Nuclear Conceptual Design for a Micro, Autonomous, and Transportable Energy generator (MATE)

Chul Gyo Seo*, Chan Bock Lee, Sung-Deok Hong, Chungchan Lee, Wang-Kee In, and Dae-Hyun Hwang
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Deajeon, 34057, Korea
**Corresponding author: cgseo@kaeri.re.kr*

1. Introduction

The role of nuclear power reactors is very important in maintaining a clean environment, and the active development of small reactors these days is very encouraging. In order to utilize uranium resources more efficiently and widely, it is necessary to develop micro reactors that are easy to move around. This paper presents recent achievements in the development of such a reactor.

2. Design Concepts

2.1 MATE

MATE(Micro, Autonomous, and Transportable Energy generator) should be very safe for easy use, and the design goal is for reactors with the following requirements [1]:

1) It should have intrinsic safety that can be operated in unattended mode, and the reactor control should be simple.
2) The weight and volume are not large, so it should be easily moved to the place where it is needed and installed.
3) It aims to provide 0.1~10 MW of electricity.
4) Basically, verified components are used, and performance verification should be easy if necessary.
5) As a modular structure, it must be able to be manufactured and supplied at the factory.

A nuclear reactor capable of natural circulation with an output of 0.1 MWe was selected as the first reactor. To stably generate electricity with small output, the adoption of the Stirling engine is being considered first.

2.2 Design Concepts

While safety is the most important, we aim for a nuclear reactor that the operator does not have to monitor all the time. TRIGA fuel was selected for a reactor with intrinsic safety. TRIGA reactor is known as a nuclear reactor that has been certified by the US NRC as having inherent safety in unattended mode. The MATE core consists of a number of nuclear fuels and moderator rods as shown in Fig. 1. Na was filled to keep the temperature of the MATE fuel low.

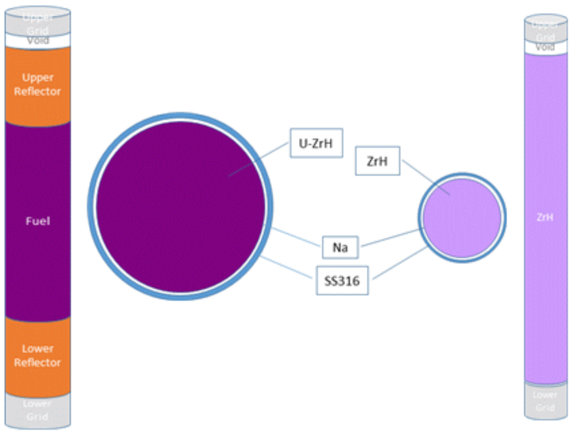

Fig. 1. Conceptual Drawing of Fuel Rod and Moderator Rod

NaK was chosen as the coolant for operation over a wide temperature range, with a melting point of -12.6 ℃ and a boiling point of 785 ℃. To be advantageous for movement, the control device adopts a cylindrical control drum(CD) and is positioned on the reflector outside the core. Fig. 2 shows the conceptual drawing of the core.

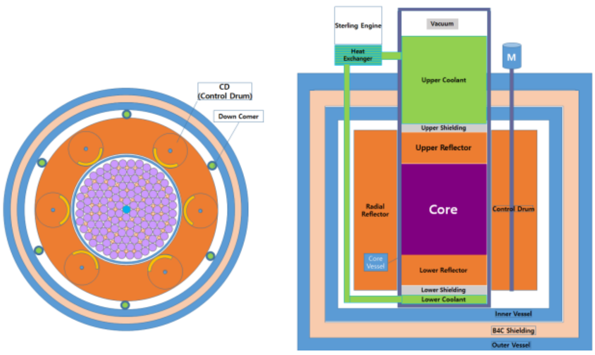

Fig. 2. Conceptual Drawing of the Core

3. Core Design

In this section, design concepts were presented in the field of nuclear design. Calculated results were obtained with McCARD[3] using ENDF-B/VIII.0.

