# ASPEN

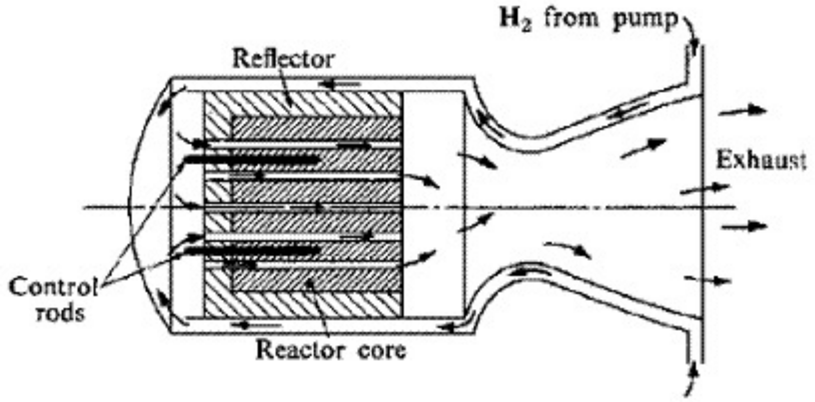
First Meeting

9/2/18

# Agenda

- Nuclear Propulsion Overview
- Hyperion-1
- Available work/projects

# What Is Nuclear Thermal Propulsion?



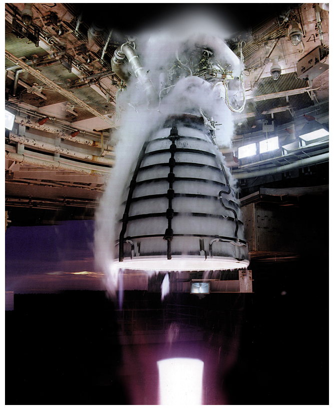

- 3 classifications:
  - Solid-core
  - Liquid-core
  - Gas-core
- Solid-core
  - WF flows around/cools the reactor support structure and neutron reflector before flowing into cooling channels in reactor core
    - This simultaneously cools the reactor and heats the WF to extreme temperatures before it is expelled through a nozzle to produce thrust

# Why Nuclear Thermal Propulsion?

## The Current State of Propulsion and Energy

**Liquid Bipropellant Rocket Engines**

- Thrust: 0.1 lbf – 1.5 million lbf
- ISP theoretically capped at ~450 s
  - Only achievable w/ LH2-Lox, which are highly volatile and difficult propellants
- High feed system weight and complexity



SSME
LH2-LOx
512,000 lbf vac
Isp: 452.3 s

SpaceX Raptor
Methalox
430,000 lbf vac
Isp: 375 s

# Why Nuclear Thermal Propulsion?

## The Current State of Propulsion and Energy

**Solid Rocket Motors**

- Used sometimes as boosters for heavy-lift launch vehicles
- Not really worth talking about

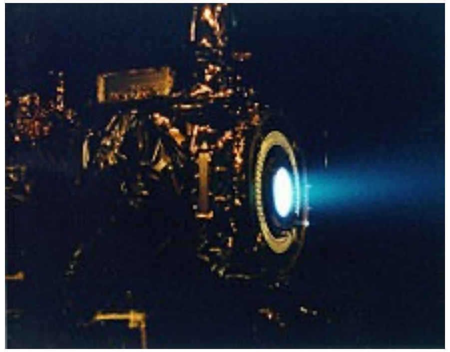
AJ-60A (Delta V)
HTPB
379,600 lbf
Isp: 279.3 s

# Why Nuclear Thermal Propulsion?

## The Current State of Propulsion and Energy

**Electric Propulsion**

- Thrust: 0.01 – 1 N thrust
    - MPD’s can reach 100 N, but limited by onset phenomena
- High efficiency (1000’s of seconds of Isp)
- Mostly used for small probes, satellite stationkeeping



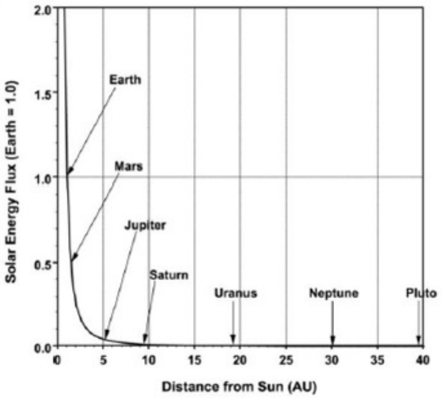
NSTAR (NASA)
Xenon
92 mN
Isp: 1700-3300 s

