Powering Space Missions with

Nuclear Fission Power and Propulsion

ANALYTICAL MECHANICS ASSOCIATES

DC Women in Nuclear & DC Women in Aerospace

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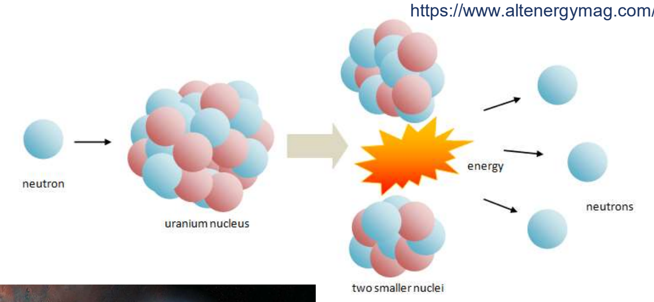
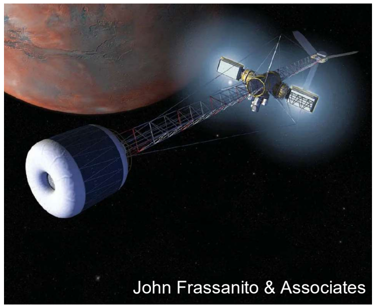
Analytical Mechanics Associates

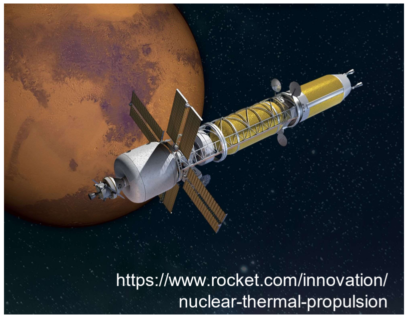
Benefits of Fission for In-Space Power and Propulsion

- **Nuclear energy has the capability to provide high power levels for long periods of time**
  - Fission provides the potential for high power density per unit mass
  - This leads to the potential for enabling more complex missions or adding robustness, capability to baseline missions
- **Three fundamental applications of space power and propulsion**
  - **Surface Power:** fission is a source of power for providing electricity to crew, life, and mission support
  - **Nuclear Electric Propulsion (NEP):** fission a source of power is converted to electricity for high efficiency thruster for long durations to enable fast transit to far away destinations
  - **Nuclear Thermal Propulsion (NTP):** fission is a heat source and reactor acts as a heat exchanger for high efficiency, high thrust applications (long or short durations outside of earth's atmosphere)
- There exists an extensive development history of these technologies, but none have yet been successfully demonstrated in space

https://www.altenergymag.com/







Nuclear Space Power and Propulsion has a rich history in the U.S. but not yet ready to support tomorrow's needs

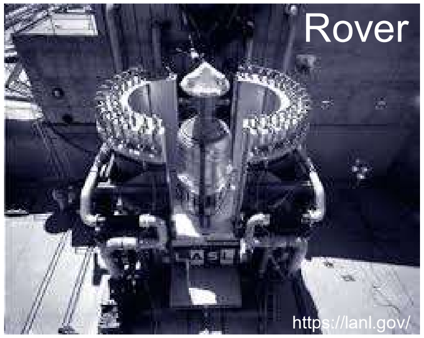
"We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard."

- "First, I believe that this nation should commit itself to achieving the goal before this decade is out, of landing a man on the moon and returning him safely to the earth…"
- "Secondly, an additional $23M, together with $7M already available, will accelerate the development of the Rover nuclear rocket. ***This gives promise of some day providing a means for even more exciting and ambitions exploration of space, perhaps beyond the moon, perhaps to the very end of the solar system itself***…"
- "Third, an additional $50M Dollars will make the most of our present leadership, by accelerating the use of space satellites for world-wide communications…"
- "Fourth, an additional $75M of which $53M is for the Weather Bureau will help five us the earliest possible time a satellite system for world-wide weather observation..."

