Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

A Study on the Thermal-hydraulic Safety Assessment of Irradiation Capsule for Mini-plate Type Fuel using RELAP5

Kyungho Nam [a*], Keenam Choo [a], Mansoon Cho [a], Seongwoo Yang [a]
[a]*Korea Atomic Energy Research Institute, , 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea*
[*]*Corresponding author: khnam@kaeri.re.kr*

1. Introduction

The High-flux Advanced Neutron Application Reactor (HANARO) is an open pool type multi-purpose research reactor with 30MW thermal power located at Korea Atomic Energy Research Institute (KAERI) in Korea [1]. The irradiation capsules have been developed at HANARO for new alloy and fuel developments and the lifetime estimation of Nuclear Power Plants (NPPs). Among the irradiation facilities, the capsule is the most useful device for coping with the various test requirements at HANARO. As shown in Figure 1, there are several vertical test holes such as CT, IR and OR in the core of HANARO. An irradiation capsule is installed in these holes to evaluate the irradiation performance of nuclear fuels and materials at HANARO. The fuel capsule is applicable to research into the irradiation characteristics of fuel pellets and to obtain the in-core performance and the design data of nuclear fuel at HANARO.

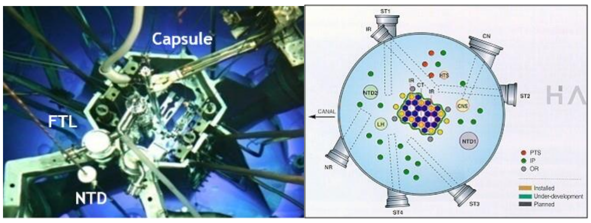

Fig. 1. Core configuration of HANARO reactor

For reliable and safe operation, Limiting Conditions for Operation (LCO) should be ensured. These parameters are listed on table 1 [2]. To assess the safety limitation, thermal margins such as Onset of Nucleate Boiling (ONB) temperature margin and Departure from Nucleate Boiling (DNBR) were estimated for reactor safety and design purposes. Additionally, cladding outer surface, and fuel centerline temperature also were estimated to assure integrity of fuel capsule. In this study, it is considered that the maximum heat flux was determined using RELAP5/MOD3.3 to meet the LCOs for fuel irradiation capsule.

Table I: LCOs for irradiation capsule

Condition	Parameter	Value
Normal	ΔT_{ONB}	3.0
	$T_{fuel\ centerline}$	200
Abnormal	$T_{fuel\ centerline}$	400
	CFHR	1.5

2. Modeling and Initial Condition

2.1 Capsule Geometry

Irradiation capsule is vertically installed on HANARO holes. The irradiation capsule which is considered in this study is designed to irradiate research reactor fuel and this fuel is of the plate type. This fuel plates are double-stacked to load a total of 8 plates as shown in figure 2. As shown in figure 3, each stack has two inner channels and four outer channels. The inner channel is heated from both sides, whereas the outer channel is heated from one side. The thickness of the inner channel is 2.2 mm and outer channel is 2.1 mm.

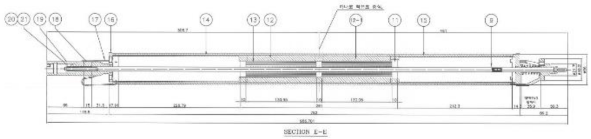

Fig. 2. Schematic diagram of irradiation capsule for plate type fuel

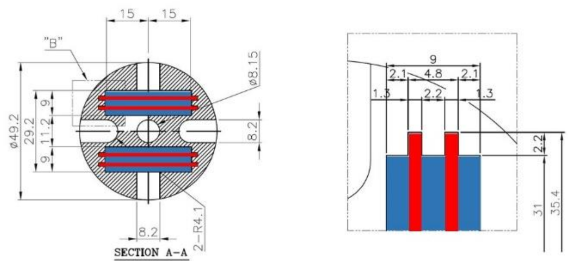

Fig 3. Coolant channel in fuel irradiation capsule (Blue: coolant, Red: U-Mo fuel plate)

The fuel is composed of U-Mo alloy and this fuel plate have a nominal dimension of 1.27×35×130 mm as shown in figure 4. The fuel meat has a thickness of 0.51 mm, width of 27 mm, and length of 75 mm. In this study, It is assumed that the plate material is stainless-steel.

