Sirius bulk shielding

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Abstract

The Brazilian Synchrotron Light Laboratory (LNLS) is designing a new 3 GeV source – Sirius. The design includes a very low natural emittance (0.3 nm.rad) storage ring and a full energy booster, both sharing the same concrete tunnel. A 150 MeV LINAC will be housed in a different tunnel. Due to the anticipated low lifetime, the system will operate in top up mode, with losses of the order of 10^{12} electrons per hour. The preliminary design of the bulk shielding, including entrance chicanes, is presented.

1. Introduction

Sirius is the second synchrotron machine of Brazilian Synchrotron Light Laboratory (LNLS). The first synchrotron light source (UVX) has been in operation since 1997. Sirius is in its final design [1], and civil construction has already started. Fig. 1 shows an aerial view of the campus, where one can see UVX and the future Sirius installation.
Full energy injection for the 3 GeV, 518 m long, storage ring will be provided by a booster housed in the same concrete tunnel. The booster is fed by a 150 MeV electron injector LINAC to be installed on the same floor level but in a separate concrete tunnel.

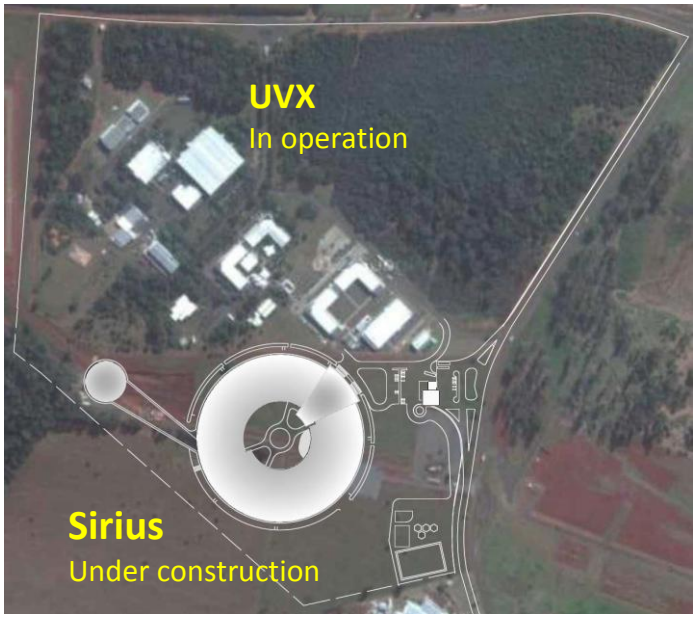

Fig. 1: Aerial view of the campus with the Sirius building inserted.

Due to the anticipated low lifetime, the system will operate in top up mode, with losses of the order of 10^{12} electrons per hour. The local shielding required to attenuate radiation due to specific electron losses, both in normal operation and in case of electron beam missteering, are not addressed in this article, except a preliminary study for the booster extraction septum.
We used the software FLUKA [2], a Monte Carlo particle transport code to calculate dose rates in the injection region of the machine from estimated electrons losses during injection and stored beam conditions in normal operation. Analytical expressions and semi-empirical data given by Swanson in the IAEA-188 Report [3] were used in some cases. However, the calculation results of both methods are not to be compared directly, since the corresponding assumptions are quite different. While FLUKA was used under more realistic grazing angle beam losses, the results derived from the Swanson's methodology are based on local

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losses in thick targets. Thus, the bulk shielding will be defined considering FLUKA results and the Swanson's formalism will be used to guide the analysis in other situations, not presented in this article.

2. The Sirius machine parameters

The main Sirius design parameters are shown on Table 1 and the layout of the building in Fig. 2. There are 20 straight sections with different lengths (10 with 6 m and 10 with 7 m). Most of the bending field is 0.58 Tesla but there are 20 short dipoles with a field of nearly 2 Tesla (Fig. 3). The experimental hall will accommodate up to 40 beamlines with lengths up to 150 m (Fig. 2).

