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Overview of the latest experiments under the JAERI/USDOE collaborative program on fusion neutronics

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The JAERI/USDOE collaborative program is going on using the FNS facility at JAERI. The phase-III is a new series on tritium breeding measurements with a totally different experimental arrangement from the previous ones that used a point neutron source geometry. The new series basically consists of an annular test blanket and a pseudo-line source to investigate the effect of source spread on the neutronic performance. A concise description is made on the features of the simulated line source, the test blanket systems for phase-IIIA and -IIIB, measured items, experimental results, and their analysis. Within the same program, nuclear heating rate, gamma-ray activities and resultant energy releases have been measured to provide experimental data for safety related issues. A comparative study was also performed among the phase-I, phase-II and phase-III.

1. Introduction

The JAERI/USDOE collaborative program started in 1984 with the objectives:

(1) to establish new experimental methods for design supportive neutronics experiments,
(2) to provide experimental data for the assessment of accuracies of nuclear data, calculational methods and response functions used in the fusion reactor design, and
(3) to develop neutronics technology for the design and testing of next D–T burning fusion devices.

The program is divided into three phases depending on the basic concepts of the source and test blanket configurations.

In the phase-I program, the basis was laid for engineering-oriented benchmark experiments, measuring technique developments and analysis comparison using slab type test blanket assemblies embedded in the experimental port [1,2]. The phase-II program was characterized by a closed geometry with a slab type test blanket and the neutron source housed in a reflective enclosure. This arrangement gave a good matching to the neutron spectrum in a fusion reactor blanket. These provided extensive data on breeding characteristics of Li_2O and the beryllium neutron multiplication effect in different configurations [3–7].

The phase-III program is motivated by a need to investigate the effect of the source distribution on the neutronic performance. While the phase-II concept is excellent to see the spatial distribution over the full blanket thickness, the point source arrangement presents a limitation in simulating the angular distribution of an extended source. The structure of the experimental program at FNS as seen from experimental systems and neutron source arrangements is illustrated in fig. 1

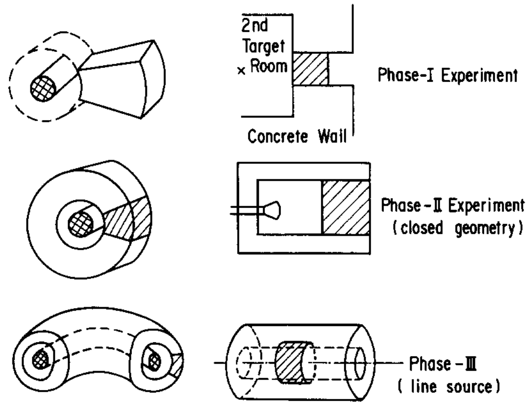

Fig. 1. Stages for the simulation of the neutron source and blanket configuration in the JAERI/USDOE collaboration program.

in connection with the corresponding area of interest in fusion reactor blankets.

2. Features of the line source

The line-source facility was installed in the target room No. 1 of FNS. The general concept illustrated in fig. 2 has been planned and was set up in the floor plan of the FNS building. An annular test blanket is assembled in a frame that is mounted on a heavy load carriage deck. The carriage shuttles back and forth on the rails so that a tritium target mounted on the tip of a long-size slim beam duct virtually travels along the central axis of the cavity inside the test blanket from one end to the other. With time averaging over a certain period, a uniform intensity line source is simulated. The following two modes are applied to the experiments:

