The gamma and neutron dose rate due to the total stored beam losses at the ALBA synchrotron

M.J. García[1], X. Rúa[2] and X. Queralt[1]

[1]*ALBA Synchrotron-CELLS, Carretera BP-1413, km 3, 08290 Cerdanyola del Vallès, Barcelona, Spain*

[2]*ACPRO - Asesoría y Control en Protección Radiológica, S.L., C/ Rafael Batlle, 24, 08017 Barcelona, Spain*

Abstract

The ALBA external shielding tunnel is formed by 19 ratchet walls. Each ratchet wall is formed by 1 meter thick side wall and 1.5 m front wall. The diameter of the external shielding wall is around 86 meters. Attached to each side wall there is one on-line radiation monitor for gamma radiation. Next to the injection zones and at some insertion devices position there is also a neutron monitor. This radiation monitor network is reinforced by 9 movable monitors located at the positions where higher radiation dose rate levels have been measured. These movables monitors are also formed by gamma and neutron detectors.

When due to some accelerator system fault (the RF or any of the magnetic family systems) the stored beam is lost suddenly, the radiation monitor network records the effect of these losses at the external side of the shielding, in the Experimental Hall-EH area. In this work, the absolute dose rate values produced during these types of events are analyzed and compared with the different causes of the losses.

1. Introduction

This paper describes how the radiation monitor network at ALBA helps to understand the phenomenon of an unexpected total electron beam current loss occurs in the ALBA Storage Ring. We have studied the equivalent dose rate characteristics (the peak values and their space distribution) outside the ALBA shielding for each total loss.

In order to describe these losses and the effects on the external side of the shielding walls, the description of the ALBA acceleration system [1], [2], [3] and the shielding walls characteristics is given in this section.

1.1. The ALBA acceleration system

The ALBA accelerators system is formed by a 110 MeV electron LINAC, a 3.0 GeV synchrotron booster and a 3.0 GeV storage ring. The LINAC accelerator is located in a bunker vault next to the tunnel that contains the booster and the storage ring (see Fig. 1), the length of the storage ring is 268.8 m. The design storage ring current is 400 mA, however nowadays the accelerator is running at 120 mA stored beam in decay mode.

The maximum quantity of beamlines that can be built are about 30. At the present time there are in operation 7 beam lines: 4 hard X-rays and 3 soft X-rays. The radiation source for the actual beamlines are 6 insertion devices and 1 storage ring bending magnet. The insertion devices are formed by 2 in vacuum undulators, 2 Apple type undulators (based in pure permanent magnets), 1 superconducting wiggler and 1 wiggler based in hybrid technology [4].

All the beamlines front ends are located inside the ALBA tunnel, and all of them have a double Bremsstrahlung shutter placed as close as possible to the front wall.

The storage ring RF system [3] is formed by 6 cavities placed in 3 different positions (about 120º each), each cavity is feeding by 2 IOT tubes in order to get redundancy to guarantee the maximum reliability of the RF system.

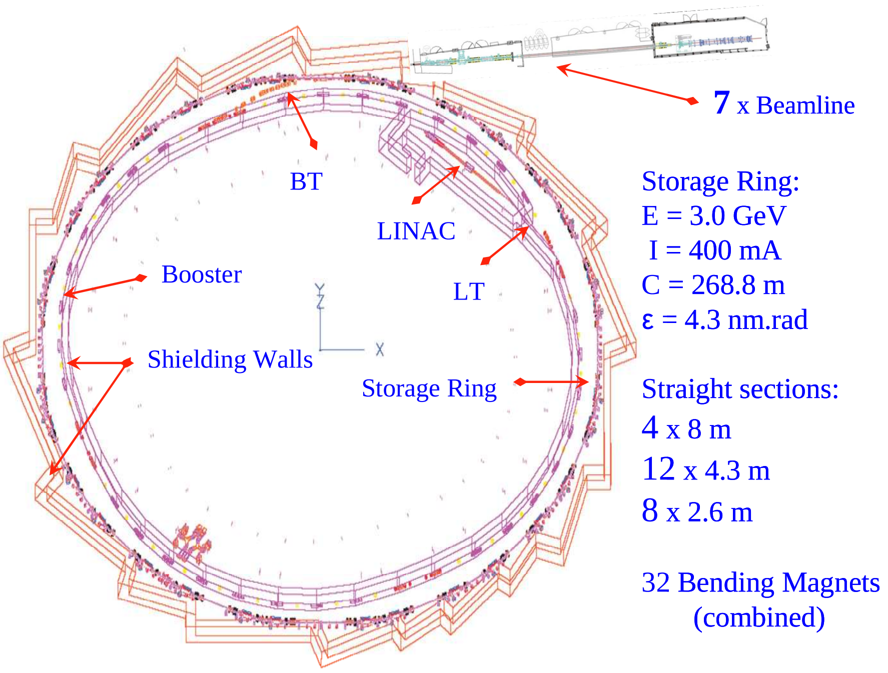

Fig.1 – ALBA accelerators system layout (LINAC, booster and storage ring) and the shielding walls.

