A New Fuel Concept for the HANARO Research Reactor

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1. Introduction

The development of a new fuel material for research reactors has been focused on the U-Mo dispersion fuel using uranium-molybdenum metallic alloy as fuel particles. The U-Mo dispersion fuel has some problems from several irradiation tests, which are caused by the reaction between U-Mo particles and Al matrix. Some new concepts that can minimize the reaction are needed. In this paper, we present a new fuel concept for rod type fuel such as HANARO fuel, nuclear and heat transfer analysis are presented.

2. A New Fuel Concept

U-Mo fuel is easy to reprocess and manufacture as high density fuel, which give us a longer cycle length and less spent fuels. U-Mo metallic alloys dispersed in an aluminum matrix have shown promise in several irradiation tests but there remain some questions about irradiation performance. These questions focus on the degree and nature of the chemical interaction between the fuel particles and the aluminum. It is thought that in the right circumstances a detrimental phase forms at the interface between the pure aluminum matrix and the fuel power [1]. The interaction occurs actively at high power operation and is rapidly increasing at higher fuel temperature. U-Mo dispersion fuel considers small silicon additions to the matrix material to overcome this phenomenon. Several other alloys are being considered as matrix replacements for pure aluminum. The matrix materials to reduce the interaction give the monolithic fuel its benefit, also. The monolithic fuel has a much lower surface area than the dispersion fuel leading to less reaction and a much higher uranium loading. A disadvantage of the monolithic fuel over the dispersion fuel is a low thermal conductivity. A new concept is required to overcome this disadvantage and presented at this paper. The cross-sectional view of a new rod type fuel such as HANARO fuel is shown as Fig. 1. We name this new fuel the multi-core rod. The concept of the multi-core rod is to divide a heat source into multiple sources for lowering maximum and surface temperature of fuel. At the same heat flux at cladding, the heat from the multi-core with larger cooling surface and shorter heat transfer distance can be well transferred to the coolant through Al matrix with the larger thermal conductivity.

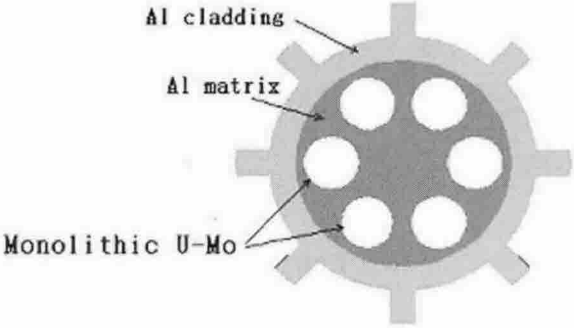


Fig. 1 Cross-sectional view of the multi-core rod

3. Nuclear Analysis

Core conversion using high density U-Mo fuel is being considered to enhance the utilization of HANARO. New fuel rod should be designed to be proper to the core conversion. Minimal core conversion considered maintains fuel shape and only changes fuel density [2]. Maximum density of U-Mo fuel without any burnable poison is limited below 6.0 gU/cc to use the same reactivity control unit of HANARO.

HANARO fuel consists of two different fuel rods to get the uniform power distribution, in which fuel rods at inner ring have large density compared to the rods at outer ring. This concept should be used at the design of the new fuel. The density of fuel rods at inner ring is set to 6.0 gU/cc and then the density at outer ring will be selected among 3.0, 4.0, 5.0 gU/cc from evaluating LHGR (linear heat generation rate) of all fuel rods loaded at the full core. The U3Si/Al core is the current HANARO core with 32 fuel assemblies, and U-Mo core has 28 fuel assemblies, in which the number of fuel assembly is reduced to increase the number of irradiation sites. At the less fuel assemblies, uranium loadings of the U-Mo cores are increased to 43, 60, 78%, respectively. The LHGR is summarized at table 1. This table shows that the uranium densities at the inner/outer ring for optimum fuel assembly is 6.0/4.0 gU/cc. The maximum LHGR of the U-Mo core is lower than the LHGR of the current core.

