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INTEGRAL TEST OF JENDL-3T THROUGH BENCHMARK EXPERIMENTS USING FNS

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Abstract: A temporary file of JENDL-3 named as JENDL-3T was examined through the analysis of fusion blanket benchmark experiments at FNS of JAERI. The experiments were carried out on the cylindrical assemblies of lithium-oxide, graphite, lithium-oxide following a graphite reflector and beryllium-sandwich lithium-oxide. Measured quantities were tritium production rates, fission rates, reaction rates of foils and so on. The transport code DOT3.5 was used for the analysis. It becomes clear from this integral test that the most of calculated reaction rates agree well with the measured ones within 10 %. In the case of Be-sandwiched assembly, however, large deviations are observed between measured and calculated results near the Be-region. Reevaluation is recommended for the nuclear data of Be in JENDL-3T.

(fusion blanket, integral test, benchmark experiment, JENDL-3, Li, C, Be, O, DOT3.5)

Introduction

Experimental examinations are required to verify the accuracy of both calculational methods and nuclear data which are used in nuclear design and analysis of a fusion reactor. The most suitable experiments for this type of method and data verification are clean benchmark experiments on a simple geometry with simple material compositions. Series of integral experiments on four types of simple geometry assemblies[1-4] have been carried out using the Fusion Neutronics Source (FNS) facility[5].

As JENDL-2 was evaluated for applying mainly to fission reactors, the accuracy of data above 5 MeV was pointed out to be insufficient for fusion neutronics study. In order to analyze the experiments at FNS, the nuclear data of selected eight nuclei, ^{6}Li, ^{7}Li, ^{9}Be, ^{12}C, ^{16}O, Cr, Fe and Ni, were evaluated as JENDL-3PR1 by Dec. 1983. A revised version JENDL-3PR2 was released in March 1985. The data of ^{6}Li, ^{7}Li and ^{12}C were modified taking into account the result of Chiba et al.[6] Both files were used successfully for analyses not only of the integral experiments at FNS and OKTAVIAN of Osaka University but of the double differential neutron emission cross sections (DDX) measured at the Universities. Many reports related to the fusion neutronics experiments and analyses were presented in various meetings. Under this situation, a Specialists' Meeting on Nuclear Data for Fusion Neutronics was held in July 23-25, 1985 at Tokai Research Establishment of JAERI[7]. Those results were applied to the evaluation of JENDL-3.

In this paper, we examined JENDL-3T† through analysis of the benchmark experiments mentioned above.

Integral Experiments

The integral experiments have been carried out on Li_2O,[1] C,[2] Li_2O-C[3] and Be-sandwich Li_2O[4] assemblies. They are summarized in Table 1. Sectional view of the Li_2O-C assembly is shown in Fig. 1. Lithium-oxide, graphite and/or beryllium blocks were stacked in a frame made of thin-wall aluminium tubes to form a cylinder in the same manner for each of the four assemblies. The blocks of Li_2O were covered with 0.2mm-thick Type 304 stainless steel to isolate from air. The area equivalent diameter was 63 cm. The D-T neutron target was located at 20 cm from the front surface of the assembly on the central axis.

Table 1 Configurations of experimental assemblies.

Assembly	Material			
Region [cm]	0-5.08	5.08-10.16	10.16-40.64	40.64-60.96
Li_2O	← Li_2O →			
C	← C →			
Li_2O-C	← Li_2O →			← C →
Be-sandwich	←Li_2O→	← Be →	← Li_2O →	

