Raising Nuclear Thermal Propulsion (NTP) Technology Readiness Above 3

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NASA Technology Readiness Level (TRL)

- **TRL 9**: Actual system “flight proven” through successful mission operations
- **TRL 8**: Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)
- **TRL 7**: System prototype demonstration in a space environment
- **TRL 6**: System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
- **TRL 5**: Component and/or breadboard validation in relevant environment
- **TRL 4**: Component and/or breadboard validation in laboratory environment
- **TRL 3**: Analytical and experimental critical function and/or characteristic proof-of-concept
- **TRL 2**: Technology concept and/or application formulated
- **TRL 1**: Basic principles observed and reported
How Does NTP Work?

- Propellant heated directly by a nuclear reactor and thermally expanded/accelerated through a nozzle
- Low molecular weight propellant – typically Hydrogen
- Thrust directly related to thermal power of reactor: 50,000 N ≈ 225 MW\textsubscript{th} at 900 sec
- Specific Impulse directly related to exhaust temperature: 830 - 1000 sec (2300 - 3100K)
- NTP Specific Impulse (~900 seconds) doubles over chemical rockets (~450 seconds) due to lower molecular weight of propellant
Rover/NERVA Engines

20 NTP engines designed built and tested during Rover/NERVA
Rover/NERVA TRL Evolution

TRL2 ➔ TRL6
Past Rover/NERVA Ground Test Infrastructure at Nevada Test Site

Engine Maintenance Assembly and Disassembly (E-MAD).

Test Cell “A”
With two 500,000 gallon dewars of LH2

Test Cell “C”

Engine Test Stand-1
**XE’ Experimental Engine - TRL 6**

- 55430 lbs thrust
- 1140 MW power using NRX-A5 type fuel
- Hot-bleed-cycle in flight type configuration
- 28 restarts in 1969
- 11 minutes at full power
- Optimum startup and shutdown sequence demonstrated [4]
NERVA Flight Engine for TRL 7 Goal

- Thrust 75,000 lbf
- Isp 825sec
- Chamber Pressure 450 psi
- 60 startups
- Minimum 10hr at rated temperature
- Design specs ready to go before program canceled
Where are we Now with NTP?

- Rover/NERVA program canceled in 1973 before flight demo
- Most Rover/NERVA ground test infrastructure too old or gone
- Only a few SME’s from Rover/NERVA still around
- Hundreds of NTP reports in the archives
- Other past NTP efforts lasted a few years before being canceled (e.g., Space Nuclear Thermal Propulsion-SNTP, Space Exploration Initiative-SEI, etc).
- NTP always has been considered for human missions to Mars.
- NTP program funded by NASA Advanced Exploration Systems Office for last 3 years and still on-going
Why has the NTP TRL gone down?

- Reactor fuel element design requirements and material “recipes” have changed
- Engine operating cycle modified
- Other misc modifications to components and subsystems

Lessons learned from J-2X

Modifications to high TRL system design and operating requirements can reduce the TRL and require redevelopment and recertification
The goal of the program is to establish adequate confidence in the affordability and viability of NTP such that it is seriously considered as a baseline technology for future NASA human exploration missions with emphasis on missions to Mars in the 2030’s.
W/UO₂ CERMET Fuel Element Fabrication: 7 Channel Element with Depleted Uranium

Above left/right: 7 channel W-UO₂ FE during HIP process

Left & above: LANL sample post fill and closeout prior to shipping

Above/Below: 7 channel WUO₂ fuel element post HIP and cross sections
Coated Graphite Composite Development (ORNL)

Above: Members of Oak Ridge National Laboratory fuels team with the graphite extruder; Left: Graphite extruder with vent lines installed for DU capability

Right: Layoff base / Graphite insert

Above: Test Piece highlighting ZrC Coating
Right: Coating primarily on external surface

Above and Left: Extrusion samples using carbon-matrix/Ha blend .75” across flats, .125” coolant channels

Uncoated graphite

ZrC coating
Short, 7 Channel W/UO$_2$ Element Fabricated and Tested in Compact Fuel Element Environmental Tester (CFEET) ~ TRL 3

CFEET System 50 kW Buildup & Checkout

Completed CFEET system. Ready for W-UO$_2$ and H$_2$ testing

Left: View looking down into the CFEET chamber during shakeout run 1. BN insulator and bright orange sample inside

Above/left: Pure W sample post shakeout run 2. Sample reached melting point (3695K) and was held in place by the BN insulator.

Initial Testing of Short W/UO$_2$ Element
NTREES provides a cost effective method for rapidly screening of candidate material and examining thermal hydraulic performance.

- The NTREES is designed to mimic the conditions (minus the radiation) to which nuclear rocket fuel elements and other components would be subjected to during reactor operation.

- The NTREES consists of a water cooled ASME code stamped pressure vessel and its associated instrumentation coupled with inductive heaters to simulate the heat provided by the fission process.

- The NTREES has been designed to allow hydrogen gas to be injected into internal flow passages of a test article mounted in the chamber.
Radionuclides released into the air from DOE facilities are regulated by the National Emission Standards for Hazardous Air Pollutants (NESHAP 40 CFR61.90):

Emissions of radionuclides to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.

An effluent treatment system is needed for NTP to insure emissions remain within regulations under all possible operating scenarios.
Possible NTP Ground Test Options for TRL 6-8

♦ Bore Hole
  • Relies on permeability of desert alluvium soil to filter engine exhaust
    • Reports from Nevada Test Site show significant effects of water saturation, turbulent flow rate, hole depth, and pressures on soil permeability.

♦ Above Ground Scrubber
  • Engine exhaust is filtered of radioactive aerosols and noble gases and directly flared to atmosphere
    • Nuclear Furnace (NF-1) ground test scrubber successfully tested at the end of Rover/NERVA project
    • DOE and ASME standards available for nuclear air cleaning and gaseous waste treatment

♦ Total Containment
  • Engine hydrogen exhaust is burned at high temperatures with oxygen and produces steam to be cooled, condensed, and collected for controlled processing and disposal
    • All analyses to date indicate system will reliability and economically accomplish task
Prototype flight test demonstrates the following:

- System operation at reduced performance requirements
- Full nozzle expansion
- Radiate heat to space,
- Perform thrust vector control with engine operating,
- Validate reactor operation without effects from facility surroundings
- Monitor radiation effects on stage
- Exposure to space environment effects
- Engine inspection with space telerobotics

Also, Lessons Learned from ARES 1-X and Reactor in Flight Test (RIFT)
Accounting for all the factors which influence the development plan and quantify the factors based on experience, analysis, analogies or similarities, will build greater justification with less uncertainty to have an authority to proceed with NTP development.


5. NERVA Engine Reference Data, S130-CP-090290AF1, Aerojet, September 1970.


