Injection with front ends open at the ESRF

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Abstract

The ESRF is planning to introduce, beginning of 2003, a new mode of operation consisting of injection with front ends open. Although it is not foreseen to run a continuous top-up mode - we will continue with our standard operation schemes, with typically two 50 mA top-ups per day in multi-bunch mode - this mode will already drastically reduce the heat load changes on the first optical components of the beamlines during injection. A number of radiation measurements have been carried out to assess the feasibility of this mode in terms of radiation protection. Indeed, the ESRF has adopted a radiation protection policy where all people working in the experimental hall are considered as non-exposed workers. With the present European legislation this means that we must respect the dose limit of 1 mSv.y^{-1} (0.5 μSv.h^{-1}). Because users normally stay for a relatively short period at the ESRF, we have translated this annual dose limit in a dose constraint of 0.5 × 4 = 2 μSv per 4-hour period. The results of the radiation measurements showed that while injection with front end open will be feasible within the present radiation policy of the ESRF, it is potentially possible to exceed the 4-hour dose limit in a single 50 mA top-up, in case of degraded injection efficiencies. It has therefore been decided to install an interlocked radiation monitoring system associated with this mode of operation. The paper summarizes the results of the radiation measurements and describes the interlocked radiation monitoring system.

1. Introduction

A number of 3rd generation light sources are using or planning to use continuous top-up to compensate for short beam lifetimes, essentially due to reduced vertical apertures to allow for small gap insertion devices. The lifetime at the ESRF is excellent (e.g. better than 60 hours at 200 mA) and continuous top-up is therefore not envisaged. However, the possibility to keep the front ends open during injection presents the obvious advantage of reducing the fluctuations of the thermal power on the beamline's optical elements.

All people working at the ESRF (staff members, users, external companies) are considered as non-exposed workers. From the annual dose limit of 1 mSv a derived 4-hour dose limit of 4 × 0.5 = 2 μSv is obtained. Interlocked radiation monitors integrated in the accelerator personal safety system guarantee this 4-hours dose limit everywhere around the storage ring. Injection with front end open could only be envisaged if it is shown to be feasible with this 4-hour dose constraint. A number of radiation measurements have therefore been carried out in the last 18 months. These measurements, described in detail in the following sections, showed that while injection with front ends open should be possible, the development of a dedicated interlocked radiation monitoring system will be necessary. The latter system will be completed during the 2002 - 2003 winter shutdown and injection with front ends open will start at the ESRF during the first weeks of operation in 2003.

2. Experimental set-up for the radiation measurements

A number of radiation measurements have been carried out to assess the feasibility within the present ESRF radiation protection policy of topping up the storage ring with front ends open. Figure 1 shows schematically the experimental set-up used for these measurements.

A lead block was placed behind the front-end pre-pumping vessel to scatter the incident bremsstrahlung. The dimensions of this block were such that the dose rates from scattered bremsstrahlung, as well as the neutron dose rates, are representative for what can be expected from a typical beamline layout. Radiation monitors outside the optics hutch were used to measure the dose integrated during an injection with front-end open. Photon doses were measured using a PTW 50 litre ionisation chamber; while neutron doses were measured using Apfel REMbrandt superheated drop monitors. Inside the optics hutch a small 0.6 cm^3 farmer-type ionisation chamber was placed in front of the lead block to measure the on-axis bremsstrahlung dose rates – this chamber was shielded with 3 mm of lead to stop the dipole synchrotron radiation.