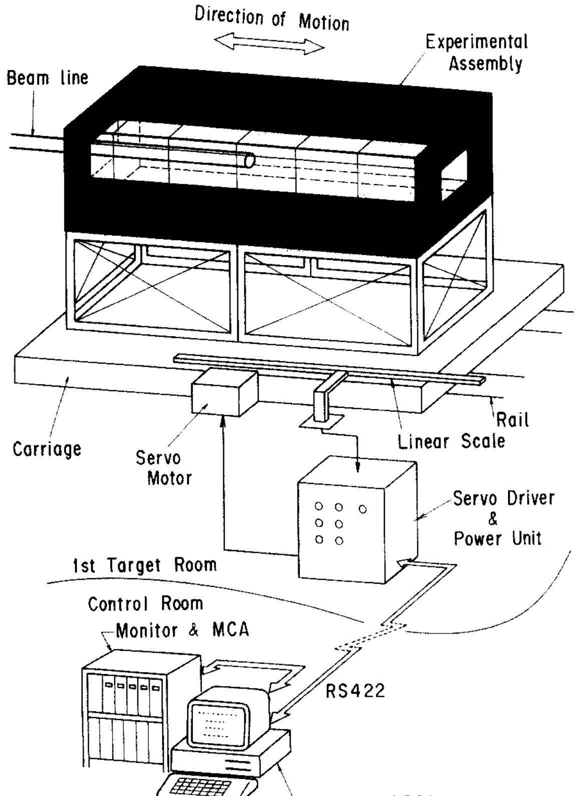

Fig. 2. General layout for the FNS line source arrangement.

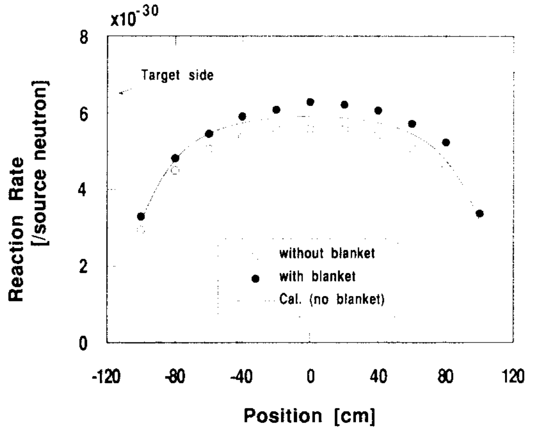

Fig. 3. Measured and calculated reaction-rate distributions for $^{27}Al(n, \alpha)^{24}Na$ with and without the phase-IIIA assembly.

Continuous mode

In the continuous mode, the experimental assembly repeats the shuttle motion at the constant speed of 6.2 mm/s except near the turning points at both ends of 2 m stroke. It takes 11 min for a complete cycle. This mode is adopted in off-line measurements, i.e., irradiation of activation foils, Li_2O samples and thermoluminescence dosimeters (TLD). Because these methods generally require high neutron fluence the stepwise mode is impracticable. A sample of measured and calculated reaction-rate distributions is shown in fig. 3 [9].

Stepwise mode

In the stepwise mode, the measurement is performed periodically at equi-spaced points over the 2 m length. This mode is applied to the on-line measurements, i.e., the technique using a high sensitive detector such as NE213 spectrometer, proton-recoil counter and Li-glass scintillator. Measured data are taken for each source position separately thus giving the importance of the different source positions to the overall result. By the control of a personal computer the assembly is positioned with an accuracy of 1 mm. The discrete source point measurements are corrected for the effect of neutron yield variation and are synthesized to obtain a line source equivalent result.

3. Phase-IIIA and -IIIB experiments

The first experiment of the phase-IIIA series has been performed with the FNS line-source and an annu-

