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INTEGRAL TEST OF NEUTRON CROSS SECTIONS IN FUSION ENVIRONMENT

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Abstract: Integral experiments in fusion environment have been carried out in a frame of JAERI-U.S. collaborative program on fusion blanket neutronics. In the experiment, a test region for blanket of Li_2O and the D-T source are enclosed by a Li_2CO_3 container in order to simulate well a fusion neutron field in the test regions with and without a beryllium multiplier in the front of it. The measured parameters are tritium production rates (TPRs) by ^{6}Li and ^{7}Li, neutron spectrum and various foil activation rates used in diagnoses of neutron field. The analysis of the experiments has been performed by using a Monte Carlo code MORSE-DD and 125 group set DDL/J3P1. The analysis indicates that the underestimation of ^{7}Li(n,n'α)t cross section in JENDL/3PR1 and the activation rate distributions with ENDF/B-IV are overestimated for Ni(n,p), Nb(n,2n) by 10 - 20 % and underestimated for Ni(n,2n) reactions by about 10 %. The newly measured cross sections, however, significantly decrease such discrepancies. A beryllium (n,2n) cross section seems to be reasonable.

(integral test, activation cross section, fusion neutron, beryllium, lithium oxide)

Introduction

In (d,t) and (d,d) fusion reactors, high intense neutrons are emitted and interact with various materials. Kinetic energy of neutrons are converted to thermal energy via nuclear heating process. Neutrons also produce tritium through the reactions ^{6}Li(n,α) and ^{7}Li(n,n'α) in a blanket region. Moreover, detection of neutrons is important as diagnoses of burning plasma. On the other hand, components of a reactor and workers should be protected from them. In this sense, shielding is important for neutrons and also for induced activity(e.g. gamma ray). Thus neutron interaction with materials must be well predicted in a design stage of fusion reactor. At present, however, accuracy of neutron cross sections are still unsatisfactory because neutrons produced in a fusion reactor have higher energy compared with those used in conventional fission reactors where many data have been accumulated. Therefore, differential measurement ,evaluation and integral test are mainly concerned for such high energy neutrons. At present work, the analysis of reaction rate measurements performed in fusion environment have been carried out for reactions which are important for diagnoses and tritium breeding and uncertainties of these cross sections have been examined. The present experiments have been performed in a frame of the JAERI/U.S. collaborative program on a fusion blanket.[1)]

Experiments and Calculation Method

The experiments have been performed by using the FNS facility at JAERI. To simulate fusion blanket environment, (d,t) neutron source and a Li_2O test zone have been enclosed in the Li_2CO_3 container as shown in Fig.1. At the inside of the container, various reaction foils have been set in order to characterize the neutron source. These reactions include ^{58}Ni(n,2n)^{57}Ni, ^{58}Ni(n,p)^{58}Co, ^{197}Au(n,2n)^{196}Au, ^{197}Au(n,γ)^{198}Au, ^{93}Nb(n,2n)^{92}Nb, ^{27}Al(n,α)^{24}Na which will be available for diagnoses of neutron source emitted in a plasma region. Additionally these foils were placed inside of the Li_2O test zone along axial direction to examine a prediction accuracy of activation rates in a blanket region depending on neutron spectrum. At the same time, the tritium production rate distributions have been measured along the same central channel. To investigate a multiplier effect, a beryllium plate with 5 cm thick has been placed in front of the Li_2O test zone and the similar measurements have been carried out as those in the reference system.

