NASA Technology Roadmap: Propulsion and Power Panel

In-Space Propulsion - High Thrust Systems
Nuclear Thermal Propulsion

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Topics

- Nuclear Thermal Propulsion Context
- Nuclear Thermal Propulsion History - Rover / NERVA Program
- Human Exploration of Mars Design Reference Architecture 5.0
- Notional NTP Technology Development Plan and Challenges
- Observations on Draft In-space Propulsion Technology Roadmap
- Conclusions
- Recommendations

Nuclear Thermal Propulsion Context

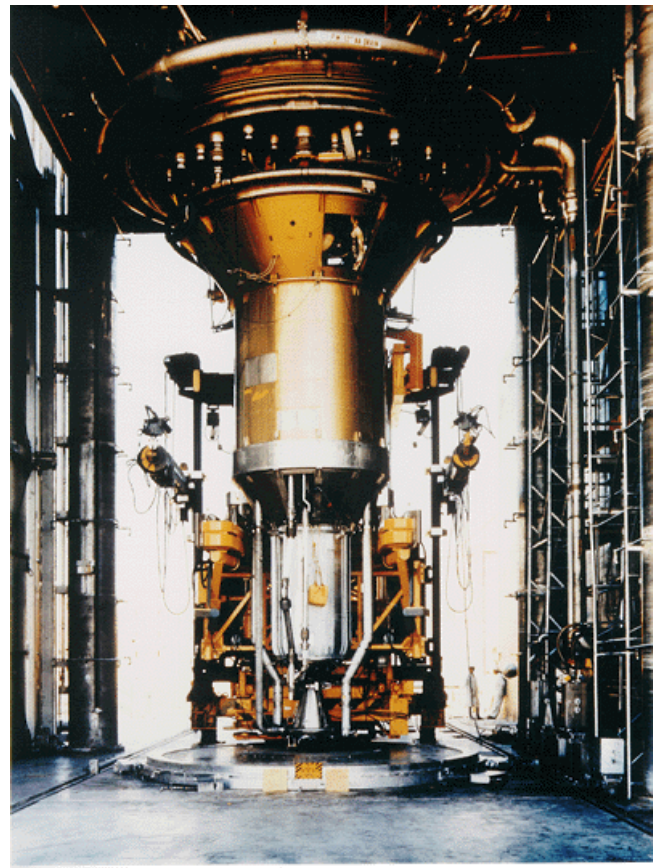
- Human Exploration of Mars Design Reference Architecture 5.0 (NASA-SP-2009-566, July 2009)
  - For the in-space transportation system for crew and cargo, the design team assessed nuclear thermal and advanced chemical propulsion, and determined that the NTR was the preferred approach, while retaining chemical / aerocapture as a backup option.
  - NEP & SEP/Chem/AB examined, considered too complex, required significant orbital assembly and spiral times, and TRL viewed as low

- National Space Policy Act of 2010 (June 28, 2010)
  - By 2025, begin crewed missions to beyond the moon, including sending humans to an asteroid. By the mid-2030s, send humans to orbit Mars and return them safely to Earth.
  - The United States shall develop and use space nuclear power systems where such systems safely enable or significantly enhance space exploration or operational capabilities.

- Space Nuclear System Development Times Are Inherently Long

Rover / NERVA Program [1959 – 1972]*

- 20 Reactor / Rocket Engines Designed, Built, and Ground Tested
- 25, 50, 75, and 250 klb_f Sizes Tested
- Specific Impulse
  - 825 – 850 sec demonstrated with hot bleed cycle NERVA-XE tests
  - 850 – 875 sec expected with expander cycle chosen for NERVA flight engine
- Demonstrated Operating Times
  ~ 62 min (50 klbf, NRX-A6, single burn)
  ~ 2 hours (50 klbf, NERVA-XE, 28 burns)



NERVA-XE (1969)
(Experimental Engine)

