ANNULAR BLANKET EXPERIMENT USING A LINE DT NEUTRON SOURCE: PHASE IIIA OF THE JAERI/USDOE COLLABORATIVE PROGRAM ON FUSION NEUTRONICS

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ABSTRACT

Neutronics experiments for an annular blanket system have been performed using a simulated line DT neutron source. The line source was simulated by moving point source in which the annular blanket was oscillated relatively on the axis of the DT neutron target. The measurements were performed in both ways of continuous and stepwise motions. The former was applied to heavy irradiation experiments such as the foil activation method for reaction rate and Li$_2$O pellet technique for tritium production rate (TPR). The latter was to on-line methods such as NE213 and Li-glass scintillators for spectrum and TPR of ^{6}Li and ^{7}Li. Especially the latter case provides contribution of neutrons generated at each point on the line source to the reaction at the detector position. This corresponds to an importance distribution at the center axis of the annular system and can be compared to the calculated adjoint flux at the source positions.

INTRODUCTION

A neutronic integral experiment in a three dimensional toroidal geometry with a line D-T neutron source has been realized and performed at the FNS (Fusion Neutronics Source facility) in Japan Atomic Energy Research Institute, under the JAERI/USDOE collaborative program on fusion blanket neutronics. The experimental systems were developed for the Phase-III experiment of the program in which the experiment came into new aspect with the more realistic neutronic environment, i.e., volumetric line source and toroidal blanket configuration.

In the previous series,[1,2] we tested neutronic performance of nuclear data and calculational method for a blanket system with a point D-T neutron source. Those systems are actually not one dimensional for blanket configuration but the incident neutrons behave as one dimensional system because of point source. The present line source and annular blanket system can simulate a tokamak geometry and also prototypical environments such as toroidal and poloidal heterogeneities.[3] Those heterogeneities appear in realistic designs of a reactor, e.g., inboard/outboard arrangement, diverter plate and blanket test module configurations, etc.

The Phase-III series provide a pseudo-line D-T neutron source by relative motion of the experimental assembly to a point source. This first experiment Phase-IIIA of the series were performed for an annular symmetrical blanket configuration. The objectives of Phase-IIIA are to establish the experimental method for the present pseudo-line source, to develop the necessary measurement techniques and to find better approaches for calculational modeling and analysis. The realization and characteristics of the experiment, and source term experiment of the line source are reported separately.[4,5] This paper focuses on experimental methods for an experiment using pseudo-line neutron source and measured results for the annular blanket.

EXPERIMENTAL ARRANGEMENT

An experiment was performed for an annular blanket emplaced on a computer controlled moving deck. The deck size is 3.4 m in width and 4 m in length. The deck moves on four rails by two servo-motors controlled by an NEC-PC9801 computer with a linear scale by optical sensing. The rails were carefully installed so as to be in parallel to the accelerator beam line within 1 mm accuracy over 2 m length. The moving speed is 6.1 mm/s and it takes 5.5 min for simulated source length of 2 m.