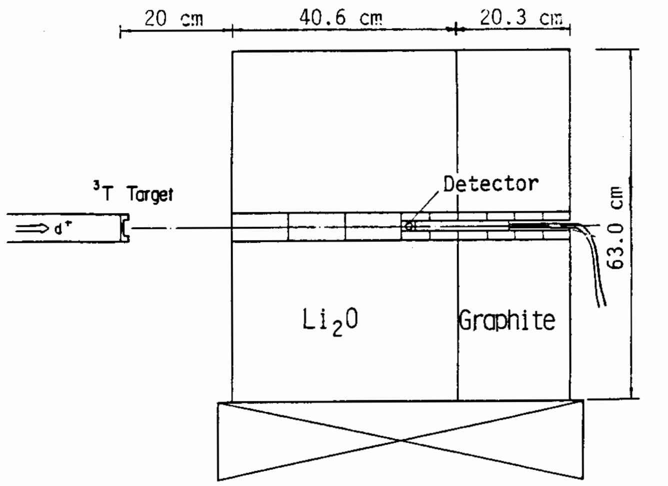

Fig. 1 Sectional view of experimental arrangement for Li_2O-C assembly.

Measured quantities and their methods are summarized in Table 2. The measurements were performed along the central axis. Neutron yields were determined by means of the associated α-particle detection method.[8]

† JENDL-3T is a temporary file for testing the evaluated data for JENDL-3. The data in JENDL-3T will be partly revised in JENDL-3.

Table 2 Measured quantities and their methods for integral experiments.

(1) Tritium production rates of ^6Li and ^7Li
- Liquid scintillation method with $^6Li_2O$ and $^7Li_2O$ pellets
- Self-irradiation method with LiF TLDs for Be-sandwich assembly
- ^6Li and ^7Li glass scintillators for T_6
- NE213 scintillator for T_7

(2) Fission rates
- Micro-fission chambers (mfc) (^{235}U, ^{238}U, ^{237}Np, ^{232}Th)
- Solid-state track detectors (SSTD) with ^{235}U, ^{238}U, and ^{232}Th foils except for Be-sandwich assembly

(3) Reaction rates
- Foil activation method
  - -- with Al, In, and Ni foils for Li_2O assembly
  - -- with Al, Au, In, Nb, Ni, and Zr foils
  - -- with Al, Au, Co, Fe, In, Mn, Nb, Ni, Ti, Zn and Zr

  for Li_2O-C and Be-sandwich assemblies

(4) Response of PIN diodes

(5) Response of TLDs (measured in Li_2O and C)
- TLD-600, -700, -100 ------- LiF
- UD-110S ------------------- $CaSO_4$
- Mg_2SiO_4, Sr_2SiO_4, Ba_2SiO_4

(6) In-system neutron spectra
- Small sphere NE213 spectrometer

Analysis

In the present analysis the DOT3.5 code[9] was used with the P_5-S_{16} approximation. The cross section set FSX125/J3T was obtained from the JENDL-3T file using the processing code PROF-GROUCH-G/B[10]. The feature is shown in Table 3. The same type group constants[11] based on JENDL-3PR1, -3PR2, ENDF/B-IV and -V (only for carbon) were used for comparison. The GRTUNCL code was used to calculate the first collision source for the succeeding DOT calculations. The calculational model for Li_2O assembly is shown in Fig. 2 with mesh numbers. Almost the same mesh-interval was applied to the other assemblies.

Table 3 Breakdown of group constant (FSX125/J3T).

Number of groups	: 125 for neutron
Process code	: PROF-GROUCH-G/B
Legendre coefficients	: P-5

Group	Energy	ΔU	Weight
1 ∿ 32 (32)	16.5 ∿ 10 MeV	0.015625	1/E
33 ∿ 60 (28)	∿ 1.74 MeV	0.0625	1/E
61 ∿ 96 (36)	∿ 19.3 keV	0.125	1/E
97 ∿ 108 (12)	∿ 961 eV	0.25	1/E
109 ∿ 124 (16)	∿ 0.32 eV	0.5	1/E
125	∿ 0.00001 eV	10.38	Maxwell

Results and Discussion

Li_2O Assembly

For the nuclear data of ^6Li and ^7Li in JENDL-3PR1 and -3PR2, pseudo-levels are adopted to reproduce the measured double differential cross section (DDX) data. The data of ^6Li in JENDL-3T are not changed from those in JENDL-3PR2. While the cross section of $^7Li(n,n't)^4He$ increases by about 8 % from that in JENDL-3PR2 to follow the data measured recently at JAERI and Osaka University. The data of ^{16}O are lacking in JENDL-2 and newly evaluated for JENDL-3. The ^{16}O data in JENDL-3T are modified from JENDL-3PR1 to reproduce the measured DDX data.