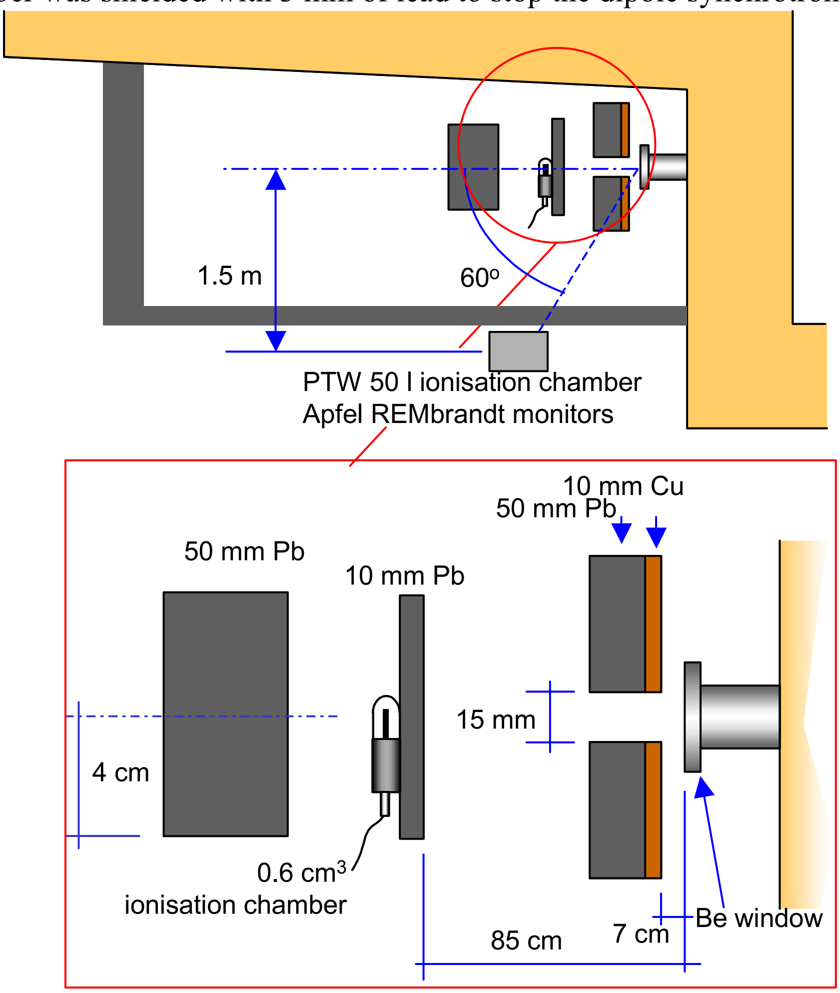

Figure 1: Experimental set-up used for the radiation measurements

A number of measurements were carried out, each measurement consisting in a dose integration for a zero to 200 mA injection with front end open. Different machine tunings were used to simulate different injection efficiencies, as explained below. Measurements were carried out on a dipole beamline (BM25) and an insertion device beamline (ID31). The straight section of this beamline was equipped with a 5-meter long 8 mm internal height vacuum vessel. All ID gaps were fully opened. The optics hutch on ID31 has a 30 mm thick lead sidewall, the BM25 hutch has an 8 mm thick lead sidewall.

Two sets of measurements have been carried out on ID31. In between the first and the second series of measurements the front end was equipped with a 4.5 mm diameter copper aperture. The second set of measurements was therefore representative for undulator beamlines, whereas the first set was representative for wiggler beamlines.

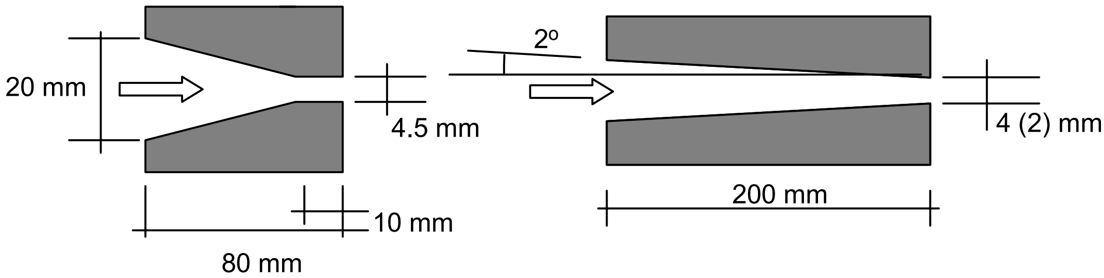

Figure 2: 4.5 mm diameter copper aperture in undulator beamlines (left). In the new high power front ends, a similar rectangular 4 × 4 mm2 (or 4 × 2 mm2) copper aperture is installed (right).

