Selection of Radiometric Monitor and Container for Long-Term Irradiation Test in HANARO

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1. Introduction

Many irradiation tests have been conducted in HANARO since it has been operated. Most of irradiation tests were necessary only short irradiation term less than 1 irradiation cycle because it was possible to achieve intended neutron fluence. However, long-term irradiation test will be needed to evaluate the irradiation performance of future nuclear system, new model research reactor and fusion system materials due to their lots of neutron fluence condition. Recently, irradiation capsule is being designed to test the irradiation performance of the structure and reflector materials of new model research reactor such as graphite, Be(beryllium) and Zircaly-4 more than 4 irradiation cycle in HANARO. Therefore, some expected problems must be checked for long-term irradiation test.

Neutron fluence is important factor that affects the irradiation performance. To evaluate and verify the neutron fluence of the irradiated material in irradiation capsule, the comparison between calculated data by computer code and measured activation data of radiometric monitor have been conducted [1]. Therefore, radiometric monitor must be selected for the exact evaluation of neutron fluence. Especially, for long-term irradiation test, the activity of radiometric monitor can be large, so the handling of one and the measurement of activity can be impossible. In this paper, the candidate radiometric monitor elements were selected and the activity was calculated for candidate radiometric monitors and its container for long-term irradiation test.

2. Methods and Results

2.1 Selection of candidate radiometric monitors

There are many radiometric monitor elements to evaluate the neutron fluence by activation [2]. They are divided 3 regions such as fast, intermediate and thermal region by neutron reaction region. To verify the exact neutron fluence, the radiometric monitors might be properly distributed each region. Because of irradiation and post-irradiation experiment schedule in HANARO and IMEF, the period from the end of irradiation to the disassembly of irradiation capsule requires more than minimum 1 month, so half-life of radiometric monitor must be longer than 5 days. To select the candidate radiometric monitors, above factors were considered and selected elements are shown in table 1. The activity calculation was conducted for the candidate radiometric monitors.

Table 1. Candidate radiometric monitors and its feature

Reaction region	Element	Reaction	Half-life	Feature
Thermal	Co	$Co^{59}(n,\gamma)Co^{60}$	5.27 y	long half-life, high γ energy
	Sc	$Sc^{45}(n,\gamma)Sc^{46}$	85 d	high γ energy
Intermediate	Lu	$Lu^{176}(n,\gamma)Lu^{177}$	6.71 d	large reaction XS
	Ta	$Ta^{181}(n,\gamma)Ta^{182}$	11 d	large reaction XS, high γ energy
	Ag	$Ag^{109}(n,\gamma)Ag^{110m}$	252 d	large reaction XS, high γ energy
	Co	$Co^{59}(n,\gamma)Co^{60}$	5.27 y	long half-life, high γ energy
	Fe	$Fe^{58}(n,\gamma)Fe^{59}$	45.1 d	-
	Sc	$Sc^{45}(n,\gamma)Sc^{46}$	85 d	high γ energy
Fast	Nb	$Nb^{93}(n,n')Nb^{93m}$	13.6 y	-
	Ni	$Ni^{58}(n,p)Co^{58}$	72 d	-
	Fe	$Fe^{54}(n,p)Mn^{54}$	310 d	-
	Ti	$Ti^{46}(n,p)Sc^{46}$	85 d	-
	Cu	$Cu^{63}(n,\alpha)Co^{60}$	5.27 y	-
	Nb	$Nb^{93}(n,2n)Nb^{92m}$	10.15 d	-
	Mn	$Mn^{55}(n,2n)Mn^{54}$	310 d	-

2.2 Activity calculation

2.2.1 Radiometric monitor container

Unlike conventional irradiation test, the radiometric monitor container for the irradiation test of new model research reactor material can be exposed the reactor coolant. The container must prevent the contact between the radiometric monitors and the reactor coolant. Therefore, the shape and the material of the container were changed to satisfy above requirements. Fig. 1 shows the image of design-changed container.

