A LINE D-T NEUTRON SOURCE FACILITY FOR ANNULAR BLANKET EXPERIMENT: PHASE III OF THE JAERI/USDOE COLLABORATIVE PROGRAM ON FUSION NEUTRONICS

T. Nakamura, Y. Oyama, Y. Ikeda
C. Konno, H. Maekawa, K. Kosako
Department of Reactor Engineering
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken, 319-11
Japan (0292) 82-6015

M. Z. Youssef and M. A. Abdou
University of California at Los Angeles
Los Angeles, CA 90024
U.S.A.
(213) 206- 0501

ABSTRACT

A new experimental arrangement using pseudo-line D-T neutron source has been developed to investigate the neutronics performance in the fusion blanket and related components. The arrangement is simple in construction and gives well-simulated fusion reactor environment combined with the flexibility in testing various factors. In examining the deficiencies in nuclear data, calculation methods or modeling, it provides a powerful means either for basic benchmark experiments in clear geometry or design-supporting experiments with complexity of the recent blanket design. The features of the line source facility and the experimental scope are described.

INTRODUCTION

Fast neutrons generated in the D-T fusion plasma bring about a number of fundamental technical conditions, directly or indirectly, on the reactor design. Neutrons entering into the surrounding components concern, through various nuclear reaction processes, to heat generation, tritium production, induced radio-activities, radiation damage and others. They, in turn, affect the material selection, heat removal, tritium extraction, shielding arrangement, maintenance scheme and rad-wastes. Therefore, prediction of basic neutronics performance in the reactor is required as accurately as possible to reduce the ambiguity in the input data for the design of other non-nuclear engineering elements.[1,2]

At the stage to initiate an engineering design activity for the next fusion devices such as ITER, FER or NET, it is required that the nuclear data and calculation methods to be well validated by experiments. Extensive Integral neutronics experiments have been conducted at Fusion Neutronics Source (FNS)[3] of JAERI, OKTAVIAN Facility[4] of Osaka University and others. However, experimental efforts so far have been limited to small-scaled, simple composition ones,[5-7] while the recent blanket design becomes rather complicated and calculation means are not confined in simple one dimension which has been used in the scoping analysis.

The JAERI/USDOE collaborative program on fusion blanket neutronics was initiated to examine the current accuracy of the nuclear prediction with the help of larger scale blanket experiments by effective use of the facility, materials, technical and analytical resources at both parties. A line neutron source was planned for the Phase III of this program.

The present paper contains a brief description on the JAERI/USDOE collaborative program, the concepts of line source, the outline and features of FNS line source and the candidate blanket configurations in the coming step. Source characteristics and experimental results obtained for Phase IIIA assembly are described in the companion papers.[8,9]

JAERI/USDOE JOINT EXPERIMENT PROGRAM

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 and, with their analyses, assess the accuracies of the nuclear data, calculation methods and response functions being used in the design and (3) to develop neutronics technology for the design and testing of next D-T burning fusion devices. The program is divided in three phases depending on the basic concepts of the source and test blanket configurations.

In the Phase I of the program, the basis was laid for engineering-oriented benchmark experiments, measuring technique development and analysis comparison using slab type test blanket assemblies embedded in a experimental port.[10,11] Revised evaluation of ^{7}Li(n,n'α)^{3}T was validated in this phase. Phase II experiment is characterized by a closed geometry with slab type test blanket and neutron source housed in a reflective enclosure. Including reflected source term, this arrangement gives good matching with fusion reactor blanket neutron spectra. Tritium production characteristics and other parameters in full radial dimension of fusion blanket have been measured and analyzed in the three experiment series in the phase. These provide extensive data on breeding characteristics of Li$_2$O and beryllium neutron multiplication effect in different configurations.[12-16]

Phase III experiment is motivated by a need to investigate the effect of source spread 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 flow of the experiment program at FNS seen from experimental system and neutron source arrangements is illustrated in Fig. 1 in connection with the area of interest in fusion reactor blanket.

