Top-up radiation study at ALBA Synchrotron

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Abstract

ALBA is the Spanish synchrotron facility formed with a 3 GeV electron synchrotron accelerator generating bright beams of synchrotron radiation, located in Cerdanyola del Vallès (near Barcelona). First, the electrons are accelerated in a 110 MeV linear accelerator. Then, the electrons enter in a synchrotron accelerator named Booster that increases the energy up to 3 GeV. Finally, the electron beam is stored in a synchrotron Storage Ring with a current up to 120 mA (the design value is 400 mA).
Since June 2014, ALBA accelerators are operating in top-up mode, injecting from the 3 GeV Booster to the Storage Ring with Front Ends opened. This study presents the radiation measurements done during top-up tests to ensure that the working areas outside the shielding (Experimental Hall and Service Area) remain public zone when operating in top-up mode. The study is completed by Monte Carlo simulations performed with FLUKA code, in order to understand the origin of the radiation produced by the top-up mode in the different areas around the accelerators and check the performance of the shielding.

1. Introduction

ALBA Synchrotron is a scientific facility composed of a 3 GeV electron synchrotron accelerator generating bright beams of synchrotron radiation [1]. It is located, in Cerdanyola del Vallès (near Barcelona) in Spain. At ALBA electrons are accelerated in a 110 MeV linear accelerator (LINAC). Then, the electrons are injected in a synchrotron accelerator named Booster (BO) that increases their energy up to 3 GeV. Finally, the electron beam is stored in a synchrotron Storage Ring (SR) with a current up to 120 mA (the design value is 400 mA). The synchrotron radiation is emitted tangentially to the SR and used in the Beamlines (BL) for a wide range of experiments. The accelerators are housed in a circular concrete bunker called Tunnel. Outside the internal Tunnel wall is the Service Area (SA), where radiofrequency (RF) fields used to accelerate the electrons are produced and guided into the RF cavities, inside the Tunnel. Around the external Tunnel wall is the Experimental Hall (EH) area, with 7 Beamlines currently in operation (with a maximum capacity of ca 30). The optical elements of the Beamlines are located inside lead hutches and separated from the Tunnel by a Front End (FE), principally composed of a Bremsstrahlung Shutter made with two tungsten blocks shutter.

Since June 2014, ALBA accelerators are operating in top-up mode, injecting the 3 GeV electron beam from the Booster accelerator to the Storage Ring accelerator with the Front Ends opened. The interlock ALBA Personal Safety System (PSS) allows operation in top-up mode only if the following conditions are fulfilled [2]:

- The Top-up key must be enabled in the control room PSS cabinet
- The second Bending Magnet of the Booster-to-Storage Transfer line must be in range
- At least 20 mA must be accumulated in the Storage Ring
- All Radiation Monitors must be below the pre-alarm level (currently at 1.5 µSv every 4h)

The objective of the study presented in this paper is to ensure that public access to the Experimental Hall and Service Area can be guaranteed when operating the ALBA accelerators in top-up mode. The results from the study are presented in 3 sections:

a) Radiation produced during routine top-up operation: analysis of the experimental radiation measurements carried out outside the ALBA Tunnel during normal top-up shifts to characterise the radiation levels produced in the EH and SA in this operation mode.
b) Radiation produced during top-up tests: analysis of the specific radiation measurements realized at the 7 Beamlines when injecting with the worst injection parameters allowed by the PSS in top-up mode, to see the radiation produced inside and outside the Beamlines in bad injection conditions.

c) Finally, the study has been completed with the design, by Monte Carlo simulations (using FLUKA code [3],[4]), of an additional shielding for Beamline 29, and with the experimental verification of the shielding efficiency to ensure a public zone classification of the area.

2. Materials and Methods

All the studies presented in this paper in top-up mode have been realized with 100 mA accumulated in the Storage Ring. The frequency of injection in top-up mode is about 1 mA injected in the SR every 20 minutes. The present filling pattern used at ALBA consists of 10 trains 32 ns long each with a gap in between of 22 ns [5].

The radiation measurements have been performed using a net of Radiation Monitor detectors [6], measuring gamma (33 Thermo FHT192 probes) and neutron (15 Thermo FHT 762 Wendi-2 probes) doses rates online. The Radiation monitor detectors are located outside the shielding and around the accelerators in the Experimental Hall and the Service Area, see *Fig. 1*. All the radiation measurements of the Radiation Monitors presented in this paper are given including the natural background.