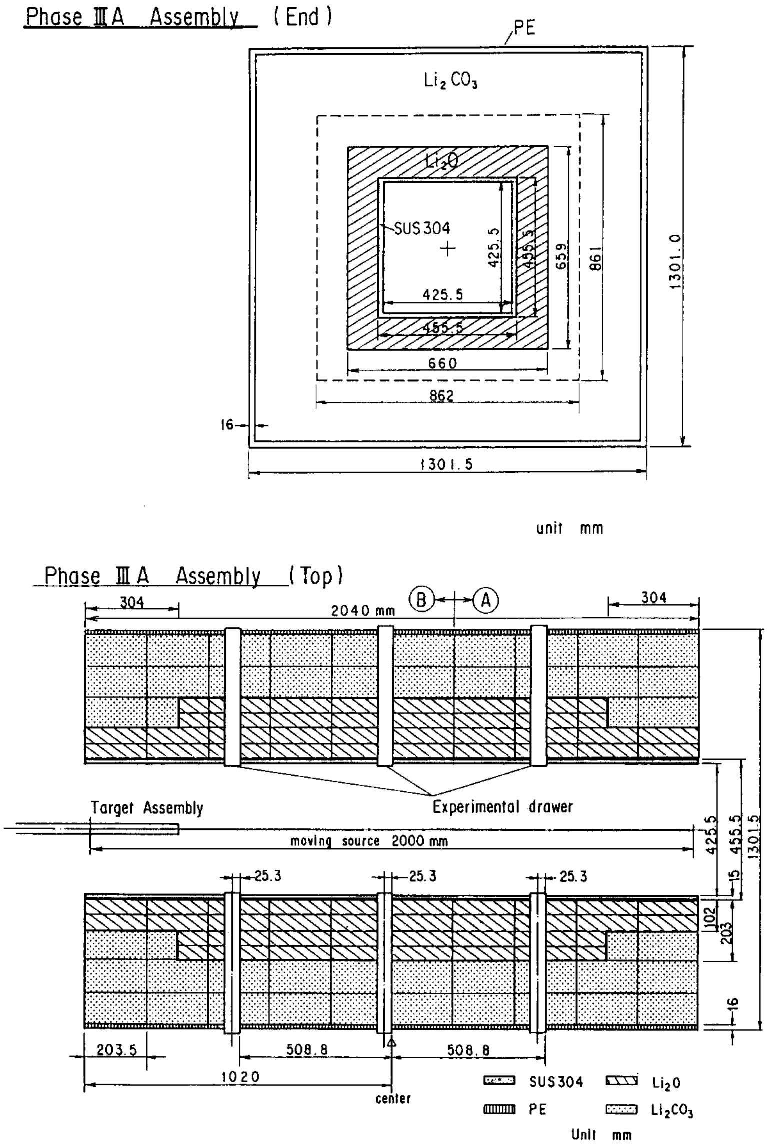

Fig. 4. Annular blanket assembly for phase-IIIA.

lar symmetrical blanket configuration in order to achieve a better approximation to a prototypical fusion reactor environment such as a toroidal geometry than was obtained in the previous series with the point source [10]. The objectives of phase-IIIA are to establish the experimental method for the present pseudoline source, to develop the necessary measurement techniques, and to find better approaches for calculational modeling and analysis.

The purpose of the second experiment phase-IIIB is to investigate the effect of a graphite armor on the tritium production rate.

3.1. Experimental arrangement

The simulated annular blanket of phase-IIIA is made of lithium-oxide and lithium-carbonate blocks as shown in fig. 4. The blanket region basically consists of a 0.2 m thick Li_2O and a 0.2 m thick Li_2CO_3 layer, which are 2 m long. The weight of Li_2O and Li_2CO_3 used is about 1.2 and 3.7 ton, respectively. A layer of 15 mm thick SS304 stainless steel is placed on the inner of surface to simulate a first wall. The blanket assembly is covered with 16 mm polyethylene and fixed in an aluminum structure.

Six experimental channels are provided in both sides for setting detectors and samples. The channel is a pair of 0.2 mm thick SS304 square tube and drawer, in which special type blocks such as the block having a hole for a detector or sample are loaded. Detector holes of 30 mm diameter are also provided in the inner face of the first wall region in order to place the samples, e.g., TLDs and foils.

In the case of phase-IIIB, a graphite layer of 25 mm covered the inner rectangular surface of the first wall region of the so-called annular assembly used in phase-IIIA experiments.

3.2. Measured items

In order to characterize the line source with the blanket assembly [9], activation foils were set at the holes in the first wall region.

The in-system neutron spectrum was measured by a small-sized NE213 scintillation detector in the high-energy range and with proton-recoil proportional counters for low energies. The tritium production rates of ^{6}Li and ^{7}Li were measured by on-line methods using a pair of ^{6}Li- and ^{7}Li-glass scintillation detectors, and using the NE213 detector. A multi-data acquisition system was applied to these on-line techniques. Namely, three of the NE213 detectors or four of the Li-glass detectors were operated in parallel.

The tritium production rates were also measured by $^6Li_2O$, $^7Li_2O$ and $^NLi_2O$ pellets. Various reaction rate distributions in the assembly were measured by activation of foils. The foil activation technique with this continuous mode calls for an additional correction of decay for short-lived nuclei during the irradiation [9].

Gamma-ray heating rate was measured by the interpolation method with TLDs and by the weighting function method with NE213 detector [3].

