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Design of a small capsule for low-temperature irradiation in HANARO

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To irradiate a small amount of samples such as SiC or Si at low temperature, a design of a small capsule and rig was reviewed. The conceptual design of a chamber and the capsule and rig, for irradiation was conducted, and the most suitable places were reviewed in the test holes. The range of errors in the estimation of the nuclear characteristics and the temperature were reviewed according to the times of the operation cycle, and the vertical and horizontal positions of the samples.

1. The design requirements

The design requirements for irradiation were as follows. The neutron fluence should be 10^{20} n/cm^2 for neutrons higher than the energy level of 0.2 MeV. The temperature of the samples during irradiation is in the range of 55℃–100℃. The SiC layer should not exceed 5mm in thickness, and the sample chamber should be made of Al 1100 or Al 6061. The difference for the temperatures and the neutron fluxes should be less than 2℃ and 2% between any two points in the chamber at any given time. The thermal conductivity of the monolithic SiC is 240 W/m·K. The weight of an individual sample is 3.2 x 10^{-5} gram. The volume of an individual sample is 0.2x0.2x0.25 mm, and thus the volume is 0.4 cm^3.

2. Neutron flux and fluence

The IP, OR, and CT holes were taken into consideration for an estimation of the neutron and fluence. The neutron flux of the IP holes is too low and it takes too long to meet the user requirement of the fluence. An analysis for the neutron flux was performed for the beginning and middle of the HANARO operation using the MCNP code for the OR5 and CT hole. The differences in the neutron flux were compared according to the times of the operation 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 an irradiation of one cycle. The 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 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. In addition, the fluence in all positions of Hole 3 exceeds the required value even in 1 cycle [1].

Table 1 Neutron flux(e>0.2Mev) and fluence

Test hole	Neutron flux (e>0.25MeV)		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	
IP15	0.37	0.39	0.72	0.77	~20
OR	3.01	3.43	5.98	6.82	~3
CT	31.1	31.8	61.8	63.2	~0.32

3. Irradiation devices

The cylindrical type chamber fits the target used for the radio-isotope production in HANARO. If it is installed in the center of the rig, the Al container is inserted in the target, and the temperature of the samples becomes lower because the conductivity of the Al container is very high. The sample chamber, Al container, target, and rig are shown in Fig. 1. The size of the target is OD 38 x ID 34 x Height (outer 160 x inner 94.8mm). The sample chamber has a size of ID 5mm x OD 8mm x Height (the inner 32mm x the outer 47.4mm). Two sample chambers can be inserted in the vertical direction in the center position of the capsule. The 4 targets are inserted in the rig as shown in Fig 1. The position of the center of the fuel is 1.6 cm below the top of the 3rd capsule.

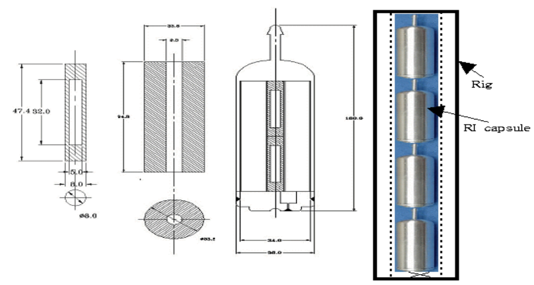

Fig. 1 Chamber, Al container, target and the rig

The 3rd capsule from the above in the rig is in the range of 0 to -15cm from the position of the fuel center. The variation of the neutron flux in the vertical direction is at least in the range of the 3rd capsule. Therefore, the 3rd target is best in an irradiation test because the variation of the neutron flux is the smallest

4. Heating and the temperatures

The temperature was calculated according to 3 types of chamber, as shown in Fig. 2.

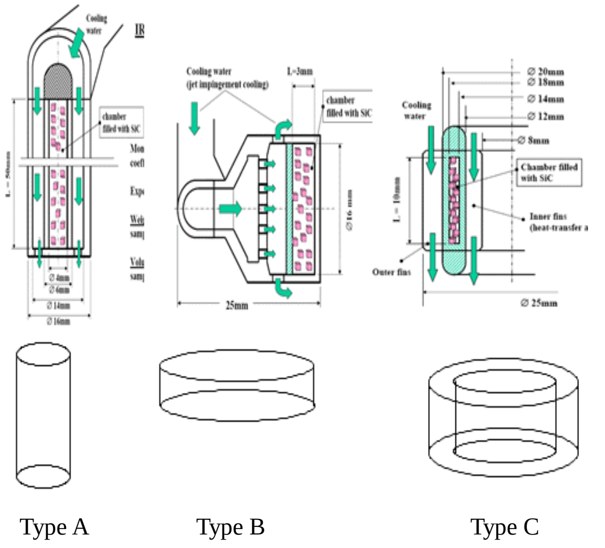

Fig. 2. 3 types of chambers

- Type A(cylinder type) : OD 6mm x ID 4mm x 50mmH ($V=628mm^3$)
- Type B(disk type) : ID 16mm x 3mmH ($V=602.88mm^3$)
- Type C(donut type) : OD 18mm x ID 14mm x 10mmH ($V=1004.8mm^3$)

The calculated temperatures of the sample and chamber are listed in Table 2.

Case	Irr. hole	Heat rate	Chamber	Temp. of sample (℃)		Temp. of chamber (℃)
				center	border	
1	OR5	2.0 W/g	Type A	40	40	36
2			Type A + Al media	62	62	58
3			Type B	72	65	37
4			Type C	57	51	37
5	CT	5.5 W/g	Type A	46	46	36
6			Type A + Al media	75	75	65
7			Type B	118	98	41
8			Type C	87	73	39

5. Effect of the thermal conductivity change of samples

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

6. Measurement of the temperature

The irradiation using the rig is like an un-instrumented capsule, and thus a thermocouple is not used. Therefore, the temperatures should be estimated depending on a theoretical calculation.

If a measurement of the temperatures is needed, a thermo-label can be used as an auxiliary measure. A thermo-label is an irreversible temperature indicating the material which changes color distinctly upon 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 correct and highly precise temperature indications. It measures the temperatures at an interval of 5℃, and has an accuracy of ±2℃ [2]. Even if the thermo-label is used, the temperatures of the samples cannot be measured directly because it should be adhered to the chamber.

7. Conclusions

A irradiation test of samples can be performed successfully in the OR5 test hole according to the user's requirements. The irradiation needs to meet the requirements if the chamber is placed at the position of the No. 3 capsule of the rig.

ACKNOWLEDGEMENTS

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