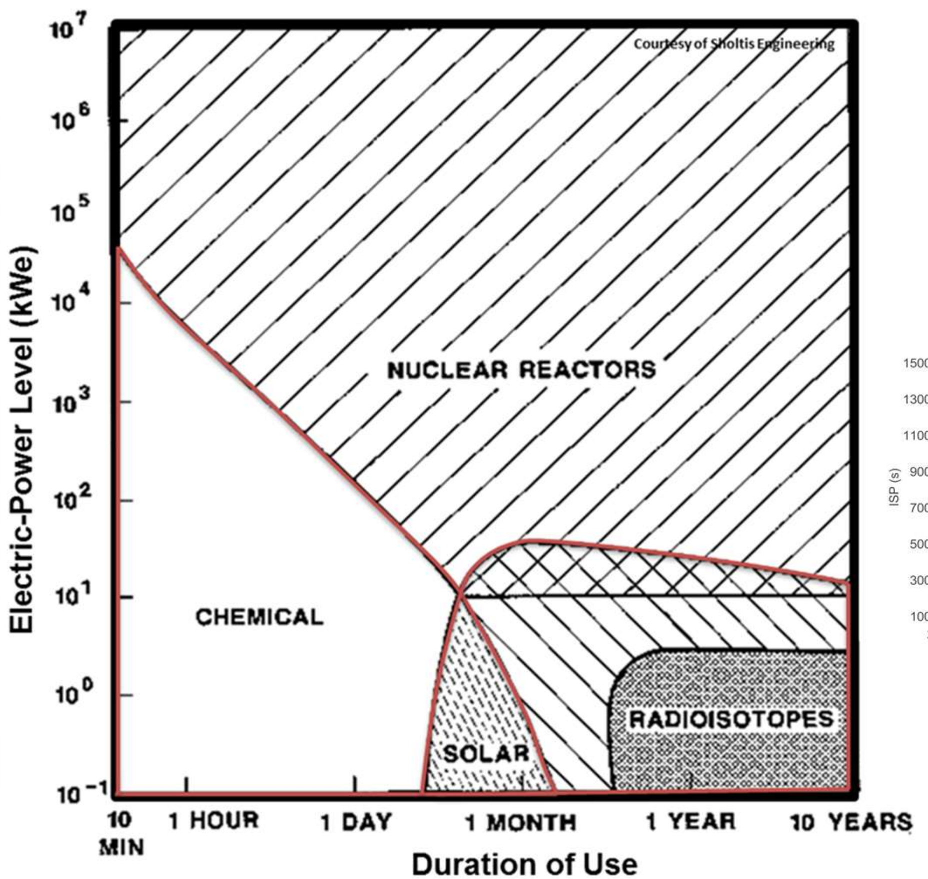
President John F. Kennedy "Moon Address" to Rice University 1962

- **Historic Nuclear Space Power Programs**
  - 1957 – 1973: Systems for Nuclear Auxiliary Power (SNAP)
  - 1961 – 1992: Topaz (total development program led by USSR)
  - 1983 – 1993: SP-100 and Multi-Megawatt
- **Historic Nuclear Thermal Propulsion Programs**
  - 1955 – 1972: Nuclear Engine for Rocket Vehicle Application (NERVA)/Rover
  - 1965 – 1968: GE-710 (also NEP application)
  - 1957 – 1968: LANL DUMBO / Argonne National Laboratory / NASA Lewis Research Center
  - 1987 – 1991: Timberwind/Space Nuclear Thermal Propulsion

President John F. Kennedy touring the nuclear rocket development station (NRDS). *Courtesy: www.energy.gov*



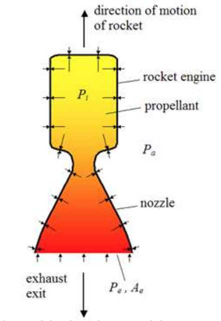
Unique Attributes of Fission Systems to Enable Space Missions