# Why Nuclear Thermal Propulsion?

## The Current State of Propulsion and Energy

**Solar Power Generation**

- Massive arrays needed to generate small amounts of power due to exponential drop-off of solar flux after Earth
    - JUNO probe: 3x 30 ft arrays ( ~60 m$^2$ SA)
        - <500 Watts of power generated
        - Low-end microwaves typically start at around 600 Watts
- Position relative to Sun is important




1 of JUNO's 3 Solar Arrays
Panel Mission Output: ~150 W

**Radioisotope Thermoelectric Generator (RTG)**

- Passively use heat generated by radioactive decay
- Typical output: <1000 W

GPHS-RTG
Output: 300 W

GE Standard 1.6 cu. ft. Kitchen Microwave
1,000 W

# Why Nuclear Thermal Propulsion?

## Nuclear Thermal Rocket Engines

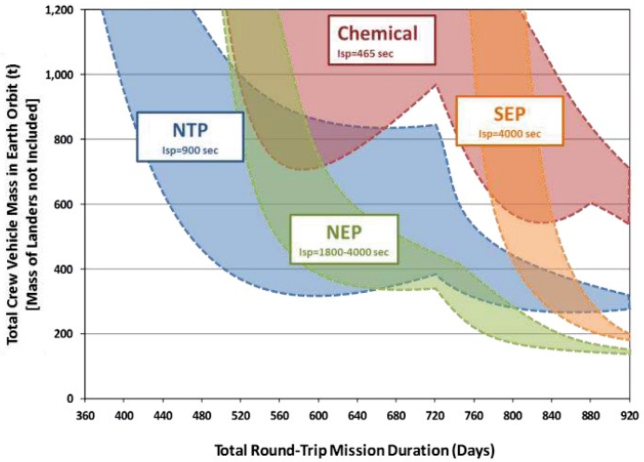
**Propulsion**

- Thrust: 75,000 lbf @SL (NERVA XE) – 550,000 lbf vac (Timberwind 250)
  - Comparable to modern launch vehicle LRE's
- Isp: 800 – 1000+ s
  - 2-3x as efficient as LRE's
  - 3000 – 5000 s possible w/ gas core, but largely untested (except for Russians)

**Power Generation**

- Bimodal engines capable of generating hundreds of kW to MW of electrical power


Phoebus-2A (Project Rover)
4000 MW(th)
Thrust: 250,000 lbf
Isp: 820 s
Firing Duration: 32 minutes
Test Date: 1968




Mass vs. Trip Time (Credit: NASA)

# What Could NTP Be Used For?

- <u>Crewed missions</u>
  - Standing next to a NTP engine primed for launch for a year would expose you to less radiation than a diagnostic X-ray (NASA)
  - Less total radiation exposure on route to Mars than conventional LRE's
  - Generates sufficient power for life support, auxiliary equipment
- <u>Deep-space probes</u>
  - Get there faster, more available power for instrumentation
- <u>Off-world resource extraction/transport</u>
  - Similar to deep-space probe benefits, but with the added benefit that excess generated heat could be used to warm electronics and extract water

# Why Now?

- This technology has been under quiet development for 60+ years
  - 1950's – Project Rover (LANL, NASA)
  - 1960's – Nuclear Engine for Rocket Vehicle Application (NASA, AEC)
  - 1980's – Project Timberwind (DoD)
  - 1990's – Space Nuclear Thermal Propulsion Program (USAF)
- Sudden resurgence in interest from NASA in last 7 years
  - 2011 – Nuclear Cryogenic Propulsion Stage (NASA, DoE)
  - 2015 – Exploration Technology Development and Demonstration (NASA, ORNL, INL, Aerojet Rocketdyne)
    - Ground test in early 2020's, lunar flyby planned for 2025
  - 2017 – Nuclear Thermal Propulsion Project (NASA MSFC, BWXT)

