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NASA's Electric Propulsion Development Activities for Space Nuclear Propulsion Applications

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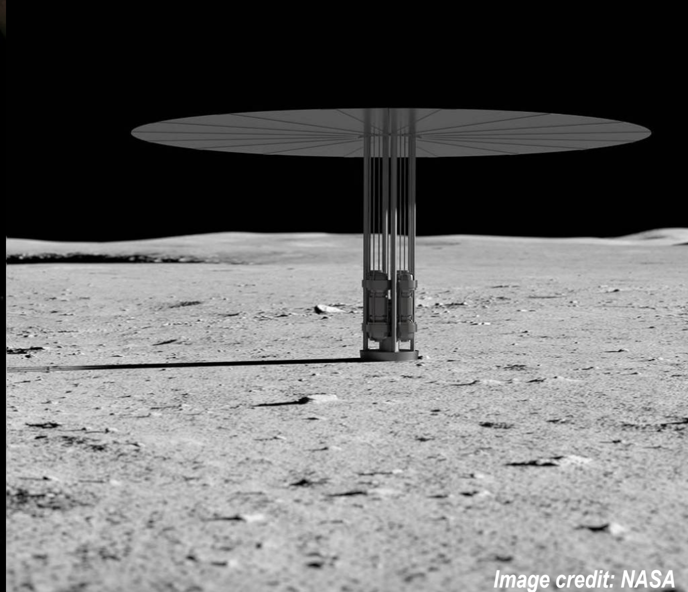
- **The Moon to Mars Architecture serves as a roadmap for NASA's Moon to Mars Objectives**
- **There are 12 areas that NASA is investing in to achieve the Moon to Mars Objectives**

- **Power Systems generate, store, condition, and distribute electricity for architectural elements.**
- **Transportation Systems convey crew and cargo to and from Earth to the Moon and Mars.**

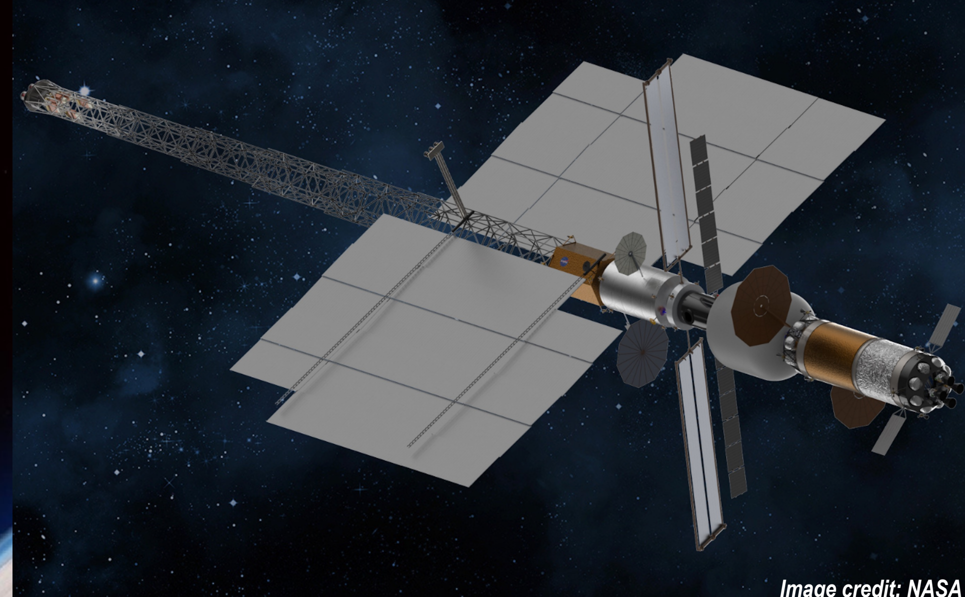
https://www.nasa.gov/moontomarsarchitecture-components/

- **Nuclear powered systems are being investigated as enabling technologies for both surface and transportation systems**

Lunar Fission Surface Power



Nuclear Electric Propulsion



https://www.nasa.gov/directorates/stmd/6-technologies-nasa-is-advancing-to-send-humans-to-mars/

- **NASA's Space Technology Mission Directorate has developed a technology maturation plan to enable future high power nuclear electric propulsion (EP)**
- **This plan has identified Hall effect thrusters (HETs) and magnetoplasmadynamic thrusters (MPDTs) as two promising technologies for investment**
- **This paper presents a framework for the development of these technologies that supports an evolution from near term systems at power levels of ~50kW to far-term applications at ≥ 2MW**
- **It's assumed that this evolution is incremental, but fast paced (~3 times increase in capability with each successive iteration)**
- **Radical or transformative rate of technology advancement (>10 times increase in capability with a single iteration), was considered unlikely without a sustained "moon-shot" type of national prioritization in this technology area.**

