Radiological studies during the ALBA Linac commissioning

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Abstract

The commissioning of the ALBA Linac started in June'08 and finalized in October'08. During this period the klystrons, the accelerating cavities, and the Diagnostic line were set up reaching a maximum electron energy of 108 MeV with a pulse charge of 4 nC and a pulse length of 112 ns at a repetition rate of 3 Hz. Outside the Linac bunker the radiation dose levels were measured by means of online gamma and neutron monitoring, passive dosimetry and portable detectors surveying. Accumulated doses inside the bunker were measured in fixed places also with passive dosimetry. After every Linac operation the activation was measured with portable detectors to control the dose rates inside the bunker. Additional lead shielding was installed next to the electron loss points. Also in order to guarantee that the 0.5 μSv/h limit was not reached, outside the bunker some zones where delimited.

1. Introduction

The ALBA pre-injector is a 100 MeV Linac supplied by THALES Communications as a turn key system. It is located in the Linac bunker with part of the Linac-to-Booster Transfer Line (LTB). A Diagnostic line is mounted next to the first bending magnet of the LTB. During the Linac commissioning, the beam was guided to the diagnostic line to study its characteristics.

1.1. The ALBA Linac and Diagnostic line

The ALBA Linac consists of a 90 kV DC thermoionic gun, followed by the buncher, designed to reduce the energy spread and the electron losses. Two travelling wave constant gradient accelerating sections increase the energy up to >100 MeV [1]. The bunching system and the two accelerating sections are feed by two klystrons located outside the Linac bunker (see Fig.1). The ALBA Linac can work in Single bunch or in Multibunch mode. The Multibunch mode can deliver 4 nC shoots at a maximum repetition rate of 3 Hz.

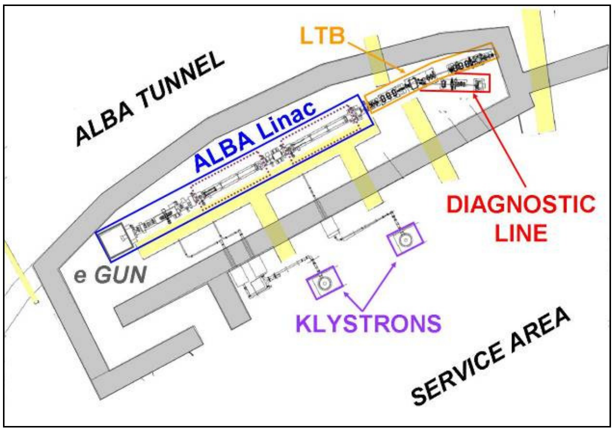

Fig.1 - Top view of the ALBA Linac bunker. The trenches used to pass signal and power cables are indicated in yellow. The heavy concrete (3.2 g/cm^3) walls are indicated in grey. The Booster, not plotted in this figure, is placed at the inner wall of the ALBA Tunnel.

After the ALBA Linac, the Linac-to-Booster transfer line (LTB) drives the electrons to the Booster synchrotron. Two dipole magnets, one inside the bunker and another outside, bend the electron trajectory to the Booster injection septum. The Diagnostic line is installed next to the first LTB bending magnet. This consists of one quadrupole, a fluorescent screen, a scraper with horizontal slits and finally, the Faraday Cup; where the beam current is measured (see Fig.2). Varying the current of the bending magnet coils and the position of the scraper slits, the profile and energy of the beam delivered by the Linac can be measured. In Fig.3 a picture of the LTB and Diagnostic line is shown during its installation period.

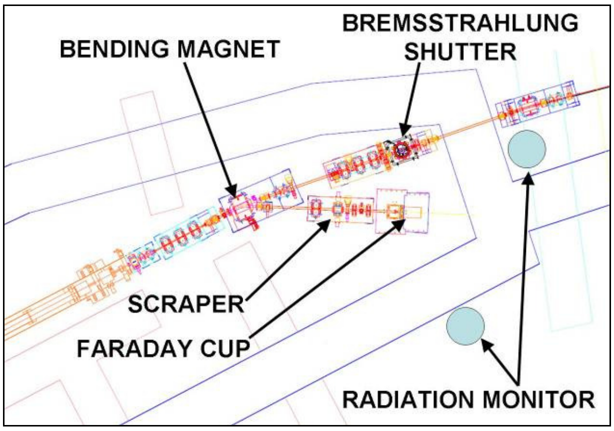

Fig.2 - Top view detail of the LTB and Diagnostic line in the Linac bunker.