# Why Now?

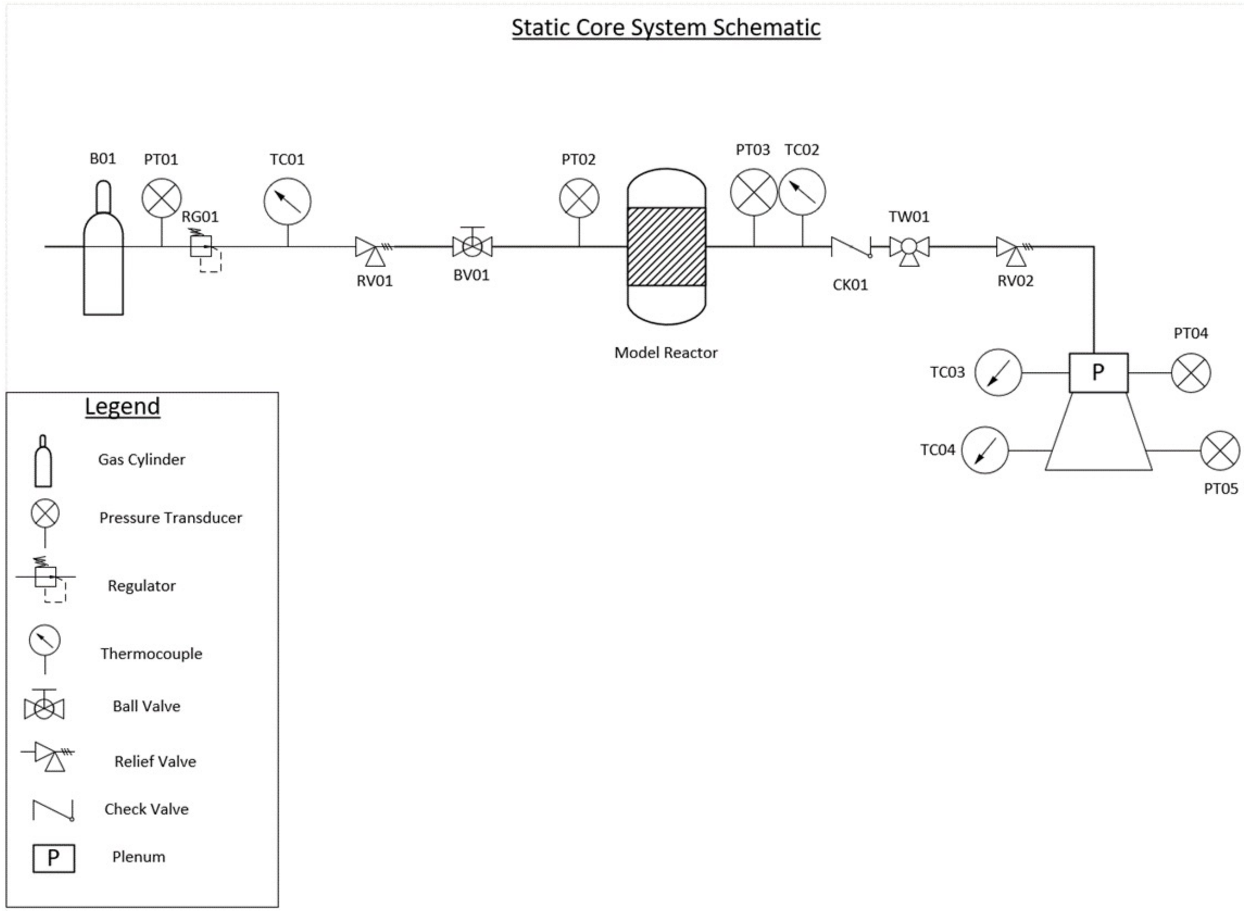
To choose one of the discussed potential applications of NTP: **Off-world mining**

- Financial sector is interested in off-world mining
  - Goldman Sachs report (key area for growth within the next 10 years)
  - Market Research Report (two weeks ago) – market worth $14.71B by 2025
  - ULA price point for lunar ice water: $500/kg
  - Commercial Space Launch Competitiveness Act (2015), Luxemburg legal framework (2017)
- Private industry (new space) is interested in off-world mining
  - Planetary Resources, Moon Express, Deep Space Industries
- Old aerospace is even interested in off-world mining
  - ULA-sponsored research ("Cislunar 1,000 Vision")
- Most (if not all) functionality can be achieved w/o crew, increasing probability of green light

