NASA Advisory Council Technology, Innovation, and Engineering (NAC TI&E) Committee

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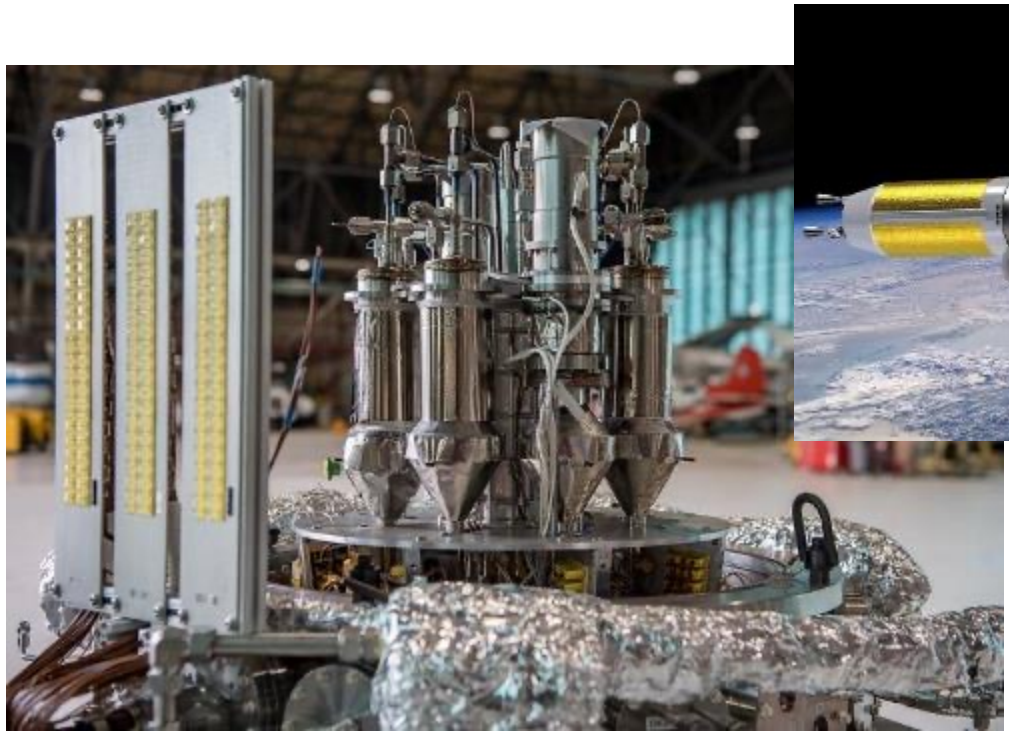
Space Nuclear Capability Benefits

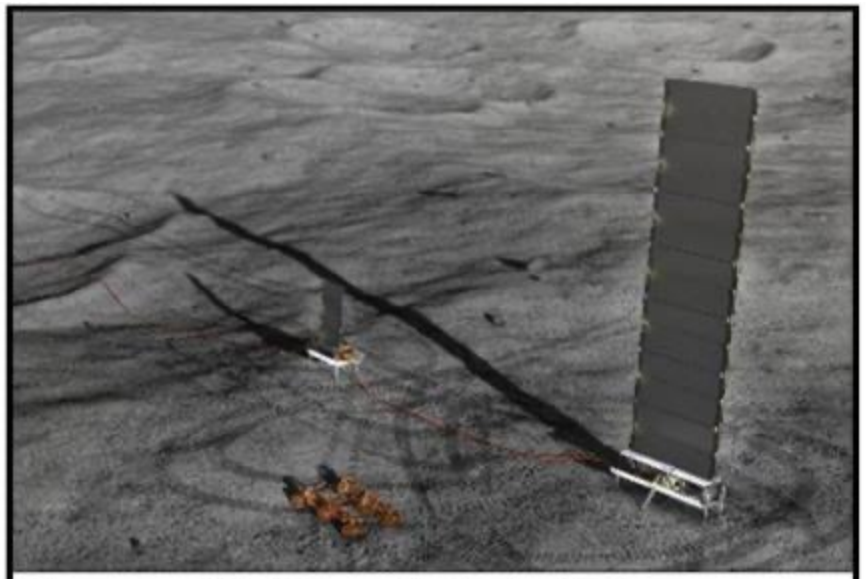
- Provides reliable energy source for both human and scientific exploration missions
- Offers energy-dense systems with high ratios of power to mass and volume
- Delivers continuous power autonomously for the extreme environments of space
- Shares strong interest with commercial space and other government organizations