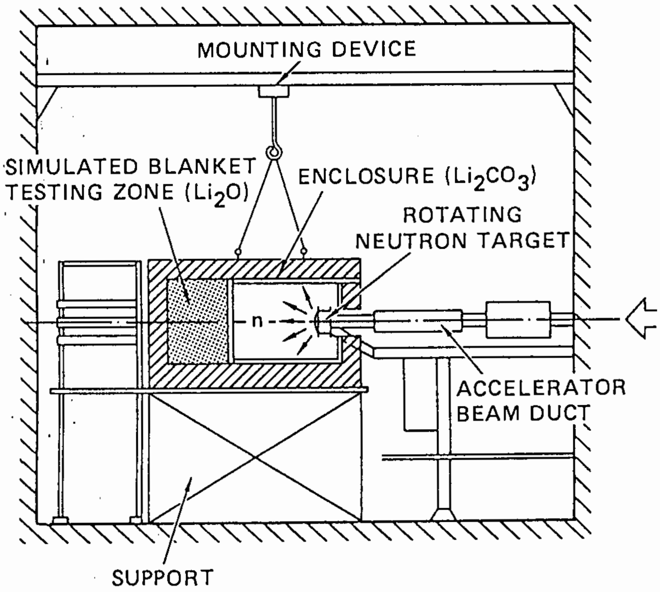

Fig.1 Phase II experimental system of JAERI/US collaborative program

In the analysis, a Monte Carlo code MORSE-DD[2)] was used for the transport calculations. The cross section set used was the 125 group double differential form library DDL/J3P1[3)] produced from JENDL-3/PR1. As the activation reaction cross sections, used were ENDF/B-IV and the new cross sections measured at the FNS by Ikeda et al.[4)] (named as the FNS file). The threshold cross sections are compared in Fig.2. The (n,2n) reactions are mainly contributed from the highest energy region of fusion source and the (n,α) and (n,p) reactions are from the lower energy region. The experimental system was modeled in three dimension for Monte Carlo calculations to simulate the actual configuration of the assembly, as precisely as possible. The energy and angular distribution of the neutrons generated at the D^+ beam spot has been calculated based on the formula of Benveniste et al.[5] and the reaction kinematics.

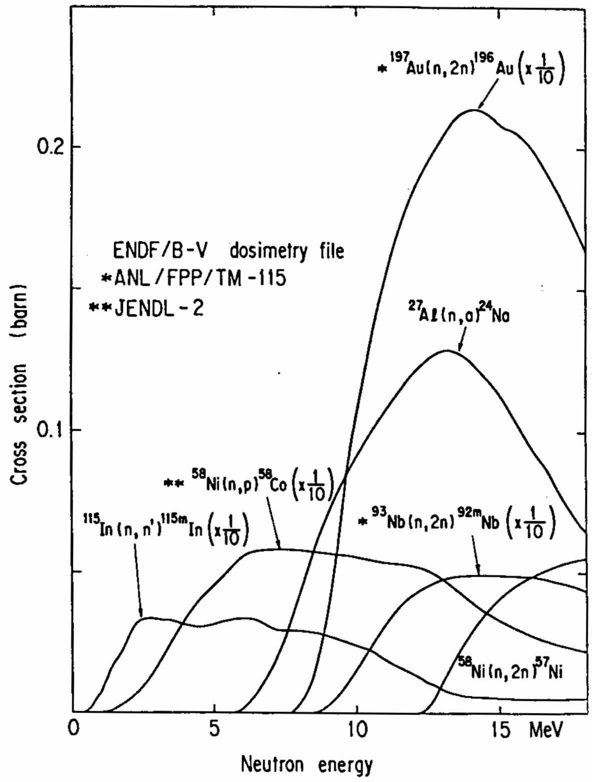

Fig.2 Threshold reaction cross sections

Activation Rate on the Surface of the Assembly

Activation rate on the Li_2CO_3 container

On the surface of Li_2CO_3 container, the activation foils are irradiated mainly by neutrons of energy 13 - 15 Mev. Therefore, such a neutron field is similar to that at the first wall of a fusion reactor. The measured and the calculated activation rates are compared for the reactions mentioned above. The map of ratios of calculated to measured(C/E) values are shown in Figs.3,4 and 5 which present the values at the same level as the RNT from the floor. Figure 3 shows the C/E values of ^{197}Au(n,2n) reaction calculated with ENDF/B-IV data. The agreement between the measurements and the calculations is very good within the statistical error (1σ=3 - 5%) of the Monte Carlo calculations. In Fig.4, the C/E values of ^{58}Ni(n,2n) reaction with ENDF/B-IV and the FNS files are compared. In general, ENDF/B-IV gives the smaller C/E values by 10% than unity,on the other hand the FNS cross sections significantly reduce the discrepancy, especially in the forward region of the RNT. This suggests that the energy dependence of cross sections for ^{58}Ni(n,2n) are different between these two files and ENDF/B-IV will underestimate it at the higher energy region. With respect to the ^{58}Ni(n,p) reaction, ENDF/B-IV overestimates the measured values by 10 - 20% as seen in Fig.5 although this reaction is often used as a standard threshold reaction to characterize a high energy neutron field with a fission source. Nevertheless the accuracy of this cross section in fusion neutron energy region is still unsatisfactory in ENDF/B-IV or -V. On the other hand, the FNS file improves the discrepancy though we can see still a slight overestimation. Further measurement is necessary for this reaction ,especially in the energy region, a few - 12 MeV. In the back locations of the RNT, large deviation of the C/E values from unity are observed in these figures. These are due to inaccuracy in the modelling of the equipment that surrounds the