The beam lifetime is about 24 h, and in normal operation for user there are 2 injections every 12 h. In the Table 1 is given the most relevant parameters for each of the accelerators system at ALBA:

ACCELERATOR PARAMETER	VALUE
Maximum LINAC energy	110 MeV
Charge per pulse	~ 4 nC
Booster energy	0.1 to 3.0 GeV
Stored beam energy	3 GeV
Booster circumference	249.6 m
Storage ring circumference	268.8 m
Maximum injection frequency	3 Hz
Stored current	120 mA
Stored charge	$6.8\cdot10^{11}$ e-
Lifetime at 120 mA	~ 24 h
Pressure	$4\cdot10^{10}$ mbar

Table 1 – The list of the most relevant parameters for the LINAC, booster and storage ring accelerators..

The 120 mA storage ring current is distributed uniformly covering the entire ring. The current is divided in 10 bunches of 64 ns long each, and they are separated 25 ns (see Fig. 2). From the fast current transformer

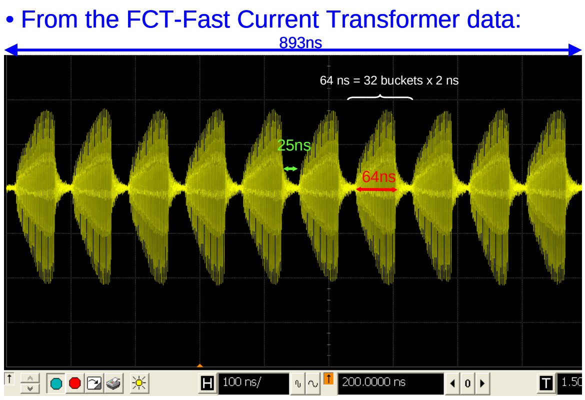

Fig.2 – The time structure for the storage ring current.

(FCT) device data it is possible to determine the bunch structure. Each bunch is formed by 32 buckets of 2 ns long current.

1.2. The ALBA shielding description

The shielding for the ALBA accelerators is formed by the bunker that contains the LINAC accelerator and the tunnel where is located the booster and the storage ring. The LINAC bunker is next to the ALBA tunnel (see Fig 3). The LINAC bunker walls and roof thickness is 1 m, and the material is heavy concrete for the walls and normal concrete for the roof.

All the internal walls for the tunnel are formed by casted walls, of a thickness between 1.65 m at the injection zone (booster to storage ring), and 1 m in all the other parts. The internal wall material is heavy concrete for the injection zones (next to the LINAC to booster and next to booster to storage ring).