Rocket Science 101: Specific Impulse and Thrust

Thrust is the forward force that accelerates the rocket

$$F_{\text{thrust}} = v\frac{dm}{dt} \approx v_e\dot{m}$$



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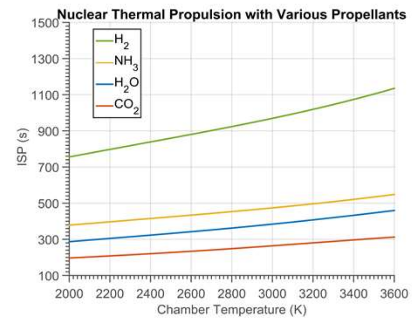
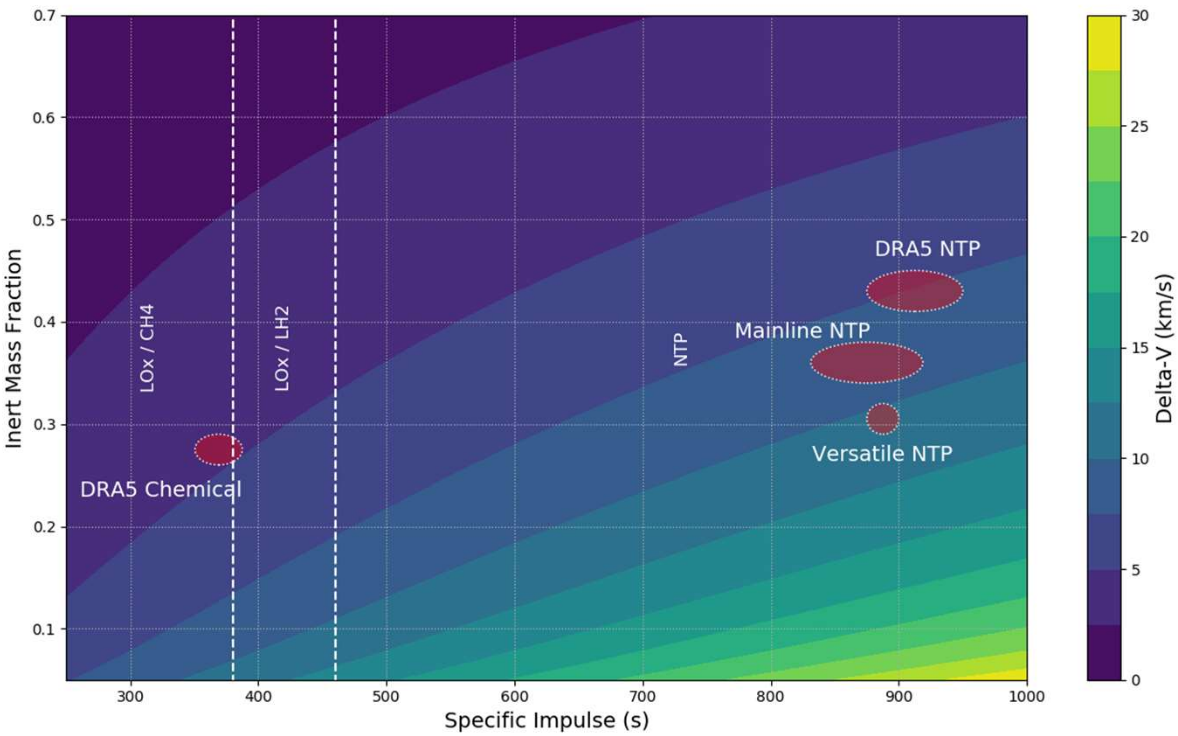