Benefits:

- ✓ Space Leadership
- ✓ Domestic Economy
- ✓ Green Energy
- ✓ National Posture
- ✓ Global Competitiveness



Fission Surface Power Strategy



Power: 40 kWe scalable to higher power
Mobility: Capable of being transported
Mass: less than 6,000 kg
Life: 10 years

Need
Establish a durable, high power, sun-independent power source for NASA missions

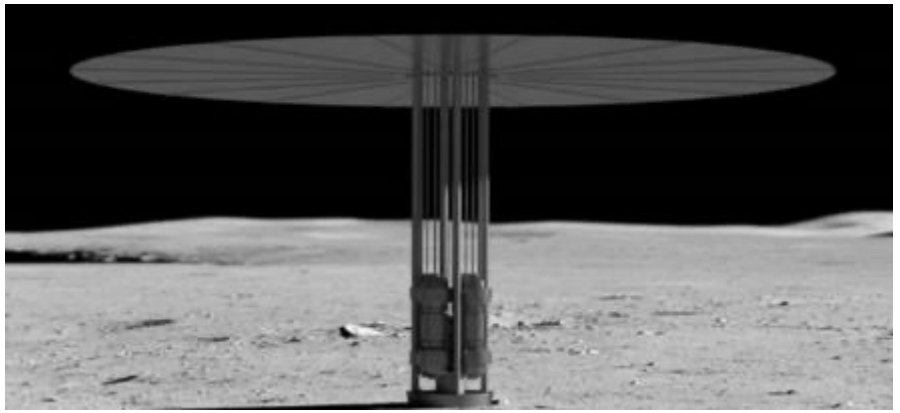
- **Support Moon and Mars mission requirements**
- **Deliver a flight qualified Lunar demonstration system**
- **Transition FSP technology to industry**

- Develop a 40 kWe lunar fission power system for a 2030 LRD
- Final design must show extensibility to support a Mars human exploration mission
- Project scope includes technology development, design, engineering, and delivery of integrated system
- Project near-term focus remains in technology development and formulation
- DOE/Idaho National Laboratory (INL) is managing nuclear industry design contracts

Established FSP system design can be leveraged for subscale NEP flight demonstrator

Industry Engagements

– Executing three, one-year design contracts
- Produce preliminary point designs of a power system
- Employ industry design standards and practices
- Provide subsystem TRL and maturity assessment
- Identify subsystem technology development needs
- Provide cost and schedule estimates for system delivery



INTUITIVE MACHINES

X energy

Westinghouse

AEROJET ROCKETDYNE

LOCKHEED MARTIN

BWXT

BWX Technologies, Inc.

