HEU/LEU Roles in the Future Development of Space

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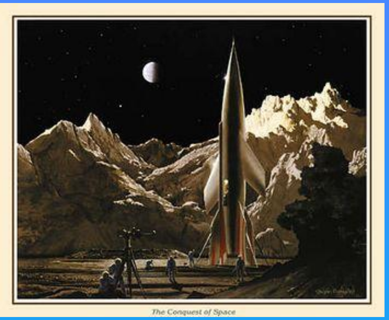
Howe Industries LLC

Space Nuclear Experience



- **PhD in Nuclear Engineering from Kansas State Univ.**
- **22 years at Los Alamos National Laboratory (LANL)**
  - LANL co-chair (NTR assessment) NASA/LANL Manned Mars Mission Study (1983)
  - LANL point of contact for NTR graphite fuel recovery (1990s)
  - Invented SAFE testing concept to reduce costs (1998)
  - Member of 3 National Research Council committees on space nuclear
- **Oct. 2005 to Aug. 2015 – founding Director of the Center for Space Nuclear Research (CSNR) at the Idaho National Laboratory (INL)**
  - Led tungsten fuel fabrication effort- prismatic form
  - Assessed INL SAFE concept
  - Developed NTR design team supported by NASA and Aerojet
    - HALEU, HEU, W, and C
- **Currently senior scientist at Howe Industries LLC**

Why nuclear?

- **Nuclear propulsion can be 2x the exhaust velocity of chemical propulsion**
- **Higher exhaust velocity means higher payload fraction and lower cost per kg of payload**
- **Higher exhaust velocity means reduction in mass (cost) or trip time (safety)**
- **Just needs to use H2 and heat- no combustion and no explosion potential**
- **The energy contained in 1 kg of uranium is 10 MILLION times that in 1 kg of LOX/LH2 or chemical explosive**

=

50 X Chemical energy in Shuttle External Tank

Energy in 12 fl oz (355 ml) of Uranium-235 (assumes total consumption)

Historical Basis – Mostly Highly Enriched

- **NASA Mars Architecture Team in 2008 concluded that:**
  - 1) nuclear surface power ENABLED a human mission to Mars and
  - 2) the Nuclear Thermal Rocket was the PREFERRED propulsion technology for a human mission to Mars

- **The NTR developed in NERVA in the 1960s used HEU**

- **The SNAP-10A reactor launched to orbit by the US in 1965 used HEU**

- **The Kilopower reactor tests performed in 2018 used HEU**

- **IS HEU required for space reactor systems?**

National vs. Private Context

- **CSNR studies found that**
  - HEU can provide lower mass reactors for space applications
  - Lower mass can translate to lower launch costs
  - However, other factors can be expensive, such as security
- **For military use, performance may be the primary objective. i.e. not cost**
  - security is inherent.
- **For civilian use, cost may be the dominant factor**

Change in direction

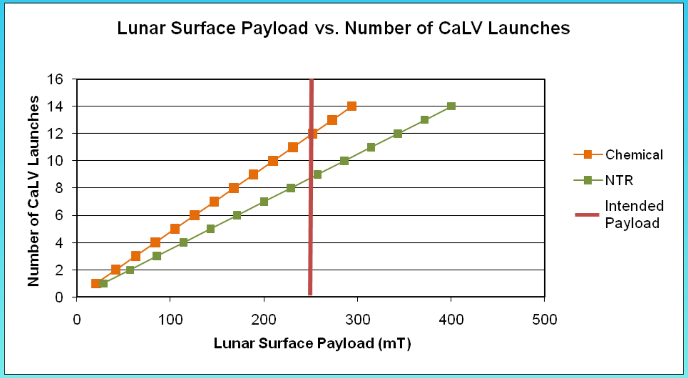
- **Premise:**
- **The world is on the cusp of Space Development as opposed to space exploration**

  - that getting private industry involved is critical
    - HEU cannot be owned by private industry but is licensed- this can curtail the level of involvement;
    - HALEU can be owned so the industry can develop its engines with NRC regulatory oversight
  - All phases of using HEU require security- “guns and guards”. This is expensive. Category 1 facilities are at least 10s of M$. So life cycle costs of HEU systems will be higher.

