# Radiation measurements around ESRF beamlines

*P. Berkvens & P. Colomp*
*European Synchrotron Radiation Facility*

**Abstract**

*Over the last 2 years radiation levels around a number of beamlines have been continuously recorded, essentially to evaluate the vacuum conditioning of newly installed vacuum vessels or in-vacuum undulators in the corresponding straight sections of the storage ring. Scattered bremsstrahlung measurements were done using PTW 50 litre ionisation chambers, and some neutron measurements have been carried out using Apfel superheated drop detectors. A number of measurements have been done inside the optics hutch of the Machine/Safety diagnostics beamline, measuring the gas-bremsstrahlung intensity on axis with a small Farmer-type ionisation chamber. A number of relevant results are presented. The radiation levels inside and outside the beamlines are compared with readings from the beam loss ionisation chambers inside the storage ring. This allows a qualitative estimation of the relative contribution of gas bremsstrahlung to the dose levels around the beamlines compared to other, non-vacuum induced beam losses. Finally, radiation levels outside the beamlines are compared with those outside the storage ring.*

## 1. Introduction

The complete upgrade of the shielding of the optics hutches at the ESRF has been completed. The reasons for this upgrade were in the first place the new European legislation concerning radiation protection, and the upgrade of the storage ring with the installation of ID vacuum vessels with reduced vertical aperture. With the new European legislation the annual dose limits for non-exposed people is reduced from 5 mSv to 1 mSv. All people working at the ESRF are considered as non-exposed, and we want to maintain this policy with the reduced legal limits. On the other hand, increased vacuum pressures inside the reduced aperture ID vessels had caused a significant increase of bremsstrahlung radiation inside the beamlines. It was therefore necessary to improve the shielding of the optics hutches of the beamlines. Two solutions have been used: either the thickness of the sidewalls has been increased to 30 mm of lead, or the freeway next to the hutch has been integrated in the interlocked and searched area to increase the minimum distance a person could approach the hutch. In the mean time a significant R&D program on the ID vacuum vessels has also led to a dramatic improvement of the vacuum inside the straight sections, essentially due to the development of NEG coatings in these vessels. The upgrade of the shielding and the improvement of the vacuum vessel technology have resulted in a situation where, after a minimum period of vacuum conditioning, beamlines can operate within these new legal requirements. Nevertheless the radiation levels outside the optics hutches of ID beamlines are still essentially determined by the vacuum conditions in the straight sections. We will illustrate this with a number of radiation measurements carried out over the last two years.

## 2. Example 1: dose measurements outside the ID9 beamline

A series of measurements have been made during 2002 around the ID9 optics hutch. An in-vacuum undulator has been installed in the straight section of cell 9 at the beginning of the year. Due to technical problems it was removed during the 3rd run of 2002, and replaced by a straight vacuum vessel. Finally, the in-vacuum undulator was reinstalled for the 4th run. We measured the evolution of the dose rate outside the optics hutch throughout this period, to follow the vacuum conditioning of the newly installed undulator, the replacement vacuum vessel, and the reconditioning of the undulator after its reinstallation.

The upgrade of the shielding of ID9 was done by interlocking the freeway next to the optics hutch. The radiation measurements were done with a PTW 50 litre ionisation chamber, placed inside the interlocked freeway. This explains why the measured dose rates are temporarily higher than the 0.5 $\mu Sv \cdot h^{-1}$ derived limit for non-exposed workers, the area being inaccessible to people during operation.

In figure 1, as an example, we show the measured dose rates outside the ID9 optics hutch and the stored beam pattern during the first month of the 4th run of 2002, following the reinstallation of the in-vacuum undulator. One notices a clear decrease in the measured dose rates, due to the vacuum conditioning of the straight section. The spikes that are measured on the dose rate correspond to vacuum bursts. When the front end is closed, or when there is no beam in the storage ring, a background dose rate of 0.09 $\mu Sv \cdot h^{-1}$ is measured.

