MARS SAMPLE RETURN AND FLIGHT TEST OF A SMALL BIMODAL NUCLEAR ROCKET AND ISRU PLANT. Jeffrey A. George, Jason J. Wolinsky, Michael B. Bilyeu, and John H. Scott, EP/Propulsion and Power Division, NASA Johnson Space Center, Houston, TX 77058.

Summary: A combined Nuclear Thermal Rocket (NTR) flight test and Mars Sample Return mission (MSR) is explored as a means of “jump-starting” NTR development. Development of a small-scale engine with relevant fuel and performance could more affordably and quickly “pathfind” the way to larger scale engines. A flight test with subsequent inflight post-irradiation evaluation may also be more affordable and expedient compared to ground testing and associated facilities and approvals. Mission trades and a reference scenario based upon a single expendable launch vehicle (ELV) are discussed. A novel “single stack” spacecraft/lander/ascent vehicle concept is described configured around a “top-mounted” downward firing NTR, reusable common tank, and “bottom-mount” bus, payload and landing gear. Requirements for a hypothetical NTR engine are described that would be capable of direct thermal propulsion with either hydrogen or methane propellant, and modest electrical power generation during cruise and Mars surface in-situ resource utilization (ISRU) propellant production.

Mission Architecture Trades: Various mission architecture aspects were traded and assessed for mass, volume, number of ELV launches, and whether return propellant could be produced within 600 days for an electrical power consistent with a small bimodal system (~2-5 kWe). Figure 1 summarizes initial mass in low earth orbit (IMLEO) for six scenarios. All assume hydrogen NTR for the initial TMI burn, and ISRU manufactured return propellant. The first two cases depart Mars surface and return directly to Earth, one with methane NTR and the other with an oxygen-methane chemical engine. Both fit on a single ELV, and allow propellant manufacture within 600 days for 5 kWe. The NTR return utilizes a single engine throughout the mission, while the chemical return requires an additional oxygen tank and propulsion system. The 3rd and 4th scenarios use nuclear and chemical ascent to deliver the sample only to Mars orbit. This is less demanding on the ascent vehicle and ISRU plant, but requires a second orbiting spacecraft, development, and ELV that is not accounted for herein. The 5th and 6th scenarios utilize nuclear and chemical return propulsion to deliver the samples into Earth orbit, were they might be recovered by a human spacecraft. The nuclear scenario is propulsively feasible, but would result in the stage being returned to Earth orbit. The chemical scenario is not feasible with an ELV.

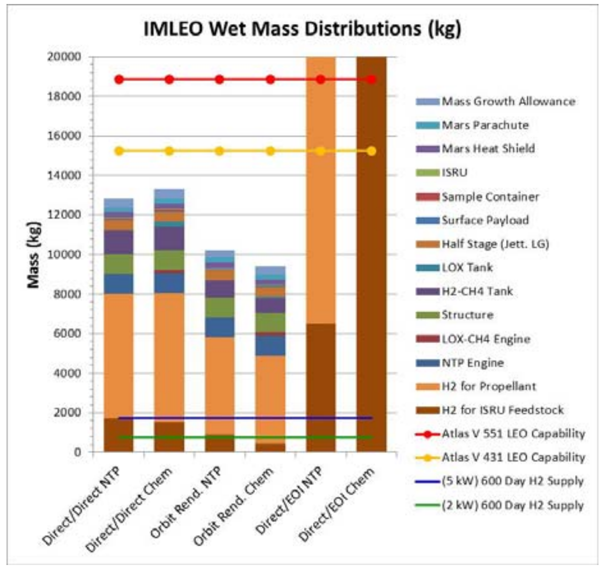

Figure 1: IMLEO for Six Mission Scenarios

Reference Mission: The first scenario was down-selected from the above trades for further development. The scenario involves a single ELV launch (Atlas V 531 or similar) of a single spacecraft “stack” proceeding to Mars surface and back, with various stage modules dropped along the way. The initial wet mass of the spacecraft is 12,800 kg, including 6,300 kg of hydrogen propellant. The wet mass at initial Mars ascent is 8,900 kg, including 6,800 kg of indigenously produced methane propellant and 10 kg of Mars samples, and excluding the left behind landing stage and ISRU plant.

An overview of the mission sequence is presented in Figure 2.

1. Launch on an Atlas V 531.
2. Trans Mars Injection (TMI) burn by the NTR with hydrogen propellant and flight test instrumentation.
3. Evaluation of flight test performance and inspection of nozzle, throat, plenum, core exit plane, and fuel channels via telerobotic access through the engine throat.
4. Cruise phase with onboard power provided by bimodal operation of the nuclear engine in electrical power generation mode. Remaining hydrogen propellant is stored with boiloff rate of no more than 0.1% per day.

