Shielding design study for the ESRF EBS project

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Abstract

The ESRF EBS (Extremely Brilliant Source) upgrade project includes the replacement of the present double-bend achromat storage ring with a hybrid multiband storage ring. The corresponding long shutdown is scheduled between end of 2018 and mid 2020.

The new storage ring will drastically reduce the horizontal emittance of the electron beam and will consequently operate with reduced beam lifetimes compared to the present storage ring.

ESRF wishes to maintain its present radiation protection policy, where nobody working at the ESRF is considered as radiation worker. In view of the increased beam loss rates, dedicated beam loss collimators must be foreseen in the EBS storage ring.

A detailed shielding design study is required to prove the adequacy between the operation of the new storage ring and the ESRF radiation protection policy. This shielding design study will be the basis of the authorization request, to be submitted by mid 2017 to the ASN (*Autorité de Sûreté Nucléaire*), the French Regulator providing the license for the operation of the ESRF.

The present paper gives a status of the shielding design study, describing in particular the shielding issues of the beam loss collimators, as well as the shielding results for normal operation and for abnormal beam losses. It included also the first results concerning residual dose rates inside the tunnel as well as shielding of the different tunnel chicanes and ducts.

Introduction

In the framework of the EBS (Extremely Brilliant Source) project, ESRF will replace its existing storage ring with a new one, which will allow delivering much more brilliant X-ray beams to the beamlines. The installation of the new storage ring will take place in 2019 and its commissioning will start in December 2019.

A detailed safety assessment study has been carried out. One of the major goals of the safety assessment study is to demonstrate that the operation of the new storage ring within the operational limits will be compatible with the present ESRF radiation protection policy. This policy states that nobody working at the ESRF should be considered as exposed worker. Since certain categories of people, such as users, visitors and short-term contractors, only stay for short periods at the ESRF, ESRF respects a derived 4-hours effective dose limit, to ensure that in all areas accessible during operation the integrated dose over 4 hours does not exceed 2 μSv.

For economical and practical reasons, the new storage ring must be installed in the existing storage ring tunnel. In other words, we keep the same bulk shielding and only local shielding can be added if necessary. From a radiation protection point of view, this implies that we need very accurate calculations to be able to demonstrate the feasibility to operate the new storage ring while maintaining the present radiation protection policy. To this end, a detailed model of the new storage ring has been built with the program FLUKA [1]. This model, combined with the results from extensive calculations of the different beam losses expected with the new storage ring, has indeed allowed us to obtain accurate and detailed results for the expected dose distributions outside the storage ring tunnel for an exhaustive list of beam loss scenarios. Figure 1 shows a view of the FLUKA model.

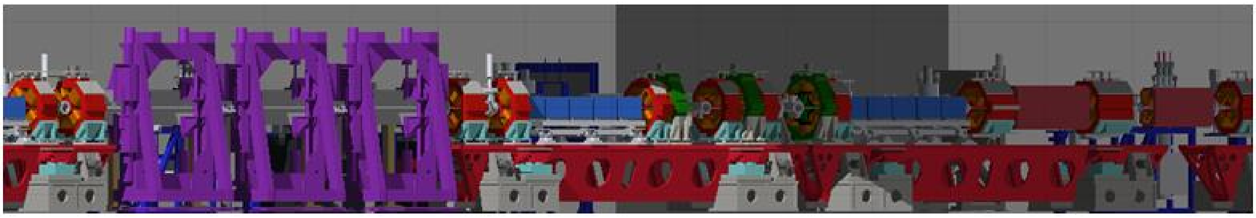

Fig.1 – FLUKA model: part of a standard unit cell with 3 out-of-vacuum insertion devices.

Beam loss collimation

Respecting the present radiation protection policy when operating the new storage ring is not a priori evident. Indeed, due to the much smaller beam emittance, the electron beam lifetime in the new storage ring will be substantially smaller compared to the present storage ring. As a consequence the new storage ring will intrinsically produce more radiation. Without any special measures taken, dose rates outside the storage ring tunnel in certain areas could easily become too high to comply with the 4-hours derived dose limit.

As part of an overall optimisation exercise, important efforts have been made to localise the beam losses in a limited number of areas along the storage ring which would then be locally shielded. This exercise has led to the design of two dedicated beam loss collimators, which will concentrate more than 70 % of the total electron beam losses. Figure 2 shows the layout of these collimators.

