Evaluation of Earth's Helium-3 Supply

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Fusion Reactions

D+D → 3He(.82MeV) + n(2.45MeV)

D+T → 4He(3.5MeV) + n(14.1MeV)

Most energy produced in the form of high energy neutrons,
~ 30% efficiency in energy conversion

D+3He → 4He(3.6MeV) + p(14.7MeV)

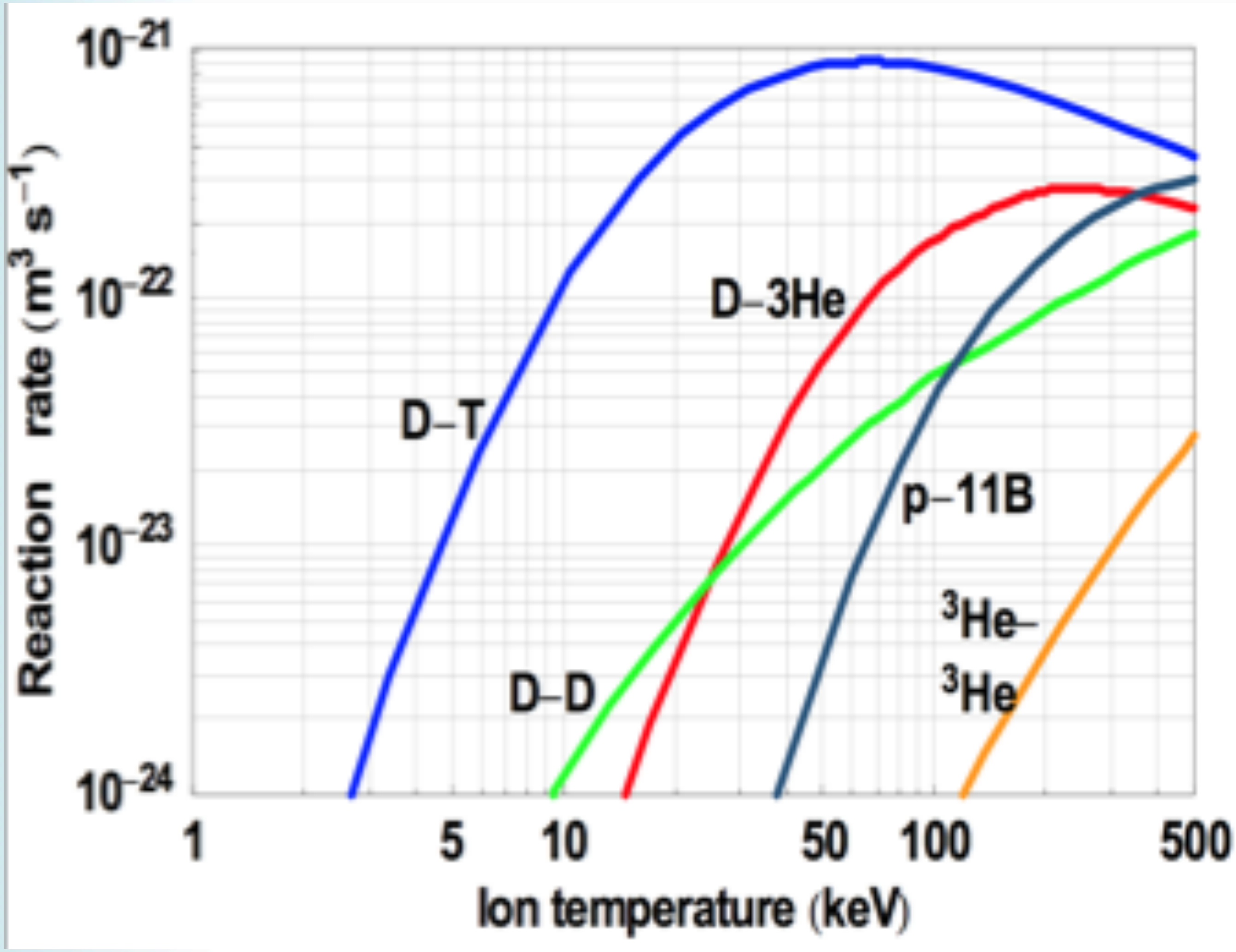
p + 11B → 3x4He + 8.7MeV

"Advanced Fuels"- few high energy neutrons resulting, products are charged particles,
possibility of > 90% efficiency in energy conversion

D-3He fuel for fusion is desirable

- Few high energy neutron products → less damage due to radioactivity
- Direct conversion → more efficient
- But still not as much heat or energy required as p-11B.......