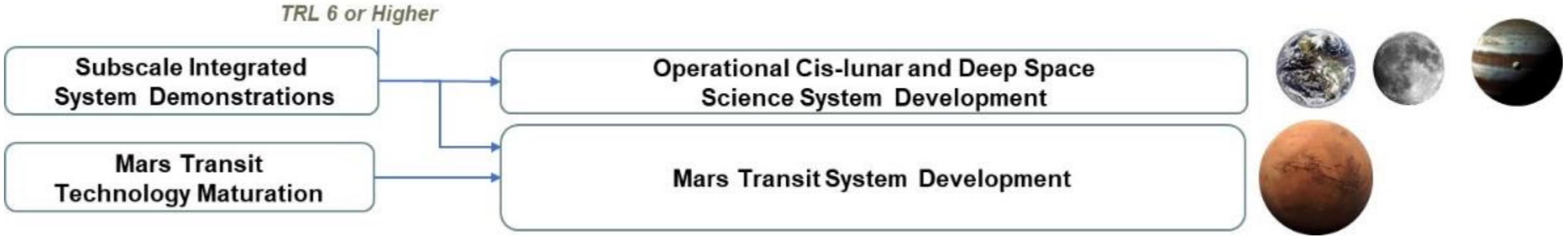
- Intermediate design reviews for IX and Westinghouse held on April 11-12, 2023, Lockheed Martin mid-term review scheduled for May 23, 2023
- Industry designs are progressing well with a planned completion by September 2023
- Final delivery products will be used to inform DDT&E requirements for final flight hardware

Fission Surface Power Highlights

- Coordination with industry designers continues as designs progress and mature
- Formulating operation plans needed to support system DDT&E, launch, and mission execution
- Refining government reference system design to support trade studies and investment decisions
  - Government investments include neutron moderators, shielding, instrumentation and power conversion
- Exploring joint technology development opportunities with interagency stakeholders

