Phase III experimental results of JAERI/USDOE collaborative program on fusion neutronics

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A pseudo-line D–T neutron source has been developed with new experimental techniques. This line source was applied in sophisticated neutronics experiments for an annular blanket arrangement simulating the tokamak geometry, as a new series in the JAERI/USDOE collaborative experimental program on fusion neutronics. The source characteristics of the present line source and the measurements for an annular assembly are described. The discussion on the experimental results focuses on the tritium production rate measured in an annular blanket and comparisons were made with the previous point source experiment, and also between the annular blankets with and without an armor reflector of graphite.

1. Introduction

A series of JAERI/USDOE collaborative experiments are planned to examine the design margins of neutronics parameters in fusion reactor development by an integral experiment. The margins due to the uncertainty in the calculation are dominated by deficiencies in nuclear data, calculation methods and modeling. The previous experimental series were performed for a simulated test blanket using a point D–T neutron source [1]. In such a geometry, the neutron behavior is essentially spherical symmetric, i.e. the spatial distribution of the neutron flux is overall dominated by an r^2-law, while a tokamak type reactor has essentially a cylindrical spatial distribution of neutrons. This means that the weight of the neutronic parameters at the front part of the blanket decreases compared to the point source case. In addition, since the incident angle of neutrons coming into the reactor components is distributed, neutronics characteristics of the components close to the plasma such as armor and first wall are sensitive to the source geometry.

The present paper describes the experimental system for a pseudo-line source, its characteristics [2], and the measurement on an annular blanket [3], briefly. The discussion focuses on the measured results of tritium production in the annular blanket. The measured data are compared between the systems with point and line sources, and between the systems with and without an armor of graphite, including the most recent results. The calculational analysis for the experiment is given separately [4].

2. Concept and characteristics of the pseudo-line source

The concept of line source and annular blanket is the natural demand for the neutronics experiment to simulate well the fusion reactor environment relevant to a tokamak or a mirror device. However, line sources have not been realized yet, because the previously proposed system [5] is rather complicated at the technical point and needs an amount of material to construct the test blanket. Actually the solid breeder material

lithium oxide is rather expensive and our inventory is not enough. By introducing the concept of a moving point source, a time averaged line source was realized easily. A forth and back motion of the test blanket relative to the point source was applied to get the moving source by step or continuous driving of the experimental deck on which the test blanket was placed. The problem of material inventory was solved by using an Li_2CO_3 buffer zone which was cheaper and contains lithium. Figure 1 shows the conceptual arrangement of the experiment with the line source. In this concept, the moving mode is strongly connected to the measurement techniques applied. The on-beam techniques such as NE213 and Li-glass scintillation detectors were applied with a stepwise motion and synchronized data acquisition. The detectors requiring heavy irradiation, such as activation foil and tritium production measurement by the liquid scintillation method, were applied with continuous motion, integrating the response over the range of motion.
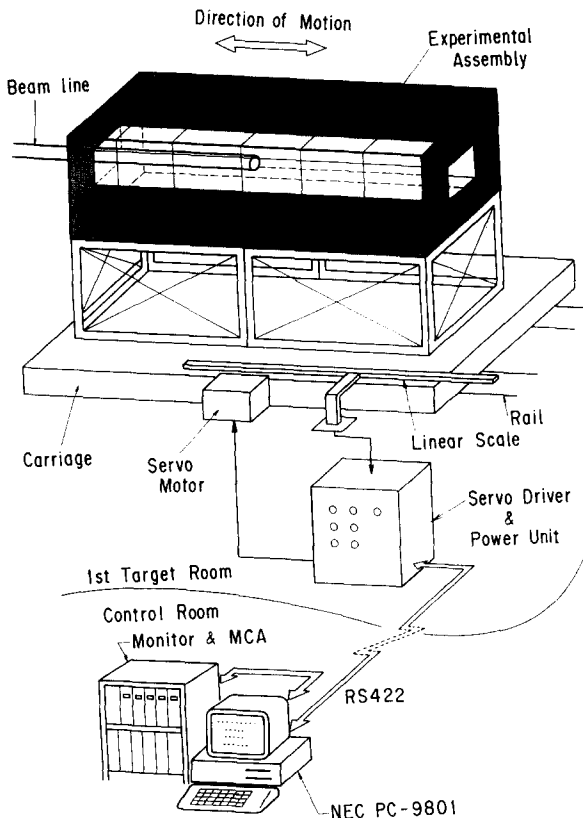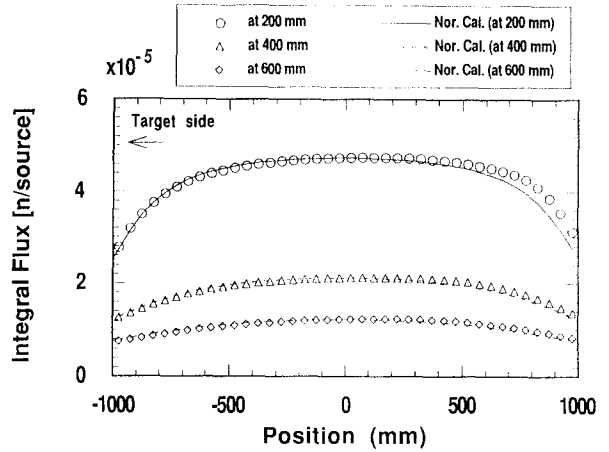