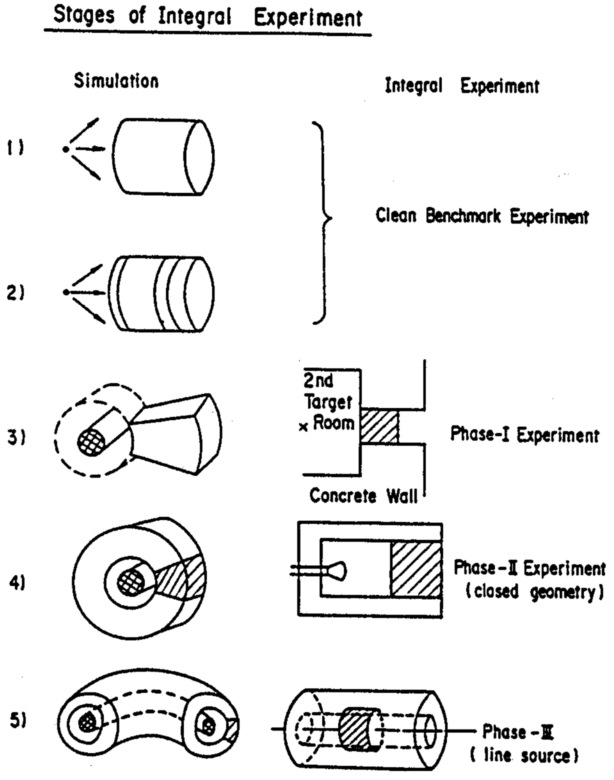

Fig. 1 Stages for the simulation of neutron source and blanket configuration in the integral experiments at FNS

LINE-SOURCE CONCEPTS

The concept of line source and annular system is not specifically novel. Symmetrical arrangement, like a sphere system with a point source at the center or a cylinder with uniform line source along its central axis, is a natural demand for neutronics experiments to assure unambiguous interpretation in the comparison between measured and calculated results. Especially line source experiment concept is attractive from not only basic benchmark but also practical purpose, since it simulates the geometry of a portion of tokamak or mirror device blankets.

Conceptual designs of cylindrical assembly with line source have been reported by Sahin[17-19] for AYMAN project and by Beller[20] for FRBS facility. Sahin proposed experimental arrangement mainly for fusion-fission hybrid configuration in cylindrical geometry and compared various radial compositions for nuclear performances such as fissile and fusile fuel production with close examination for experimental prospect. He assumed a movable point source for simulating the line source, but technical explanation was not given on the means and experimental prospect relating source characteristics. Beller reported a conceptual design of cylindrical blanket system with a cosine-shaped intensity line source. The source design consisted of a deuteron beam, introduced through a slit on the side of the blanket, sweeping over an elongated target. Using blanket compositions from BCCS, he discussed the neutronic evaluation of two azimuthal effects from the side slit in the blanket and neutron energy/yield variation. Though he seemed optimistic, the results impose a limitation in the use of the facility, especially for design-oriented experiment.

So far line source experiments have not been conducted yet. First problem is due to the technical difficulty in producing acceptablly uniform line source with minimum distortion in primary neutron spectrum. Once succeeded in realizing a line source, one can proceed to practical design of the test blanket. But the second problem is the pertinent choice of system and preparation of materials for it. In practice, a simulation of blanket configuration in cylindrical geometry with reasonably long axial length requires large material inventory, hence, costs much. The first problem was solved by a simple idea, that is, a go-and-back motion of the simulated blanket relative to a fixed point neutron source. For the second, we best use the material inventory and the expertize accumulated in the Phase II experiment series in planning the test blanket assembly.

FEATURES OF FNS LNE SOURCE

The FNS line-source (FNSLS) facility is

installed in the target room No. 1 of the FNS as shown in Fig. 2. The general concept is illustrated in Fig. 3. An annular test blanket is assembled in a frame that is mounted on a heavy duty carriage deck. The carriage shuttles back and forth on the rails so as to the tritium target mounted on the tip of long-size slim beam duct virtually travel repeatedly along the the central axis of the cavity inside the blanket from one end to the other. On the time averaging for certain period, a uniform intensity line neutron source is achieved on the axis.

