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DT Neutronics Benchmark Experiment on Lead at JAEA-FNS

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Lead is one of the most important candidate materials for nuclear fusion reactor blankets. We have carried out an integral benchmark experiment on lead at the DT neutron source facility of JAEA, FNS. A cubic lead assembly on a side of 45.3 cm was set up and was irradiated with the DT neutron source. Reaction rates of the ^{27}Al(n,α)^{24}Na, ^{93}Nb($n,2n$)^{92m}Nb, ^{90}Zr($n,2n$)^{89}Zr, and ^{115}In(n,n')^{115m}In reactions and neutron spectra above 2 MeV were measured inside the assembly with activation foil and a small NE213 spectrometer, respectively. A Monte Carlo code, MCNP5, was adopted to calculate the reaction rates and neutron spectra. The latest nuclear data libraries, JENDL-3.3 ENDF/B-VII.0, JEFF-3.1 and FENDL-2.1, were used in the calculation. The calculation results with the three libraries except for JENDL-3.3 agreed with the measured reaction rates and neutron spectra. On the other hand, that with JENDL-3.3 underestimated the measured ones with the depth. We found out that the inappropriate evaluation of the $(n,2n)$, elastic scattering and inelastic scattering reactions in the lead isotopes of JENDL-3.3 caused the disagreements

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I. INTRODUCTION

Lead is an important candidate material as a multiplier in nuclear fusion reactor blankets. In the past, double differential cross section data of lead have been measured with DT neutrons [1], but few DT neutron integral benchmark experiments were performed for lead. Therefore, we have carried out an integral benchmark experiment on lead at the DT neutron source facility of JAEA, FNS.

II. EXPERIMENT AND ANALYSIS

1. Experiment

A cubic natural lead assembly on a side of 45.3 cm was fabricated and was irradiated at 20-cm distance from the DT neutron source. Figure 1 shows a vertical cross sectional view of the lead experimental set up. A 14-mm φ spherical scintillation detector (NE213) was used for the measurement of neutron spectra above 2 MeV. The NE213 detector was set at 5 depth positions, 0, 10, 20, 30 and 40 cm in the center lead blocks of the assembly. Lead blocks with 21-mm φ hole were prepared for installing the NE213 detector into the assembly. Measured continuum signal spectra with the NE213 detector were unfolded with a code MAXED in UMG-3.3 [2] in order to obtain neutron spectra.

Reaction rates of the ^{27}Al(n,α)^{24}Na, ^{93}Nb($n,2n$)^{92m}Nb, ^{90}Zr($n,2n$)^{89}Zr and ^{115}In(n,n')^{115m}In reactions were measured with four kinds of activation foil (Al, Zr, Nb, In) as fast neutron spectrum indices at 5 depth positions, 0, 10, 20, 30 and 40 cm of the assembly. The assembly was irradiated for 6 hours under the DT neutron intensity of 1.5 x 10^{11} sec^{-1}.

2. Analysis

For the neutron transport calculation in the lead assembly, the Monte Carlo code, MCNP5-1.4 [3], was used with the following four nuclear data libraries, JENDL-3.3 [4], ENDF/B-VII.0 [5], JEFF-3.1 [6] and FENDL-2.1 [7]. The natural lead consists of ^{208}Pb (52.4%), ^{206}Pb (24.1%), ^{207}Pb (22.1%) and ^{204}Pb (1.4%) stable iso-

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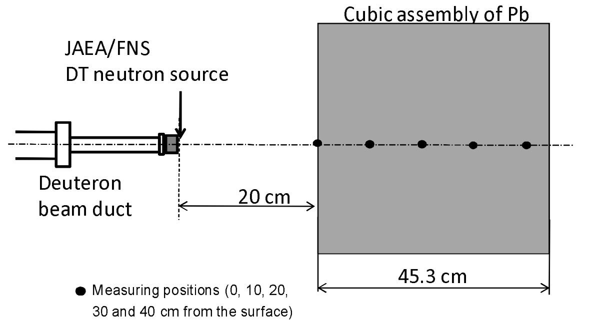

Fig. 1. Cross sectional view of Pb experimental set up.