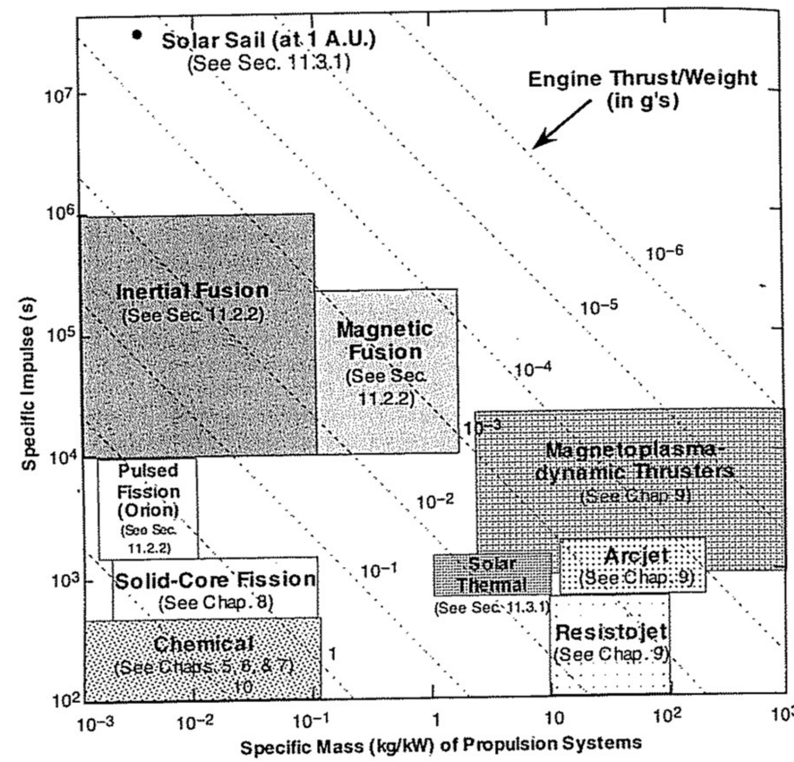
Specific impulse is a measure of rocket efficiency

$$I_{sp} = \frac{F_{thrust}}{\dot{m}} = \frac{1}{g_0}\sqrt{\left[\frac{2\gamma}{\gamma-1}\frac{RT}{M}\right]\left[1-\frac{p_e}{p_c}\right]^{\frac{\gamma-1}{\gamma}}} \propto \sqrt{\frac{T}{M}}$$

Type of Propulsion	Specific Impulse (s)	Thrust (klbf)	Propellant	Time of Single Burn (s)
Chemical (SSME)	452	471	$LH_2 + LO_2$	10^3
NTP	800 - 900	25 - 250	LH_2	10^3
Ion NEP	6,000 – 8,000	0.001 - 0.1	Xe	10^7