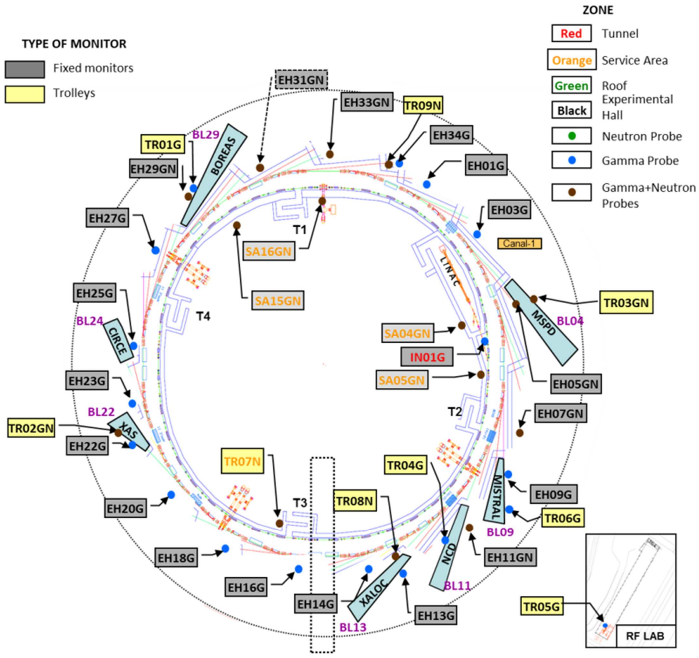

Fig. 1 - Radiation monitor network at ALBA Synchrotron facility

Monte Carlo simulations have been performed using FLUKA code. The transport kinetic energy cut off has been set to 1 MeV for electrons and positrons and 10 keV for photons. The results are given as equivalent dose rates applying proper normalization factors.

3. Results and discussion

3.1 Radiation measurements in routine top-up operation

The first results of this study show the radiation measurements done in the EH and the SA during routine operation in top-up mode. As presented in *Fig. 2*, patterns of radiation dose rate peaks have been detected during some injections when operating in top up mode. A pattern of gamma dose rates higher than 0.2 µSv/h have been measured in 6 detectors distributed outside the Tunnel (see *Fig. 1* for detector position), with maximum dose rates up to 10 µSv/h near Beamline 29 sidewall (EH29). A pattern of neutron dose rates higher than 0.2 µSv/h has also been measured following the injections at 2 neutron detectors outside the Tunnel (see *Fig. 2*). One of the neutron detectors is located near the injection area (EH33) and the other one is at Beamline 29 sidewall (EH29).

These gamma and neutron radiation dose rate patterns have only a significant contribution to the integrated dose in the case of Beamline 29 detector (EH29). As it can be seen in *Fig. 3*, at BL29 sidewall the total accumulated dose has reached values up to 1.0 µSv in 4 hours during routine top-up operation. The dose rate peaks observed at other locations, like the ones shown in *Fig. 2*, do not contribute significantly to the integrated dose every 4h.

