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Neutronics performance and decay heat calculation of a solid target for a spallation neutron source

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Abstract

A solid target is expected to give higher neutron intensity than a liquid target of mercury at a spallation neutron source with a power of around 1 MW. We have studied the neutronic performance of a target-moderator-reflector assembly with a tungsten solid target. It is found that the neutron intensities from moderators were higher in the solid target system than in the mercury liquid target. However, the tungsten target required cladding to prevent tungsten from the corrosion of cooling water. A tungsten target with tantalum cladding has been already developed although tantalum has high decay heat. Therefore, we estimated the decay heat of the target and found that the decay heat of 0.5 mm thick tantalum was still high. We need a thinner tantalum or new cladding materials. It was revealed that adoption of a thinner tantalum or new cladding material such as chrome nitride reduced the decay heat effectively.

1. Introduction

Up to now, solid targets have been used as spallation targets, for example, at IPNS(US), KENS (Japan) and ISIS (UK), since the solid target has high mass density and brings higher neutron intensity at the power level of those facilities, namely less than 0.16 MW. One-MW class spallation neutron sources are now under construction in Japan and the USA. They use mercury as a target material since at the initial stage of development of those MW class sources they planned to build 5 MW sources and the choice of target would be uniquely mercury at 5 MW. Furthermore, it was believed that the solid target could not be used even at 1 MW because of serious radiation damage. However, recently it has been revealed that the solid target can be used at 1–2 MW sources from the radiation damage point of view. As a material for solid targets, tungsten and tantalum are so far used. Tungsten has higher mass density than tantalum and it gives higher neutron intensity. But it has the problem of corrosiveness against water under high radiation field. On the other hand, tantalum has problem of high decay heat after irradiation. Therefore, tungsten with cladding would be the best material. Recently, tantalum cladding to tungsten has been developed for the spallation neutron source. [1] So, a candidate of the spallation target at 1 MW class power is tungsten with tantalum cladding. For such a target,

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we should estimate the decay heat of the target. In this research, we study the neutronic performance of the solid target system and make comparisons with the mercury target system. Furthermore, we have studied the decay heat of the tungsten target with tantalum cladding. The decay heat is calculated by using two codes, CINDER'90 [2] and DCHAIN-SP 2001 [3] and the difference between the two codes is also discussed.

2. Calculation conditions and flows

2.1. Calculation conditions

We used MCNPX [4], CINDER'90 and NMTC/JAM [5], MCNP4C [6], DCHAIN-SP 2001 as calculation codes. Cross section data are ENDF-B/VI, V, the incident particles are 3 GeV proton and the beam profile is parabolic with a height of 5 cm and a width of 13 cm. Beam current is 0.333 as for the JSNS project. Fig. 1 shows the geometry of the target-moderator-reflector of JSNS project using a beryllium reflector with a mercury target. We adopted this geometry as a calculation model. To consider the solid target, we replaced the whole mercury target with a solid target and D_2O coolant. As a solid target, we used tungsten plates. Thickness data of the plates are shown in Table 1. Leading plate is numbered as number 1. The tungsten plate has a cladding of tantalum to prevent water corrosion. The thickness of cladding is 0.5 mm. The material of moderators is liquid para-hydrogen. Three moderators are placed in this system. A coupled moderator is put under the target, and a decoupled and a poisoned moderator are put above target. The neutron intensity of the coupled moderator is the highest of the three moderators, aiming for the highest intensity neutron source. The decoupled moderator is a short-pulse type neutron moderator. The poisoned moderator has shorter pulses than the simply-decoupled moderator, which aims to be the high resolution neutron source. The decoupler works as a high-energy pass and low-energy neutron absorber. The material is AIC which is composed of 81% silver, 14% indium and 5% cadmium in atom density. The reflector is beryllium surrounded by stainless steel shielding. Fig. 2 shows the calculation geometry used for MCNPX. The proton beam is incident on the target perpendicularly to the paper. Using such models, we calculated intensity ratios defined by the intensity of the solid target case divided by that of the mercury case. We used MCNPX for the calculation of the neutronic performance.