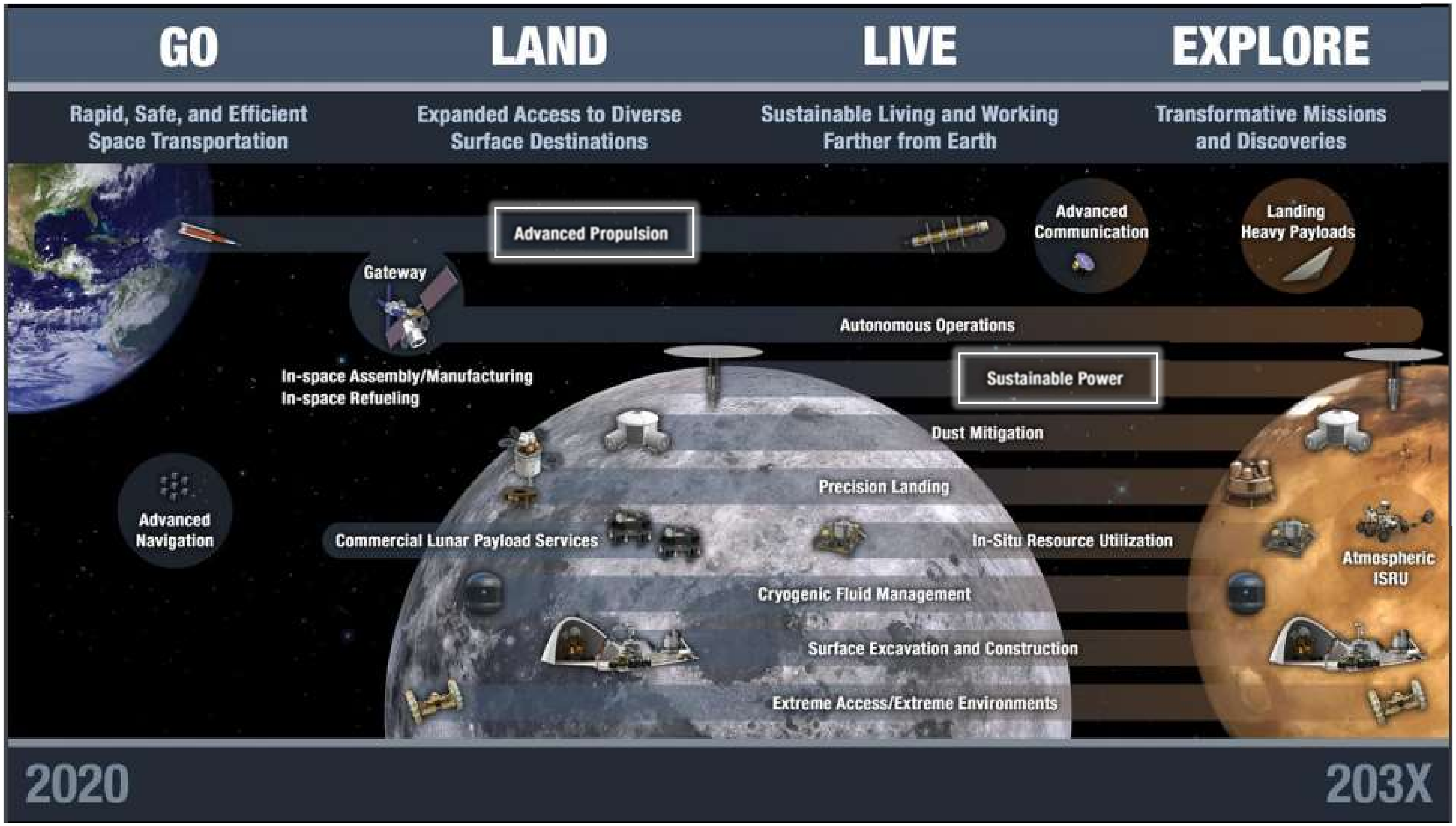
Ultimately, these needs lead to a complex trade space for selection of the most desirable advanced propulsion system





Goal of future propulsion systems is to maximize performance (thrust and specific impulse) while minimizing mass

Fission Power and Propulsion Technologies Support NASA's Future Needs

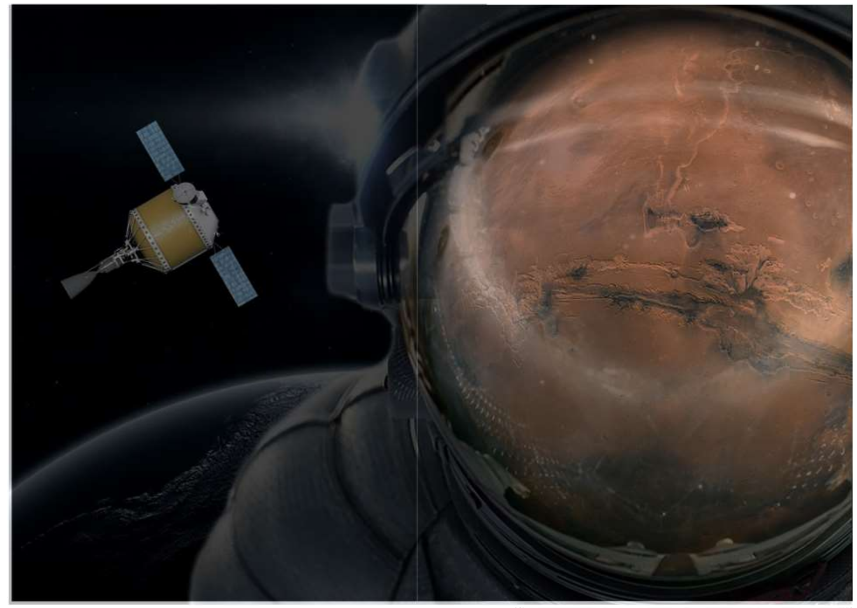


Reuter, J. "NASA Advisory Council Technology, Innovation & Engineering Committee Meeting". The National Aeronautics and Space Administration. Washington, D.C. 2019

