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Calculation of neutron flux and spectrum in the irradiation test capsule at HANARO

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1. Introduction

Many materials have been irradiation-tested at HANARO to verify their irradiation performance[1]. The irradiation test capsules were mostly used for the irradiation test in CT and OR5 irradiation hole. Since the neutron fluence is an important factor, fluence monitor(F/M)s were inserted in the irradiation test capsule in order to measure the neutron fluence of test specimen. Not only the good measurement technique but also the calculation data is necessary to accurately evaluate the neutron fluence of irradiated material. Therefore, following factors should be calculated for detailed evaluation of the neutron fluence;

(1) Neutron flux and spectrum with the position of control absorber rod(CAR)
(2) Neutron flux and spectrum at the candidate F/M irradiated position
(3) Neutron fluence difference between F/M and specimen

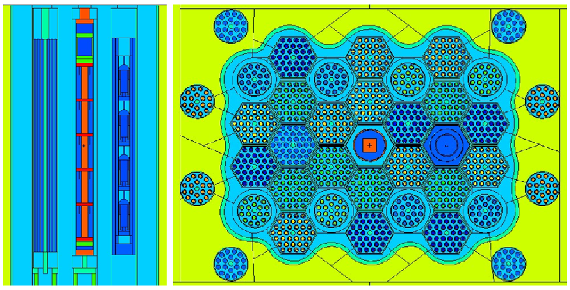
From this calculation data, the neutron fluence of irradiated specimen and F/M can be predicted.

In this paper, the neutron flux and spectrum were calculated for the irradiation capsule. This data can be a basic data of neutron dosimetry for the irradiation test and applied to select the optimum F/M installation position and verify the neutron fluence of the specimen.

2. Methods and Results

2.1 Calculation methods

MCNP(Monte Carlo N-Particle) code that was a design verification code of HANARO core was used for this calculation. ENDF/B-VII was used as the main cross section library. Fig.1 shows the model of irradiation test capsule and HANARO core in this calculation. The equilibrium HANARO core was assumed. Because the position of CAR is changed with the increase of operation time, the neutron flux and spectrum was calculated at the CAR positions of 350, 450, and 550 mm to observe the influence of CAR position. The irradiation test capsule of 09M-02K[2] was assumed, center-concentrating specimen shape. The irradiation test capsule was composed of 5 vertical sections. The F/M irradiated position is the highest position of each section. To observe the differences by the irradiated position of F/M, the neutron flux and spectrum was calculated at 12 angular positions in a same section that is located at the angles of 0^o, 30^o, 60^o, 90^o, 120^o, 150^o, 180^o, 210^o, 240^o, 270^o, 300^o, 330^o.



(a) (b)

Fig. 1. The MCNP calculation (a)vertical and (b)horizontal model of HANARO core (The irradiation test capsule was loaded in CT irradiation hole.)

2.2 The comparison of neutron flux and spectrum

The CT irradiation hole is located at the center of the core, however, OR5 is located in the flow tube outside the core in the reflector region. Therefore, it is expected that the difference between the specimen and F/M may be observed according to the position of F/M in OR5 irradiation hole. To evaluate its influence, the differences with 12 positions were calculated in the CT and OR5 irradiation hole. Fig. 2 shows the neutron flux differences with 12 positions of the irradiation test capsule. The average neutron flux approximately corresponded with the neutron flux of specimen. Although the maximum difference of 7.31% was observed, most of results showed good agreement in CT irradiation hole. In OR5 irradiation hole, large differences were observed.

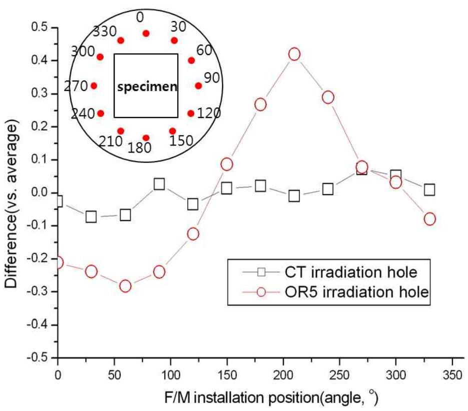


Fig. 2. The neutron flux(E > 1MeV) differences with the F/M irradiated position (CAR = 450 mm, in the middle section of the irradiation test capsule)

Table 1 shows the fast and thermal neutron flux fractions versus total neutron flux with 12 angular positions. From this calculation, the spectral difference between CT and OR5 irradiation hole was observed. Also, spectral difference was detected in OR5 irradiation hole despite the same section.

Table 1. Fast* and thermal** neutron flux fractions with F/M installation positions (CAR = 450 mm, in the middle section of the irradiation capsule)

Angle(°)	CT irradiation hole		OR5 irradiation hole	
	Fast fraction	Thermal fraction	Fast fraction	Thermal fraction
0	17.76%	23.89%	5.80%	53.91%
30	17.21%	23.90%	5.96%	54.68%
60	17.39%	24.47%	5.68%	55.76%
90	18.93%	24.57%	5.57%	51.86%
120	17.87%	25.24%	5.70%	52.36%
150	18.55%	23.97%	6.56%	48.95%
180	18.69%	23.81%	7.33%	47.58%
210	18.24%	24.59%	8.13%	46.71%
240	18.15%	23.06%	7.09%	48.78%
270	19.91%	23.98%	6.55%	49.78%
300	19.13%	23.69%	6.63%	53.82%
330	18.21%	24.23%	6.41%	53.82%

*fast : E > 1 MeV, **thermal : E < 0.625 eV

2.3 Spectral averaged cross section of CT and OR5 irradiation hole

The fast neutron(E > 1 MeV) fluence is an important factor of material irradiation test[3], so the fast neutron fluence must be evaluated for the test specimen. To evaluate the fast neutron fluence, in JMTR[4] and HFR[5], Fe wire was used as F/M material. It is measured by $Fe^{54}(n,p)Mn^{54}$ activation reaction. The fast neutron flux can be calculated as following equation;

$$\phi = R/\overline{\sigma}$$

Where, ϕ is the neutron flux, R is the reaction rate of target reaction, and $\overline{\sigma}$ is the spectral averaged cross section. R can be calculated by measured data. If the spectral averaged cross sections can be calculated in the corresponding spectrum region, the measured neutron flux can be easily calculated. The spectral averaged cross section can be calculated from following equation;

$$\overline{\sigma} = \frac{\int \phi \, \sigma \, dE}{\int \phi \, dE}$$

Table 2 shows the calculated spectral averaged cross section of $Fe^{54}(n,p)Mn^{54}$ activation reaction and application results. Because the difference of angular position in OR5 irradiation hole was large, the spectrum of realistic F/M installation position was used. From this evaluation, good agreement was shown between measured and calculated data within 20%.

Table 2. The calculated spectral averaged cross section of $Fe^{54}(n,p)Mn^{54}$ activation reaction and application results

Activation reaction	Spectral averaged cross section for fast neutron flux(E>1MeV)	
	CT irradiation hole	OR5 irradiation hole
$Fe^{54}(n,p)Mn^{54}$	87.06 mb	99.45 mb
Maximum difference using above spectral averaged cross section	9.47% (10M-01K)	17.13% (09M-02K)

3. Conclusions

The neutron flux and spectrum was calculated for irradiation test capsule. The difference of neutron flux and spectrum of the irradiation test capsule in CT and OR5 irradiation hole was observed. Also the spectral averaged cross section was calculated and applied to the fast neutron fluence evaluation. As a result of this evaluation, the good agreement between calculated and measured data was shown.

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