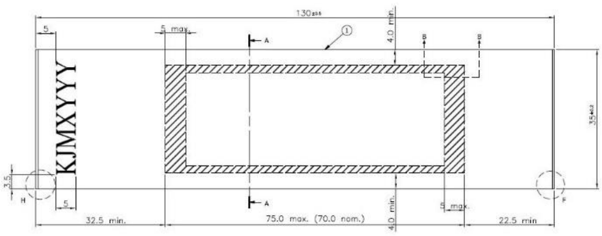

Fig. 4. Dimensions of plate type fuel for irradiation test

2.1 Control volume and Nodalization

The control volume and its boundary are selected as shown in figure 5. The capsule in this study is designed that the coolant flows from bottom inlet to top outlet. And the fuel plate is cooled by this coolant. Therefore, the boundary of a control volume for fluid flow is taken as the physical boundary of the fuel plate part.

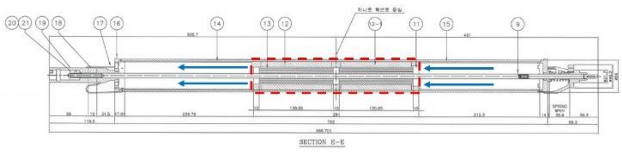

Fig. 5. Control volume, coolant inlet and outlet

Schematic diagram of nodalizing the capsule is shown in figure 6. As show in figure 3, the 6 parts of coolant channel exist in capsule and these flow path is simulated by ‘pipe’ function of RELAP5. Fuel plates are simulated by ‘heat structure’ function of that. The coolant channel is divided so that the ‘Branch’ function is used for simulating the coolant flow path.

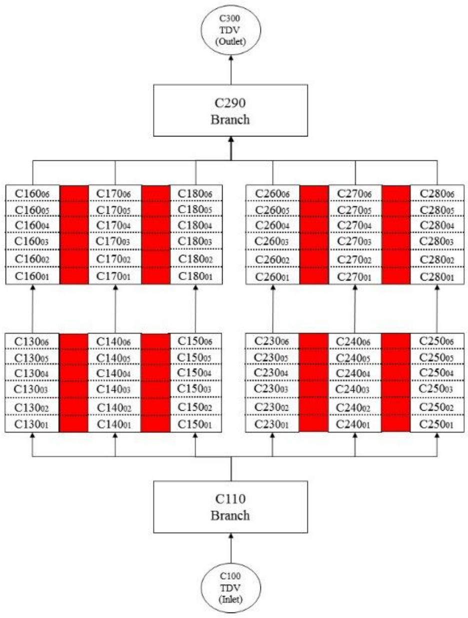

Fig. 6. Modeling of fuel irradiation capsule using RELAP5 (Red: heat structure)

2.2 Initial Condition

2.2.1 Temperature and pressure

The maximum coolant temperature is maintained at 35°C. Additionally, it is conservative that the measurement uncertainty of 0.83°C is considered. Therefore, the primary coolant temperature is assumed 35.85°C (309K). The HANARO reactor operated at atmosphere condition so that initial pressure is 1 atm (101.325 kPa).

2.2.2 Flow rate

As mentioned above, there are several vertical test holes such as CT, OR and IP in the core of HANARO. The fuel plate which is installed in capsule is cooled by upward forced convective flow through coolant channel. Therefore, the flow rate was found to be a dominant factor that determined the LCOs during irradiation. The design flow rate of CT and OR are 19.6 kg/s and 12.7 kg/s, respectively. The section of IP hole is not forced convection by the coolant pump but pool section. The natural convection rate is calculated as 0.83 kg/s [3]. Since these design flow rate through the irradiation capsule are at HANARO is limited, the flow rate through the fuel plate needs to be considered. The indraft of coolant occurs on bottom of capsule and this coolant is divided as inner channel and outer channel, respectively. Therefore, the initial flow rate is calculated using the area ratio.

