Shielding designs for the electron transport line of XFEL facility, SACLA to SPring-8 storage ring

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ABSTRACT The electron beam transport line from SACLA to SPring-8 has been constructed to obtain more effective use of high performance electron beam. The shielding design of the beam transport line has been performed under the fundamental two concepts. For the normal operation, the bulk shield has been designed by using empirical formula under the assumption of 1 % electron beam loss at any points. For the abnormal conditions, the shielding design has been performed to make full use of so called local shield in good combination with safety interlock systems. With these concepts, it has been confirmed to keep radiation safety effectively for transportation of the electron beam.

I. INTRODUCTION

At the SPring-8 site, an 8 GeV class synchrotron radiation facility, “SPring-8” and an X-ray free electron laser facility, “SACLA” are now operating. The accelerator of SACLA is the electron linear accelerator with the energy of up to 8.5 GeV(1), and can produce an extremely high quality electron beam to oscillate X –ray laser. SPring-8 was designed to construct 61 beamlines and now 55 beamlines are under operation and 2 beamlines are under construction(2). To get higher quality with higher brightness of synchrotron radiation beams at SPring-8 with a lower emittance, that means the upgrade of SPring-8, we have a plan to use the SACLA electron beam for the injector of SPring-8. The SACLA electron beam, therefore, will be transported about 200m distance from the SACLA undulator section to the SPring-8 Synchrotron-Synchrotron beam transport line with the vertical interval of about 10m. This electron beam transport from SACLA XFEL to SPring-8 “XSBT line” has been designed by using FLUKA(3), empirical formulas(4) and has been constructed under the fundamental concepts of the shielding design to keep safety with efficiency and effectiveness. For the normal condition of the electron transportation, the bulk shield wall has been designed under the assumption of the 1 % electron beam loss at any points. For the abnormal conditions, the shielding design has been performed to make full use of so called local shield in good

combination with safety interlock systems.

II. XSBT LINE

The physical relationship of SACLA and SPring-8 is shown as Fig.1. An electron beam of SPring-8 comes from the injector and booster synchrotron. The SACLA electron beam comes to the SACLA beam dump at the undulator section and X-ray free electron laser comes to the experimental hall along the electron beam axis and SACla-SPring-8 experimental relation building. Some of the electron beam will be distributed to the XSBT line at the undulator section and transferred to the dump of the booster synchrotron or synchrotron –synchrotron beamline to the SPring-8 ring. The length of the XSBT is about 200 m and the vertical interval between SACLA and the booster synchrotron is about 10m and the beam bend from SACLA is about 50 degrees. Fig.2 shows the map of the XSBT line. The XSBT line has one maze and the beam is down with the inclination of 10 degrees along the pass. In the figure, BV1 to BV5 indicate the key bending magnets. The switching magnet is important. However the electrons cannot go to the XSBT line when the mismatching of the switching magnet is occurred at the switching magnet. The first important bending magnet is BV1 and 6 bending magnets power is connected in series, and when the power of BV1 is changed, 6 bending magnets powers are changed automatically. Second BM is BV2 and 2 bending magnets power is connected in series. Third bending magnet BV3 is 2 bending magnet and the beam is down with the inclination angle of 10 degrees. BV4 is also 2 bending magnets and the electron beam is up to keep horizontal position. And BV5 is one bending magnet to connect to synchrotron dump line with 6 degrees bend in horizontal.