Fig. 2. Measured neutron flux distribution along the line source. The solid curves show the analytical calculation of the isotropic finite line source which is normalized to the experimental values.

The feasibility of a moving point source to realize a line source is discussed in the previous paper [6]. The calculation showed that a number of distributed point sources can simulate a line source within allowable accuracy. An interval of 100 mm pitch is enough to simulate a continuous line source.

To obtain a better line source, the target assembly was made as light as possible especially near the reaction point by adopting a cap type structure. The drift tube was made to be 2.3 m long without support stand to be able to insert it into the annular assembly. The characteristics of the neutron field around this simulated line source was measured by both a NE213 detector with the stepwise mode and activation foils with the continuous mode. The flux map obtained by the NE213 is shown in fig. 2 together with a calculation of the simple isotropic case. The actual flux is lower than the calculation because of scattering by the target backing material. The energy spectrum of neutrons emitted from the DT fixed-point target varies with the emission angle. The peak energy is 14.8 MeV in the forward and 13.6 MeV in the backward direction. Thus the present line source has an asymmetry of the neutron spectrum between both ways of motion.

3. Annular blanket experiments

The annular blanket was simulated by a rectangular tube shape as shown in fig. 1. The blanket consists of a

Fig. 1. Concept of the Phase III experiment.

15 mm thick first wall of type 304 stainless steel, 200 mm thick Li_2O solid breeder and a 200 mm thick Li_2CO_3 buffer zone, shown in fig. 3. The axial length is 2040 mm. The internal cavity surrounded by the first wall is made with a rectangular cross section of 425 mm × 425 mm. The fixed DT source moves relatively on the central axis of this cavity. The Li_2CO_3 zone was used to reduce the material cost keeping similar neutronic performance to the Li_2O. Both materials are made of blocks and the total weight is 5.7 ton. The

Li_2O blocks are covered with 0.3 mm stainless steel. The three radial experimental channels to insert the detectors are placed in both sides of the test blanket. The first experiment (Phase IIIA) has been carried out using this arrangement, while second one, as Phase IIIB, is designed so as to simulate the reactor with a graphite armor. The 25 mm thick graphite plates are placed inside the first wall for that experiment.

