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ARTICLE

Neutron Dose Rate Measurements in J-PARC MLF

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In high energy particle accelerator facilities, high energy neutron contribution to dose is of the great interest as it has significant contribution to the total dose and thus determines the shielding design. The neutron dose rate was measured at Materials and Life Science Facility (MLF) of J-PARC with two types of active detector which can be applied in high energy neutron field: one is the modified type of an ordinary rem meter using a ^{3}He proportional counter with a polyethylene moderator and an additional lead to improve the sensitivity to high energy neutrons, and the other is the phoswitch-type scintillation detector, DARWIN (Dose monitoring system Applicable to various Radiations with WIde energy raNges) which consists of a liquid organic scintillator BC501A coupled with ZnS(Ag) scintillation sheets doped with ^{6}Li, developed in JAEA.

Neutron dose rate was measured on the pre-shield of the neutron beam line No.12 (BL12), which is located in the Experimental hall No.1 of MLF, and oriented to backward direction relative to the proton beam of the target station.

The neutron spectrum was also measured by DARWIN, and the result showed that the high energy neutrons over 20 MeV had a contribution comparable with those of 1 ~ 20 MeV.

KEYWORDS: J-PARC, MLF, high-energy neutron, DARWIN

I. Introduction

The J-PARC (Japan Proton Accelerator Research Complex) [1] is the high intensity proton accelerator facilities aiming to pursue frontier science in particle physics, nuclear physics, materials science, life science and nuclear technology. This project has progressed under the collaboration between Japan Atomic Energy Agency (JAEA) and High Energy Accelerator Research Organization (KEK). The complex is settled at the Nuclear Science Research Institute of JAEA in Tokai village. In the first stage of this project, three accelerator facilities and three experimental facilities are constructed: 400MeV linear accelerator (Linac), 3-GeV Rapid Cycling Synchrotron (RCS), 50-GeV Synchrotron, 1-MW neutron target station (MLF: Materials and Life Science Facility), Hadron Experimental Facility, and Neutrino Facility. By April 2009, the whole facilities has completed and started operation although the energy of Linac was limited to 181MeV. The whole layout of J-PARC is shown in **Figure 1**.

As well as other high energy particle accelerator facilities, high energy neutron contribution to dose is of the great interest in J-PARC, as it has significant contribution to the total dose. In order to examine the high energy neutron contribution, the neutron dose rates were measured at MLF with two types of active detector which can be applied in high energy neutron field.

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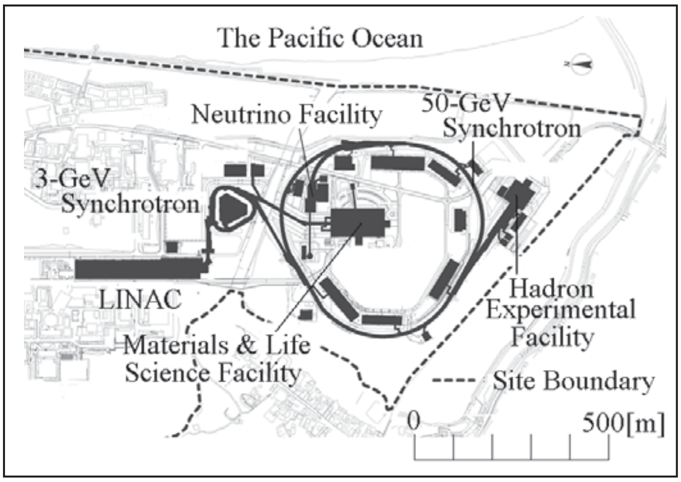

Fig. 1 The whole layout of J-PARC facilities.

II. Measurement

Figure 2 is the plan view of the MLF. The MLF building is 158 meters in length and 70 meters in width. There is a 1MW target station for neutron source in center of the building. And two large experimental halls are located on either side of the concrete ridge in which the proton beam transport line is installed. A muon production target is also located at the upstream. The 1MW target station[2] for neutron source consists of a mercury target system, three kind of neutron moderators, reflectors, helium vessel, neutron beam shutters and shutter driving systems, and biological shield. These components are housed within a 7 meter radius from the target. There are pre-shield blocks