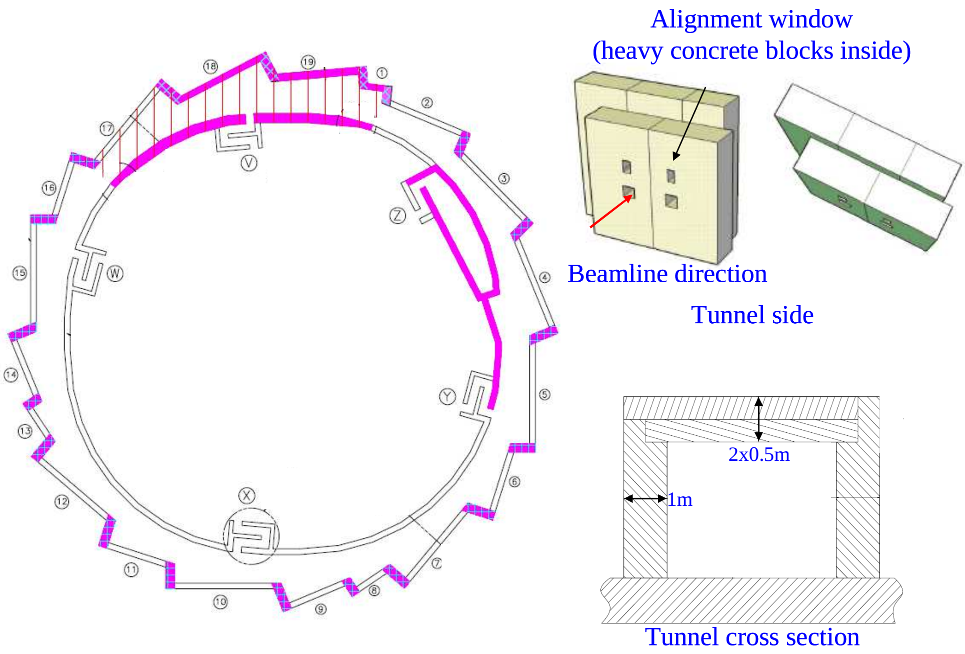

Fig.3 – Different views for the ALBA shielding elements. On the left side, a layout of the shielding walls (in pink colored is marked the heavy concrete zones), and the slashes area is for 3 layers beam roof structure at the injection zone. On the top right side, a detailed view of a front wall for 2 beamlines (2 layers block configuration), and on the bottom right side a tunnel cross section detail, where a 2 layers beams for the roof structure is shown.

The external tunnel walls are formed by casted (for the so called side wall) and 2 layers heavy concrete blocks (see Fig. 3). These walls are the limit between the storage ring area and the EH, where the 7 beamlines are installed. The external wall is formed by 19 ratchet structure, and the thickness of all the front walls is 1.5 m, and the side walls thickness is 1 m for all of them but in the injection area is 1.25 m.

WALL PARAMETER	VALUE
Inner and side walls thickness	1 m
Inner wall thickness at injection	1.65 m
Side wall thickness at injection	1.25 m
Roof thickness	1 m
Roof thickness at injection	1.4 m
Linac walls thickness	1 m
Labyrinths walls thickness	0.7 m
Front walls thickness	1.5 m
Number of side/front walls	19
Concrete density	2.4 g/cm^3
Heavy concrete density	3.2 g/cm^3

Table 2 – List of the main parameters that describe the ALBA shielding walls.

The bunker and tunnel roof material is normal concrete, and the structure is formed by 2 layers of concrete beams, and 3 layers next to the injection area (booster to storage ring), see the slashed part in the Fig. 3.

In the Table 2 is collected all the relevant parameters for the LINAC bunker and the tunnel. All the chosen thickness and material for the different components have been selected to assure an annual dose of 1 mSv, assuming that the storage ring current is 400 mA, over a period of 2000 hours per worker.

1.3. The radiation monitor network system

The ALBA radiation monitor network is formed by 33 units, 24 are fixed and 9 are in movables trolleys. All the 24 fixed radiation monitors are part of the safety interlock system (PSS: Personnel Safety System), in such a way that if there is an accumulated dose higher that 2 μSv in 4 hours, the PSS stops all the ALBA accelerators in a redundant and diverse way.

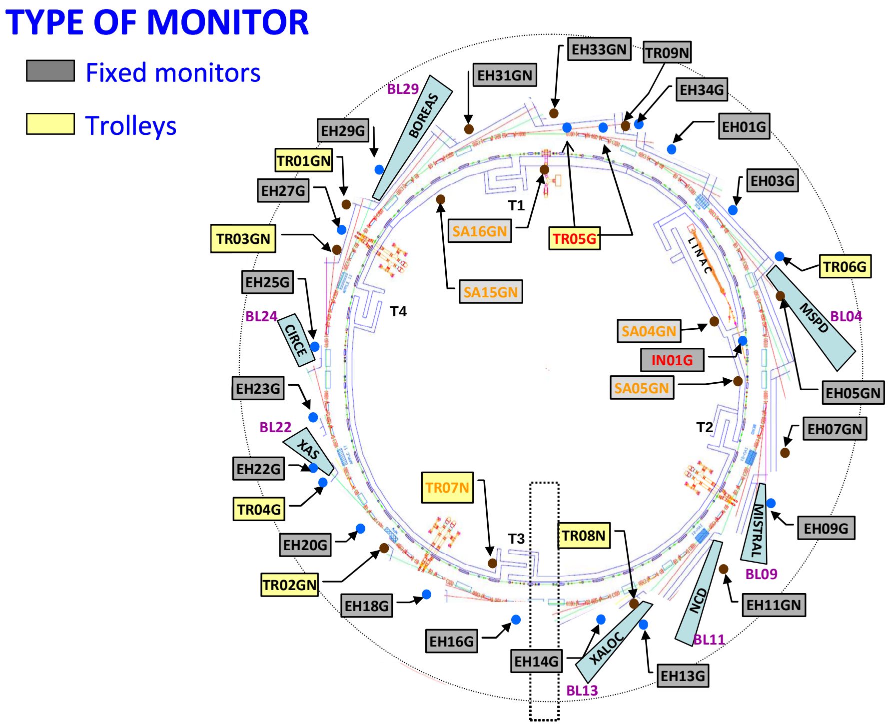

Fig.4 – Present distribution of the radiation monitor network next to the LINAC bunker and the tunnel (both for the internal and the external walls). In gray colored labels are all the fixed radiation monitors, and the yellow ones are the radiation monitors placed in a trolleys. The letter 'G' and 'N' means a gamma and neutron detector respectively.