The measurements of the tritium production rate were performed with the indirect method using the
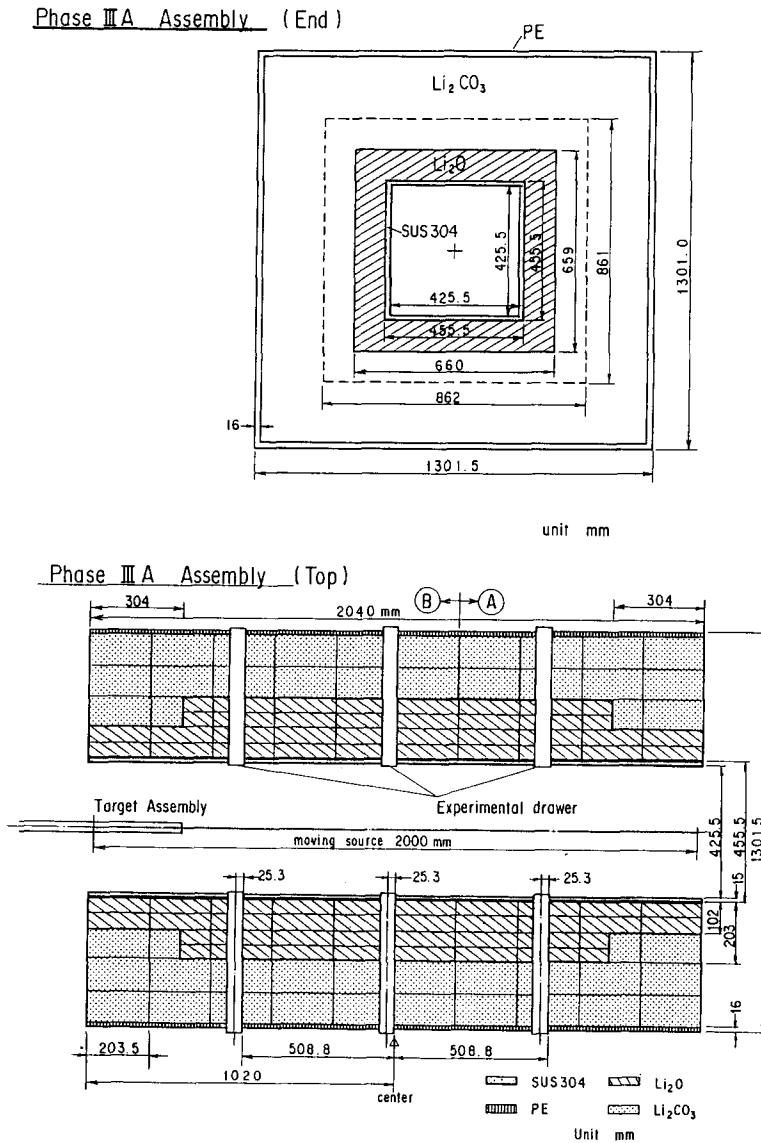

Fig. 3. Annular test blanket assembly for Phase III.

NE213 scintillator and with the subtraction method using a pair of Li-glass scintillators and with the step-wise moving mode. The liquid scintillation technique for irradiated Li_2O pellets was applied with the continuous moving mode. For the neutron spectrum, the NE213 and the proton recoil gas proportional counter were applied, and for reaction rates, the activation foil technique was adopted. While for gamma-ray heating, a thermo-luminescence detector (TLD) was applied. Most of the techniques applied here were developed in the previous phases [6]. For the on-beam method such as scintillation counters, the stepwise mode and position-wise data taking were carried out so as to obtain source position dependent data [2]. The step length was 100 mm and the measurement time was 300 to 500 s for each position. For the continuous mode, the moving speed was about 6 mm/s and the data of the neutron yield monitor was recorded every 10 s. The moving control and data acquisition were controlled by an NEC-PC9801 desk-top computer.

For the irradiation experiments it should be noticed that the stepwise scheme is not applicable since those experiments need much time and should give results by one irradiation. This requires the continuous moving mode. In the continuous mode, the response by reactions such as activation is integrated over the irradiation time, when the neutron flux at the detector varies with the source positions. For this experimental mode, the time dependent correction scheme for a nonuniform source caused by variations of the position and neutron emission rate of the source was also applied here. This correction can be generally extended to the detector used in heavy irradiation with the continuous mode such as the pellet method for tritium production measurement.