Typical calculation to experiment ratio (C/E) distributions are shown in Figs. 3 ∿ 5. In the case of tritium production rate (TPR) of ^6Li (T_6), C/E values based on JENDL-3T are a few percents higher than those based on JENDL-3PR2. The same result is observed for the C/E values of U-235 fission rate. On the other hand, C/E values of $^{27}Al(n,\alpha)^{24}Na$ based on JENDL-3T are a few percent lower than those based on JENDL-3PR2. The same situations are observed for the other threshold reactions. Most of calculated reaction rates based on JENDLs and ENDF/B-IV files agree well with measured ones within 10 %.

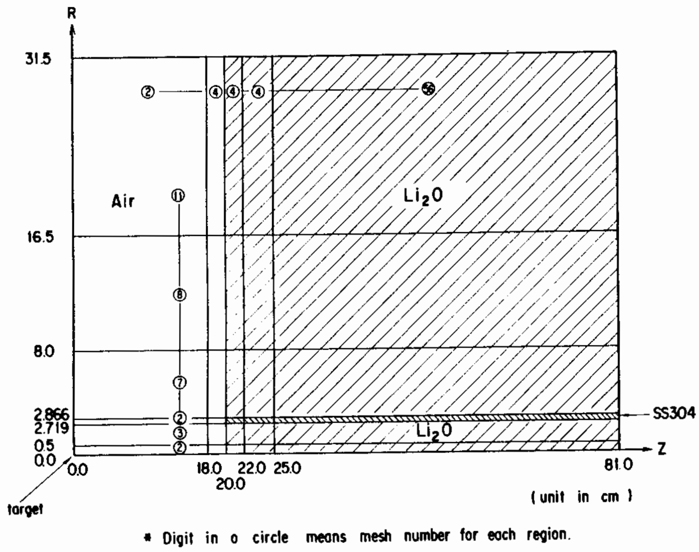

Fig. 2 Calculational model for Li_2O assembly.

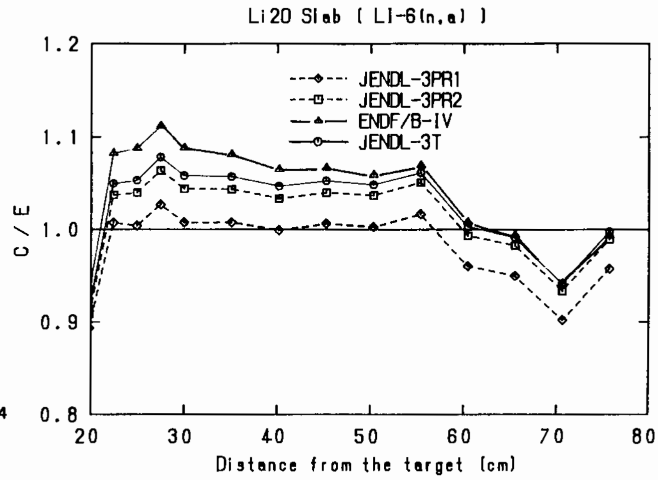

Fig. 3 Comparison of C/E values for tritium production rate of ^6Li in Li_2O assembly.