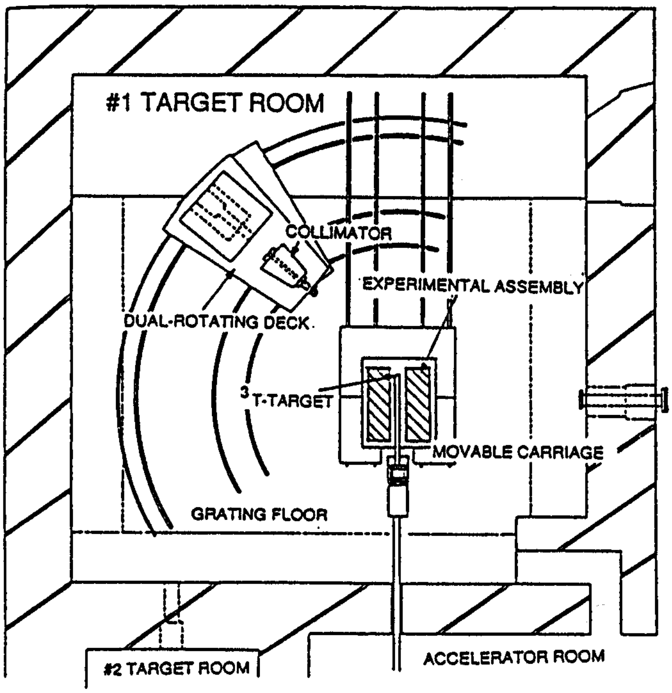

Fig. 2 Experimental arrangement for the line neutron source in the FNS target room No. 1

Neutron Target

A condition for the good line-source is well defined, clean characteristics, that is, angular isotropy and uniformity along the axis. The accelerator-based D-T neutron source inevitably deviates from isotropic source in the plasma in two reasons. One is due to incident beam energy dependent reaction kinematics[21] and the other the energy/angle/yield distortion by scattering on the target structure. While the former is intrinsic, the latter depends on the system strongly. For example, the large size of the elongated target proposed for FRBS, must be handicapped by complex and heavy structure to assure vacuum, heat removal and mechanical strength.

One excellent feature of FNSLS is that it has small and light structured target system. Figure 4 shows the cup-shape target developed at FNS originally for cross section measurement.[22] Distortion of neutron spectrum is kept minimum over wide solid angle by shifting the bulk parts for target fixing and vacuum seal away from the neutron producing point. In azimuthal angle, symmetry is maintained from the the cylindrical shape of the cup. However, there is angle dependent anisotropy in beam direction. This angle dependence of neutron energy spectra have been measured in detail by time-of-flight method for the standard target assembly. Since the part of cup is exactly identical, all the data are