Parameter	Value	Unit
Energy	3.0	GeV
Maximum current	500	mA
Circumference	518.25	m
RF frequency	500	MHz
Straight sections (SS), number x length	10 x 7 10 x 6	m m
Emittance (without IDs)	0.28	nm.rad
Harmonic number	864	
Bending field (dipoles / ”superbends”)	0.58 / 2.0	Tesla
Critical energy from “superbends”	11.7	keV
Beamsize @ superbend, HxV	11 x 4.0	μm^2
Beamsize @ short SS, HxV	33 x 1.4	μm^2

Table 1: Sirius main parameters.

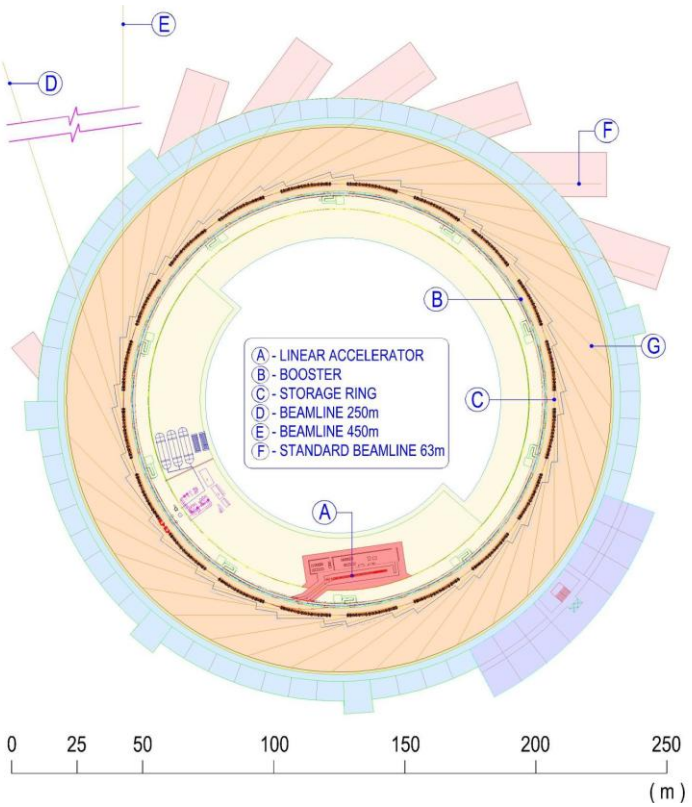

Fig. 2: Sirius injectors, storage ring and experimental hall schem.

Fig. 3 shows a schematic drawing of one Sirius 5BA achromatic cell with the high field thin dipole BC sandwiched in the center dipole B3-BC-B3. The injection system (LINAC, booster and transport lines) will

be installed on the same level of the storage ring (Fig. 4 e Fig. 5). The injection system main parameters are shown in Table 2 and Table 3.

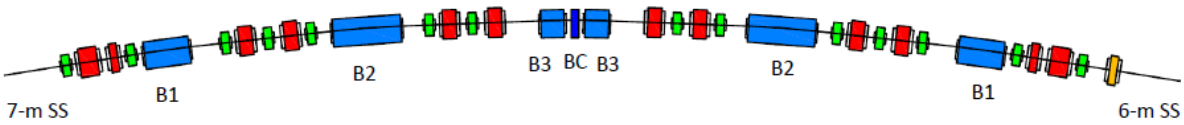

Fig. 3: Layout of the 5BA arc showing the high field 2 Tesla thin dipole BC (dark blue) sandwiched in the center dipole B3-BC-B3. Also shown are the 2 types of straight sections, with 7-m and 6-m in length. The 6-m straight section is exactly the same as the 7-m one except for an extra quadrupole at the extremity, shown in orange at the right side. Other quadrupoles are represented in red and sextupoles in green.