Defining the Problem

- **Space is vast-**
  - destinations are far apart
  - required velocities are high or mission durations are long
  - high energy density sources are required
- **Developing space assets will require the very best of technology – this means nuclear power and propulsion**
- **The solution will need to be financially attractive**

2006- CSNR fellows showed lunar habitat construction with an NTR **Saved 4 launches of Heavy Lift Vehicle, i.e. $4B** (Howe, S. D., "Using a Nuclear Rocket to Support a Lunar Outpost: Is It Cost Effective", Proceedings American Nuclear Society Space Nuclear Conference, Boston, 2007)



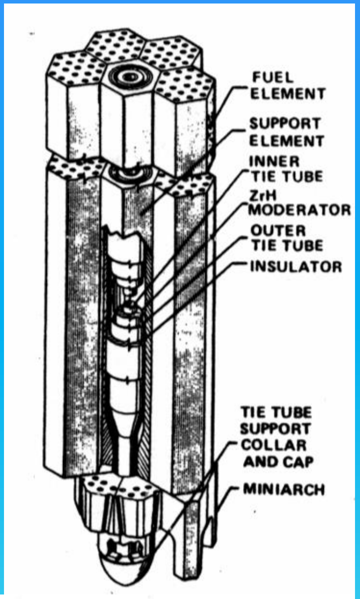
2013- CSNR fellows determined a private NTR payback within 5 years.

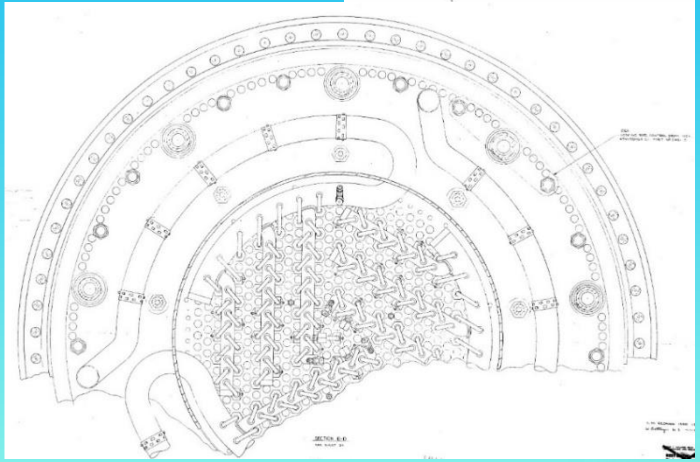
("Business Case for a Nuclear Thermal Rocket Ferry", NETS 2014)

ROI enhanced by use of LEU (7,200$/kg=>1.5M$/core) versus previous HEU designs (3$M/kg => 50M$/core)

Requirements Dictate Reactor Design Solution

- **IF HEU is not an option, a thermal reactor is needed**
- **IF W-184 is NOT available, then graphite is a solution**
- **Thermal graphite prismatic fuel form used in NERVA has problems**
  - is hard to coat uniformly so leaks radioactivity- mid-band corrosion
  - requires complex manifolds to feed moderator elements
  - must utilize variable loading or fuel:moderator ratio to flatten power peaking
  - suffers from coolant to power profile mismatch

