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# Study on low activation decoupler material for MW-class spallation neutron sources

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ABSTRACT

The Japan Spallation Neutron Source (JSNS) at the Japan Proton Accelerator Research Complex (J-PARC) has started its operation on May 30, 2008. The Ag–In–Cd (AIC) alloy was adopted as a decoupler material for two decoupled moderators. A high decoupling energy at 1 eV was for the first time achieved in MW-class spallation neutron sources due to the adoption of the AIC alloy. Although the AIC decoupler is superior in the neutronic performance, it has a demerit in high residual radioactivity due to production of Ag-110 m (half life: 250 days) and Ag-108 m (half life: 418 years). To overcome this demerit, we studied on possibilities of a low activation decoupler material with high decoupling energy as the AIC alloy, that is, Au–In–Cd (AuIC) alloy. Neutronic performance of this material was investigated by using neutronics calculations. As a result, it was found that the AuIC decoupler could provide neutron pulses with almost the same characteristics as those for the AIC decoupler even when the burn-up effects were considered. Excellent low activation property of the AuIC alloy to the AIC alloy was demonstrated by residual radioactivity calculations. On viewpoint of neutronics performance, it was concluded that the AuIC decoupler was available as the substitute of the AIC decoupler.



## 1. Introduction

The Japan Spallation Neutron Source (JSNS) at the Japan Proton Accelerator Research Complex (J-PARC) produced the first neutrons on May 30, 2008. As shown in Fig. 1, a Mercury (Hg) target, a Beryllium (Be)–Iron (Fe) combined type of reflector and three supercritical Hydrogen ($H_2$) moderators compose the central part of the JSNS. The three moderators in JSNS are coupled one (CM) to provide a high intensity pulse, unpoisoned decoupled one (DM) and poisoned decoupled one (PM) to provide a narrow pulse with a short tail. Fig. 2 shows a detailed figure of DM of the JSNS. For DM and PM, a decoupler, thermal neutron absorber, is located around the moderator to eliminate slow neutrons into the moderator. A decoupling energy ($E_d$), which is the energy to be $1/e$ neutron transmission, is index of performance of a decoupler. A decoupled moderator with higher $E_d$ provides a shorter tail pulse with a certain intensity penalty.

For high resolution experiments in the JSNS, the decoupled moderators with higher $E_d$ are desirable. Until recently, a candidate of decoupler material to realize $E_d \sim 1$ eV was only boron (B) provided by boron carbide ($B_4C$). However, in the intense neutron source, the large helium (He) gas production rate due to the $^{10}B(n,\alpha)$ reaction leads to serious problems (swelling). In addition, $E_d$ of $B_4C$ changes according to a burn-up of B. Therefore, such a candidate is limited to a decoupler material based on the $(n,\gamma)$ reaction. The $E_d$ for cadmium (Cd) decoupler that is often used for intense spallation neutron sources is only 0.3 eV. In order to realize $E_d = 1$ eV, we considered to combine thermal neutron absorber and neutron absorbers with resonance absorption. As such the decoupler material, we proposed silver–indium–cadmium (Ag–In–Cd, AIC) alloy used as a control rod in the Pressured Water Reactor [1]. Fig. 3 shows transmissions of the AIC decoupler and the $B_4C$ one as a function of neutron energy, $E_n$. This $B_4C$ decoupler is controlled by density of $^{10}B$ to be $E_d = 1$ eV. The curve of the AIC is fluctuating around the $B_4C$ curve, which is proportional to $1/\sqrt{E}$ and $E_d$ of the AIC seems to be about 1 eV. By optimizing the thickness and the composition of the AIC decoupler from results of neutronics calculations, excellent pulse shape can be sustained until the assumed life time of 30,000 h in 1 MW operation (30,000 MWh as a time-integrated proton beam power). At the same time, it is satisfied that the AIC alloy stays in a single phase until the assumed life time to keep material properties stable. Via not only such the optimization study, but also the manufacturing feasibility test and the bonding test with aluminum alloy, $E_d = 1$ eV has been realized for the two decoupled moderators of JSNS for the first time in MW-class spallation neutron sources by the adoption of AIC decoupler [2,3].

The AIC alloy has a significant demerit of high residual radioactivity due to production of $^{110m}Ag$ (half life ($T_{1/2}$): 250 days) and $^{108m}Ag$ ($T_{1/2}$: 418 years). This demerit makes handling and storages of used moderators difficult. Of course, this is taken into account in the design of JSNS. However, recently, this is closed up on viewpoint of an improvement of the storage scenario and a promotion

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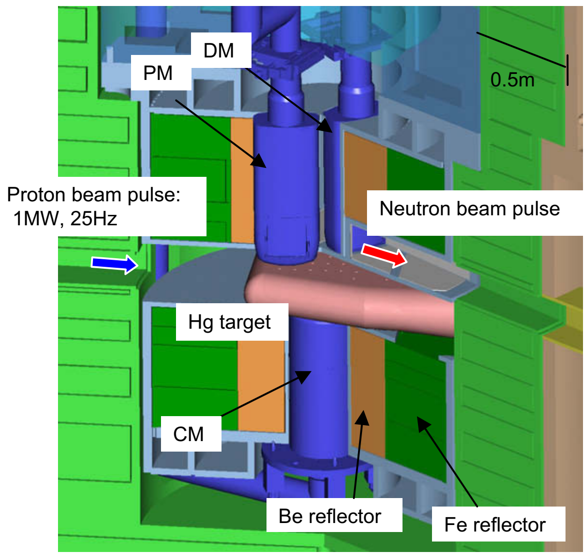