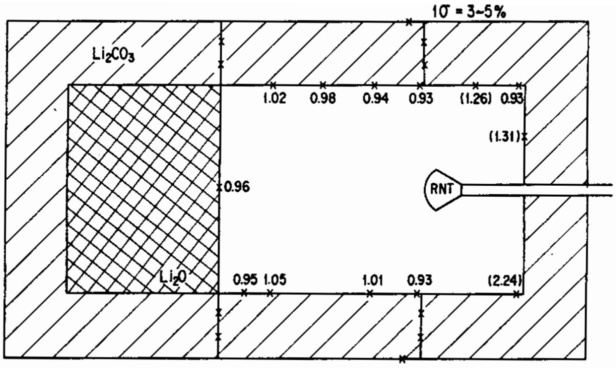

Fig.3 The C/E map for ^{197}Au(n,2n)^{196}Au activation rates at the inner surface of the container

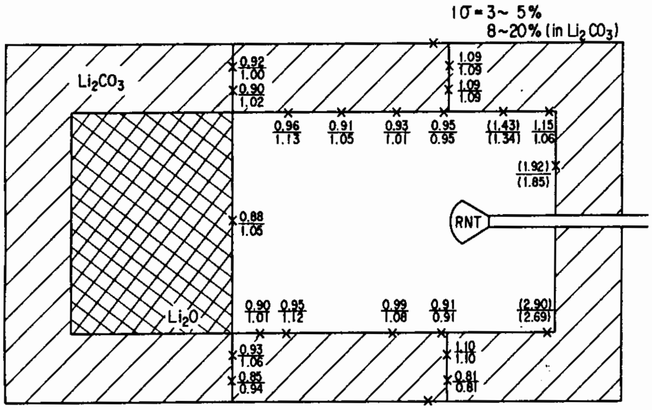

Fig.4 The C/E map for ^{58}Ni(n,2n)^{57}Ni activation rates at the inner surface of the container. The upper and lower values are calculated with ENDF/B-IV and FNS files, respectively.

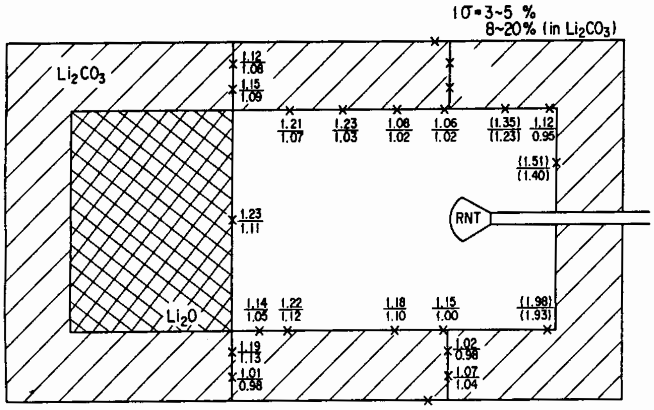

Fig.5 The C/E map for ^{58}Ni(n,p)^{58}Co activation rates at the inner surface of the container. The upper and lower values are calculated with ENDF/B-IV and FNS files, respectively.

RNT(e.g. a motor, position and compositions of tubes containing cooling water).