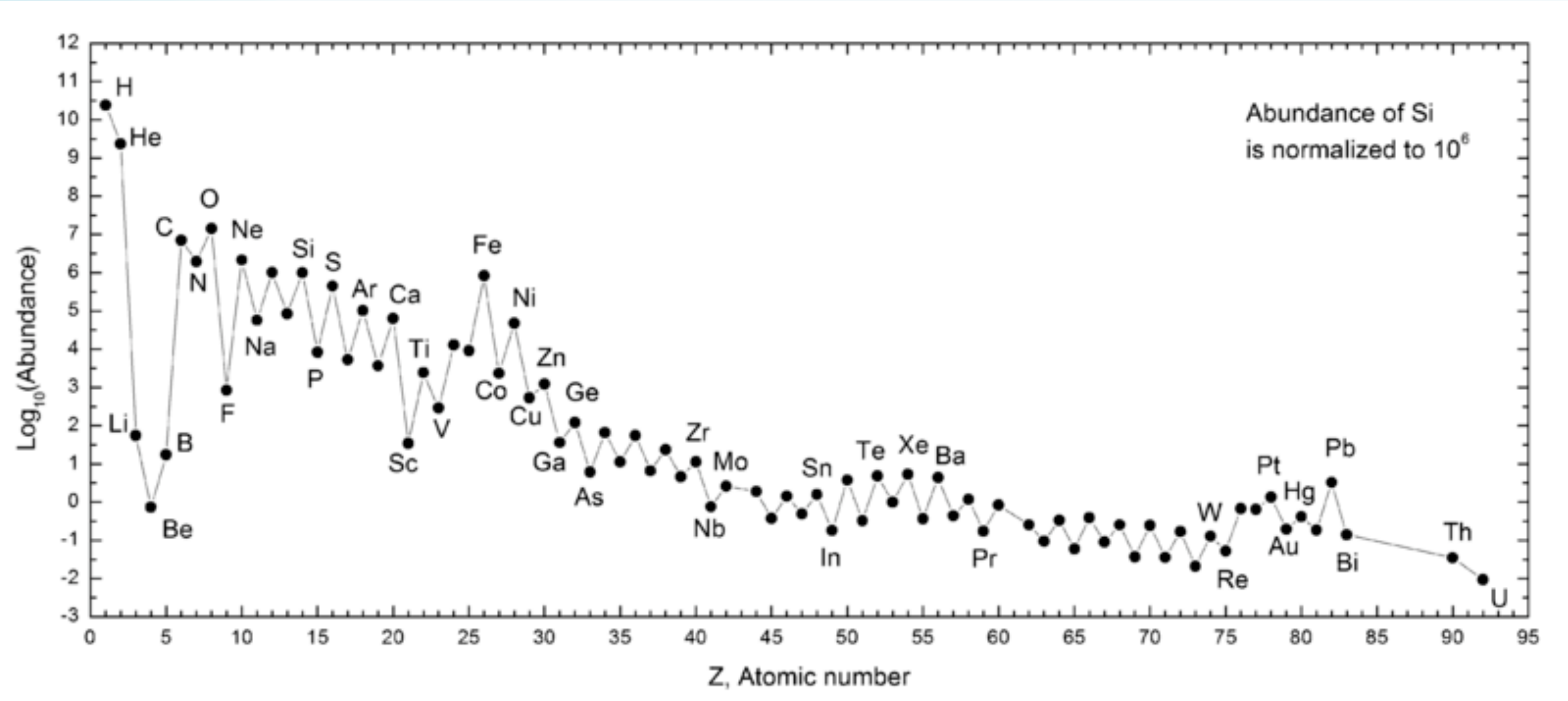
D-3He Fuel does not require as much heat as p-11B to achieve a given reaction rate



Motivation

- One of the major advantages of the FRC is its compatibility with this fuel
- Realizing an adequate supply of helium-3 and demonstrating the success of D-3He as a fuel will confirm the FRC's compatibility with advanced fuel as a real advantage
- Run a number of small reactors for about 30 years
  - Dual goals: $$ and improvements
    - Could be used in power grids or transportable devices
    - Easy to make changes and improvements
  - If successful, would demonstrate feasibility of D-3He fuel in the FRC, may encourage pursuit of lunar sources

