Dose rate measurements around the electron extraction at FLASH

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Abstract

The free-electron-laser FLASH at DESY was upgraded with a second undulator beam line in a separate tunnel. The safety concept regarding the electron beam extraction was confirmed by measurements. Here, LB 6419 devices of the PANDORA - system were used.

1. Introduction

FLASH is the name of the Free-Electron Laser in Hamburg. It's on the campus of the Deutsches Elektronen-Synchrotron (DESY) in Hamburg. Presently, FLASH operates a superconducting electron accelerator with an electron beam that is distributed into 2 different undulator beam lines (FLASH1, FLASH2) located in separated tunnels as shown in fig. 1.

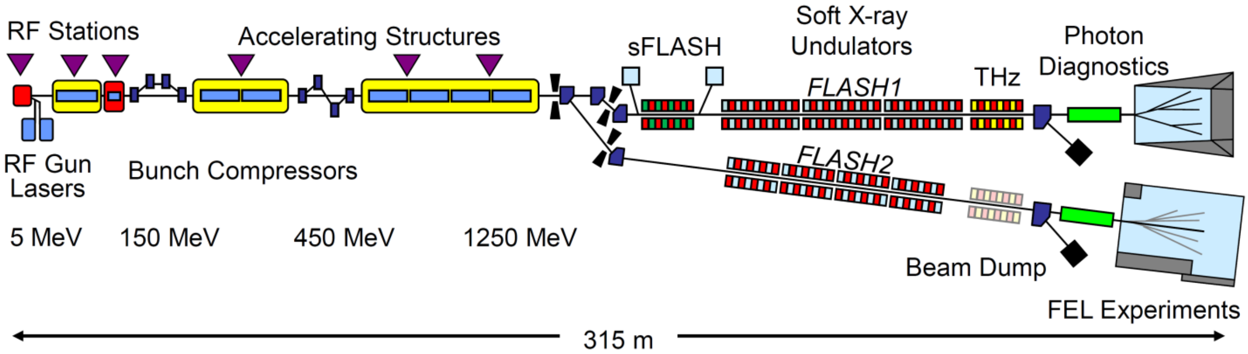

Fig. 1 – Schematic layout of FLASH. Not to scale.

The parameters of the electron beam are:

particle energy (max) = 1.6 GeV,
average power (max) = 100 kW,
charge per pulse = 1 nC,
pulses per pulse train = 6400 and
pulse train repetition rate = 10 Hz.

By passing the undulator section the electrons generate photons in the wavelength range from 4 to 52 nm and with pulse energies up to 0.5 mJ. For more details see [1].

The FLASH2 – tunnel can be open for access while FALSH1 is in operation (but not vice versa). The electron enclosure in the extraction area is obtained by 2 different measures: Firstly, all magnets of the FLASH2 beam line between the septum and the concrete wall are switched off and secondly, the beam shutter in front of the wall is closed. These are ensured by the personnel interlock system. The extracting elements, that are kickers and septum, are intentionally not part of the safety system. Their magnetic stray fields influence the FLASH1 beam. So, these elements are expected to run continuously in order not to change anything for the FLASH1 beam. Ideally, there is no electron pulse in the time window during the kick. The safety concept is expected to be tolerant when this is not the case and beam is extracted into FLASH2. In order to verify this assumption the radiation field was measured in a particular run with this failure case.

The ambient dose rates were measured by the PANDORA – system of DESY. It consists of the LB 6419 devices. Around the extraction area the system was extended by additional 5 devices to get as much information from this run as possible.

In the following section the LB 6419 detectors are described in more detail. The second part contains how the measurement was performed and its results.

2. Capabilities of the LB6419 in pulsed fields

The instrument comprises a 3He proportional counter tube as a thermal neutron detector in a moderator for neutron detection and a plastic scintillator with a photomultiplier for beta and gamma detection [2].

