Shielding Design for Radiation Safety for the Super SOR Project

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Abstract

A concept for the construction of a shielding design for a high-energy accelerator is discussed, taking into consideration of the dose estimation on the Super SOR project at the University of Tokyo. The Super SOR supplies a third generation VUV and a soft X-ray synchrotron light source (1.6GeV). In order to calculate the annual effective dose around the facility, the Swanson-Braeuer, Jenkins, and Stevenson-Thomas formulas were used for simple prospective estimations. Both the direct radiation from the storage ring beam and the skyshine dose are considered. The newest shielding design can accomplish the target dose of 0.05 $mSvy^{-1}$for the public. In addition, because the dose is significant, special care should be taken when constructing tall buildings near the storage ring.

1. INTRODUCTION

The "Super SOR" project, which supplies a third-generation VUV and soft X-ray synchrotron light source, is planned for construction on the Kashiwa Campus of the University of Tokyo in Japan. The main facilities of the project are a 1.6 GeV Linear Accelerator (LINAC) and a 1.6 GeV Light Source Ring (LSR). The layout of the facility is shown in Figures 1-1 and 1-2.

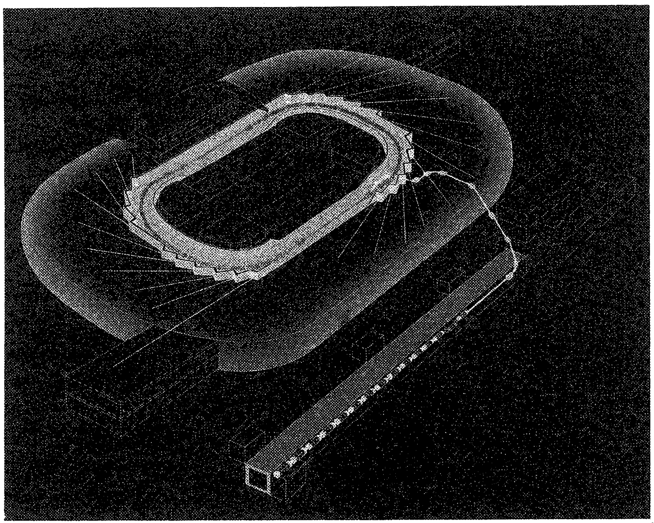

Fig. 1-1 Super SOR

The length of the LINAC is about 100m, and this facility is located underground. The circuit length of the LSR, which is in the shape of a racetrack, is about 230m and is located at ground level. Estimates of the likely radiation and radioactivity levels are needed at the design stage of the accelerator for radiation safety, machine layout, and cost.

This study presents (1) a concept for a shielding design and (2) an annual effective dose due to direct radiation and skyshine around the facility boundary. This paper presents the newest information based on the Super SOR design in February 2000 for the following: LSR operation mode, beam parameters, calculation formula used for the dose estimation, safety margins, and a shielding design.

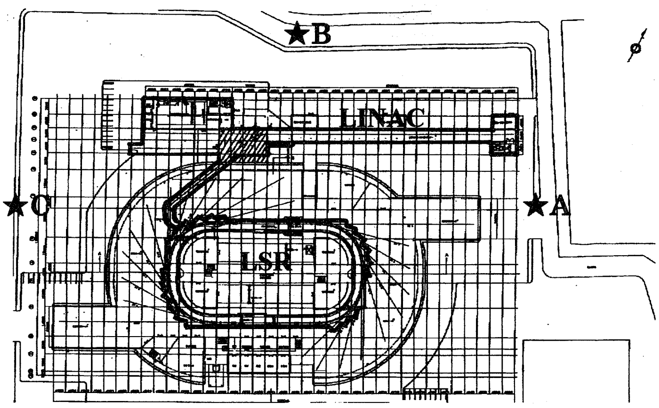

Fig. 1-2 Super SOR Layout
LINAC: 1.6 GeV Linear Accelerator
LSR: 1.6 GeV Light Source Ring (storage ring)
A-C: Dose-estimated positions

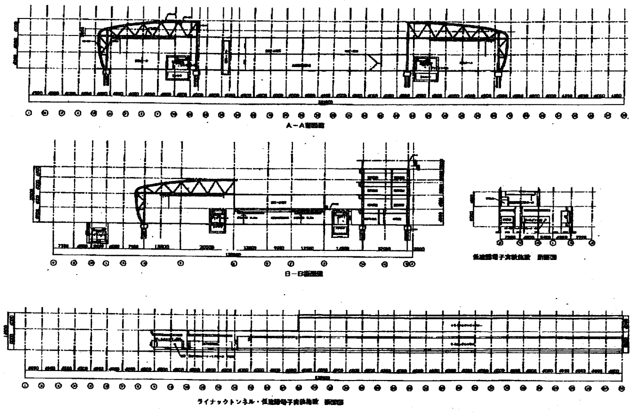

Fig. 2 Super SOR Cross-section

2. OPERATION MODE AND CALCULATION CONDITIONS

The plan for the annual operation pattern of the LSR is shown in Table 1.