He-3 is relatively abundant in the universe……



http://upload.wikimedia.org/wikipedia/commons/e/e6/SolarSystemAbundances.png

Helium is the second most abundant element in the universe with He-3 accounting for .03%

Abundant Sources of He-3 On/Near Earth

- 10^9 kg = $7.54x10^{12}$ L on the surface of the moon, deposited there by the solar wind*
  - Earth's geomagnetic field and atmosphere prevented accumulation
- 4 million kg of He-3 in atmosphere
- At least 13,260 kg in oceans and natural gas wells

*Reference point: 1kg He-3 = 10^5 barrels of oil

U.S. consumes about 7 billion barrels per year

World consumes about $3.17x10^{10}$ barrels per year

So lunar supply would last for about 3150 years

He-3 From Decay of Tritium in U.S.

- T → He-3 + e
  - Beta-decay, 12.3 year half-life
- Until 1988, tritium was produced by K-reactor at Savannah River Site for use in nuclear weapons stockpile
  - Owned by National Nuclear Security Administration (NNSA)
  - Tritium production stopped in 1988 due to problems with the reactor
  - In 2003, tritium production through the irradiation of lithium was started at TVA's Watts Bar reactor
    - Li-6 + n → He-4 + T
    - Tritium extracted at Savannah River Site's Tritium Extraction Facility (TEF)
    - Production still limited, so NNSA mainly still recycles tritium from dismantled weapons
- Since then, He-3 has been produced as a by-product of tritium decay
  - NNSA extracts 8,000-10,000L of He-3 annually from remaining tritium stockpile

He-3 From Decay of Tritium in U.S.

- Stored in pressurized cylinders at Savannah River Site
- Sold through Isotope Program
  - MOU with NNSA allocating at least 10,000L for sale each year
- From 2003-2009, Isotope Program held public auctions of helium-3, with the two only buyers being Linde Specialty Gases and GE Reuter Stokes
- Starting in 2009, policy committee determines allocations of He-3 through process

Timeline of He-3 Production in U.S.

NNSA extracts only 8-10,000L/ year due to arms reduction

Around 1955: U.S. begins producing tritium at Savannah River Site to supply nuclear weapons arsenal

1988: K-reactor at Savannah River shut down

1990-2001: Attempting to recover cost of He-3 extraction, NNSA ships He-3 to Isotope Program to sell.

2003: Tritium production at Watts Bar reactor begins

2009: Policy committee formed to regulate allocation process of He-3

1950 1960 1970 1980 1990 2000 2010

2003-2009: Public auctions held by Isotope Program, causing decrease in He-3 inventory

U.S. Helium-3 Stockpile Increases Until 2001

He-3 Allocation Process Since 2009

He-3 extracted by NNSA from tritium in nuclear weapons stockpile

→ He-3 stored in pressurized cylinders at Savannah River Site

→ A request for He-3 is approved by an allocation policy committee

→ Requested amount of He-3 is sent by Isotope Program to Linde, which purifies it

→ He-3 allotment sold through Linde at price* set by Isotope Program to customer

*Current cost estimate per liter: $600 for government agencies
$1000 for other commercial users

Cost largely determined by cost of manufacturing He-3, rather than by its rarity

He-3 Allocations from 2009-11

Table 2: Quantities of Helium-3 Allocated and Used, in Liters, from Fiscal Year 2009 to Fiscal Year 2011