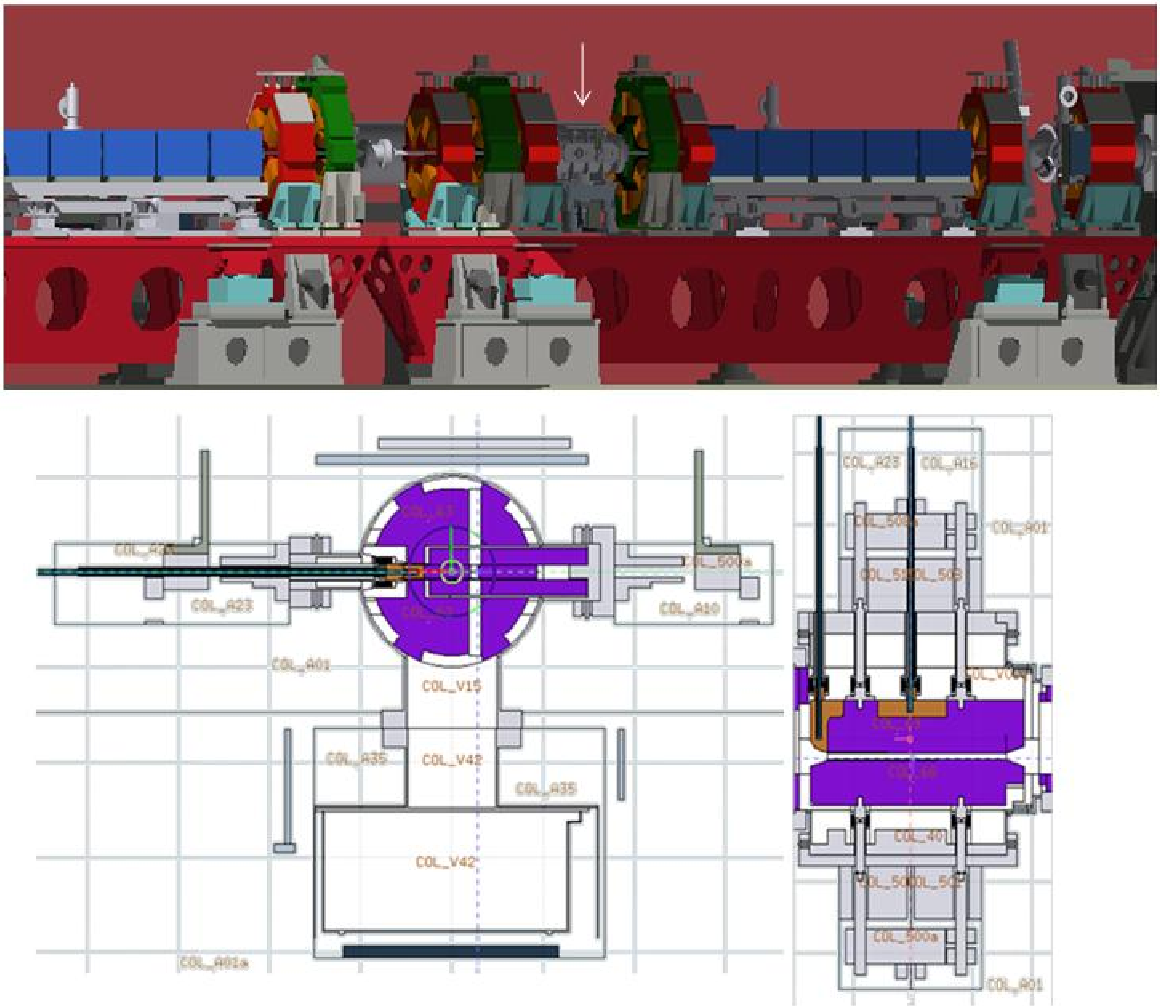

Fig.2 – FLUKA model of the beam loss collimator. Top: part of the beam loss collimator cell. Bottom: left: vertical section; right: horizontal section.

The results of the shielding study show that dose rates outside the storage ring tunnel will be comfortably low with respect to the 4-hours derived dose limit. In the vicinity of the beam loss collimators, sufficiently low values are obtained thanks to a compact, highly self-shielded design of the collimators and from the installation of high density concrete local shielding elements inside the storage ring tunnel. As an example, Figure 3 shows the effective dose rate distribution in a horizontal plane at beam height around one of the collimators during a 92 mA, 1.8 h lifetime stored beam decay.