. Fig. 1 Photo at SACLA and SPring-8

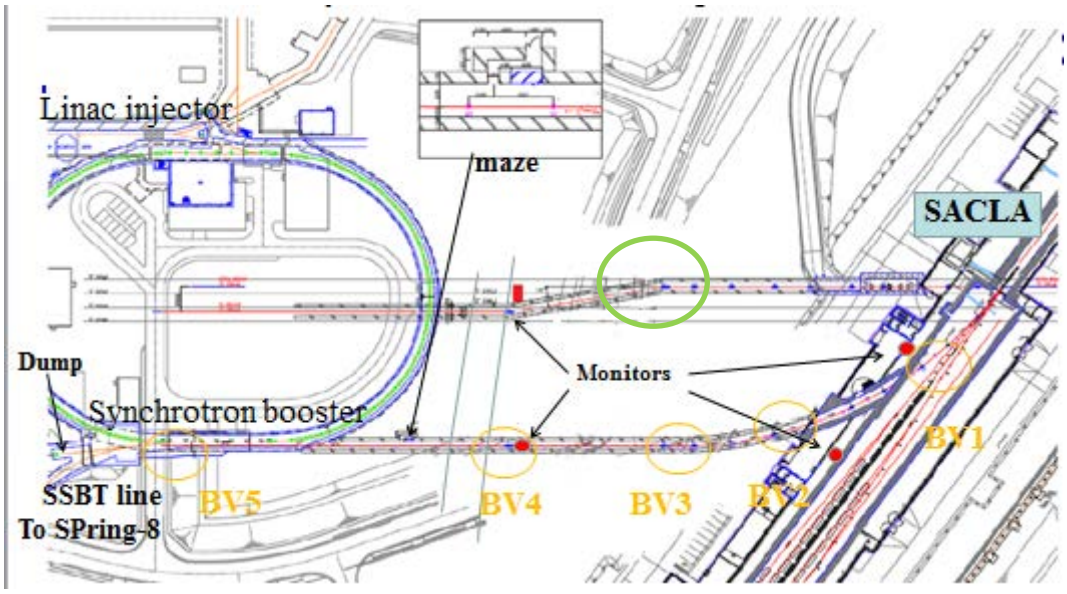

Fig.2 XFEL-Synchrotron beam transport line, XSBT including the elevation view. The Green circle indicates the position that the XSBT line goes down with inclination of 10 degrees

III. SHIELDING DESIGN

For the XSBT line, the maximum permissible number of transport electrons is 5.67×10^{14} electrons in a week and that is the same as the maximum permissible injection electrons to the SPring-8 ring in a week. The XSBT line has two shutters, one is in the SACLA undulator hall and the other is in the synchrotron booster tunnel to access to the XSBT line during the operation of SACLA or the booster. The shielding design of the XSBT line was performed under the two criteria for normal operations. One is the design criteria of the dose to be lower than 100μSv/week (1.3mSv/3 months) at the boundary of the controlled area that means out of the shield wall. The other is the 1% beam loss scenario at any points. Under these conditions, we decided the thickness of shield wall to be more than 1.1m ordinary concrete with the density of more than 2.2g/cm3. For the incident or accidental conditions, such as mismatching between the electron energy and the power of the bending magnets, we take countermeasures by making full use of local shield, safety interlock systems, connections the BM power in series as much as possible, and monitors.

III-1. Shielding design for normal operation condition.

Leakage dose estimations were performed by using Jenkins' formula and the SHIELD 11 code[(5)] for normal operation under the 1% electron beam loss scenario. Fig.3 shows the leakage distribution depending on the scattering angle from the electron beam axis. In the figure, (A) show the cross sectional view of the XSBT line with the 1.1 m wall thickness of ordinary

concrete for the side wall and the roof. Fig.3 (B) shows the estimation of the leakage distributions by using two methods. As shown in the figure, the leakage dose will be less than 0.6 μSv/h and gamma dose will be higher than the neutron dose. In comparison with the results of Jenkins' formula and the SHIELD 11, the neutron doses are almost same, and the gamma dose distribution by using SHIELD11 is slightly higher than that of Jenkins' formula so that the total leakage doses by using SHIELD11 are slightly higher than that of Jenkins' formula. The XSBT line has the vertical interval of about 10m so the leakage dose outside the inclined roof with 10 degrees as indicated in Fig.2 under the 1% beam loss at the nearest bending magnet has been estimated as shown in Fig. 4. In this case, there are some different from the other wall case, and the leakage dose is less than 0.6 μSv/h and the maximum dose will be appeared near the scattering angle of 60 degrees from the electron beam axis.