* NERVA: Nuclear Engine for Rocket Vehicle Applications

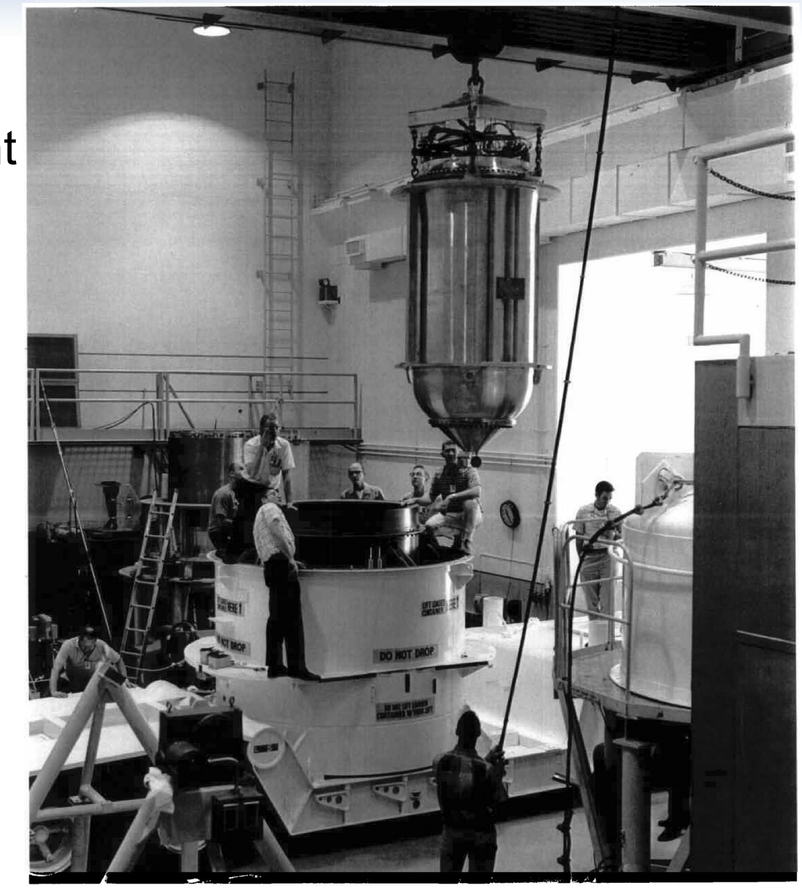
Two of the Engines Ground Tested At Nevada Test Site Under Joint NASA / AEC Program

Phoebus-1B Engine
Operated at Full Power and Thrust
(~1500 MW_{th}, 75 klb_f, ~30 min)
February 23, 1967

Phoebus-2A Engine
Nominal Design Parameters
~ 5000 MW_{th}, ~250 klb_f, 820 sec I_{sp}
Four Tests in June - July 1968
Peak Power 4082 MW_{th}

Pewee 1 Engine

- Design directed toward providing realistic nuclear, thermal, and structural environment for fuel in a small engine
- 25 klbf thrust, 500 MWth
- Full power tests demonstrated 845 sec Isp
- 25 klbf engine (in a three engine cluster) is the baseline for Mars DRA 5.0
- Smallest engine tested 40+ years ago appears suitable for future human Mars mission



The Pewee 1 engine being loaded for transport*

*Steven Howe, LAUR-05-1583, 2/25/2005)