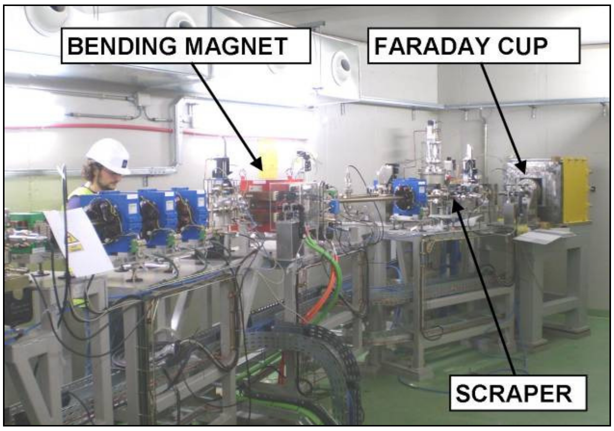

Fig.3 - Picture of the LTB and Diagnostic line in the Linac bunker.

The ALBA Linac commissioning started on June '08 with the startup of the Klystrons and the conditioning of the buncher and the accelerating cavities. After the 12 hours test at the maximum power, on October 16th, the Linac commissioning stopped to replace the provisional water cooling and power supply to the permanent one. In Table.1 the Linac specification values for the Multibunch mode are compared with the final commissioning results.

Parameter	**Specification**	**Measured**
Pulse length	0.3 to 1 μs	112 ns
Charge	≥ 3 nC (in 1 μs)	4 nC
Energy	≥ 100MeV	108 MeV
Pulse to pulse energy variation	≤ 0.25 % (rms)	0.06 % (rms)
Relative energy spread	≤ 0.5 % (rms)	0.23 % (rms)
Norm. Emittance (1σ)	≤ 30 π mm mrad (both planes)	< 25 π mm mrad (both planes)
Pulse to pulse time jitter	≤ 100 ps (rms)	25 ps (rms)
Repetition rate	3 to 5 Hz	1-3 Hz

Table.1 - Comparison between the specifications and the measured values for the Multibunch mode Linac characteristics.

1.2. The safety systems

The Linac bunker concrete walls and the Personal Safety System (PSS) allow the operation of the ALBA Linac at maximum power keeping the personnel radiation doses below the public limit; 1 mSv/y. This zones includes the ALBA Tunnel, which can be accessed while the Linac is operating with the Diagnostic line (Linac Only mode). This goal has been verified by the radiation detection means during the commissioning process.

The Linac bunker consist on 1 m heavy concrete (3.2 g·cm^{-3}) walls and a 1 m normal concrete (2.4 g·cm^{-3}) roof. The roof is formed by two layers of prefabricated blocks that can be removed. These blocks are placed in a way that there is not direct line of sight from inside to outside the bunker. The bunker has floor apertures and wall apertures. The first ones are the trenches through which the power and signal cables enter into the bunker. The second ones are the RF labyrinths used for introducing the RF power into the bunker, the alignment windows, the LTB hole, and the labyrinth entrance door.

The PSS avoid that anyone is irradiated while the Linac is on. This implies that there is no permit of operation if there are personnel inside the bunker, neither if the radiation dose rate levels are higher than 0.5 μSv/h outside the bunker. This system, based on PLC technology, is composed by certified SIL3 components: search and emergency buttons, a door locker and switch, light panels, beepers, access cards, relays and a safety PLC [2]. Also, it is connected to two radiation monitors, one installed in the Service Area and another in the ALBA Tunnel (see Fig.2). Both are placed at the downstream area of the bunker, where the electron energy is larger and most part of the electron losses is expected. The monitor in the ALBA Tunnel has a gamma detector and the one in the Service Area has a gamma and a neutron detectors. When the required conditions are fulfilled, the Linac PSS allow the operation of the electron gun and the klystrons (HVPS and RF signal). The Bremsstrahlung shutter permit is also controlled by the PSS.

In order to verify that the public dose limit is not exceeded, the following types of radiation measurements tools are used: portable detectors, radiation monitors and Termoluminsicent dosimeters (TLDs). The dose rates are controlled with portable detectors during operation in the ALBA Tunnel, the Service Area and the roof, including all the apertures mentioned before. In addition, the dose rates are measured online with the radiation monitors: the two mentioned above plus six monitors mounted on six trolleys, distributed around the Linac bunker. Finally, TLDs provided by an external certified service are placed outside the bunker and read monthly.

Inside the bunker, the activation of the accelerator components is measured with portable detectors after every Linac shift. Also TLDs are placed at the walls inside the bunker to measure the accumulated monthly dose.

2. Radiation measurements

2.1. Passive dosimetry

TLDs are placed outside and inside the bunker attached to the walls at beam height (140 cm). During June ’08 the startup of the electron gun and conditioning of the accelerating cavities and the buncher took place. In Fig.4 the TLDs data of this month is shown. The TLDs that presented higher doses are the closest to the buncher and to the accelerating structures. This is because during the conditioning, X-rays are produced in the cavities [3].