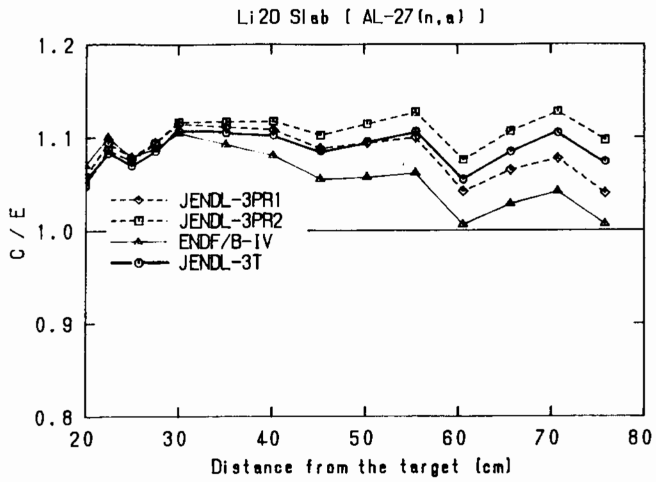

Fig. 4 Comparison of C/E values for $^{27}Al(n,\alpha)$ ^{24}Na in Li_2O assembly.

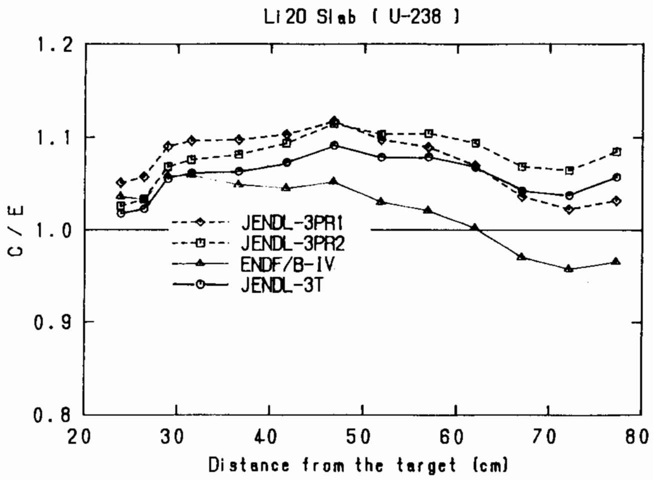

Fig. 5 Comparison of C/E values for fission rate of U-238 in Li_2O assembly.

Graphite (C) Assembly

Three discrete levels (4.43, 7.65, 9.64 MeV) were considered in the evaluation of ^{12}C in JENDL-3PR2. There is no change between JENDL-3T and -3PR2.

Only one sample, i.e., C/E distribution of $^{27}Al(n,\alpha)^{24}Na$, is shown in Fig. 6. The similar results were obtained for the other reaction rates. The calculation based on JENDL-3PR2 (-3T) shows an improvement comparing to that based on JENDL-3PR1.

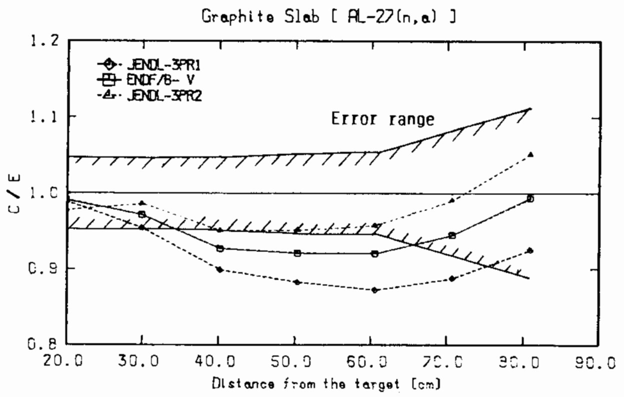

Fig. 6 Comparison of C/E values for fission rate of U-238 in graphite assembly.

Li_2O-C Assembly

Figures 7 and 8 show the C/E distributions for fission rates of U-235 and U-238, respectively. In the cases of reaction rates being sensitive to low-energy neutrons, there is a large discrepancy between experimental and calculated data near the graphite reflector, i.e., the calculation underestimate the low-energy neutrons reflected from the graphite region. While the agreements are very good for the threshold reactions between the experiments and calculations based on both JENDL-3T and -3PR2.