A reactor with a fission power of 0.4 MW was designed to obtain an electrical output of 0.1 MW using Stirling engine. The nuclear fuel uses low-enriched uranium with less than 20% enrichment and is U-ZrH1.6 fuel rods. The core consists of 126 fuel rods and 54 moderator rods. To facilitate reactor control, erbium was incorporated into the fuel as a burnable absorber. It is possible to control the reactivity change within 5 mk during the 20-year operation period, and the calculation results are shown in Fig. 3.

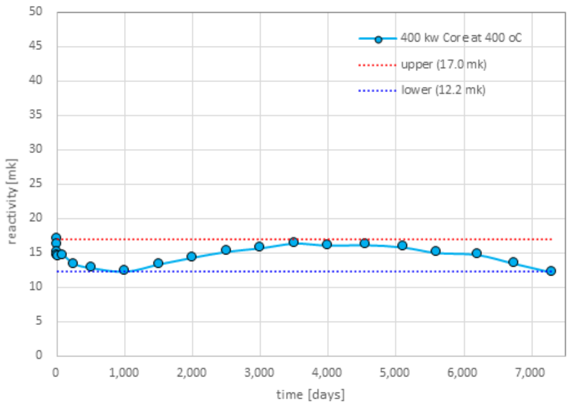

Fig. 3. Reactivity Variation Over Lifetime

There are 6 control drums and the neutron absorbing material is B_4C. As shown in Table 1, it was confirmed that the excess reactivity was 37.8 mk and the shutdown margin was 17.5 mk, which satisfies the limit, 10.0 mk.

Table 1. Core Reactivities at Several Core Status [mk]

Core Status	All CDs Out	All CDs In	(N-1) CDs In
Reactivity	37.8	-29.8	**-17.5**

TRIGA fuel has a large Doppler effect, which gives the reactor inherent safety. As the core temperature increases, the excess reactivity decreases due to thermal neutron spectrum hardening effect, Doppler broadening of resonances, and neutron leakage from the core. The MATE core is evaluated to become subcritical when the temperature exceeds 700 ℃, as shown in Fig. 4.

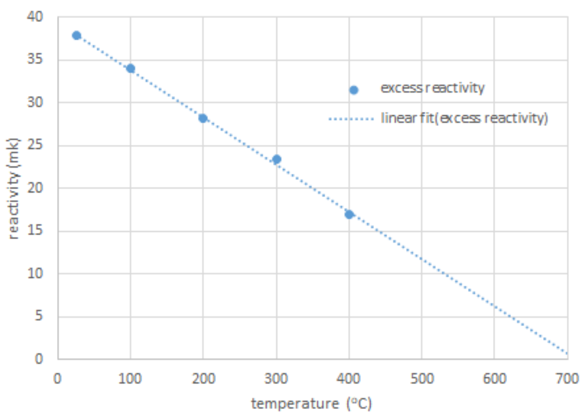

Fig. 4. Variation of core excess reactivity with temperature

As shown in Fig. 3, the core reactivity was kept above 12 mk during the lifetime for conservative design considering the reactivity effect by thermal expansion [4]. If the reactivity effect by thermal expansion is applied, the maximum core temperature will be lowered.

The MATE core is a new concept reactor in which the temperature of the reactor does not exceed the maximum design temperature even when the controls fail or natural convection cooling fails. The reactor concept of inherent safety is realized with a combination of TRIGA fuel, metal coolant, and burnable absorber, which are proven technologies.

4. Conclusions

Nuclear conceptual design for a 0.1 MWe micro reactor was performed and it is confirmed that this reactor could be built with core calculations. Based on this research, the conceptual design of reactors on a large scale is scheduled to be studied. The nuclear reactor presented in this paper is confirmed to have inherent safety and is expected to be used for the safe and wide utilization of uranium resources.

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