3. Results and discussion

		nominal	scraper closed	scrapers open	coupling correction off
without 4.5 mm copper aperture	integrated dose (200 mA fill)	n: 1.44 μSv γ: 0.48 μSv total: 1.93 μSv	n: 0.38 μSv γ: 0.11 μSv total: 0.49 μSv	n: 4.05 μSv γ: 1.40 μSv total: 5.45 μSv	n: 40.9 μSv γ: 14.9 μSv total: 55.8 μSv
	ID31 injection losses (% of 200 mA stored beam)	0.16 %	0.033 %	0.36 %	6.3 %
with 4.5 mm copper aperture	integrated dose (200 mA fill)	n: 0.10 μSv γ: 0.04 μSv total: 0.14 μSv	n: 0 μSv γ: 0 μSv total: 0 μSv	n: 0.6 μSv γ: 0.1 μSv total: 0.7 μSv	n: 2.1 μSv γ: 0.44 μSv total: 2.54 μSv
	ID31 injection losses (% of 200 mA stored beam)	2.8 %	0 %	4.7 %	11.4 %

Table 1: Results of ID31 measurements.

Table 1 shows the results of the measurements on ID31. As explained above a number of 200 mA injections were carried out, and the integrated photon and neutron doses were recorded. Four different injection conditions were used. Under the nominal conditions an overall injection efficiency of 75 % was obtained. By closing the scrapers in the injection area, the overall injection efficiency was degraded, but the local losses in the cell 31 straight section were reduced. By opening these scrapers the local losses in cell 31 were increased. Finally by switching off the coupling correction these local injection losses were further increased.

The injection losses in cell 31 were roughly quantified by using the integrated dose measured with Apfel neutron monitors placed on the roof of the storage ring. Earlier measurements resulted in a conversion factor between electron loss power and dose rate of 2.5 $\mu Sv.kJ^{-1}$ (see reference [1]). The estimated local losses are given in table 1, expressed as % of a 200 mA stored beam (e.g. 4.7 % means $0.047 \times 5.6\ 10^{-7}$ C = 26 nC or 158 J)

All measurements were carried out with an injection repetition rate of 1 Hz. Whereas the PTW ionisation chambers have a 100% collection efficiency under these conditions, the results from the Apfel monitors were corrected using an efficiency curve that we obtained earlier, from radiation measurements using different values of the current extracted from the booster. This efficiency curve is shown in figure 3.

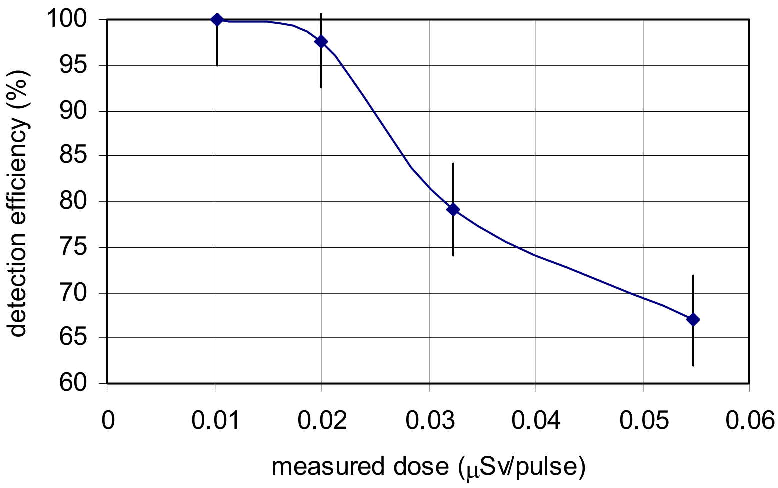

Figure 3: Experimentally determined efficiency curve for measuring pulsed radiation with the Apfel REMbrandt neutron monitor.

Finally, it was observed that the integrated dose measured with the on-axis thimble ionisation chamber was proportional, under all conditions, with the bremsstrahlung dose measured outside the hutch. This result was used to further quantify injection with front-end open for non-standard filling patterns (see hereafter).

The results shown in table 1 should be interpreted in the following way. The typical operation of the ESRF in the standard 2/3 or uniform filling mode consists in a top-up every twelve hours. With lifetimes in these standard filling patterns above 60 hours, roughly 50 mA are injected during these top-ups. As explained above, the radiation protection policy at the ESRF consists in guaranteeing the derived dose-limits for non-exposed workers during 4-hour periods (2 μSv). Injection with front-ends open will therefore be compatible with the present radiation protection policy if the added dose due to a 50 mA top-up would not exceed this 2 μSv dose-limit. This comparison is made in table 2.

	nominal	scraper closed	scrapers open	coupling correction off
without aperture	0.48 μSv	0.12 μSv	1.36 μSv	13.9 μSv
with aperture	0.04 μSv	0 μSv	0.18 μSv	0.64 μSv

Table 2: Total dose integrated during a 50 mA top-up.