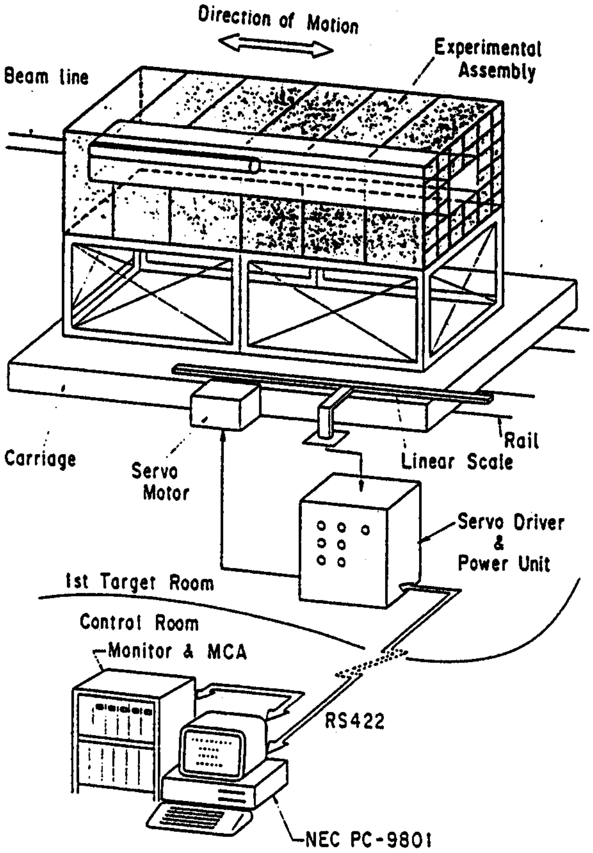

Fig. 3 General concept for the FNS line-source arrangement (Phase III system)

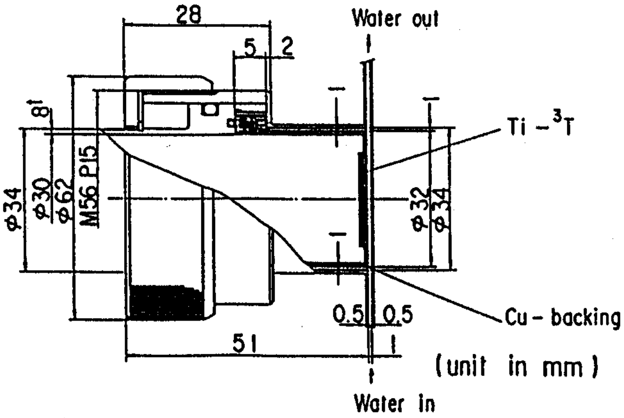

Fig. 4 Cup-shape target that has smaller scattering effect over wide solid angle

directly available for the long-type target assembly in this arrangement. In the line source operation, the anisotropy is smeared out and gives a smooth uniform distribution, though a forward bias remains at primary high energy region. On-line neutron yield monitor is an essential component for the simulation of line source by the relative movement of point source. The associated alpha particle detector built in the beam duct is usable without any modification or recalibration, because the structure of assembly remains the same except the length.

Carriage Deck and Driving Device

The movable deck is the most important component in the FNSLS which uses the relative motion of experimental assembly to the fixed source. The carriage deck set on four rails is 3.4 m wide and 4 m long in size, and consists of front and rear halves with a driving servo-motor on each. Using the linear scale position indicator by optical sensing, the axial move of the carriage is precisely controlled under an NEC-PC 9801 computer over the full stroke of 2 m. Exactly positioned target assembly by a laser transit and carefully aligned rails in parallel to the beam axis guarantee the shift of source point in transverse direction less than 1 mm over the stroke. The traverse speed is 6.1 mm/sec and continuous movement takes 11 min for a single cycle. Figure 5 shows a part of the diagram continuous traverse along with the variation of the neutron yield curve. Although the decay of yield for fixed target is considerably fast, the uniform intensity is well kept during the cycle. Other than continuous motion, flexible traverse and measurement patterns in discrete steps can be selected by a computer program as required from research subjects, using the data on the time, deck position, neutron monitor counts, detector counts. The pseudo-line source shape superposed from 50 mm equi-spaced step motion is given in Fig. 6 at the first wall position. Central 1 m region shows a flat distributin within 5 %.

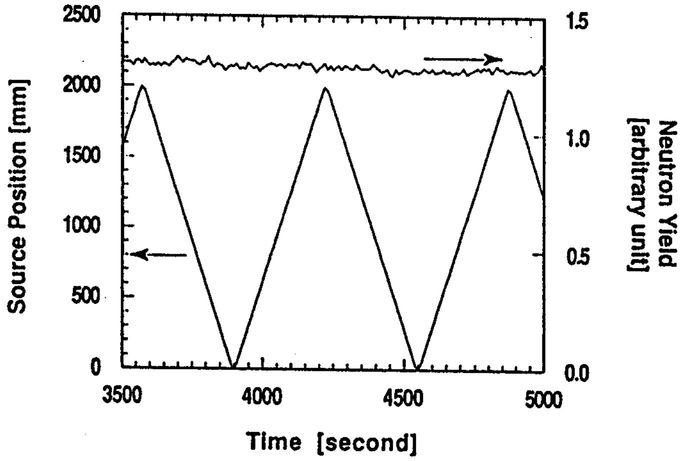

Fig. 5 Time-source position diagram for continuous mode and neutron yield variation during the cycle