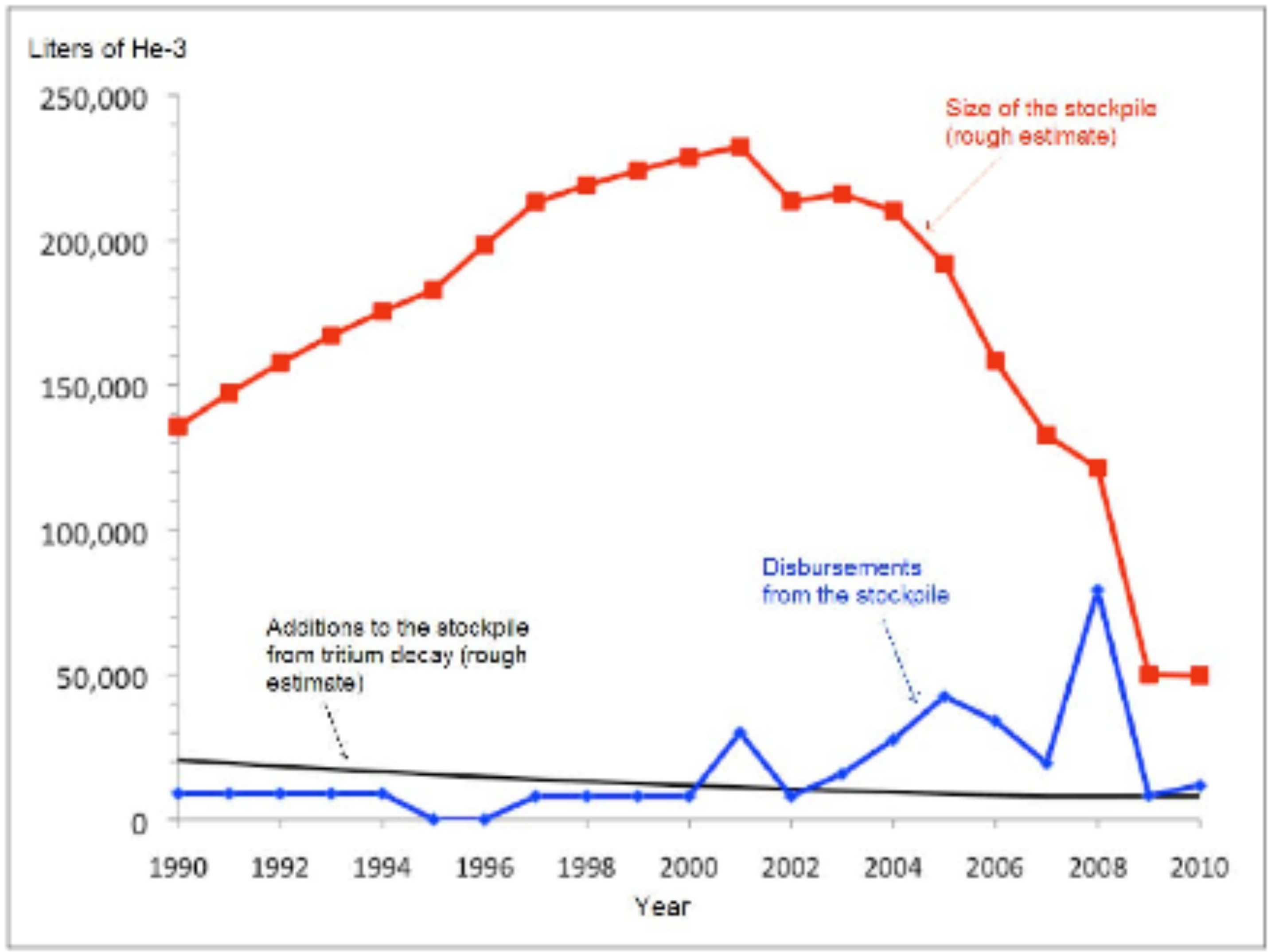
	Quantities		
Customer	**FY 2009**	**FY 2010**	**FY 2011**
Low temperature research	N/A[a]	452[b]	700
DHS	N/A[a]	438[c]	1,218
DOD	N/A[a]	1,530	3,521
NNSA	6,367	5,098[d]	5,791
DOE's Office of Science	2,400	341	315
Intelligence Community	N/A[a]	N/A[a]	763
NIH	N/A[a]	260[e]	1,400
NIST	N/A[a]	607[f]	236
Oil and gas industry	N/A[a]	695[g]	1,000
Road construction industry	N/A[a]	N/A[a]	350
Total	**8,767**	**9,421**	**15,294**

Source: GAO analysis of information from the interagency policy committee and Linde.