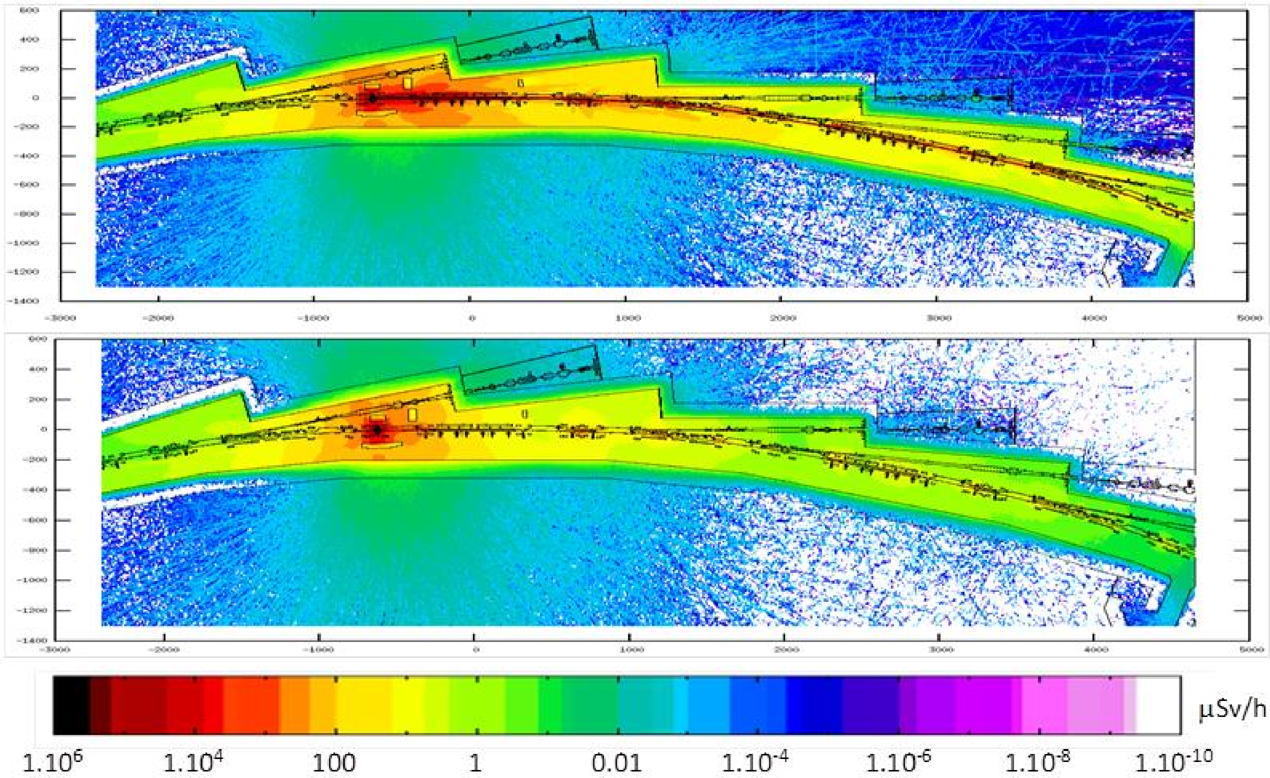

Fig.3 – Effective dose rate distribution around the collimator in cell 13 during a 92 mA, 1.8 h lifetime stored beam decay. Dose distribution in horizontal plane at beam height. Top: total dose – Bottom: neutron dose. Dimensions in cm.

Abnormal beam losses

Within the abnormal beam losses, only a few scenarios concern stored beam losses, the majority being indeed related to injection problems. According to the Council Directive 2013/59/EURATOM, most of the abnormal beam loss scenarios should be considered as minor incidents, and should therefore be included in the “normal exposure”. All of these abnormal beam loss scenarios produce dose values outside the storage ring tunnel which are sufficiently small to be compatible with the 4-hours derived dose limit. A few incidents could be considered as potential exposures, due to their low probability of occurrence. Doses from these events will not be included in the normal exposures, but the associated doses remain relatively low, with a maximum value of less than 30 μSv per event. Because of this relative low value and because of the low probability of these events, which is estimated as $< 10^{-2}\ y^{-1}$, no further mitigation actions will be necessary.

