Helium Production Cross Section Measurement of Pb and Sn for 14.9MeV Neutrons

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Helium production cross sections of lead and tin for 14.9MeV neutrons were measured by helium accumulation method. Lead and tin samples were irradiated with FNS, an intense d-T neutron source of JAERI. The amount of helium produced in the samples by the neutron irradiation was measured with the Helium Atoms Measurement System (HAMS) at Kyushu University. As the samples contained a small amount of helium because of their small helium production cross sections at 14.9MeV, the samples were evaporated by radiation from a tungsten filament to decrease background gases at helium measurement. Uncertainties of the present results were less than ±4.4%. The results were compared with other experimental data in the literature and also compared with the evaluated values in JENDL-3.2.

1. Introduction

In design for structural materials of fusion reactors, helium production cross sections are required to predict the property changes and the life of the fusion materials. The structural materials such as a first wall are exposed to heavy irradiation of high-energy neutrons and are damaged by gas production reactions induced by neutrons. Helium production reaction is especially important, because the produced helium causes mechanical property changes and embrittlement of the structural materials. Although helium production cross sections are important by these reasons, the experimentally measured ones are few.

Helium accumulation method is one of the useful techniques to measure helium production cross sections, because helium production cross sections are directly determined from the amount of helium produced in samples by neutron irradiation. We have been measured helium production cross sections by this method and by using the Helium Atoms Measurement System (HAMS)[1].

In the present study, Lead and tin samples were irradiated with 14.9MeV neutrons with FNS, an intense d-T neutron source of JAERI. The amount of helium produced in

the samples by the neutron irradiation was measured with the HAMS at Kyushu University and helium production cross sections of lead: Pb(n,He) cross section, and tin: Sn(n,He) cross section, were determined. Lead and tin are minor constituents of stainless steels; however, helium production cross sections for many elements are required in detailed structural material design. The irradiated lead and tin samples contained very few helium atoms ($<10^{10}$ He atoms) because of their small helium production cross sections, so the samples were vaporized with using a special furnace of a radiant heat type. The furnace is available for a sample, which has a low melting point, to evaporate it without producing a large amount of background gases.

2. Experimental

2.1. Sample Preparation

Pb samples had a size of $12\times8\times0.5mm^3$ and a nominal chemical purity of 99.999%. Sn samples had a size of $12\times8\times1mm^3$ and a nominal chemical purity of 99.999%.The samples were cut out of as-given plates of natural material. Three Pb samples were covered with a Pb plate (thickness of 0.5mm, a nominal chemical purity of 99.999%). Three Sn ones were also done with a Sn plate (thickness of 0.5mm, a nominal chemical purity of 99.999%). This structure of the covered samples got rid of the outgoing phenomenon of energetic α-particles produced by nuclear reactions from the sample surface. The incoming α-particles from the cover plate canceled out the outgoing ones from the samples. These samples and covers were cleaned ultrasonically in an acetone bath for 20 minutes and were then heated at a pressure of less than 7×10^{-4}Pa for an hour of outgassing at 553K(Pb) and 473K(Sn). The covered samples and Nb foils for neutron fluence monitors were assembled into a sample set. We measured the produced He atoms in the samples after removing the cover plates from the covered samples.

2.2. Neutron Irradiation

The sample set were irradiated by d-T neutrons at Fusion Neutronics Source (FNS) of an intense d-T neutron source at Japan Atomic Energy Research Institute (JAERI). The sample set was set at the neutron emission angles of 20° and the distance of 3cm from the neutron source. Neutron energy was 14.9MeV at the positon. The arrangement of the sample set in the neutron irradiation field and the arrangement of the samples in the sample set are shown in Fig.1. Neutron energy was determined with MORSE-DD of a Monte Carlo code. The neutron fluence decided by referring to the $^{93}Nb(n,2n)^{92m}Nb$ cross section of 455mb±2%[2] and was ranged from $4.2x10^{15}$ to $7.5x10^{15}$ n/cm^2.

