A Feasibility Study for an Irradiation of SiC in the HANARO

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1. Introduction

In order to study the feasibility for an irradiation of SiC in the HANARO, the neutron flux, fluence and the heating rates are estimated for the CT and the OR test holes. The conceptual design of the SiC chamber and the capsule and the rig for an irradiation was completed and the most suitable places were reviewed in the test holes. The range of errors in the estimation of the nuclear characteristics and temperatures were reviewed according to the operation time, the calculation code, the vertical and horizontal positions of the samples.

2. User's requirements

The user's requirements for the SiC irradiation test were as follows. The neutron flux and fluence should be 10^{14}n/cm^2 .s for neutrons higher than the energy level of 0.18MeV and 2x10^{20} n/cm^2. The temperature of the SiC samples during an irradiation is in the range of 55°C~100 °C. The SiC layer should not exceed 5mm in thickness, and the SiC chamber should be made of Al 1100 or Al 6061. The difference for the temperatures and the neutron fluxes should be less than 2 °C and 2 % between any two points in the chamber at any given time. The SiC samples are granules of 40,000 numbers or more. The thermal conductivity of the monolithic SiC is 240 W/m·K. The weight of an individual SiC sample is 3.2 x 10^{-5} gram. The size of an individual sample is 0.2x0.2x0.25 mm, and so the volume is 0.4 cm^3.

3. Neutron flux and fluence

The IP, OR and CT holes were taken into consideration for an estimation of the neutron flux and fluence. The IP holes were excluded from the consideration because the neutron flux is too low. An analysis for the neutron flux was performed at the beginning and the middle of the HANARO operation using the MCNP code for the OR5 and CT hole. The differences for the neutron fluxes were compared according to the operation time and the locations in the horizontal and vertical directions.

The OR5 hole was chosen because the fluence in the CT hole exceeds the required value even by the irradiation of one cycle. Table 1 shows the neutron flux and fluence in the two test holes. The required fluence can be reached in the No 2 or 3 capsules of the Hole 2. It is reached by the operation of 4 cycles in the No 2 capsule and the operation of 3 cycles in the No 3 capsule of the OR5 hole. And the fluence in all position of the Hole 3 exceeds the required value even in one cycle [1].

Table 1 Neutron flux (E>0.18 Mev) and fluence

Test hole	Neutron flux (E>0.18MeV)		Fluence per cycle		Irradiation time
	(x10^{13} n/cm^2.s)		(x10^{19} n/cm^2)		(cycles)
	CR 350mm	CR 450mm	CR 350mm	CR 450mm	
OR	3.01	3.43	5.98	6.82	~3
CT	31.1	31.8	61.8	63.2	~0.32

4. Irradiation devices

The SiC chamber with a cylindrical type fits to the capsule used for the radio-isotope production in the HANARO. If it is installed in the center of the RI capsule and the outer tube is inserted between the SiC chamber and the RI capsule, then the temperature of the SiC samples comes to be in the required range. The SiC chamber, the RI capsule and the rig are shown in Figure 1. The size of the RI capsule is OD 38 x ID 34 x Height (outer 160 x inner 94.8mm). The SiC chamber has a size of ID 5mm x OD 8mm x Height (the inner 32mm x the outer 47.4mm). Two SiC chambers can be inserted in the vertical direction in the center position of the capsule. 4 pieces of the RI capsules are inserted in the rig as in Figure 1. The center position of the HANARO fuel is on 1.6cm below the top of the 3rd capsule. Therefore, the 4 capsules are arranged as in the above of Figure 2.