From table 2 we can conclude that, within the present ESRF radiation protection policy, only extremely detuned beam conditions could lead to unacceptable high doses on wiggler beamlines. On the other hand the results also show that a significant dose increase can be expected from less extreme storage ring conditions, on both wiggler and undulator beamlines. Although the front-end mask drastically reduces the doses outside undulator beamlines compared to wiggler beamlines, these undulator beamlines are expected to have higher local beam losses due to the presence of small gap insertion device vacuum vessels.

The general conclusion from our radiation measurements is therefore that under normal operational conditions, injection with front end open is absolutely compatible with our present radiation policy. However the results of these radiation measurements also show that under certain degraded storage ring optics, doses outside the optics hutches could exceed the derived 4-hour dose limits. It was therefore decided to (a) go for this new mode of operation and (b) develop a dedicated interlocked radiation monitoring system for it.

The results of the radiation measurements on the bending magnet beamline BM25 did not reveal any significant dose increase due to injection with front-end open. However, as a conservative safety measure it was decided to equally equip the bending magnet beamlines with an interlocked radiation monitor.

4. Non-standard filling patterns

A number of "non-standard" filling patterns are used at the ESRF: single-bunch, 16 bunch and hybrid filling mode. Although the injected charge per top-up in these modes is smaller (typically 35 mA every 6 hours in 16-bunch and 9 mA every 4 hours in single bunch) or only slightly higher (typically 70 mA every 12 hours in hybrid mode), a potential problem with injection with front-end open may come from the cleaning of the individual bunches. A number of measurements have therefore been carried out to assess the feasibility of injection with front ends open in these "non-standard" filling modes. These measurements were carried out on the ID6 Machine/Safety diagnostics beamline. This undulator beamline is installed on a straight section equipped with an 8 mm ID vessel, which shows one of the highest local beam losses. We have used the dose readings from a 0.6 cm^3 ionisation chamber placed on-axis in the optics hutch – it was shown before that the dose from such a chamber is proportional to the dose measured outside the optics hutch.

We show hereafter the results obtained in hybrid mode, the conclusions for the other modes being similar. Note that hybrid mode is a mode consisting of a (≈ 6 mA) single bunch and a (≈ 195 mA) 1/3rd fill bunch train. After top-up, the single bunch is cleaned. Figure 4 shows the measured dose-rates on-axis inside the optics hutch during 8 days of hybrid mode operation.