Table 1. LHGR of U3Si/Al and U-Mo core at 30 MW
[(1): R01~R20, (2): CAR1~4, (3): SOR1~4, (4): OR1,2,7,8]

Core	U loading ratio (outer/inner ring)	LHGR max/avg (kW/m)	LHGR ratio (outer/inner ring)
U3Si/Al core (3.15 gU/cc)	0.75	89.4/43.1(1) 110.8/39.7(2) 113.8/58.4(3) 87.6/52.3(4)	1.05(1) 1.23(2) 1.26(3) 1.38(4)
U-Mo core (6.0/3.0 gU/cc)	0.50	101.7/47.7(1) 111.3/57.5(2) 114.1/46.5(3)	0.94(1) 0.87(2) 0.83(3)
U-Mo core (6.0/4.0 gU/cc)	0.67	109.7/47.6(1) 112.1/58.2(2) 111.7/47.2(3)	1.14(1) 1.07(2) 1.02(3)
U-Mo core (6.0/5.0 gU/cc)	0.83	115.3/47.5(1) 118.6/58.9(2) 119.8/47.5(3)	1.31(1) 1.23(2) 1.18(3)

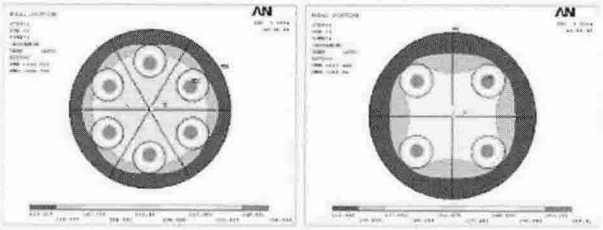
3. Heat Transfer Analysis

Fuel temperature is closely related to LHGR, which is set to 120 kW/m for this analysis. First, temperatures of dispersion fuel with 6.0 gU/cc of 0.635 cm diameter and monolithic fuel with equivalent linear fuel loading are calculated. Simple and conservative assumption without cooling fins is chosen to get analytic solutions, which are temperatures at maximum and surface temperature of fuel. Maximum fuel temperature, LHGR, thermal conductivities, and some physical sizes are related as follows [3]:

$$T_m = \frac{q'}{2\pi}\left(\frac{1}{2k_f} + \frac{\ln\left(1+\dfrac{t}{R}\right)}{k_c} + \frac{1}{(R+t)h}\right) + T_b$$

In this expression, T_m is maximum fuel temperature; q' is LHGR; k_f is the conductivity of fuel; k_c is the conductivity of cladding; t is the thickness of cladding; R is the radius of fuel; h is the heat transfer coefficient; T_b is the temperature of coolant.

Maximum temperature of the dispersion fuel is 214 ℃ and Maximum and fuel surface temperature at the monolithic fuel are 813 and 177 ℃. The surface temperature of the monolithic fuel is lower than the maximum interface temperature of the dispersion, but maximum temperature of the monolithic fuel exceed 600 ℃, which is known as the maximum stable temperature of U-Mo alloy. We expect that the multi-core concept help us overcome this problem. Maximum temperatures of the multi-core rods with 3,4,6 cores are 375, 322, 266 ℃, which are calculated using the ANSYS code [4]. The maximum temperatures of the multi-core rods are reduced dramatically below 600 ℃. Using the same core diameter of the multi-core rod, the 6.0/4.0 gU/cc fuel rods consist of the 4- and 6-core rods. At the same maximum LHGR with the 6-core rod, the maximum temperature of the 4-core rod is 316 ℃. The temperature distributions of the 4-core and 6-core rods are shown at Fig. 2.



6-core rod 4-core rod

Fig. 2Temperaturedistributions of the multi-core rods

4. Conclusion

A new fuel concept of the multi-core rod for the core conversion of HANARO is presented. Optimum densities of inner and outer rods in the fuel assembly are selected as 6.0/4.0 gU/cc. It is found that the new concept could lower maximum and surface temperatures of fuel from the heat transfer analysis. As the concept of the multi-core rod give a promising prospect, the development of the fabrication technology and the irradiation test should be followed.

Acknowledgements

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