The simulated annular blanket is made by

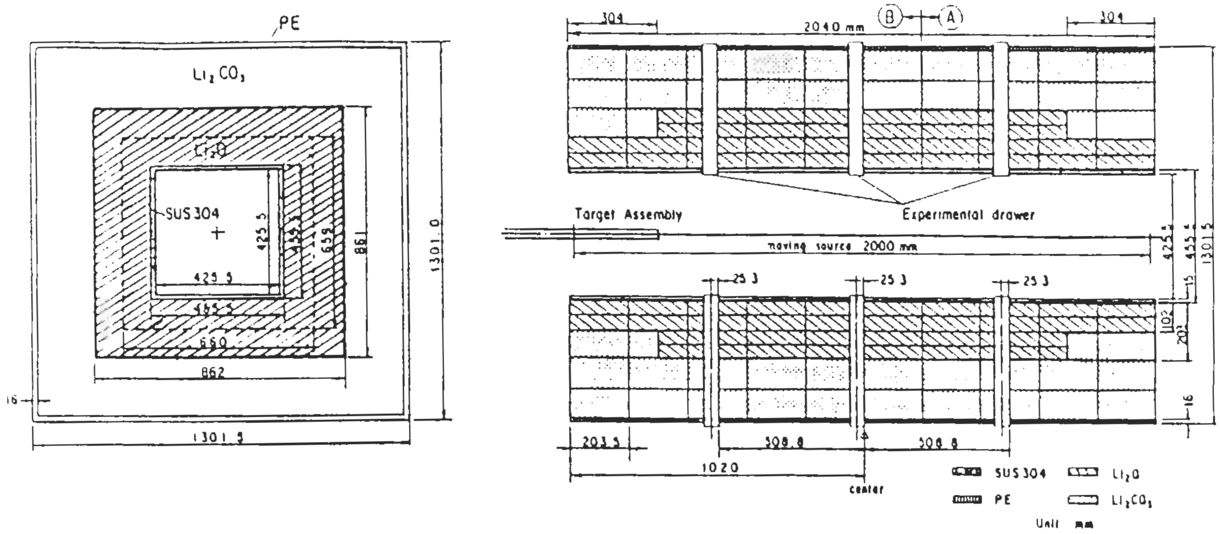

Fig. 1 Experimental annular assembly

lithium-oxide and lithium-carbonate blocks as shown in Fig. 1. The blanket region basically consists of 200 mm-thick Li_2O and 200 mm-thick Li_2CO_3, and the total length is 2040 mm. The overall weights of Li_2O and Li_2CO_3 used here are about 2 ton and 3.7 ton, respectively. The first wall simulated by type 304 stainless steel of 15 mm in thick is placed on the inner surface at the distance of 213 mm from the source line. The Li_2O blocks are made of 50.6 mm unit bricks covered with 0.3 mm-thick stainless steel. The Li_2CO_3 blocks are of 100 mm unit painted with epoxy resin to protect against humidity. All blocks are fastened by aluminum frames and supported inside by 15 mm-thick stainless steel of the first wall. Then the cavity of 425 mm square and 2040 mm in length is made by the simulated first wall. The DT source moves at the central axis of this cavity.

The annular assembly has six experimental channels in both sides with 500 mm pitch. The channels are made of thin stainless steel, in which the drawer is used to insert the detectors together with special blocks having a hole of 20 mm square. For the inner face of the first wall of 304SS, the detector holes of 30 mm in diameter, with pitch of 50 mm, are machined to be able to set the samples, e.g., TLDs and foils, inside the first wall.

MEASUREMENT AND TECHNIQUES

Measurements were performed at the inner surface of the first wall and inside of the blanket region. The surface measurement was done to characterize a source term described in the separated paper.5) The in-system measurement was carried out to obtain neutronic parameters for the annular blanket system. Two types of operational modes of the moving source were applied to the measurements. One is a stepwise operation in which the stationary measurement is performed at every source positions over 2 m length with equal distance of separation. This mode is used for the on-line detectors such as small NE213 liquid scintillation spectrometer,6) Li-glass scintillator for tritium production7) and proton recoil counter for low energy neutron spectrometry. After taking the data for each position, all data are summed up normalizing by neutron yield data at each position and superposed into the response for the line source. The other is a continuous moving mode. In this mode, the deck moves back and forth continuously for 54 times. One cycle takes 11 min with moving speed of 6.1 mm/s. The results obtained from this mode are time-averaged for all cycles in total irradiation time of about 10 hr. The continuous mode was applied to the techniques requiring the heavy neutron irradiation such as foil activation method for reaction rate and Li_2O pellet for TPR.

The measurements using NE213 and Li-glass scintillation detectors were performed by multi-detector data acquisition system as shown in Fig. 2. Three or four detectors are operated in parallel. The pulse height spectrum data are stored in a floppy diskette with neutron yield data obtained from an associated alpha detector and source position data from linear scale for every source steps. An NEC-PC9801 desk-top computer manages the data acqusition and the moving control of the assembly. The computer also converts the spectrum data to the neutron flux and TPR with the spectrum weighting function methods8) for NE213 detector and the ^{6}Li-^{7}Li subtraction method for Li-glass detectors, respectively. The spectrum weighting function method is very useful to process quickly a number of spectrum data into some response such as integrated neutron flux and TPR, because the spectrum data are just

