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To Mars and Beyond with Nuclear Power -
Design Concept of Korea Advanced Nuclear Thermal Engine Rocket

Seung Hyun Nam*, Soon Heung Chang

Dept, Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology
373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea
*Corresponding author: rashkid@kaist.ac.kr

1. Introduction

Republic of Korea (ROK) launched successfully a two-stage NARO rocket carrying a research satellite, a first for a space program Jan. 30, 2013. With this launch, ROK became the 11th country to put a satellite into space with a rocket developed by itself. The President Park of ROK has also expressed support for space program promotion, praising the success of NARO as evidence of a positive outlook. These events hint a strong signal that ROK's space program will be accelerated by the national eager desire. In this national eager desire for space program, the policymakers and the aerospace engineers need to pay attention to the advanced nuclear technology of ROK that is set to a major world nuclear energy country, even exporting the technology. The space nuclear application is a very much attractive option because its energy density is the most enormous among available energy sources in space.

This paper presents the design concept of Korea Advanced Nuclear Thermal Engine Rocket (KANuTER) that is one of the advanced nuclear thermal rocket engine developing in Korea Advanced Institute of Science and Technology (KAIST) for space application.

2. Why Nuclear Thermal Propulsion in Space?

2.1 General Principle of Nuclear Thermal Propulsion

Nuclear Thermal Rocket (NTR) depicted in Fig. 1 conducts nuclear fission similar to those safely employed in nuclear power plants and propulsion ships. The enormous nuclear energy of NTR is used to heat a single low molecular weight H_2 propellant (up to 3,000 K) in Extremely High Temperature Gas cooled Reactor (EHTGR) and then accelerate it through a thermodynamic nozzle in same way that Chemical Rockets (CRs) do.

Essentially no radiation shall be released from NTR at the time of launch in the Earth's atmosphere because it is not used to lift off the Earth. The operation from the Earth surface to Low Earth Orbit (LEO: 185 km) is in charge of conventional CR carrying NTR. And then NTR starts up from LEO to deep space destination.

2.2 Advantages of Nuclear Thermal Propulsion

Nuclear propulsion and its auxiliary power are indispensable in exploring and exploiting deep space. The performance of NTR is considered to be over twice more efficient than that of conventional CR. NTR can possibly achieve as high as 1,000 s of specific impulse (I_{sp}) representing the ratio of thrust over propellant consumption like "miles per gallon", as compared to only 425 s of the best CR. Thereupon NTR can achieve longer space missions at a lower cost due to the reduction in propellant requirement (more than three times). If one reflects on the mission to Mars, the NTR would reduce the round trip time to less than 300 days, instead of over 600 days with CR by the same amount of propellant [1].

In addition, NTR technology has already been set up, successfully tested, and well-endowed by the U.S. and the former U.S.S.R. since the 1950s although it has been unknown to the public. It is simpler in overall concept and could be applicable with contemporary vehicles [2].

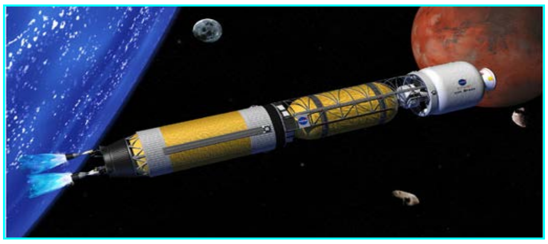

Fig. 1. NTR Crew Transfer Vehicle taken from NASA Homepage

3. Nuclear Thermal Rocket Applications

The first attractive application is manned or unmanned solar system exploration to Mars or beyond. It is largely because NTR is more reliable and flexible for long distance space mission at a lower cost than CR [3].

The second shall be transportation of International Space Station (ISS). Using NTRs the ISS can be placed into a lunar cycle orbit for lunar exploitation [4].

Also, NTR appears particularly attractive for carrying out missions to investigate threats or intercept of Near Earth Objects (NEOs), whether asteroids or meteoroids. NTR enables flight velocities over 2 times those achievable with CR, allowing interaction with a potential NEOs threat at much shorter time and greater range [5].

4. KANuTER Design Concept

KANuTER is an advanced ultra small and compact bi-modal NTR engine derived from the recent 3rd generation engines like Thermal Engine Rocket Adventurer (TERA) of Seoul National University in ROK [6], Square Lattice HoneyComb (SLHC) NTR engine of Florida University [7] and bi-modal MIniature ReacTor EnginE (MITEE) of Brookhaven National Lab. in USA [4].