4. Results and discussion

The source position-wise tritium production rates were obtained using both scintillator methods. The result for ^6Li (T_6) are shown in fig. 4. This profile shows the importance of each source position to T_6 at the location of interest in the blanket, while the integral of the profile gives T_6 for the line source. The source position-wise profile for T_7 almost follows by an r-squared law of the distance between the source and the detector positions, because the high-energy neutrons from the source incident directly on the detector. But for T_6, the profile is broader than that expected by an r-squared law. This reflects directly the effect of the line source and annular system.
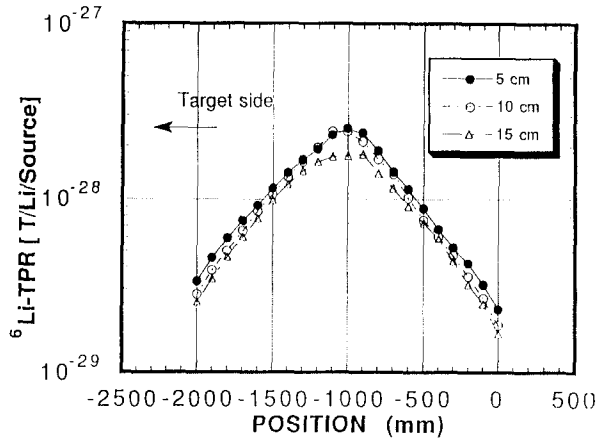

Fig. 4. Tritium production rate of ^6Li for each source position in the step moving mode at various detector positions in the center drawer of the test blanket.

Figure 5 compares the T_7 results with the Phase IIA results [7] in which the point source was used. In the figure, the positions of the Phase IIA results are adjusted so as get a corresponding distance from the surface of breeder zone. The Li_2O zone of Phase IIA is 600 mm in depth and without the first wall. One can see that the gradient of the present result is similar at the deep positions but steeper at the front. This is also caused by difference of the source geometry. It also can be pointed out that the front part blanket near the plasma be comes more important for the line source. The same type of comparison is made for T_6 as shown in fig. 6. In this case, the gradient in the annular system is rather flat at the front. It is seen in fig. 4 that the source far from the detector contributes to T_6 at
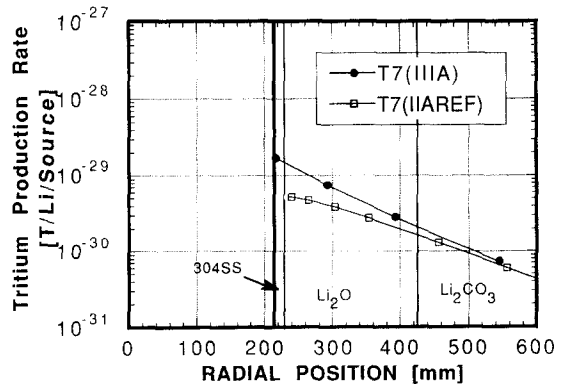