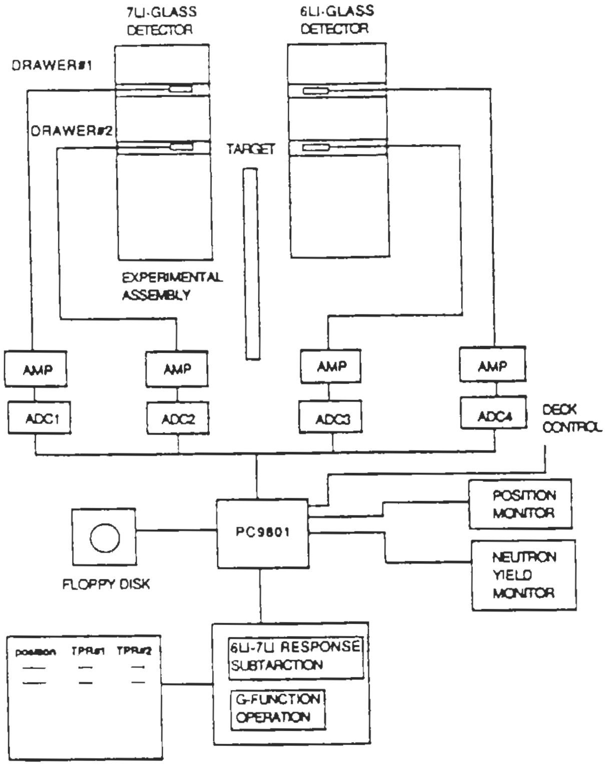

Fig. 2 Multi-detector system for Li-glass detectors

multiplied by the weighting function in a single operation. Figure 3 shows an example of effective response of the present NE213 detector made by weighting function operation for the integrated flux above 10 MeV. In the case of Li-glasss detector, a pair of ^{6}Li and ^{7}Li detectors are placed at symmetrical positions of both sides of the annular assembly to take the both detector responses simultaneously.

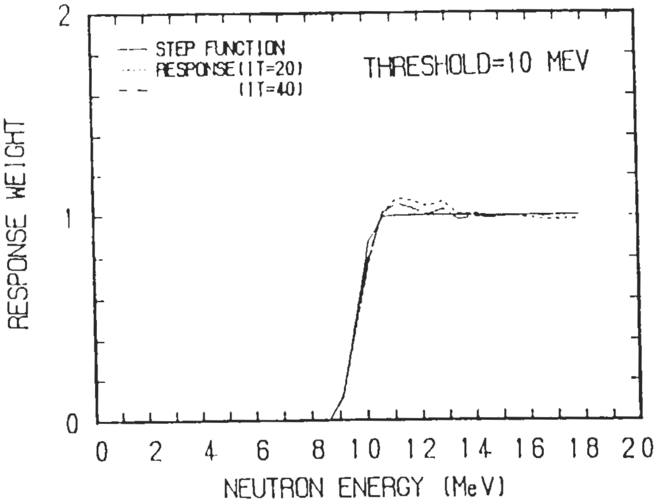

Fig. 3 Weighting function response
Solid line is ideal response, and broken lines are obtained responses.

New technique for the proton recoil counter has been developed to shorten the measurement time. In stead of several measurements with different high voltages, a ramped high voltage operation was applied and three dimensional data acquisition system was developed.9) The new system scans the applied high voltage so as to cover a dynamic range of recoil proton energy. The gas multiplication factor is operated to the output signals corresponding to the voltage fed at that time. Six cycles of voltage scannig is performed during the measurement time of 16 min at each source position. This improvement makes the stepwise measurement possible to be in allowable time.

Foil activation technique with continuous mode operation needs a correction of decay of activation during irradiation for short-lived nuclei as described in the separated paper.5) The reaction cross sections were measured separately at the FNS.10) They are ^{27}Al(n,α), ^{58}Ni(n,2n), ^{58}Ni(n,p), ^{90}Zr(n,2n), ^{115}In(n,n'), ^{197}Au(n,γ) and so on. The measurement was performed on the inner surface of the cavity, and in the central and the forward drawers. For absolute measurement of TPR, Li$_2$O pellets of 20 mm in diameter and 3 mm in thick were irradiated. The irradiation samples were resolved into water and measured with a liquid scintillation counting method. Total neutron yield for that irradiation experiment was 7×10^{15} n in 4π solid angle as a point source.