It consists mainly of an EHTGR utilizing H_2 propellant (coolant), a propulsion system housing turbo-pump assembly, multi-nozzle assembly, flight control, propellant management, thrust vector control, etc., and an electricity generation system as shown in Fig. 2-A.

4.1 Fuel Element

Each fuel element comprises a high strength & thermal resist fuel assembly, moderators (Pyrotic Graphite: PG, ^{7}LiH), a pressure tube (Be), a top reflector (^{7}LiH) and a small nozzle (PG) as a very compact design as presented in Fig 2-A & B. The fuel assembly is fabricated of 93% enriched 1 ~ 2 mm (U,Zr,Nb)C wafers (3,800 K melting point) in 30% voided Square Lattice Honeycomb (SLHC) geometry [7]. The H_2 propellant passes through these voided square flow channels in fuel assembly. In this design the SLHC fuel design satisfies not only the required power density, but also better durability & fabricability at lower cost. The materials of moderator and reflector have very good neutronic characteristics and lightweight. The multiple small nozzles and the Be moderator pressure tubes of fuel elements substitute a conventional heavy nozzle and a pressure vessel [4]. These compact modifications will tend to decrease largely the total mass of KANuTER.

4.2 Core & Reflector

EHTGR is a bi-modal type hybrid reactor whose core has a total of 37 compact fuel elements for propulsion and electricity generation. The fuel elements are arranged in hexagonal prisms (pitch/diameter: 2) in the core and surrounded by outer reflector (^{7}LiH & Be layers). The plenums between fuel elements and reflector are filled with supercritical H_2 flowing down from turbo-pump in order to moderate neutron, cool the components, and then be fed into fuel elements. In fuel elements the H_2 flows up through a ring plenum between moderators for heatsink and then comes into turbines to transfer power for propellant pumping and electricity generation. After the power conversion, the H_2 streams down into SLHC fuel assemblies in fuel elements again for being heated up to 3,000 K and then expanded out tremendously through multi nozzles for propulsion. In order to control reactor, 6 cylindrical rotating control drums comprising boron partially are placed in radial reflector symmetrically. Figs. 2-A & C shows schematic view of EHTGR.

4.3 Design Parameters & advantages

The reference design parameters are 100 MW_{th} power, 21,000 N thrust, 1,000 s specific impulse, ~ 15 kW_e consistent electricity generation, 50 cm × 50 cm reactor diameter & height, and 210 kg engine mass including a reactor and a propulsion system. Thereupon KANuTER has advantages over higher efficient & long burn time, bi-modal capability (propulsion & electricity generation), compact & lightweight, simpler & easier manufacturability than NERVA prototype engines of 850 s and 11 metric tons in the 1960s [2] and also conventional CR engines.

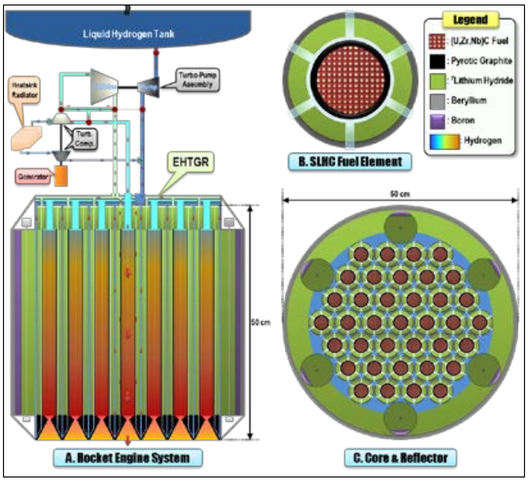

Fig. 2. Schematic View of KANuTER

5. Conclusion

Solar system exploration relying on CRs suffers from long trip time and high cost. In this regard, nuclear propulsion is a very attractive option for that because of higher performance and already demonstrated technology.

Although ROK was a late entrant into elite global space club, its prospect as a space racer is very bright because of the national eager desire and its advanced technology. Especially it is greatly meaningful that ROK has potential capability to launch its nuclear technology into space as a global nuclear energy leader and a soaring space adventurer. In this regard, KANuTER will be a kind of bridgehead for Korean space nuclear application.

In future, KANuTER's engine cycle and thermo-hydrodynamic analysis will be made to validate design performance and adjust design parameters of it.

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