The National Aeronautics and Space Administration "NASA Strategic Plan 2018". Washington, D.C. 2018

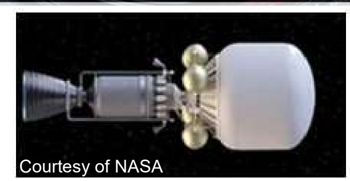
Current Nuclear Power and Propulsion Development Efforts

- **On-going NASA Nuclear Power and Propulsion Efforts**
  - **Surface Power**
    - Kilopower Project: NASA Game Changing Development (GCD) (2016 –2019), 2020 transitioning to TDM
    - Demonstrated many principal reactor technologies needed to enable near term space mission needs
  - **Nuclear Propulsion**
    - NTP Project: NASA GCD (2016 – 2019)
    - NASA Technology Demonstration Mission (TDM) Space Nuclear Propulsion Project (2020 -)
- **Nuclear Propulsion is in a phase of planning**
  - Multiple FY20 studies looking at propulsion architecture selection for Mars (NEP, NTP)
    - Mars Transportation Assessment Study (MTAS)
    - NASA Engineering and Safety Center (NESC)
    - National Academy of Sciences, Engineering, and Medicine (NASEM)
  - Multiple FY19/FY20 studies NTP in-space demonstration
    - FD-1: Nearest Term, Traceable, High TRL (Target Soonest Flight Hardware Delivery, NASA led)
    - FD-2: Near Term, Enabling Capability (TBD availability Date, NASA led, DoE reactor support)
    - Industry NTP Flight Demonstration Study (TBD availability Date, led by Analytical Mechanics Associates Inc.)



www.energy.gov

Courtesy of NASA



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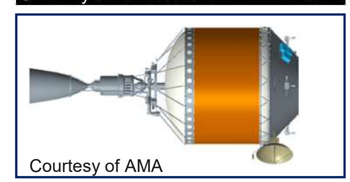
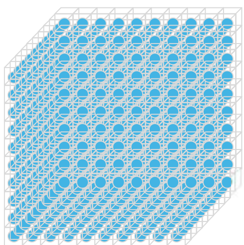


Courtesy of AMA

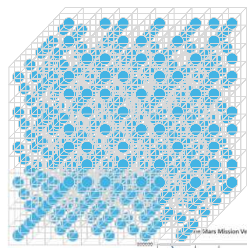
Industry Study: Nuclear Thermal Propulsion Demonstration Mission

A variety of heritage or current industry technologies exist which can be adapted to meet tomorrow's needs.

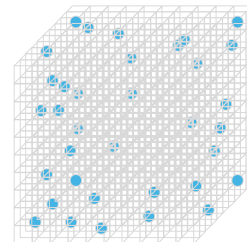
Broad design space outlined with parametric modeling and heritage information



Number of designs reduced through system sizing, concept definition, and trade studies

