SHIELDING DESIGN STUDY FOR CANDLE FACILITY

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Abstract

The radiation shielding design study for the third generation synchrotron light source CANDLE is carried out. The electron beam loss estimates are done for all stages from linac to storage ring. A well-known macroscopic model describing the dose rate for point losses has been used to calculate the shielding design requirements of the facility.

ELECTRON BEAM LOSS ESTIMATES

The CANDLE Radiation Safety considerations and in particular the operation schedule and beam loss estimates of the facility are presented in [1-3].

In this paper more detailed and extensive data, which had not been described before, are presented on the estimations for electron beam loss in CANDLE during the standard operation regimes: start-up, scientific program, and machine development [4].

As a pattern for our design, and for estimating beam properties, we are mainly based on Corbett's et all proposed model of beam loss estimation for SPEAR3 [5].

Beam Loss during Injection

For the purpose of electron beam loss estimation of CANDLE we take the multi-bunch operation mode as more conservative case, then the maximum duration of the bunch train at the electron gun exit, which is equal to 600 nsec, with maximum total charge of 6 nC (10 mA pulse current). Taking into account also the booster synchrotron repetition rate of 2 Hz, the beam current, which could be measured by the first Faraday Cup located just after the gun exit is expected to be of 12 nA. From this initial value the anticipated electron beam loss for CANDLE is shown in Figure 1.

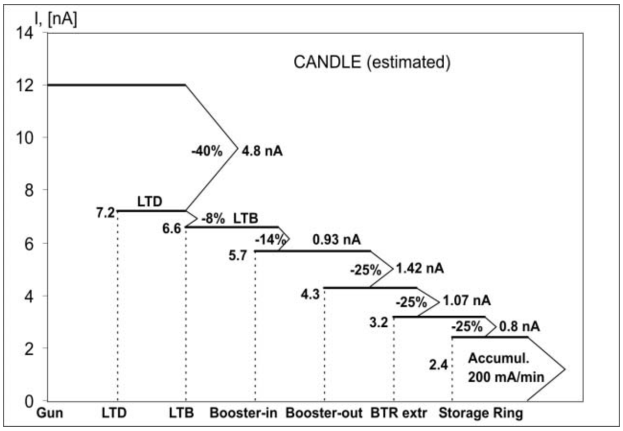

Figure 1: Electron beam loss channels for CANDLE.

Integrated Charge Loss

For CANDLE in the normal operation mode, the charge from a previous fill will not be 'dumped', rather the beam current will be 'topped-up' back to 350 mA each fill cycle. To estimate the total charge loss in the accelerator tunnel, we assume one 0-350 mA fill, one 'top-up' fill after 12 hours normal operations and one beam dump per day (total of two 12-hour fills per day). The choice of such kind of filling regime for CANDLE is stipulated by following considerations.

The beam dump followed by a 0-350 mA fill is used to account the intentional or accidental beam loss. To compute the total electron beam loss we add the beam loss due to normal lifetime decay with the injection losses.

For the initial 0-350 mA fill each day, $1.575\text{x}10^{12}$ particles will be stored and $5.25\text{x}10^{11}$ particles will be lost (75% injection efficiency). The number of particles lost in the storage ring in 12 hours is:

$$N_{lost}^{12hour} = N_0 \cdot \left[1 - \exp\left(-t/\tau\right)\right] = 0.76 \cdot 10^{12}$$

The number of particles stored in the storage ring after 12 hours is : $N_0^{12hour} = N_o - N_{lost}^{12hour} = 0.815 \cdot 10^{12}$, which guarantees 181.1mA current in the storage ring, that in its turn is still sufficient to provide the user demands.

Summary of Losses

Table 1 summarizes losses for a typical 24 day start-up period followed by a 10 month operational cycle including machine development periods of 1 day per week. The cumulative estimates are based also on calculations of two categories of beam loss: direct beam loss with 100% due to limiting apertures, and slow loss of beam due to the charge deposition of the transport mechanisms to one or more vacuum chamber components. The detailed calculations are presented in [4]. The range of annual dose expected on individual components of CANDLE storage ring is specified as follows: the distribution of lost particles during the injection is expected basically at the injection septum (30%) and residuary 70% of loss is expected uniformly distributed around the ring at the locations with 10 small apertures. The stored beam particle loss is expected to dominate in horizontal plane, so 30% loss associates with 16 focusing central quadrupoles (high-dispersion points), 30% at the locations with acceptance-limiting apertures and the rest 40% of the normal beam decay losses will go to the rf beam dump (elastic, inelastic and Touschek scattering caused particle losses of the rf bucket).

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Table 1: Summary of losses for CANDLE.
(Average Power = e-/run x 1.6 x 10^{-19} x 3 GeV /
/ (10 mo x 30 day/mo x 24 hr/day x 3600 sec/hr)).