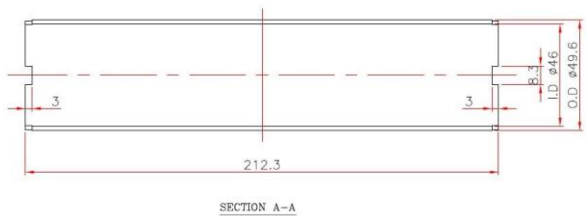

Fig. 7. Inner diameter of designed capsule inlet

As shown in figure 7, the inner diameter of capsule is 46 mm and the cross section area of capsule is $\pi \times (46/2)^2 = 1662\ mm^2$. The coolant is divided into coolant channels and total cross section area of coolant channel is $2 \times \{(2 \times 2.1 \times 30) + (2.2 \times 30)\} = 384\ mm^2$. The coolant flow rate which flows through the coolant channel is same as the total cross section area ratio coolant channel to capsule. Therefore, the input of flow rate is as follows.

CT hole: 19.6 kg/s × (384 / 1662) = 4.53 kg/s
OR hole: 12.6 kg/s × (384 / 1662) = 2.91 kg/s
IP hole: 0.83 kg/s × (384 / 1662) = 0.19 kg/s

3. Results and Discussion

Flow rate is calculated as shown in figure 7. In case of CT hole, outer channel is 0.7357 kg/s and inner channel is 0.7937 kg/s, respectively. In case of OR hole, outer channel is 0.4757 kg/s and inner channel is 0.5135 kg/s, respectively. In case of IP hole, outer channel is 0.0312 kg/s and inner channel is 0.0326 kg/s, respectively. The cross section area of inner channel is larger than outer channel of that. Therefore, the flow rate of inner channel is also higher that outer channel of that.

The heat transfer coefficients in case of CT, OR and IP hole are 32,800 $W/m^2°C$, 23,200 $W/m^2°C$, and 2,750 $W/m^2°C$, respectively.

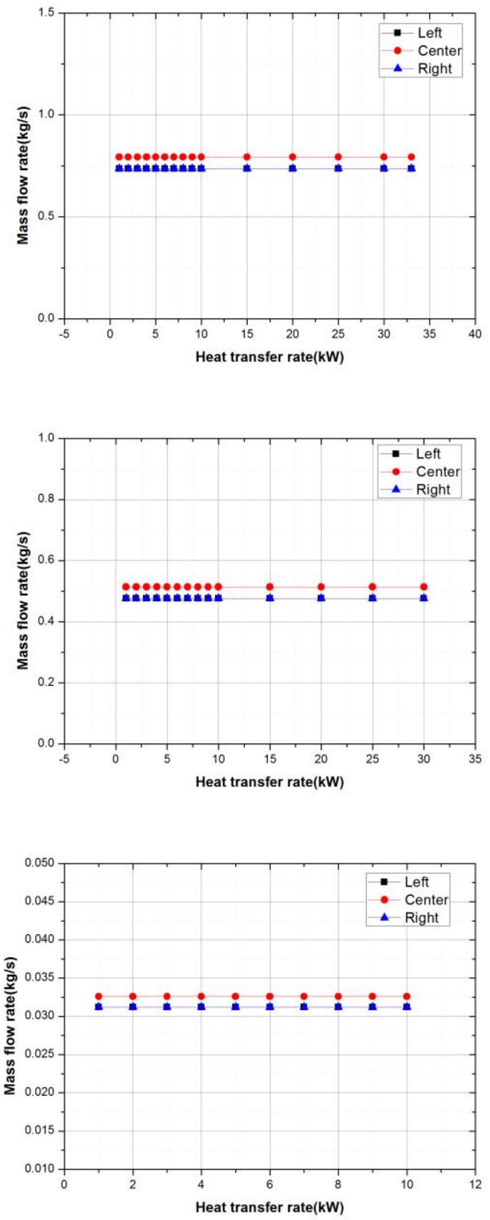

Fig. 7. Flow rate through coolant channel on CT (top), OR (middle), IP (bottom) holes