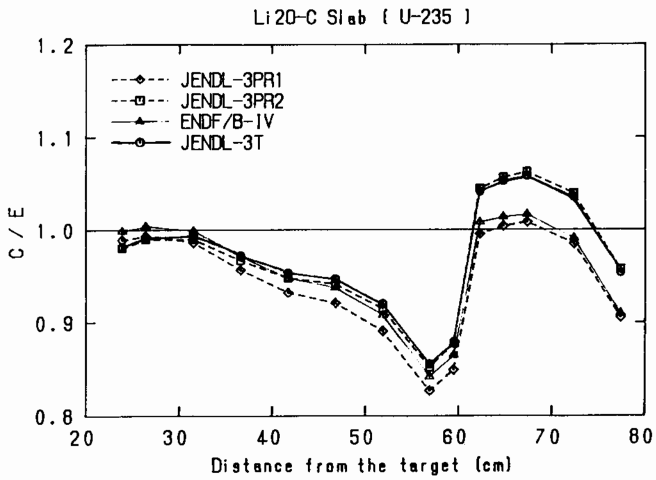

Fig. 7 Comparison of C/E values for fission rate of U-235 in Li_2O-C assembly.

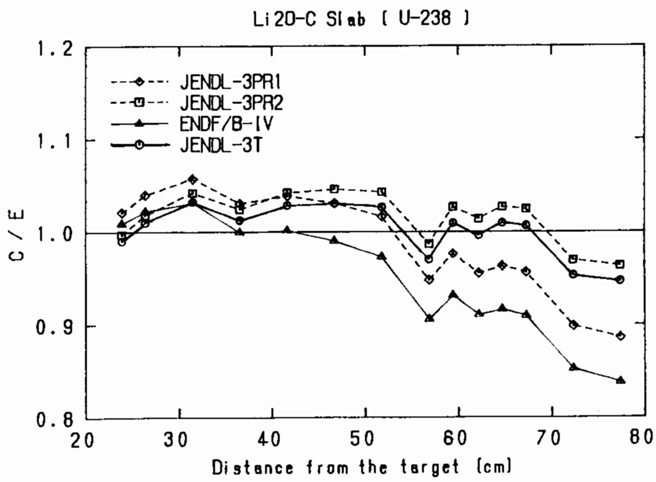

Fig. 8 Comparison of C/E values for fission rate of U-238 in Li_2O-C assembly.

Be-sandwich Assembly

The reaction of $^9Be(n,2n)^8Be$ was assumed as cascade decay in JENDL-3T. The elastic cross section of Be in JENDL-3T at 14 MeV is 3 % lower than that in JENDL-3PR1, while the inelastic cross section is higher by 10 %. The inelastic cross section for 6.8 MeV level in JENDL-3T is increased by a factor of two in comparison to that in JENDL-3PR1 and -3PR2.

The C/E distributions for T_6, T_7 and $^{115}In(n,n')^{115m}In$ are shown in Figs. 9 ∿ 11. There are large differences between the experimental and calculated data before and after the Be-region. The same results were found in the analyses of JAERI/USDOE Collaborative Program on Fusion Blanket Neutronics[12]. This fact suggests that the accuracy of Be data in JENDL-3T is insufficient for the assessment of tritium breeding ratio in a fusion blanket with beryllium neutron multiplier.

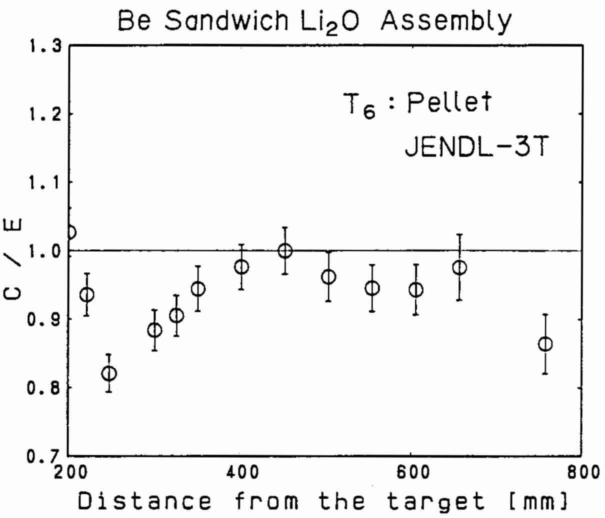

Fig. 9 Comparison of C/E values for T_6 in Be-sandwich Li_2O assembly.

