HEU/LEU Roles in the Future Development of Space

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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

Chemical energy in Shuttle External Tank

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

50 X
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 SPRINT 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
• 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