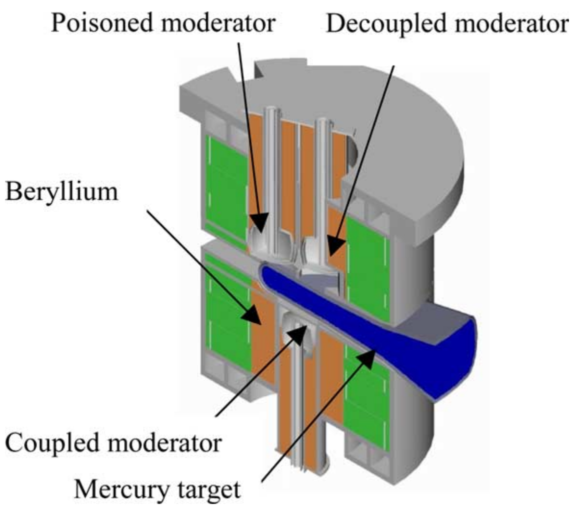

Fig. 1. Calculation model simulating JSNS.

Table 1
Thickness data of target

Plate number	Thickness (mm)
1	6.3
2	6.7
3	6.4
4	6.3
5	6.3
6	6.4
7	6.5
8	6.7
9	7.0
10	7.3
11	7.7
12	8.2
13	8.8
14	9.4
15	10.2
16	11.0
17	11.8
18	12.7
19	13.8
20	15.0
21	16.5
22	18.3
23	20.5
24	23.3
25	26.7
26	31.2
27	37.3

2.2. Calculation flows

For the decay heat calculation, we need more than two codes. For the CINDER'90 we combined MCNPX, and for the DCHAIN-SP 2001 we combined NMTC/JAM and MCNP4C. The flows of calculations are shown in Figs. 3 and 4. We calculate the decrease of the decay heat after 1-year irradiation.

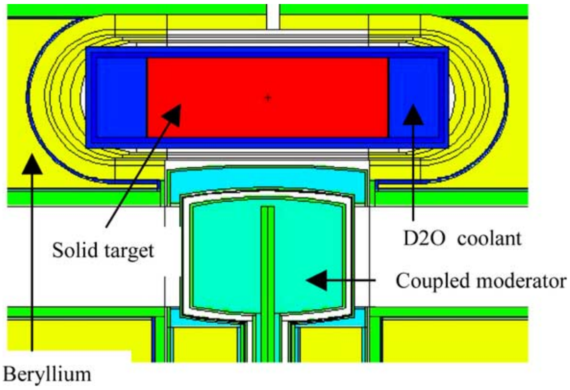

Fig. 2. Calculation geometry around the target.

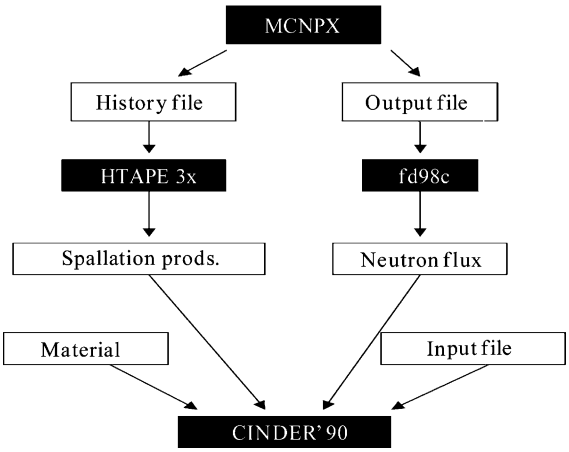

Fig. 3. Calculation flows for CINDER'90.

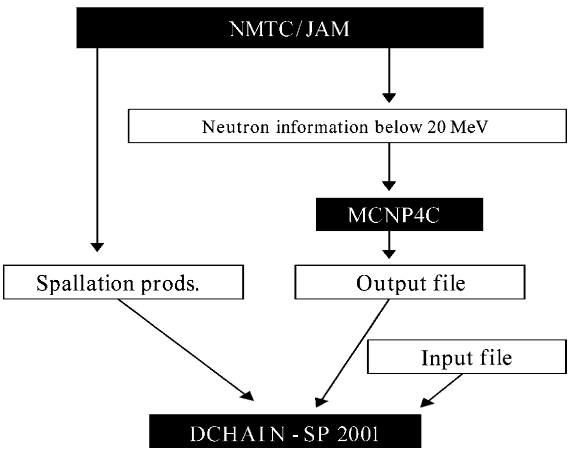

Fig. 4. Calculation flows for DCHAIN-SP 2001.