# Why Now?

We are the first student group in the country to pursue NTP-related technologies

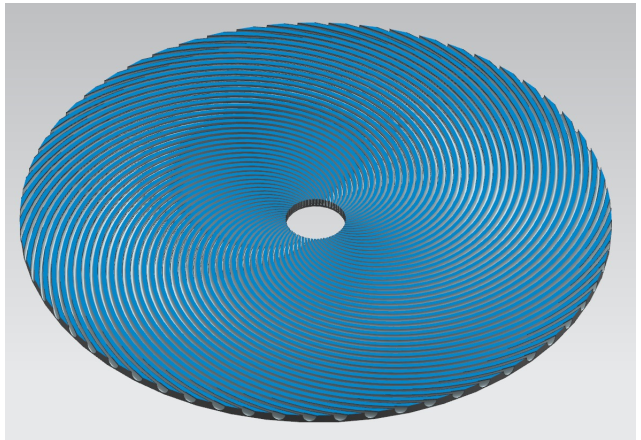
# Hyperion-1



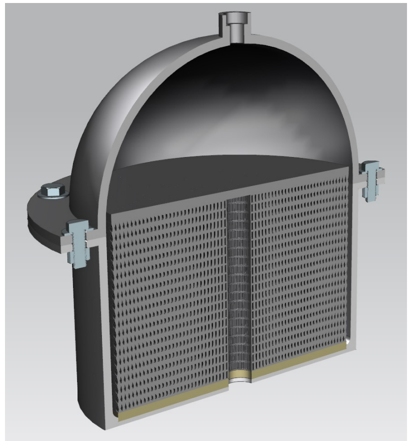
Static Core System Schematic
B01
PT01
RG01
TC01
RV01
BV01
PT02
Model Reactor
PT03
TC02
CK01
TW01
RV02
PT04
TC03
P
TC04
PT05
Legend
Gas Cylinder
Pressure Transducer
Regulator
Thermocouple
Ball Valve
Relief Valve
Check Valve
P
Plenum

# Hyperion-1

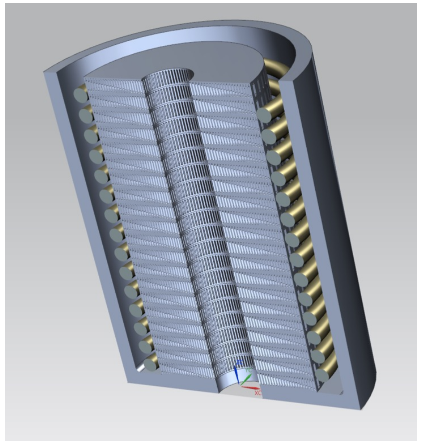
- Modeling a grooved-disc-type (solid core variant) NTRE by substituting fissile fuel with resistive (or inductive) heating elements.
    - Grooved-disc type was chosen because of theoretical thermal stability improvements over particle-bed engines
- Working fluid is GHe, but GN2/compressed air will be used for all pre-firing flows
- Target thrust: ~1 kN
- Target Isp: > 300 sec
- Heating method drives core configuration
    - Resistive: Printed Inco core, separate annulus/PV, sealed wire ports in sidewalls, electrically-insulating elements required to clock/restrain core
    - Inductive: One-piece SS core/annulus, separate coil, separate lid, sealed ports for coil leads in lid (or Swage them through separate ports)
        - Power supply determines heating penetration depth, most likely will need to split core into “cartridges” whose outlets are manifolded and piped into separate exhaust plenum