In case of CT hole, the fuel centerline temperature is 195.88 °C when the heat flux is 43.96 W/cm^2. Considering the fuel centerline temperature margin, this heat flux can be considered as the design limitation on CT hole. In case of OR hole, the fuel centerline temperature is 196.85 °C when the heat flux is 42.58 W/cm^2. Unlike case of CT and OR hole, the fuel cladding temperature on IP hole reaches the ONB limitation before the fuel centerline temperature meets the limitation value. The fuel cladding temperature is 98.22 °C when the heat flux is 13.74 W/cm^2. The CHFR was very high so that it did not have to consider.

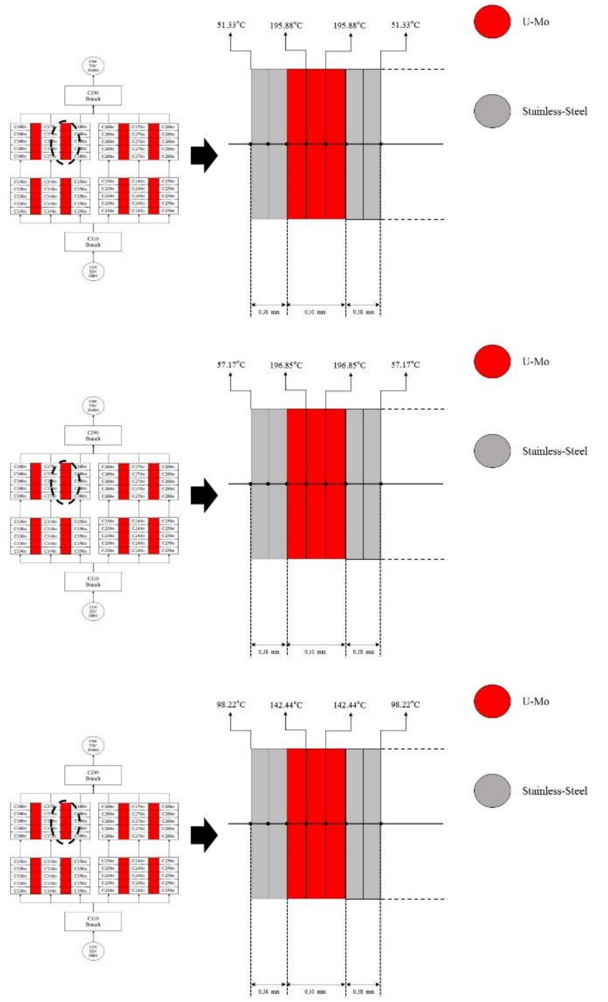

Fig. 8. Fuel cladding and centerline temperature on CT (top), OR (middle), IP (bottom) holes

3. Conclusions

The thermal margin of plate type U-Mo fuel capsule was calculated for safety assessment using thermal-hydraulic system code RELAP5/MOD3.3. The analysis results lead to the following conclusions:

1) Fuel centerline temperature is a key concern during the forced convection.
2) In case of CT and OR hole, heat flux is limited at 43.96 W/cm^2 and 42.58 W/cm^2, respectively.
3) The ONB margin is dominant at low flow rate.
4) Heat flux is limited at 13.74 W/cm^2 in case of IP hole.

These results can be considered to design the irradiation capsule.

REFERENCES

[1] K. N. Choo, M. S. Cho, S. W. Yang, and S. J. Park, Contribution of HANARO Irradiation Technologies to National Nuclear R&D, Nuclear Engineering and Technology, Vol.46, No.4, 2014.

[2] Technical Specification for HANARO, KAERI/TR-3215/2006, 2012.
[3] Development of a Device for a Material Irradiation Test in the OR Test Hole, KAERI/TR-3561/2008, 2008.
[4] RELAP5/MOD3.3 CODE MANUAL, U.S. NRC, 2016.