3. Results and discussion

3.1. Neutronic performance

We changed the target height and width to find the optimum size. Fig. 5 shows the change of the intensity ratio as a function of the height in the case of the coupled moderator. The intensity ratio is at the maximum for a target height of 8 cm. The limit of target height is about 8 cm in these geometric dimensions of cask size and coolant channel. In Fig. 6, we show the effect of the

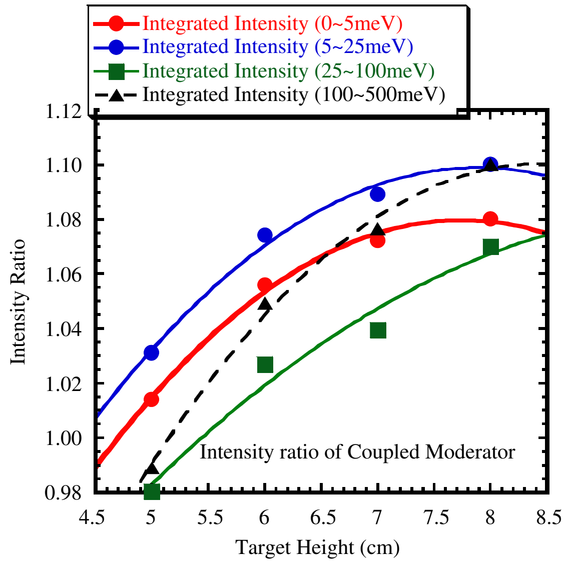

Fig. 5. Intensity ratios as a function of the height.

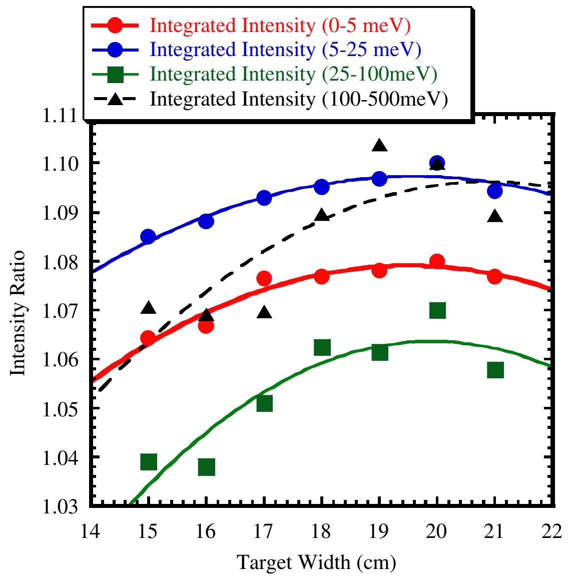

Fig. 6. Intensity ratios as a function of the width.

Table 2
Intensity ratios between solid target and mercury target

	Coupled	Decoupled	Poisoned
Intensity ratio (0–5 meV)	1.08	1.05	1.05
Intensity ratio (5–25 meV)	1.10	1.11	1.07
Intensity ratio (25–100 meV)	1.07	1.11	1.02
Intensity ratio (100–500 meV)	1.10	1.10	0.99

target width. At a target width of 20 cm, intensity ratio became the maximum. So we chose a target height of 8 cm and a width of 20 cm. Table 2 shows the intensity ratio at 8 cm height and 20 cm width. From the table, it can be recognized the solid target gives about 10% higher neutron intensity than the mercury target.

3.2. Decay heat

We calculated the decay heat and the spatial distribution by CINDER'90 and DCHAIN-SP 2001. Fig. 7 shows the decay heat density of each plate just after 1-year irradiation. Total decay heat is about 7960 W in the case of CINDER'90 and 6500 W in the case of DCHAIN-SP 2001. The difference is almost 20% and it is not so large considering the purpose. The plate that has highest decay heat density is plate 1 in both cases. So, we decided to calculate the decay heat distribution in number 1 plate since maximum heat density is important for thermal hydraulic design. Fig. 8 shows the decay heat distribution of plate 1 calculated by CINDER'90.