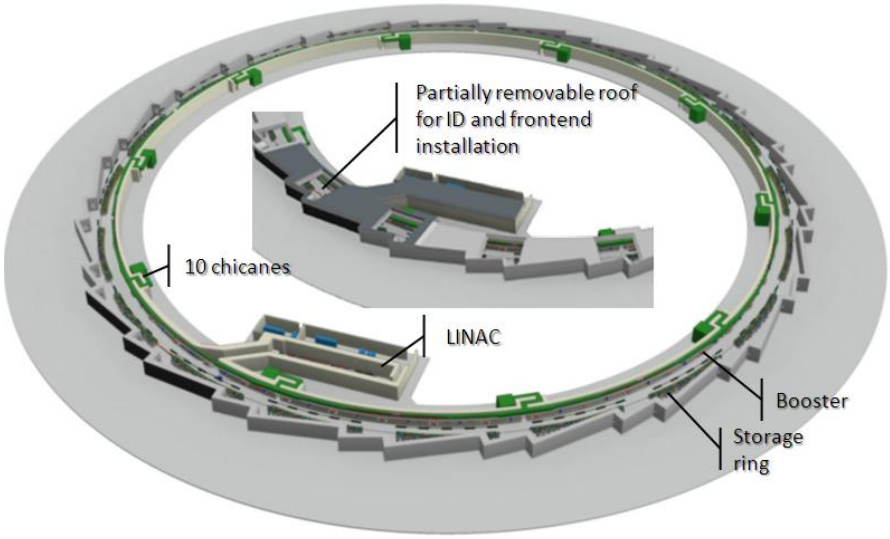

Fig. 4: Layout of Sirius machine, showing the LINAC, booster, storage ring, the 10 chicanes, and the indication for the partially removable roof for ID and frontend installations.

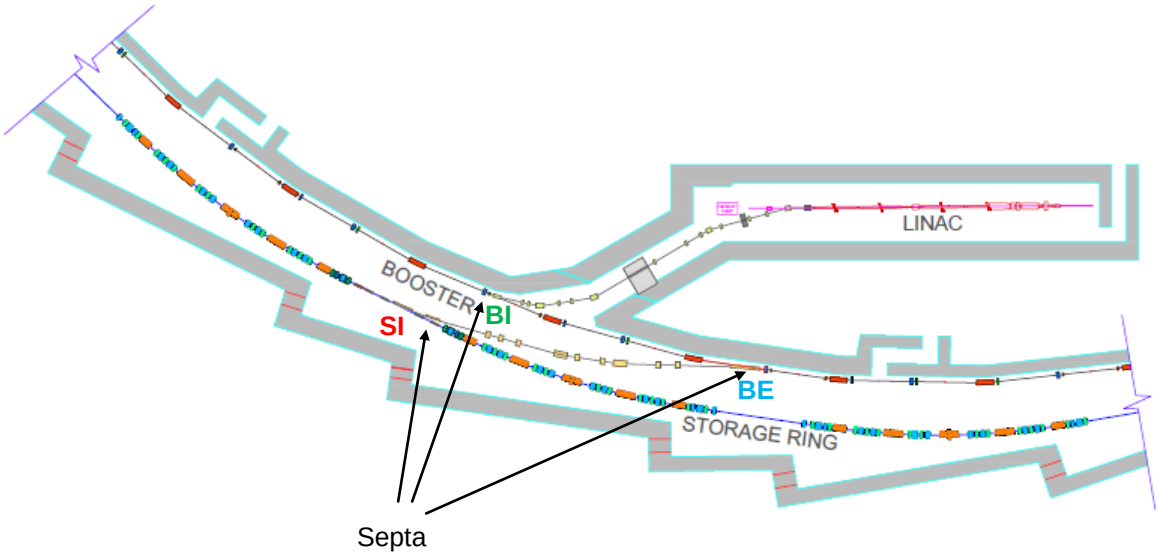

Fig. 5: Layout of Sirius injection system with a 150 MeV LINAC and a 3 GeV booster, this one at the same tunnel as the storage ring. Also shown are the spots BI, BE and SI, where occur the main electron losses during injection.

Parameter	Multi-bunch	Single-bunch	Unit
Energy	150	150	MeV
Relative energy spread (rms)	< 0.5	<0.5	%
Pulse charge	~ 3	~ 1	nC
Pulse width	50 to 300	< 1	ns
Repetition rate	2	2	Hz

Table 2: Main parameters of LINAC in multi-bunch and single-bunch operation modes.

Parameter	Value	Unit
Extraction energy	3.0	GeV
Injection energy	150	MeV
Maximum current	2.0	mA
Circumference	496.8	m
Revolution period	1.66	µs
Cycling frequency	2	Hz
Harmonic number	828	

Table 3: Parameters of the booster injector.