2.3. Helium Atom Measurement

The amount of He atoms accumulated in the samples were measured with the HAMS. Figure 2 shows the block diagram of the HAMS. The HAMS consisted of three blocks: a gas releaser, a mass spectrometer, and a standard He supply. Each block was evacuated with a turbo-molecular pump to keep it at an ultra-high vacuum. We used the special furnace of a radiant heat type (Fig.3), because the samples contained very few helium atoms. By using it, very low level helium can be detected because of low level background gas. In the case of a resist heat type furnace, a sample was heated on a evaporating boat and the boat was damaged by alloying with molten sample. The damaged evaporating boat produced a large amount of background gases from itself and from the inside wall, heated unexpectedly, of the furnace. In the case of a radiant heat

type one, a sample was put on a Cu boat under a W filament and was evaporated by the radiation from the electrically heated filament. The filament was not damaged by alloying. The gas released from the sample was purified with the trap of Ti-getter pump. The purified gas was then admitted into the quadrupole mass spectrometer (QMS), controlled by a personal computer (PC), and was analyzed to determine the mass distribution. The obtained mass distribution was converted into the numerical data. The data was stored in the PC and was displayed on the CRT of the PC. The number of He atoms was calculated from the integration of the mass 4 current in the mass distribution.

The efficiency of the HAMS in He measurement was calibrated by a series of measurements of standard He gases: a known amount of He gas prepared with the standard He supply.

2.4. Experimental Errors

The overall errors for the measurement of individual samples were estimated to be 4.3%(Pb) and 4.4%(Sn). Major errors were 2% for the ^{93}Nb(n,2n) cross section[2], ～1.5% for the γ-ray counting efficiency, 2～2.5% for the γ-ray counting statistical uncertainty, 1.5% for the fluctuation of He measuring efficiency of the QMS, 2.3% for the calibration of the HAMS, and 0.7%(Pb) for the fluctuation of the mass-4 background and 1.2%(Sn) for it. The measurement uncertainties are summarized in Table 1.

3. Results and Discussion

The results of this measurement are shown in Fig.4 and 5 together with cross sections measured in available experiments and the most recent evaluations (JENDL-3.2) of the Pb(n,He) and Sn(n,He) excitation function from 13.5 to 15MeV.

Pb(n,He) cross section has been measured by Kneff et al.[3]. The Kneff et al. is in good agreement with the present measurement. Yu et al.[4] and Maslov et al. [5] measured ^{206}Pb(n,α)^{203}Hg cross sections by activation method. Both the results are discrepant. Coleman et al.[6] measured ^{208}Pb(n,α)^{205}Hg with activation measurement. Those results by activation method cannot compared with our result directly, but the results supports our result for the Pb(n,He) cross section.

Sn(n,He) cross section has been measured by Kneff et al.[3]. The kneff et al.; their value is higher than our measurement. Activation measurements have been made for (n, α) reactions in two of the ten stable tin isotopes. Yu[7] measured ^{120}Sn(n,α)^{117}Cd cross section. Ikeda et al.[8] measured ^{120}Sn(n,α)^{117m}Cd and ^{120}Sn(n,α)^{117g}Cd cross sections. Both results agree with in the error. ^{118}Sn(n,α)^{115g}Cd cross sections were measured by Levkovskii et al.[9] and Bayhurst et al.[10]. These results by activation measurements cannot be compared with our results, but support our measured result.

The comparison with the evaluated values of JENDL-3.2 indicates that the JENDL-3.2 values are almost higher than the present measurements.

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Table 1. Sources of uncertainty and uncertainties in the measured Pb(n,He) and Sn(n,He) cross sections.