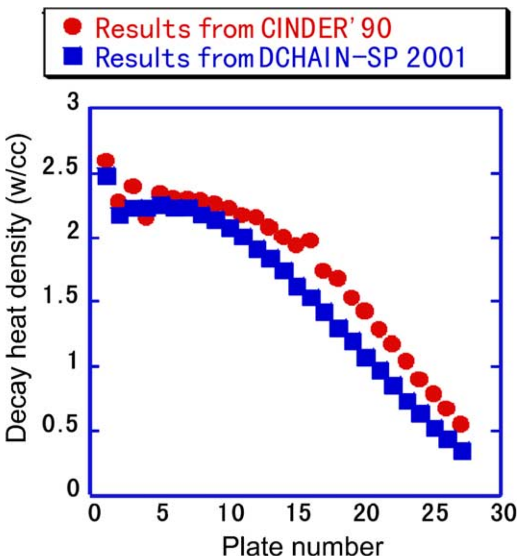

Fig. 7. Decay heat density of the target.

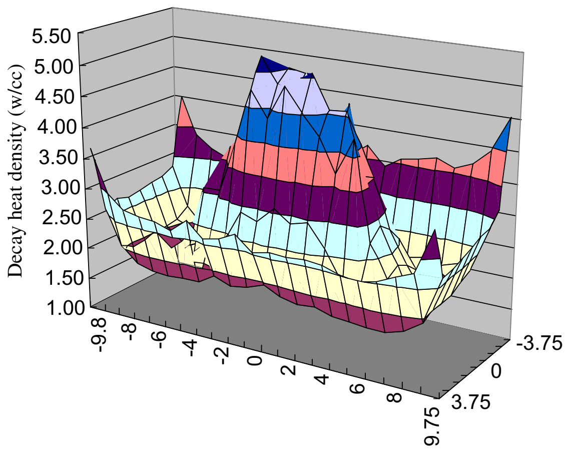

Fig. 8. Spatial decay heat distribution of plate 1 calculated by CINDER'90.

Peak decay heat density was 5.7 W/cc for CINDER'90, and 6.1 W/cc for DCHAIN-SP 2001. Fig. 9 shows the change of the decay heat of the plate 1 as a function of cooling time. Even at 100 days after beam off, the decay heat is still high. This is due to existence of Ta-182. This will make target exchange scenario difficult.

The decay heat indicated before was due to particles and gamma-rays produced in the target. The charged particles move very little in a high mass density material. So, the contributions from these particles are taken into account correctly. However, gamma rays move through

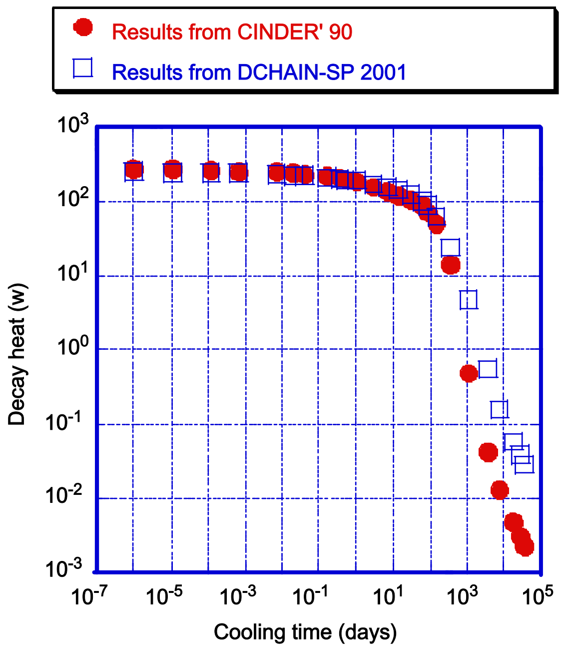

Fig. 9. Decay heat decrease with time for plate 1.

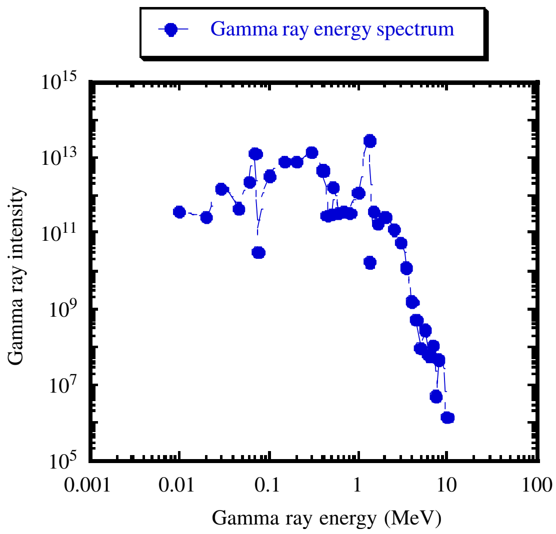

Fig. 10. Gamma ray energy spectrum.