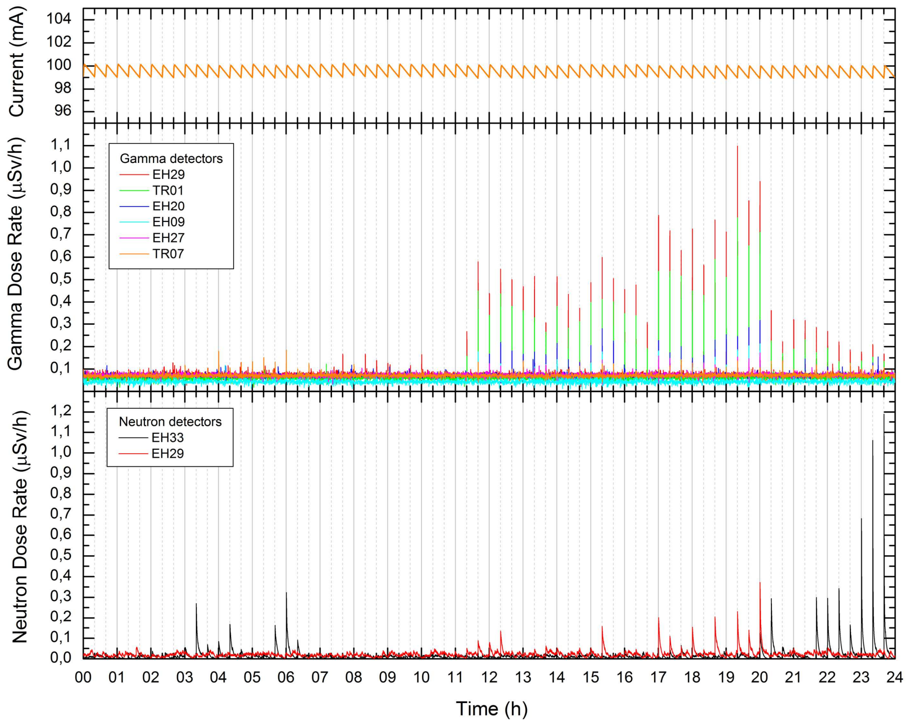

Fig. 2 - Gamma and neutron dose rates outside the Tunnel in the EH and SA during routine top-up operation

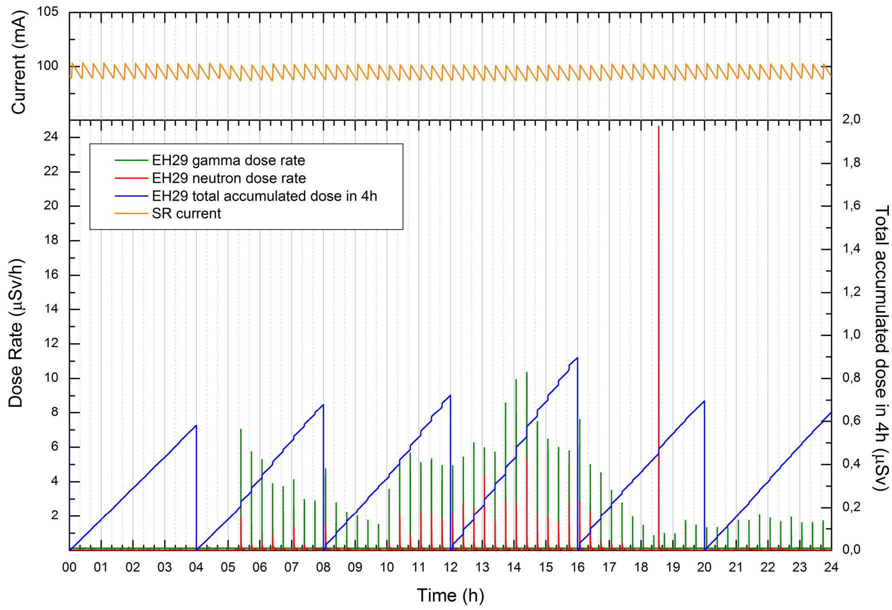

Fig. 3 - Gamma dose rate, neutron dose rate and total accumulated dose in 4h at BL29 Beamline

The dose rate patterns may be explained by the electron losses produced due to the instability of the beam during the injections. These losses can be evaluated through the injection efficiency from BO to SR, defined as:

$$eff_{BO-SR} = \frac{(\Delta I_{SR} * T_{revSR})}{(I_{Bo} * T_{revBO})} \quad (1)$$

where, ΔI is the current injected in the SR at each injection, I_{B0} is the total current extracted from the BO during the injection, T_{revBO} is the BO revolution time and T_{revSR} is the SR revolution time.

The correlation between both quantities is shown in *Fig. 4*, where it can be seen that the dose rate at BL29 radiation monitor in routine top-up operation increases when the injection efficiency from BO to SR decreases, especially below 40%. The presence of dose rate peaks at higher injection efficiencies has also been observed for BL29 particular case. This may be due to the use of certain BL29 Beamline parameters that also contribute to the generation of scattered radiation near the lead hutch.