The XSBT line has one maze to enter the shield tunnel as shown in Fig.2 and the size is shown in Fig.5. For the maze streaming case, leakage doses were estimated by using SHIELD11 and Tesch's formula [(6)]. Table 1 indicates the estimation results of the leakage dose under the assumption of the beam loss of 1% at the nearest point of the Maze. As shown in the table, the leakage dose at the entrance of the maze is very low in comparison with the direct attenuation dose of 0.6 μSv/h at the outside of the shield wall.

III-2. Leakage dose due to accidental conditions

At the XSBT line, there are possibilities of the accidental conditions due to mismatching the electron energy and the bending magnet powers of BV1 to BV5 as shown in Fig.2. For example, the bending magnet power has lost and 8GeV electrons inject into the XSBT line, continually. In this paper, the interlock systems are only here without considering. Fig.6 shows the dose distributions during the electrons hitting the shield wall of XSBT due to losing the power of the bending magnets of BV2. In this case, the maximum dose rates outside the shield tunnel are 31 and 110 μSv/h for gamma and neutron doses, respectively. At the BV3 area that the electron beam goes down with inclination angle of 10 degrees, leakage dose distributions are shown in Fig.7 due to the power loss of the BV3 bending magnets. In this case, the maximum dose rates outside the shield roof are 78 and 210 μSv/h for gamma and neutron doses, respectively. At the outside of side wall, the maximum dose rates are 1.6 and 15 μSv/h, respectively. At the BV4 area that the electron beam goes up with inclination angle of 10 degrees, leakage dose distributions are shown in Fig.8 due to the power loss of the BV4 bending magnets. In this case, the maximum dose rates outside the shield roof are 2.8 and 9.7 μSv/h for gamma and neutron doses, respectively. At the outside of side wall, the maximum dose rates are 9.7 and 18 μSv/h, respectively.

To reduce the leakage dose, the local shield which make of ordinary concrete or lead will

be installed into each bending magnet sections. For example, in the case of the installation of the local shield of 30cm lead sandwiched with 10cm ordinary concrete, and at the opposite side, 20cm ordinary concrete at the BV2 bending magnet section, the dose distributions are shown in Fig.9. In this case, the maximum leakage doses are 0.48 and 6.3 μSv/h for gamma and neutron doses, respectively. At the opposite side, 1.1 and 9.9 μSv/h for gamma and neutron doses, respectively. In the case of installing the local shield of 40 cm ordinary concrete and 20 cm lead at the BV3 section as shown in Fig.10, the maximum doses at the roof are 0.47 and 8.1 μSv/h for gamma and neutron, and at the side, 1.3μSv/h for both gamma and neutron maximum leakage doses. Fig.11 shows the leakage dose distributions at the BV4 section with installing the local shield of 10cm lead and 50cm ordinary concrete. In this case, the maximum doses at roof are 0.91 and 5.3μSv/h for gamma and neutron doses, respectively. At the side, the doses are 2.1 and 1.3μSv/h for gamma and neutron doses, respectively.

In comparison with and without installing local shield as shown in Figs. 6 to 11, it is clear that there are some benefits by using local shied for electron transport line. One is that the leakage doses will be reduced by small size shield materials. One is that the electro-magnetic shower production point can be moved to close the electron beam transfer line so that the leakage dose outside the shield tunnel will be reduced effectively by the effect of the inverse square distance, especially neutron leakage dose can be reduced drastically. The other is that it will be determined the maximum leakage dose point easily and to be set the monitors at the point so that the accidental condition will be detected smoothly.

