A Preliminary Core Design of the Space Nuclear Reactor

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1. Introduction

Space reactors require a reliable, high power, long term energy source for the long dark period where the sunlight density decreased in the space. Nuclear power reactors satisfy all of the needs of the spacecraft and they also take advantage high energy with low weight, which is very important for the spacecraft operation such as launching and taking off. Los Alamos national laboratory(LANL) is the first developer to use uranium in space reactors instead of plutonium which used for the first time by NASA [1],[2].

In this paper, we proposed a new concept of the space reactor based on the thorium fuel with helium gas cooling. Some design parameters are proposed including neutron distribution and spectrum by using MCNP6.1[3] code system. In Addition, a depletion analysis is carried out to estimate the life cycle of the suggested space reactor.

2. Nuclear Design of space reactor

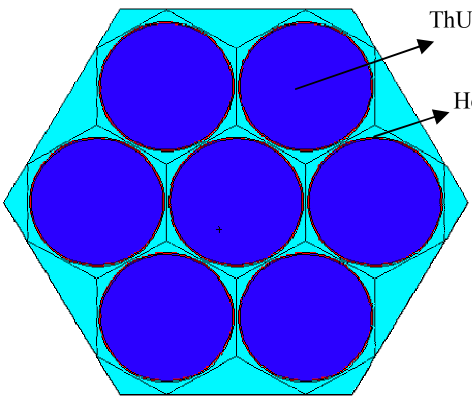


Fig. 1. Fuel assembly configuration

The fuel rod is in the shape of circular cylinder and 7 fuel rods are composed of a hexagonal fuel assembly. A metal fuel is considered such as ThUZrH ($^{232}Th^{233}U$~90wt: $^{40}Zr^{1}H$~10wt). The hydrogen content is 0.01 wt% for enhanced epithermal neutron spectrum.

Configuration of a fuel assembly for the space reactor is depicted in Fig. 1. The core is composed of 49 FAs with 6 heat pipes as shown in Fig 2. Table 1 provides design characteristics of the proposed space reactor. The designed core power is about 100 MWth, which is equivalent to about 30 MWe. It is adequate for the propulsion and travel.

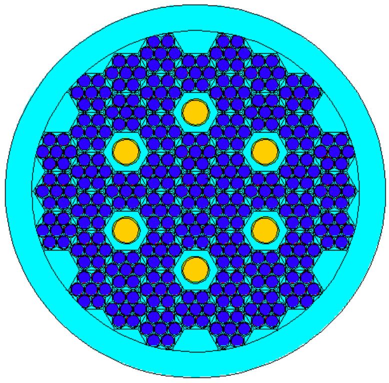


Fig. 2. Horizontal configuration of the space reactor core.

Table1.Nuclear design characteristics of the space reactor

Nuclear Design	*Value*
Reactor Power	100 MWth
Fuel type/FA array	ThUZrH / Hexagonal
# of FRs per FA	7 FRs
# of FAs in core	49 FAs
Coolant material	Helium Gas
Core diameter	24.2 cm

MCNP6.1 code is used for the core design and depletion analysis, which provides accurate solutions and is very flexible for 3-dimenstional modeling.[3] For the analysis with MCNP6.1, the KCODE card is used with ENDF/B-VII.1 libraries. In the calculation, 10,000 neutron histories are used to run for 250 active cycles with inactive 50 cycles.

3. Result and discussion

Neutron distribution of the space reactor is shown in the three different energy ranges such as thermal, epithermal and fast energies as shown in Fig. 3. It shows that the spectrum is dominated in the fast energy region. Fig. 4 depicts the neutron spectrum, which shows the typical fast spectrum.

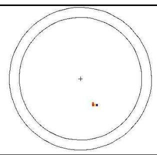
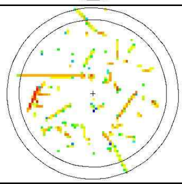
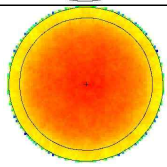
Energy Range	$ThUZrH_{0.01}$
Thermal energy (0 ~ 0.625 eV)	
Epithermal Energy (0.625 eV ~ 1 MeV)	
Fast Energy (1 MeV ~ 10 MeV)	

Fig. 3. Neutron distribution for the space reactor

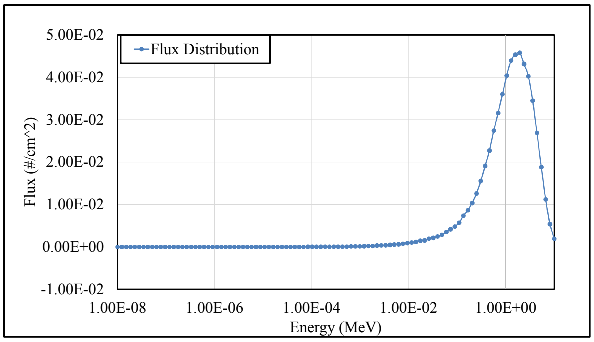


Fig. 4. Neutron spectrum of the space reactor in the fuel region.

The depletion calculation of the space reactor is performed by using the BURN card, which is combined with CINDER depletion module. It is estimated that about 5 years cycle is possible with this design as shown in Fig. 5. And it is expected to increase upto 30 years by changing the composition of U-233 contents and core configuration.

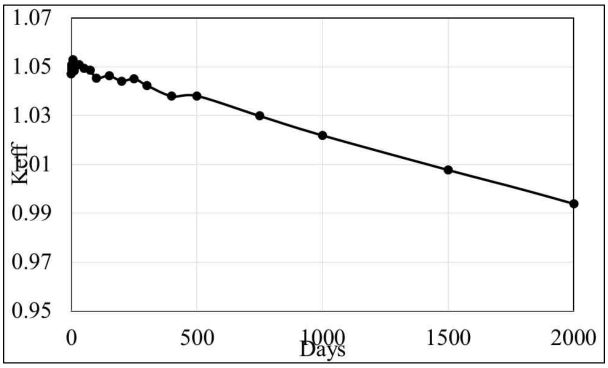


Fig. 5. Depletion analysis of the space reactor

4. Conclusions

A space reactor is proposed based on the thorium fuel. Some preliminary results are shown including neutron spectrum and depletion analysis. It is under design and some data will be updated to ensure sufficiently long reactor cycle and better core performances including advanced control systems.

REFERENCES

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[2] IAEA," The Role of Nuclear Power and Nuclear Propulsion in the Peaceful Exploration of Space" , International Atomic Energy Agency - IAEA, Pub 1197 (2005).

[3] Pelowitz, Denise B. "MCNP6 user' s manual version 1.0." Vol. LA-CP-13-00634, Rev. 0 (2013).