NNSA Helium-3 Supply Since 2003

- 260,000L in 2003
  - 210,000L sold through annual public auctions
  - 8,000-10,000L added annually to stockpile from tritium decay
- ~120,000L in 2009
- Almost 31,000L in 2011

U.S. He-3 Stockpile 1990-2010



From Congressional Research Services' *Helium-3 Shortage: Supply, Demand, and Options for Congress*

He-3 from Decay of Tritium in Russia

- Main supplier of He-3 to U.S. from 1995-2001 (Isotope Program did not sell He-3 but rather supplied it for NNSA's Accelerator Production of Tritium project)
- 2004-2008: U.S. imported ~25,000L/year from Russia
- 2008: Russia announced that it was reserving its supply for domestic use
- 20,000L/year He-3 total produced by U.S. and Russia– according to Brad Miller, House subcommittee chair and Democratic representative from North Carolina

CANDU Reactor: Alternate Source of Helium-3

- Heavy water (deuterium-oxide) used as moderator in nuclear power plant to mitigate problem of absorbed neutrons
- When neutron is absorbed by heavy water molecule, tritium is created
- Extracted tritium decays into helium-3

Ontario Power Generation (OPG)

- Owned by province of Ontario
- 16 CANDU reactors
- Extract tritium to reduce radioactivity of reactors
- Average of 15Mci (11707.2L) tritium extracted from heavy water annually
- Tritium stored in Immobilized-Tritium Containers
- Estimated initial yield of about 100,000L from existing tritium supply
- Able to provide about 10,000L/year additionally
- DOE still in discussions with OPG about making this He-3 available
  - According to Scott Preston, representative from OPG and Bob Rabun, representative from Savannah River Site

Ontario Power Generation (OPG)

Additional CANDU reactors

- India
  - extracts tritium from CANDU heavy water reactors at Bhabha Atomic Research Center
  - Authorities unwilling to disclose information regarding whether they are storing the tritium and how much they have
- South Korea
  - Started extracting tritium from 4 CANDU heavy water reactors in summer 2007
  - Have extracted 4kg (about 30,121L) tritium so far
  - Not long enough to yield significant amounts of He-3 yet

CANDU reactors also located in China, Romania, Pakistan, and Argentina; unclear if they are used in these places to produce tritium.

Natural Sources of He-3

- National Helium Reserve in Amarillo, Texas
  - Owned by Bureau of Land Management
  - Estimated 125,000L He-3* (with a total of around 10^12L of natural helium)
  - Feasibility study required to determine whether He-3 extraction would be cost-efficient
- Natural helium reserve in Big Piney, Wyoming
  - Predicted to supply 10% of world's helium by Scott Stinson, project manager of the plant
  - Estimated 200,000L He-3*
  - Also requires feasibility study

*according to GAO report, 2011

Big Piney, Wyoming

The Wyoming plant that extracts helium from natural gas began operation in November 2011, and was still undergoing construction the summer before.

Alternate Sources of He-3

- DOE survey estimates 1500L can be recovered from unused equipment and supplies in national labs
- DOE estimates extraction of 8,000-10,000L He-3 every 8-10 years from retired tritium beds at TEF

Summary of Earth's Potentially Accessible He-3 Supply

Approximate Current Inventory(L)	Annual Production Rate (L/year)	Current Form (S-separated, NS-mixed)	Location	Source	Ref.
31,000	8,000-10,000	S	Savannah River Site	Decayed tritium of nuclear weapons stockpile	[1]
100,000	10,000	NS, w/ tritium	Ontario Power Generation	Decayed tritium from heavy water reactors	[1]
125,000		NS, w/ 4He	Amarillo, Texas	Natural helium gas in earth	[1]
200,000		NS, w/ 4He or natural gas	Wyoming	Natural helium gas in earth	[1]
1500	8,000-10,000 every 8-10 years	NS	National labs; Savannah River's TEF	Unused equipment and supplies; retired tritium beds	[1]
undisclosed	undisclosed	NS, w/ tritium	Russia, India, South Korea	Decayed tritium	[1],[4],[7]