3. Beam losses scenarios

The critical regions for estimation of beam losses are the injection and extraction septa, named BI, BE and SI, for booster injection, booster extraction and storage ring injection, respectively. Table 4 shows the beam loss estimation for injection and extraction (localized), and Table 5 shows the ramping and lifetime losses (distributed). Fig. 6 resumes the injection losses in BI, BE and SI spots, and the lifetime and ramping losses.

Septum	Losses	Electron energy	Incoming electrons	Incoming power	Expected losses at this point	
		[GeV]	[e^-/h]	[W]	[e^-/h]	[W]
BI	20%	0.15	3.3E+12	0.022	6.6E+11	0.0044
BE	20%	3.00	2.1E+12	0.281	4.2E+11	0.0562
SI	20%	3.00	1.7E+12	0.225	3.4E+11	0.0450

BI: booster injection septum
BE: booster extraction septum
SI: storage ring injection septum

Table 4: Injection and extraction losses at septa BI, BE and SI (localized).

	Electron energy	Expected losses	
	[GeV]	[e^-/h]	[W]
Storage ring	**3.00**	**1.3E+12**	**0.180**
Booster	**0.15 to 3 GeV**	**5.3E+11**	**0.070**

Table 5: Lifetime and ramping losses (distributed).

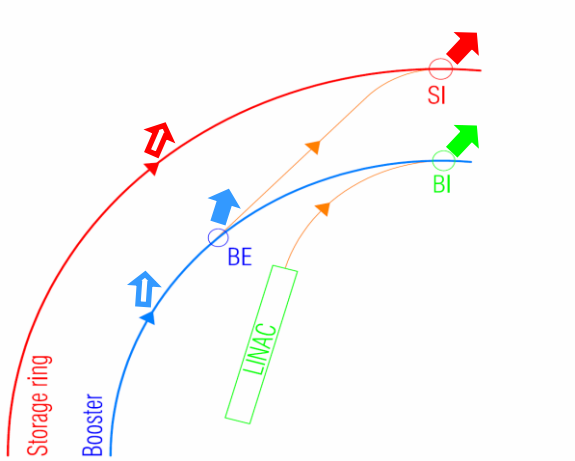

Fig. 6: Schematic draw of the injection region with the estimated electron losses during normal operation (topup). The localized losses are shown with solid arrows and the distributed losses with hollow arrows.

4. Shielding

The concrete shielding tunnel geometries used in simulations are shown in Fig. 7 and Fig. 8. The dose was measured, using FLUKA, outside the concrete shielding at several locations: chicane, RF-chicane, cable passage, roof, etc.

