国際リニアコライダー電子ビームドライブ方式陽電子減のターゲット周辺の施設設計

FACILITY DESIGN FOR THE POSITRON PRODUCTION TARGET STATION OF ILC E-DRIVEN POSITRON SOURCE

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Abstract

ILC (International Linear Collider) is an e+e- linear collider with CME from 250 GeV to 1000 GeV which would be constructed in Japan. In ILC, positron is generated in pair-creation process in target. Because ILC requires many positron than ring colliders, a high radiation activity is expected around the positron production target. In this article, we consider the radiation protection of the ILC positron source from the radiation safety point of view. We also consider the target maintenance, because the target will be exchanged annually, because the radiation damage of the target.

1. INTRODUCTION

ILC (International Linear Collider) [1] is an e+ e- linear collider with CME from 250 GeV to 1000 GeV. In linear collider, the beam pass through the interaction point only once. Although the high luminosity in order of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is realized by squeezing the beam size at the interaction point with the limited beam current, the average current provided by the injector is much larger than that of a typical ring collider, 35 μA. Therefore, a large amount of electron and positron has to be newly produced. Because there is no positron in nature, positron has to be produced artificially by the pair-creation.

Figure 1 shows the section and the length of the ILC positron source. 3.0 GeV electron beam with 4.0 nC bunch charge is injected on 16 mm thickness W-Re alloy target. From the target, positron and electron with a large energy spread and a large spread of transverse momentum are generated. The generated positron is captured in the RF bucket by a linear accelerator, the capture linac. At the end of the capture linac, a chicane is placed to remove the electron. During the capture process, many electron and positron are lost by hitting the wall of the accelerating cavity and the beam pipe. Not only from the target, but also the entire capture linac is a source of radiation and radiation activity.

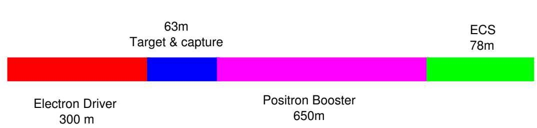

Figure 1: The section and the length of the ILC E-Driven positron source.

By considering the facility of the E-Driven positron source from the radiation safety point of view, the following points have to be considered.

(1) Radiation safety for workers.
(2) Radiation safety for equipment.
(3) Radiation safety for environment.

(1) and (2) are common, but (3) might require additional explanations. ILC will be constructed in a tunnel under ground of mountain area. Outside of the tunnel wall is natural rock. Because nobody enters in the rock area, the radiation environment of the natural rock doesn't matter from the human protection point of view. On the other hand, the natural rock is a part of the mountain area which is a common property shared by human and any pollution to the shared property is not feasible. From this point of view, some additional consideration for the environment is necessary in the ILC case. By considering these two facts, nobody enters in the natural rock and the natural rock is a part of shared property, we should suppress the radiation activity of the natural rock after the experiment, well below the clearance level of radionuclides. The clearance level is determined by IAEA in 1996 [2] as the level of radionuclides below which regulatory control is relinquished.

These points should be considered various situations. For example, during the operation, during the daily maintenance, during the special maintenance, after the shutdown, etc. By product of the item and the situation, many aspects should be considered, but we concentrating on the following aspects.

(a) Radiation safety of equipment in the service tunnel during the operation.
(b) Radiation safety of workers during the special maintenance.
(c) Radiation safety of the environment after the shut-

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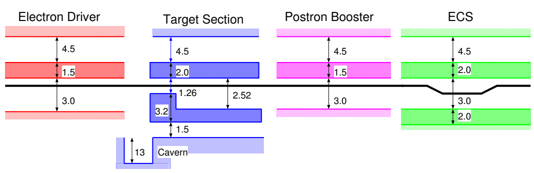
down.

In the following sections, we explain the facility design of the ILC positron source.

2 . FACILITY DESIGN OF ILC POSITRON SOURCE

Figure 2 show the horizontal layout of each section; From the left to right, Electron driver, the target and capture section, positron booster, and ECS. For all sections, the upper area is the service tunnel where the power source and other hardware are placed in. The lower area is the accelerator tunnel where the accelerator is placed. The exception is the target and capture; The middle is the accelerator tunnel and the lower is the corridor. There is a cavern where the used target module is stored.



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The radiation environment in Electron driver and Positron booster is expected to be in a same level as an ordinal electron accelerator. The service tunnel is isolated from the accelerator tunnel with 1.5 m thick Boronated concrete block. As a regulation of the ILC radiation safety, access to the service tunnel during the operation is not allowed. From this point of view, all we have to consider is the safety of equipment in the service tunnel. The cross section of the tunnel in Electron driver and Positron booster is shown in Fig. 3. Tunnel is dug in the natural rock and the size is 9 m in width, 3.6 m in height. The height doesn't include the roof area. The tunnel wall is finished with an ordinal manner, e.g. spraying concrete and no special attention for the radiation safety, because the expected radiation activity is quite low. The square in the service tunnel shows the size of the RF power source. The service tunnel width is determined to move the power source after the initial installation.

