Lunar Nuclear Thermal Transport

ER43 Propulsion Thermal Analysis Branch

Space Launch System (SLS)

The Space Launch System is NASA's newest heavy lift rocket

- 77 tons of payload in block 1 configuration evolving to 143 tons
- 2 solid rocket motors each with 3,600,000 lbs thrust for 126 seconds
- 4 RS25 liquid rocket motors each with 512,000 lbs of thrust for 8 minutes

The SLS Orion Crew Module will sustain astronauts during deep space travel and provide safe reentry from deep space return velocities

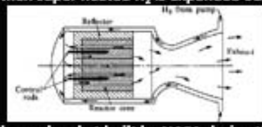
Why a Lunar Nuclear Thermal Transport

- We are not going to the moon because its there
  - We already did that!

- Going back to the moon will prepare our engineering and infrastructure capabilities to be able to safely deliver an astronaut to and from Mars
- One technically and infrastructural-ally demanding component will be the rocket engine that gets us there
- Nuclear Thermal Propulsion is the mathematically superior choice for deep space travel
  - The further the distance the better nuclear power performs against other options
  - A Long lead time item that should be included in our Lunar plans
  - A simple design is both valuable for Lunar Station support and to hone our engineering skills

General NTR Background

- First proposed in the 1960's a Nuclear Thermal Rocket (NTR) offers a combination of high thrust and efficiency making it ideal for moving heavy hardware to and from the moon and beyond
  - The NTR is a long game investment that would ensure NASA missions for many decades to come
  - Typically employs a uranium fueled nuclear reactor core and hydrogen (H_2) gas working fluid
- The H_2 gas acts first as fuel rod coolant as it passes through the nuclear reactor core followed by rocket working fluid when the then super heated H_2 is expanded out of a nozzle to produce thrust



- The Pewee solid core nuclear thermal rocket built by NASA during the Rover NERVA program produced 25,000 lbs of thrust, had a thrust to weight ratio of 3.5 to 1, and Isp of 940 seconds
- Pewee was proposed as a single engine for space tug use or as a cluster of three for a Mars mission
- Pewee was limited to 4 runs probably due to its high operating temperatures and pressures
  - Operating temperature >3500 K, 5400 R, 5000 F
  - Operating pressure 6894 Kpa, 1000 psi

Lunar Space Station

- Launched by SLS the Orion command and service module will be used for beyond low Earth orbit (LEO) missions
- Orion missions now include the transportation and assembly of a Lunar Observation Platform (LOP)

Low Temperature Low Pressure Reactor

- A Lunar Nuclear Thermal Transport could ferry both supplies and astronauts from Low Earth Orbit (LEO) to the space station at higher efficiencies than traditional chemical rocket engines
- The reactor for a Lunar Nuclear Thermal Transport would be expected to support in excess of 160 restarts (essentially infinite restart)
  - 1 mission every six months for 20 years
    - –Based on International Space Station life and schedule
  - 4 start ups per mission
- A by design 90 minute runtime would make this NTR useful for a host of missions
- Assuming a relatively low reactor core coolant exit temperature (1700K, 2600F, 3060R) ensures high restart capability
- Assuming a low reactor core coolant inlet pressure (P_{in}) of 3102 Kpa (449.91 psi) ensures a mechanically simple reliable design
- A low temperature, low pressure reactor results in a thermally and mechanically simple Nuclear Thermal Propulsion design that would fill the valuable roll of Lunar Space Station support
  - Would establish the long lead time Nuclear Thermal Propulsion infrastructure that is best suited for maned exploration of our solar system
    - Infrastructure development would both spur and readily absorb technology advances
      - Such as extreme temperature fuel rods
      - High pressure reactor cores and the pumps that feed them
      - While maintaining high restart capability to support multi mission architectures

Free Propellant!