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NASA

Technology Maturation Plan for High Power Nuclear Electric Propulsion

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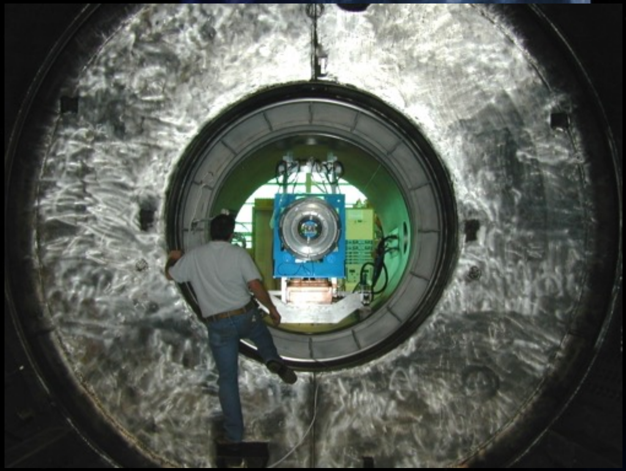
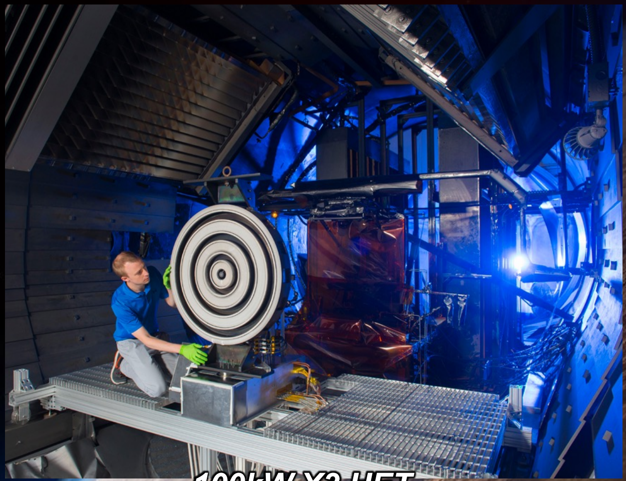
https://ntrs.nasa.gov/api/citations/20260001499/downloads/NEPTMP_SNP-PLAN-0043Ver1_1Baselined.pdf

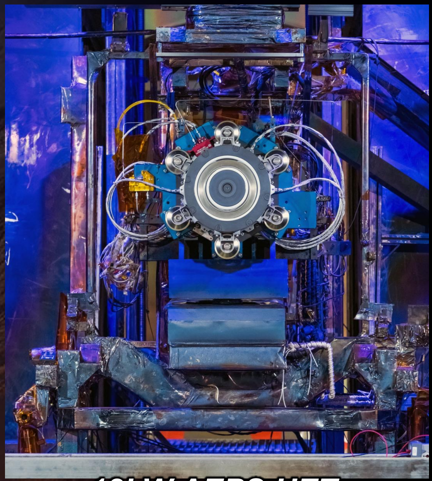
- HETs are a mature electric propulsion technology with systems in operational use continuously since the early 1970's
- There are currently well over a thousand spacecraft flying HET propulsion systems with single unit power levels of up to 5 kilowatts
- HETs have also been built and tested at power levels up 100 kilowatts; facility effects for P>10^{-5} Torr



50kW NASA-457M HET



100kW X3 HET



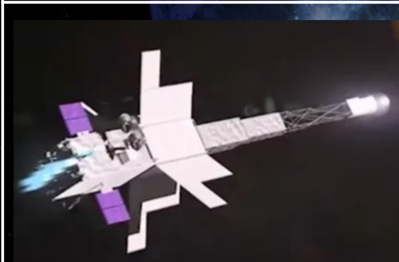
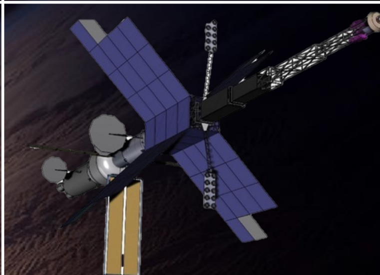
12kW AEPS HET

- **MPDTs are an electric propulsion technology that has been the investigated intermittently since the 1960's**
- **The physical processes responsible for propellant ionization and acceleration in MPDTs become increasingly efficient at high power making them an attractive option MW-class applications**
- **Much of the past research into MPDTs has investigated pulsed operation because of the very high power required for efficient operation**
- **Significant exceptions to pulsed or quasi-static developments were conducted in late 60's and early 70's when Soviet engineers first demonstrated steady-state, self-field operation at a power level of 500 kilowatts using lithium propellant**