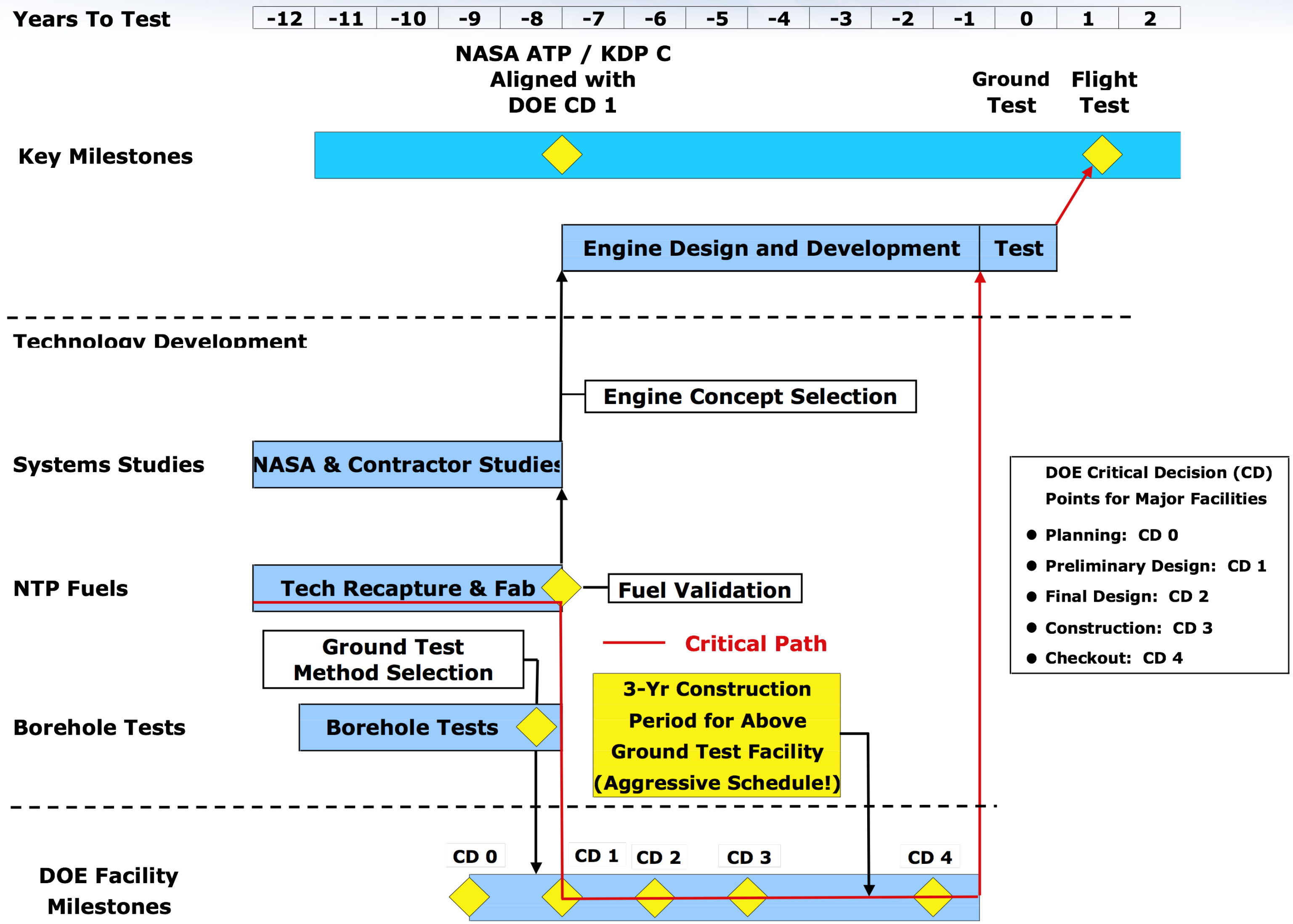
Human Exploration of Mars Design Reference Architecture 5.0

Key Findings

- Mission Type
  - Conjunction (Long Surface Stay) Over Opposition (Short Surface Stay)
- Cargo Deployment
  - Pre-Deploy (Split Cargo & Crew) Over All-Up
- Mars Capture
  - Propulsive for Crew and Aerocapture for Cargo
- In-Space Propulsion
  - NTR was the Preferred Approach (9 Heavy Lift Launches)
  - Retained Chemical / Aerocapture As Backup (12 Heavy Lift Launches)

- AIAA-2009-5308 showed “7 launch” NTR Mars option viable for DRA 5.0 with HLV lift capability of ~140 t and usable payload volume of ~10 m D x 30 m L (-> shroud dimensions of ~12 m D x 42.5 m L)