Sample grooved disc element

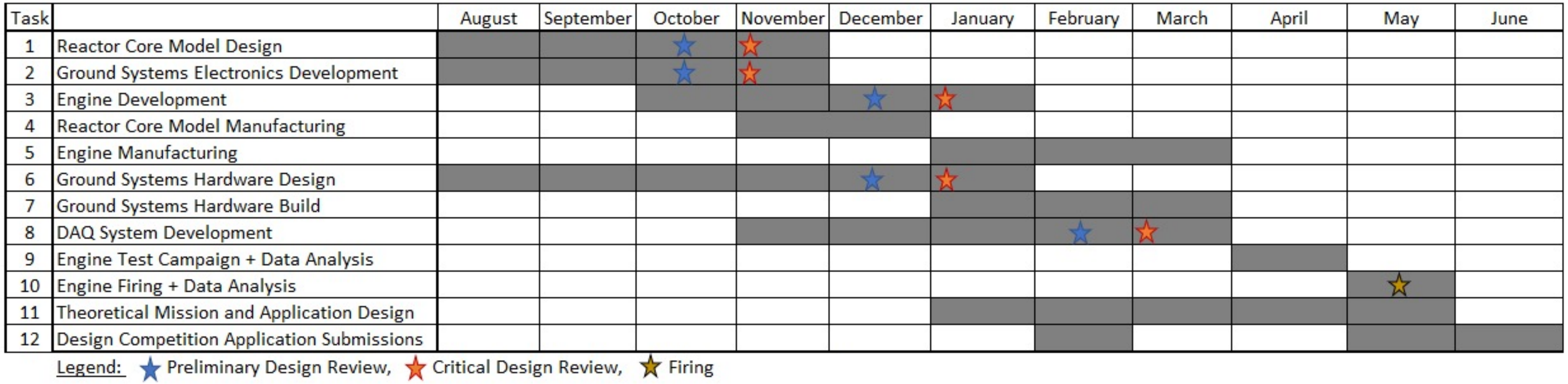


Sample resistive configuration



Sample inductive configuration

# Hyperion-1




<u>Reactor core model</u>
- Disc thermal model
- Annulus/PV design
- High temp/pres seals

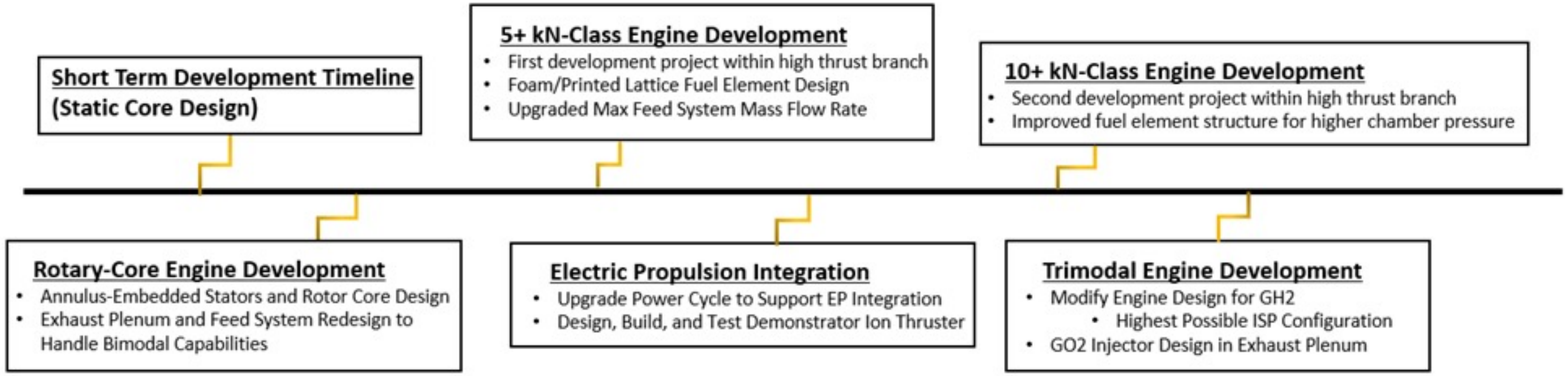
<u>GS Electronics</u>
- Power supply sizing
- Power system schematics
- Electrical isolation

<u>GS Hardware</u>
- Test stand structure
- Engine feed system

<u>DAQ</u>
- Sensor array
- Data visualization

<u>Less technical:</u> Sponsorships, vendor interactions, theoretical mission design (ex: asteroid selection?)

# Future Projects



# Questions?

# References


- “The Nuclear Cryogenic Propulsion Stage”, PPT, NASA
- “Space: The Next Investment Frontier”, Goldman Sachs
- “Global Space Mining Market 2025”, Market Research Reports
- “On Orbit Refueling: Supporting a Robust Space Economy”, ULA
- “Overview of Rover Engine Tests, Final Report”, NASA