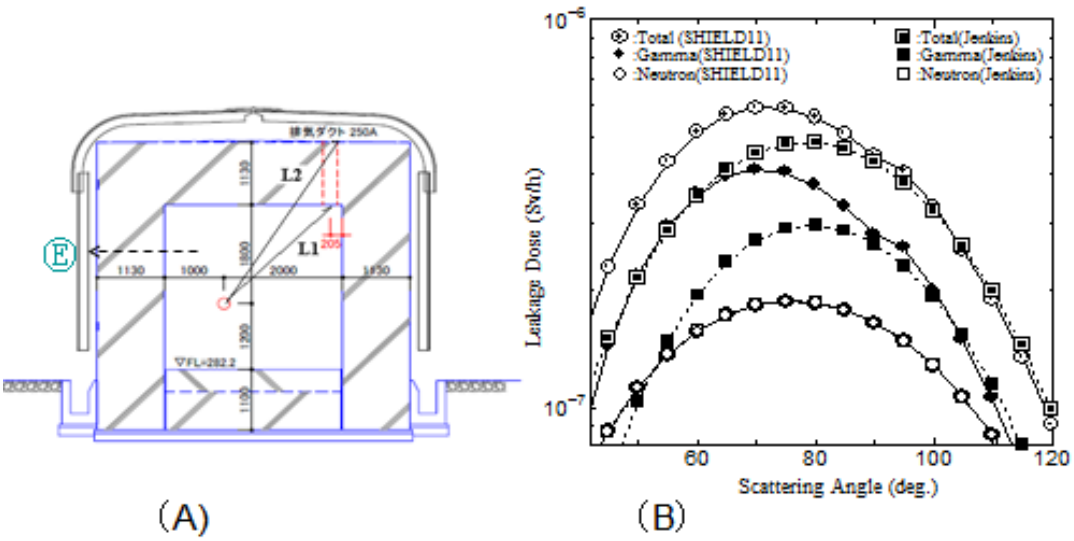

Fig.3 Leakage dose distribution outside the shield tunnel at the XSBT line. (A) shows cross sectional view of XSBT and (B) is the estimation results of the leakage doses depending on the scattering angle from the electron beam axis by using SHIELD 11 and Jenkins' formula.

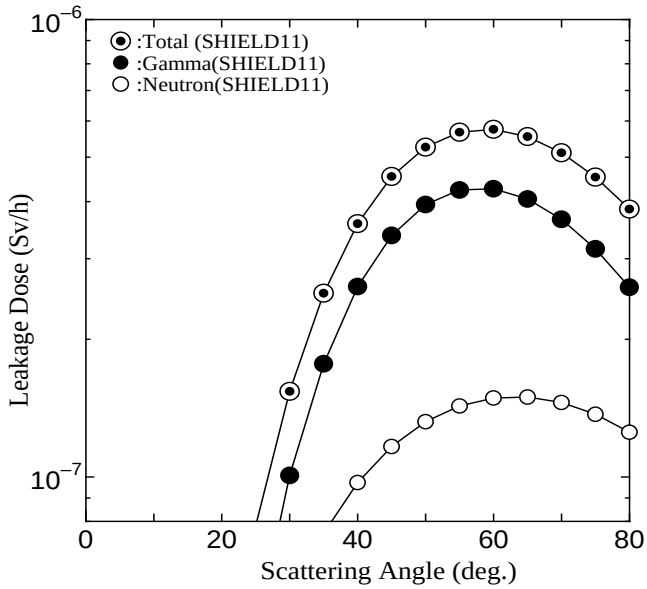

Fig.4 Leakage dose distribution outside the roof of the XSBT line at the downside with inclination of 10 degrees.

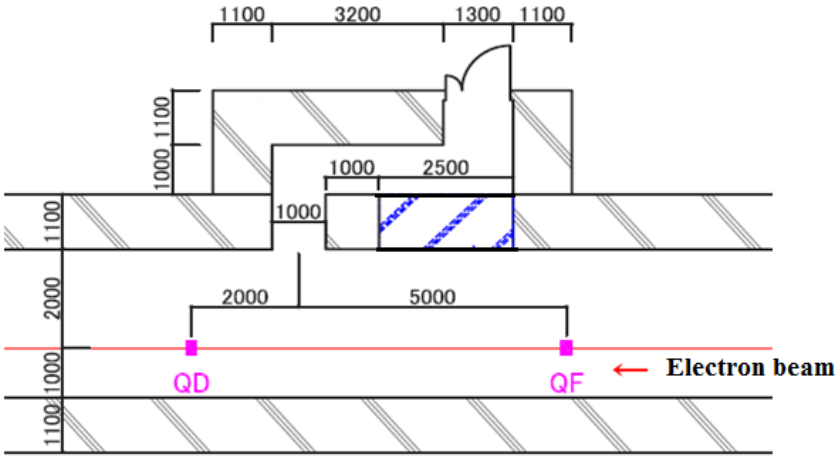

Fig.5 The dimension of the maze of the XSBT line.