Gamma-ray heating rate was measured by TLDs and NE213 weighting function methods. The TLDs used are BeO, ^{7}LiF, Mg$_2$SiO$_4$, Sr$_2$SiO$_4$ and Ba$_2$SiO$_4$ in turn of effective atomic number. The gamma-ray heating rate for a material with specific atomic number is interpolated from those TLD responses with respect to the effective atomic number. The weighting function for NE213 detector is obtained from the KERMA factor of gamma-ray calculated by ARDENT code.11)

RESULTS AND DISCUSSION

The measured tritium production rates of ^{6}Li and ^{7}Li are shown in Fig. 4 and 5 along the central drawer for the on-line and Li$_2$O pellet methods. Both methods show good agreements, except for the front data of Li-glass. In the front position of the assembly, since there are much gamma-ray coming from the first wall compared to the ^{6}Li(n,α) reaction in the scintillator, the subtraction method does not work well and makes large error. But in deep positions the agreement is good. The measured results show that: the ^{6}Li-TPR distribution is flat and very different from the results in the previous Phase-II geometry, while the ^{7}Li-TPR decreases exponentially and similar to the previous ones.

The stepwise response of the both on-line

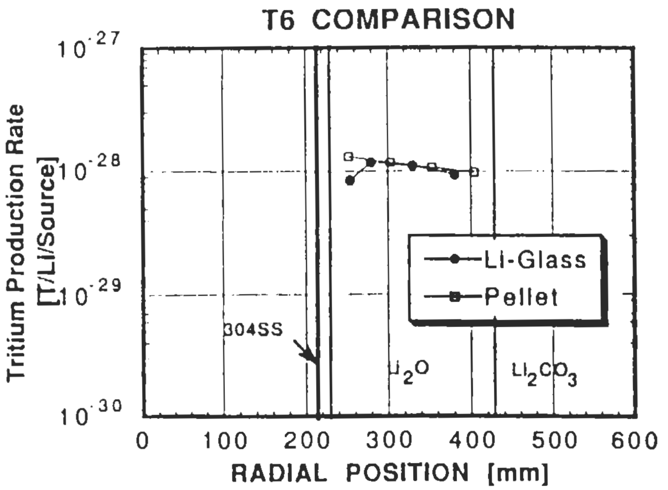

Fig. 4 ^{6}Li-TPR distribution in the central drawer

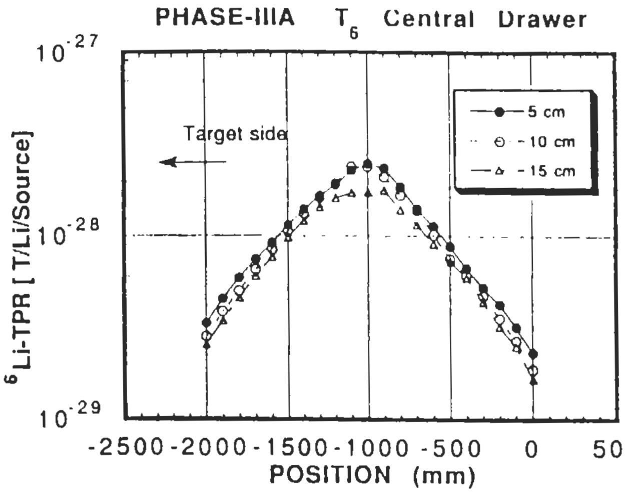

Fig. 6 ^{6}Li-TPR profile of contribution from each source position

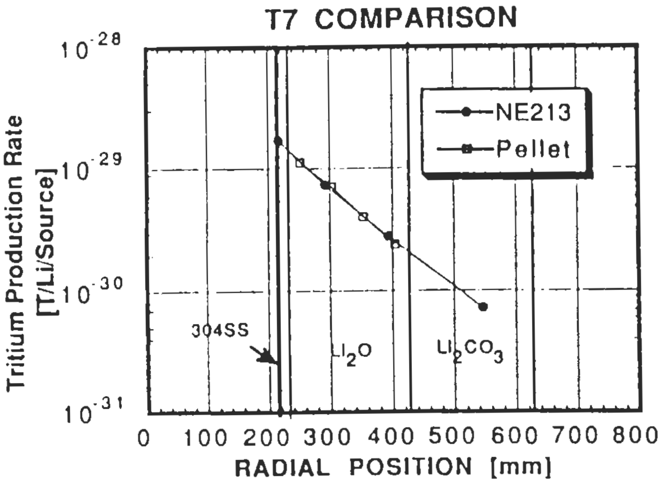

Fig. 5 ^{7}Li-TPR distribution in the central drawer

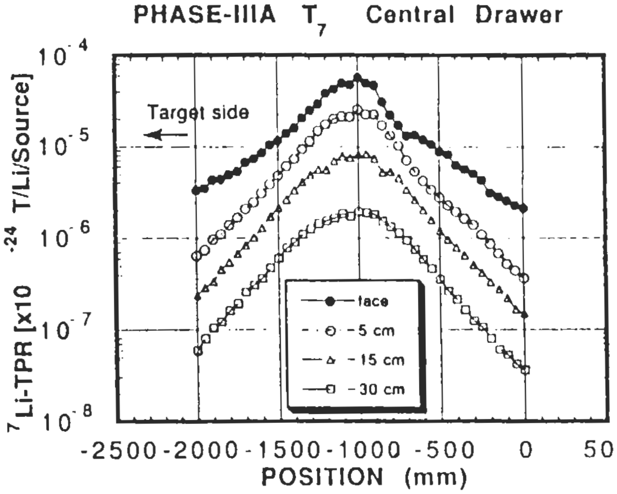

Fig. 7 ^{7}Li-TPR profile of contribution from each source position