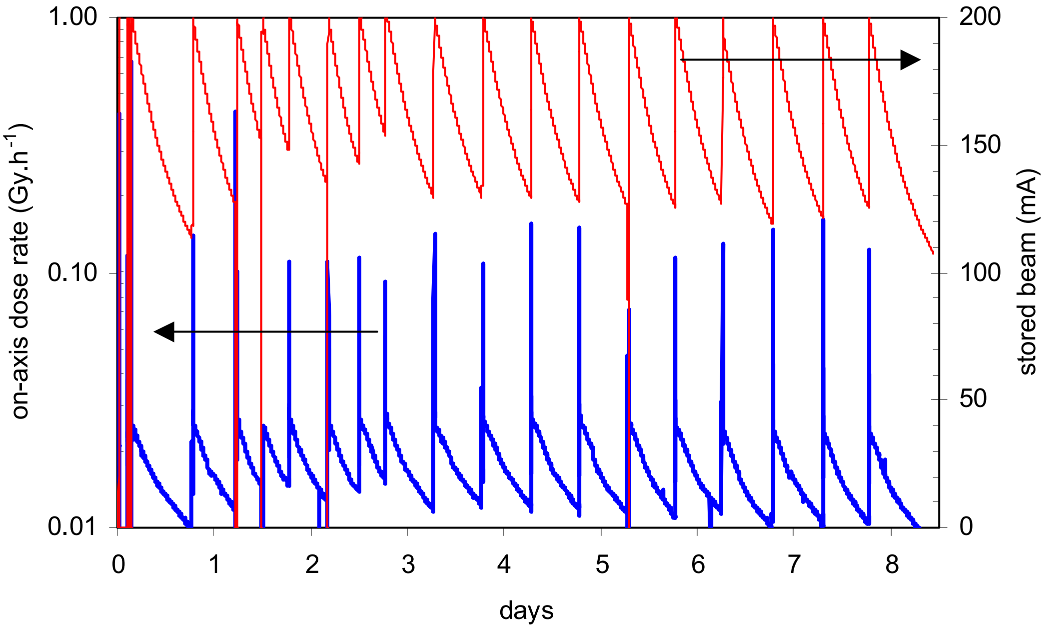

Figure 4: Measured on-axis dose-rates inside the ID6 optics hutch during 8 days of hybrid mode operation.

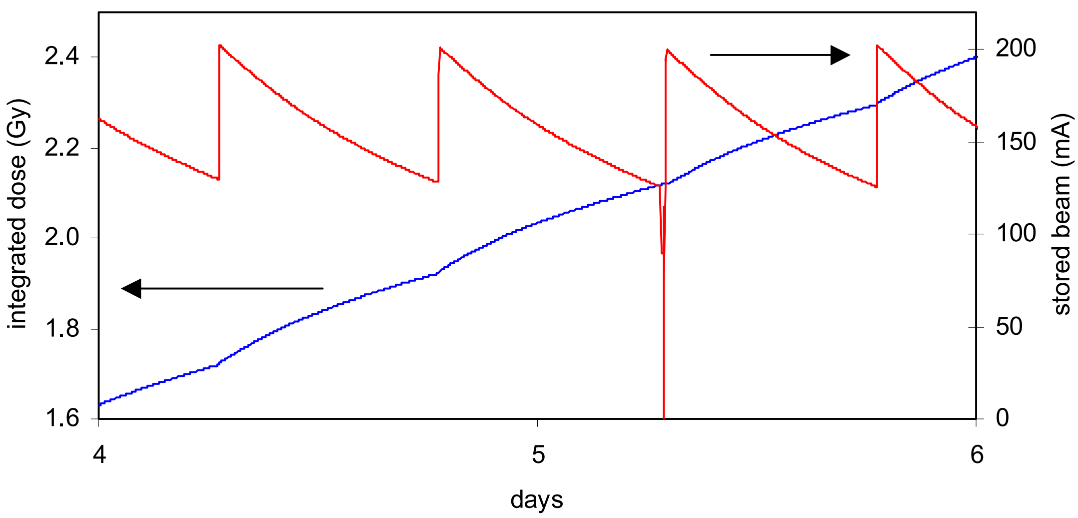

Figure 5: Integrated on-axis dose inside the ID6 optics hutch during 2 days of hybrid mode operation.

One sees the gas-bremsstrahlung contribution during beam decay, and the momentary increased dose rates during injection or following a beam trip. Figure 5 shows the integrated dose over two days during this period, clearly indicating that the contribution of the dose during injection to the total integrated dose is completely negligible. Details of the dose contributions during a typical top-up are shown in figure 6. We see that the dose due to the cleaning of the single bunch is extremely small. The cleaning uses a scraper located in cell 22. From the beam loss monitors we know that maximum beam losses during cleaning occur in cell 23 (ID23 is an undulator beamline with a front end similar to ID6). These losses are about 10 times higher than the losses during cleaning occurring in cell 6. This means that in 16-bunch dose rates during cleaning outside ID23 could be more than 100 times higher than those recorded for ID6 during hybrid mode cleaning. But even then, the integrated dose due to cleaning will be small. Injection with front ends open will therefore also be allowed during the “non standard” beam modes.