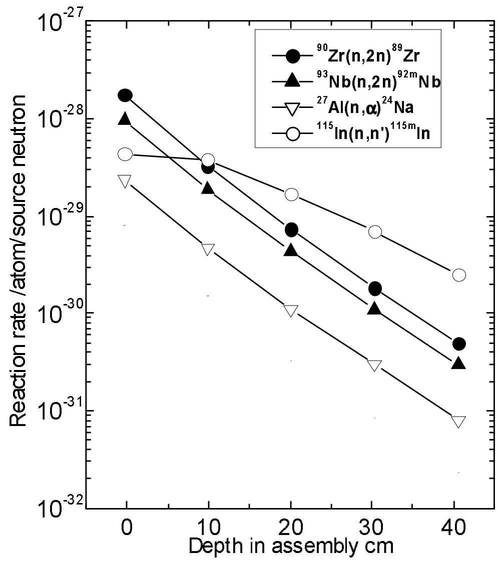

Fig. 2. Measured reaction rates in Pb assembly.

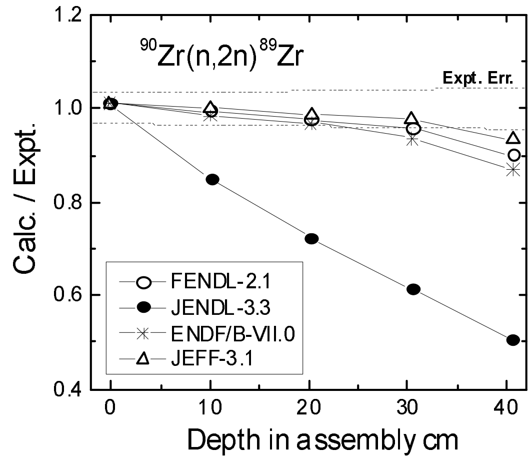

Fig. 3. C/E of ^{90}Zr$(n, 2n)^{89}$Zr reaction rate.

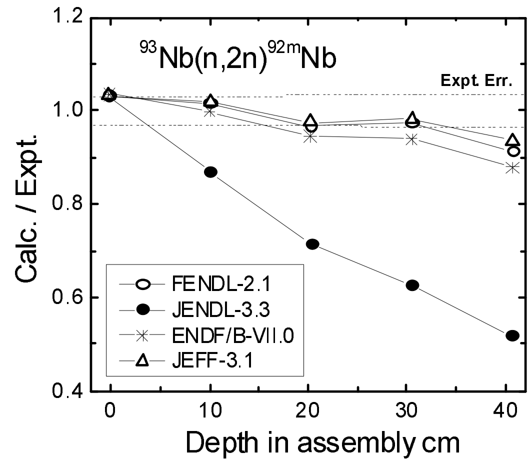

Fig. 4. C/E of ^{93}Nb$(n, 2n)^{92\text{m}}$Nb reaction rate.

topes. The ^{208}Pb data in ENDF/B-VII.0 is an original evaluation, while other lead isotopes in ENDF/B-VII.0 come from JEFF-3.1. The lead data in FENDL-2.1 are those in ENDF/B-VI.8. JENDL Dosimetry File 99 [8] was used as the response data of the reaction rate calculation.

III. RESULTS AND DISCUSSION

1. Reaction Rates of Activation Foil

Figure 2 shows the measured reaction rates. The reaction rates of the ^{90}Zr$(n, 2n)^{89}$Zr, ^{93}Nb$(n, 2n)^{92\text{m}}$Nb and ^{27}Al$(n,\alpha)^{24}$Na reactions decrease with the depth similarly. Since the ^{115}In$(n, n')^{115\text{m}}$In reaction is also sensitive to moderated neutrons, the tendency of the reaction rate is different from those of other reaction rates.