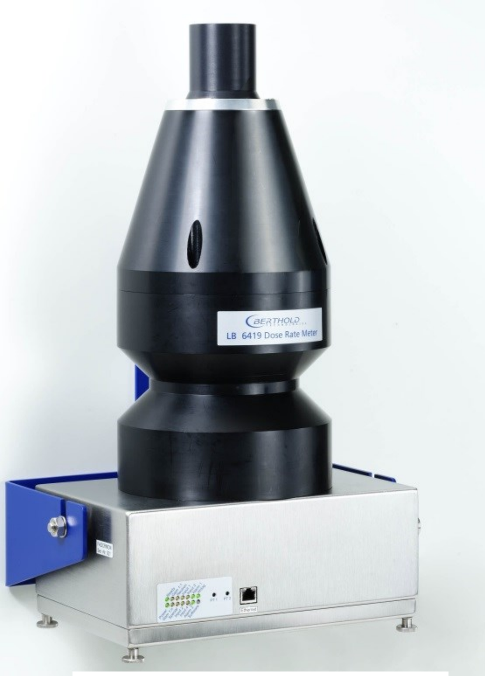

Fig. 2 – LB 6419 side view

The ^{3}He tube has a diameter of Ø40 mm, a length of 100 mm and an active length of 40 mm. The cylindrical moderator made out of polyethylene has a maximum diameter of Ø200 mm and a length of 360 mm. The plastic scintillator has a diameter of Ø41 mm and a length of 41 mm.
The scintillation light is detected by a compact and fast photomultiplier with a wide dynamic range. These two detectors are recording decay particles from the instable nuclides as well as direct radiation.
Power supplies, analogue electronics and a fast FADC readout and analysis module which records pulse heights together with time-stamps are assembled in an electronic box. The system auto-synchronizes with the time structure of the pulsed radiation field and accumulates time distributions of the recorded events relative to the radiation burst. The delayed decay products are identified by analyzing their timing characteristics. Doses are calculated from different types of events. These pulsed dose measurements are not affected by dead-time effects. An overview of the detector responses due to neutron radiation are given in table 1.
The data transfer for monitoring is done via Ethernet and by means of two relays the monitors can be connected with the hardwired personnel interlock system of an accelerator. The device is prepared for wall assembly and its external dimensions are 530 mm × 200 mm × 300 mm. At DESY there are now 90 units in operation for example at the electron storage ring PETRA III and at FLASH. The instrument is available on the market as BERTHOLD LB 6419.

Time structure / Type of radiation	Continuous Total response, no pileup	Burst Delayed response only
High energy neutrons > 20 MeV	Scintillator: H(n,n)H → recoil protons	Scintillator: ^{12}C(n,p)^{12}B → ^{12}C + β + ν
Low energy neutrons < 20 MeV	Moderated ^{3}He – tube: ^{3}He(n,p)^{3}T	Moderated ^{3}He – tube: ^{3}He(n,p)^{3}T delayed by TOF

Table 1 – Overview of the LB 6419 responses due to neutron radiation.

The fig. 3 shows how the count rate of the scintillator behaves for a pulsed exposure with a repetition rate of 10 Hz in a neutron field behind a lateral shielding of a beam dump of 1 GeV electrons. This time distribution

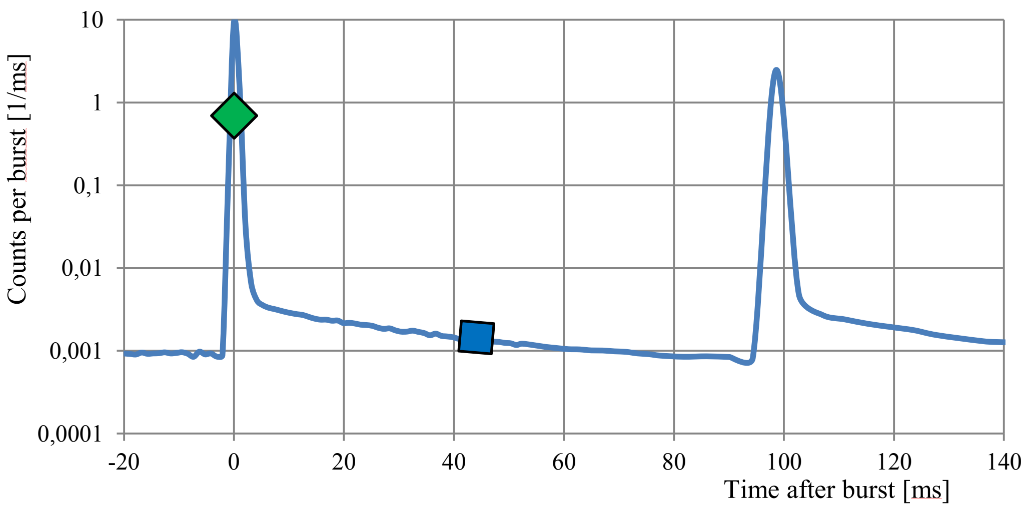

Fig. 3 – Time behavior of the scintillator count rate per burst. Average of 10^{5} bursts.

was obtained by averaging over 10^5 radiation bursts. The blue marker represents the delayed response between 32 and 64 ms after the burst. It can only be obtained when radiation bursts are triggered. The green marker represents the total response and doesn't depend on burst triggering. Its main contribution is the prompt response that suffers from dead time effects at high intensities first. As long that is not the case pulsed radiation can be regarded as continuous radiation. So burst triggering enables to separate the delayed response from the total response.