All 24 fixed radiation monitors are distributed in the following way: 1 inside the tunnel (for the 'Only LINAC mode' operation), 4 next to the internal tunnel wall (called Service Area), and 19 in the external tunnel walls (next to the EH). 7 of 19 are installed attached to the optical hutch beamline wall, and the other 12 are placed on the side walls (see the present distribution in Fig 4.).

All the 24 fixed monitors have a gamma detector, and 9 of them have also a neutron probe. In the case of the trolley ones, they have 3 with gamma and neutron detectors, 3 with only gamma and 3 with only neutron. The 33 radiation monitor network is collecting dose rate data every 2 seconds.

The technical specifications for the gamma and neutron detectors are given in Table 3.

	FHT192	FHT 762 Wendi-2
Manufacturer	Thermo Electron GmbH	Thermo Electron GmbH
Particle	Photons	Neutrons
Energy range	30 keV – 7 MeV	25 meV – 5 GeV
Measuring range	100 nSv/h – 1 Sv/h	1 nSv/h – 100 mSv/h
Calibration Factor	Related with Cs-137 For low dose rate: 0.01 - 0.02 (μSv/h)/cps For high dose rate: 1.9 - 2.2 (μSv/h)/cps	1.14 (μSv/h)/cps
Unit measure	Hp(10)	Hp(10)
Type	Active Ionization chamber	Active Proportional counter
Sensitive material	Inert gas (7 bar)	He-3 (2 bar) + polyethylene moderator + Tungsten
Dead Time	For high dose rate: 6-7 μs	1.8 μs
Amplifier	FHT 6020 (v1.21): 2 channels	

Table 3 – Gamma (photons) and neutron detectors specifications.

The radiation monitor position has been decided taking into account the possible electron losses points in the storage ring during the injection process (in the case of the fixed ones) and according to the places of the places next to the tunnel walls where the dose rates have given significant values. In Table 4 is given the angular position for the 33 radiation monitors and the storage ring component that is located next to each detector. Taking into account the radiation monitors located in the EH (starting with the letters 'EH') and 8 trolleys (labeled as 'TR'), it is clear to realize the uniformity distribution of this network across the EH area (see the 'Angle' data from Table 4).

	RADMON	Angle (°)	Component		RADMON	Angle (°)	Component		RADMON	Angle (°)	Component
1	TR05	8		**12**	EH07	118	RF Plant-1	**23**	EH22	243	ID-BL24
2	TR09	15		**13**	EH11	132	ID-BL13	**24**	EH23	256	
3	EH34	16		**14**	EH13	152		**25**	EH25	271	
4	EH01	23	RF Plant-2	**15**	TR08	161		**26**	TR03	291	ID-BL29
5	EH03	43	ID-BL04	**16**	EH14	162		**27**	EH27	292	RF Plant-3
6	EH05	64		**17**	EH16	181		**28**	TR01	303	
7	TR06	66		**18**	EH18	203		**29**	EH29	310	
8	SA04	75	BM-LT	**19**	TR07	204		**30**	SA15	330	Septum-E Bo
9	IN01	76		**20**	TR02	218		**31**	EH31	334	Septum-E Bo
10	SA05	89	Septum-I Bo	**21**	EH20	230	ID-BL22	**32**	SA16	353	Septum SR
11	EH09	112		**22**	TR04	241		**33**	EH33	356	Septum SR

Table 4 – List of the position for all the 33 radiation monitors, specifying the name (TR: trolley, EH: Experimental Hall and SA: Service Area), their actual angular position and the most relevant storage ring component.

2. Measurements

The ALBA storage ring is working for user operation since May 2012 [1], during the operation time it has been observed sudden and unexpected total current losses causes by different factors related with storage ring systems, like RF cavity trips, IOTs trips or magnet power supply trips among others. The contribution to the year accumulated dose in the EH, where all the beamlines are located, has not been very significant. However the radiation pattern in the EH due to these losses has not been characterize until now.

In this paper we describe how is this radiation pattern (for gamma and neutron radiation) depending on the current loss origin.

2.1. The electron beam losses characterization

Here we present 10 different events of current losses in the storage ring. In the Table 5 is given the main characteristic values of these losses:

- The total current lost stored just before the loss
- The storage ring system that has caused this loss
- The angle position for the accelerator system that has produced the loss (the origin of the angle of loss is the position of the injection septum magnet in the storage ring given in degree).