An exhaustive list of abnormal beam loss scenarios has been treated in the shielding assessment study. This has allowed defining for both stored beam losses and injection losses the envelope accidents, defined as the scenario producing the highest doses outside the shield walls. Both envelope accidents should be considered as potential exposures, due to their low probability.

In the case of stored beam losses, the envelope accident concerns a full 200 mA beam loss on a closing vacuum valve in a straight section with the corresponding ID front end open. Figure 4 shows the integrated effective dose distribution in a horizontal plane at beam height, due to a 200 mA beam loss caused by the closing of the 1st gate valve in the straight section. A maximum dose of 28 μSv occurs in the freeway next to the corresponding ID optics hutch. This is a low occupancy area. Access to this area during operation of the

ID beamline typically only concerns beamline staff (although their presence in this part of the freeway will typically happen when the front end is closed, meaning that there is no longer an increased dose integration during a similar beam dump). Theoretically however, a staff member could be present during the beam dump and would therefore be exposed to a maximum dose of 28 μSv. Users and contractors do not go to this part of the freeway during operation. For these two categories of workers, the experiments hutch or control hutch of the neighbouring BM beamline will represent the highest dose spot. The maximum integrated dose is 12 μSv.

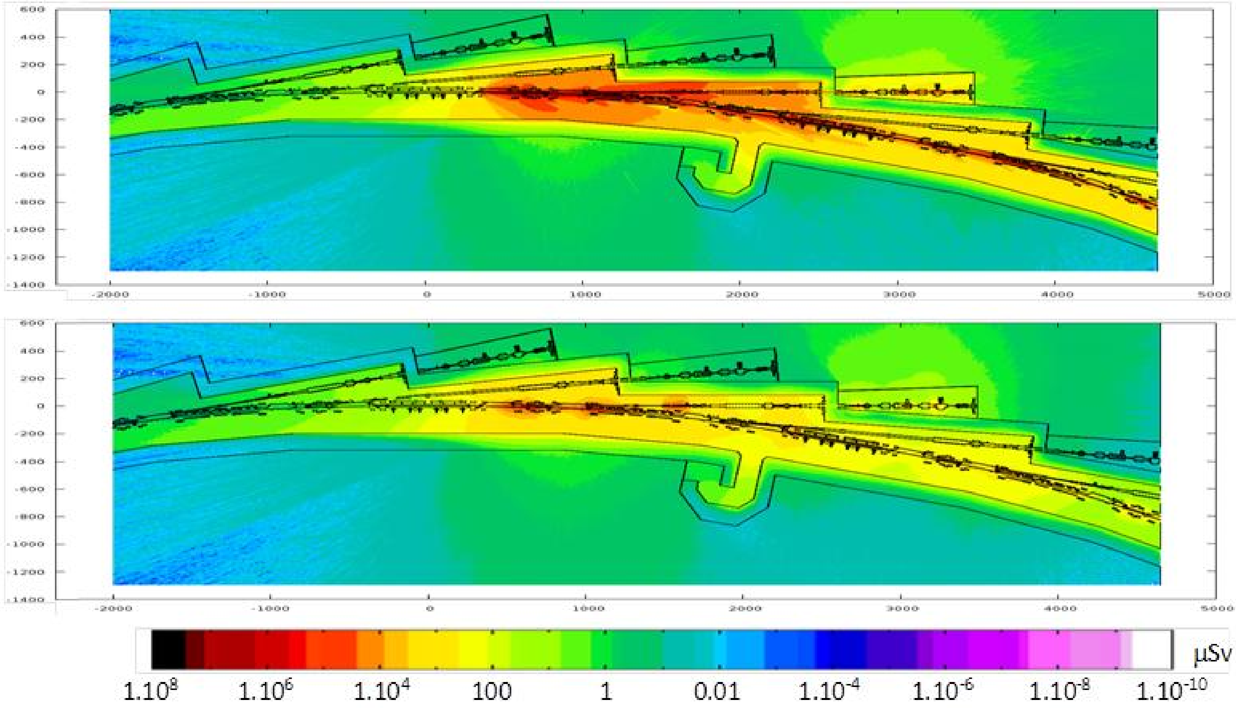

Fig.4 – Integrated effective dose distribution due to 200 mA beam loss caused by closing of 1st gate valve in the central unit cell. Dose distribution in horizontal plane at beam height. Top: total dose – Bottom: neutron dose. Dimensions in cm.