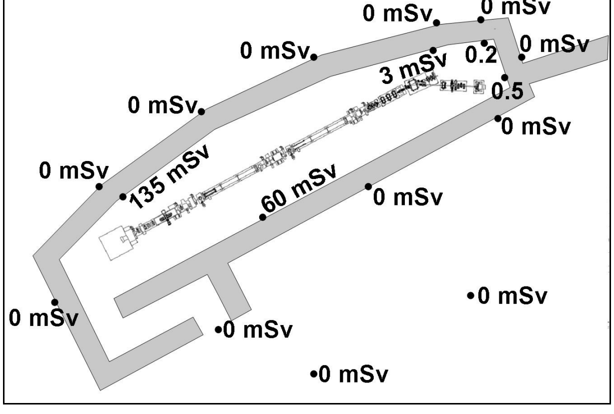

Fig.4 - TLDs data from June ’08. All TLDs are placed at the beam height. The data is shown in mSv.

During October ’08, Linac commissioning at average conditions of 107 MeV, 3 nC and 2 Hz was done. In this case, the TLDs that present higher doses are the ones that are close to the LTB bending magnet and to the Diagnostic line (see Fig.5). This is because the commissioning tests produce larger electron losses at these Linac components.

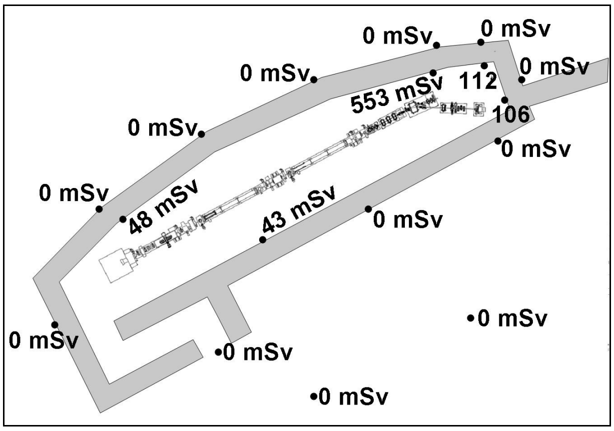

Fig.5 - TLDs data from October '08. All TLDs are placed at the beam height. The data is shown in mSv.

All the TLDs placed outside the bunker at beam height measured 0 mSv from June '08 to October '08. Additionally, twelve dosimeters were placed at the apertures of the bunker mentioned before. They also measured 0 mSv from June '08 to October '08. Only the one placed inside the ALBA Tunnel trench measured 0.5 mSv during October.

2.2. Radiation surveys

During every operation of the Linac, surveys with portable radiation detectors were done outside the bunker. The measurements showed that the dose rates levels are below 0.5 μSv/h except in three places: the klystrons surface opposite to the Linac, the bunker downstream wall and the roof concrete blocks gaps. In the first case, two iron plates 1 cm thick were installed at the klystrons to reduce the dose rate below 0.5 μSv/h. In the second scenario, lead blocks were placed near the LTB bending magnet and the scraper in order to reduce the dose rates near the downstream wall (shadow shielding). Additionally, the area where the dose rate could exceed the 0.5 μSv/h limit, 2m from the downstream wall, was labeled and restricted. Finally, for the third case, the roof access was fenced, even though the access is not permitted. These radioprotection actions guarantee that the radiation dose rate levels are below the public limit at the accessible zones.

2.3. Radiation monitoring

Eight radiation monitors, the two fixed and the six on trolleys, measure the dose rate every two seconds. The two fixed monitors are connected to the PSS. The one in the ALBA Tunnel is a gamma detector that has a dose rate alarm level at 0.5 μSv/h. During the Linac commissioning scans with the LTB bending magnet were done to determine the energy and energy dispersion of the beam. During these scans, part of the beam was not lost in the Faraday Cup but in the scraper and other elements of the diagnostic line. For this reason the mentioned alarm level was increased to 1.2 μSv/h. However, the accumulated dose never exceeded 2 μSv in 4 hours (0.5 μSv/h in average).

The changes in the Linac operation characteristics (increasing the pulse charge or closeing the scraper) can be related with the dose rate; which is proportional to the electron losses. In the Linac Only mode, the magnetic field is reduced when starting a bending magnet scan. Then, the electron beam is directed between the LTB and the Diagnostic line; in the direction of the zone where the detector at the ALBA Tunnel is placed. In Fig.6 a plot of the measured dose rate by the monitor placed at the ALBA Tunnel is shown. During this day the shadow shielding was still not installed and thus, the PSS tripped the Linac operation due to a dose rate alarm level when starting a bending magnet scan.