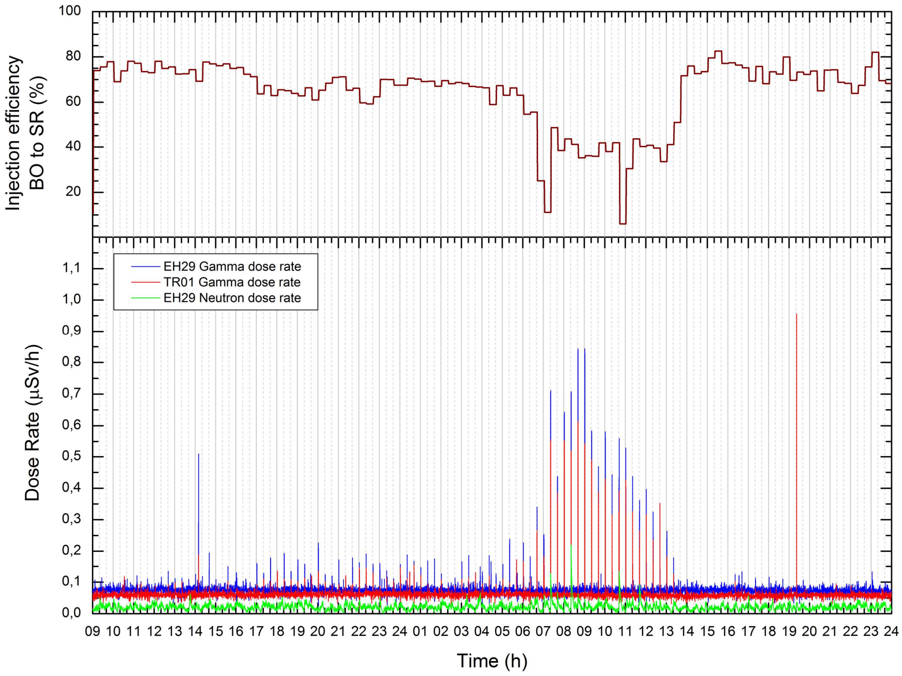

Fig. 4 - Gamma and neutron dose rate at BL29 Beamline compared with BO to SR injection efficiency

3.2 Radiation measurement during top-up tests

The second part of the results of the top-up studies realised at ALBA Synchrotron has allowed the characterization of the radiation produced at the 7 Beamlines while worsening the BO to SR injection parameters with FEs opened (i.e. in top-up mode). The aim of these tests is to estimate the highest dose rates which can be produced inside and outside the Beamlines due to abnormal top-up operation. *Table 1* summarises the maximum gamma and neutron dose rates measured inside and outside the 7 Beamlines during these top-up tests.

The results presented in *Table 1* reveal that, when operating in bad top-up conditions, significant high gamma instant dose rates are detected at every Beamline: from 0.44 µSv/h outside BL13 up to $1.0 \cdot 10^2$ µSv/h outside BL29. In addition, neutron instant dose rates higher than 0.10 µSv/h have been measured at 2 Beamlines: 1.8 µSv/h outside BL11 and 50 µSv/h outside BL29. These high intense dose rates have been measured as short peaks of radiation during the beam losses provoked by the bad injections, and are not present in routine top-up operation.

	BL04	***BL09***	***BL11***	***BL13***	***BL22***	***BL24***	***BL29***
Inside BL Gamma dose rate (µSv/h)	206	141	128	64	24	28	$14 \cdot 10^4$
Inside BL Neutron dose rate (µSv/h)	0.03	2.9	9.0	2.9	7.9	1.7	$2.7 \cdot 10^2$
Outside BL Gamma dose rate (µSv/h)	2.0	2.0	0.97	0.44	0.97	1.6	$1.0 \cdot 10^2$
Outside BL Neutron dose rate (µSv/h)	0.05	-	1.8	-	-	-	50

Table 1 - Gamma and neutron dose rates inside and outside the 7 Beamlines during bad injection top-up tests

The results presented for both situations: routine and abnormal top-up, have shown that the highest dose rates are produced at BL29, affecting significantly the accumulated doses registered in that area. For the rest of the EH and SA, the radiation levels produced during top-up are comparable to those seen in decay mode operation, when the injection from BO to SR is realized with the FEs closed. The differences observed may be explained by the fact that BL29 is the only BL at ALBA that has the first set of movable masks installed inside the lead hutch, instead of inside the Tunnel as the rest of BLs.

Consequently, to guarantee a public access in the entire EH and SA in top-up operation, even in BL29 area, there is the necessity to add an additional shielding at Beamline 29.

3.2 Design and verification of an additional shielding for top-up operation

To understand the origin of the radiation produced in Beamline 29, Monte Carlo simulations have been performed with FLUKA code by simulating 3 GeV electron losses in a copper target located at the beginning of the Beamline 29 FE, inside the Tunnel [7]. The particles produced by the electromagnetic cascade are then transported through the FE into the Beamline.

The left column in *Fig. 5* shows the simulated maps of gamma and neutron dose equivalent rates at BL29 in µSv/h, normalized for a current loss of 1 nA. The maps confirm that the particles generated by solid bremsstrahlung radiation of the electrons losses inside the Tunnel, hit the movable masks inside the Optical Hutch and produce the peaks of radiation measured inside and outside Beamline 29. A ratio of 5:1 for the gamma/neutron components outside the Beamline shall be expected, in agreement with the results obtained experimentally. As a result, an additional shielding had been designed to shield the gamma radiation produced by the scattered radiation of the movable masks.