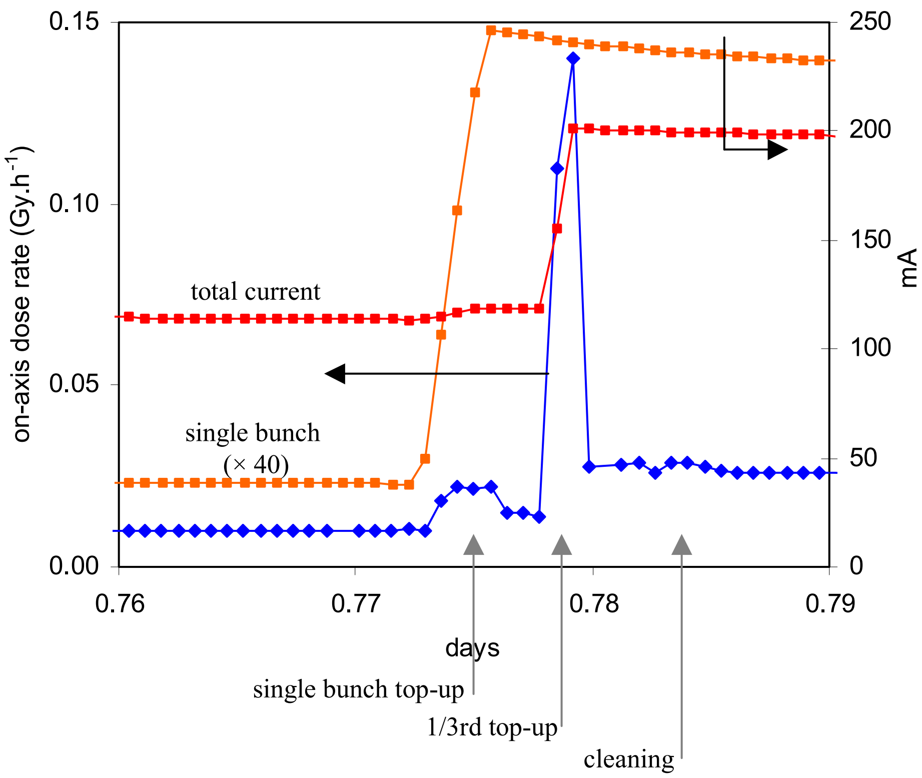

Figure 6: Dose-rate pattern during hybrid mode top-up.

5. Interlocked radiation monitors

We have chosen for the interlocked radiation monitors 50 litre ionisation chambers combined with Unidos electrometers from the company PTW. These monitors were selected because of their reliability, high sensitivity, large dynamical range and compatibility for pulsed radiation. The otherwise standard Unidos electrometers are equipped with an interlock relay, providing interlock contacts that open when the integrated dose exceeds a programmable set point. These interlocked contacts are integrated into the corresponding beamline personal safety system as explained later in this section.

Figure 7 shows a typical dose rate pattern that will be measured with these monitors. The measured dose rate is the sum of the background $\dot{H}_{back}$ and the scattered bremsstrahlung contribution $\dot{H}_{\gamma}$. As a conservative measure we will include the background contribution in our dose constraint. We also have to take into account the neutron contribution. From reference (2) we know that the neutron dose rate will be typically twice as high as the scattered bremsstrahlung contribution – the fact that the results in table 1 show a neutron dose 3 times higher than the photon dose is due to the fact that there is substantial photon attenuation in the lead block, more than in typical optical elements. The dose limit on the measured integrated dose for the interlock relays is therefore obtained in the following way.