Notional NTP Development Plan & Challenges



Pre-Decisional For Discussion Purposes Only

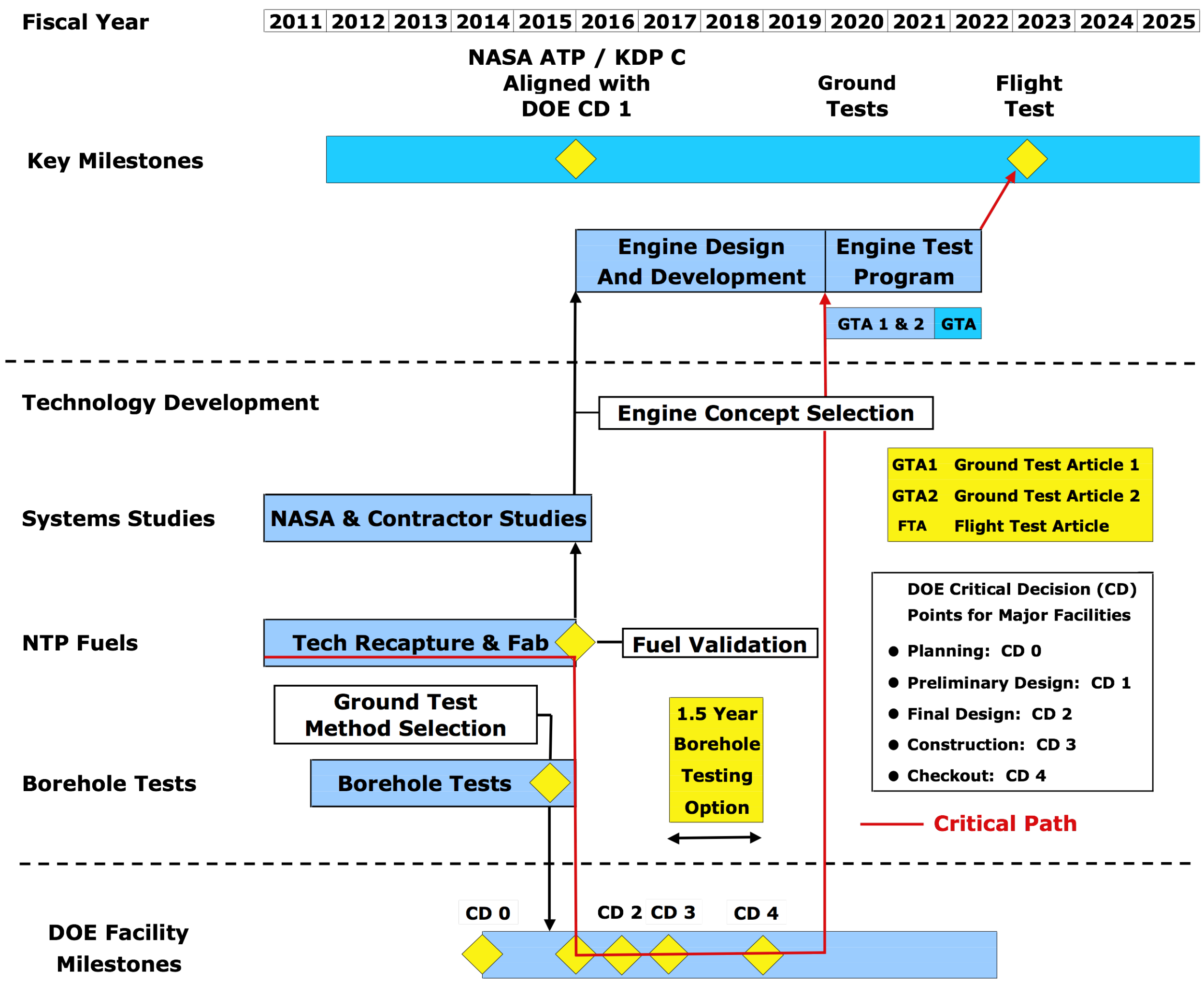
DOE O 413.3A: Acquisition of Capital Assets Tailoring MAY Be Applicable for Borehole Testing Could Significantly Reduce Development Time

- CD 0: Approve of Mission Need
- CD 1: Approve Alternative Selection and Cost Range (Conceptual Design)
- CD 2: Approve Performance Baseline (Preliminary Design Completed)
- CD 3: Approve Start of Construction (Completed Final Design Review & NEPA)
- CD 4: Approve Start of Operations (Operational Readiness Review Completed)

“The amount of time between decisions will vary. Projects may quickly proceed through the early Critical Decisions due to a lack of complexity, the presence of constraints that reduce available alternatives, or the absence of significant technology and development requirements. In these cases, more than one Critical Decision may be approved simultaneously. Conversely, there may be a need to split a Critical Decision.”

“Tailoring is an essential element of the acquisition process and must be appropriate considering the risk, complexity, cost, safety, security, and schedule of the project.”

