Business Case for a Commercially Developed Nuclear Thermal Rocket. R. T. Beeson[1,2], and A. C. Faler[1,3], [1]Center for Space Nuclear Research, 995 University Blvd., Idaho Falls, ID 83402, [2]Department of Aerospace Engineering, University of Illinois Urbana-Champaign, Urbana, IL 61820, [3]Department of Astronautical Engineering, University of Southern California, Los Angeles, CA 90089.

Introduction: Although nuclear thermal rockets (NTR) were developed in the United States from 1955-72 under Project Rover and NERVA, none have yet been used in space. The strengths of NTRs lend themselves to be best suited for large Δv missions, especially those that require a sufficient level of thrust to reduce transfer times. An obvious choice for their application is for manned missions to near-Earth objects and Mars, which is proposed in NASA's Design Reference Architecture 5 (DRA5) [1]. Industry has never followed through on the development of an NTR independent from government funding. The reasoning is that an NTR requires a significant initial investment and due to long development timelines industry can not generate revenue until nearly 10-12 years from the start of the project. The long timeline and cost are not overburdensome if the revenue stream is guaranteed. But unfortunately, missions like DRA5 are subject to the whim of the President and Congress.

The authors have conducted an initial feasibility study on whether an evolvable NTR could be made commercial viable. Two metrics were used to measure commercial viability. The first was limiting the initial investment costs to under $0.5B and the second was generating a 20% return on investment (ROI). An evolvable NTR was designed to act as a ferry in three configurations. The first configuration would target a consistent revenue stream of geostationary transfer orbits (GTO). This design was able to stay relatively simple and lower the initial investment to get NTRs into space. Details on the GTO NTR are given in *Beeson et. al.* [2]. Later configurations target ferrying for robotic interplanetary missions and eventually DRA5.

Cost Modeling: For the production, integration, testing and developing costs of the NTR, a model initially used for the Triton acquired from Aerojet Corp. was modified. The LOX-augmented and bimodal assumptions of the cost model were removed and updated material and manufacturing costs were added. The overall lot size of production was assumed to be 23 units with 5 development units (including a spare and test unit) over a 12 year timeline. Core costs were based off the mass breakdowns of a 25klbf LEU core. The enrichment of ^{235}U, fabrication of fuel elements, and the security as well as government oversight needed were strong cost drivers. With a learning factor of 0.90 for 23 units, the average cost per unit for an NTR was $20.6M. The initial investment costs were $501M. This did not include the construction of special test facilities, although affordable methods have been suggested [3][4].

Operational cost for the GTO missions were obtained via two separate models: NAFCOM, NASA's common reference cost estimator and a custom cost model for comparison based on simplified and augmented cost estimates for the Space Shuttle. Using these models, GTO missions have a per mission operational cost of $1.1M and DRA5 is $16.7M.

Revenue Streams: The first NTR configuration will target GTO missions. These missions are high frequency with current rates of 30 addressable missions per year [5]. Extrapolation from the past two decades puts GTO missions at 46 addressable in 2045. Dual launches on the expensive Ariane V are popular for transferring payloads to geosynchronous orbits (GEO). The optimization of the NTR for ferrying in low-Earth orbit (LEO) has shown that the same dual payload can be launched on Atlas or Delta vehicles from 28.5^{o} when couple with the NTR [2]. This would otherwise not be possible. The coupling of an NTR with any existing launch vehicle allows for increased mass margin, which can be sold to the payload for additional revenue. A caveat is that a longer fairing is sometimes necessary. On average (using Ariane V, Proton M, and Atlas V 5xx), $17.74M of additional mass margin is available for purchase. It is assumed that 80% of this additional margin can be sold with 70% of the revenue going towards the NTR.

Robotic Interplanetary The second generation NTR will target robotic interplanetary missions. A survey of existing and future robotic interplanetary missions suggests that there is at least one opportunity per year. The analysis of a payload delivery via direct injection [6] using an NTR of similar specifications was used to arrive at an average revenue generation of $23.9M, with the NTR recovering 90% of this amount.