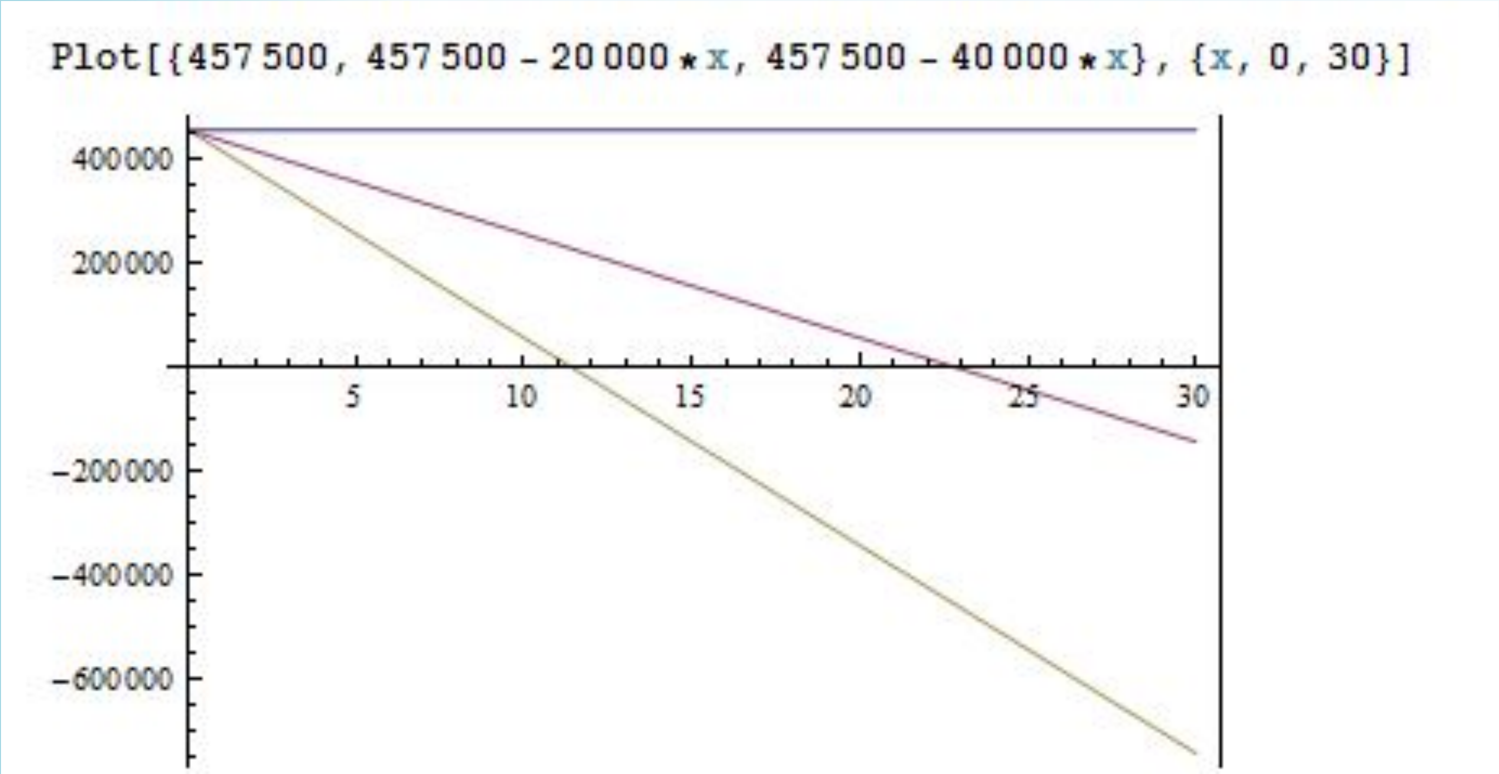
Power Calculations

- D + 3He → 18.3MeV
- 1 MW-year = 400L He-3
- NNSA He-3 supply:
  31,000L = 77.5 MW-years = 15.5 5MW-years
- Total accessible supply on earth (except unknown sources):
  457,500L = 1143.75 MW-years = 228.75 5MW-years
- Man-made supply:
  132,500L = 331.25 MW-years = 66.25 5MW-years + foreign supply