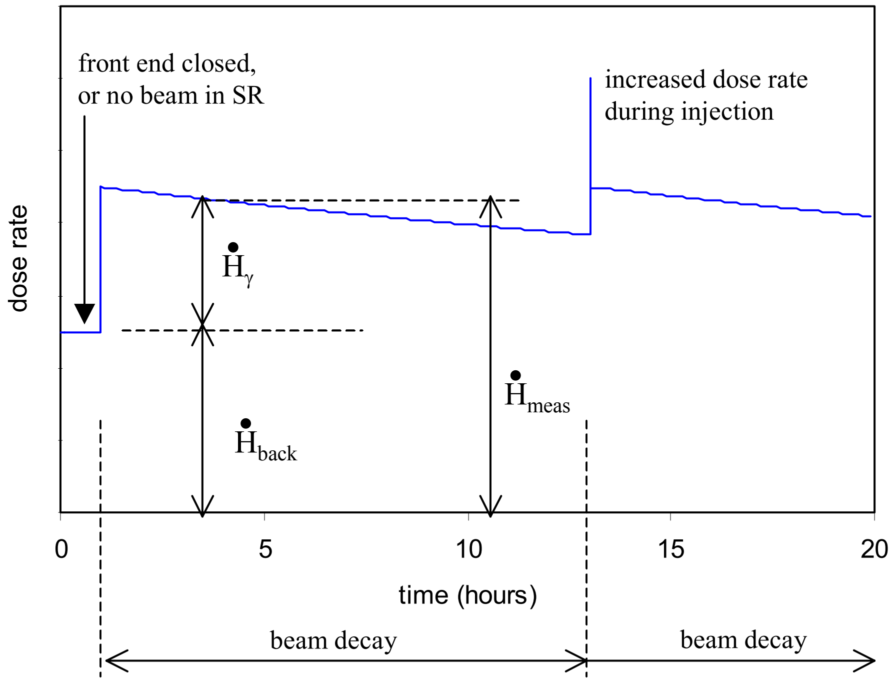

Figure 7: Typical measured dose rate pattern.

Our dose constraint limits the total integrated dose over 4 hours to 2 μSv, the derived dose limit for non-exposed workers:

$$\int_0^t \dot{H}_{total}\, dt < 2\ \mu Sv,\ t \le 4 \text{ hours}$$

with

$$\dot{H}_{total} = \dot{H}_{back} + \dot{H}_{\gamma} + \dot{H}_{n}$$

$$\dot{H}_{n} = 2 \times \dot{H}_{\gamma}$$

Thus:

$$\int_0^t \left(\dot{H}_{back} + 3 \times \dot{H}_{\gamma} \right) dt < 2\ \mu Sv,\ t \le 4 \text{ hours}$$

or

$$\int_0^t \left(3 \times \dot{H}_{back} - 2 \times \dot{H}_{back} \right) dt < 2\ \mu Sv,\ t \le 4 \text{ hours}$$

or finally

$$\int_0^t \dot{H}_{meas}\, dt < \frac{2 + 2 \times \int_0^{4h} \dot{H}_{back}\, dt}{3}\ \mu Sv,\ t \le 4 \text{ hours}$$

A typical value for $\dot{H}_{back}$ is 0.08 $\mu Sv.h^{-1}$, which then gives a dose limit of 0.88 μSv for the measured photon dose.

The integration of these new radiation monitors in the personal safety systems (PSS) is done in the following way. Figure 8 shows schematically the logic used until now in the machine and beamline personal safety systems associated with the storage ring injection.

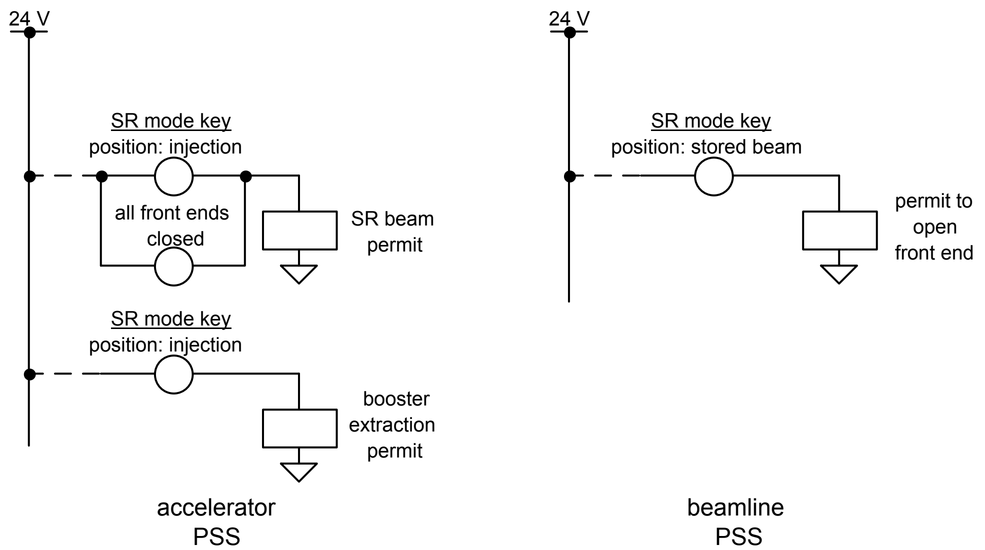

Figure 8: Logic used until now in the machine and beamline personal safety systems associated with the storage ring injection.