Activation rate on the surface of Li_2O test zone

The test zone consisting of Li_2O with and without a beryllium multiplier is positioned in the forward direction to the RNT as seen in Fig.1. To investigate the prediction accuracy of incident neutron intensity in detail, similar foils discussed above were placed across the surface in vertical and horizontal direction. Figures 6 and 7 show the distributions of C/E values for the ^{27}Al(n,α) and ^{197}Au(n,2n) reactions. At the all points, the calculations agree well with the measurements and hence these reactions will be able to accurately predict neutron intensity in diagnoses of fusion neutron source. In the case of ^{58}Ni(n,2n) reaction, the same trend shown in Fig.4 can be observed on the surface of test zone. ENDF/B-IV underestimates the activation rates by 10% in contrast with the FNS files which can predict fairly well them. For the ^{93}Nb(n,2n) reaction, ENDF/B-IV gives higher C/E values than unity but the FNS cross sections does very close values to unity as shown in Fig.8.

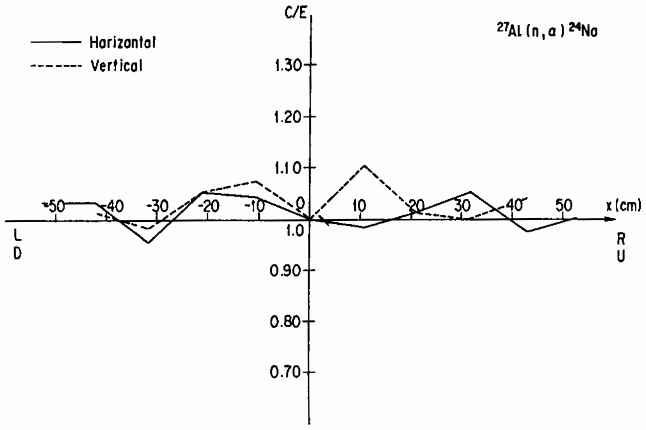

Fig.6 The C/E values for ^{27}Al(n,α)^{24}Na activation rates on the surface of Li_2O test zone

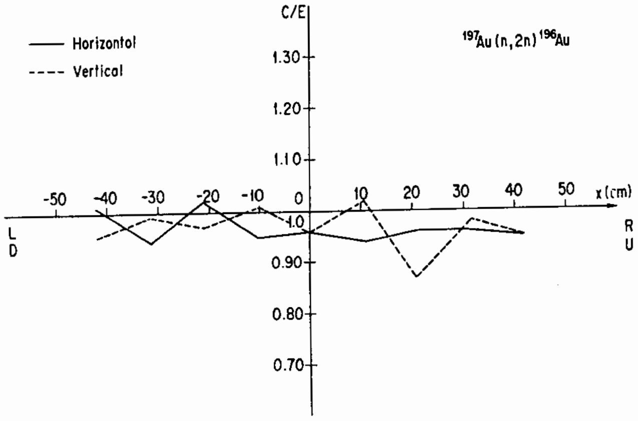

Fig.7 The C/E values for ^{197}Au(n,2n)^{196}Au activation rates on the surface of Li_2O test zone

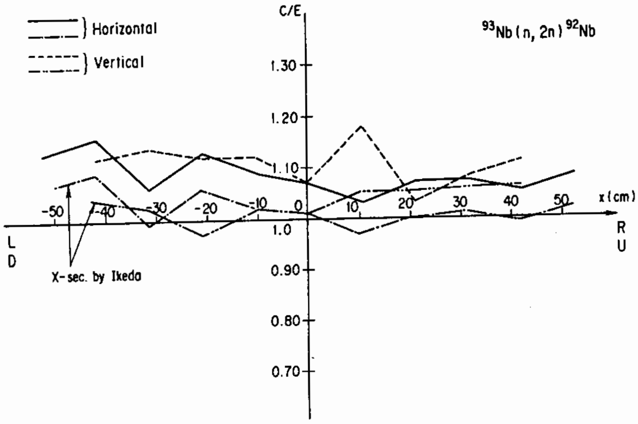

Fig.8 The C/E values for ^{93}Nb(n,2n)^{92}Nb activation rates on the surface of Li_2O test zone. The calculated values are based on ENDF/B-IV and FNS files.