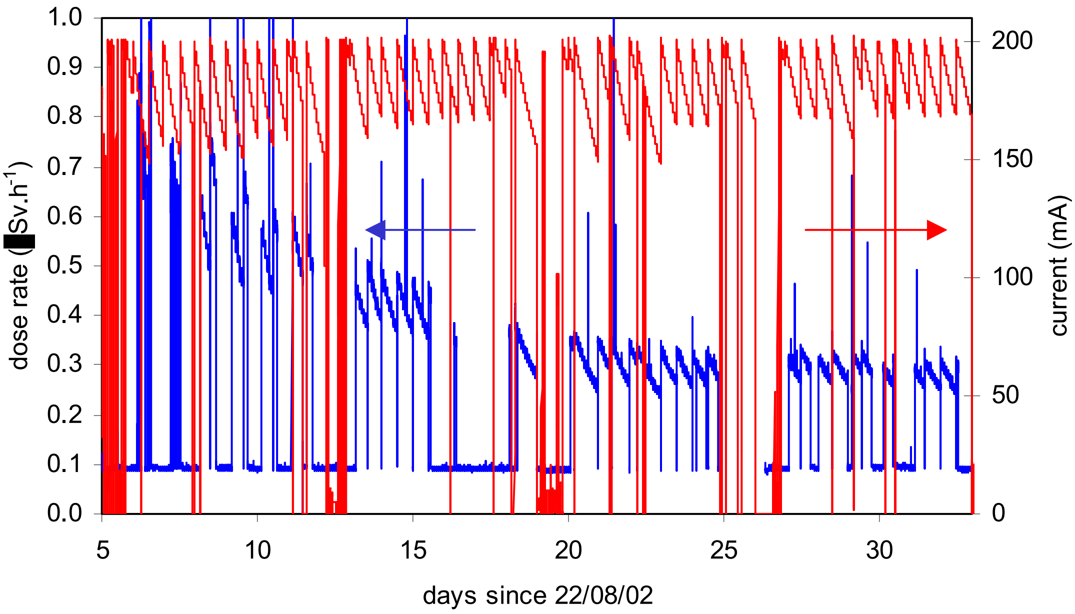


Figure 1: Measured dose rates outside the ID9 optics hutch (blue) and stored beam pattern (red) during the first month of the 4th run of 2002, following the reinstallation of the in-vacuum undulator.

The relation between the measured dose rates and the vacuum conditioning is clearly illustrated in figure 2, where for the same period we show the measured net dose rates, and the product of stored beam times the pressure in the straight section, the gas bremsstrahlung being proportional to the latter product. Since we do not know the exact value of the average pressure in the straight section we have used the pressure reading of the first penning gauge of cell 9, situated at the beginning of the 5 m ID free space. From figure 2 we see that at the beginning of the run the vacuum conditioning goes faster than the pressure reading from this gauge would indicate.

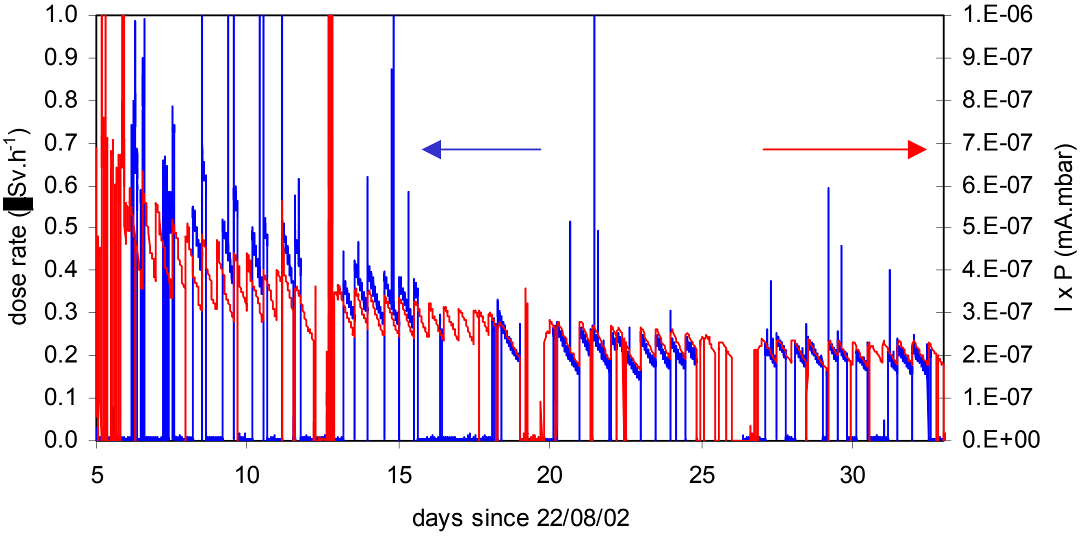


Figure 2: Measured dose rates outside the ID9 optics hutch (blue) and the product of the stored beam times the pressure reading from the first penning gauge (red).

At a given time, the pressure in the straight section will be proportional to the stored current, since the vacuum is dominated by synchrotron radiation induced outgassing. The dose rate will therefore be proportional to the square of the stored beam. The conditioning itself is done by the synchrotron radiation, and depends therefore on the stored beam. The vacuum conditioning of a straight section is therefore best shown by plotting the normalised measured net dose rates, i.e. the net dose rate divided by the square of the stored beam, as a function of the integrated electron dose, i.e. the integral of the stored current with time. The results of the measurements during the $1^{st}$, $3^{rd}$ and $4^{th}$ run of 2002 are presented in this way in figure 3. On a log-log scale, the normalised dose rate versus integrated electron dose is roughly a straight line, its slope indicating how fast the conditioning goes. The steps that are visible during this conditioning are due to the different filling patterns, since the dynamic pressure depends on the filling pattern.