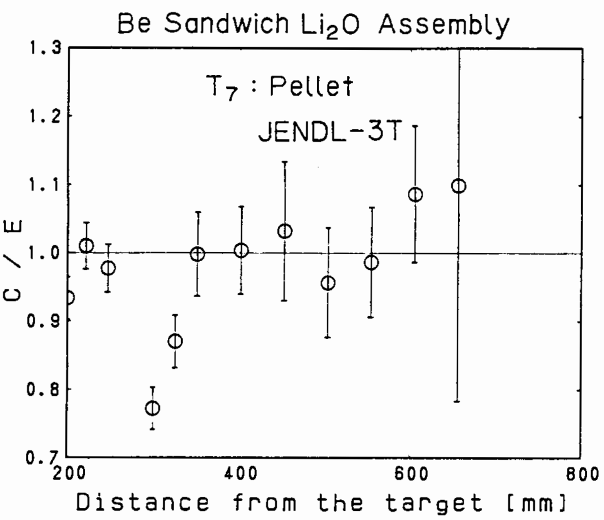

Fig. 10 Comparison of C/E values for T_7 in Be-sandwich Li_2O assembly.

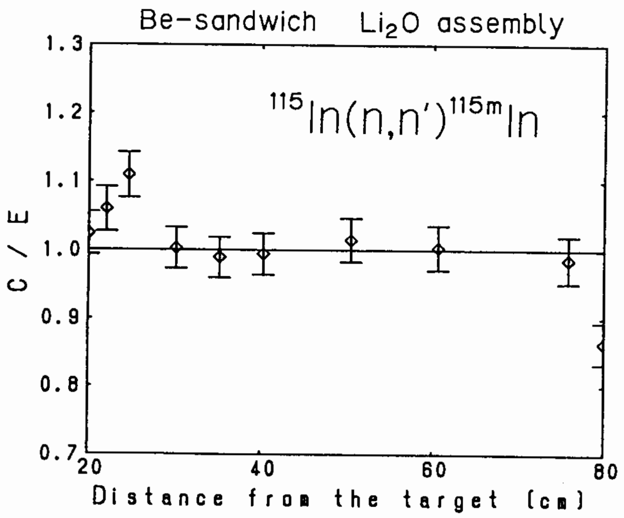

Fig. 11 Comparison of C/E values for $^{115}In(n,n')$ ^{115m}In in Be-sandwich Li_2O assembly.

Concluding Remarks

From the comparison between calculated and experimental results, the following facts are pointed out for JENDL-3T:

(1) Good agreement is observed within 5 ∿ 10 % for T_6 and T_7 in the Li_2O assembly. While in the Be-sandwich Li_2O assembly, the calculation does not reproduced well the measured data near the Be-region.
(2) Most part of C/E values deviate from unity by less than 10 %.
(3) The C/E values based on JENDL-3T for the reactions having high thresholds are lower than those based on JENDL-3PR2 by a few percents. On the other hand, the C/E values for reactions sensitive to low energy neutrons, such as T_6 and the ^{235}U fission rate, are higher by a few percents.

It can be concluded that the nuclear data of ^6Li, ^7Li, ^{12}C and ^{16}O in JENDL-3T are now good enough in accuracy of 5 ∿ 10 % for the calculation of integral values such as T_6 and T_7 in a typical fusion blanket without beryllium. On the other hand, beryllium is the most promising neutron multiplier. Reevaluation of Be data in JENDL-3T is recommended for the application to fusion blanket neutronics.

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