Activation Rates in the Li_2O Test Zone

The activation rate distributions have been measured along the central channel of the Li_2O test zone with and without a beryllium multiplier. The reaction types measured are ^{58}Ni(n,2n), ^{58}Ni(n,p), ^{197}Au(n,2n), ^{197}Au(n,γ), ^{115}In(n,n'), ^{7}Li(n,n'α) and ^{6}Li(n,α). Since these reactions have different threshold energy and neutron spectrum softens as seen in Fig.9, where a component of neutron flux above 10 MeV is shown, with increasing distance from the front surface, a comparison between the measurements and calculations will provide useful information on the energy dependence of these cross sections and on the lithium and oxygen cross sections. In Fig.10, a comparison of the C/E values is made for the ^{58}Ni(n,p) reaction rates. The FNS file gives the closer C/E values to unity than those with ENDF/B-IV cross sections throughout the all zone. The C/E values by ENDF/B-IV are higher by several percent compared with those with the FNS file. The C/E values for ^{7}Li(n,n'α) reaction rates is presented in Fig.11, which have been calculated with use of DDL/J3P1 cross section. Apparently, this reaction rate is underestimated by about several to 10% even in the front region. Accordingly, the ^{7}Li(n,n'α) reaction cross section seems to be too small by several percent. We can see a trend for both reactions that the C/E values decrease with increasing distance from the front surface, that is, these tend to be smaller in the region with softer neutron spectrum than in the region with harder one.

Figures 12 and 13 show the C/E values of ^{58}Ni(n,2n) and ^{27}Al(n,α) reactions for the system with and without a multiplier where beryllium is placed at the distance 5 - 10 cm from the front surface. We can see that the C/E values are closer to unity for the reference system compared with the system with beryllium of which C/E values are smaller than those in the reference system. Such a difference will be caused from improper energy spectrum of secondary neutrons emitted by (n,n') and/or (n,2n) reaction with beryllium. However, a neutron multiplication due to (n,2n) reaction of beryllium is convinced to be fairly well predicted by the analysis of tritium production rate. It can be also seen that the same trend as the ^{58}Ni(n,p) and ^{7}Li(n,n'α) reactions on space dependence is observed in these reactions. Such a trend suggests that lithium oxide has too large total cross section or cause overmoderation for neutrons at high energy region because all of these reactions are threshold type ones. In the case of nonthreshold type reaction such as the ^{197}Au(n,γ)^{198}Au reaction, the spatial dependence is almost flat throughout the all zone.

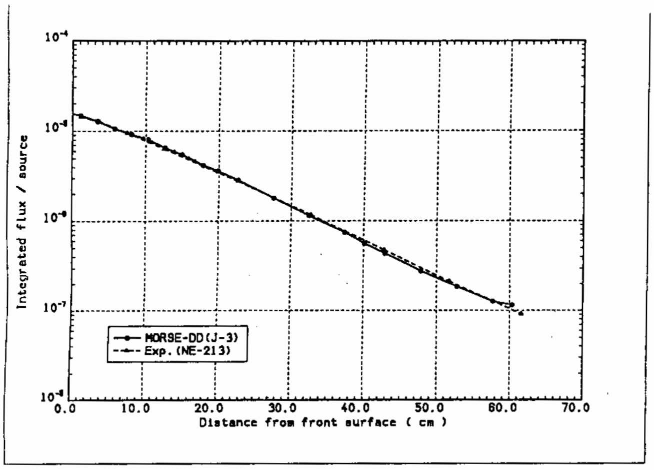

Fig.9 Neutron spectrum component above 10 MeV in the reference system

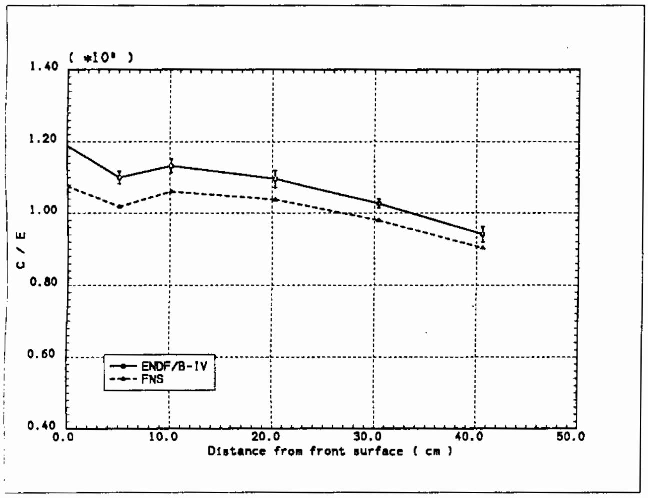

Fig.10 The C/E values for ^{58}Ni(n,p)^{58}Co activation rates along the central axis of the test zone. The calculated values are based on ENDF/B-IV and FNS files.