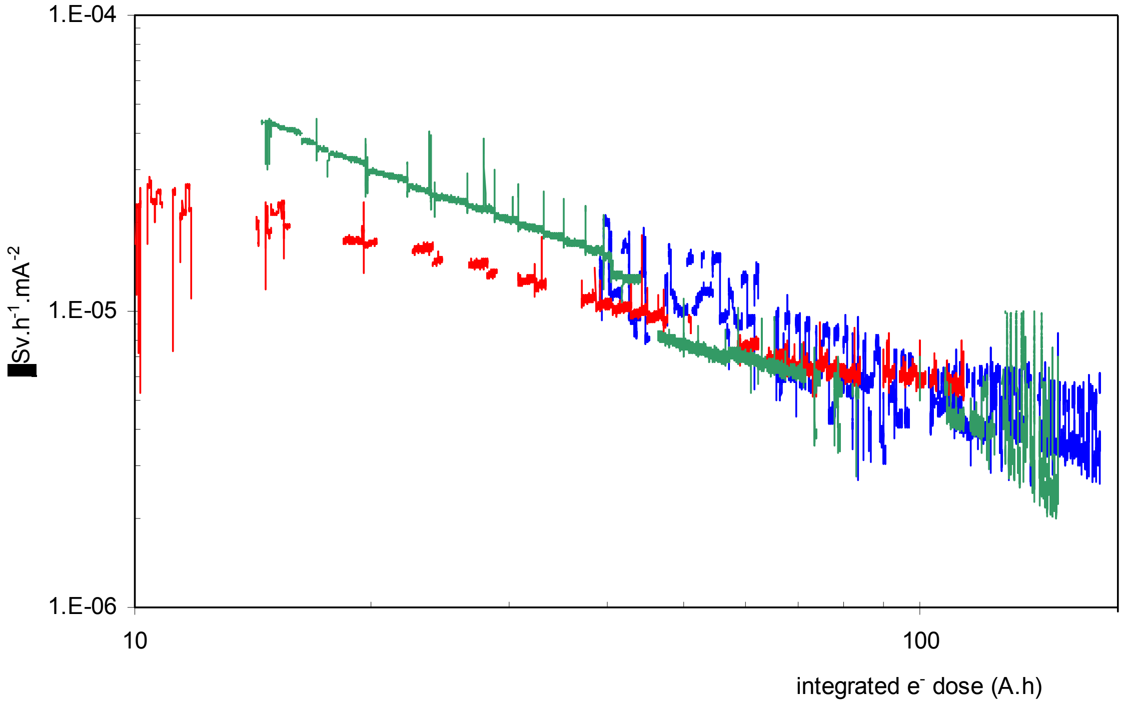


Figure 3: Normalised net dose rates measured outside the ID9 optics hutch versus integrated electron dose, during the first run (blue), third run (green) and fourth run (red) of 2002.

## 3. Example 2: bremsstrahlung measurements inside the ID6 optics hutch

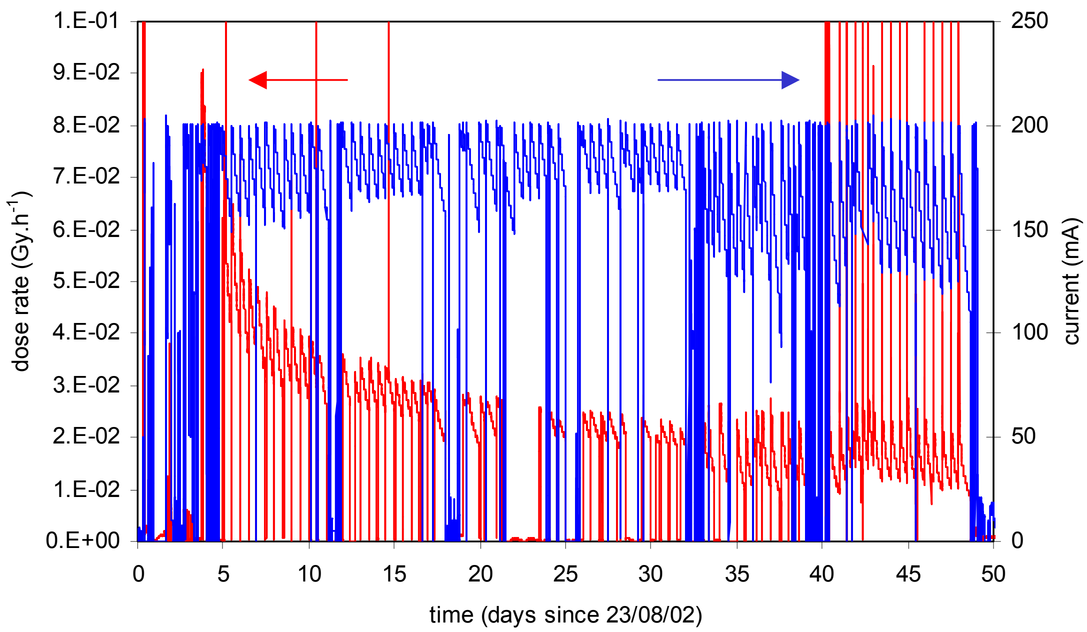


Figure 4: Measured on-axis dose rates inside the ID6 optics hutch (red) and the stored beam (blue) during the 4th run of 2002.