Figures 3 - 6 show ratios of calculated values to experimental ones (C/E) for each reaction rate, respectively. The calculation result with JENDL-3.3 underestimates all he reaction rates drastically with the depth. On the other hand, those with ENDF/B-VII.0, JEFF-3.1 and FENDL-2.1 agree with the measured reaction rates of the ^{90}Zr$(n, 2n)^{89}$Zr, ^{93}Nb$(n, 2n)^{92\text{m}}$Nb and ^{27}Al$(n,\alpha)^{24}$Na reactions well and slightly underestimate the measured reaction rate of the ^{115}In$(n, n')^{115\text{m}}$In reaction with the depth.

2. Neutron Flux

Figure 7 shows the measured neutron spectrum at 20-cm depth in the lead assembly as a typical result. The calculation results with JEFF-3.1 and JENDL-3.3 also are plotted in Fig. 7. Figures 8 and 9 show the C/E of the neutron flux deduced from the calculated and measured neutron spectra. This C/E tendency is similar with those for the reaction rates.

3. Problems in Lead Data of JENDL-3.3

We investigated why the calculation result with JENDL-3.3 underestimates the measured reaction rates and neutron flux drastically with the depth based on JEFF-3.1.

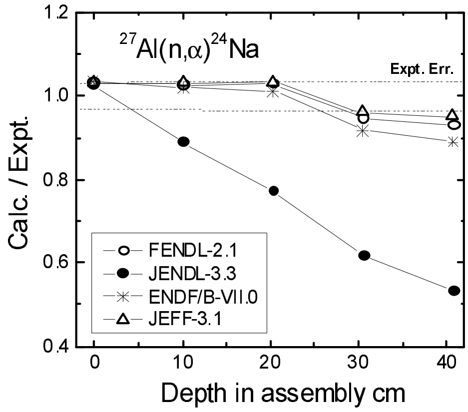

Fig. 5. C/E of ^{27}Al$(n,\alpha)^{24}$Na reaction rate.

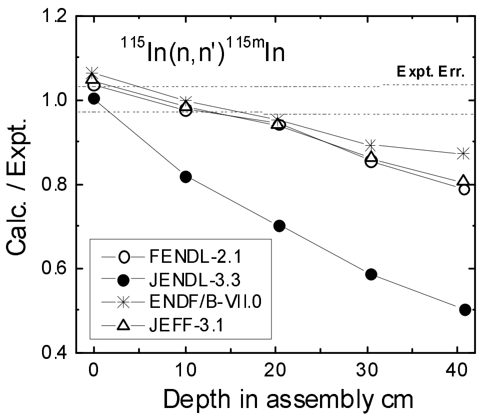

Fig. 6. C/E of ^{115}In$(n,n')^{115\text{m}}$ reaction rate.

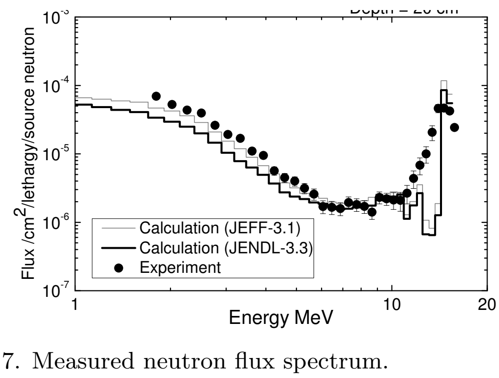

Fig. 7. Measured neutron flux spectrum.

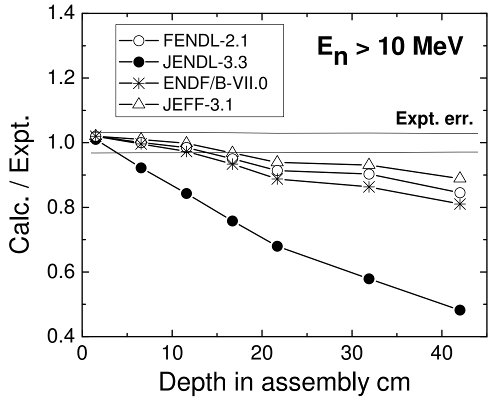

Fig. 8. Measured neutron flux above 10 MeV.