DRA5 The largest single source of revenue for any NTR mission will come from a DRA5 mission plan. These missions will require three nuclear engines for each vehicle. Only 6 reusable NTRs are needed for the DRA5 as opposed to 9 single use NTRs. NTRs will save 9 heavy lift launch vehicles during DRA5. At a low price of $6000/kg this results in a total savings of $7.02B. It is reasonable to assume that a company producing the NTR will receive 40% of the savings and payments starting 5 years prior to delivery.

Results: A full mission timeline for the application of NTRs is shown in Fig.1, DRA timeline in Fig.2 and the resulting cumulative ROI in Fig.3. Three key scenarios given in Fig.3 show that if DRA5 proceeds with first launch in 2033 then investment costs will be recovered by 2030, which hits the goal of 20% ROI. A delay in DRA5 to 2037 will delay total recovery of investment until 2034. Lastly, if DRA5 is canceled, the total investment can be recovered, but not until 2045 or later. The earlier date is accomplished by assuming that a corporation, such as Aerojet Rocketdyne, will reap secondary benefits from GTO NTRs by selling additional conventional liquid engines for launchers like Atlas V or Delta IV.

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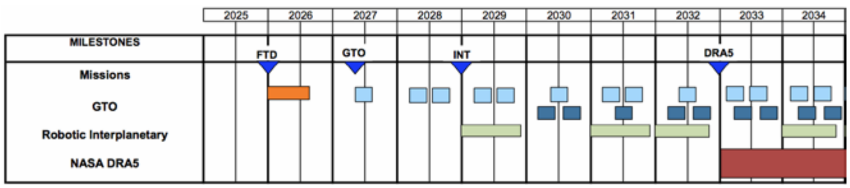

Fig.1 Mission Timeline for Evolvable NTR

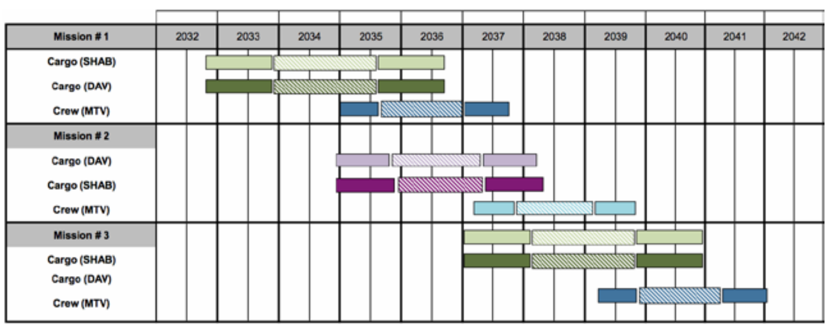

Fig.2 DRA5 Timeline and Color Coded NTR Schedule

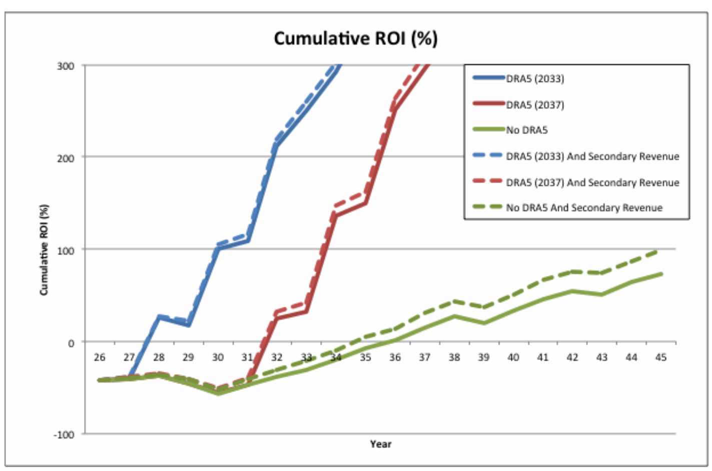

Fig.3 Cumulative Return on Investment for 6 Scenarios