- In space H_2 storage has become a significant obstacle to long duration missions due to H_2 boil off
- The Space Shuttle program rarely launched at maximum lift off weight
  - NASA's newest rocket the Space Launch System (SLS) is likely to follow suit
- By ballasting the SLS with ammonia NH_3 it could always be launched at maximum lift off weight
  - The impact to the cost of the launch of the biggest rocket in the world would be insignificant
- When shaded from sunlight Ammonia can be kept cool enough that it suffers no boil off in space
  - Ammonia is easily storable, it freezes at -107.77 F, 351.9 R, 195.5 Kelvin
- Ammonia Reactor coolant could be stored at a Low Earth Orbit (LEO) "Gas Station"
  - Payload delivery propellant margins would stay at the Lunar Space Station
- A 25,000 lbs vacuum thrust, 450 psi operating pressure, Ammonia (NH3) cooled NTR would have a vacuum Isp of 233 seconds at a fuel rod operating temperature of 2600 F
  - Requires CerMet fuel rods
  - Predicted to have a fantastic thrust to weight ratio of 6.7 to 1, weighing just 3,732 lbs
  - Increasing operating pressure to 1200 psi increases Isp to 245 seconds at 26,248 lbs of thrust
- A 25,000 lbs vacuum thrust, 450 psi operating pressure, Ammonia (NH3) cooled NTR would have a vacuum Isp of 272 seconds at a fuel rod operating temperature of 3700 F
  - Increasing operating pressure to 1200 psi increases Isp to 286 seconds at 26,340 lbs of thrust

Orion

- The SLS staged development plan means that the launch vehicle will have a 105 metric ton to LEO capability during Lunar Space Station Assembly
- This puts a great deal of demand on Orion to transport/maneuver space station components that are potentially heavier than was originally planned for the current Orion system

An artists rendition of the Orion Command and Service Module with an attached propulsion stage

Nuclear Thermal Rocket Projections

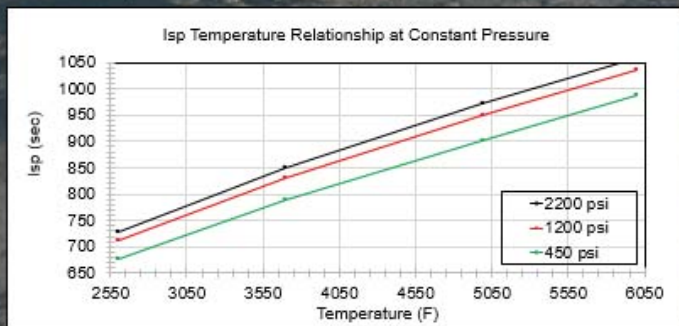
- Design challenge to increase reactor core fuel rod temperatures while maintaining the goal of 160 restarts with run times of up to 90 minutes
  - The product is a reliable propulsion device for exploring our solar system

Isp (sec) Sea Level	Thrust (lbf) Sea Level	Isp (sec) Vacuum	Thrust (lbf) Vacuum	Reactor Core Pressure (psi)	Fuel Rod Temp (F)	Reactor Thermal Power (Mw)
824	22,230	926[1]	25,000	450	5000	593[1,2]
600	25,179	677	28,408	450	2600	525
654	27,486	712	29,880	1200	2600	525
700	25,068	789	28,281	450	3700	635
764	27,363	830	29,746	1200	3700	635
800	25,154	902	28,380	450	4985	765
873	27,459	950	29,851	1200	4985	765
879	25,054	987	28,170	450	6002	852
952	27,140	1035	29,504	1200	6002	852

1) [illegible]
2) All others assume 98% efficient nozzle, 90% Hydrogen cooling efficiency, and 0.03 friction in coolant channels
3) Sea level assumes nozzle expansion to 14.7 psi, and vacuum assumes expansion to 3 psi

Operating Pressures Effect on Isp

- NTR designs benefit greatly from increased reactor core operating pressure
- Note the minimum 35 second improvement to Isp when going from 450 to 1200 psi
  - 48 second improvement to Isp at 5,000 F



Assumes 98% efficient nozzle, and 90% Hydrogen cooling efficiency for all designs