The maximum doses from the stored beam envelope accident obtained under conservative assumptions for members of staff, for users and contractors and for members of the public are sufficiently small and show that such an event should not be considered as a significant event, as defined by the French Nuclear Safety Authority (ASN).

The envelope accident for injection losses concerns injection with the DQ1D combined dipole-quadrupole magnet switched off. This scenario results in the injected beam being directed into the corresponding BM front end. As this scenario is not possible in the presence of a stored beam, the Personnel Safety Sytem (PSS) guarantees that all front ends are closed. Figure 5 shows the corresponding integrated effective dose distribution in a horizontal plane at beam height from a 5 nC pulse from the booster lost due to a zero field in the DQ1D magnet. A maximum dose of 1 μSv per 5 nC pulse is obtained outside the corresponding BM optics hutch. This value remains sufficiently small to be correctly handled by the interlocked radiation monitors. Despite this low value, the current in the DQ1D magnets will be hardwired interlocked to the PSS, preventing injection if one of the DQ1D magnets would show an abnormally low current in its coils. Because of this interlock, the second envelope accident is again to be considered as a potential exposure. The very low integrated doses per injection pulse imply that this event should again not be considered as a significant event, as defined by the ASN.

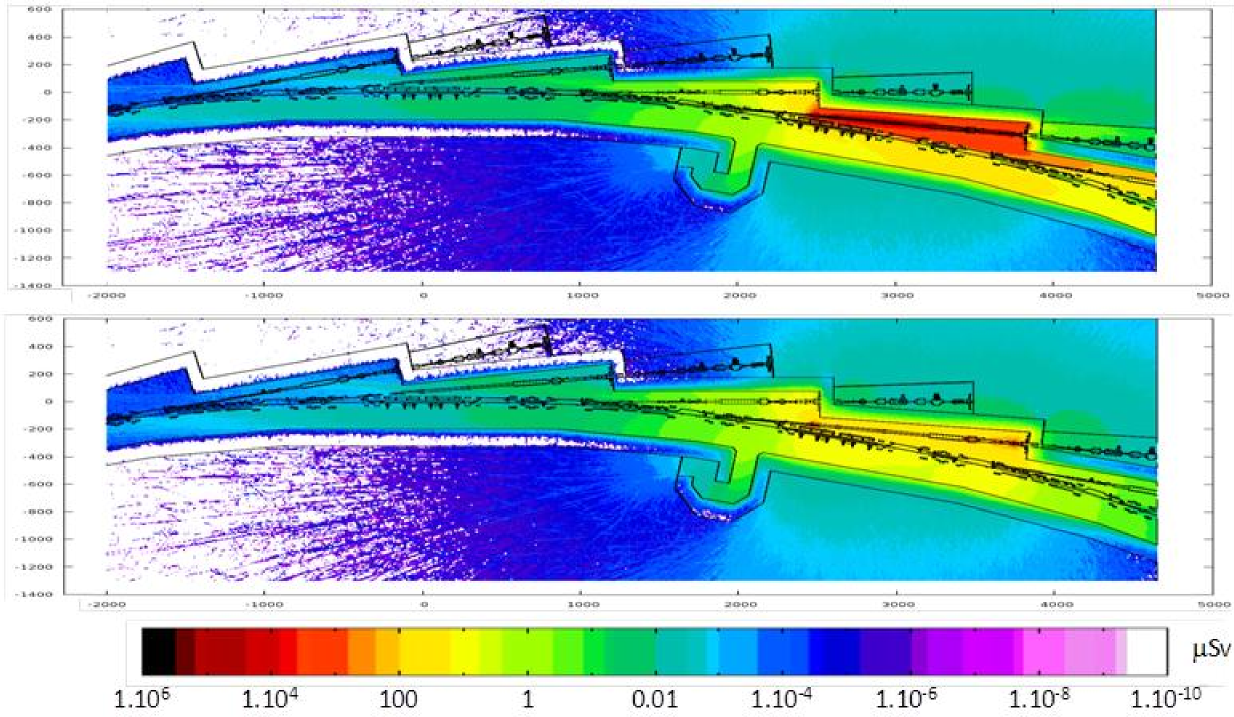

Fig.5 – Integrated effective dose distribution from a 5 nC pulse from the booster lost due to zero field in the DQ1D magnet in the central unit cell. Dose distribution in horizontal plane at beam height. Top: total dose – Bottom: neutron dose. Dimensions in cm.