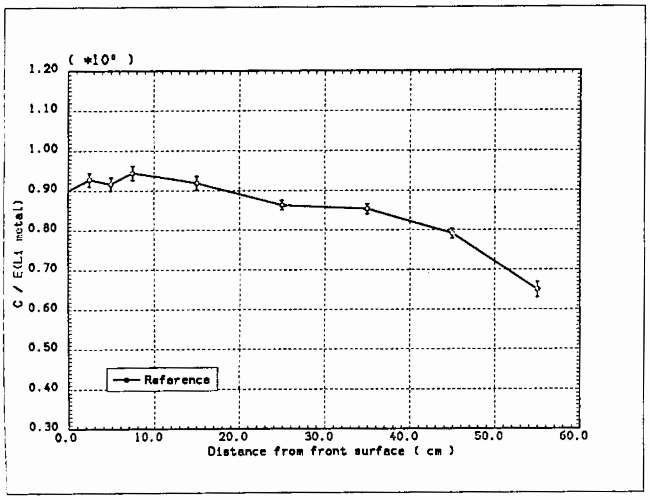

Fig.11 The C/E values for ^{7}Li(n,n'α) reaction rates along the central axis of the test zone.

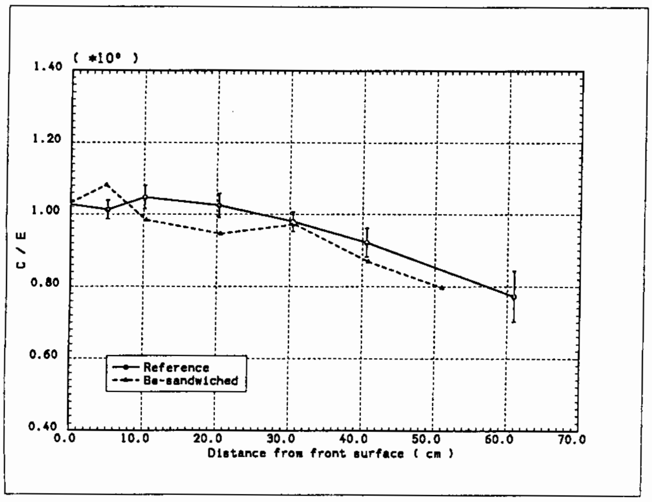

Fig.12 The C/E values for ^{58}Ni(n,2n)^{57}Ni activation rates along the central axis of the test zone with and without a multiplier.

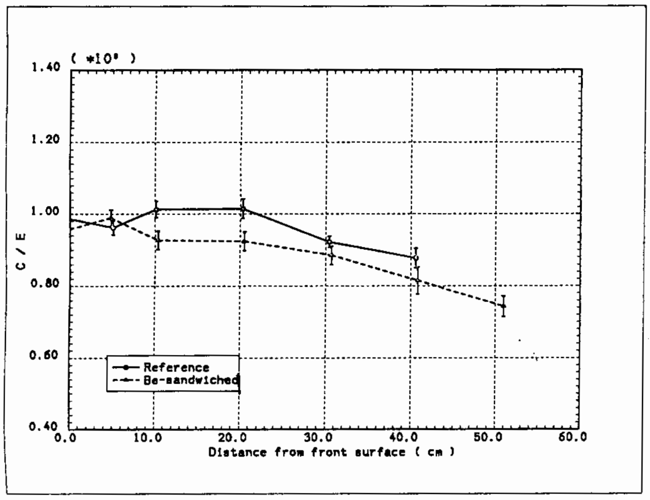

Fig.13 The C/E values for ^{27}Al(n,α)^{24}Na activation rates along the central axis of the test zone with and without a multiplier.

Summary

The analysis of integral measurements in fusion environment has been performed by using a Monte Carlo method and JENDL3/PR1 library. Various types of activation rates have been calculated based on ENDF/B-IV and the new cross sections measured at the FNS and compared with the measurements. The latter cross sections can reduce significantly the discrepancies which are observed about the calculated values with ENDF/B-IV.

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