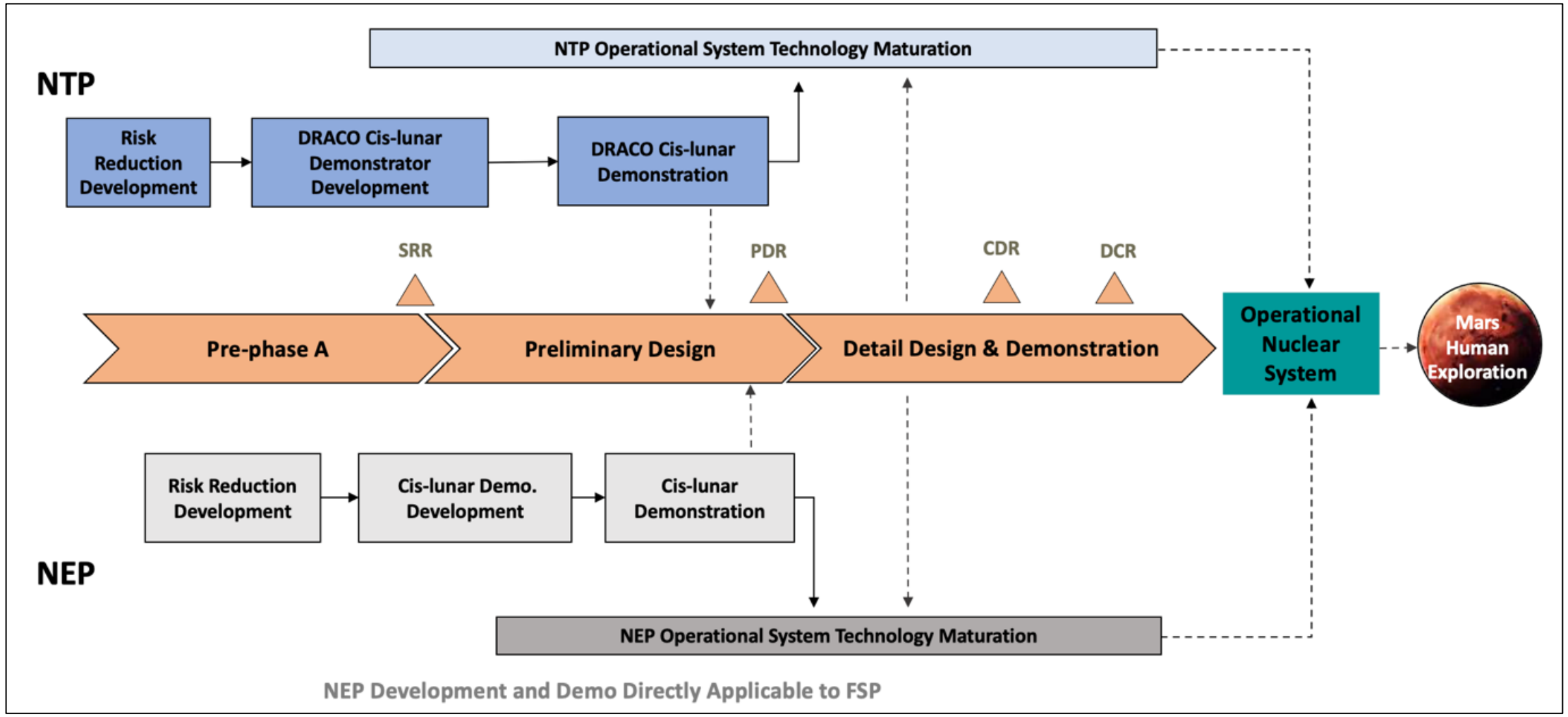
Space Nuclear Propulsion Strategy

- Balance technology and capability development with relevant system design and demonstration
- Maximize opportunities for cost sharing by supporting multiple mission spaces and stakeholders
- Leverage technology investments where capabilities overlap with other NASA projects, other government agencies, and commercial organizations
- Identify testing and launch regulatory requirements and mitigate issues
- Advance passive and active CFM systems to support nuclear propulsion mission need



Develop and demonstrate subscale systems with capability that is relevant to Cis-lunar applications and can be evolved to meet NASA's future missions including crewed and large cargo Mars transit

Nuclear Propulsion Development Strategy

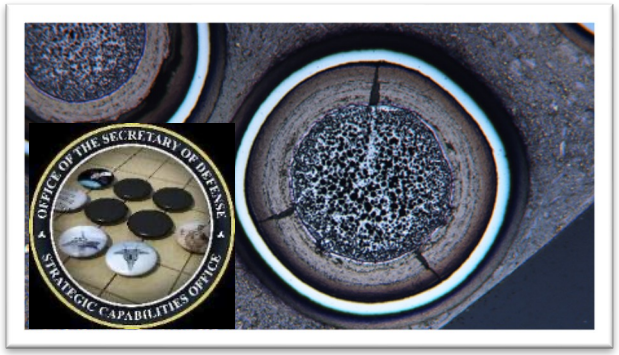


Interagency and Industry Collaboration

Reactor Contracts, Materials, Testing

Multiple National Labs

Fuel Manufacturing



DoD Strategic Capabilities Office

DRACO Spacecraft

NTP Flight Demo Partnership

NEP Tech Assessment & Trades

Potential NEP Partnership

- **Space Nuclear Propulsion (SNP) Project completed 3 industry reactor design efforts in FY22**

Current plan is for follow on fuel element fabrication demos that occur in FY23/24 with 2 industry partners

USNC
ULTRA•SAFE•NUCLEAR

- USNC partnered with Blue Origin, General Electric, and Framatone

BWXT
BWX Technologies, Inc.