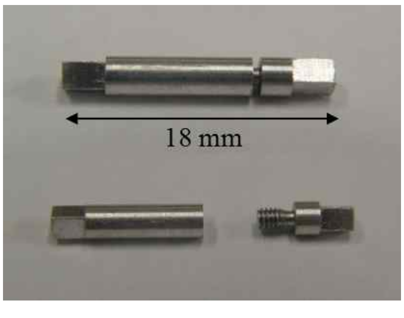

Fig. 1. The image of design-changed container

Al 1060 has been used as conventional container material due to its outstanding irradiation performance. However, its mechanical strength is poor, so sealing integrity can't be guaranteed in coolant flow irradiation capsule. Al 6061 relatively has a good strength than Al 1060. It contains more impurity than Al 1060 that may affect the activation of container. ORIGEN 2.1 code was used for the activity calculation. Calculation condition was conservatively set. Fig.2 shows the activity calculation results by increasing irradiation cycle. The cooling time of 50 days was assumed. Although Al 6061 has higher activity than that of Al 1060, it is much lower than the limit activity of glove box for handling, 1 Ci.

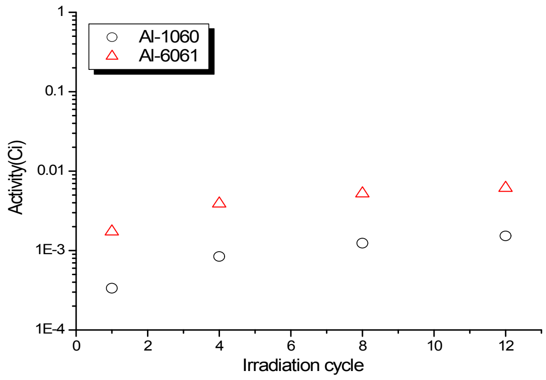

Fig. 2. Calculated activity of container by increasing irradiation cycle (Cooling time : 50 days)

2.2.2 Candidate radiometric monitor

Fe, Ni and Ti wires were used as the radiometric monitor of conventional irradiation test. They could measure the neutron fluence above 1 MeV. However, the neutron fluence above 0.18 MeV must be measured in the irradiation test for the materials of new model research reactor. After the irradiation test, the activity of radiometric monitor was measured from gamma radiation analysis by HPGe detector. The activity of 40 μCi is the limit for measuring gamma radiation. Therefore, activity calculation was conducted for selected candidate radiometric monitor. ORIGEN 2.1 code was used for calculation. Calculation condition was conservatively set. Fig. 3 shows calculated results of candidate radiometric monitor after irradiation by increasing irradiation cycle. The cooling time of 150 days was assumed. The calculated activity of Ag, Co, Sc and Ta monitor showed much higher activity than the limit, 40 μCi. The calculated activity of Ti, Cu and Mn monitor showed lower. The calculated activity of Fe, Lu, Ni and Nb was approached with the limit. It may be satisfied with the limit by extension of cooling time and reducing the mass of monitor.

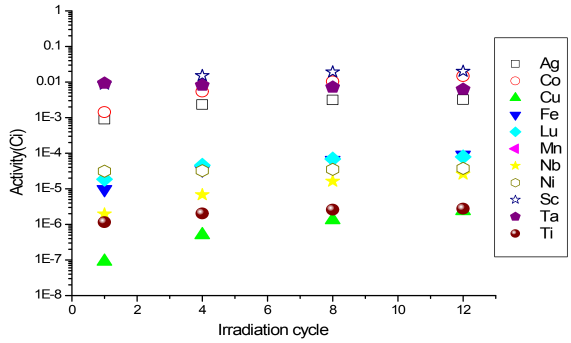

Fig. 3. Calculated activity of candidate radiometric monitor by increasing irradiation cycle (Cooling time : 150 days)

3. Conclusions

Selection of the candidate radiometric monitor and the container and the activity calculation for them were conducted to exactly evaluate the neutron fluence for the long-term irradiation test. The design-changed container would be satisfied with the handling limit of the glove box throughout the activity calculation, so it can be used for the long-term irradiation test. As the results of the activity calculation, Ag, Co, Sc and Ta can't be used for the long-term irradiation test. To use Fe, Lu, Ni and Nb monitors, reducing the mass of monitor and the extension of cooling time may be needed. Ti, Cu and Mn can be used as radiometric monitor.

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