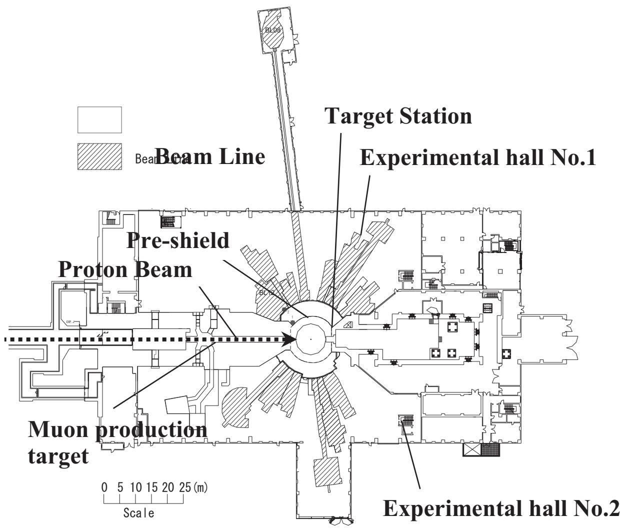

Fig. 2 Plan view of the MLF.

facing to the target station to reduce unwanted neutron in the neutron beam lines. Total 23 neutron beam lines (18 lines are in use or under construction) can be settled around the target station.

Two types of active detectors, which can be applied in high energy neutron field, were used for this measurement. One is the modified type[3] of an ordinary rem meter (Fuji Electric Systems: NCN2), which has much higher sensitivity for high energy neutrons by adding a lead layer within the surrounding polyethylene moderator. The lead improves the detector response in high energy range by neutron multiplication such as ^{208}Pb(n, Xn) reactions. The detector is a 2-inches in diameter spherical ^{3}He (5 atm) proportional counter. The neutron energy response of this rem meter was calculated up to 150 MeV. This type of rem meter is used for neutron area monitor in J-PARC.

The other is the phoswitch-type scintillation detector, DARWIN[4-6] (Dose monitoring system Applicable to various Radiations with WIde energy raNges) which consists of a liquid organic scintillator BC501A coupled with ZnS(Ag) scintillation sheets doped with ^{6}Li. It was developed in JAEA. In the present work, the scintillator is a cylinder, 3-inches in diameter and long. The neutron energy response of the detector was calculated up to 1 GeV.

The ordinary rem meter (Fuji Electric Systems: NCN1) and the normal neutron survey meter (Aloka: TPS-451C) were also used as reference. The detector locations and the shielding structure are shown in **Figure 3**.

At first, the neutron dose rate was measured at the location 1, which is located on a pre-shield of the neutron beam line No.12 (BL12), on the boundary between the proton beam transport tunnel and the biological shield of the target station. The neutron dose from the target station is designed to be less than 12.5μSv/h on the surface of biological shield made of the magnetite concrete, at 1 MW proton beam on the target station. Furthermore, the beam loss in the proton beam transport line due to the upstream target for muon production raises the neutron dose at the location 1. The shielding structure of the proton beam transport line is rather weak for this direction because the penetrating direction is upward from the neutron beam line elevation. The beam loss fraction by this target is 10.1%[7]. This location 1 was chosen from the preliminary survey by the normal neutron survey meter TPS-451C.

The measurement was done under the condition of 25Hz, 3GeV-210kW proton beam to MLF.

At the location 1, the neutron dose rate by the modified rem meter was 52 μSv/h, while those by the ordinary rem meter and TPS-451C were 32 μSv/h and 29 μSv/h, respectively. The difference between the modified rem meter and the normal ones which have no sensitivity to high energy neutrons above 20 MeV showed the presence of the high energy neutrons over 20 MeV. From these values, about 60 % of the neutron dose rate is due to neutrons with energy below 20 MeV.

On the other hand, we could not measure neutrons by DARWIN at the same location, because it was not possible to distinguish the particle type due to frequent pile-up in the pulse-shape and height discrimination process. This is attributed to the pulsed beam feature: The cycle of the proton beam is 25 Hz, and one macro pulse consists of 2 bunches of 120 nano-seconds duration in 600 nano-seconds interval. Therefore the peak value of one bunch is over 11 amperes although the average current is 70 μA. Consequently, the observed dose rate of 52 μSv/h will become momentary very high and beyond the upper-limit dose that DARWIN can handle. In the case of the modified rem meter which essentially detects the neutrons after slowing-down process in its moderator, several microseconds of the slowing-down time serves the time variation to ease the momentary peak.

