Nuclear Heating Analysis for HANARO Cold Neuron Source

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1. Introduction

The HANARO research reactor is operating at 30 MW thermal power and being utilized actively at various research fields. For more utilization, HANARO is developing a cold neutron source (CNS), which is very important in the condensed matter neutron research and in the fundamental neutron physics. The cold neutron source should be optimized for intense cold neutrons and low heat load. The heating rate estimation for CNS is very important factor to design a cryogenic system. This paper presents the nuclear heating analysis of HANARO CNS.

2. Methods

The code and the model for evaluating the heating rate are described. The heat sources can be divided into two categories, prompt and delayed. As the code does not deal with delayed components, the calculation techniques about delayed components are described in detail.

2.1 Code and Basic Model

The nuclear heating calculations of CNS were performed by using MCNP-4C, a Monte Carlo neutron and photon transport code developed at Los Alamos National Laboratory [1]. MCNP has been widely used and validated at HANARO. A basic core model for this analysis is a HANARO full core model, in which the average core burnup is 29.41 %U-235. To simulate the burnup core, total 142 nuclides including fission products and actinides are used. The nuclides selected are appropriate for the transport of photon as well as neutron.

As the CNS facility will be operating regardless of the core condition, the core condition giving the maximum heat load should be selected. The severe condition is found out that the outer core close to the CN hole is loaded with a fresh test fuel.

2.2 Beta Particles from Al-28

Aluminum alloys are popular as CNS structural material. Al is a tedious element in the nuclear heating analysis due to its neutron activation product, Al-28. Al-28 has a half-life of 2.25 minutes, and is present in its equilibrium concentration at short operation of the reactor. The beta particles emitted in its decay have its continuous energy spectrum, but can be simplified as an average energy of 1.247 MeV [2]. Because the range of such electrons is quite short compared to the dimensions of Al structures, it is assumed that 100% of the electron energy is deposited in Al structures. The production rate of Al-28, which equals the rate of decay, can be determined directly by MCNP. The flux tally is used to calculate the neutron reaction rate, Al-27(n,γ)Al-28, which determine the energy deposited by beta particles.

2.3 Delayed gamma rays

MCNP does not track the creation of radioisotopes nor the radiation emitted in their decay, but these heat sources must be determined so as not to underestimate the heat load. The delayed gamma rays are emitted from neutron activation products and fission products. The delayed gamma rays from neutron activation products are complicated and dependent on its environment. As HANARO fuel and CNS structure use a large amount of Al, delayed gamma from the decay of Al-28 should be considered. The complex geometry model urge to modify the Al cross section library, in which the photon production data for Al is expanded on gamma ray emitted in the decay of Al-28.

The delayed gamma from fission products is large heat source. To simulate the gamma ray, two-step procedure is used. The delayed gamma rays are generated proportional to the power distribution of the fuel rod. The gamma source distribution is obtained from KCODE mode. Gamma transport at SDEF mode give us the heating from the delayed gamma. The F. C. Maienschein formula [3], $N(E) = 7.4 \exp(-1.10E)[MeV^{-1}]$ is adopted to calculate the delayed gamma, where E is the energy of photon.

3. Results

Several moderator cells for HANARO CNS have been studied [4]. Fig. 1 shows the MCNP model of a moderator cell, which is best for HANARO CNS.

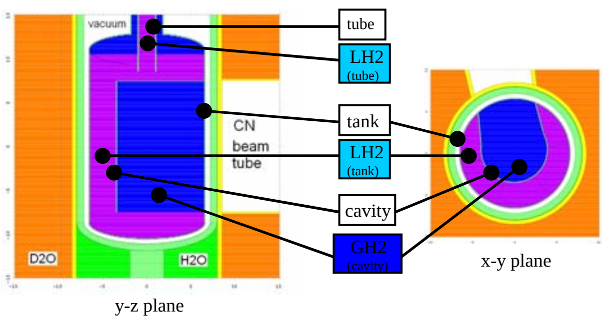

Fig. 1. CNS modeling for the MCNP calculation

This model is called a double cylinder with open cavity. Liquid hydrogen (LH2) is adopted as a cold neutron moderator. Cavity filled with gas hydrogen (GH2) gives more chance for cold neutrons to stream out to CN beam tube.

The nuclear heating rate of CNS is summarized at Table 1. Gamma is most significant heat source at Al structures. Neutron heating is more prominent at hydrogen. As most heating is generated at Al structure, thickness of Al structure is important. Total nuclear heating to be removed is 629.0 Watt. Others are hydrogen and tube above 60 cm, which is the height of the D2O reflector from the core center.

Table 1. Nuclear heating rate

Class. / Component	Specific heating rate (Watt/g)				Heating rate (Watt)	
	Neutron	Gamma	Beta	Sum	Mass	Heating
Tank	0.0034	0.4238	0.1503	0.58	360.6	208.2
Cavity	0.0039	0.4786	0.2389	0.72	127.1	91.7
Tube	0.0019	0.2264	0.0857	0.31	422.2	132.6
LH2(tank)	0.9828	0.9482	-	1.93	87.5	168.9
GH2(cavity)	0.8607	0.7782	-	1.64	2.4	4.0
LH2(tube)	0.5243	0.4580	-	0.98	9.8	9.6
Others				-	661.4	13.9
Total	-	-	-	-	1670.9	629.0

Fig. 2 shows the axial distribution of the nuclear heating. Compared the power distribution of the fuel in the core, the heating rate reduces slowly due to more axial leakage of neutron.

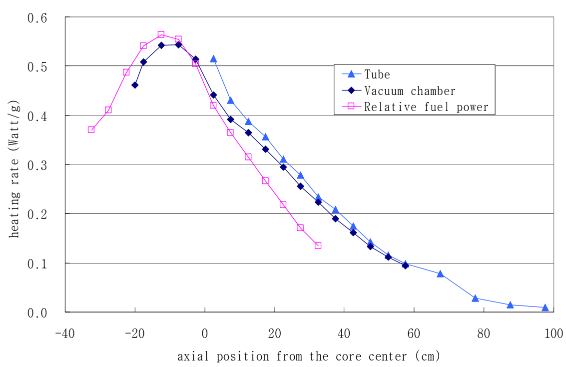

Fig. 2. Axial distribution of the nuclear heating

Fig. 3 shows the radial distributions of the nuclear heating. The region close to the core is high. The heating from neutron reduces rapidly compared to the heating from gamma. The region far away from the core is not the lowest from characteristics of the cavity.

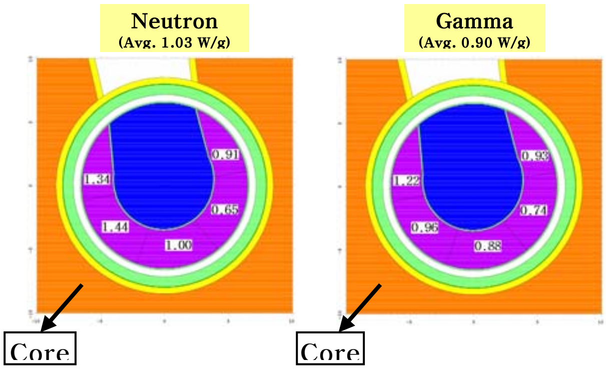

Fig. 3. Radial distribution of the nuclear heating

4. Concluding Remarks

The heat load estimation of HANARO CNS is conducted. The total nuclear heating, 629.0 Watt, should be removed by the cryogenic system. This study is based on the basic design of CNS. As the main heat source is Al structure, its thickness is very important. This result would be reflected to the final design of CNS.

Acknowledgements

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