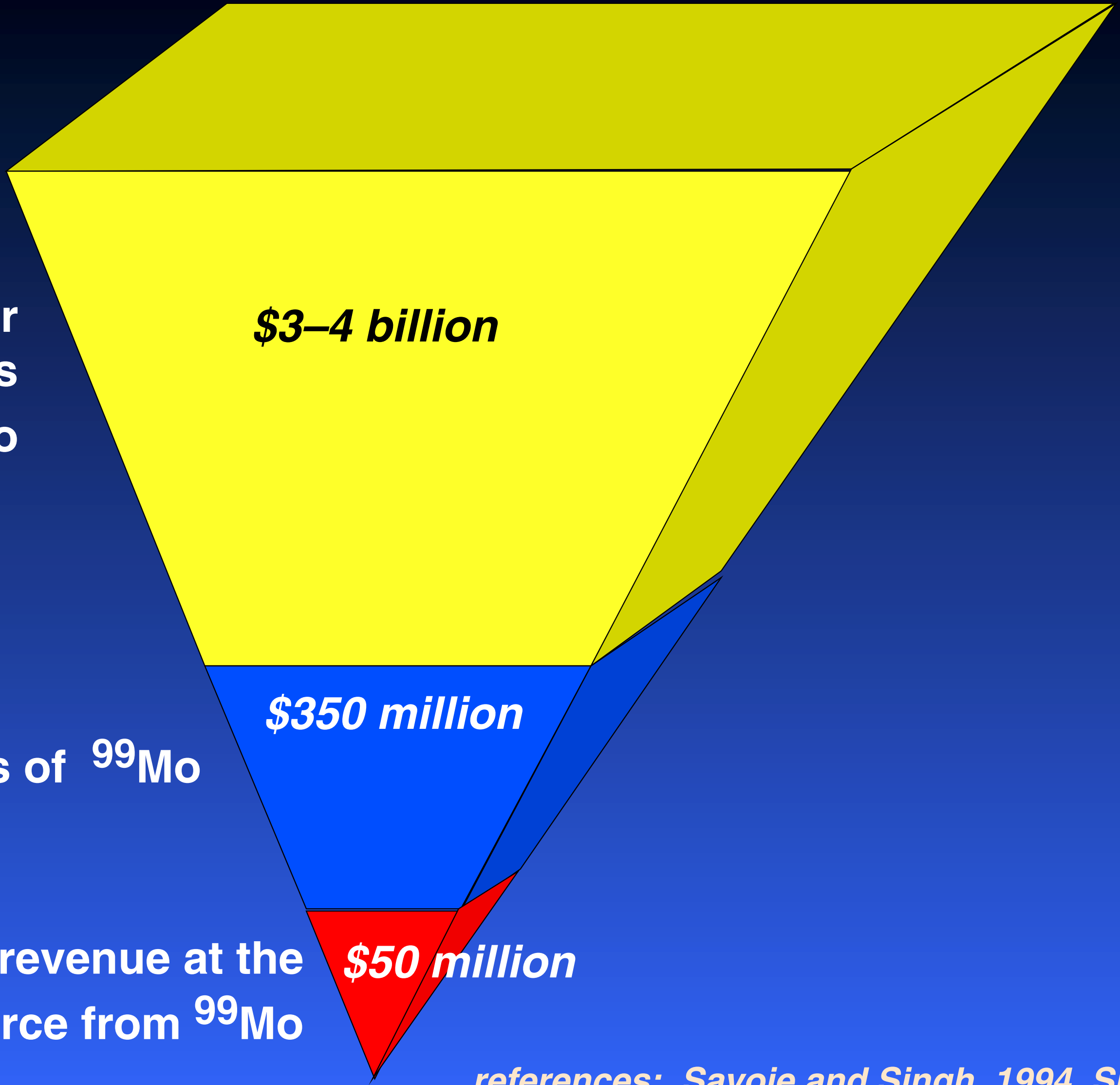
^{98}Mo (n,γ) ^{99}Mo ^{100}Mo (n,2n) ^{99}Mo

0.05 Ci/g for IEC – 10^{15} DT n/s	3 kW fusion power
0.5 Ci/g for IEC – 10^{16} DT n/s	30 kW fusion power

The ^{100}Mo(p,2n)^{99m}Tc Cross Section Peaks at the Energy of the D^{3}He Proton