Notional Accelerated NTP Borehole Testing Plan (Requires DOE 413.3 Acquisition Plan Tailoring)



Pre-Decisional For Discussion Purposes Only

Observations on Draft In-space Propulsion Technology Roadmap

- Chemical, Electric, and Advanced Propulsion Well Represented

- NTP Importance and Maturity Not Well Represented in Draft Roadmap

- NTP Schedule Does Not Appear to Have Been Coordinated with Current ETDD Program Showing Initial Ground Testing of Small 5K Engine in 2020

- Roadmap Depicts 5K Engine Ground Test in 2019
  - Forces less than 3 year DOE test facility construction phase
    - Difficult, but may be possible for borehole tunnel testing
    - Very unlikely for above ground testing with required full effluent cleanup
  - Compresses fuel technology development period
    - Depends on fuel validation using separate effects testing
    - Full fuel validation extends into engine design phase after ATP

- Significant schedule risk under current ETDD program funding profile

Conclusions

- Nuclear thermal propulsion (NTP) has the potential to enable future human Mars missions with reasonable mass requirements and credible numbers of heavy lift launches (from NASA-SP-2009, Mars DRA 5.0)
- Same system can be used in crewed NEO precursor mission
- NTP is a proven technology demonstrated to a high technology readiness level (TRL ~5/6) in the 1960s – 1970s
- Many non-nuclear engine components (TPA, nozzles and skirts) needed for NTP have already flown in space, are at higher TRL, and will benefit greatly from strong synergy with chemical propulsion systems
- Long development times are required for space nuclear systems
- Recapture of NTP fuels fabrication capability required
- Successful demonstration of borehole testing offers the potential of reducing NTP ground testing costs and schedule risk

Recommendations

- Technology pursuits advocated within the In-Space Propulsion Technology Roadmap should be consistent with the technology priorities recommended in Human Exploration of Mars DRA 5.0

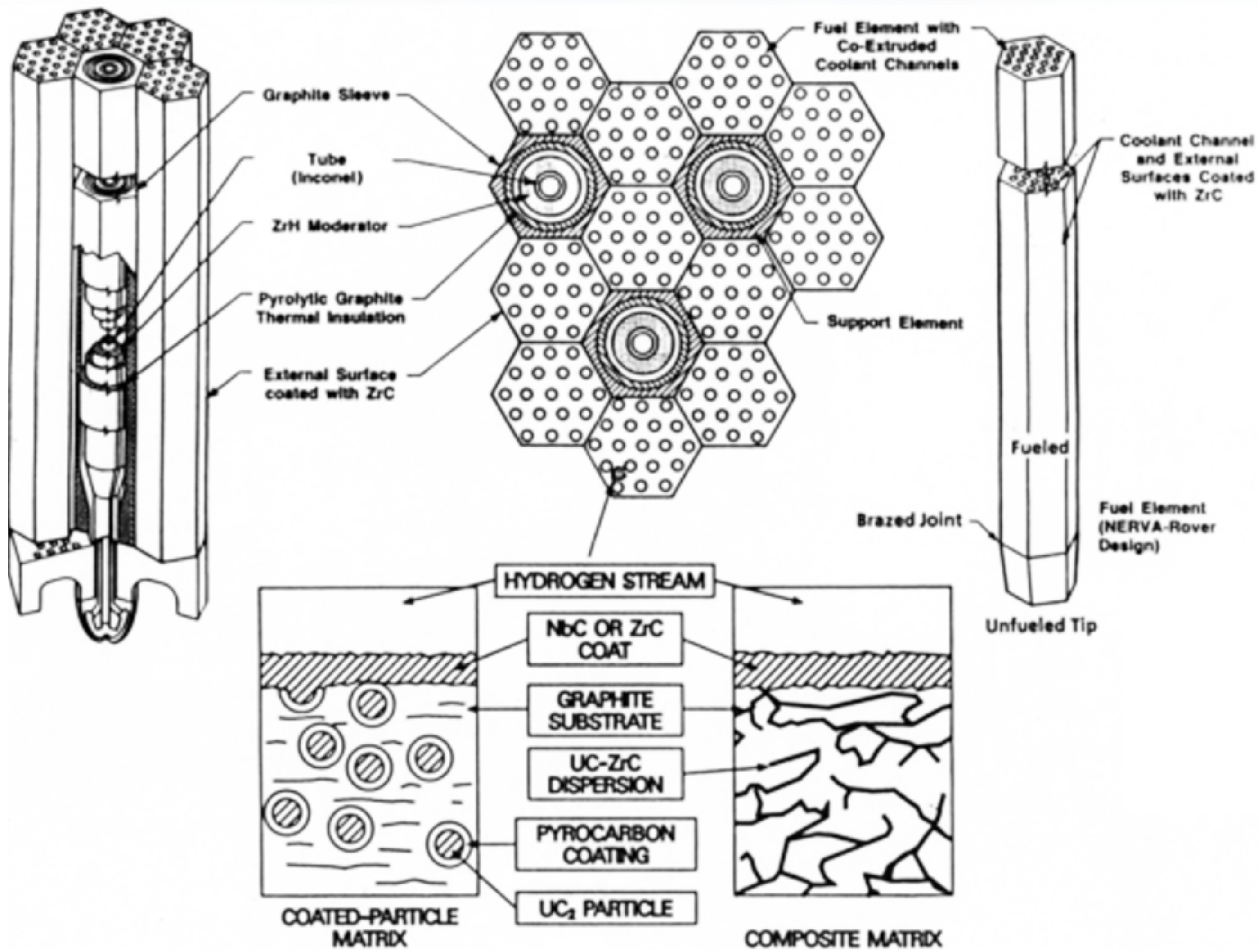
- The NASA In-Space Propulsion Technology Roadmap should be coordinated with and consistent with NASA's current Exploration Technology Development and Demonstration (ETDD) Program