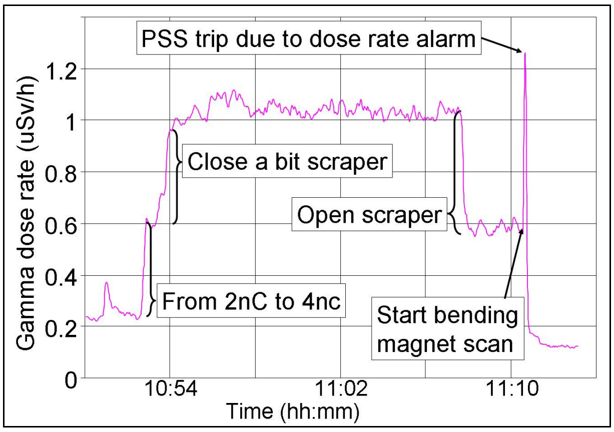

Fig.6 - Measured dose rate at the ALBA Tunnel near the downstream wall on September 26th. The shadow shielding near the bending magnet and the scraper was not installed.

2.4. Activation

The loss of electrons of energies higher than 7-20 MeV produces neutron radiation and activation [4]. The activated material usually generates electromagnetic radiation when the unstable isotope decays. The amount of radiation depends on the amount of electrons lost in that element and the lifetimes of the generated isotopes. The electromagnetic radiation can exit the elements generating a radiation dose rate in the Linac bunker after the Linac operation. The dose rate due to activation was measured along the ALBA Linac, LTB and Diagnostic line after every operation of the Linac by means of portable detectors. These measurements showed also the electron loss points.

In Fig.7 the measurements (in µSv/h) of the radiation due to activation on October 16th are shown. This day, the Linac was operated during 13 hours at 108 MeV, 4 nC and 1 Hz. The Linac most activated components were the Bending magnet and the scraper. This is because these are the components that present largest electron losses. The dose rate due to activation at the bending magnet surface during 12 days is presented in Fig.8 as a function of the time between the Linac operation and the activation measurement.

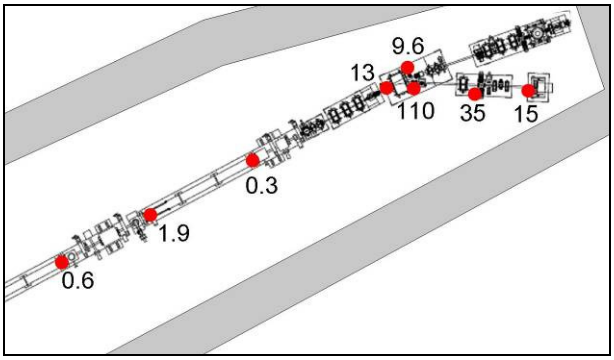

Fig.7 - Radiation measurements due to activation at the surface of the Linac and Diagnostic line elements on October 16th; just after13 hours of operation at 108 MeV, 4 nC and 1 Hz (all data in µSv/h).

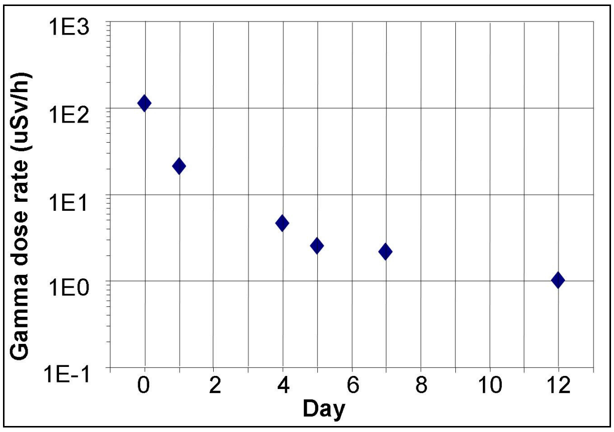

Fig.8 - Radiation measurements due to activation at the bending magnet surface for 12 days starting on October 16th.

The activation measurements were done just after every Linac operation to control the radiation levels and limit the zones that requires it. This protocol verifies that the radiation dose received by the workers do not exceed the public limit. For that reason, the Linac bunker access is controlled by administrative procedures.

3. Conclusions

The radiation dose measurements during the Linac commissioning have been presented as well as the radioprotection actions. The experimental data has shown that the Linac bunker maintains the dose rates outside the shielding below the public limit of 0.5 μSv/h. During Linac commissioning, the beam can be intercepted by the scraper when scanning the beam with the bending magnet. In this scenario extra radiation is produced and then, extra shielding is required. In this case, the use of local lead bricks shielding showed good results. Permanent lead screens are going to be installed.

The dose rate monitoring has been also presented. This equipment allows a precise and instantaneous follow up of the radiation levels due to the electron losses in the Linac bunker. The fast response of the PSS when exceeding a dose rate alarm has also been verified.

Finally, the activation measurements of Linac components have shown the need of an access control procedure after the Linac operation. This will be implemented through an administrative procedure and through the PSS; that will not allow the access into the Linac bunker during a given period of time after the Linac use.

Acknowledgments

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References

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