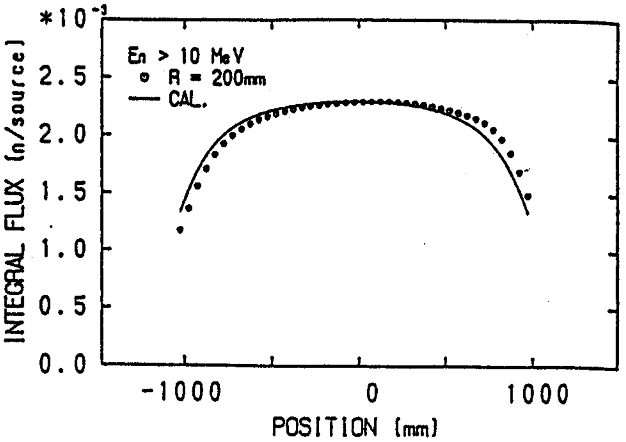

Fig. 6 Spatial distribution of integrated neutron flux for step mode

Test Blanket System

There are many options on the choice of the test blanket system, either clean geometry benchmark system or composite prototypical one. Close simulation, however, of the plasma cavity and blanket radial dimensions with appropriate axial length requires prohibitively large amount of experimental materials. Due to the limitation of the material inventory, the present research interest is concentrated on the neutronic characteristic near the front part of the blanket. The neutronics performance in this region needs to be evaluated exactly taking the effect of source spread, since most of tritium production and gamma-ray generation by neutron inelastic scattering occur near the source. On the other hand, scoping calculation showed that above about 0.5 m, the cavity diameter has small impact on the blanket performance such as tritium production or nuclear heating rate distributions.[23] These conditions have set the basic configuration of Phase III experiment system, along with the features succeeded from previous FNS experiment, i.e., a parallel-piped geometry by assembling the unit-sized blocks

The present blanket assembly has a central cavity of 426 mm square cross section framed by a 15 mm thick stainless steel sheath that play the role of the first wall. The surrounding test region is 406 mm thick on each side. The axial length of the system is 2040 mm. Using the flexibility of the unit block combination, various simulated blanket configuration, symmetrical or asymmetrical, could be assembled in the test region. The configuration of the first blanket assembly, the Phase IIIA system is described in Ref. 8. The first assembly is open-ended to examine the most simple basic characteristics of the present arrangement. According to the research item, reflective slabs at both ends will be added to compensate for the axial leakage from the cavity based on the Phase IIIA data.

FUTURE PROSPECT

The present experimental arrangement has large flexibility in system construction, including heterogeneity or asymmetry problems, for examining neutronic aspect of the next fusion devices and demo reactors. Figure 7 illustrates schematically some additional candidate subjects for the FNS line-source facility.

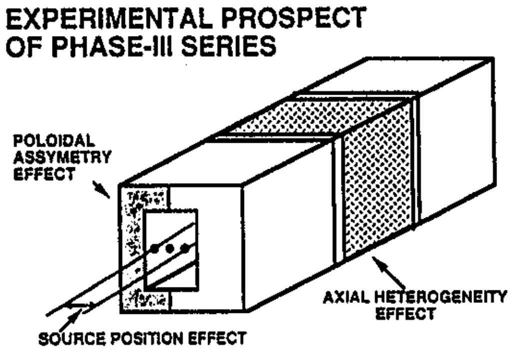

Fig. 7 Combined illustration of candidate blanket configurations that have asymmetry or heterogeneity

Asymmetrical effect in poloidal direction

Recent fusion device adopts vertically elongated plasma shape to improve the stability. Also it has diverter or limitter region at the top, bottom or both of them. Moreover, the inboard blanket has an additional yet important function to protect the superconducting TF magnets against radiation besides the heat generation and tritium breeding. All of these conditions impose an asymmetrical structure in the blanket design. Tritium breeding, for example, is evaluated by combining the results from two one dimensional calculations for inner and outer blankets or by a two dimension calculations in complicated X-Y geometry. Experimental confirmation is, hence, needed whether the accuracy assigned by current calculational prediction for such geometry is satisfactory or not.