Figure 4 shows the cross section of the tunnel in ECS. In this section, the accelerator tunnel is surrounded by BC with 2.0 m thickness. In ECS, 5 GeV positron pass through the chicane and some radiation loss is expected. By considering only the safety of the equipment in the service tunnel, it doesn't matter, but the radioactivity of the natural rock after the shutdown matter. To prevent the activity in the natural rock, BC surrounds the accelerator tunnel. To mount the shield on the roof of the accelerator tunnel, a crane is placed.

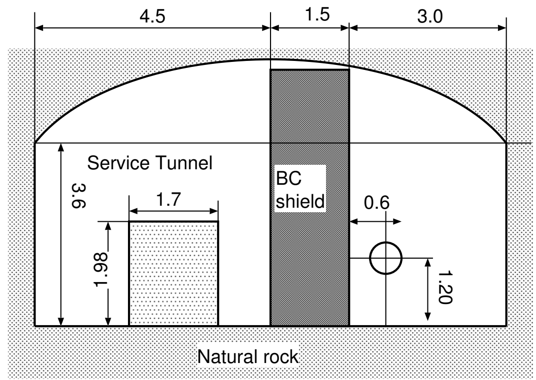

Figure 3: Cross section of Electron driver and Positron booster section. Tunnel is dug in the natural rock and the size is 9 m in width, 3.6 m in height. The height doesn't include the roof area.

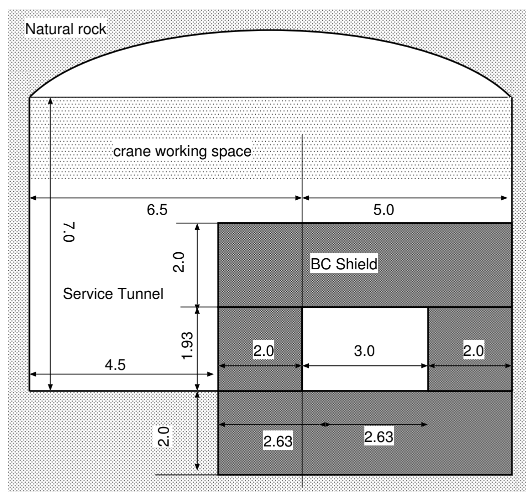

Figure 4: Cross section of ECS section. The accelerator tunnel is surrounded by 2 m BC shield to prevent the radio activity of the natural rock.

3 . TARGET SECTION AND THE MAINTENANCE

In this section, we describe the target section and the maintenance. Figure 5 shows the horizontal view of the upstream part of the target section. The service tunnel is isolated from the accelerator tunnel with 2.0 m BC shield. The red solid box shows the size of the target module.

Figure 6 shows the cross sectional view of the target section. The center red square shows the target module. The module is surrounded by 2 m thick BC shield, not only the horizontal direction, but also vertical direction. Above the shield, working space for the crane is prepared. The size

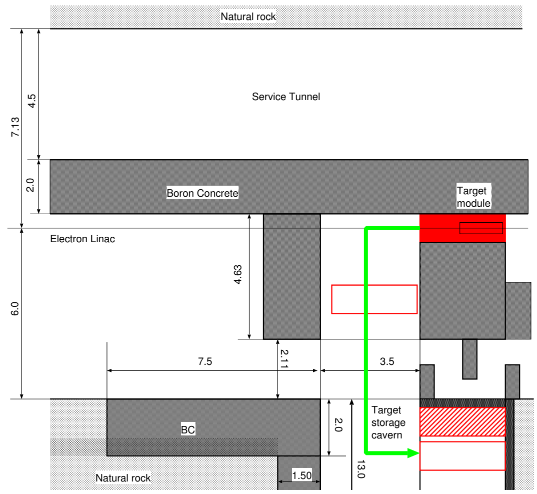

Figure 5: Horizontal view of the upstream part of the target section.

of the cavern is 13 m, but it is shrink in the figure.

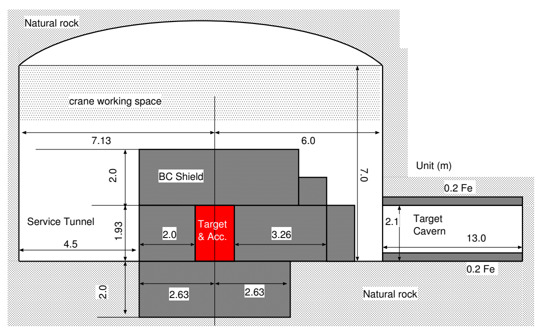

Figure 6: Cross sectional view of the target section. The center red square shows the target module. The module is surrounded by 2 m thick BC shield, not only the horizontal direction, but also vertical direction. Above the shield, working space for the crane is prepared. The size of the cavern is shrink in the figure.