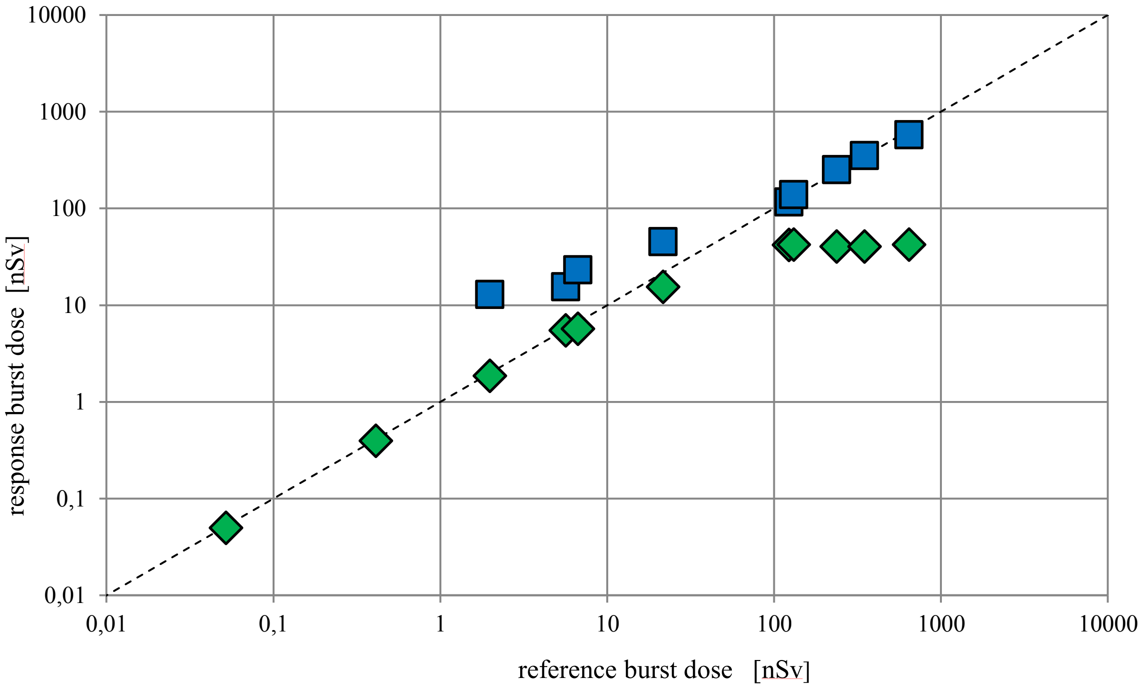

Figure 4 – Measured responses due to high energy neutrons. Green markers: total response; blue markers: delayed response.

In fig. 4 the ambient dose responses due to high energy neutrons are plotted. The total response (green markers) starts to saturate above 10 nSv/burst. It never reaches the 100 nSv/burst level. The burst intensity has to fulfill a preset minimal trigger condition for the delayed response (blue markers). It sets in at about 2 nSv/burst with a low trigger efficiency leading to a dose overestimation. Above 100 nSv/burst a linear behavior over at least 3 orders of magnitude can be expected. With an earlier measurement doses of 23000 nSv/burst were achieved [3]. It's shown that these 2 responses can be linked together in order to build a response of a dynamic range of more than 7 orders of magnitude.

3. Measurement at FLASH and results

The design of the safety measures for FLASH contains the definition of a failure event. It is expected to occur at a rate of one in 10 years of operation. The corresponding exposures should be less than 0.5 mSv in a surveyed area and less than 6 mSv in a controlled area. This event is defined as a total point loss of the entire 100 kW beam lasting up to 6 minutes limited by the welding capabilities of this beam.
In order to further limit a possible exposure 15 PANDORAs are permanently located on positions of interest at FLASH. There are 3 of them around the extraction. The alarm philosophy is the common averaging over a 4-hour-period. The ambient dose is accumulated in the period. When it exceeds a given limit of 2 µSv (per 4 h equates to 1 mSv per 2000 h) then the LINAC is blocked until the next 4-hour-interval starts. This method very well suits for pulsed accelerators as FLASH were high dose rates can occur but in a short time and so with a low dose increment. The limit of 2 µSv/4h is applied if 8h – working places are to be surveyed. For other locations with much lower occupancy rates the limit is set to be 10 µSv/4h.