detectors are shown in Fig. 6 and 7 for each position in the central drawer. The above results of TPR are obtained from these responses by summation. In comparison of both detectors, one can see that ^{6}Li response comes from broad region along the cavity axis, while ^{7}Li response is narrow. The widths of half maximum are about 1 m and 0.4 m for ^{6}Li and ^{7}Li, respectively. This means that the importance for ^{6}Li-TPR along the source position is distributed over the long distance from the detector position. Hence it could be guessed that ^{6}Li-TPR is much influenced by toroidal configuration and important specially in test module arrangement.

Figure 8 shows the results of neutron spectrum measured by proton recoil proportional counter (PRC) and NE213 scintillation counter at the depth of 50 mm in Li_2O region. The PRC and the NE213 data are taken by 100 mm-step and 50 mm-step, respectively. After summing up those pulse height data, the resulted proton-recoil spectra are converted to neutron spectra. The spectrum unfolding method is the differentiating code PSNS[12] and FORIST[13], respectively. The energy width of the 14 MeV peak is not corresponding to energy spread due to various emission angles depending on the source position.[14] This shows that the NE213 detector and FORIST system does not have enough energy resolution to reflect that energy spread. On the energy range in the measurement by PRC, it shows three clear resonance by ^{6}Li and Oxygen in the range from 100 keV to 1 MeV. But the spectrum seems to be lower below 10 keV due to energy dependence of ionization energy.

Reaction rate distributions in the central drawer are shown in Fig. 9. Higher threshold reactions such as ^{58}Ni(n,2n), ^{90}Zr(n,2n), etc. show exponential decreases with steep gradient,