- BWXT joined with Lockheed Martin and Aerojet Rocketdyne

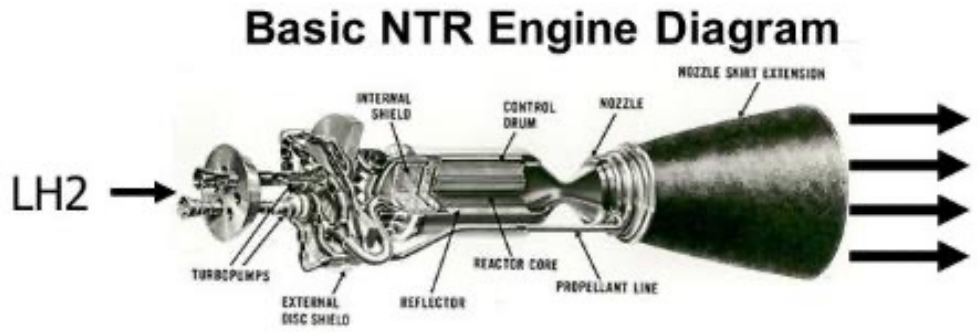
GENERAL ATOMICS

- General Atomics teamed with X-Energy and Aerojet Rocketdyne

Space Nuclear Propulsion Recent Developments

- Strategic pivot to cis-lunar technology development and demonstration
  - Advance prototype design to a cislunar operational system and evolve performance and reliability for Mars
- Established a joint flight demonstration project with Defense Advanced Research Projects Agency (DARPA)
- Rebalanced existing NASA SNP project scope and development approach
- **NASA/DARPA Demonstration Rocket for Agile Cis-Lunar Operations (DRACO) provides:**
  - An NTRE prototype design and performance data that can support NASA mission needs
  - A pathfinder for establishing nuclear regulatory processes and procedures for space fission systems
  - In-space liquid hydrogen storage and transfer knowledge supporting cryogenic fluid models
  - Operational feasibility supporting the use High-Assay Low Enriched Uranium (HALEU) fuels

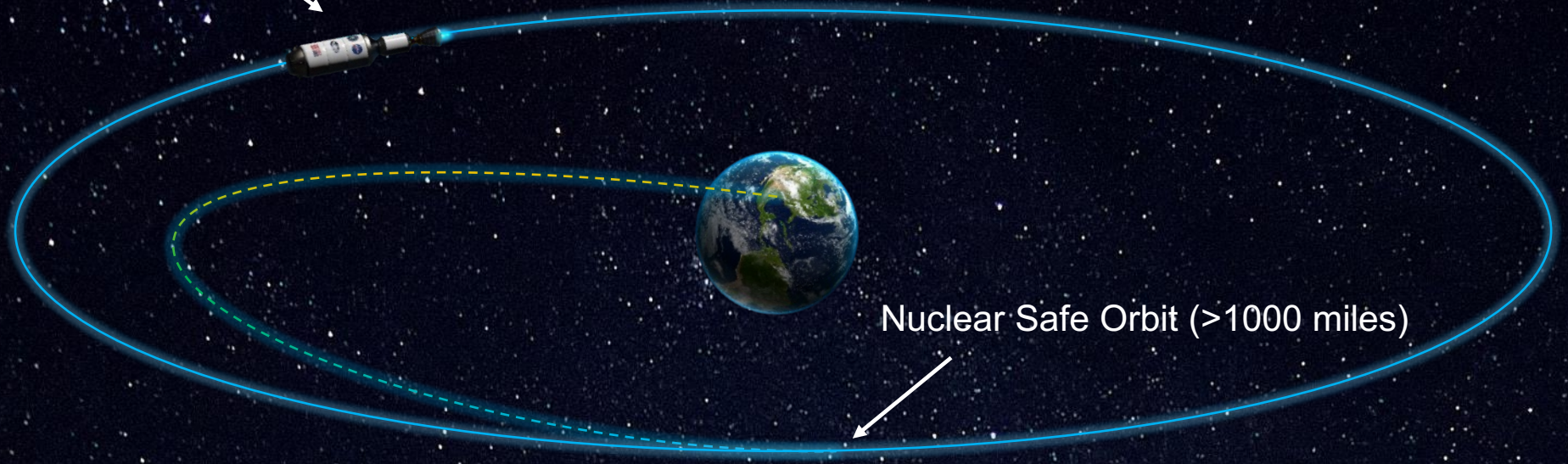
- **DRACO Mission Goals**
  - Demonstrate robust reactor power up and shutdown
  - Control operation at partial and full thrust levels
  - Demonstrate engine shut down and restart operations
  - Provide engineering model validation data
  - Inform development of future operational system