Figure 7 shows the vertical cross section of the target module moving from the target mount to the traverser. The target module contains not only the target, but also FC (Flux Concentrator magnet), the first accelerator tube, solenoid magnets, and front shields with BC and iron plate. In the maintenance, the target module is moved by the module. As shown in the Fig. 5, the target is ejected to the upstream direction. The module is mounted on the traverser, a wagon which can move transverse direction to the beam line on rails fixed on the floor. The traverser transport the module to the cavern where the used target is stored. In the cavern, there are 10 places where store the target module. The target is moved from the traverser to the storage.

Because the target module has thick shield by BC and iron plate as shown in Fig. 7, the expected radiation level just upstream side of the module is 50 $\mu Sv/h$ which enable the maintenance work by workers. The side of the module is shielded by an iron plate with 5 cm thickness mounted on the traverser. The expected radiation level on the side is 1 m Sv/h which is slightly high to work safely, but any work at the side is not expected. On the back side, there is no shield and expected radiation level is extremely high, but this side is effectively shielded by the fixed BC shield on the ground during the transportation on the traverser. In the storage area, the backside is also shielded by the used target.

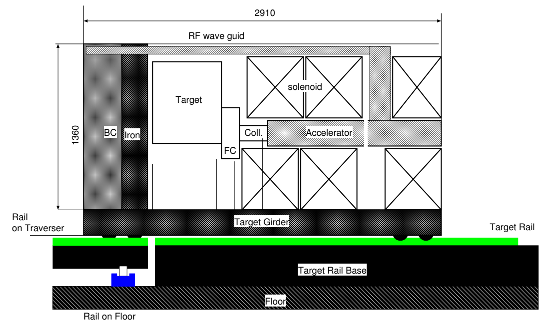

Figure 7: Vertical cross section of the target module moving from the target mount to the traverser. The target module contains not only the target, but also FC (Flux Concentrator magnet), the first accelerator tube, solenoid magnets, and front shields with BC and iron plate.

Figure 8 shows a detail view of the cavern for the target storage. The target module i stored in the storage surrounded by iron plates for the radiation shield. There is only a tiny gap, between the iron shield on the traverser and that in the storage area, the radiation from the target is confined in the area including during the transportation.

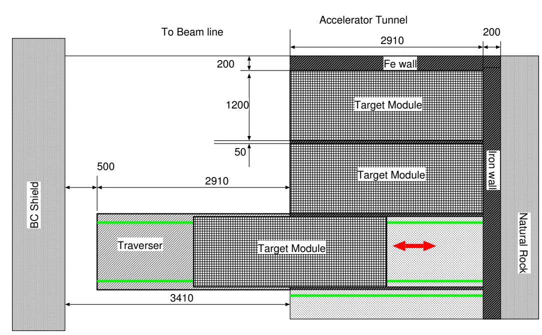

Figure 8: The horizontal view of the cavern. Target storage area is surrounded by iron plates for the radiation shield.

In the maintenance of the target, installing and uninstalling the module, we have to connect and disconnect many joints, e.g. water, electricity, RF wave guide, many electrical cables for controlling and monitoring. Installation is easy because the target is not activated, but the extraction should be carefully considered. To prevent any unnecessary radiation exposure, these joints are assembled on the front panel of the module as shown in Fig. 9.

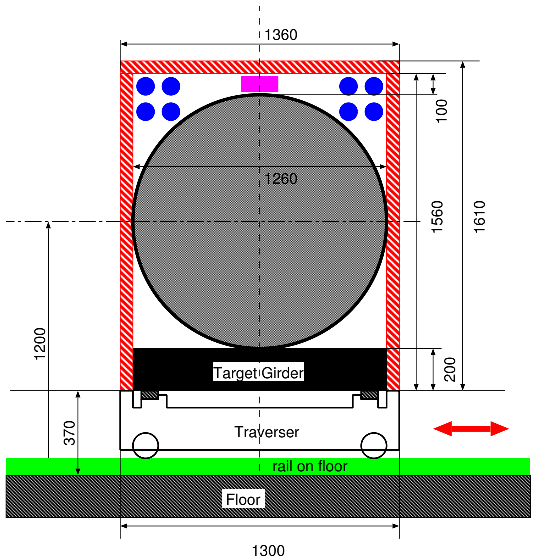

Figure 9: Front view of the target module on traverser. The module is surrounded by 5 cm iron shield. The 8 circles and one square on top of the shield show the joints and RF waveguide.