Table 1 Leakage dose estimation at the XSBT maze.

	Length (m)	Width ＊0.5 (m)	Cross section (m^2)	Inlet dose (μSv/h)	Outlet dose (μSv/h)
Second labyrinth	3.45	0.5	2.0	γ:28.0	γ:0.17
				N: 11.0	N: 0.19
Third labyrinth	1.60	0.65	2.6	γ:0.17	γ:0.0046
				N: 0.19	N: 0.015

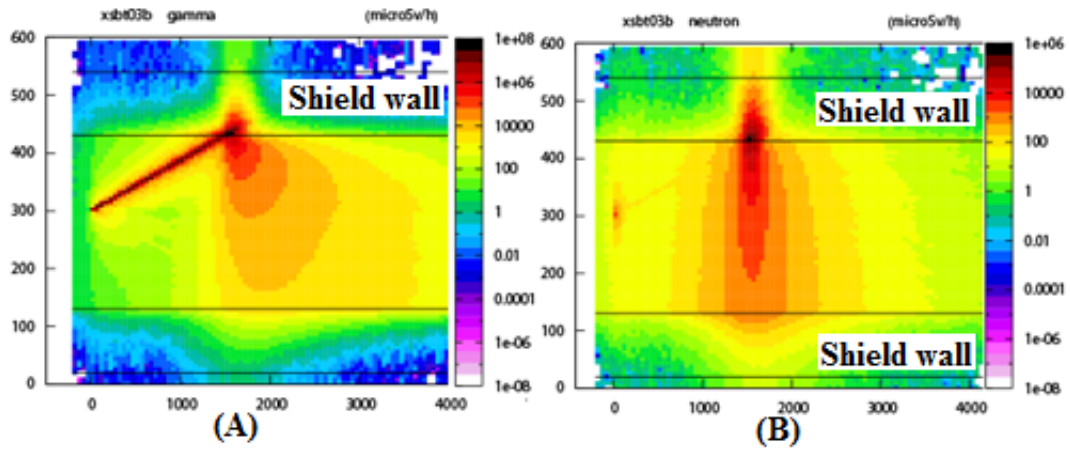

Fig.6 Dose distribution due to the loss of BV2 bending power. (A) is gamma dose distribution and (B) is neutron dose distribution.

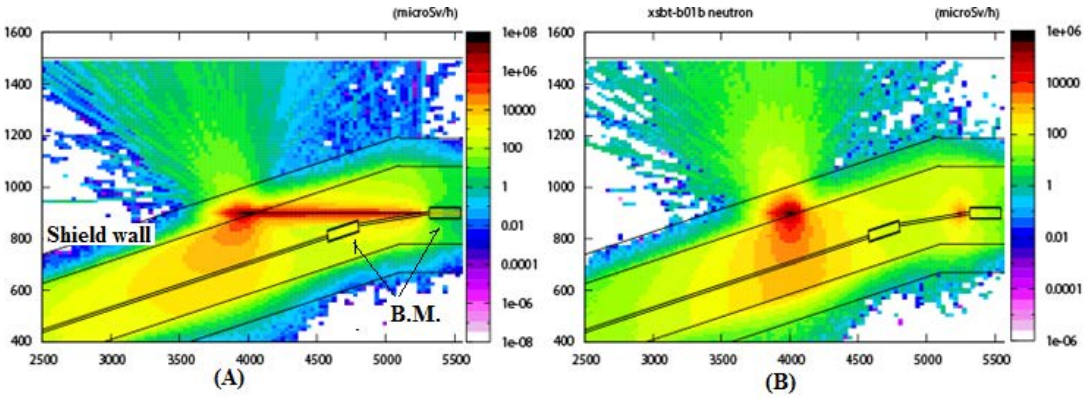

Fig.7 Dose distribution due to the loss of BV3 bending power. (A) is gamma dose distribution and (B) is neutron dose distribution.