NASA-DARPA Draco Flight Demonstrator

DRACO Vehicle
- Cislunar relevant thrust and Isp
- Evolvable to Mars relevant capability

Nuclear Launch Safety
- DRACO vehicle is the launch vehicle payload
- Reactor can be disrupted to prevent inadvertent criticality
- Reactor will be ‘cold’ and ‘poisoned’
- Reactor activated after successful orbit insertion



Mission Objectives
- High-Thrust, Low I_{sp} Propulsion: (~hours)
- Low-Thrust, High I_{sp} Propulsion: (~days)
- High-Thrust, High I_{sp} Propulsion: (~minutes)

Redirected Project Scope

NASA Marshall remains lead center for nuclear propulsion technology

Government Reference Engine Design & Development

Non-Nuclear Engine Component Risk Reduction and Development

Fuel and Moderator Development

Significant Consolidation

Reactor and Engine Ground Test Capability Development

Reactor Design and Development

Reduced Industry Reactor Contract efforts

DRACO Insight, collaboration, and risk reduction

NTP Operational system technology maturation and ground test capability needed to support of human rating

Maintains college and university commitments, and attempts to sustain internal critical teams

DARPA-NASA In-Space Flight Demonstration

- Interagency Agreement defines roles and responsibilities in a jointly managed effort
- NASA has responsibility to fund and manage the development, design, and test of the nuclear thermal propulsion engine
- DARPA has responsibility to fund and manage development and design of the flight vehicle, assembly, integration and testing of the integrated system, launch of the demonstrator and in-space flight operations

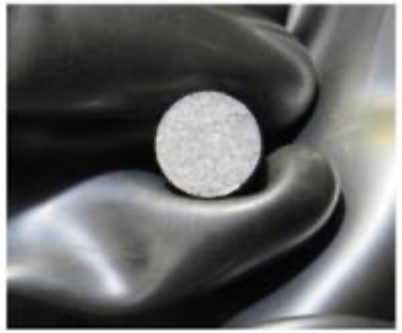
- U.S. Space Force issued a memo of commitment for launch vehicle and launch support
- Department of Energy/National Nuclear Security Administration is providing HALEU fuel
- Prime contractor expected to be awarded in May 2023 with flight currently planned for 2027

Recent Reactor Fuel Testing

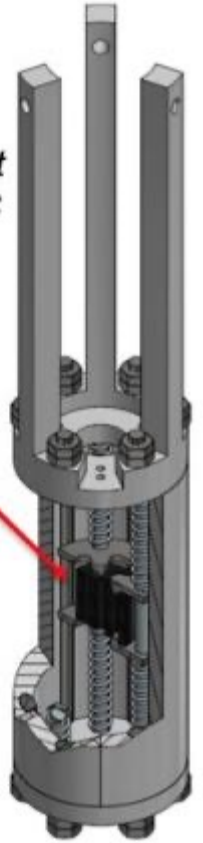
Transient Reactor Test (TREAT) Facility, INL

- Completed the irradiation test series of a SNP ceramic-ceramic (cercer) fuel specimen
  - Uranium nitride fuel in a zirconium carbide matrix, 20% fuel loading (HALEU), cylindrical geometry with 7 flow channels
  - Tests run in a static hydrogen environment
- Completed 8 power transient runs with a target heat up rate of 100 K/sec and target peak temperature 2800K
  - Reached a maximum temperature of 3000K during 4th full power run, the highest recorded temperature to date in the current test campaign of all specimens
  - Initial radiography indicates the test specimen survived with no major failure
    - Specimen will be allowed to radiologically cool before post irradiation examination in the INL Hot Fuel Examination Facility (HFEF)