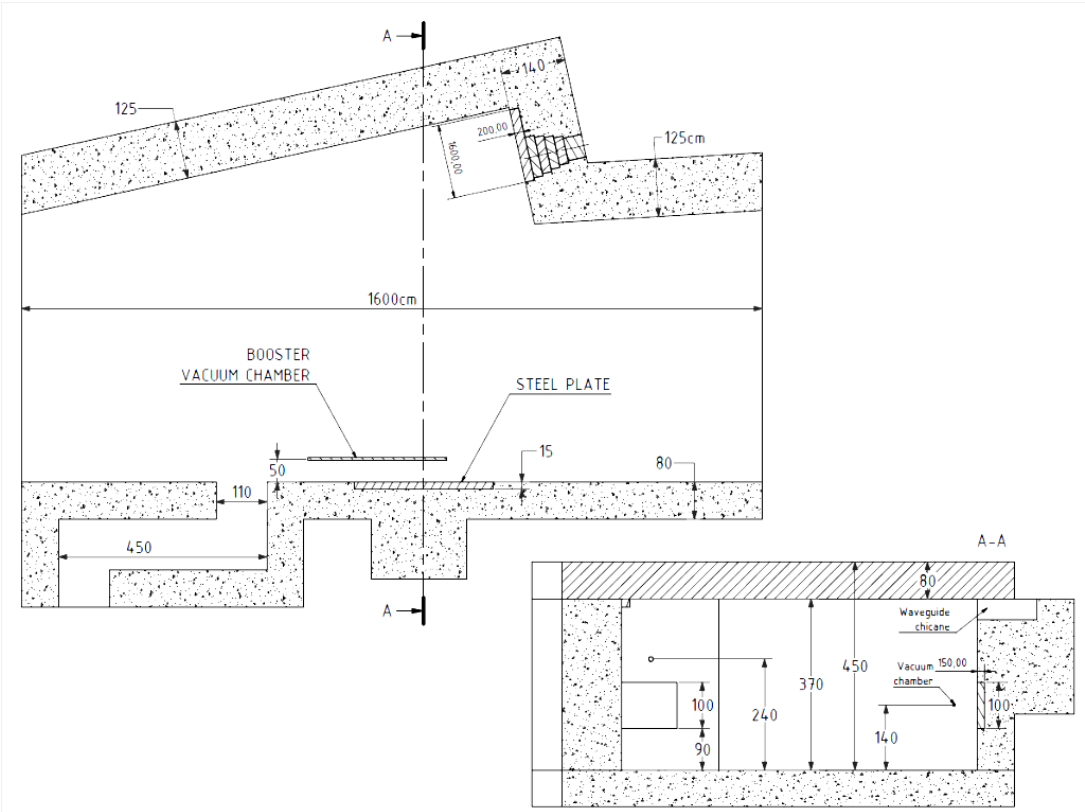

Fig. 7: Bulk shielding geometry used in simulations for the losses in the booster. A similar geometry was used for the losses in the storage ring. Dimensions are in cm.

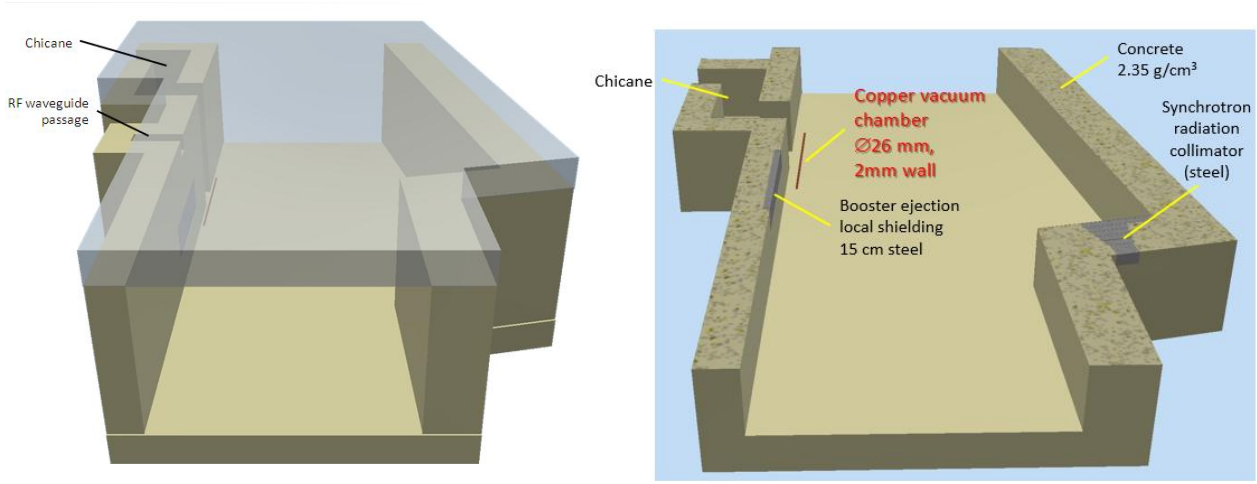

Fig. 8: 3D view of the shielding geometry.

4.1. Monte Carlo simulations

The goal is to evaluate if the considered shielding is adequate to mitigate the radiation levels. For each situation, an input file was built considering the machine operation conditions, such as the primary beam type and its energy, material definitions, geometry, etc. We consider the beam colliding at grazing angle with the vacuum chamber.

The code provides the dose equivalent per primary particle (electrons in our case) of the incident beam whose parameters are adjusted such that it represents the distribution of the estimated lost electrons. Finally, the dose rate at any point of the simulated region is obtained by multiplying the FLUKA results at that point by the estimated number of lost electrons as discussed above. We used the 2011.2.8 version of FLUKA [2] with the Flair interface version 1.0-2 (R2013) [4].

