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Bulk Shielding Estimation on 1 GeV Electron Synchrotron Radiation Facility

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Abstract

Concept on the bulk shielding design for high-energy accelerator was discussed through estimates of dose rates on the VSX (VUV and soft X ray) project of the University of Tokyo. Main facilities are (1) 1 GeV Linear Accelerator (LINAC) and (2) 1 GeV Light Source Ring (LSR). Dose limits to be achieved around the facility for the project were determined with a large margin for safety allowance as follows; controlled area; 17 μ Sv/h (1mSv/w × 2/3) and boundary of a controlled area; 1.7 μ Sv/h (1.3mSv/3M × 2/3). Beam parameters used in bulk shielding calculations were also determined with large margins. Dose rates from photon, neutron and μ particle around the facility were calculated by "Swanson-Braeuer formula" and "Jenkins formula". High-dose areas were located around an electron/positron conversion target (E/P target) of LINAC and around a beam incident point of LSR. Thickness of bulk shield for LINAC was 250cm of ordinary concrete (OC) and 20cm of supplemental iron (Fe) blocks for E/P target. Thickness of that for LSR is 65cm-OC plus 15-40cm supplemental Fe for forward direction and 60cm-OC for side direction. The maximum dose rates of these high-dose areas were estimated around/over 17 μ Sv/h. Therefore some regions would be controlled areas with working-hours limit. Dose rates at the other regions in controlled area were estimated between 0.2 – 2.6 μ Sv/h during the maximum beam operation mode. Therefore the bulk shielding design of the VSX project was estimated to be successful.

1 Introduction

An estimate of likely radiation and radioactivity levels is needed at the design stage of an accelerator for deciding the radiation safety features to be incorporated in the infrastructure of the machine and for predicting where radiation damage possibilities will have to be taken into account. Both these aspects can have a significant influence on the machine layout and cost. Failure to make a reasonable assessment at the right time may have far reaching consequences for future costs. Therefore these prospective radiation level should be certainly estimated.

Purpose of this study is to discuss a concept on the construction of bulk shielding design for a high-energy electron synchrotron facility through estimates of dose rates on the VSX (VUV and soft X ray) project of the University of Tokyo. In this paper, overview of the project, calculation formula for the dose estimation, beam parameters, safety margin decision and calculated results are mentioned. These calculations are based on the newest plan for the VSX project as of June 1999.

2 Overview of the VSX Project

The VSX is a Japanese third-generation VUV and soft X-ray source. Its main distinctive feature is extremely high prospective brilliance. The VSX project will achieve the world-highest brilliance of 10^{19} - 10^{20} [photons/s/mm^2/mrad^2/0.1%b.w.] at the energy region of 100-200 eV. For more information on the specification of the VSX, see the web site of http://www.issp.u-tokyo.ac.jp/labs/sor/ .

Main facilities of the project are (1) 1 GeV Linear Accelerator (LINAC) and (2) 1 GeV Light Source Ring (LSR). The layout of the facility is shown by figure 1. The length of LINAC is about 100m and this facility is located under the ground. The circuit length of LSR is about 230m whose shape is a race track type, and this is located at the ground level.

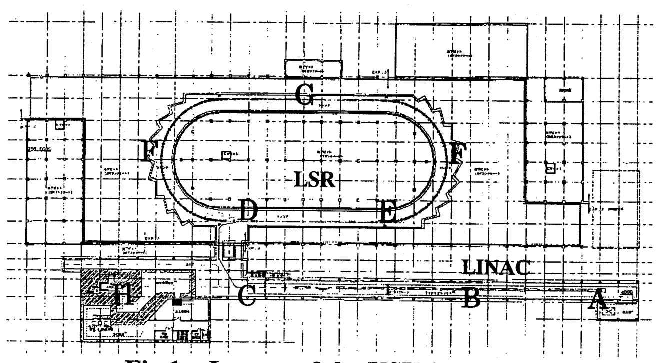

Fig.1 Layout of the VSX facility
LINAC; 1 GeV Linear Accelerator
LSR; 1 GeV Light Source Ring
A-H; main radiation point sources

Four patterns of beam operation mode are planned for LINAC. Table 1 shows the beam operation patterns of LINAC and their beam parameters.

Table 1 Beam operation mode of LINAC

Mode	Ope-time [hrs/y]	Energy [MeV]	Pulse-width [nsec]	Current [mA]
ES	245	1,000	1	400
ESL	220	1,000	30	400
EL	4560	400	(?)	37.5×10^{-3}
PS	20	250	1	E;10^4 P;10

ES; electron short pulse mode
ESL; electron semi-long pulse mode
EL; electron long pulse mode
PS; positron short pulse mode

In addition, annual operation pattern of LSR is also planned as table 2.

Table 2 Annual operation pattern of LSR

Operation mode	Ope-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		

3 Calculation Formulas of Radiation Level for Bulk Shield

A large number of calculation formulas for estimation of dose rates around a high-energy accelerator have been reported since early 1960's [for example, 1-6]. Selection from these formulas should strongly depend on the stage of design and on the purpose of calculation. In terms of the present study, the stage of design for the facility is comparatively early and is still not fixed. Therefore the main purpose of the calculation is rough estimate of dose rate under the newest design. Then the following formulas were selected in the present study because these formulas estimate reliable values based on easy arithmetical operations using smaller number of parameters. The dose rate calculations are classified into two categories: forward or side fraction toward beam line direction.