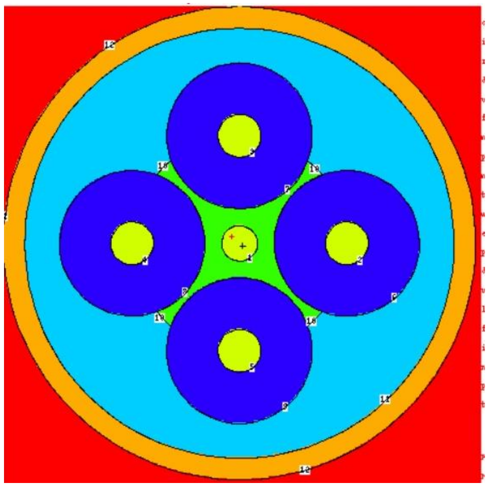


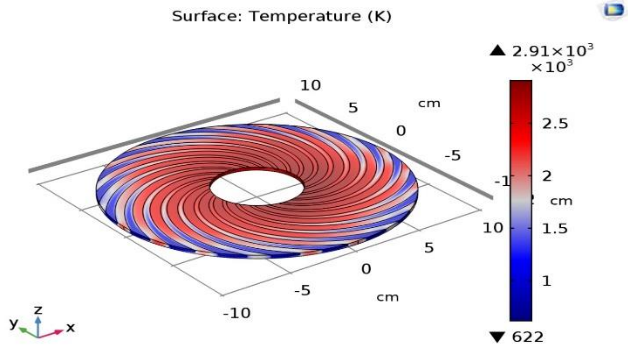


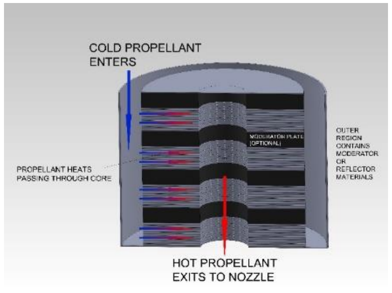
Drawing 43Y-150000 E4 – bottom view of core configuration (LANL)

SPRINTR - Scored Plate Reactor for an Innovative Nuclear Thermal Rocket

- The SPRINTR design changes the fuel geometry from long thin rods to circular plates.
- The plates are stacked together to form subcores, and the propellant flows radially through the stack.
- Subcores are assembled in arrays and surrounded by moderator to use HALEU or HEU.
- Graphite plates can be reliably coated with ZrC to prevent corrosion and retain radioactivity.
- Design better matches power density to cooling flow to produce near equi-temperature fuel.

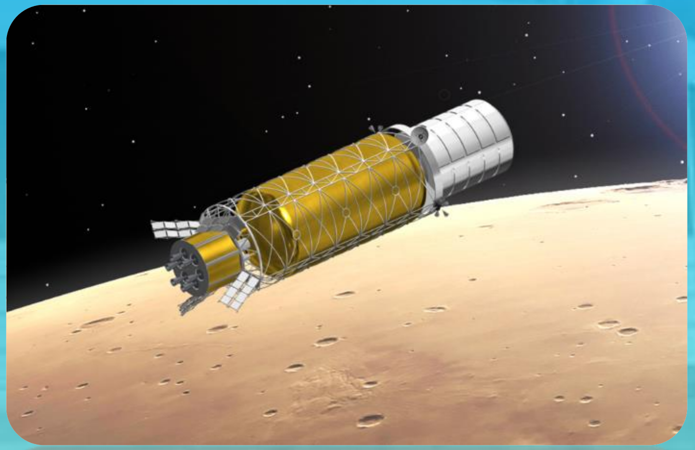






SPRINTR

- Has specific impulse values over 850s - more than double that of chemical rockets.
- High thrust-to-weight ratios allow for faster transit than electric or chemical propulsion.
- Can perform human trip to Mars in 1 year (as opposed to 3 w/chemical); the only method to avoid a hazardous dose of cosmic radiation to the crew.
- Can deliver a lunar base to the moon in 1/3 the launches from Earth.
- Can refuel from hydrogen sources (water/ice) on other planets.
- Can deliver large payloads to/from asteroids for mining.



The SPRINTR concept provides high performance and low cost due to a simple and effective design.

HEU vs SPRINTR HALEU Comparison

HEU Tungsten Pewee

Benefits

- Natural tungsten
- Established design
- No fission product leakage
- High performance
- **Issues**
  - HEU
    - CAT1 facility
    - Govt owned
    - Proliferation
    - Design will not be used by NASA or private entities in the future
    - Expensive- $Ms/kg

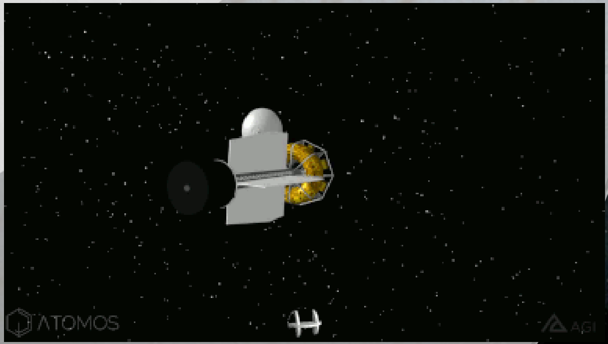
HALEU Graphite SPRINTR

Benefits

- Graphite plates
- Inexpensive- $7200/kg
- No fission product leakage
- High performance
- Can be adapted to NASA and private use
- Uses LEU
- **Issues**
  - New design
  - Graphite manufacturing/development