- Technology development should be prioritized with greater focus on technologies that are actually enabling rather than simply enhancing for achieving NASA's goals as outlined in the 2010 Space Policy Act, specifically the human exploration of Mars

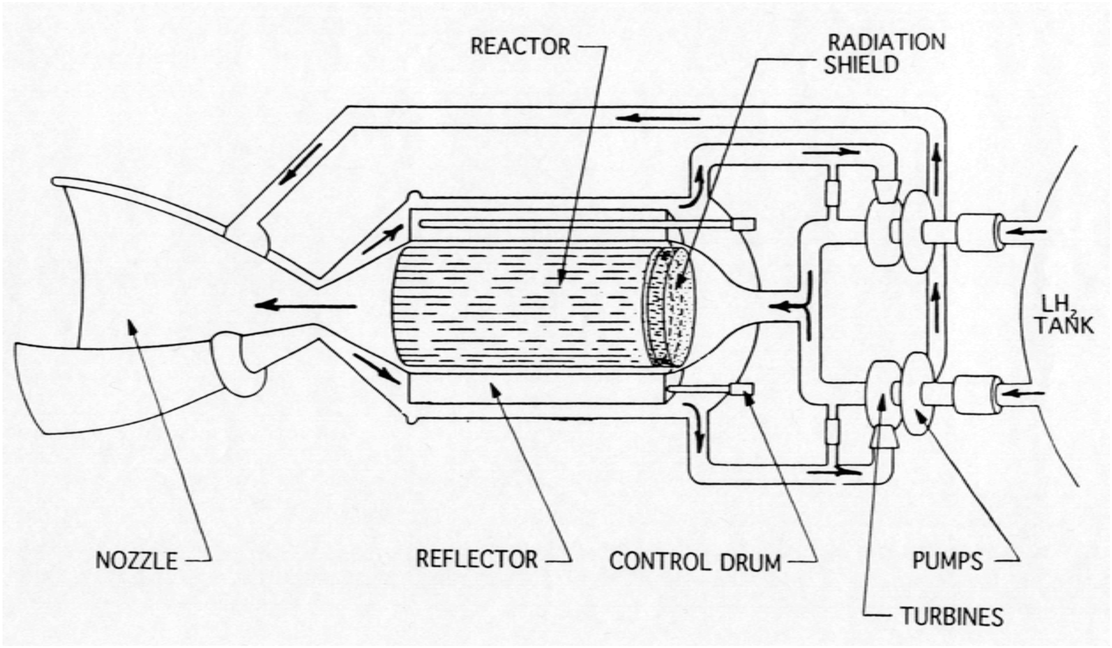
- NTP appears to be the most mature non-chemical system identified in NASA's roadmap offering high thrust and Isp (100% increase over chemical) and should be a high priority technology development area supporting future human missions to the Moon, NEOs, and Mars