CERCER fuel compact for Sirius-2C experiment



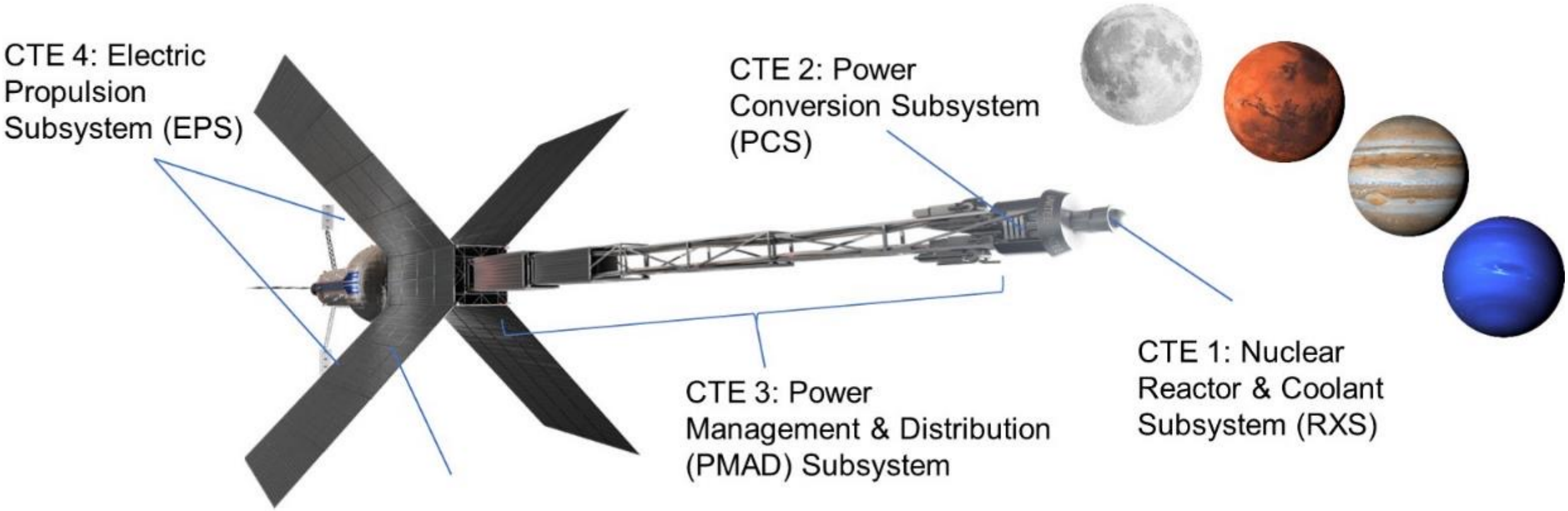
As-sintered CERCER compact



Graphic of CERCER fuel compact in experiment holder

Nuclear Electric Propulsion (NEP) System

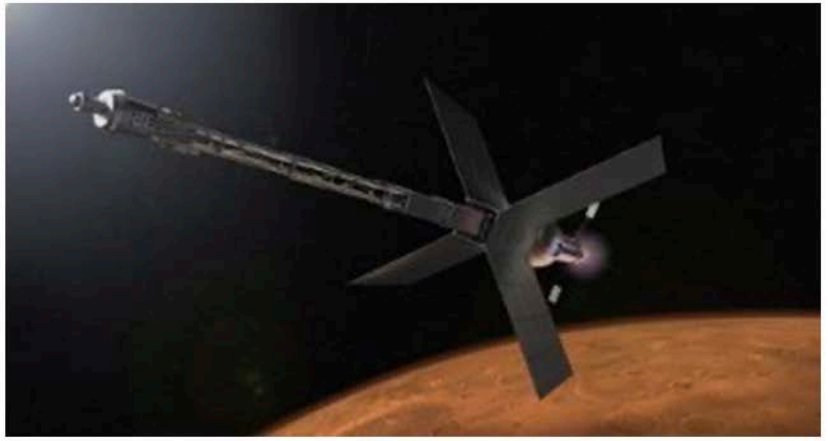
Five (5) Integrated Critical Technology Elements (CTEs)