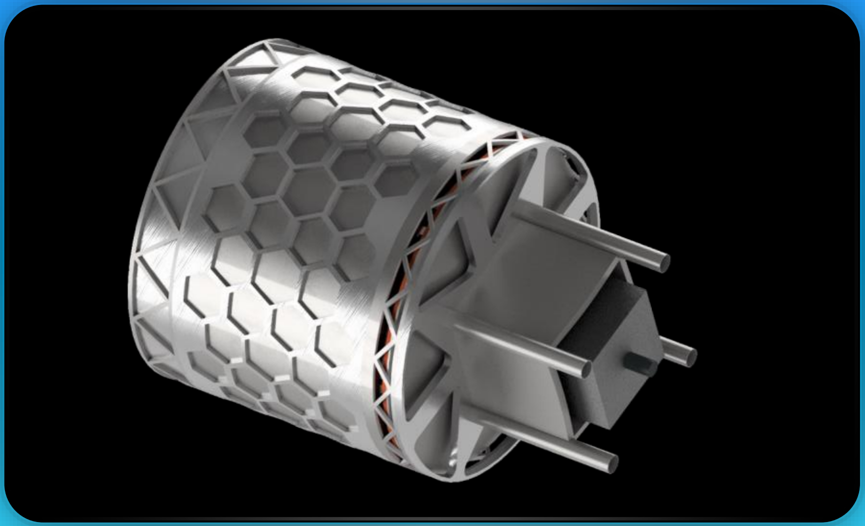
SPEAR concept

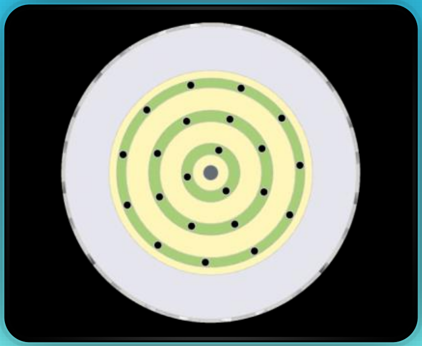
- The Swarm Probe Enabling ATEG Reactor (SPEAR) uses nuclear electric propulsion (NEP) with advanced thermoelectric generators (ATEGs).
- The high efficiency ATEG devices allow for lower operating temperatures and smaller reactors.
- ATEG units are enabled by using reactor radiation to ionize materials and increase electrical conductivity.
- Current estimates for the ship are:
  - 1300 kg wet mass (w/margin)
  - 10-year flight time to Europa
  - 70kg payload
  - 4-meter length
  - Reactor produces 12 kW-th/3 kW-e

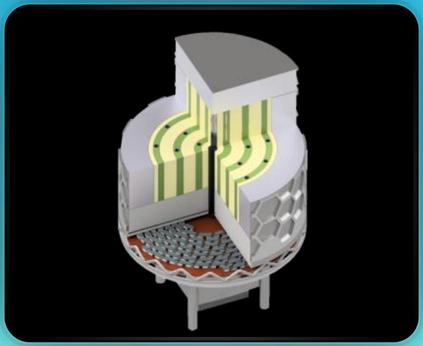


SPEAR reactor

- **Reactor uses LiH and low enriched uranium metal.**
- **Mass is 135kg**
- **Has no moving parts**
- **Models in MCNP have shown criticality can be achieved**
- **ATEG converters can be used on SPEAR or adapted for use on other small reactors**
- **Custom reactors will be necessary for optimizing different missions- using LEU will allow industrial partners to participate.**







Summary

- **Howe Industries is pursuing the design of innovative nuclear reactors for propulsion and power**
- **The designs can use either HEU or HALEU**
- **HEU is a valuable resource to the US, having cost significant expense to produce, and should be retained for specialized applications and some military space missions**
- **HALEU systems will be somewhat heavier but not sufficiently to warrant use of HEU**
- **HALEU systems are attractive to the private sector and may increase participation in space exploration**