^{99}Mo Revenue Chain



Annual cost of nuclear medicine procedures using ^{99}Mo

$3–4 billion

Annual retail sales of ^{99}Mo

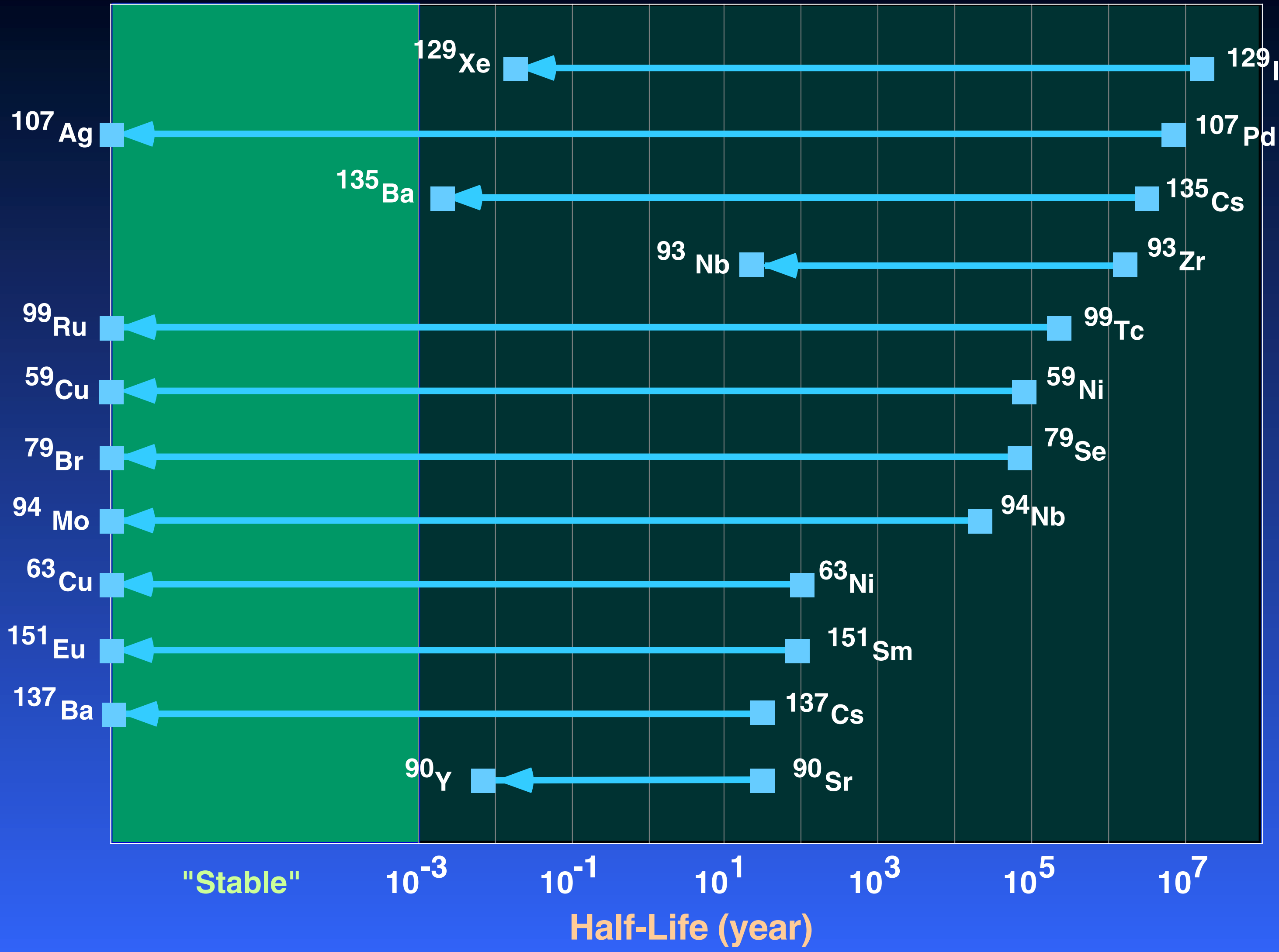
$350 million

Annual revenue at the production source from ^{99}Mo

$50 million

references: Savoie and Singh, 1994, Spicer, 1997

Protons from the D^{3}He Reaction Can Be Used to "Burn Up" Long Lived Nuclear Waste



August 1997

The Use of D-^{3}He Reactors for Burning Fission Waste

- The waste is injected into the plasma as impurity and the high 14.7 MeV proton flux (10^{20} protons/s) is used for transmuting the waste via mostly (p,n) reactions.

- At present, typical cyclotrons can produce 100 μA of 10 MeV protons at a capital cost of $2 million.

- A 200 MWt D-^{3}He reactor would produce about 10 A of 14.7 MeV protons. This is equivalent to 100,000 cyclotrons.

- For example, such a D-^{3}He reactor is roughly capable of burning all of the ^{90}Sr produced by a 1200 MW_{th} fission reactor in a year.

- The burning of ^{90}Sr ($t_{1/2}$ = 28.82 y) via (p,n) reactions would result in the production of ^{90}Y ($t_{1/2}$ = 64.06 hr) and ^{90m}Y ($t_{1/2}$ = 3.19 hr).

Potential Non-Electric Commercial Opportunities Associated with the Long Range Development of Fusion Electrical Power

	Near Term	*Intermediate Term*
Medical	– Isotope Production – Cancer Therapy	
Civilian Commercial Market	– Positron Emitter Production – Proton Activation Analysis – Gemstone Enhancement – Neutron Radiography	– Production of Tritium – Neutron Irradiation Facility – Production of Hydrogen
Environmental	– Detection of Chemical Spills	– Destruction of Fission Products
Defense	– Detection of Explosives – Detection of Chemical Weapons	– Destruction of Pu & Actinides – Production of Tritium

Phased Approach to the Development of Safe, Clean and Economical Fusion Electrical Power Plants

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

Phase 2

Intermediate Term Application 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 Application from a Q < 1 Device

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

Conclusions

- There is an immediate future (next 5-10 years) for commercial products from fusion.
- The unique energy and type of nuclear particles from the DT, DD, and D^3He fuel cycle can produce products even though the confinement concept may be far below Q=1.
- One of the most promising products in the near term may be the production of radioisotopes.

Conclusions

- In the intermediate time range (20–40 years) non-electric applications related to the production of neutrons for irradiation damage studies, the destruction of fission wastes, or the production of hydrogen could become important.

- The fusion program must expand its horizons to new applications if it is to maintain public support for a 50+ year program to develop electric power plants.