Overview of the application of nuclear technology to propulsion and space nuclear power systems

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1. Introduction

After regime change of Korea, governmental energy policy was modified. Nuclear energy has been used to be considered an essential base load for national energy mix. However, it has been reconsidered along with renewable energy expansion policy. As renewable energy policy promoted, nuclear power generation faded out. Consequentially, capacity factor of nuclear power plants (NPPs) are dropped around 50 percent (55.32% based on data of 2018.03.19 [1]). It is the lowest rate among over 10 years' operation. (**Figure 1**)

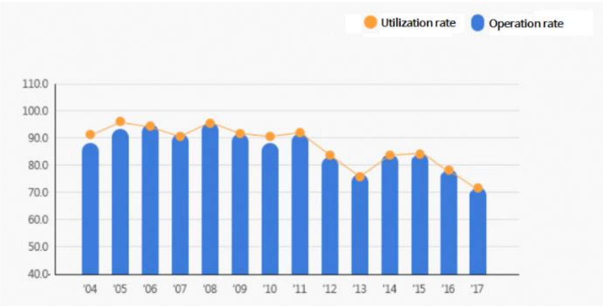

Figure 1 Usage rate and operation rate of NPPs ('04~'17) [1]

Since academia, industry and research institute of nuclear energy has been highly dependent on operation of NPPs, they have been influenced by low operation rate. The number of new students of nuclear engineering department of university decreased and the scale of government funding for research was reduced. Although a nuclear community suffers from stagnation, new governmental energy policy can be a new opportunity.

From now on, the goal of nuclear R&D in Korea was concentrated on designing better plant. The major research topics were enhancing safety level of plant and reducing cost. Some other researches related to an application of radioisotope were also supported but their portions were small.

However, this situation is generally happened for any country who started to use nuclear energy. When the USA started to operate NPPs, they concentrated on developing new type of plant. Middle of 1960s to 1970s was a booming season for the nuclear industry. Several NPPs were constructed and, research and development were actively done by government. But their energy policy had been changed because of the Three Mile Island accident. Several national laboratories such as Argonne National Laboratory (ANL) and Idaho National Laboratory were affected by governmental policy and they changed their R&D strategy [2].

They diversified their research area. For example, ANL changed their main item from nuclear reactor safety research to self-protected plant, environment and life science. Also, they added their role to support a research of other institute by sharing their research facility. Through these transformation of research item of the institution, they have survived to keep their research competence.

Now, Korea is in similar situation. Because of the Fukushima accident, public opinion about NPPs have been deteriorated and governmental nuclear R&D fund was reduced. Therefore, it is the timing for preparing next step. The authors suggest space nuclear technology as a new R&D item. Several countries and institutions are struggling to develop an applied technology for space. Here, not only basic concepts of these technologies but also some state-of-the-art technologies will be introduced. However, to establish space nuclear policy, local situation of the country should be considered. At the end of this article, policy environment of Korea and the USA, who is the leader of this field, will be compared to develop local space nuclear policy.

2. Overview of space nuclear technologies

Since nuclear energy has a high energy density comparing with other energy sources, volume of nuclear-powered system is relatively smaller than those of other power systems having similar power level. In addition, it can provide high power which can contribute to short voyage time. It is also not affected by condition of outer system unlike solar power which is usually considered primary energy source for space mission. Based on these advantages of nuclear energy, there are two major applications, the nuclear propulsion systems and the nuclear power systems.

2.1. Nuclear propulsion systems

Nuclear propulsion systems are propulsion designs using nuclear energy. The research goals of these systems are manned mission, deep space investigation, outer space voyage, etc. which are hard to be achieved by existing energy sources such as chemical and solar power systems. There are two major ways for energy usage from nuclear. The first one is using a thermal energy from nuclear to gain thrust by heating propellant such as hydrogen. The second way is generating electricity from small reactor for driving engine. It also has two ways: To ionize particles such as Xe and Ar and to make plasma and accelerate plasma for obtaining thrust.

2.1.1. Nuclear thermal rocket.

Nuclear thermal rocket uses heat from reactor to expand propellant for making thrust. Hydrogen is usually used as propellant because it is the lightest material which can be a major advantage to make maximum thrust. This is the initial and well-developed technology for nuclear propulsion. There were various projects to make nuclear thermal rocket in the USA (**Table 1**). NASA has plan to send a spacecraft which is propelled by nuclear thermal energy to the Mars until 2033. For this mission, NASA and other cooperators are developing related technologies to complete the nuclear thermal rocket.

Table 1 The major projects to develop nuclear thermal rockets

Names of projects	Period	Major managing research institutes	Major outcomes
Project Rover	1955-1968	Atomic energy commission (AEC) & NASA	KIWI, Phoebus, Pewee, etc.
Nerva	1959-1973	SNPO & Westinghouse	NERVA NRX, NERVA XE, etc.
Copernicus	-2033	NASA	(TBC)

The major obstacle of development of nuclear thermal rocket is fuel and material developments because the system should withstand very high temperature of hydrogen gas. Therefore, their current research topics are concentrated on investigation of thermal effect on fuel and system material [3].