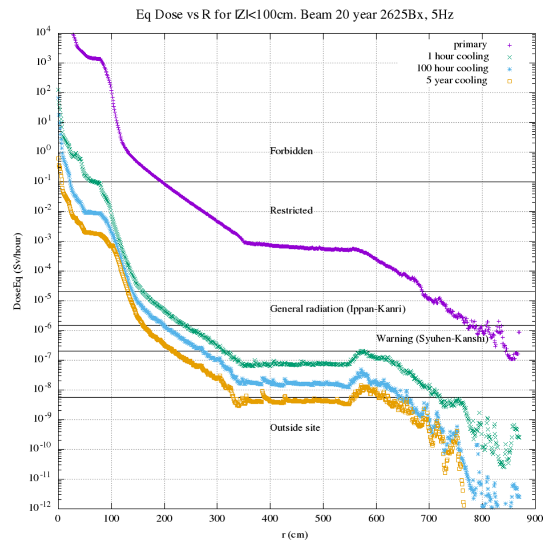

Figure 10: Radiation level after 20 years operation with various cooling time. Purple cross is just after the operation, x is 1 hour later, star is 100 hours later, and open box is 5 years later. The areas divided by horizontal lines show the category of radiation safety. From the top to bottom, the areas correspond to the forbidden area, restricted area, generals radiation area, warning area, general area, and outside of the site.

4 . RADIOACTIVITY AFTER THE SHUTDOWN

As we already mentioned, the radiation activity on the natural rock after the shutdown matters. We performed a simulation to estimate the activity after the operation by assuming a rotation symmetrical geometry. The accelerator (target) is placed on the center axis and the accelerator tunnel is 1 m radius. 2 m BC shield surrounds the accelerator tunnel, 1 m to 3 m from the axis. 2 m open space (3 m to 5 m from the axis) represents the service tunnel. At the wall of the service tunnel, 0.1 m normal concrete and 0.1 m water are placed to represent spray concrete and ground water. Outside of this layer is 3 m thick natural rock made from 50% oxygen, 29% Si, Al, Fe, Ca, Na, etc. The contents are a typical example of a natural rock.

Figure 10 shows radiation level after 20 years operation with various cooling time. Purple cross is just after the operation, x is 1 hour later, star is 100 hours later, and open box is 5 years later. The areas divided by horizontal lines show the category of radiation safety. From the top to bottom, the areas correspond to the forbidden area, restricted area, general radiation area, warning area, general area, and outside of the site. According to the result, the radiation dose of the accelerator area (target) is still high, but the radiation dose service tunnel (3 m to 5 m) becomes quite low after 1 hour cooling. It corresponds to general area of laboratory.

Figure 11 shows the clearance level of various elements found in the natural rock and the sum of them. In the regulation determined by IAEA [2], the sum of the clearance level should be less than 1 as

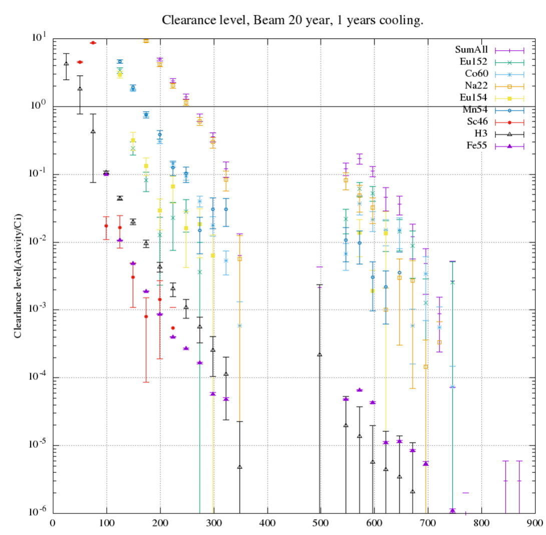

Figure 11: Clearance level of various elements and sum of them, as a function of the distance from the accelerator (target). The sum is below the clearance level at the natural rock, more than 500 cm from the axis.

$$\sum_{i}^{n} \frac{C_i}{C_{Li}} \leq 1 \qquad (1)$$

where C_i is the concentration of radionuclides i in the material, (Bq/g), and C_{Li} is the clearance level of radionuclides i (Bq/g), n is number of radionuclides. If this sum is less than 1, the material complies with the clearance requirements. According to our result, the sum of the index is 0.2 which is well below the limit, 1. That means that the material doesn't require any control as an active element.

5 . SUMMARY

We studied the radiation environment and safety of the E-Driven ILC positron source including the maintenance. We designed the target exchange procedure to reserve the radiation safety for workers. We estimated the radiation level of the target area and we found that the radiation level one hour after the operation in the service tunnel is workable. Radiation activity in the natural rock after the shutdown is below than the clearance level.

REFERENCES

[1] ILC Technical Design Report, KEK-Report 2013-1(2013).
[2] IAEA-TECDOC-855(1996).