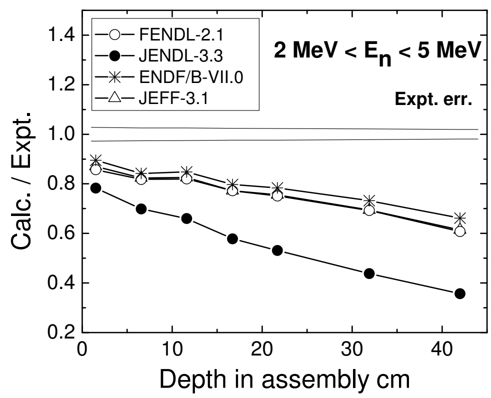

Fig. 9. Measured neutron flux from 2 to 5 MeV.

Figure 10 shows the comparison of $^{206,\,207\,\text{and}\,208}$Pb cross section data between JENDL-3.3 and JEFF-3.1. The $(n,2n)$ cross section data above 12 MeV of JENDL-3.3 is larger than those of JEFF-3.1, while the elastic scattering cross section data above 12 MeV of JENDL-3.3 is smaller than those of JEFF-3.1. Moreover the inelastic scattering cross section data of JENDL-3.3 are slightly different from those of JEFF-3.1.

In order to examine effects of difference between the lead data in JENDL-3.3 and JEFF-3.1 to C/E values, we modified the lead data of JENDL-3.3 tentatively and analyzed the experiment with the modified JENDL-3.3.

At first the $(n,2n)$ and elastic scattering cross section data of ^{206}Pb, ^{207}Pb and ^{208}Pb in JENDL-3.3 in the energy range between 11 and 14 MeV were reduced and increased by 16, 21 and 15%, respectively (JENDL-3.3mod1). Those of ^{204}Pb were not modified because the natural abundance is very small. Moreover we also replaced the inelastic cross section data of ^{206}Pb and ^{207}Pb in JENDL-3.3mod1 with those of JEFF-3.1 (JENDL-3.3mod2).

Figures 11 - 14 show the C/E with JENDL-3.3mod1 and JENDL-3.3mod2. The C/E of the ^{93}Nb$(n,2n)^{92\text{m}}$Nb reaction rate and neutron flux above 10 MeV with JENDL-3.3mod1 is similar to that with JEFF-3.1. On the contrary, JENDL-3.3mod1 is not sufficient for the ^{115}In$(n,n')^{115\text{m}}$In reaction rate and the neutron flux at the energy range of 2-5 MeV as shown in Figs. 12 and 14. The C/E of the ^{115}In$(n,n')^{115\text{m}}$In reaction rate and the neutron flux at the energy range of 2-5 MeV with JENDL-3.3mod2 is much closer to that with JEFF-3.1 than that with JENDL-3.3mod1.

It is concluded that the cross section data of the $(n,2n)$ reaction, elastic scattering and inelastic scattering of the lead isotopes in JENDL-3.3 are not adequate and should be revised based on this experiment.