4.2. Dose rates using Swanson's formalism

With the beam loss estimative discussed above, given in watts or joules, it is possible to calculate the dose and the dose rate after shielding through the following expression:

$$H = \sum_i \frac{T_i}{d^2} P.10^{-x/TVL_i} \tag{1}$$

H is the dose equivalent rate summed over all radiation components (μSv/h); T_i is the radiation dose equivalent factors (source-terms) for the corresponding radiation of the *i*th component (μSv.m^2/J); *P* the electron energy dissipation (Joules/h); *d* the total distance of the dose point from the source (m); *x* the shielding thickness (cm); and TVL_i the tenth value layer of the *i*th radiation component for the considered material shielding (cm).

Two types of radiation are of major concern for the shielding calculations: bremsstrahlung and photoneutron production from the giant dipole resonance (GRN: giant resonance neutrons). Muon and high energy neutron production are negligible for the present calculations.

The radiation source parameters (source-terms) adopted in this report are summarized in Table 6 [3]. The TVL values for some shielding materials are given in the Table 7.

Bremsstrahlung at 90° [rem*m^2/J]	Giant-resonance neutrons [rem*m^2/J]
1.4*10^{-3}	6*10^{-4}

Table 6: Radiation source parameters.

Material	Density (gm/cm^3)	TLV (cm)	
		Bremsstrahlung	GRN
Normal concrete	2.35	47	39
Lead	11.35	5	-
Iron	7.87	10.8	-

Table 7: TVL for some shielding materials.

Using these values (Table 6, Table 7), the beam loss scenarios (Table 4, Table 5), and considering the shielding thicknesses and applicable distances, we find the results shown in Fig. 9 in parallel to those calculated by the Monte Carlo method.

5. Results and discussions

As shown in Table 4, the worst case (the one with the highest power loss; 0.0562 W) corresponds to the region BE. Accordingly we considered a number of 4.2e+11 e^-/h lost in the BE spot, on a 2 mm thick copper vacuum chamber wall, at grazing angle (Fig. 9).

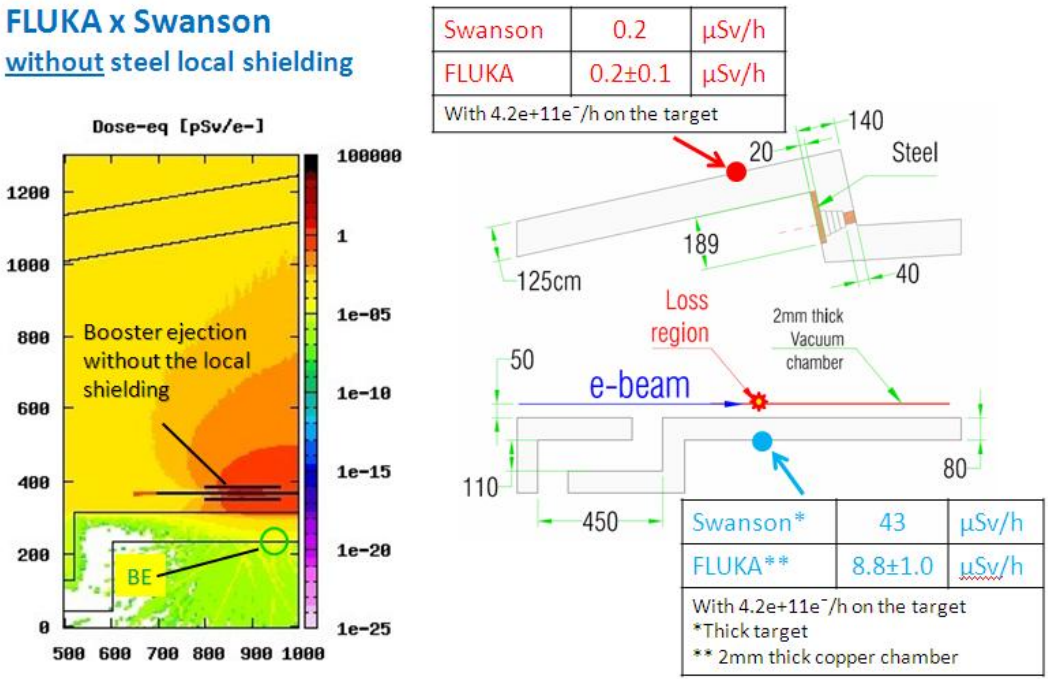

Fig. 9: Dose rate results using FLUKA and Swanson's method, in two regions: 1) lateral external wall of the storage ring and, 2) Booster ejection, without local shielding.