Lithium MPD thruster

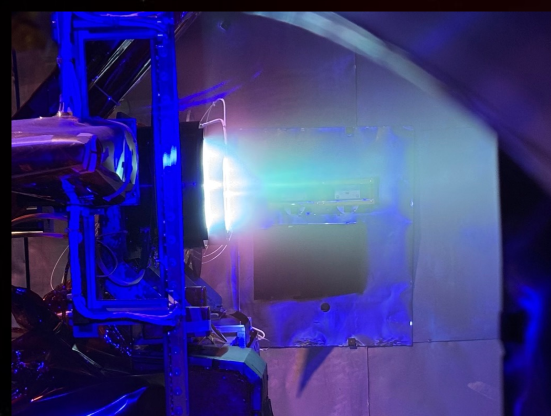
Image credit: NASA

- **A framework for incremental development was developed based on time frame and power level**
- **Near term missions assumed use of exiting technology; far term missions utilize technology selected for the technology maturation plan (HET & MPDT)**
- **Intermediate applications assumed use of 25/50kW HET with Kr instead of Xe for cost savings**

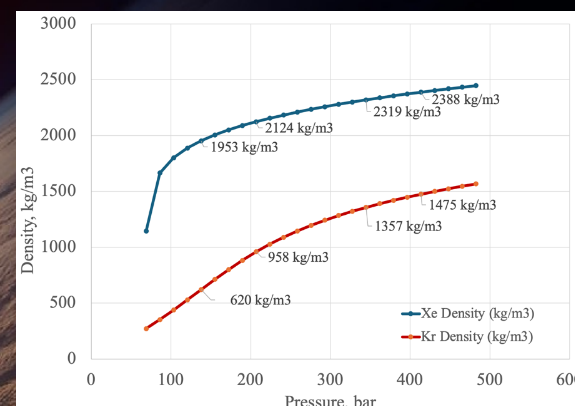
Present (< 3 years)	Near Term (3-5 years)	Mid Term (5-10 years)	Far Term (>10 years)
			
20-50 kW	200-300 kW	500-700 kW	2 MW
12 kW HET	12-25 kW HET	50 kW HET	50kW HET or 500kW MPDT
xenon propellant	Xe or Kr propellant	Krypton propellant	Kr or Li propellant

- **HET development work to date has focused on thruster-to-thruster interactions with Xe & Kr**
- **Wear testing with Kr to determine effectiveness of AEPS magnetic shielding technology to achieve sufficient lifetime**
- **Investigations in Kr storage have indicated increased storage pressure likely needed to minimize volume penalty associated with lower stage density**

GRC VF6 Test Facility

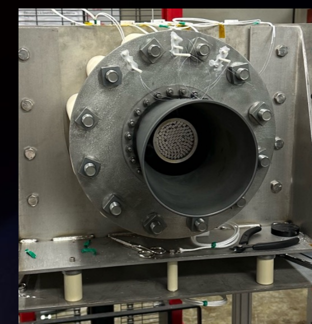


Clustered HET operation on Xe & Kr

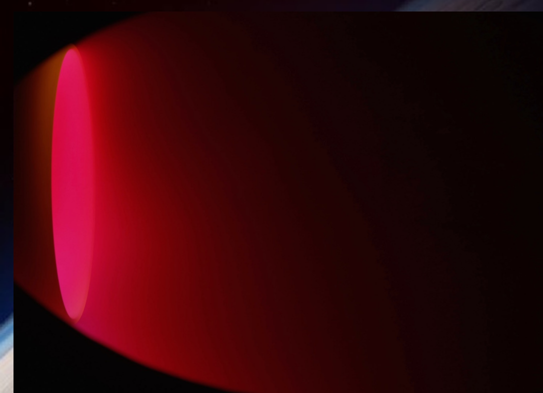


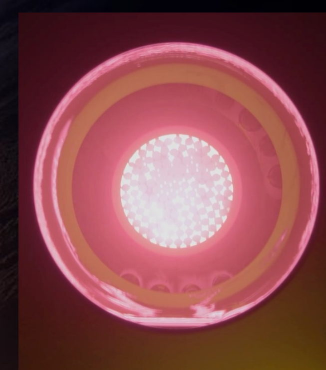
Xe & Ke storage density at 25˚C

- **Condensable Metal Test (CoMeT) Facility commissioned at the Jet Propulsion Laboratory**
- **3m in diameter and 8m long, water-cooled liner capable of absorbing up to 2 megawatts of power, anticipated pumping capacity of 3,000,000 liter per second for lithium vapor.**
- **Initial proof of concept MPDT operation successfully performed at 120 kW and 4250 Amperes**



JPL CoMET Test Facility





MPDT operation

Summary

- A framework was developed to guide the NASA nuclear electric propulsion development strategy assuming an incremental rate of advancement supporting applications ranging from 50 kilowatts to 2 megawatts
- This approach was designed to support near term missions such as a 50-kilowatt class nuclear electric propulsion demonstration mission as well as multimegawatt applications as envisioned for human exploration class missions to Mars utilizing a hybrid chemical NEP transportation architecture
- The propulsion technologies selected for development are HETs and MPDTs
- Initial HET efforts have focused on characterizing clustered operation on Xe and Kr at 12kW and evaluating wear rates of existing magnetically shielded thruster design
- Initial MPDT efforts have focused on commissioning a new test facility at JPL capable of testing thrusters at power levels ≥ 500kW
- Follow on activities are being planned to continue these developments to enable future missions