$S(t) = I + Rt$

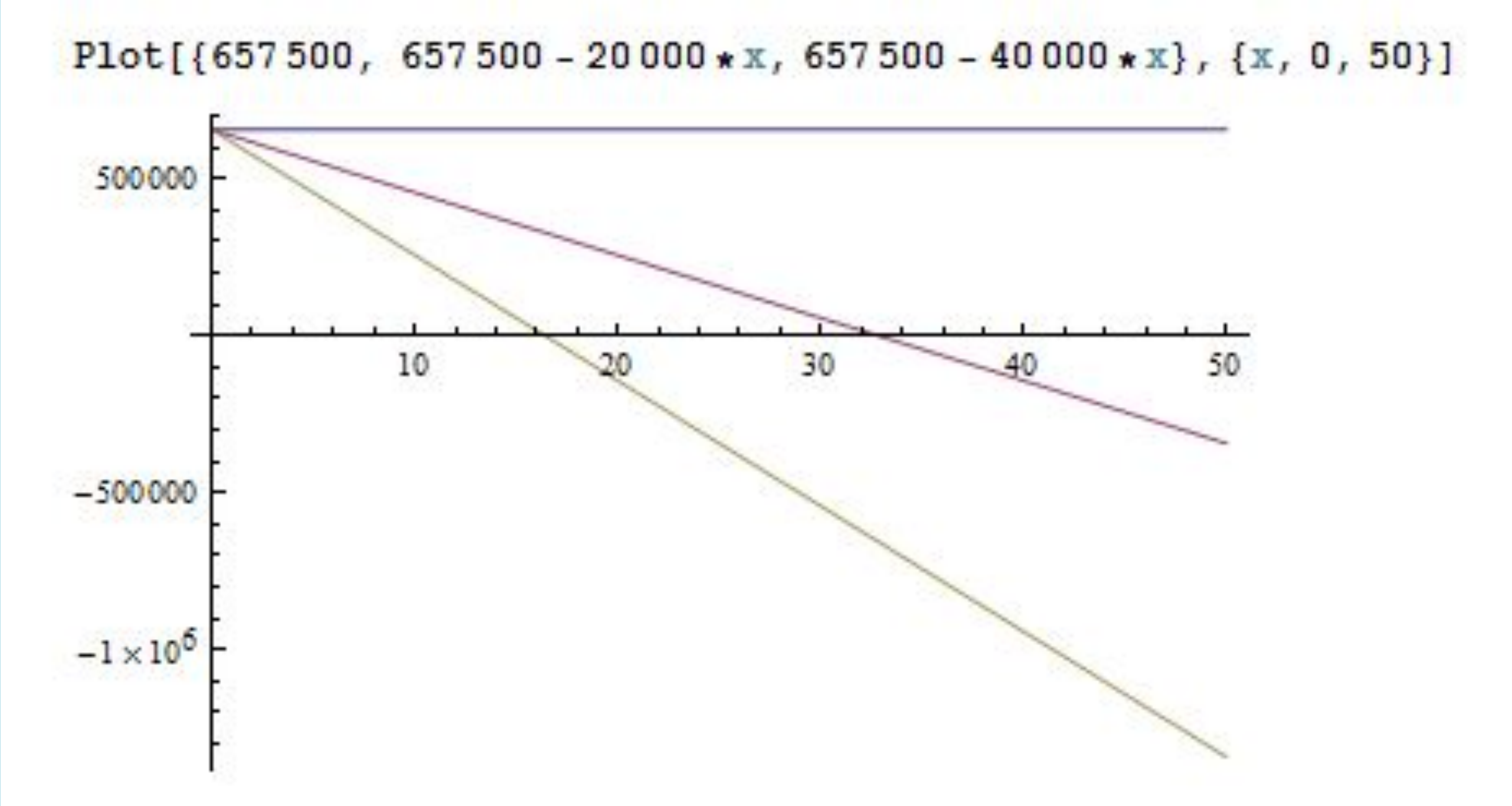
- S= supply of He-3
- I = inventory = 457500L + A*(years since 2012)
- R = rate = A-D
- A = annual additions to supply
- D = annual disbursements from supply =2000n
- n= number of 5MW reactors
- t= time (in years) since reactors start running

S(t) = 457,500 + (20,000-D)t



Blue: 10 5MW reactors
Purple: 20 5MW reactors lasts 22.875 years
Brown: 30 5MW reactors lasts 11.437 years

S(t) = 657,500 + (20,000-D)t [wait 10 years]