	Sources of uncertainty	uncertainty (%)
Determination of neutron fluence	γ-ray counting statistics	±2.0~2.5
	Reference cross section of ^{93}Nb(n,2n)^{92m}Nb	±2.0
	Efficiency of γ-ray counting	±1.0~1.5
Helium atoms measurement	Fluctuation of ^{4}He background	±0.7 (Pb) ±1.2 (Sn)
	HAMS absolute calibration (Uncertainty of Standard Gas and fluctuation of QMS efficiency)	±2.3
Combined uncertainty		±4.3 (Pb) ±4.4 (Sn)

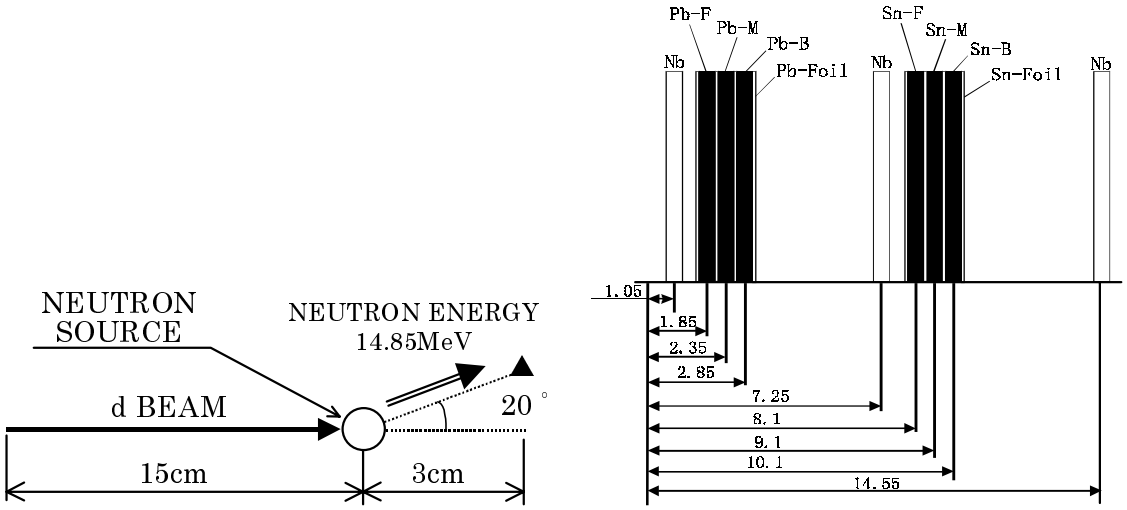

Fig.1. The sample setting position in the neutron field and the sample arrangement in the sample set.