Mode	Hours	I,nA	Electrons	<P>,mW
LTB/LTD				
Start-Up	376	7.2	$6.09\cdot10^{16}$	
Scient. Prog.	5,720	7.2	$9.3\ \cdot10^{17}$	
Machine Develop.	720	7.2	$1.2\ \cdot10^{17}$	
Total	6,816		$1.11\cdot10^{18}$	
Booster				
Start-Up, 100MeV	30	7.2	$4.86\cdot10^{15}$	
Start-Up, 3 GeV	100	7.2	$1.62\cdot10^{16}$	
Scient.Prog.	1,560	7.2	$2.53\cdot10^{17}$	
Machine Develop.	240	7.2	$3.9\ \cdot10^{16}$	
Total	1,930		$3.13\cdot10^{17}$	
BTR Screens				
Start-Up	28	3.2	$2.02\cdot10^{15}$	
Scient. Prog.	15.2	3.2	$1.07\cdot10^{14}$	
Machine Develop.	2.6	3.2	$1.9\ \cdot10^{14}$	
Total	45.8		$2.32\cdot10^{15}$	
StorageRing Injection				
Start-Up	42	3.2	$3.02\cdot10^{15}$	
Scient. Prog.	6,240	3.2	$8.11\cdot10^{15}$	
Machine Develop.	3.5	3.2	$2.5\ \cdot10^{14}$	
Total Septum			$3.84\cdot10^{14}$	7.1 mW
Total Dump			$1.30\cdot10^{15}$	24.1 mW
Total QFC			$5.95\cdot10^{13}$	1.1 mW
Tot.Apertures			$1.48\cdot10^{14}$	2.8 mW
Tot. Uniform			$2.44\cdot10^{14}$	4.5 mW
Total			$1.35\cdot10^{16}$	

MODEL OF CALCULATION

For the radiation shielding calculation depending upon the energy of the accelerated particles (electrons), one or more of three radiation components, each with different attenuation lengths in a given medium, must be dealt with [6]. These are bremsstrahlung (BREM), giant resonance neutrons (GRN), and high-energy neutrons (HEN).

Well-known analytical macroscopic model describing the shielding for point losses allows one evaluate the shielding requirements for a storage ring according to the following expression for the dose rates for the given secondary radiation:

$$\dot{H} = \sum_i \frac{S_i P e^{-d/\lambda_i}}{R^2}, \qquad (1)$$

where $\dot{H}$ is the dose equivalent rate (Sv·h^{-1}), at a distance R meters from the beam interaction point, after the scattered radiation has passed through the thickness d of a shielding with a corresponding attenuation length λ_i of the radiation for the considered shielding and for the first radiation component (BREM, GRN, and HEN). P is the beam loss power (kW) of the electrons intercepted on the target, and S_i is the so called source term relating (converting) the intercepted beam power to the dose rate (Sv·h^{-1}·kW^{-1} at 1m), for the first radiation component.

The values of S_i factors and the attenuation length λ_i, with their different calculation approaches, for different types of radiations, absorber materials, and angles under which the radiation is considered are compiled, in a more approachable form for the usage, in [7] from the literature consulted for shielding information.

SHIELDING MATERIAL & DOSE LIMITS

It was arranged to use barites concrete (CCT) (3.5g/cm^3) as shielding material in CANDLE because of its abundant in Armenia *(i.e.,* it has very low cost) and minimum thickness of shield. The annual dose limits for the employees and members of the public are established for CANDLE 15 mSv/y and 1 mSv/y respectively, which is equivalent to 0.5 μSv/h for 2000 h/y working regime.
During the definition of the threshold of the linac shielding, the accidental losses will be taken into account by a system of radiation detection, integrated in the PSS system, that will cut automatically the linac in case of exceeding the threshold (for example, the dose equivalent integrated over fore hours ≥ 2μSv) [7,8].

Table 2: Linac shielding

Outer Wall Location	Distance from the source, [m]	Thickness of the wall, [m] & material	Dose rate, [μSv/h]
Stretched up to the 1st accel. section	3.5	0.75 Barites concrete	γ: 1.14 n: 0.26
Along of the first section	3.5	0.85 Barites CCT	γ: 1.3 n: 0.3
Between the 1st section & the 2nd section	3.5	0.70 Barites CCT	γ: 0.84 n: 0.19
Along the second section	3.5	1.0 Barites CCT	γ: 0.71 n: 0.16

SHIELDING DESIGN

The detailed calculation of the CANDLE shielding design is presented in [8].

Inasmuch as CANDLE booster and storage ring are assembled in one tunnel, the dose rate outside of the common tunnel will be determined by jointcontribution of booster and storage ring. The estimated thickness for the accelerators according to the microscopic model calculations are presented in Tables 2 and 3. The alternative partial use of lead absorber in combination with barites concrete for the ratchet end wall (under 0 degree) is proposed.

Table 3: Booster and Storage ring shielding

Location	**Thickness, [m] and material**	**Dose rate, [µSv/h]**
Inner Wall, under 90°	0.7 Barites concrete	0.529
Outer Wall, under 90°	0.75 Barites concrete	0.384
Roof, under 90°	0.7 Barites concrete	0.479
Ratchet end wall, under 0°	1.5 Barites concrete	0.342
Ratchet end wall, under 0°	0.28 Lead 0.27 Lead	0.362 0.488
Ratchet end wall, under 0°	0.14 Lead + 0.75 Barites concrete	< 0.5

CONCLUSION

In this presentation a macroscopic model describing the dose rate for point losses was used to calculate the shielding design requirements of the CANDLE facility.

Detailed and extensive considerations of radiation safety aspects for the linac, booster and storage ring accelerators of the CANDLE facility supplemented with the simulations by DOSRZnrc and FLUKA Monte-Carlo codes, and the comparison of the results with presented analytical calculations will be given elsewhere.

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