Labyrinths and ducts

The shielding capacity of the different labyrinths and ducts has also been evaluated. None of the existing penetrations will present particular radiation protection issues, in part due to the fact that the new storage ring will produce significantly less dipole synchrotron radiation than the existing storage ring.

The RF power for the new HOM-free RF cavities is transported into the tunnel via coaxial waveguides, through the storage ring tunnel roof. These coaxial waveguides allow a significant reduction of the dimensions of the holes through the storage ring tunnel. As a consequence, simple lead disk obstructing these holes around the coaxial lines are sufficient to reduce the residual dose rates outside the ducts to very low values. The present heavy lead shielding on the storage ring roof around the RF ducts can therefore be abandoned.

Figure 6, as an example, shows the total and neutron effective dose rates above the storage ring tunnel roof, averaged over the length of one of the RF duct, as a function of the horizontal distance from the beam axis, corresponding to 92 mA, 1.8 h lifetime beam decay. One sees that the maximum dose rates above the hole are completely negligible.

Figure 7 shows the corresponding synchrotron radiation effective dose rates through one of the RF ducts, during 200 mA stored beam. Without the lead disk, dose rates above the hole up to 200 μSv/h are obtained. The installation of the lead disks mentioned above reduces these dose rates to negligibly small values.

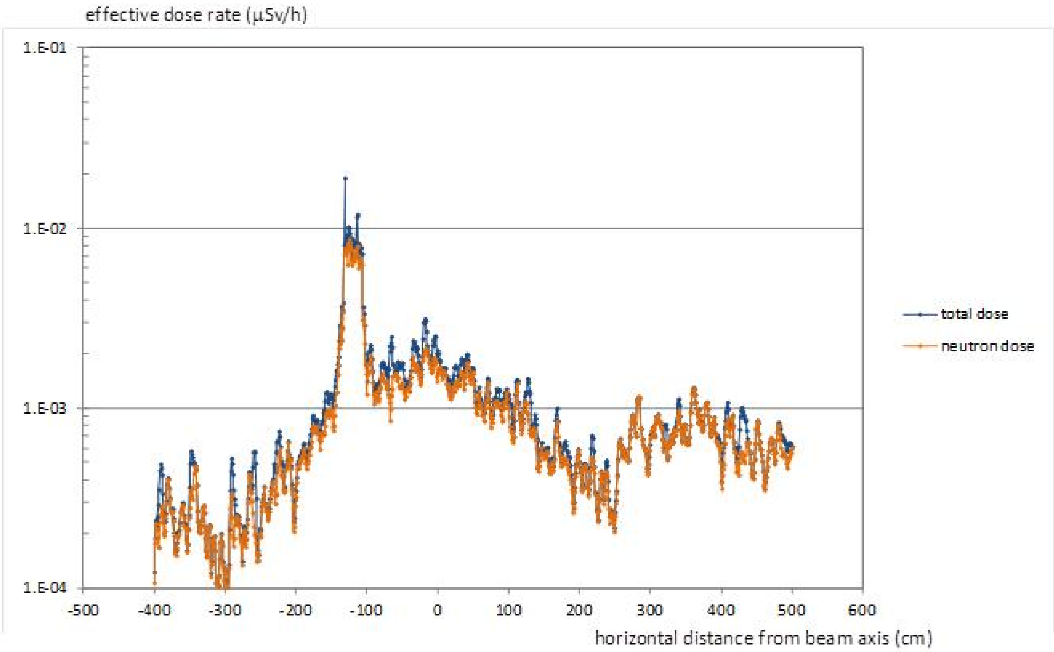

Fig.6 – Total and neutron effective dose rates above the storage ring tunnel roof, averaged over the length of the RF duct, as a function of the horizontal distance from the beam axis. 92 mA, 1.8 h lifetime beam decay.