**Fig. 1.** Schematic view of Target–Moderator–Reflector assembly in JSNS.

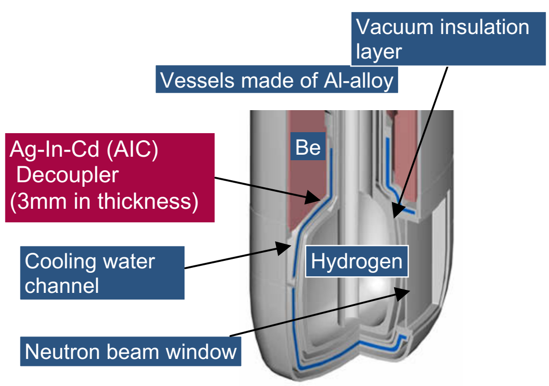


**Fig. 2.** Schematic view of DM.

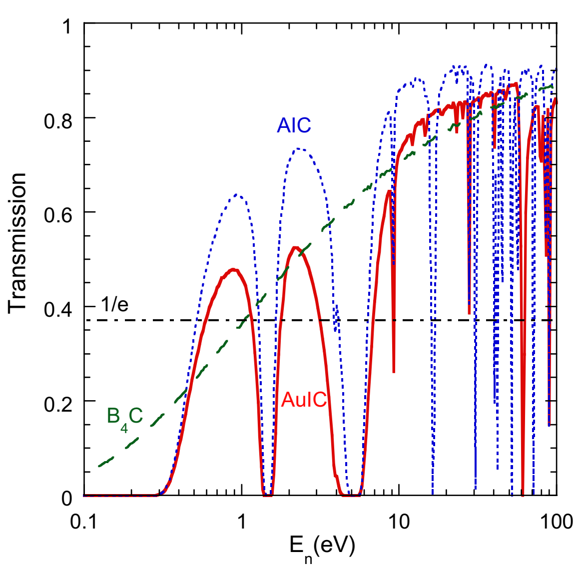


**Fig. 3.** Neutron transmission of AuIC, AIC and $B_4C$ ($E_d$ = 1 eV).

of the environmental preservation. Therefore, development of a new decoupler material with keeping high $E_d$ and good material property like the AIC decoupler is indispensable. As alternative decoupler materials, B based one and Cd one are generally considered. The both decouplers have low residual radioactivity. However, as already mentioned, the B based decoupler has the burn-up problem and $E_d$ = 1 eV cannot be achieved by the Cd decoupler. To overcome this situation, we propose a new decoupler material, gold–indium–cadmium (Au–In–Cd, AuIC) alloy, as a composite decoupler. Ag in the AIC alloy that is the origin of high radioactivity is replaced with Au in the AuIC alloy. Note that Au and Ag are in the same group in the periodic table, and Au can solve In and Cd like Ag. It is an advantage as a decoupler material that Au itself is a neutron absorber. As shown in Fig. 3, the transmission curve of the AuIC is similar to that of the AIC and $E_d$ of the AuIC also seems to be about 1 eV. As the first stage, by a comparison with the AIC decoupler on viewpoint of neutronics, it needs to clarify whether the AuIC decoupler can be used as the substitute of the AIC decoupler or not.

In this paper, we studied the AuIC decoupler by neutronics calculation on viewpoint of pulse characteristics, residual radioactivity and burn-up effect. By comparison with the AIC decoupler, we discussed about feasibility of the AuIC decoupler.

## 2. Calculation model and method

A simple calculation model of JSNS was used in the neutronics calculation. In this model, a rectangular parallelepiped Hg target, a rectangular parallelepiped $H_2$ moderator, the Be–Fe reflectors with neutron beam hole and the decoupler were taken into account. Any containers were not equipped with in these components. An incident proton beam into the target is 3 GeV and 1 MW with the repetition rate of 25 Hz. Major parameters in the simple calculation model summary in Table 1. Fig. 4 shows vertical cross sectional view of the simple calculation model at the moderator center.

For the neutronics calculation, the PHITS code [4] and the MCNP code [5] with JENDL evaluated cross section library [6,7] were used. These codes simulate proton and neutron transports in the all energy region and provide neutron flux spectra. For the pulse characteristics calculation, a point estimator at 10 m from the moderator surface was used.

For the calculation of the residual radioactivity, the DCHAIN-SP code [8] was used. For this calculation, the proton beam power of 1 MW and the operation time of 6 years (5000 h per year) were assumed. Irradiation pattern per one year is combination of a 5000 h operation and a 3760 h cooling after it. The time-integrated proton beam power is indicated as ($P_i$), and $P_i$ = 30,000 MWh corresponds to the assumed life time of the moderator.

**Table 1**
Major parameters for simple calculation model.

| | | |
|---|---|---|
| Target | Material | Hg |
| | Shape | Rectangular parallelepiped |
| | Size | $40^W \times 8^H \times 60^L$ $cm^3$ |
| Moderator | Material | Super-critical $H_2$ |
| | Temperature | 20 K |
| | Pressure | 1.5 MPa |
| | Shape | Rectangular parallelepiped |
| | Size | $12^W \times 12^H \times 5^T$ $cm^3$ |
| | Position | Below the target |
| Decoupler | Material | AuIC |
| | Thickness | 3 mm |
| Reflector | Material | Inner: Be |
| | | Outer: Fe |
| | Shape | Cylindrical |
| | Size | Inner: $60^\varphi \times 60^H$ $cm^3$ |
| | | Outer: $120^\varphi \times 120^H$ $cm^3$ |
| Neutron beam line | Size | $10 \times 10$ $cm^2$ |
| | Opening angle | 25° on both sides |