A Versatile Nuclear Thermal Propulsion (NTP) System

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Background: **NTP Benefits**

- For human Mars missions, NTP can reduce crew time away from earth from >900 days to <500 days while still allowing ample time for surface exploration
  - Reduce crew exposure to space radiation, microgravity, other hazards
- NTP can enable abort modes not available with other architectures
  - Potential to return to earth anytime within 3 months of earth departure burn, also to return immediately upon arrival at Mars
- Stage/habitat optimized for use with NTP could further reduce crew exposure to cosmic rays and provide shielding against any conceivable solar flare
- NTP can reduce cadence and total number of SLS launches
- NTP has potential for reducing cost, increasing flexibility, and enabling faster response times in cis-lunar space
- First generation NTP is a stepping stone to fission power systems and highly advanced nuclear propulsion systems that could further improve crew safety and architectural robustness
Optimize Shielding Approach for Multiple Purposes

• Baseline approach: External shield for neutron and gamma shielding
  Potentially ~1 mT / engine
  Mitigates potential of nucleate boiling within propellant tank
• Consider: No external shield
  Energy absorbed by propellant is used to help autogenously pressurize tank
  » Constant pressure requires 290 W of latent heat of vaporization / 1 MW reactor power
  Challenge is to effectively harness energy so that it goes directly into heat of vaporization of propellant
  » May not require any modifications to standard tank design
• Use boost pump to maintain desired turbopump inlet conditions
Transitioning Shielding Mass from Inert Weight to ECLSS Water

- Mass reduction in the habitat strains water reclamation requirements
  Pushes technology requirements of ECLSS system
- External shield mass allocation may be transitioned to useable water for the ECLSS system
  Serves as a radiation “storm” shelter
  Reduces water reclamation requirement
- Water reclamation requirement may be reduced from >0.95 to <0.65

References:

Changing the neutron and gamma shielding approach to a “storm” shelter has the added benefit of reducing water reclamation requirements in the crew habitat.
Introduction of a boost pump prior to main turbo pump allows for a wider range of propellant outlet conditions from the propellant tank.

- Autogenous pressurization may not be able to maintain steady state pressure of the tank
  - Analysis indicates a drop of ~12 psia during longest burn
  - Boost pump brings propellant back up to turbopump inlet conditions
  - Allows some saturated vapor to exit from the main propellant tank (risk mitigation to nucleate boiling)
- Investigating electric or hydraulic options
  - May have relatively small impact to system mass
  - May add additional approach to engine control
Reactor Energy for Hot H₂ Orbital Maneuvering

- Leveraged for Mars and Earth Sphere of Influence
  - E.g. NRHO to LDRO, Mars plane changes
- Hydrogen flow path through existing tie tubes
  - Integrates with core without changing fuel element or tie tubes
  - Additional valves on tie tube circuit
- Performance exceeds storable bi-propellant
  - Isp = ~500s
  - Benefit of removing mass and overhead of bi-propellant systems
- Investigating approaches to leverage hot H₂ for RCS, e.g. attitude control
- Including heat exchanger provides potential for power generation.

The low molecular weight of hydrogen combined with the superfluous power of NTP creates an opportunity for low-impulse orbital maneuvering.
Evaluating New Mission Architectures

- Reduce staging orbit from LDHEO / LDRO to 407x13,400 km provides 68.5 mT vehicles with 8.4m SLS fairing
- Consider staging of in-line tanks at Mars
- Reduction in trip time reduces radiation exposure
- Evaluation of orbital debris and thermal environmental impacts pending
Opposition Class Mission Architectures

- Reduced systems (higher prop) mass fraction and performance enables greater delta-V
- Some opposition class missions are achievable
- Core + 3 or 4 inline stages (68.5 mT wet mass) or Staging, e.g., leaving, stages at Mars provides additional capability

Versatile NTP may enable “short” stay opposition class mission architectures.
Observations

• Space fission power and propulsion systems are game changing technologies for space exploration.

• First generation NTP systems could provide significant benefits to sustained human Mars exploration and other missions.

  Potential for Earth-Mars transit times of 120 days; 540 day total Mars mission times; reduced crew health effects from cosmic radiation and exposure to microgravity; robust Mars architectures including abort capability.

  Faster response times, improved capability, and reduced cost for cis-lunar operations. NTP derivatives could enable very high power systems on lunar surface (ISRU) and in space.

• Advanced space fission power and propulsion systems could enable extremely ambitious space exploration and development.