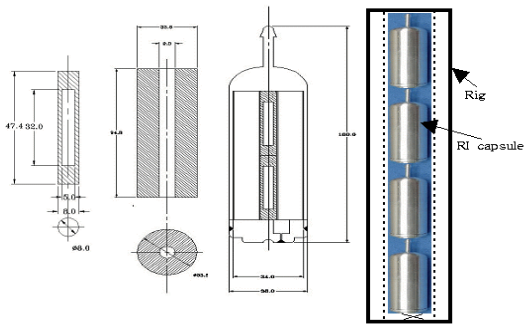

Fig. 1 SiC chamber, Al container, capsule and the rig

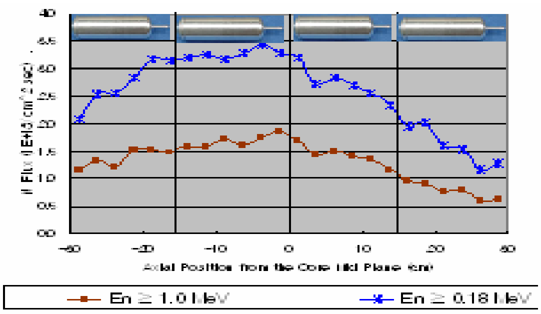

Fig. 2 Neutron flux in the OR5

The 3rd capsule installed in the rig is located at the same level as the center position of the HANARO fuel. It is best for the SiC chamber to be placed there as the variation of neutron fluxes is the least

5. Gamma heating and temperatures

The heating ratio and the temperatures are as listed in Table 2~3. Table 2 shows the differences of the temperatures between at the beginning (CR 350mm) and the middle (CR 450mm) of the HANARO operation cycle in the OR5. The difference of the temperatures is about 4°C. And it shows the temperature differences of the SiC samples in the two SiC chambers in a capsule too. It is 3°C. Table 3 shows the temperature differences in the vertical direction. It is about 4°C.

Table 2 Temperatures of SiC (control rods)

CR (mm)	SiC Cham-ber	Heating W/g	Temperature °C			Gap mm
		SiC	SIC center	SiC border	Cham-ber	Inner/ Outer
350	upper	1.07	79	79	76	0.5/0.2
	lower	1.12	80	80	77	
450	upper	1.14	81	81	78	0.5/0.2
	lower	1.22	84	84	81	

Table 3 Temperatures of SiC (vertical position)

CR (mm)		Gamma heating W/g	Temperature °C			Gap mm
		SiC	SIC center	SiC border	Cham-ber	Inner/ Outer
450	Max.	1.24	85	85	82	0.5/0.2
	Min.	1.14	81	81	78	

6. Thermal conductivity by SiC granules

A change of the temperatures was calculated in order to consider the effect of density in two ways. One is to change only the density and the other is to change both the density and the thermal conductivity of SiC. As a result, the temperature of the SiC samples changes by 1°C when the density and the thermal conductivity of SiC change by 10%. It shows that the density change of SiC has not a great effect on the change of the temperatures. It seems to be because the volume of the SiC samples is very small. Therefore, it is not necessary to mix the graphite in the SiC samples to raise the thermal conductivity.

7. Measurement of temperatures

The irradiation using the rig for RI production is like the un-instrumented capsule, and so a thermocouple cannot be used. Therefore, the temperatures should be estimated depending on a theoretical calculation.

If a measurement of the temperatures is needed, the thermo-label can be used as an auxiliary measure. The thermo-label is an irreversible temperature indicating material which changes color distinctly on reaching a specific temperature and does not revert to its original color once it has undergone a color change. The temperature indicating elements utilize the melting point of specially refined stable material to give the correct and highly precise temperature indications. It measures the temperatures at an interval of 5 °C, and it has an accuracy of ±2 °C [2]. Even if the thermo-label would be used, the temperatures of the SiC samples cannot be measured directly because it should be adhered to the SiC chamber. Therefore, the temperature of the SiC samples should be guessed by comparing the measured temperature of the chamber with that estimated in the calculation.

8. Error range

There are many factors that give rise to errors in the irradiation as in Table 4. The error according to the operation time is so high that all other errors can be included in it. And the maximum error for the heating rate is 8.2 % by the calculation of the MCNP code.

Table 4 Estimation of the errors in the irradiation test

Item	Require -ments	Sources of errors (%)			
		MCNP	Vertical position	Cycle time early /middle	Total error
Neutron	<2 %	8.2	7.3	32	32
Temperature	±2 ℃	8.2	8	7.2	8.2

9. Conclusions

The irradiation test of the SiC samples can be performed successfully in the OR5 test hole according to the user's requirements. The irradiation during 3 cycles of the HANARO operation is necessary to meet the requirements if the SiC chamber is placed at the position of No 3 capsule of the rig for RI production.

Acknowledgements

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