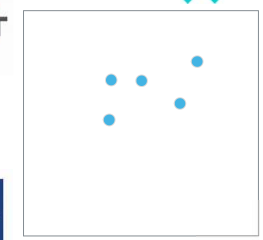


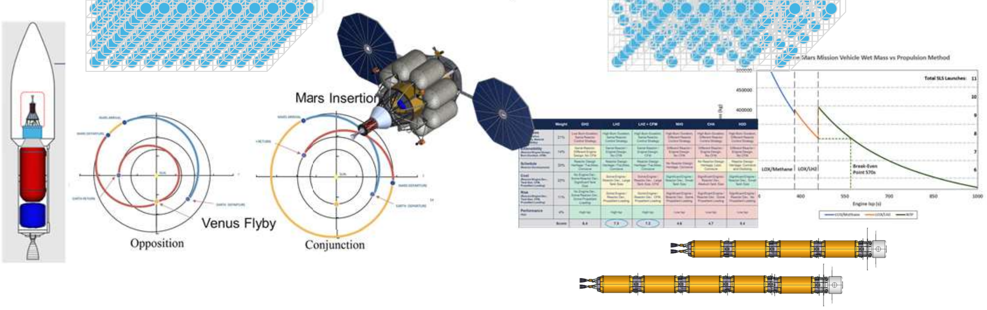
Further down-selection and development of designs taken through cost and schedule analysis



Data Call 5

Reactor Design Only – More specific KPPs and KSAs narrow reactor designs





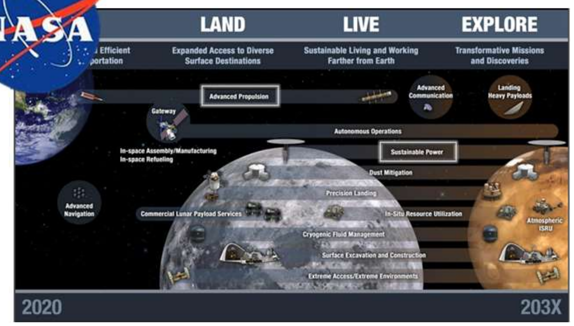
<u>Initial Study Surveyed:</u>
4 spacecraft / missions
6 engines (non-nuclear)
9 reactors

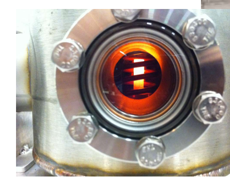
<u>NTP reactor concepts can be designed to meet a range KPPs, materials will limit technology breakpoints</u>

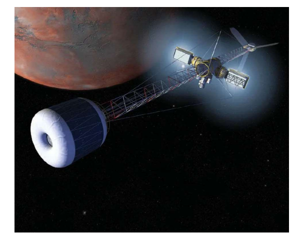
- Study started with a very broad and ambitious, multi-dimensional design space
  - Study key performance parameters (KPPs) supplied by NASA and other government stakeholders
  - Design space was refined / reduced throughout the study (sparse matrix approach)
- Industry concepts allowed a wide survey of the possible performance space (specific impulse, thrust levels)
  - Industry supplied inputs for spacecraft, engine, and reactor concepts
  - A NTP flight demonstration is feasible, reactor development will likely be the schedule limiting technology
  - Participating industry participants for reactor: BWX Technologies LLC, General Atomics, X-Energy LLC, USNC Technologies LLC

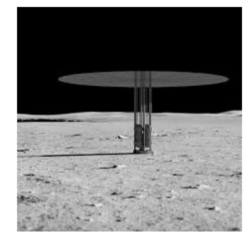
New in-space challenges will require new innovations!

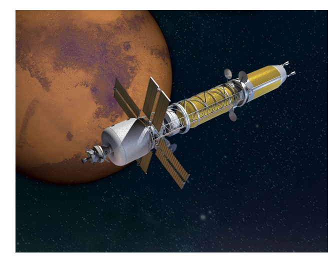
- Reactor technologies can enable high energy densities for more capable propulsion and power technologies
  - NEP & NTP: advanced in-space propulsion with demonstrable performance benefits compared to state-of-the-art chemical methods
  - FSP: versatile, robust, high power (kW – MW) source for sustainable surface operations / exploration
- Industry has the opportunity to play a key role in the development and demonstration of space fission power and propulsion systems
- Future NASA Demonstration Missions:
  - Requests for Information
    - Fission Surface Power
  - Pre-Solicitation Notice
    - Space Nuclear Propulsion
- Future DARPA Demonstration Mission:
  - Broad Agency Announcement
    - Demonstration Rocket for Agile Cislunar Operations (DRACO)









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Thank you!