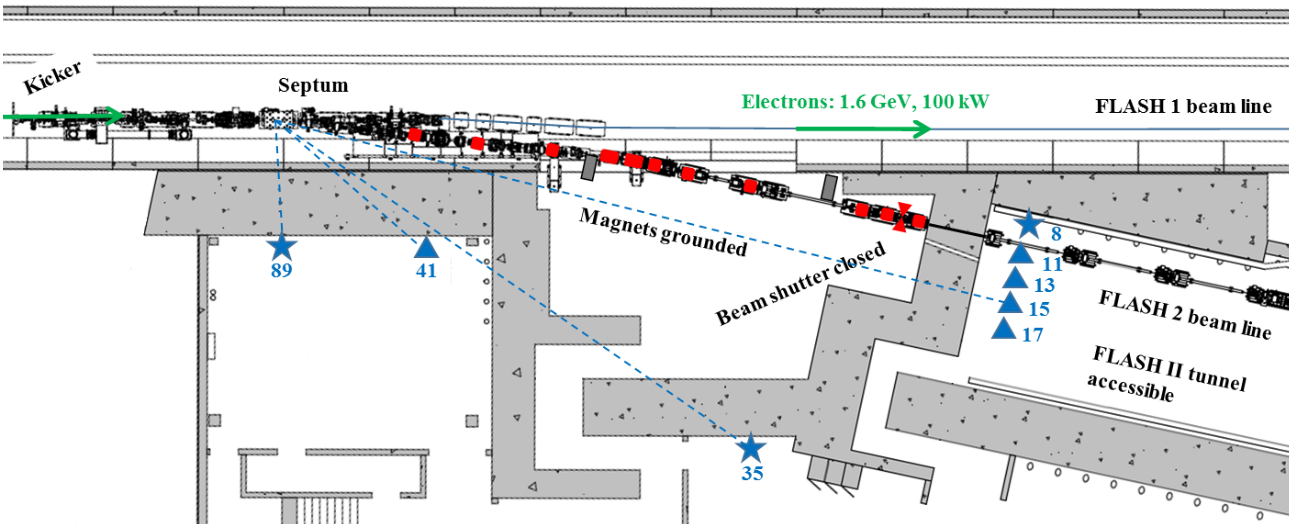

Figure 5 – Top view of the experimental setup. The blue markers point to the positions of the LB 6419 devices. They are labelled with their angle with respect to the septum.

The measurements were performed at the electron energy of 715 MeV and a beam power of 24 W. The natural background is subtracted before the reading is scaled to the permitted beam power of 100 kW. The scaling factor is approximately 4000. The result is given in mSv/event rather than in mSv/h. The detection limit is estimated to be 0.005 mSv/event. The natural background of 0.1 µSv/h would be blown up to 0.04 mSv/event by this scaling procedure.
The detector positions with permanent monitoring are market with a blue star, the additional ones are market with a blue triangle. The labels 8, 11,…,89 describe the angle of the detector position around the septum. The FLASH 1 electron beam defines the 0 degree direction. The first part of the FLASH 2 beamline behind the septum is at 6 degree.