Event #	Current loss (mA)	Cause Type	Angle Losses (°)
1	126.4	RF Plant-1 trip	118
2	19.1	RF Plant-1 trip	118
3	80.3	Fluorence Screen trip	163
4	129.5	RF Plant-2 trip	209
5	126.8	RF Plant-3 trip	298
6	129.5	RF Plant-3 trip	298
7	129.6	RF Plant-3 trip	298
8	128.9	RF Plant-3 trip	298
9	117.8	RF Plant-3 trip	298
10	118.1	RF Plant-3 trip	298

Table 5 – List of the 10 storage ring beam current loss events with the value of the current at the moment of the loss (in mA), the storage ring component that has caused the loss and the angle position of the related component (in degree).

A DCCT (DC Current Transformer) device installed in the storage ring has been used to measure the current profile during the loss. In Fig. 5 it is shown the current values of the storage ring recorded every second.

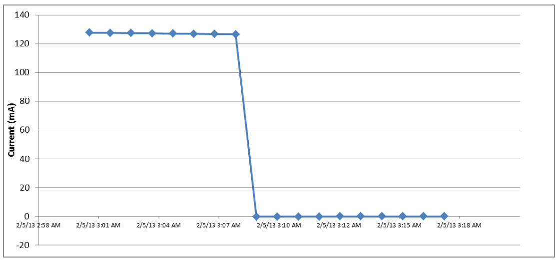

Fig.5 – Example of the storage ring beam current profile at the moment of the current loss recorded by the DCCT (Direct Current, Current Transformer) for one of the current loss event listed in Table 5, each point correspond to 1 second data.

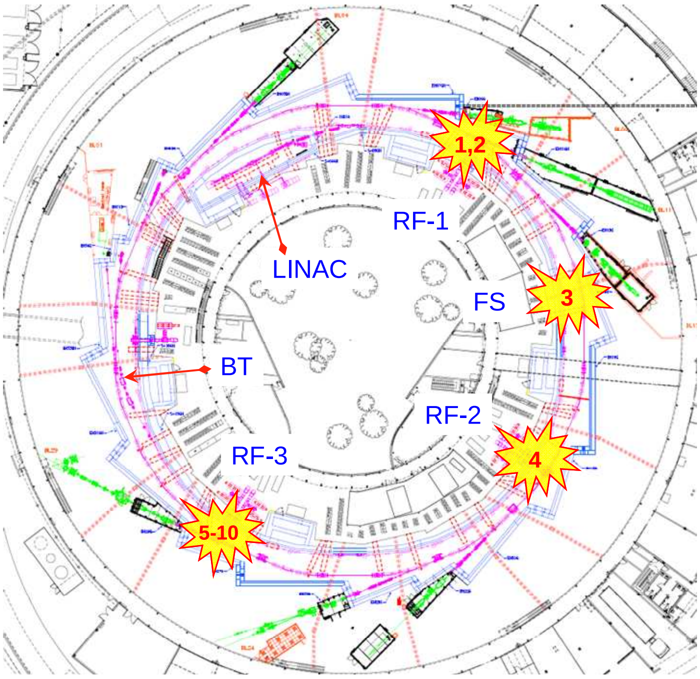

Fig.6 – The layout of the 4 different positions for the total current losses relative to the accelerator LINAC position and the booster to storage ring transfer line (BT). Each number corresponds to the event listed in Table 5.

In the Fig. 6 is shown the loss point position angle given from the Table 5 on the ALBA storage ring layout. All the 10 loss events have been distributed in 4 different locations: the 3 RF plants (RF-1, RF-2 and RF-3) and one fluoresce screen (FS) allocated between RF-1 and RF-2.

2.2. Dose rate peak values and their distribution

Each one of the 10 current loss events has created a gamma and neutron dose rate signal along the radiation monitors placed in the external ALBA tunnel walls. For each current loss event we have considered the angle position of the detector that has recorded the maximum dose rate value (peak value), the relative value (in %) related with the second peak and finally, the number of detectors that has recorded any value above the background signal. This set of data has been collected for both gamma and neutron detectors. It has to be pointed out that all the radiation monitors has a gamma detector, but not all of them has a neutron one. The Table 6 shows all these values for all the 10 events considered in this work.