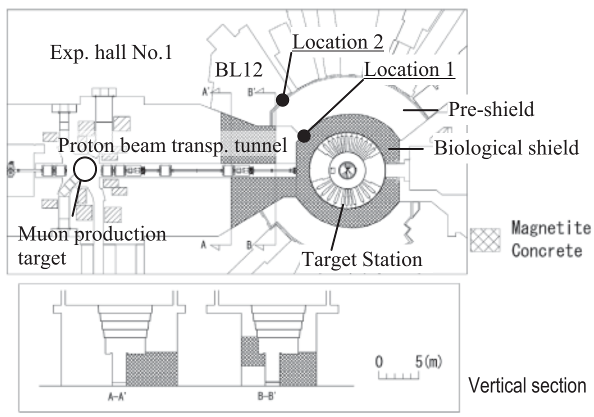

Fig. 3 Illustration of detector locations and shield structure.

As the location is neither in the working area nor in the neutron beam line, the detailed dose calculation has not been carried out yet. From the neutron dose distribution roughly calculated by PHITS[8], the average neutron dose rate of a few meters in height direction around the location is ~ 100 μSv/h at 1 MW proton beam to MLF. So the measured value (52μSv/h at 210 kW) seems to be consistent with calculation.

To enable the measurement by DARWIN, we moved it to location 2, about 5 meters away from the location 1. At this location, the effect of the pulsed beam is not so serious and the neutron dose rate measured by TPS-451C was 0.8 μSv/h.

By DARWIN, the dose rate by neutrons over 1 MeV was 0.95 μSv/h. Assuming 1/E energy spectrum below 1MeV down to 1 keV, the dose rate reached to 1.3 μSv/h. So the normal neutron survey meter TPS-451C was thought to count 60 % of the total neutron dose.

Figure 4 shows the neutron energy spectrum measured and unfolded by DARWIN at the location 2. High energy neutrons over 20MeV were significantly observed and constructed the peak around 100 MeV. From the measured neutron spectrum, the contribution of 1-20 MeV neutrons to dose rate was 0.49 μSv/h, and that of >20 MeV neutrons was 0.43 μSv/h. So the high energy component of >20 MeV have comparable contribution by neutrons of 1-20 MeV. Furthermore, the anticipated dose rate by the normal rem meter (1.3 - 0.43 = 0.87μSv/h) was consistent with the measured value (0.8μSv/h) by TPS-451C.

From the measurement by DARWIN, the contributions to dose of other particles were 0.096 μSv/h by photons and 0.028μSv/h by muons and high-energy photons. As is usually recognized, this indicated that neutron is the most important in the shielding design.

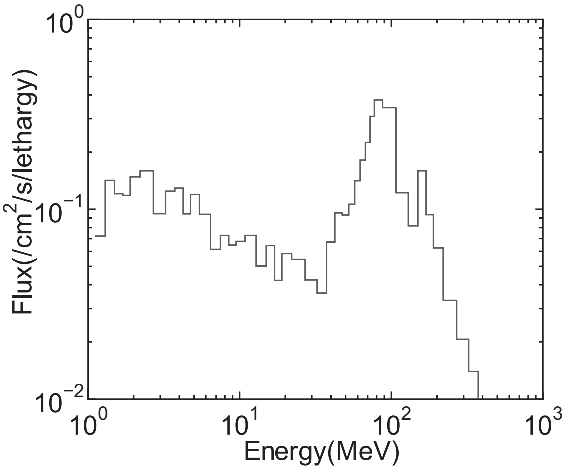

Fig.4 Neutron spectrum measured by DARWIN.

III. Conclusion

Neutron dose measurements were done in the experimental hall No.1, during the condition of 25Hz, 3GeV-210kW proton beam to MLF. By the measurements,

1. Neutron dose rate measured by the modified rem meter was 52 μSv/h at the location 1. About 60 % of the neutron dose rate was measured by the ordinary rem meter, if based on that by the modified rem meter,
2. Due to the pulsed beam, there were so many pile-ups in the measurement by DARWIN even that the average dose rate are some tens μSv/h,
3. The neutron spectrum was measured by DARWIN, confirmed the high energy neutron components above 20 MeV,
4. Neutron dose measured by DARWIN was 1.3μSv/h, assuming 1/E spectrum below 1 MeV down to 1keV at the location 2. The high energy component of >20 MeV have comparable contribution by neutrons of 1 ~ 20 MeV. Conventional neutron survey meter TPS-451C was thought to count about 60% of total neutron dose.

The similar measurements at other places in J-PARC will be done to confirm whether the differences between the modified rem meter and the normal ones are similar or not. Further inspection for the pulse height counting of the modified rem meter, and detailed shielding calculation by simulation code will be performed.

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