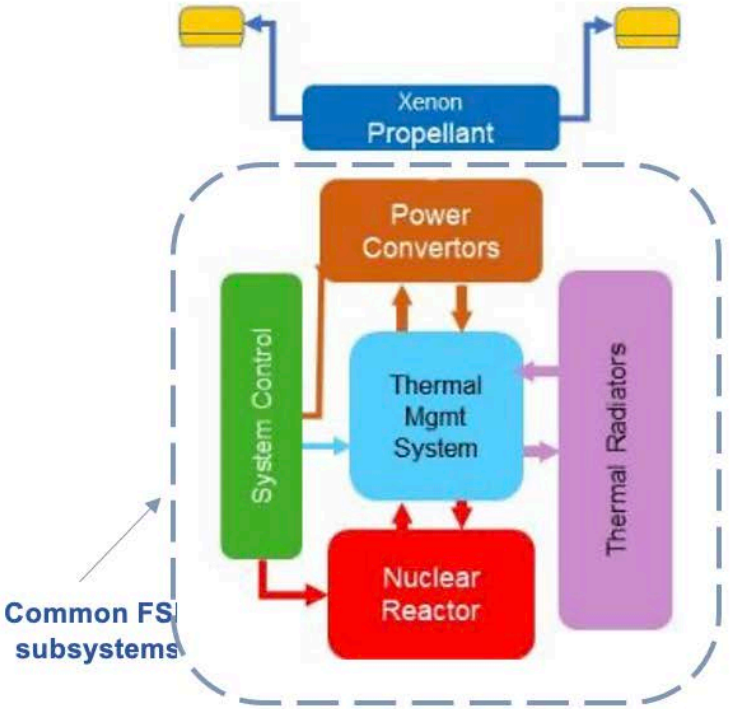


NEP has potential common technology development with NASA FSP, DOE Small Modular Reactors, and AFRL low power demonstrations for cis-lunar space

Nuclear Electric Propulsion (NEP) Status

- Completed draft NEP Technology Maturation Plan (TMP)
  - TMP developed and reviewed by NASA subject matter experts, interagency stakeholders, and potential industry partners
  - Agency baseline release planned by June 2023
  - Final TMP will serve to guide NEP technology investment ad development
  - Technology solutions will take advantage of relevant multi-agency investments with a strategy that aligns with industry participation
- Current (FY23) investment of $1.3M is being used to examine Li-MPD thruster testing, Brayton PCS development, and NEP concept designs
- NASA proposed development path addresses integrated subscale NEP technology development and demonstration with advancements that support human exploration scale capabilities
  - Subscale development allows leveraged investments from fission surface power and solar electric propulsion
  - Exploring potential planetary science applications for deep space exploration missions
  - Synergy with U.S. Space Force/AFRL/DARPA interest for low power NEP cislunar capability





Space Nuclear Technology Key Takeaways

- NASA is actively engaged with internal and external agency groups to establish cooperative technology practices, procedures, and roadmap that leverage common priorities and resources
- NASA advancements leverage investments from terrestrial and other government agency activities to develop space-based nuclear design, safety, launch, operation, and governance practices
  - DRACO Partnership provides extensive cost sharing between NASA and DOD for a flight demonstration of a Nuclear Thermal Rocket Engine
    - Addresses key challenges to overlapping stakeholder interest, leveraged funding, industry indemnification, space nuclear regulatory processes and procedures
  - Similar potential exists for NEP cis-lunar demonstration opportunities with the USSF, AFRL and DARPA that mirror the DRACO partnership
- NASA continues to closely engage commercial capabilities and innovations to advanced small, low mass HALEU reactor solutions
- NASA technology investments are also targeting key non-nuclear systems needs, including cryogenic fluid management and Brayton engine capability development critical to nuclear systems