It is interesting to note that, at 90° (just outside the concrete wall in Fig. 9), FLUKA and Swanson's method give about the same dose rate results, even though the calculations suppose quit different geometries. At the BE region, however, FLUKA gives 8.8 µSv/h and the Swanson's method 43 µSv/h, without steel local shielding (Fig. 9). If one adds a 15 cm thick steel plate as shown in Fig. 10, the dose rates in the same region outside the wall are reduced to 1.7 µSv/h. The FLUKA run is used to calculate the spected dose rate just above the roof: 1.1 µSv/h (Fig. 9).

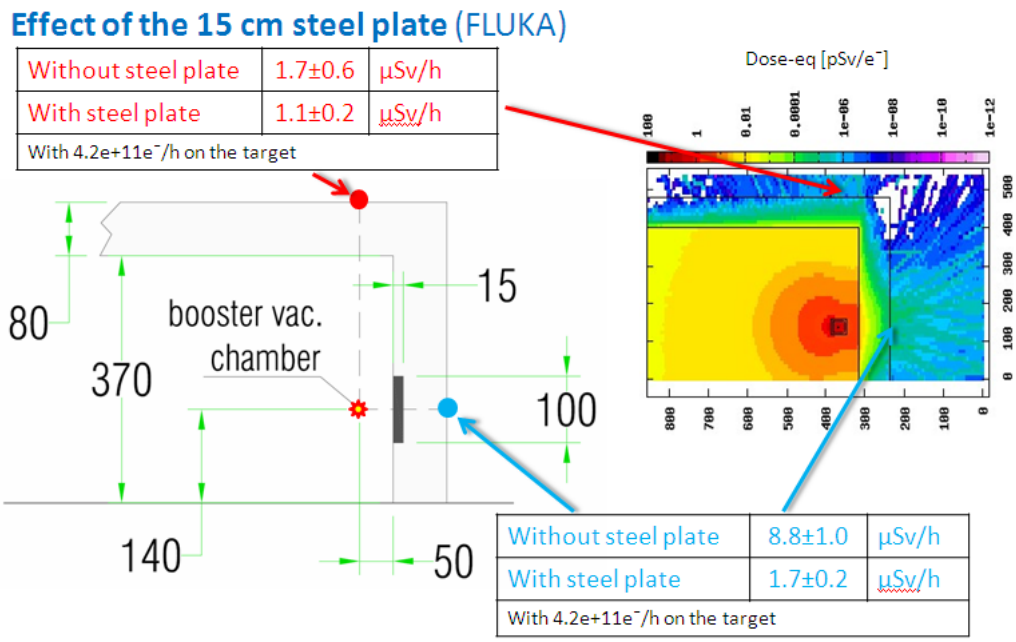

Fig. 10: Dose rates according to FLUKA simulation on the roof and near the lateral wall at the booster extraction region. Two cases are considered: without local shielding and with 15 cm thick local steel plate.

The passage for the RF cavity waveguides is a chicane through the concrete shield (Fig. 11), after which the dose rate calculated by FLUKA was 0.2 µSv/h.