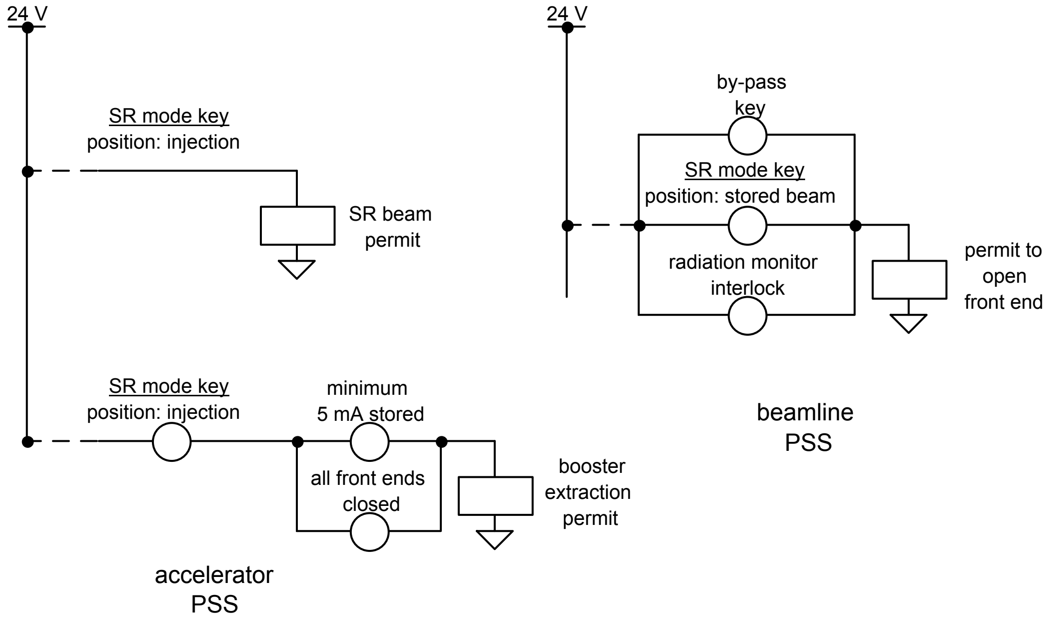

Figure 9: Logic used to implement injection with front ends open in the machine and beamline personal safety systems.

A PSS key located in the central accelerator control room is used to differentiate between injection mode and stored beam mode. When this key is in the position "stored beam" the front ends can be opened, while the booster extraction is blocked. When it is put in the position "injection" to allow the booster extraction all front ends are closed. The logic of the "SR beam permit" which raises the permits for the storage ring RF and for the linac equally guarantee that no injection is possible if not all front ends are closed.

The new corresponding PSS logic is shown in figure 9. The condition concerning the closing of the front ends is removed from the "SR beam permit". Booster extraction is still conditioned with the SR mode key, and injection with front ends open is allowed if minimum 5 mA are stored (via the interlock from the dedicated current monitors). The latter conditions guarantees that no injected beam could be accidentally directed into a beamline, due to an error in the storage ring beam optics. In the beamline PSS, the permit to open the front end during injection is given by the dose limit interlock from the dedicated radiation monitor. During stored beam conditions (booster extraction blocked) the active radiation monitor interlock is by-passed. In this case an alarm in the central control room will be generated if any of the interlocked monitors exceeds 75 % of the corresponding dose limit. This alarm will trigger an intervention of the Radiation Protection Group, and the necessary action will be decided after verification. The distinction between injection and stored beam conditions avoids unnecessary closing of a front end in case of a radiation monitor failure. During stored beam the dose outside a beamline can only increase slowly, leaving enough time for a manual verification before, if necessary, deciding to close the corresponding front end. Finally, inside every beamline PSS a local key is foreseen to by-pass the radiation monitor in case of a technical problem with the latter.

The installation and integration into the PSS of radiation monitors is scheduled for the winter shutdown 2002-2003. All 42 optics hutches will be equipped. Figure 10 shows one of the installed monitors.

Figure 10: Picture of one of the radiation monitors installed outside an optics hutch.

References

[1] P. Colomp, "Application de la directive Euratom/96/29 à l'ESRF, 1999, thesis, not published

[2] P. Berkvens & P. Colomp, Radiation measurements around ESRF beamlines, these proceedings