Heterogeneity effect along the plasma

Fusion device has heterogeneous structure along the plasma axis, as it is divided in many segments from component exchange, maintenance or cooling circuit design. The effects of segment structure such as streaming, sharp spectrum variation, etc. can be handled in the FNSLS by incorporating the model structures such as simulation of segment boundary in the central 1 meter of virtually flat region.

Radial Source Location

Plasma source is actually a volumetric source that has a cross sectional distribution. Neutronics parameters at off-axis source positions can be measured by shifting the FNSLS blanket assembly in transversal direction. The impact of the plasma position deviation and shape can be assessed by superposing the data at different positions.

Experiments mentioned above could provide benchmark problems on model configuration to examine the typical features extracted from the three-dimensional structure, and afford experimental data on each item. With pertinent combination of the results, more exact prediction would be achieved on the the blanket nuclear performance.

SUMMARY AND CONCLUSIONS

A new experimental arrangement using pseudo-line D-T neutron source has been developed. The features are the simplicity in construction and well-simulated fusion reactor environments combined with the flexibility in testing various factors. Various elements were examined, and devices and expertises have been combined to materialize good quality line source and annular experiment system. A practically flat distribution source over 1m has been observed in the source characterization.

It provides a powerful tool and opens a new experimental area either for benthmark experiments that examine the deficiencies in basic nuclear data and calculational methods or design-supporting engineering experiments that contain the complexity of inhomogeneous and assymetric blanket configurations. Some of the candidates for coming experiment are discussed.

ACKNOWLEDGMENT

The US activities are supported by the US Department of Energy, Office of Fusion Energy.

REFERENCES

1. M. A. Abdou et al., "A Study of the Issues and Experiments for Fusion Nuclear Technology," *Fusion Technol.*, 8. 2595, (1985)

2. Y. Oyama, M. Z. Youssef and M. A. Abdou, "Operating and Geometrical Arrangement Requirements for Fusion Neutronics Testing", *Fusion Technol.*, 8, 1484, (1985)

3. T. Nakamura, H. Maekawa, Y. Ikeda and Y. Oyama, "A D-T Neutron Source for Fusion Neutronics Experiments at the JAERI," *Proc. Int'nl Ion Engineering Congress-ISIAT '83 & IPAT '83*, 567, Kyoto, (1983)

4. K. Sumita et al., "Osaka University 14 MeV Intense Neutron Source and its Utilization for Fusion Studies," *Fusion Technology 1982 Vol. 1 (Pergamon Press)*, 675, (1983)

5. H. Maekawa, et al., "Fusion Blanket Benchmark Experiments on a 60 cm-Thick LLithium

Oxide Cylindrical Assembly," *JAERI-M 86-182* (1986)

6. Y. Oyama and H. Maekawa, "Measurement and Analysis of an Angular Neutron Flux on a Beryllium Slab Irradiated with Deuterium Tritium Neutrons," *Nucl. Sci. Eng.*, 97, 220, (1987)

7. A. Takahashi, M. Kawata and A. Masago, "Tritium Breeding Experiment for a Thermal Blanket Model of Pb-Li-C," *Fusion Engineering and Design*, 9, 333, (1989)

8. Y. Oyama, C. Konno, Y. Ikeda, H. Maekawa, K. Kosako, T. Nakamura, A. Kumar, M. Z. Youssef, M.A. Abdou and E. F. Bennett, "Annular Blanket Experiment Using A Line DT Neutron Source: Phase IIIA of the JAERI/USDOE Collaborative Program on Fusion Neutronics," *this meeting*