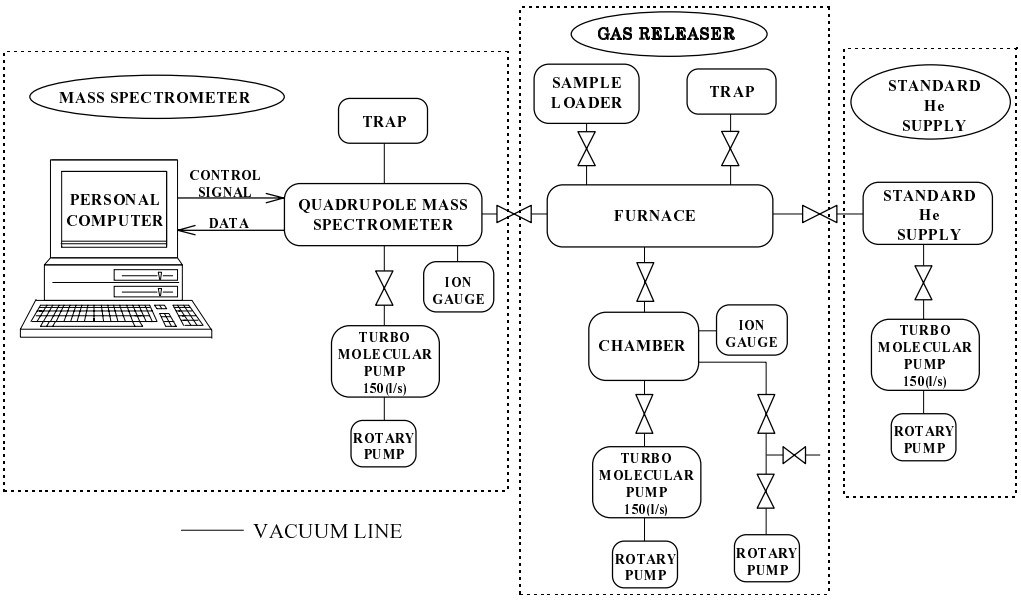

Fig.2. Block diagram of the helium atoms measurement system (HAMS).

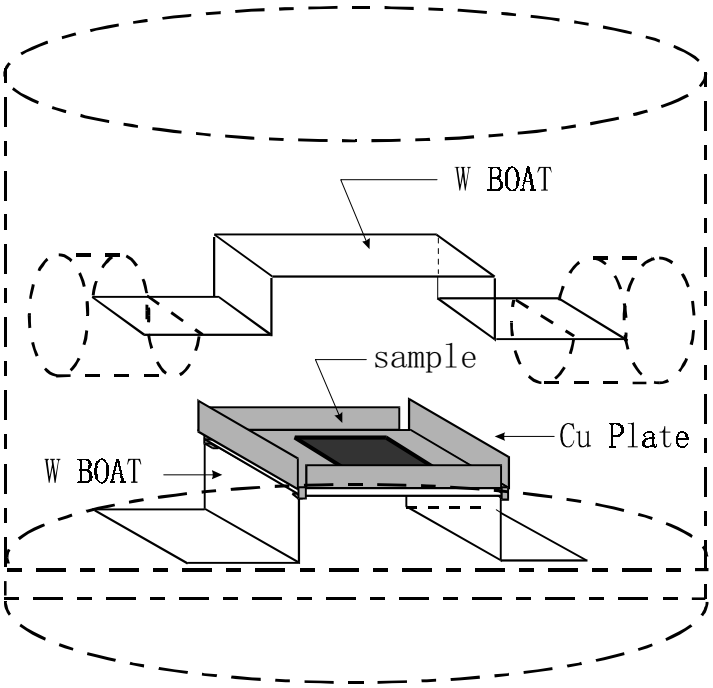

Fig.3. Arrangement of heating devices and a sample in the furnace.