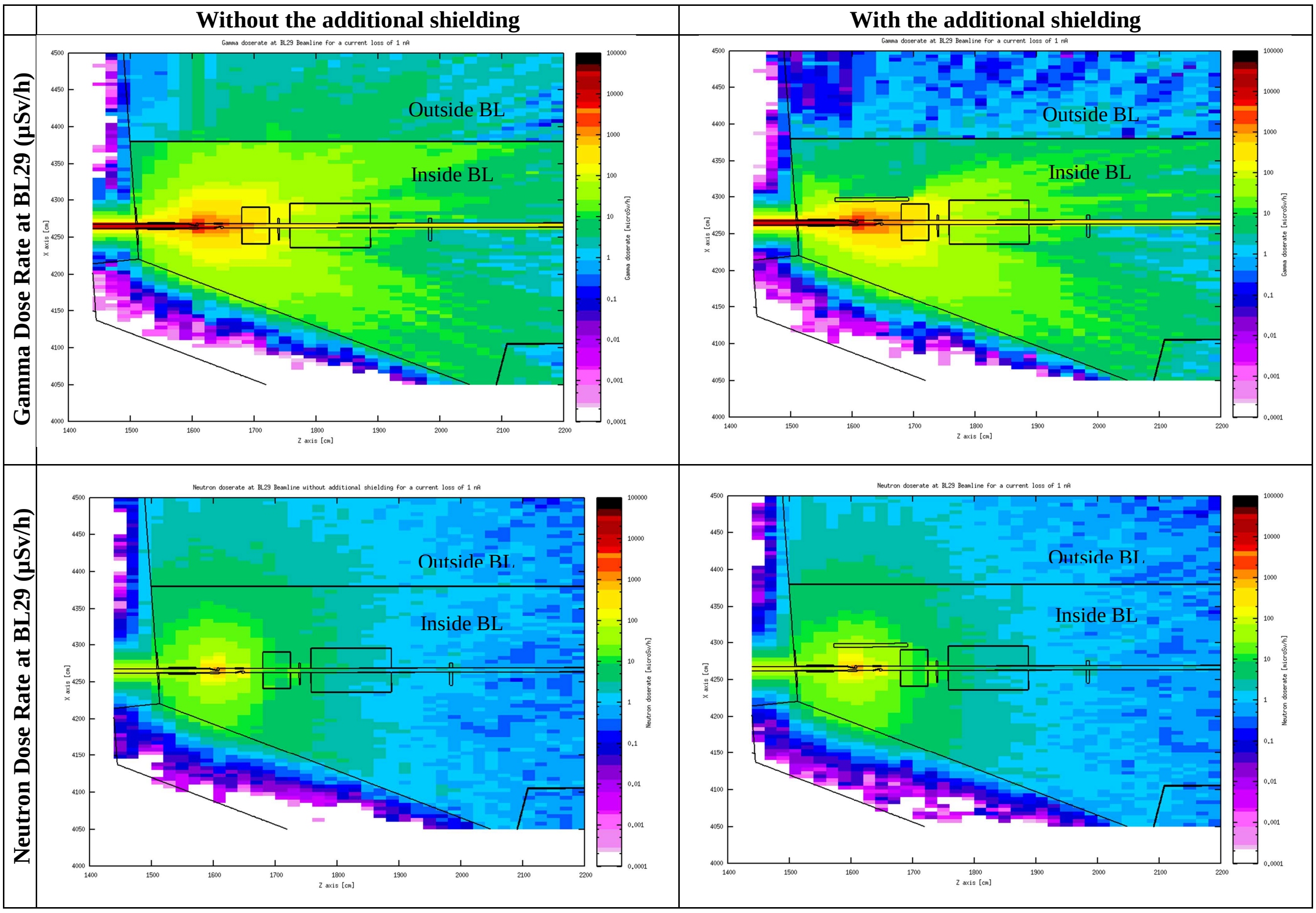

Fig. 5 - Gamma and neutron dose rates at Beamline 29 calculated with FLUKA with and without the additional shielding for a current loss of 1 nA.

The additional shielding consists of a lead screen 5 cm thick centered at 140 cm height level (beam level) and located next to the movable masks inside the Optical Hutch of BL29 (*Fig. 6*).