		GAMMA PROBE				NEUTRON PROBE			
Event #	Current loss (mA)	Angle (º)	Peak (μSv/h)	Peak ratio	Detectors involved	Angle (º)	Peak (μSv/h)	Peak ratio	Detectors involved
1	126.4	161	759.2	27.1%	9	218	110.4	74.8%	3
2	19.1	48	0.7	-	14	70	0.0	-	4
3	80.3	218	919.3	43.3%	7	218	190.3	36.3%	3
4	129.5	222	50.0	20.3%	9	104	34.4	64.3%	2
5	126.8	161	679.3	30.0%	10	218	114.4	87.1%	3
6	129.5	161	788.2	30.0%	10	218	86.6	87.1%	4
7	129.6	161	784.7	29.1%	10	218	83.0	92.6%	4
8	128.9	161	616.5	28.6%	11	218	126.2	59.3%	4
9	117.8	355	7.8	94.9%	5	355	95.8	49.6%	4
10	118.1	222	49.2	13.2%	10	104	36.5	50.7%	2

Table 6 – Characteristic for the peak dose rate values and position for each of the 10 current loss events (separated according to the detector type, gamma and neutron). Also is given the angle position for each detector, the ration between the peak value and the 2nd detected peak, and in the last column the number of detectors from the network that have recorded a dose rate value.

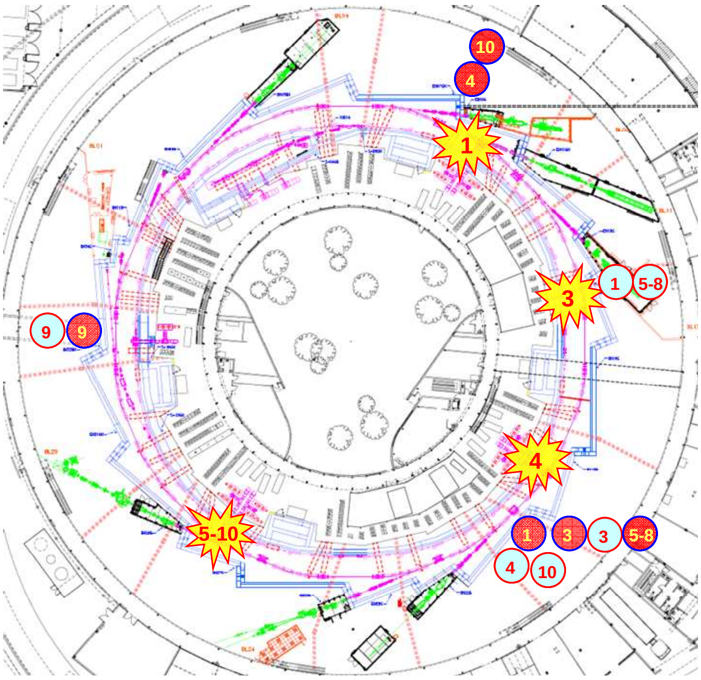

Fig.7 – The layout of the radiation monitor position (in blue and red circles) that have given the maximum dose rate value (peak relative position to the 4 different current loss points). The 'blue' circles correspond to the gamma peaks and the 'red' to the neutron ones. The circle number corresponds to the loss event label from Table 5.

The relative position of the maximum peak (gamma or neutron) recorded by the radiation monitors and the location of the loss point is shown in the Fig. 7. The number in the circle refers to the number of the current loss event that has created the maximum dose rate value (peak), either for gamma (blue circles) or neutron (red circles).

If we plot the dose rate peak values for all the radiation monitors that has recorded any value above the background, as a function of the detector angular position (for gamma and neutron), and also we plot the angular position where is place the system that has created this current loss, we can see that this plot is like the 'finger print' of the current loss. From Fig. 8 to Fig.13 we show the different pattern of this plot for 6 of the 10 loss events.

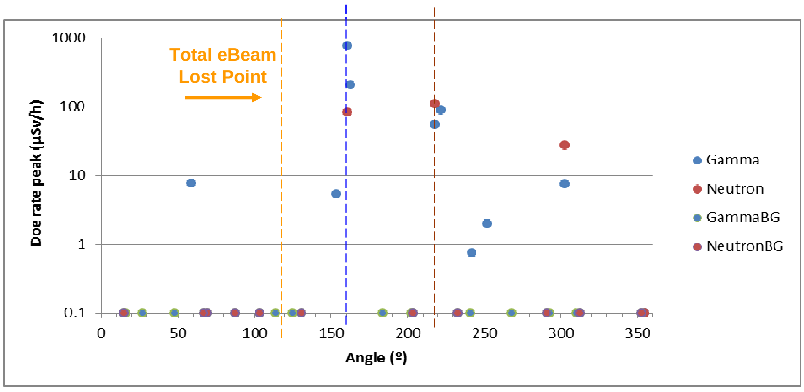

Fig.8 – Angular radiation monitor position vs dose rate peak values for the entire radiation monitors network for the Event#1 (see Table 5). The labeled 'BG' detectors are the ones that have record no peak at all. Also is shown the total current loss position.