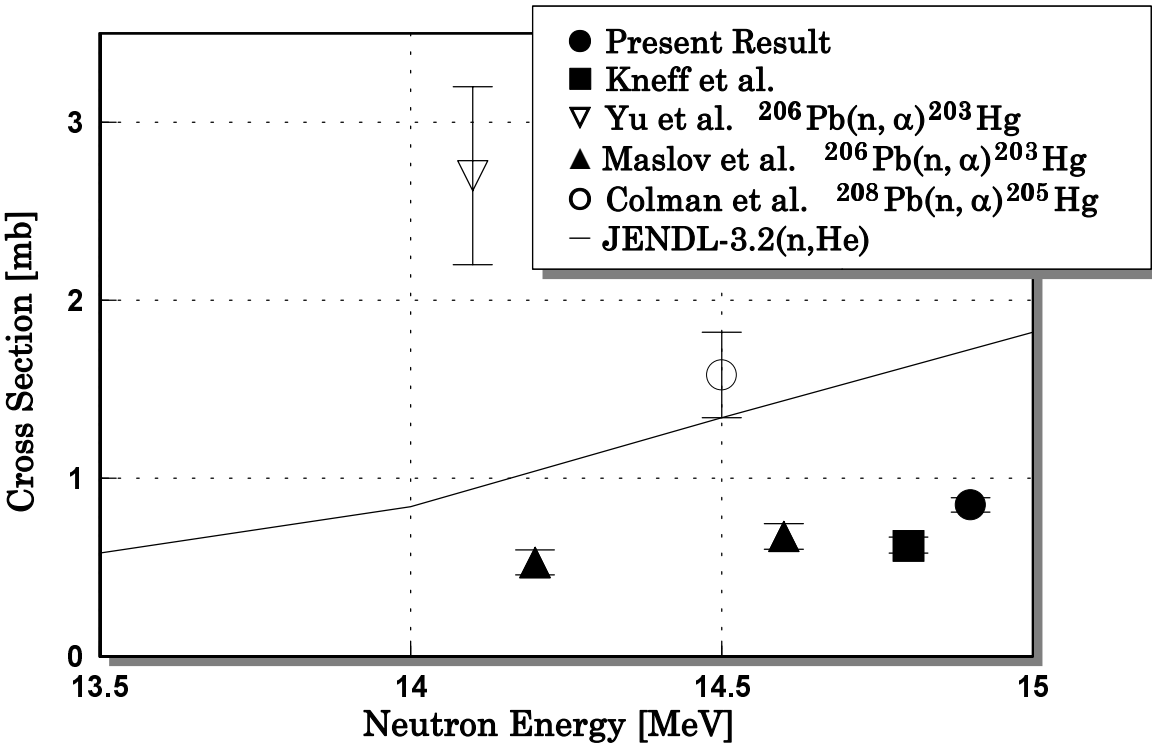

Fig.4. The measured result of Pb(n,He) cross section.

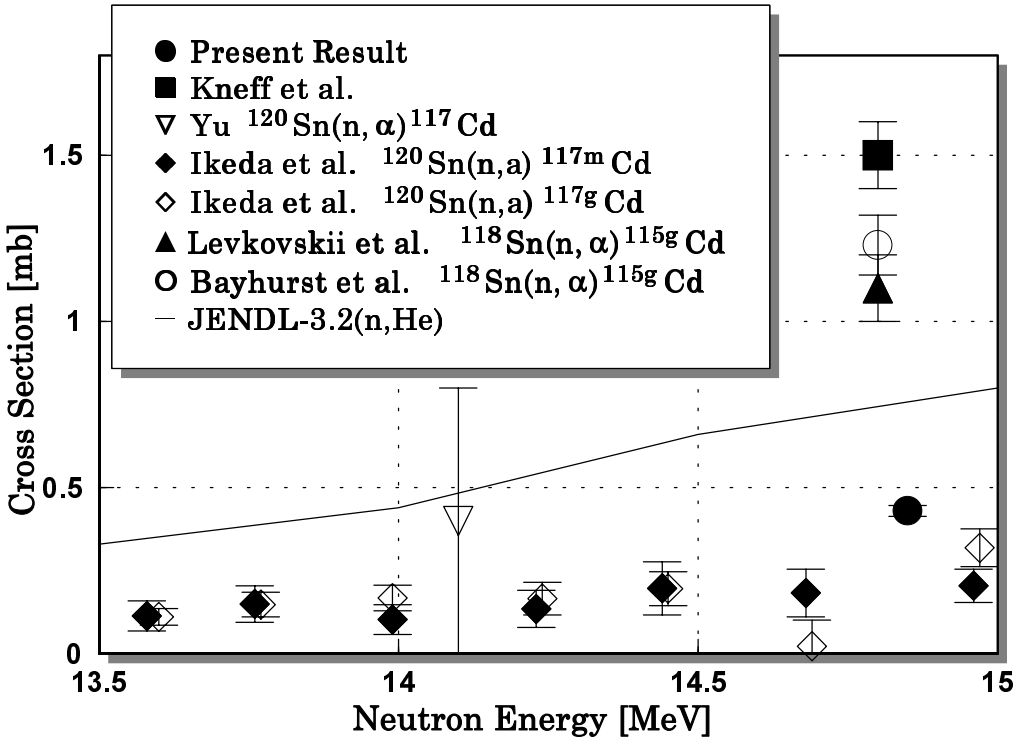

Fig.5. The measured result of Sn(n,He) cross section.