5. Mars Entry, Descent and Landing (EDL) using an inflatable aeroshell, 700 m/s hydrogen NTR burn, and deployable landing gear.
6. Mars surface stay of 500-600 days. Remaining hydrogen and Mars atmospheric carbon dioxide is converted to methane via the Sabatier reaction and onboard ISRU plant. Mars samples are accepted from a prior rover mission such as Mars 2020, or are acquired in the vicinity of the landing site.
7. Mars Ascent burn by the NTR with methane propellant.
8. Trans Earth Insertion (TEI) burn by the NTR with methane propellant.
9. Separation of the nuclear stage and targeting of the samples and entry vehicle for Earth.
10. The nuclear stage deployed in a safe solar orbit.
11. Earth entry and recovery of the samples and entry vehicle, analogous to Genesis and Stardust.

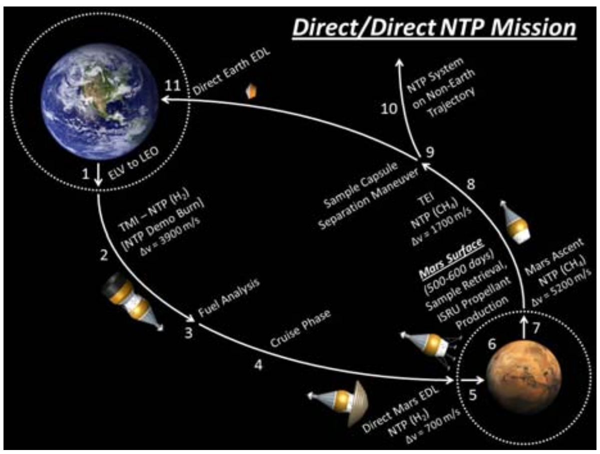

Figure 2: Direct/Direct NTP Mission Sequence

Reference System: An initial spacecraft concept is shown in Figure 3 (Left as launched, Right as landed). To facilitate landing and surface operations, the NTR is atypically positioned at the top of the vehicle with thrust ducted down and canted outward, similar to the Orion abort motor. Bimodal waste heat is rejected through 15 m^2 of radiators. A 30 m^3 core propellant tank stores outbound hydrogen for EDL and ISRU feed, as well as methane ascent propellant as it is produced (assuming liquid methane pools at bottom, with gaseous hydrogen feed pulled from top.) Bus and enclosed Earth Return Vehicle are housed below the central tank (providing some radiation shielding). TMI hydrogen propellant is housed in a drop tank at bottom.

Hypothetical Nuclear Engine Requirements:

- Thrust: 7,500 lbf (H_2)
- Specific Impulse: 800s (H_2), 550s (CH_4)
- Power Generation: 5 kWe

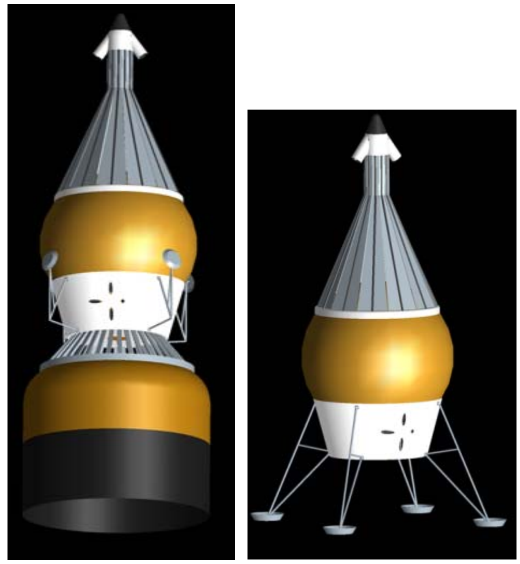

Figure 3: Vehicle & Engine Configurations
Left: ELV Packaging, Right: Landed on Mars

Concepts, Ideas & Approaches to "Jump-Start" NTR Development: A number of presented ideas and approaches may facilitate quicker and affordable development of NTRs:

- *Small-scale NTR* (few klbs) with relevant fuel and performance as an affordable pathfinder to larger engines.
- *Flight test and inflight post-irradiation examination* of NTRs as a substitute or augment to expensive and long-lead ground test, facilities & approvals.
- *Science missions* performed or enabled by small NTRs as additional "mission-pull" and cost share.
- *Bimodal Power & Propulsion* capability in a small NTR to provide onboard power and broaden deep space application.
- *Methane* as a storable and Mars producible propellant for NTRs.
- *ISRU powered by Bimodal NTR* for return propellant production.
- *Common Tank* for outbound hydrogen propellant (TMI), hydrogen feedstock (ISRU), and return methane propellant (ascent & TEI).
- *Nuclear Lander/Ascent Vehicle* concept with top-mount NTR and reverse-thrust nozzles, and payload ease-of-access to the surface.
- *Single ELV launch Mars Sample Return* mission, possibly as an "opportunity" mission after a suc-

cessful flight test & TMI burn, and either acquiring ad-hoc or “Mars 2020 Rover” collected samples.