3.3. Experimental analysis by JAERI

The source neutron spectrum in 125 energy groups was calculated by MORSE-DD [11] for every 5 degrees using an accurate model of the target assembly. To simulate the line source, i.e., to distribute the angle-dependent point source on the z-axis, the FNSUNCL code was written for DOT3.5 [12] calculations by modifying the GRTUNCL code. The P_5S_{16} approximation was used in the calculations. In the calculational model, the square-shaped cross section was represented by circles. In the case of the Monte Carlo code MORSE-DD, a random sampling module was added to obtain the line source. The group constants of FUSION-J3 (125-groups for neutrons and 40-groups for gamma-rays) and DDXLIB-J3 were prepared from JENDL-3 for DOT3.5 and MORSE-DD, respectively.

3.4. Experimental analysis by the US

The incident neutron spectrum from the target was calculated separately by the MCNP Monte Carlo code. The result was used as input for the RUFF first collision source and DOT5.1 codes. The RUFF code was similar to the FNSUNCL code. The MATXS5 library of 30-group based on ENDF/B-V version 2 was used in P_3S_8 approximation.

3.5. Typical results and discussions

The measured tritium production rate (TPR) of ^{6}Li is shown in fig. 5 along the central drawer for Li-glass and Li_2O pellet methods. A good agreement is observed between the two methods except for the front data. Since there is a high amount of gamma-rays coming from the first wall region, the data of Li-glass at the front position have large errors due to an over-subtraction of the gamma-ray contribution. Reaction rate distribution curves along the central drawer decrease exponentially with a steep gradient for high threshold reactions such as ^{58}Ni(n, 2n) and ^{90}Sr(n, 2n), whereas the curves of the ^{6}Li(n, α) ^{3}T and

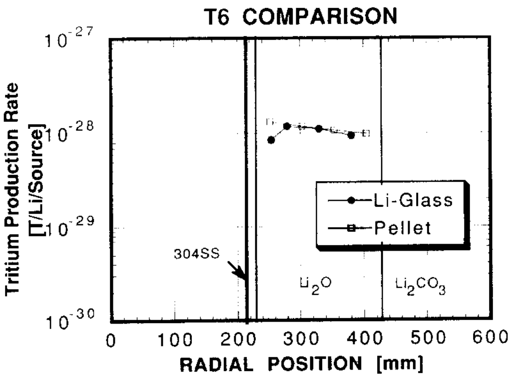

Fig. 5. Tritium production rate distribution of ^{6}Li along the central drawer.

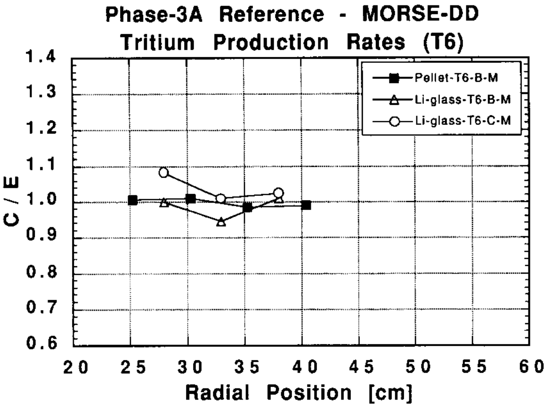

Fig. 6. C/E distribution for the tritium production rate along the central drawer.

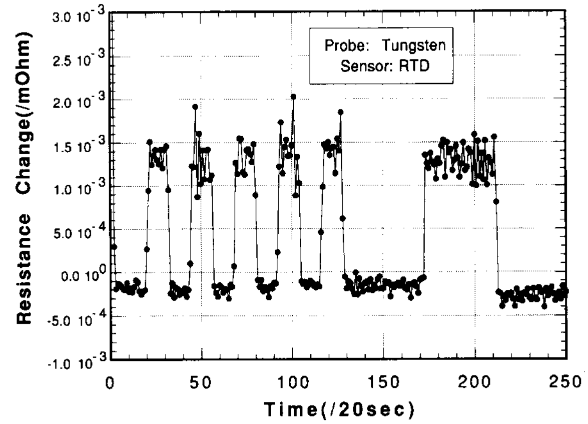

Fig. 7. Row data of temperature change in tungsten probe measured by RTD.