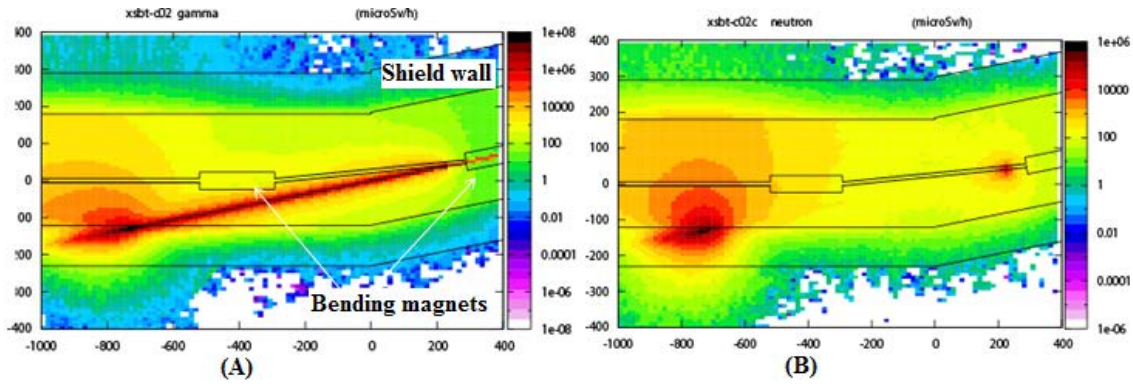

Fig.8 Dose distribution due to the loss of BV4 bending power. (A) is gamma dose distribution and (B) is neutron dose distribution.

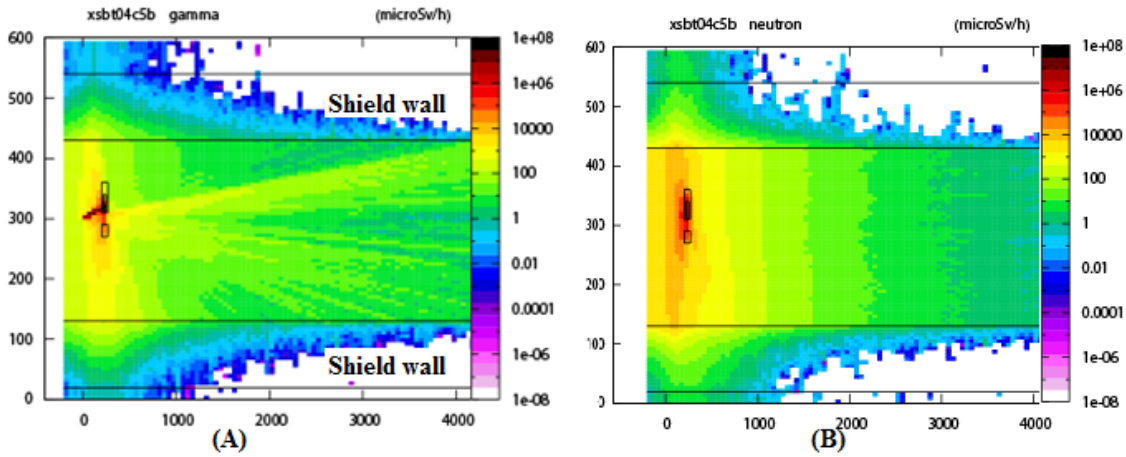

Fig.9 Leakage dose distribution at the BV2 section in the case of 8GeV electrons coming into the XSBT line and the loss of the bending magnets power, and installing the local shield of 30cm lead sandwiched with 10cm ordinary concretes, and 20cm ordinary concrete at the opposite side. A; gamma dose, B; neutron dose