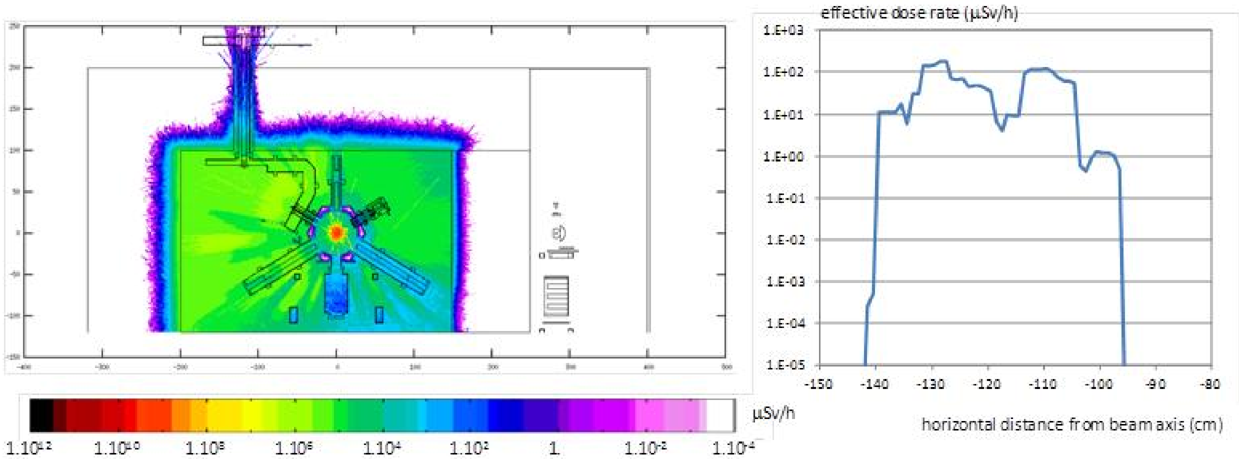

Fig.7 – Synchrotron radiation effective dose rates through one of the RF ducts. Left: dose distribution in vertical plane, averaged over duct. Right: effective dose rates on top of the roof as a function of the horizontal distance from the beam axis. Conditions: 200 mA stored beam.

Activation issues

Residual dose rates inside the storage ring tunnel due to the activation of the accelerator components have been evaluated. Residual dose rates are generally very small, except, as expected, around the beam loss collimators. Access restrictions in these areas at the beginning of shutdowns must be implemented but, thanks to the efficient self-shielding of the collimators, interventions around the collimators will remain possible, with simple ALARA optimisations when planning interventions.

Figure 8 shows the saturation residual effective dose rates inside the storage ring tunnel cells 19, 20 and 21, for a 1 day decay period (calculated after 21 years of operation). One sees that the dose rates remain very low and are compatible with the 4-hours derived dose limit of 2 µSv.