Backup

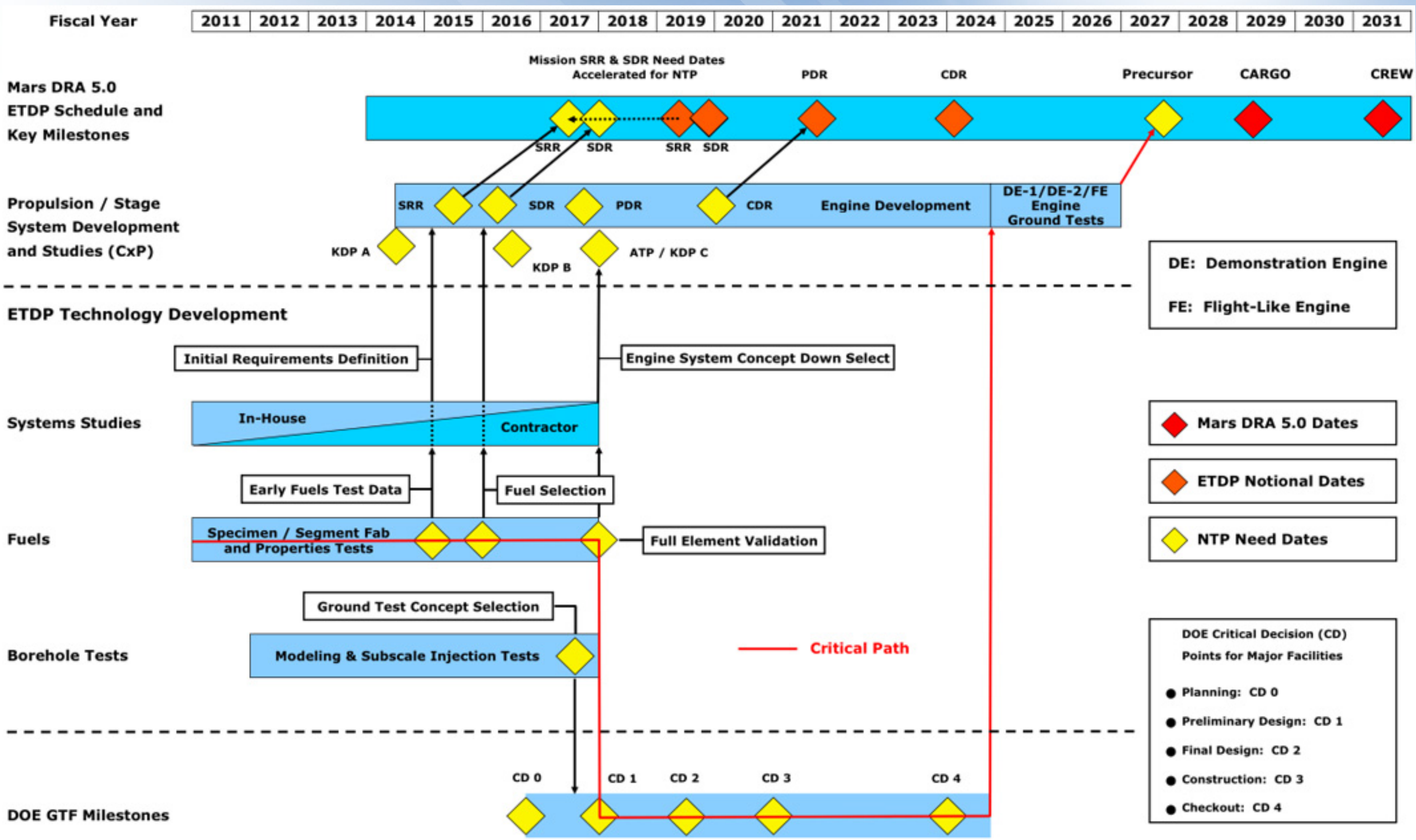
Heritage Graphite Based NTR Fuel



Nuclear Thermal Rocket Engine Expander Cycle



Representative NTP Development Schedule for DRA 5.0



Pre-Decisional, For Discussion Purposes Only

Source: S. K. Borowski, NASA Glenn Research Center, Space 2010 Conference, Anaheim, CA