Several beam parameters are necessary for dose calculation formulas when providing for safe estimates. The sources for the shape of the lines of the LSR are converted into a 27-point representation. There are two points for straight positions, 24 points for bending-magnet positions, and one point for a beam-incidence position from LINAC.

Beam-loss ratios at the point sources, which are extremely difficult to calculate in advance, have been determined with a large safety margin and are shown in Tables 2-1 and 2-2.

Table 1 Annual LSR operation mode

Operation mode	Operation time [hrs/y]	Current [mA]	Incidence frequency [times]
Multi Bunch (storage)	4,000	400	3 /day
Multi Bunch (incidence)	320	400	3 /day
Single Bunch (storage)	500	10	5 /day
Single Bunch (incidence)	80	10	5 /day
Setup	150	10	20 /6hrs
Burning	200		
Machine Study	400		
Incidence Machine Study	200		
Incidence Machine Setup	100		
Standby	50		

Table 2-1 Beam-loss ratio at LSR for operation mode

Operation mode	Estimated ratio
Multi Bunch (storage)	100% beam loss
Multi Bunch (incidence)	30% incidence ratio
Single Bunch (storage)	100% beam loss
Single Bunch (incidence)	30% incidence ratio
Setup	10% incidence ratio
Burning	Two times the multi bunch mode
Machine Study	Two times the multi bunch mode

Table 2-2 Beam-loss ratio at LSR for positions

Mode	Estimated beam-loss ratio [%]			
	90-degree bending point	Incidence point	Bending -magnet area	Straight point
Setup	40	40	9x2	1x2
Incidence	0	50	24x2	1x2
Storage	0	98		1x2

3. FORMULAS

A large number of formulas that have been used to calculate the dose rates that occur in the vicinity of high-energy accelerators have been developed since the early 1960s. Deciding which formulas to use depends on the stage of the design and the purpose of the calculation. The design for the current facility is still in a comparatively early stage and is consequently not yet fixed. Therefore, the main purpose of these calculations is to develop a rough estimate of the dosages with the newest designs. Therefore, the following formulas were selected because of their reliability for determining values and because they are based on easy arithmetical operations that require a small number of parameters. Two kinds of doses, namely (a) direct and (b) skyshine, must be considered when calculating doses around the boundaries of a facility. In the (a) calculation, there are two categories: forward or side fraction in the beam-line direction.

For an annual dose of the forward fraction in the beam-line direction, the Swanson-Braeuer formula [1,2] was selected, as follows:

$$\text{photon; } H = (P/r^2) \times S \exp(-d/\lambda_i)$$

$$\text{neutron; } H = (P/r^2) \times S \exp(-d/\lambda_i) \times 2.0 \times \varepsilon$$

$$\mu \text{ particle; } H = 25/(25+X/X_0) \times (X(Ee)-X)/X(Ee) \times H_0 \quad (X(Ee) > X)$$

$$H = 0.0 \ (X(Ee) \leqq X) \quad H_0 = 8.0 \times 10^{-15} \text{ J } Ee/r^2.$$

For an annual dose of the side fraction in the beam-line direction, the Jenkins formula [5] was selected:

$$\text{photon; } H = 3.6 \times 10^{-14} \text{ J } Ee/r^2 \ \varepsilon \times [133\exp(-d/\lambda \sin\phi)/(1-0.98\cos\theta)^{1.2} + f_1\, 0.267\exp(-d/\lambda_1 \sin\phi)/(1-0.72\cos\theta)^2]$$

$$\text{neutron; } H = 3.6 \times 10^{-14} \text{ J } Ee/r^2 \ \varepsilon \times [f_1 \exp(-d/\lambda_1 \sin\phi)/(1-0.72\cos\theta)^2 + f_2\, 10\exp(-d/\lambda_3 \sin\phi)/(1-0.75\cos\theta)] + 3.79\, Z^{0.73}\exp(-d/\lambda_2 \sin\phi)] \times 2$$

H: annual dose [Svy^{-1}]
P: power equivalent to beam loss [W]
r: distance [m]
S: source [$Svh^{-1}m^2kW^{-1}$]
d: bulk shield thickness [cm]
λ_i: attenuation distance [cm]
ε : duty factor [-]
X_0: radiation length [cm]
J: beam-loss rate [electron s^{-1}]
Ee: electron energy [GeV]
X(Ee): maximum range of μ particle at energy of Ee [cm]
θ : angle toward beam-line direction [degree]
ϕ : shield angle [degree]
f: source correction factor [-]