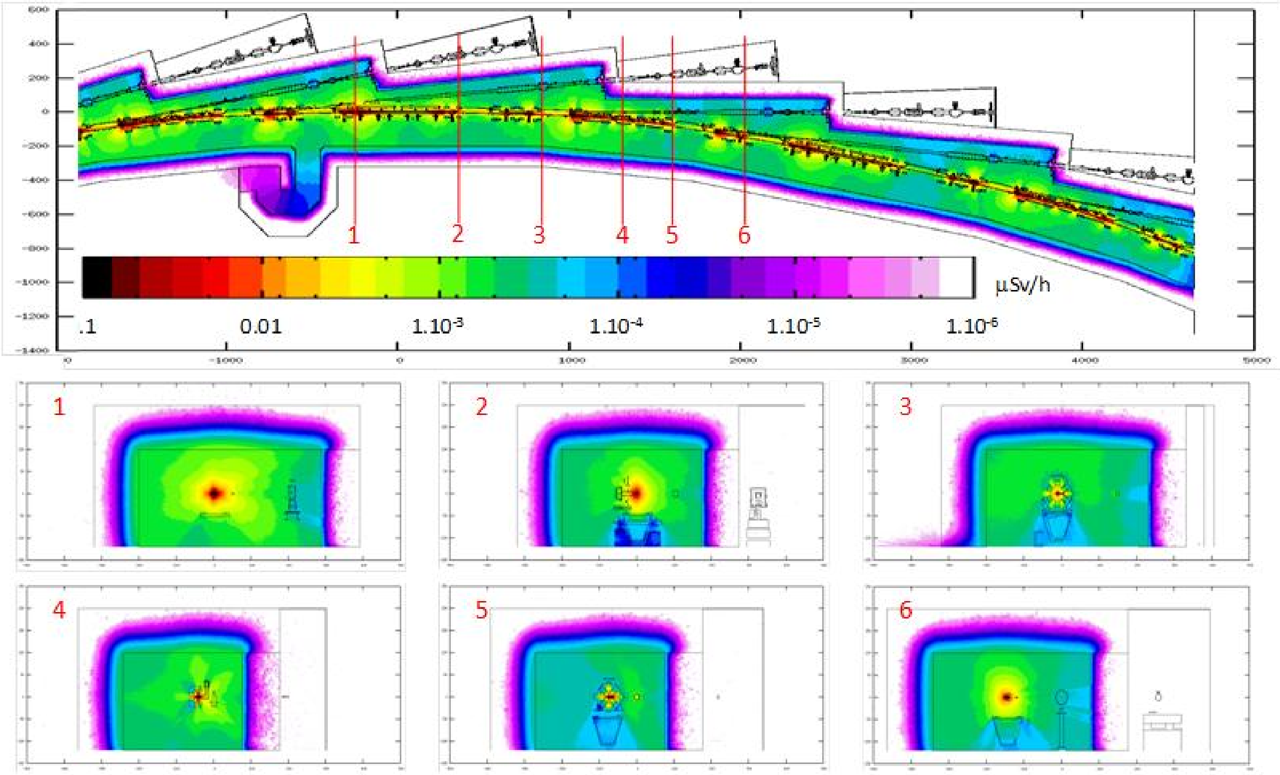

Fig.8 – Residual effective dose rates inside the storage ring tunnel cells 19, 20 and 21, for a 1 day decay period, after 21 years of operation. Top: effective dose rates in horizontal plane at beam height. Bottom: effective dose rates in 6 selected vertical planes.

Figure 9 shows the residual effective dose rates at 1 m from the beam axis (walkway) rates inside the storage ring tunnel around the beam loss collimator, for 3 different decay periods (1 minute, 1 hour and 1 day respectively), after 21 years of operation.

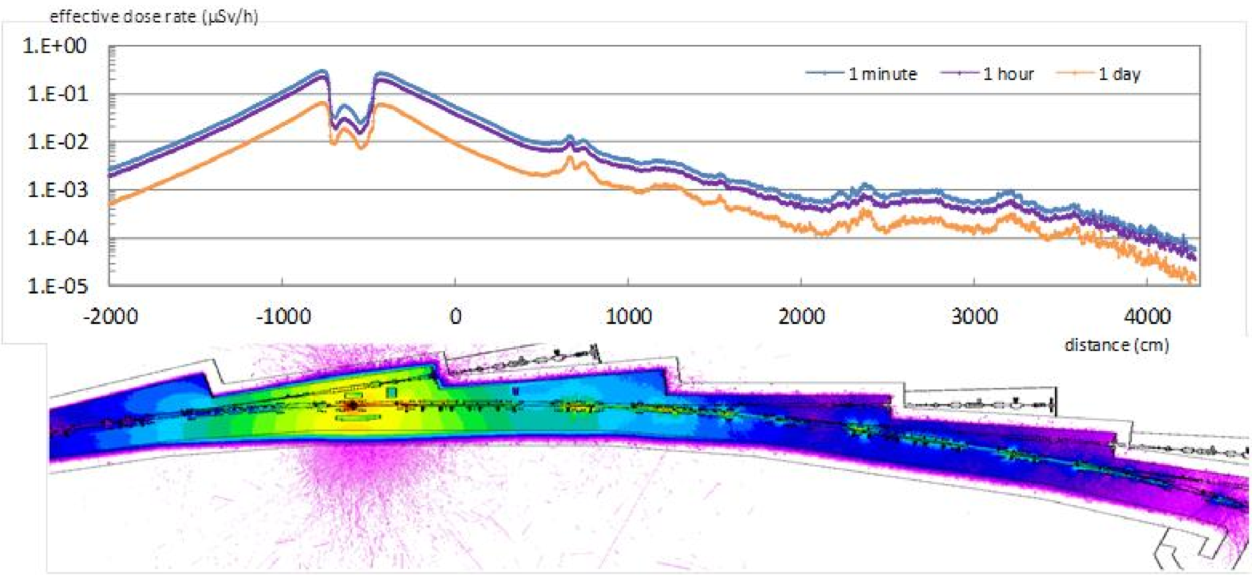

Fig.8 – Residual effective dose rates at 1 m from the beam axis (walkway) rates inside the storage ring tunnel around the beam loss collimator, for 3 different decay periods (1 minute, 1 hour and 1 day respectively), after 21 years. Dose rates given in horizontal plane at beam height.

References

[1] A. Fassò et al., FLUKA : a Multi-Particle Transport Code, CERN-2005-10,INFN/TC_05/11, SLAC-R-773,2005