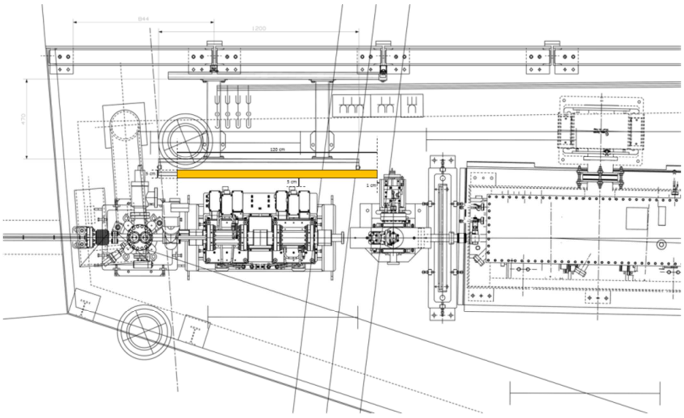

Fig. 6 - Additional shielding at BL29 (in yellow)

Monte Carlo simulations have been performed to check the suitability of the thickness and location of the shielding. The simulated maps of the of gamma and neutron dose equivalent rates are shown on the right column of *Fig. 5*, normalised to 1 nA lost current. The gamma dose rate outside BL29 diminishes by a factor 10 approximately with the additional shielding (from 10 µSv/h without the additional shielding to 1 µSv/h with it). It can also be observed that, as expected, the neutron dose rate remain on the same order in both cases.

The experimental radiation measurements at BL29 area after installing the additional shielding are presented in Fig. 7 and show that the gamma dose rate peaks at BL29 are now below 1 µSv/h. This represents a reduction of a factor 10 compared to the experimental results without the additional shielding (*Fig. 3*), in fair agreement with the Monte Carlo simulation. Moreover, the efficiency of the additional shielding is confirmed by the fact that the contribution to the total accumulated dose is now below 0.5 µSv in 4 hours in operation (*Fig. 7*) at BL29, enough to ensure public zone in EH and SA during top up operation.

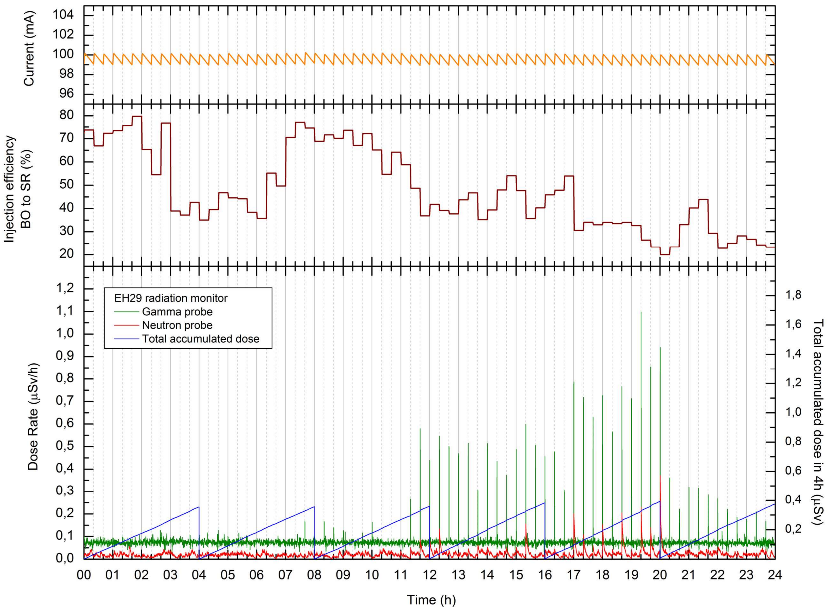

Fig. 7 - Gamma and neutron dose rates and total accumulated dose at BL29 Beamline with additional shielding

4. Conclusion

The radiation levels produced in ALBA in top-up mode have been characterised experimentally in routine top-up operation and in dedicated top-up tests where injection was worsened. In particular, the study presented in this paper has revealed a pattern of gamma and neutron dose rate measured outside the Tunnel and the Beamlines, at each injection realized in top-up operation. The radiation peaks pattern measured has no significant contribution to the total accumulated dose, excepted for Beamline 29 area. An additional shielding has been designed and installed at the Beamline. The suitability of the shielding has been simulated with Monte Carlo calculations and verified with experimental radiation measurements to guarantee a public access to the Experimental Hall and Service Area in top-up operation of the ALBA accelerators.

5. References

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