It seems from these data that the subtraction of the angular peak position for gamma and neutron is a parameter that may characterize the current loss event. For instance in Fig. 9 and Fig. 12 the increment of these angular values is 0º.

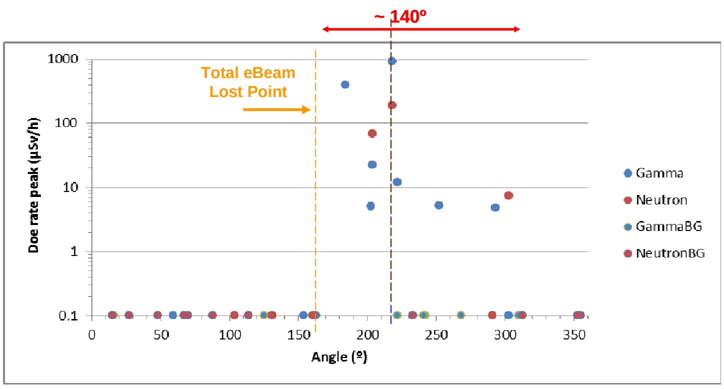

Fig.9 - Angular radiation monitor position vs dose rate peak values for the entire radiation monitors network for the Event#3 (see Table 5). The labeled 'BG' detectors are the ones that have record no peak at all. Also is shown the total current loss position.

Also another behavior for these plots is the angular distribution of the detectors that has recorded a value higher that the background. For instance in the case of the event #3, the detectors are spread in about 140º, while in most of the cases the spread is about 300º (Fig. 8, 10, 11 and 13).

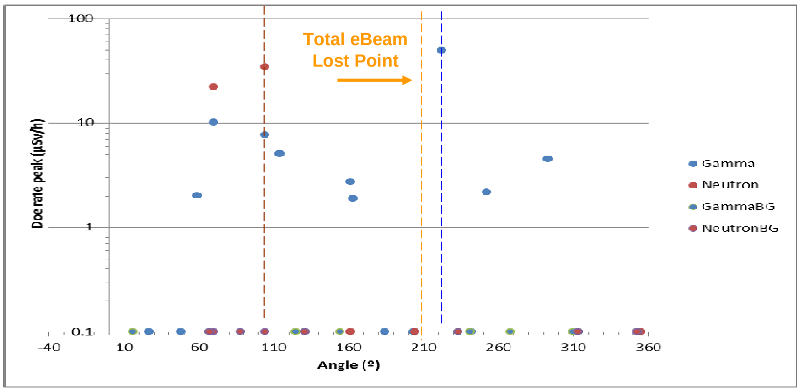

Fig.10 - Angular radiation monitor position vs dose rate peak values for the entire radiation monitors network for the Event#4 (see Table 5). The labeled 'BG' detectors are the ones that have record no peak at all. Also is shown the total current loss position.

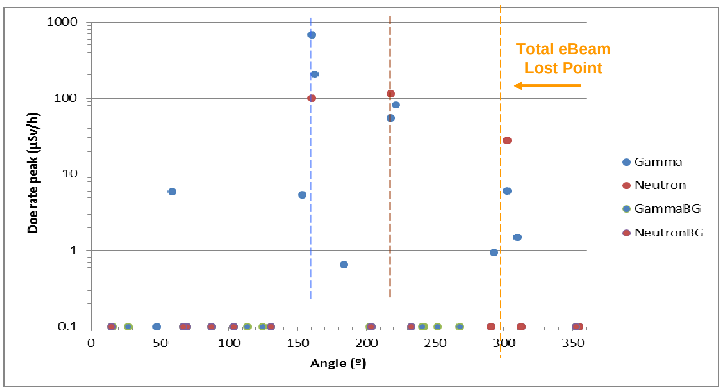

Fig.11 - Angular radiation monitor position vs dose rate peak values for the entire radiation monitors network for the Event#5 (see Table 5). The labeled 'BG' detectors are the ones that have record no peak at all. Also is shown the total current loss position.