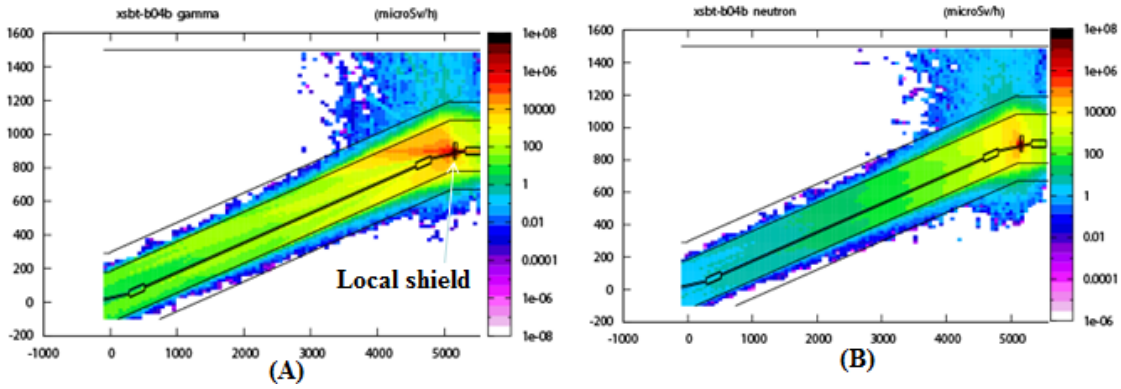

Fig.10 Leakage dose distribution at the BV3 section in comparison with Fig.7 case with the local shield of 40 cm ordinary concrete and 20cm lead. A; gamma dose, B; neutron dose.

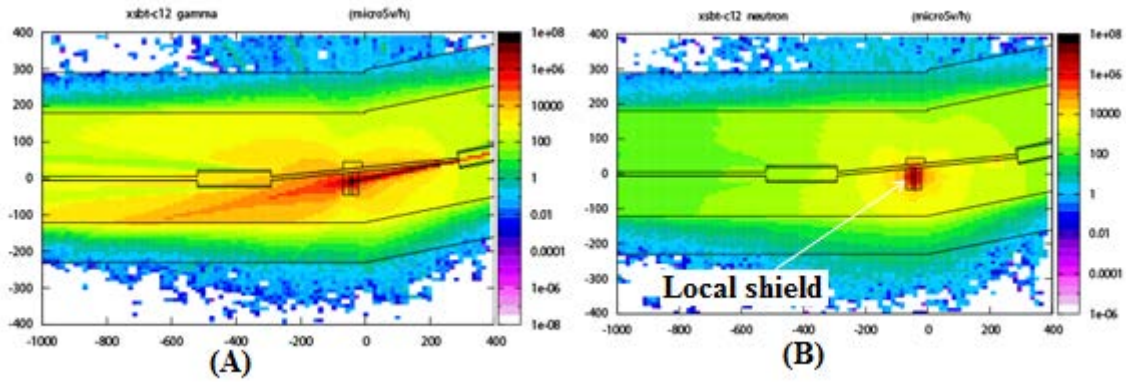

Fig.11 Leakage dose distribution at the BV4 section in comparison with Fig.8 case with the local shield of 50 cm ordinary concrete and 10cm lead. A; gamma dose, B; neutron dose.

IV. SAMMARY

In order to using high performance SACLA electron beam to the SPring-8 injector, the XFEL-Synchrotron beam transfer line was designed by using empirical formula, SHIELD11, and FLUKA under these fundamental concepts; (1) The bulk shield is designed under the normal operation with the assumption of 1% electron beam loss at any points. (2) For accidental conditions, we make full use of so called local shield to prevent serious conditions.

As the results, (1) leakage dose is less than 0.6μ Sv/h during normal operation, and (2) by using local shields, we can get the leakage dose under control to be less than 20μSv even the 1 hour operation under the accidental conditions. Moreover, it has been clarify that using local shields has some valuable merits to reduce leakage doses and keep safety.

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