For annual dose of forward fraction toward beam line direction, the Swanson-Braeuer formula [1,2] is selected as follows,

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

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

μ particle; $H = 25/(25+X/X_0)\times(X(Ee)-X)/X(Ee)\times H_0$ $(X(Ee)>X)$

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

For annual dose of side fraction toward beam line direction, Jenkins formula [5] is selected.

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

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

H; annual dose [Svy^{-1}]
P; power being 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 [-]

4 Beam Parameters

Several determinations for beam parameters are needed for a safety-side estimate when dose rates around the facility are calculated by the formulas mentioned above.

Each radiation source is assumed to be a point source. Line-shape sources, like LINAC beam line and LSR beam line, are converted into several representative point sources. In addition, beam loss ratios at the point sources of slit, target, beam dump and representative point of beam line, whose advance estimation by calculation is extremely difficult, are determined with a large safety margin as table 3, table 4-1 and table 4-2.

Table 3 Beam loss ratio at LINAC

Main source points	Estimated beam loss ratio [%]
Bunching point	30
Slit point (A)	10
E/P target (B)	100 (PS operation mode) 1 (the other modes)
E/P target (H)	100 (EL operation mode) 1(the other modes)
Beam dump	100
Others	1

E/P target; electron/positron conversion target

Table 4-1 Beam loss ratio at LSR

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	twice of multi bunch mode
Machine Study	twice of multi bunch mode

e/s; electron per second

Table 4-2 Beam loss ratio at LSR
(Beam loss distribution along beam-line of LSR)

Mode	Estimated beam loss ratio [%]: 90 degree bending point (C, D)	incident point (E)	curved area (F)	line-shape area (G)
Setup	45	45	9	1
Incident	40	40	19	1
Storage	0	99		1

5 Safety Margin for Dose Limits

For the dose rate estimation at the design stage of facility, larger safety margin for dose limits on radiation level should be taken into account. Table 5 shows the dose limits established by law. In addition, since a new law based on the recommendation of ICRP Publication 60 is to be enforced, its prospective values of dose limits are also written in Table 5. Based on the new law, dose limits to be achieved around the facility for the project are determined with a large safety margin as follows; controlled area; 17 μSv/h and boundary of a controlled area; 1.7 μSv/h. Safety allowance factor is determined as 2/3 for in-site region. In addition, since the dose limit values to be achieved are given as the unit of "μSv/h", further more safety margin is assumed. In this conversion, "working hours" is calculated as 40 hrs/w.

Table 5 Dose rate limits

Area category	Existing law	New law, prospective value	Limits to be achieved
CA	1mSv/w	1mSv/w	17 μSv/h
CA Boundary	300 μSv/w	1.3mSv/3M	1.7 μSv/h

CA; controlled area without working-hours limit

6 Results and Discussion

Table 6 shows dose rate values at the floor of klystron room over a beam line of LINAC. Thickness of the ceiling as a bulk shielding concrete of LINAC is designed as 250cm. 25cm of supplemental iron block is equipped around the electron/positron conversion target (source B). Klystron room is to be a controlled area. The dose rate at the region 5 (around source B) has probability to beyond the limited level of general controlled area. In that case, the region will be a controlled area "with" working-hours limit. Other regions in the klystron room meet the level of controlled area. Therefore existing bulk shielding design is successful. Concerning the other electron/positron conversion target of H, the design of target and the surrounding geometrical arrangement have not been discussed in detail so far. Therefore the target of H is not treated in the present study. However, since a beam dump and other activated materials will be in tight formation around the source H, more careful and early discussion is needed for this area.

Table 6 Results of dose rate around LINAC

Floor of Klystron room Region No.	Dose rate MAX [μSv/h]	Annual dose [mSv/y]
1	1.1	5.2
2 (slit; A)	0.26	1.2
3	0.24	1.1
4	0.50	2.5
5 (E/P target; B)	17	6
6	1.1	5.1
7 (bending point; C)	2.6	12

E/P target; electron/positron conversion target

In practice of radiation safety for the whole facility, since other radiation than photon, neutron and μ particle, like X rays of bremsstrahlung emitting from the klystron itself, cannot be discriminated from leaking radiation by measurement, then safety margin plays an important part in the design stage.

Table 7 shows representative values of dose rates around a beam incident point (E) of LSR. Thickness of bulk shielding material of LSR is as follows; forward direction toward beam line direction = 65cm (concrete) plus 15-40cm (iron), and side direction = 60cm (concrete). Dose rates of all the other regions than the incident point indicate under 1.5 μSv/h during maximum beam operation mode. Area around LSR is a controlled area therefore these regions meet the dose limits.

Like the B (and H) region (electron/positron conversion target), the E region of beam incident point in LSR has probability to beyond the limited level. Full of care should be taken about the practical values.

Table 7 Results of dose rate around LSR

Beam incident point (E) Region No.	Dose rate MAX [μSv/h]	Annual dose [mSv/y]
1	24	17
2	13	9.6
3	14	11
4	10	9.3

7 Conclusion

Concept on the construction of bulk shielding design for high-energy accelerator was discussed through estimates of dose rates on the VSX (VUV and soft X ray) project of the University of Tokyo. In order to calculate dose rates around the facility, "Swanson-Braeuer formula" and "Jenkins formula" were used for simple prospective estimation. According to these calculations with a large safety margin, several regions around big radiation sources like an electron/positron conversion target of LINAC or a beam incidence point of LSR will be controlled areas with working-hours limit if necessary based on practical data. Dose rates at the other regions were estimated between 0.2–2.6 μSv/h during maximum beam operation mode. Therefore the present bulk shielding design was estimated to be successful.

8 References

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