9. C. Konno, Y. Oyama, Y. Ikeda, K. Kosako, H. Maekawa, T. Nakamura, A. Kumar, Y. Z. Youssef, M. A. Abdou," Measurements of the Source Term for Annular Blanket Experiment with a Line Source: Phase-IIIA of the JAERI/USDOE Collaborative Program on Fusion Neutronics," *ibid.*

10. T. Nakamura and M. A. Abdou, "Summary of Recent Results from the JAERI/U.S. Fusion Neutronics Phase I Experiment," *Fusion Technol.*, 10, 541 (1986)

11. M. Nakagawa, M. Z. Youssef et al., " U.S./JAERI Collaborative Program on Fusion Neutronics - Phase I Fusion Integral Experiments, Analysis -," *JAERI-M 88-177/UCLA-ENG-88-15*, (1988)

12. Y. Oyama, et al., " Phase-IIA and -IIB Experiments of JAERI/USDOE Collaborative Program on Fusion Blanket Neutronics," *JAERI-M 89-215*, (1989)

13. M. Nakagawa, T. Mori, K. Kosako Y. Oyama and T. Nakamura,, "JAERI/USDOE Collaborative Program on Fusion Blanket Neutronics-Analysis of Phase IIA and IIB Experiments-," *JAERI-M 89-154*, (1989).

14. M. Z. Youssef,M. A. Abdou, Y. Watanabe and P. M. Song, "U.S./ JAERI Collaborative Program on Fusion Neutronics -Phase IIA and IIB Fusion Integral Experiments, The U.S. Analysis-" *UCLA-ENG-90-14 FNT-31*, (1989)

15. Y. Oyama, S. Yamaguchi, K. Tsuda, C. Konno, Y. Ikeda, H. Maekawa, T. Nakamura, K. G. Porges and E. F. Bennett, "Measured Characteristics of Be Multi-Layered and Coolant Channel Blankets: Phase IIC Experiments of the JAERI/USDOE Collaborative Program," *This Meeting*

16. M. Z. Youssef et al., "Analysis for Heterogeneous Blankets and Comparison to Measurements: Phase IIC Experiments of the JAERI/USDOE Collaborative Program on Fusion Neutronics," *ibid.*

17. S. Sahin and A. Kumar, "Neutronics Analysis of Deuterium-Tritium-Driven Experimental Hybrid Blankets," *Fusion Technol.*, 6, 97 (1984)

18. S. Sahin and T. A. Al-Kusayer, "Conceptual Design Studies of a Cylindrical Experimental ThO_2 Hybrid Blanket with (D,D) Driver," *Atomkernenergie*, 47, 259 (1985)

19. S. Sahin, T. A. Al-kusayer, and M. A. Raoof, "Preliminary Design Studies of a Cylindrical Experimental Hybrid Blanket with Deuterium-Tritium Driver," *Fusion Technol.*, 10, 84, (1986)

20. D. E. Beller, K. O. Ott and W. K. Terry, "Conceptual Design and Neutronics Analyses of a Fusion Reactor Blanket Simulation Facility," *Nucl. Sci. Eng.*, 97, 175 (1987)

21. S. Yamaguchi, Y. Oyama and H. Maekawa, "Calculation of Anisotropy Correction Factor for Determination of D-T Neutron Yield by Associated α-Particle Method," *JAERI-M 84-109*, (1984)

22. Y. Ikeda, C. Konno, K. Oishi, T. Nakamura, H. Miyade, K. Kawade, H. Yamamoto and T. Katoh, "Activation Cross Section Measurements fot Fusion Reactor Structural Materials at Neutron Energy from 13.3 to 15.0 MeV Using FNS Facility," *JAERI-1312* (1988)

23. Y. Oyama and K. Kosako," Survey Calculation on Neutron Source Effect in Various Blanket Configurations" private communication