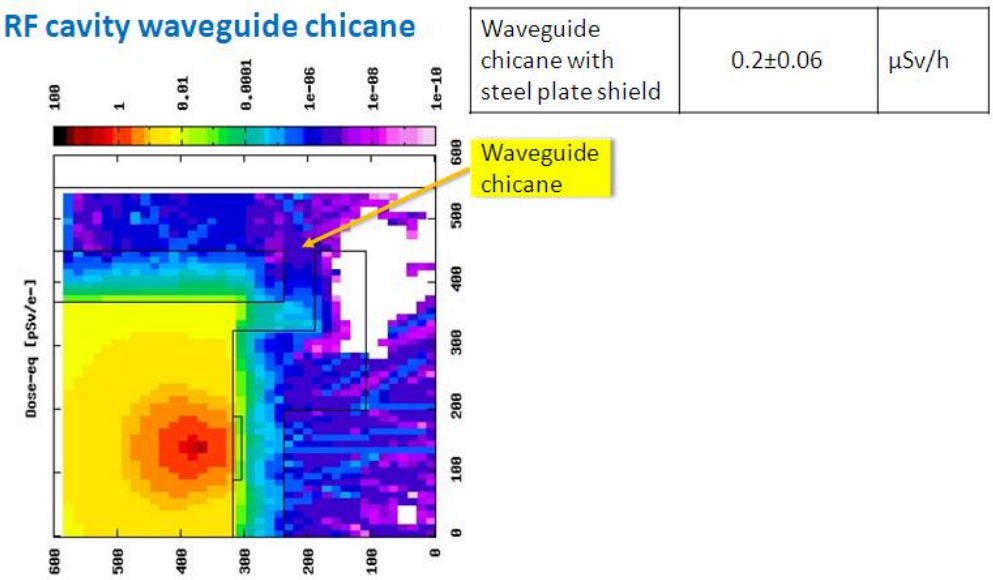

Fig. 11: Results by FLUKA for the RF cavity waveguide chicane.

Dose rates around the tunnel chicane in the injection region are shown in Fig. 12. At the chicane entrance the calculated dose rate, for the considered electron losses, was 0.05 µSv/h.

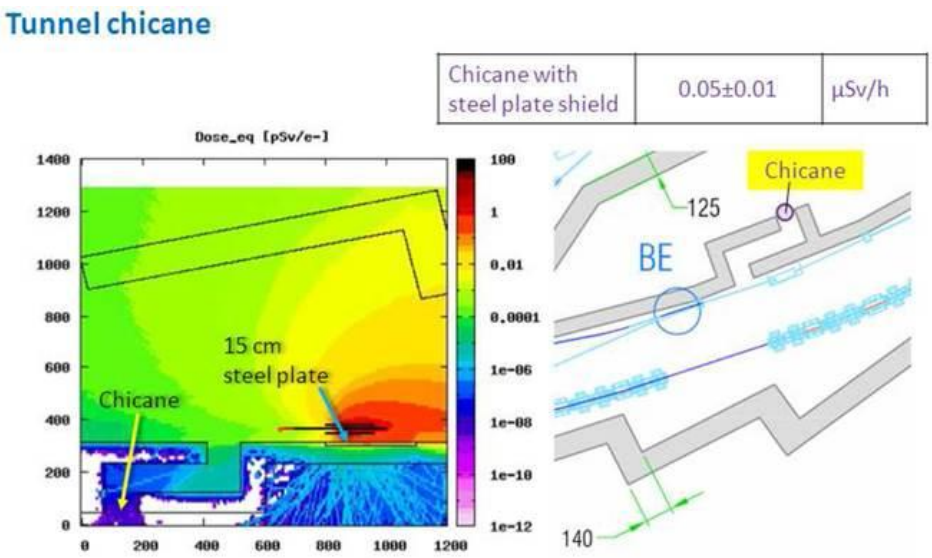

Fig. 12: The tunnel chicanes with dose rates calculated by FLUKA.

6. Conclusions

The estimated electron losses during normal operation and the dose rates obtained using the FLUKA for the preliminary bulk shielding design around the injection region was presented. Further work is on the way to improve Sirius shielding design, including localized radiation strengthening to guaranty safe operation even in abnormal situations such as operation and installation errors.

References

[1] X. A. F. H. S. H. J. L. Lin, "Sirius:A 5BA Low-emittance Lattice with Superbends for the New Brazilian Synchrotron Light Source," *Synchrotron Radiation News*, vol. 26, n. 3, pp. 34-38, 2013.

[2] P. S. A. F. a. J. R. A. Ferrari, "FLUKA: a multi-particle transport code," CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773, (http://www.fluka.org/), 2005.

[3] W. Swanson, "Radiological Safety Aspects of Electron Linear Accelerators," IAEA-188, Vienna, 1979.

[4] V. Vlachoudis, 2013. [Online]. Available: http://www.fluka.org/flair/.

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