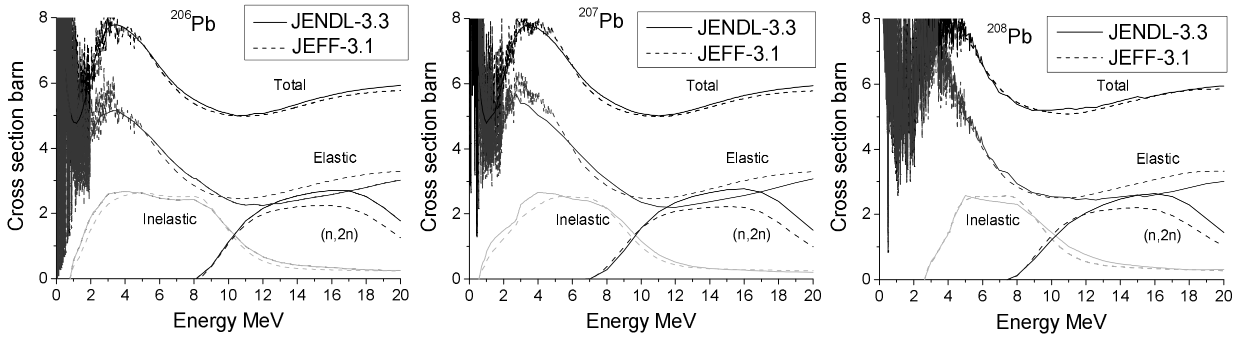

Fig. 10. Comparison of Pb cross section data between JENDL-3.3 and JEFF-3.1.

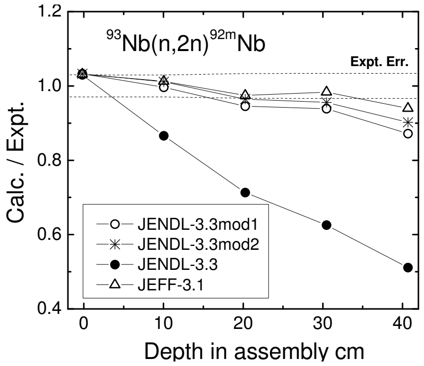

Fig. 11. C/E of ^{93}Nb$(n, 2n)^{92\text{m}}$Nb reaction rate.

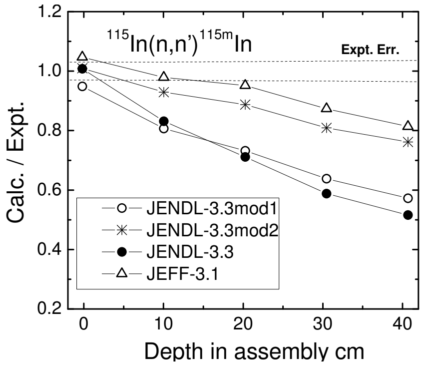

Fig. 12. C/E of ^{115}In$(n, n')^{115\text{m}}$ reaction rate.

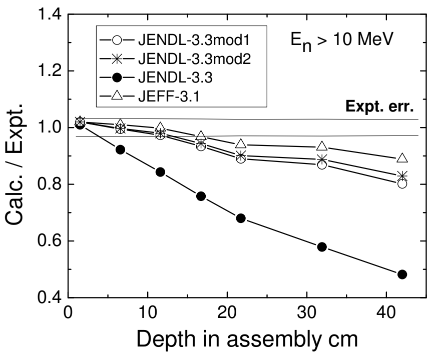

Fig. 13. C/E of neutron flux above 10 MeV.

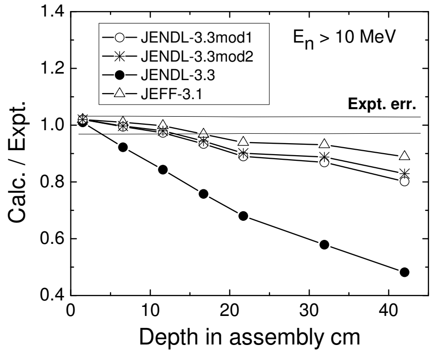

Fig. 14. C/E of neutron flux from 2 to 5 MeV.

IV. SUMMARY

We have conducted the lead benchmark experiment with the DT neutron source at JAEA-FNS. Four reaction rates and neutron spectra were measured with activation foil and a small NE213 detector, respectively. Validation of lead data in JENDL-3.3, ENDF/B-VII.0, JEFF-3.1 and FENDL-2.1 were carried out through the experimental analysis with the MCNP code. The calculation results with three libraries except for JENDL-3.3 agreed with the experimental data. It was pointed out that the cross section data of the $(n, 2n)$ reaction, elastic scattering and inelastic scattering of the lead isotopes in JENDL-3.3 were not adequate.

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