In the (b) calculation, the equation of Stevenson -Thomas [7-9] was applied:

$$H = 3.0 \times 10^{-15} \exp(-r/\lambda) / r^2 \times S \times 3600$$

H: skysine dose (Svh^{-1})
λ : attenuation length in air of high-energy neutrons (m)
r: distance from a source to a specific
S: total neutron source intensity on the surface of the building's ceiling (ns^{-1})

The estimation procedure for the source neutron intensity on the ceiling is as follows:

① Bulk shielding estimation on the ceiling by the Jenkins formula [5].
② Neutron flux estimation based on the obtained dose by assuming the 1/E spectrum.
③ Total neutron intensity, S, estimation by multiplying the total ceiling surface.
④ Skyshine estimation by Stevenson-Thomas formula [7-9] to each point source.
⑤ Total skyshine estimation by summing up each dose component from each source point.

This method provides a conservative estimate of the dose because the assumption for 1/E allows for a wide safety margin, and the Stevenson-Thomas formula overestimates the distance by about 100m.

4. SAFETY MARGIN FOR THE DOSE LIMIT

For an annual estimate of the dose during the design stage of the facility, larger safety margins should be built into the plan. A new law in Japan that is based on a recommendation from ICRP Publication 60 prescribes that the public dose limit in the vicinity of a facility boundary is 1 mSvy^{-1}. We established a target annual dose of 0.05 mSv, which was based on safety designs for radiation used for power plants in Japan. The limit we established is 1/20 of the limit due to the Japanese regulation. The shielding design of the LSR for this project has been established to meet the target dose, which includes both direct radiation and the skyshine.

5. RESULTS AND DISCUSSION

Table 3 shows the determined shielding design.

Table 3 LSR or Super SOR Shielding Design

Position	Material and Thickness
Sidewall of storage ring	50 cm of OC
Forward wall to beam line	70 cm of OC + 20 cm of lead
Ceiling of storage ring	50 cm of OC
Building wall of LSR	50 cm of OC

OC: Ordinary Concrete

In the presented calculation, the values shown in Table 3 are used. However, additional shielding material might be needed in the area of the ceiling that is over the beam's incidence position from the LINAC. In addition, the thickness of the sidewall of the storage ring depends on how the experimental hall beside the LSR beam is used. If the area immediately adjacent to the LSR wall will be frequently used for experiments, additional shielding material will be necessary. Table 4 shows the annual dose at the boundaries of the facility. The estimated positions are indicated as ★ in Figure 1-2.

Table 4 Annual dose values at boundaries

Position name of boundary	Position ID	Annual dose [mSvy^{-1}]	Target dose mSvy^{-1}]
Northeast	A	0.026	0.050
Northwest	B	0.012	0.050
South	C	0.127	--

For the estimated point of A, the direct radiation dose is 0.009 mSvy^{-1}, and the skysine dose is 0.017 mSvy^{-1}. For the estimated point of B, the direct radiation dose is 0.000 mSvy^{-1}, and the skysine dose is 0.012 mSvy^{-1}. These positions represent the public dose at the boundaries of the facility. They are the nearest to the facility and would make the highest annual dose. The direct radiation dose of position A is much higher than that of position B. This depends strongly on the beam direction of the storage ring. At the forward position of the beam direction, the dose would be higher than it would at the side position based on the formulas in section 3.

The south boundary is far from the storage ring. Therefore, if the northeast (A) and northwest (B) boundaries can accomplish the target dose for public, the south could do so too. However, there is a plan to construct a five-floor building around position C, as shown in Figure 1. In this case, people working and studying on the higher floors, for example four and five, would be exposed to a higher dose of radiation directly from the storage ring because they would be directly over the ring beam separated by a comparatively thin concrete ceiling. Position C is absolutely inside the boundary. Therefore, there is no need for it to be below the target dose for the public. According to Japanese regulations, the dose limit at position C is considered to be 1.3 mSv per 3M for the boundary limit of the controlled area. However, it is important to roughly estimate the annual dose around such positions because they will become special points with comparatively high doses. As a result, the estimated annual dose at position C around the ring-side glass window at the fifth floor is 0.127 mSvy^{-1}. The direct radiation dose is 0.101 mSvy^{-1}, and the skyshine dose is 0.026 mSvy^{-1}.

6. CONCLUSION

The concept for the construction of a shielding design for a high-energy accelerator was discussed using estimates of dose rates on the Super SOR project at the University of Tokyo. In order to calculate dose rates around the facility, several formulas, including the Swanson-Braeuer, Jenkins, and Stevenson-Thomas, were used for simple prospective estimations. In order to calculate the annual dose around the facility boundary, direct radiation from the storage ring beam and skyshine were considered. The newest shielding design can meet the target dose for the public, which is 1/20 of that indicated by Japanese regulations. In addition, because the dose is significant, special care should be taken when constructing tall buildings near the storage ring.

7. REFERENCES

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