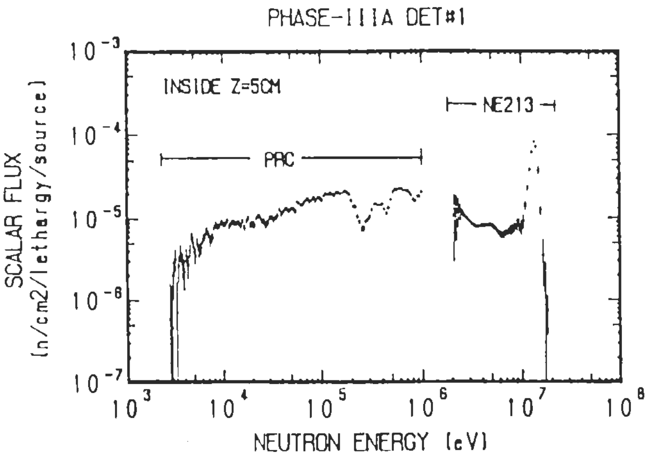

Fig. 8 Measured neutron spectrum

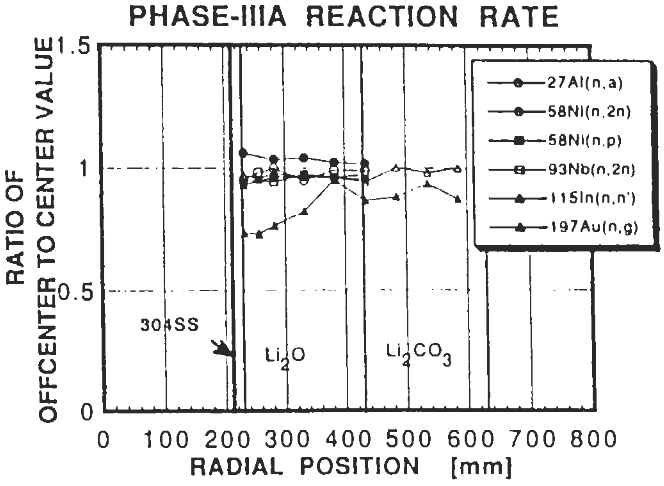

Fig. 10 Comparison of reaction rates between two drawers

while ^{197}Au(n,γ) reaction , sensitive to low energy neutrons, shows no spatial dependence along radial direction. Lower threshold reaction as ^{115}In(n,n') is rather moderate. Figure 10 compares the reaction rates in the central drawer to those in the drawer placed forward at the distance of 500 mm from the central drawer. The figure plots the ratios of the reaction rates. The reason why the ratio of the ^{58}Ni(n,2n) reaction rate is larger than 1.0 is due to anisotropic emission of the DT neutron source. The neutron energy of forward emission is higher than the backward by about 1.2 MeV. Hence the reaction with the threshold energy above 13-14 MeV changes much the activation production rate between the forward and the backward direction of the target. The lower value of the ^{197}Au(n,γ) reaction rate at the forward drawer is consistent with the ^{6}Li-TPR results by Li-glass detector. It suggests that the low energy neutrons is much leaking through the end of the annular blanket.

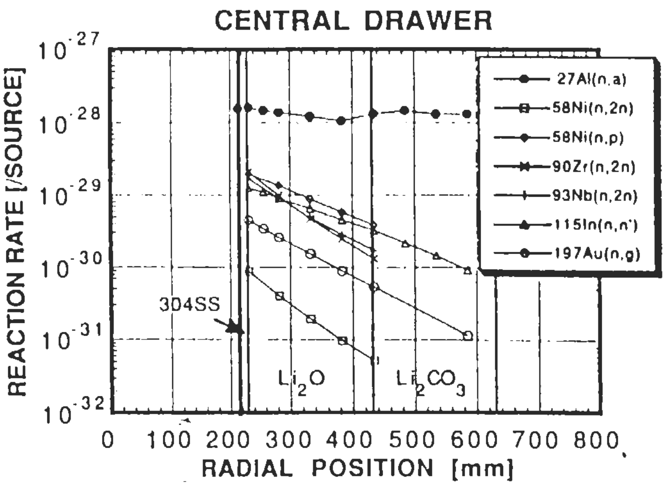

Fig. 9 Reaction rate distribution in the central drawer

Gamma-ray heating rate distribution inside of the first wall of 304SS in parallel to the source axis measured by TLDs showed very flat distribution along the axis. The raw data of TLDs are scattered within 10-20 % between positions. Some corrections for obtained TL yield are still needed, for example, due to the gamma-rays emitted from the target assembly and the response by neutron reaction in the TLD samples. These corrections will be performed by assistance of calculational analysis. However, this flat distribution suggests the gamma-ray production is mostly contributed by the direct incident neutrons.

SUMMARY

Neutronics parameters of the annular blanket system with a line source were measured. The experiment was performed with new techniques such as line source simulation system, new data acquisition technique of PRC, multi-detector system with spectrum weighting function method, etc. The present experimental concept is completely different from the previous one. The experiment can provide three dimensional simulation of the tokamak reactor, and new parameter as adjoint flux.

The experimental results showed that both stepwise and continuous operation modes worked well. The agreement between the results of the on-line and Li$_2$O pellet methods proved that both modes gave almost equivalent results.

The experimental system with the pseudo-line source and the annular blanket assembly can simulate three dimensional configuration relevant to a tokamak reactor. This system also can simulate a variation of source intensity along the toroidal direction. This also provides a capability for simulation of neutronics test in a experimental reactor such as ITER.

ACKNOWLEDGMENT

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