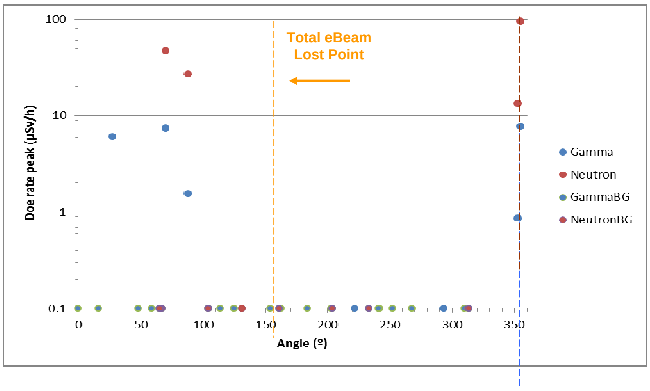

Fig.12 - Angular radiation monitor position vs dose rate peak values for the entire radiation monitors network for the Event#9 (see Table 5). The labeled 'BG' detectors are the ones that have record no peak at all. Also is shown the total current loss position.

The same behavior of these plots is shown in Fig. 10 and Fig. 13 where the distance between the gamma and the neutron peaks is the longest.

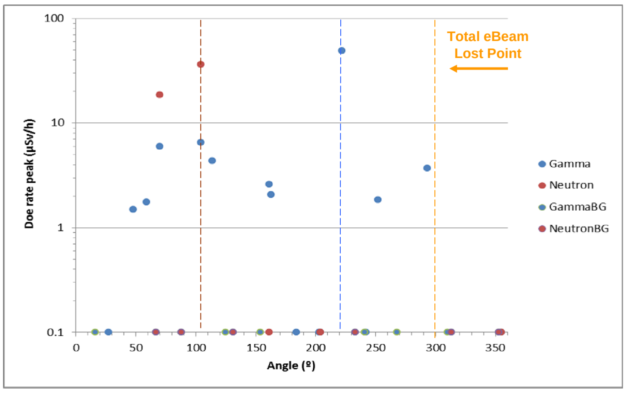

Fig.13 - Angular radiation monitor position vs dose rate peak values for the entire radiation monitors network for the Event#10 (see Table 5). The labeled 'BG' detectors are the ones that have record no peak at all. Also is shown the total current loss position.

3. Final results

The behavior of peak values vs angle plots is more evident if we compute the subtraction between gamma and the neutron peaks (see last column of the Table 7). From this table it is shown that there are only 4 values for the subtraction that is repeated in all the loss events: 0º, 22º, 57º and 242º. It seems from this data that there is a strong correlation between the position where the loss has happened and the position where is detected the maximum peak for gamma or for neutron.

Event #	Loss Point Angle (º)	GAMMA PROBE Angle (º)	NEUTRON PROBE Angle (º)	γ-Step Angle (º)	n-Step Angle (º)	γ-n Angle (º)
1	118	161	218	43	100	57
2	118	48	70	290	312	22
3	163	218	218	55	55	0
4	209	222	104	13	255	242
5	298	161	218	223	280	57
6	298	161	218	223	280	57
7	298	161	218	223	280	57
8	298	161	218	223	280	57
9	298	355	355	57	57	0
10	298	222	104	284	166	242

Table 7 – List of following values: a) the current loss point angle ('Loss Point'); b) the peaks corresponding to the gamma; c) the peaks corresponding to the neutron detectors; d) the angular subtraction values for gamma peaks (b)-(a); e) the angular subtraction values for neutron peaks (c)-(a) and f) the angular subtraction for the gamma and neutron peaks (e)-(d).

4. Conclusions

From the data reported in this paper we can conclude that the radiation monitor network installed at ALBA records any of the total current loss events. In average each event has been recorded by ~ 9 gamma detectors and ~ 3 neutron detectors.

It is clear also that the concrete shielding is not enough to reduce the instant dose rate coming from a total current loss event, which is something expected, because the shielding material and thickness were chosen to achieve the annual dose as a public zone for the Experimental Hall.

As it has been shown from the data coming from a prompt event caused by the fluorescence screen (FS), event #3, the radiation produced by this event is detected almost over a half turn (140º).

In contrary, for a distributed current loss event (like the RF trips) the radiation created by these events could be detected over a whole turn (at least).

Acknowledgements

We are especially indebted to the ALBA Accelerator Division, especially to our colleagues Francis Pérez and Montse Pont, for many fruitful discussions and help given to understand the results given in this paper.

References

[1] F. Pérez, “First year operation of the ALBA synchrotron light source”, Proceedings of IPAC2013, Shangai, China.
[2] M. Pont, “Operation status of the ALBA synchrotron light source”, Proceedings of IPAC2012, New Orleans, Lousiana, USA.
[3] F. Pérez, B. Bravo, “Commissioning of the ALBA storage ring RF system”, Proceedings of IPAC2011, San Sebastian, Spain.
[4] J. Campmany, D. Einfeld, J. Marcos and V. Massana, “General description of IDs initially installed at ALBA”, Proceedings of IPAC2010, Kyoto, Japan.