2.1.2. Nuclear electric rocket.

Nuclear electric rocket has two types which are the ion thrust engine and the plasma ion engine. Two types are similar that uses electricity from reactor to ionize particles. These engine types are very stable with high fuel efficiency. Although they have low thrust, it does not matter in space because it does not have friction of air. Also, since they consumes large amount of electricity to ionize particles, using nuclear energy is a good option for these type of engine.

Especially, the plasma ion engine is the most advanced technology for propulsion. It is a kind of ion thrust engine but it can raise energy of particles to very high levels over several million Celsius. Therefore, it can make very high velocity for spacecraft. NASA is developing VASIMR which is a plasma ion engine for MARS mission. They started this project on 1983 to reach the MARS within 39 days. It is still developing and it can realize the dream of MARS travel.

2.2. Nuclear power systems

2.2.1. Radioisotope power systems.

Radioisotope power systems are supply both electricity and heat to system from radioisotope. The main item is radioisotope thermoelectric generators (RTGs). They usually use Pu-238 as a heat source. Then, they convert heat to electricity using thermocouple devices [4]. RTGs have been used for various space mission as an essential energy source accordance along with solar panels. Since it has long life time and less environmental restricts, it is used for long-term missions. Especially, 100We MMRTG is suggested for long-term moon investigation mission rather than solar energy usage.

These days, RTGs such as multi-mission RTGs (MMRTGs), eMMRTGs and dynamic RTGs are continuously being developed. The major research institutes such as the jet propulsion laboratory and the Oak Ridge National Laboratory study to enhance efficiency of RTG by experiments and simulations about fuel and material. In addition, UK is investigating the capability of Am-241 as a fuel of RTG with NASA.

2.2.2. Fission power systems.

Since fission power systems (FPSs) have better electricity supply capability, small fission reactors are suggested for specific missions. One fission reactor has same ability as 28 MMRTG has [3]. For example, the Kilopower project by NASA is to develop reactor and engine for supplying surface power. 1kWe full scale surface reactor has been tested by NASA. Although it has security, political and budget issues, it is an attractive option which can be used as a bridge technology for developing propulsion system for the MARS mission.

Current surface reactors are powered by high enriched fissile material due to its high efficiency. Therefore, all of invented reactor types are based on this type of fuel. However, threshold of research will be lower if low enriched material is used as fuel. Also, it will give a chance for space industry to develop commercial space reactors.

3. Policy implications

From now on, overall space nuclear technologies are reviewed. To establish space nuclear policy in Korea, policy environment should be assessed first. In this part, several space nuclear policies will be suggested based on the comparisons between Korea and other leading countries.

3.1. Nuclear propulsion systems

3.1.1. Absence of rocket technology.

Unlike the USA who has well developed and high level technologies for space engineering, Korea even does not have rocket technology which is a basis of development of nuclear rocket. In common, the countries who are developing nuclear rocket have rocket technology which should be obtained in advance to develop and use nuclear rocket. Nowadays, although KARI is developing a rocket technology for moon investigation, it will take very long time to develop nuclear rocket. Therefore, to cooperate with other countries who already have rocket technology can be a practical option if it is possible to resolve an international non-proliferation issue.

3.1.2. Prohibited usage of HEU fuel.

There are only few countries who has permitted to use HEU fuel without any restriction. These countries are freely developing various forms of fuels for various objectives. Not only national research institutions but also academia and industry are proceeding researches using HEU. However, Korea has prohibited to use HEU as a second mover of nuclear industry and has utilize only LEU for generation of electricity.

To make high thrust of nuclear rocket, HEU is essential. Therefore, there are two options to develop nuclear rocket: Co-work with other leading countries or development of alternative technology using LEU. Currently, some researchers are struggling to develop LEU fueled technology because it is easy to handle. If Korea decides to develop LEU fuel, these researches can be reference studies.

3.2. Nuclear power systems

To send a spacecraft, the lighter one is the better one. Therefore, the total weight of spacecraft should be reduced by reducing the weight of engine systems. Hence, Korea should concentrate on developing micro space reactor with high power density. Other countries also trying to make small reactor by applying new type of cycles and engines such as Brayton cycle and Stirling engine. Since Korea has high technological level of heat transfer system, development of efficient and small system is highly probable.

In addition, space reactor with LEU fuel also can be a new and attractive research item since Korea has good LEU reactor technology. The only difference between ground reactor and space reactor is neutron control. Because neutron ejection from space reactor do not need to be controlled, it is possible to design based on current ground reactor technology. However, since it has higher temperature comparing with that of ground reactor, space reactor should be developed from VHTR technology. Therefore, developing VHTR technology can be beneficial to develop space reactor in the future.

4. Conclusions

Space nuclear field might be very attractive research item since developing large NPPs for electricity generation is currently losing driving force. However, it has a restriction to develop space nuclear technologies solely. From the examples of ESA and UK, it is important to make MOU with the leading countries such as the USA and Russia. With transferred technologies and Korean reactor technology, Korea can take our own region in space nuclear field.

REFERENCES

[1] KHNP, khnp.kr [Accessed: 2018.03.19]
[2] Argonne National Laboratory, 1946-96, Jack M.Holl, University of Illinois press, Urbana and Chicago, 1997.
[3] Presentation materials of NETS-2018, Held by ANS, Las Vegas.
[4] NASA, rps.nasa.gov [Accessed: 2018.03.19]