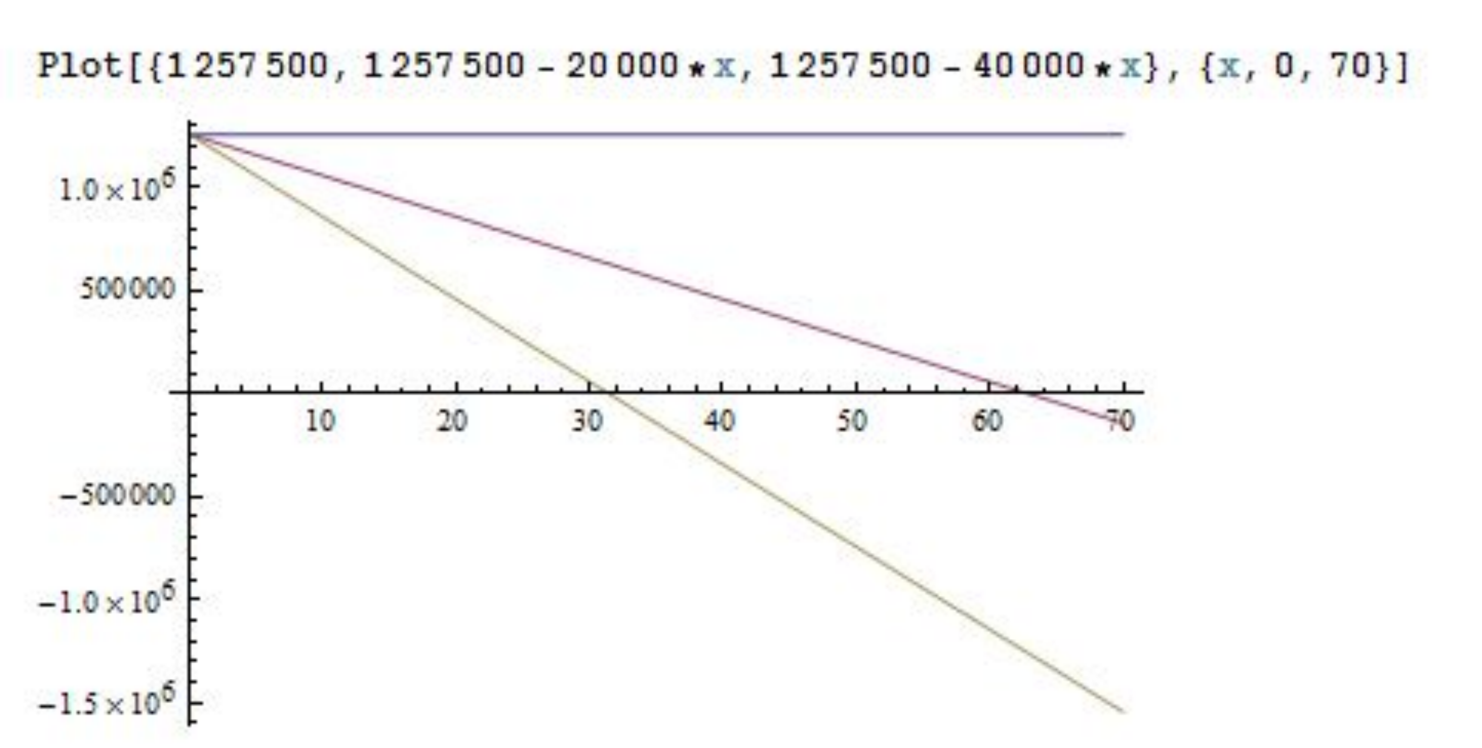


Blue: 10 5MW reactors

Purple: 20 5MW reactors lasts 32.875 years

Brown: 30 5MW reactors lasts 16.4375 years

S(t) = 1,257,500 + (20,000-D)t [wait 40 years]



Blue: 10 5MW reactors
Purple: 20 5MW reactors lasts 62.875 years
Brown: 30 5MW reactors lasts 31.4375 years

Efforts Made to Maximize Accessible Supply

- Increase NNSA supply by finding alternatives to decrease allocations
  - Lithium-6 and boron-10 could replace helium-3 used in neutron detection applications
- NNSA currently in discussions with OPG about making their supply available
- NNSA plans to begin tritium production at two additional reactors (Sequoyah Units 1&2) at TVA

General Conclusions

- Although He-3 is relatively abundant in the universe, it is much less plentiful, as well as difficult to access, on Earth.
- The increased- and increasing- demand of He-3 in 2001, and the government's failure to recognize this until 2009, has led to a He-3 shortage.
- The main source of He-3 today is the decay of tritium used in nuclear weapons.
- There are several other potential sources that could be tapped in the future.
- Efforts are currently being made to increase access to these sources.

References

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- [2] Wittenberg, L.J. *Non-Lunar He-3 Sources.* Fusion Technology Institute, University of Wisconsin, Madison, July 1994.
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- [7] conversation with Bob Rabun, representative of Savannah River Site
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- [9] Monkhorst, Hendrick J. et. al. *Controlled Fusion in a Field Reversed Configuration and Direct Energy Conversion.* United States Patent, August, 2003.