^{197}Au(n, γ)^{198}Au reaction rates, which are sensitive to low energy neutrons, show little spatial dependency along the radial direction.

The spectra calculated by MORSE-DD using JENDL-3 agree very well with measured ones. Distributions of the ratio of calculated to experimental values (C/E) are shown in fig. 6 for the tritium production rates. It is clearly seen that the calculation based on JENDL-3 predicts the TPR for the line source configuration to within 10%.

4. Induced activity, afterheat and nuclear heating

Induced activity was measured in samples of Fe, Ni, Cr, Mo, SS316, MnCu alloy, Co, V, Ti, Nb, W, Pb, Sn, Zn, Ag, Ta, Si, Mg, In and Sr in a fusion neutron environment for different irradiation and cooling times. Different neutron energy spectra were realized by placing the samples in the assemblies of phase-IIC and -IIIA. Radioactive isotopes of half-lives ranging from 2 min to 5 y were targeted. Four leading radioactivity calculation codes, THIDA-2, REAC2, DKRICF and RACC were used to analyze the measured decay gamma spectra.

The nuclear heat deposition rates in a D–T fusion environment have been measured by a calorimetric technique to provide the data for testing kerma factor libraries. Thermistors and platinum RTDs were employed as thermal sensors within calorimeters made of single materials (or probes) of Fe, Al, C, Cu and W. Each of these calorimeters was placed inside a vacuum chamber and set in front of the target at the distance of about 80 mm. The calorimeters were subjected to spaced neutron pulses of 3 to 10 min duration. Figure 7 shows row data of the temperature change in a W probe measured by RTD. The measured heat deposition rates ranged from 7 to 30 μW/g for a normalized source strength of 10^{12} n/s.

5. Comparative study of systems and nuclear data

Calculated results for the phase-I, -II and -III experiments have been compared with the experimental ones on the same bases of nuclear data and calculational methods [13,14]. A sample of the gross range of calculated-to-experimental values the ratio (C/E) is shown in fig. 8 for tritium production in ^{6}Li. The label in the figure means the assembly configuration (see references). The minimum and maximum values of C/E indicate the possible range of discrepancy between the calculation and experiment. This comparative study suggests that there is a good consistency among the measured data and that the beryllium introduces some systematic effects on the reaction rates such as tritium production rate of ^{6}Li (T_6). It can be concluded that the predicted accuracy for the reaction rates are expected to be 5–10%.

6. Concluding remarks

The JAERI/USDOE collaborative program is going on well using the FNS facility. The program has given important results for fusion neutronics studies and is of mutual benefit.

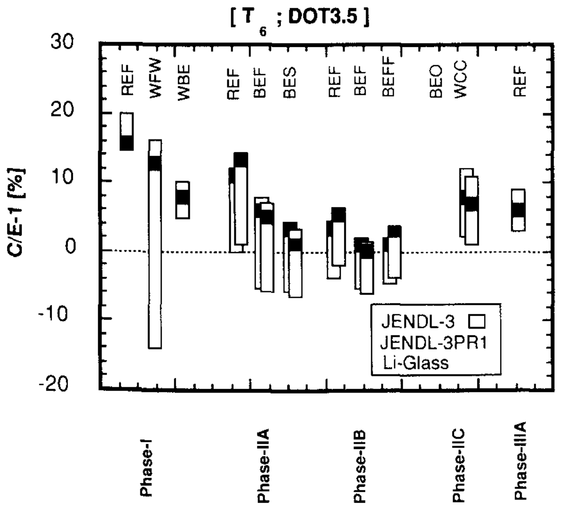

Fig. 8. Gross trend of the C/E of tritium production rate of ^{6}Li through the whole experiment series for the case of DOT3.5 calculations.

From the source distribution measurement for the pseudo-line source it is clearly seen that both stepwise and continuous modes simulate the ideal line source very well. This line source improves prototypical conditions of a fusion reactor blanket. The phase-IIIA experiments has provided the information of a distributed neutron source and an annular blanket, while the phase-IIIB experiment adds the effect of graphite armor on reaction rates especially of the tritium production.

Future experiments of phase-III series will be planned to study the effect of the geometrical asymmetry in the poloidal direction and/or axial heterogeneity on blanket characteristics.

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