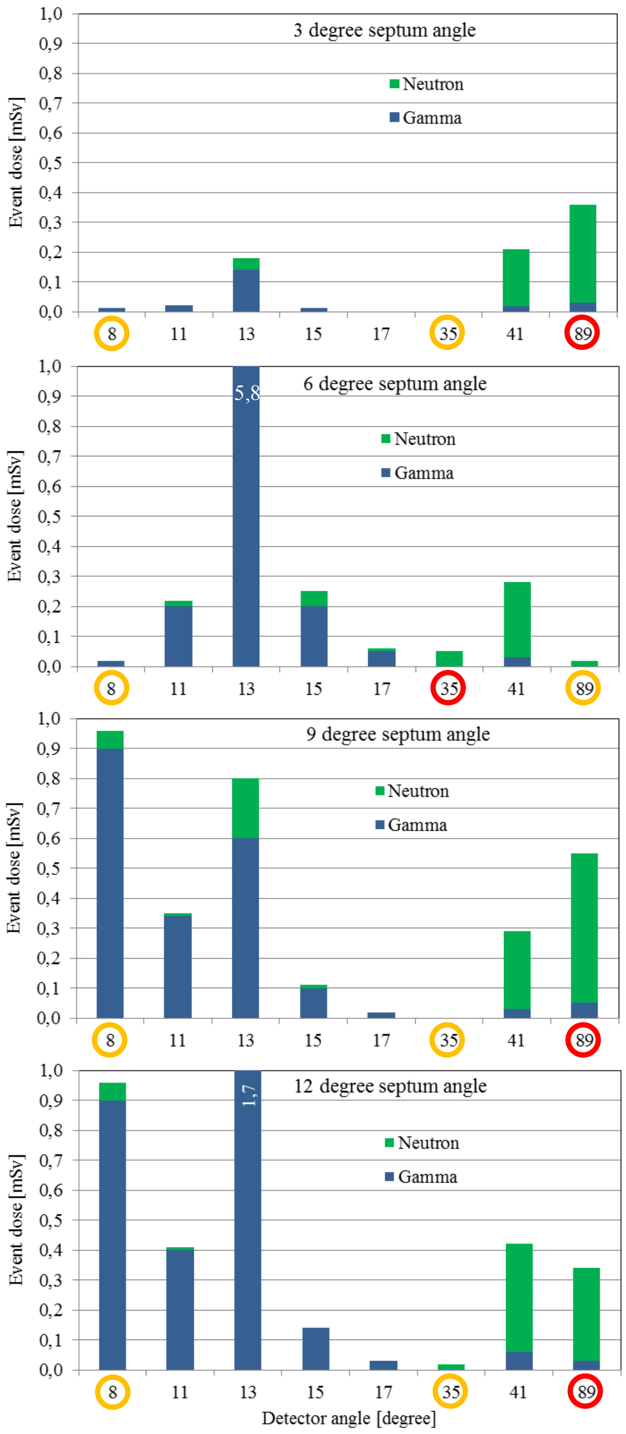

Figure 6 – Readings of the dose meters in mSv per event (1/10th hour) at 4 different deflection angles of the septum. The 6 degree setting fits to the beam energy. The blue part is the **γ -** *dose and the green one the neutron dose.*

As expected the doses at forward angles (detectors 8...17) are dominated by γ – radiation (fig.6, blue color) while the doses at larger angles (detectors 35...89) are dominated by neutron – radiation (fig.6, green color).

The readings of detector 13 are in general a factor of 10 higher than its neighbors. Intentionally, this position was chosen behind a whole through the shielding for the future upgrade with the FLASH3 beam line. Presently, it is filled by 2 plugs with a thickness of 0.5 m each while the wall is 2 m thick.

The detectors 8, 35, and 89 belong to the personnel interlock system and are permanent on their positions. They are marked with an orange circle (blue star in fig.5). The red one would have sent an alarm signal to the interlock system first in case of the particular loss scenario.

The detectors 8…17 are located in a controlled area. The maximum event dose was measured to be 5.8 mSv at position 13 (see fig.6). This meets the limit for a failure event of 6 mSv. Taking into account the action of the PANDORA 35 the maximum event dose of 5.8 mSv would be reduced to 1.2 mSv just by switching the beam off after 1.2 min.

The detectors 35…89 are located in surveyed areas. The maximum event dose was measured to be 0.55 mSv at position 89 (see fig.6). This meets the limit for a failure event of 1 mSv. Taking into account the action of the PANDORA 89 the maximum event dose of 0.55 mSv would be reduced to 0.01 mSv just by switching the beam off after 7 s.

4. Conclusion

The concept of the radiation safety of FLASH is based on the definition of a failure event among others: a full beam point-loss at the maximum power of 100 kW lasts 1/10th of an hour. The corresponding exposure should not exceed 1 mSv in a surveyed area and 6 mSv in a controlled area respectively.
The ambient doses around FLASH are measured by the PANDORA – system consisting of the LB 6419 detectors. This two-sensor device shows separate responses from γ – radiation, low – and high energy neutron – radiation. Additionally, it is capable to discriminate between prompt and delayed responses in pulsed radiation fields caused by FLASH (10 Hz). The LB 6419 achieves a dynamic range of more than 7 orders of magnitude by linking together the prompt and delayed responses from high energy neutrons.
In order to validate the safety concept from above a set of those failure events were generated at low power and the results were scaled up to the maximum power. The ambient doses were measured by the LB 6419 detectors. The result is that the passive measures like shielding and shadow walls just meet the goal. But by taking the PANDORA – system into account the accelerator is switched off by the personnel interlock system much earlier than the defined 1/10th of an hour. So the exposure would be reduced considerably (at least by a factor of 5).

References

[1] FLASH home page, http://flash.desy.de
[2] A. Klett, A. Leuschner, N. Tesch, „A dose meter for pulsed neutron fields“, Radiation Measurements 45 (2010) 1242 – 1244.
[3] A. Klett, A. Leuschner, “A pulsed neutron dose monitor”, Nuclear Science Symposium Conference Record, 2007. NSS '07. IEEE, Year: 2007, Volume: 3, Pages: 1982 - 1983