Fig. 5. Measured T_7 distribution in the central drawer in comparison with the Phase-IIA results with the point source.
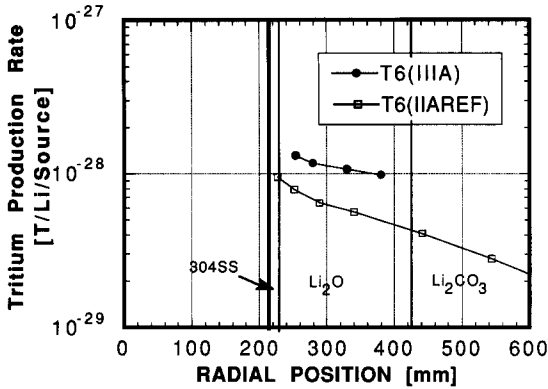
Fig. 6. Measured T_6 distribution in the central drawer in comparison with the Phase-IIA results with the point source.
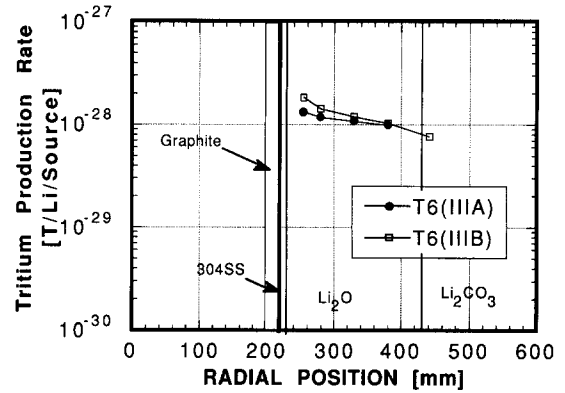

Fig. 8. Measured T_6 distribution in the central drawer for the reference (IIIA) and the armor (IIIB) systems.

deep positions as well as at front positions. This can explain the flat distribution in the annular system.

The effect of the line source also appears in the neutron spectrum at the surface of the test blanket. The high-energy neutron spectra of both the point (Phase IIA) and the line source (phase IIIA) are compared in fig. 7. One can see that both spectra are different in the peak energy and width. The spectrum of Phase IIA is peaking at 14.8 MeV because the test blanket is placed in front of the target, and the energy of neutrons emitted forward is 14.8 MeV by a kinematics relation. On the other hand, the line source spectrum is produced by neutrons emitted forward and backward, so the superposed spectrum is composed of neutrons with an energy from 14.6 MeT to 13.6 MeV.
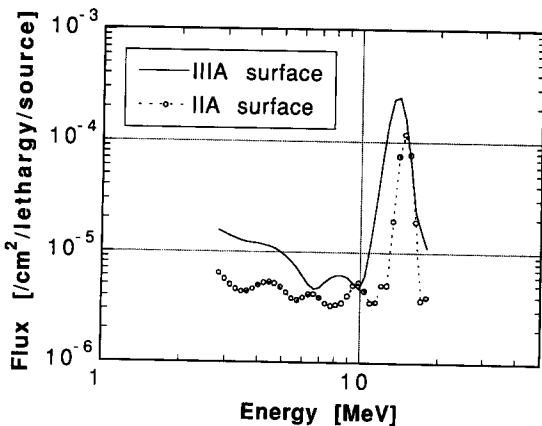
This makes the spectrum twice as broad as that of the point source and shifts the peak energy of Phase IIIA.

The comparison of T_6 with the IIIB-system lined by a graphite armor is shown in fig. 8. Since the cavity surrounded by the graphite armor changes the DT neutron energy to be lower than for the IIIA (reference) system, T_6 increases at the front zone of the blanket by 30–40% as seen in the figure. At the back, the values of T_6 in both cases do not make any difference. For T_7, the values decreases by about 10% in the whole region. Thus the total tritium production increases slightly at the front.

5. Conclusions

An experimental system with a pseudo-line source and annular blanket has been developed with a moving point source. Two types of source moving mode were utilized to perform the on-beam and the heavy irradiation experiments. The neutron field characteristics of the present line source was confirmed experimentally. The neutron distribution was flat enough to simulate the line source features, but the flux was asymmetric at both end positions. The neutronics parameters in the Li_2O test blanket were measured and compared to the point source results of the previous Phase IIA experiment. The results showed clearly the difference due to the effects of the line source. The armor arrangement also showed the effect of energy shift by slowing down. The present measured results will be compared with calculations to test the capability of the current calculational code and nuclear data system in a further study.

Fig. 7. Measured high-energy neutron spectrum at the surface of the test blanket in comparison with the result in Phase-IIA.

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