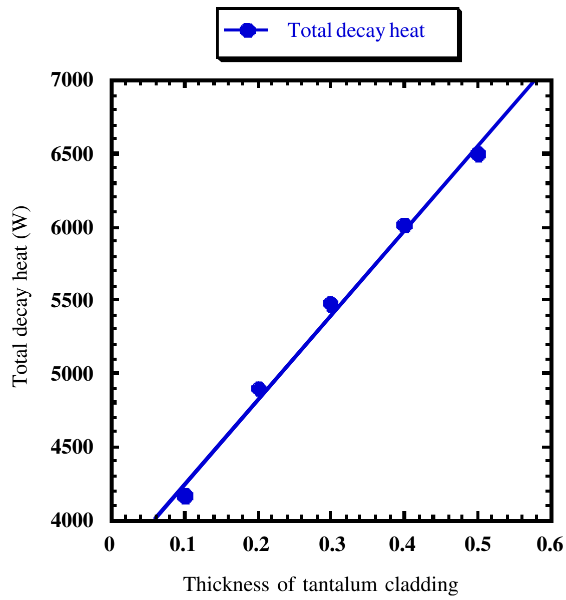

Fig. 11. Decay heat from 0.1 to 0.5 mm thick tantalum cladding.

a wider area as compared with the charged particles. Therefore, we need to estimate the effect of the transport of the gamma rays, which would be expected to reduce the maximum heat density. Gamma ray transport calculations were done by MCNPX. Fig. 10 shows the gamma ray energy spectrum that is discharged from plate 1 after 1-year irradiation. Table 3 shows the result from gamma ray transport calculation. The decay heat of the tungsten part increases and that of the tantalum cladding decreases. Total decay heat decreases by about 17%. This is due to the fact that tantalum has higher decay heat density than tungsten near the tantalum cladding. So, the gamma rays from tantalum give energy to tungsten, which increase the decay heat of tungsten near the cladding.

Finally, we consider methods to reduce the decay heat. The total decay heat of the tungsten plate target with 0.5 mm cladding is more than 2 times larger than that of the ISIS tantalum target as shown in Table 3. So it may not be so easy to handle such a target. To reduce decay heat, we thought two methods. One is thinner cladding and another is change of cladding material. For the former, we calculated decay heat with 0.1 mm–0.5 mm tantalum claddings, and for the latter, we adopted chrome nitride (CrN) cladding. [7] We performed these calculations by DCHAIN-SP 2001. Fig. 11 shows the decay heat for 0.1 mm–0.5 mm thick tantalum cladding. Total decay heat is in proportion to the thickness of the tantalum cladding. In the case of 0.1 mm tantalum cladding, the total decay heat is about 4170 W. Here we did not perform the gamma ray transport calculation; if it were taken into account, the value would reduce to about 3500 W, still higher than that of the ISIS tantalum target. The total decay heat of the target with chrome nitride cladding is about 3200 W. This value would be acceptable for target handling.

Table 3
Decay heat after gamma ray transport

Tungsten part (without gamma ray transport)	2980 W
Tungsten part (with gamma ray transport)	4000 W
Tantalum cladding (without gamma ray transport)	3520 W
Tantalum cladding (with gamma ray transport)	1420 W
Total decay heat (without gamma ray transport)	6500 W
Total decay heat (with gamma ray transport)	5420 W
Total decay heat of ISIS Tantalum target	2000 W

4. Conclusion

We set a solid target in the target-moderator reflector model. For the coupled moderator and decoupled moderator, the solid target model gave about 10% higher neutron intensity compared with that of the mercury target. For the poisoned moderator, the solid target gives about 5% higher intensity than the mercury target.

The total decay heat of the tungsten target with the tantalum cladding (0.5 mm thickness) is much higher than that of the ISIS tantalum target. The peak decay heat density is about 6 W/cc. The decrease of the decay heat is too slow when using the tantalum cladding, which may cause difficulty in the target exchange scenario. However thinner tantalum cladding reduces decay heat, especially, in the case of 0.1 mm tantalum cladding; total decay heat is about 35% smaller than that of 0.5 mm tantalum cladding. Using chrome nitride cladding, total decay heat becomes low. From these results, it should be concluded that a solid target system gives higher neutron intensity than the mercury target and the problem of the decay heat would be solved by using thinner tantalum cladding or another cladding material such as a chrome nitride.

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