New ID vacuum vessels are installed in the straight section of cell 6, corresponding to the Machine/Safety diagnostics beamline. A 0.6 $cm^3$ ionisation chamber, placed on-axis, allows us to do (relative) bremsstrahlung measurements to follow the vacuum conditioning of the new vessel. During these measurements the gaps of the ID6 undulators are completely open. The ionisation chamber is shielded with 3 mm of lead to eliminate the upstream and downstream dipole synchrotron radiation. Figure 4 shows the measured dose rates during the 4th run of 2002, following the installation of a new 5 m long, 8 mm internal height, NEG coated stainless steel vessel. Note that at the end of the run, the front end of ID6 stayed open during the top-ups. Figure 5 shows the normalized dose rates versus integrated electron dose, showing a steady conditioning.

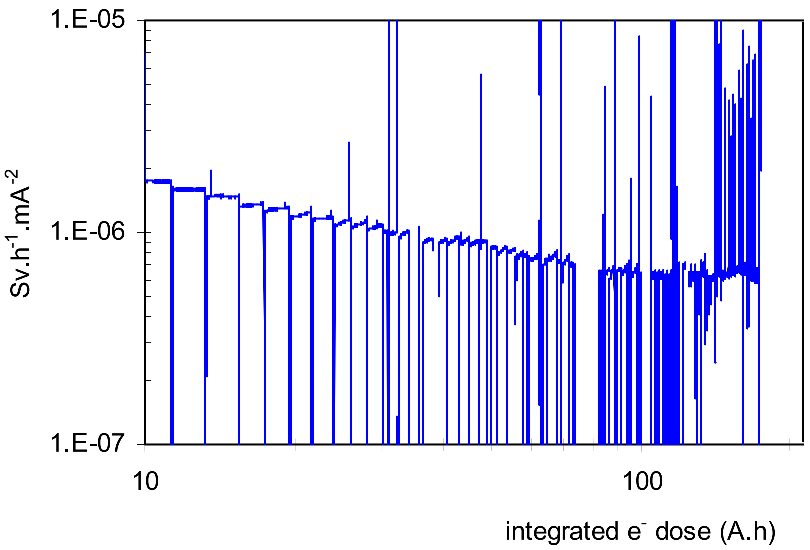


Figure 5: Normalised dose rates measured inside the ID6 optics hutch versus integrated electron dose, during the fourth run of 2002.

## 4. Comparison between the vacuum and non-vacuum contributions to dose rates outside an optics hutch

Scattered bremsstrahlung measured around beamlines will be essentially due to gas-bremsstrahlung produced in the corresponding straight section. However, bremsstrahlung originating from other electron interactions can also enter the beamlines, for instance bremsstrahlung produced by electron lost on the small gap ID vacuum vessels or in-vacuum undulators. At the ESRF the dose rates outside the beamlines are fortunately much less sensitive to this type of non-vacuum beam losses, in the sense that the same amount of electrons lost will cause much smaller dose rates. We will illustrate this with a typical measurement carried out on ID9.

A closer look at the dose rates measured with the unidos beam loss monitors inside the storage ring and the dose rates measured outside the optics hutch allows a comparison between the vacuum and non-vacuum contributions to the dose rates outside the beamlines. Figure 6 compares the dose rates measured inside cell 9 and outside the optics hutch of ID9, during a refill and a consequent gap change of the in-vacuum undulator. Initially the gap is at 10 mm, and with this wide gap the beam losses inside cell 9 are essentially due to vacuum. The beam loss monitor inside cell 9 reads 0.085 µSv $h^{-1}$ at 168 mA and 0.12 µSv $h^{-1}$ at 200 mA, respectively before and after the top-up, corresponding to a vacuum-induced dose rate of 3. $10^{-6}$ µSv·$h^{-1}$·$mA^{-2}$. The ionisation chamber outside the optics hutch reads 0.30 µSv $h^{-1}$ at 168 mA and 0.41 µSv $h^{-1}$ at 200 mA, respectively before and after the top-up, corresponding to a vacuum-induced dose rate of 1.05 $10^{-5}$ µSv·$h^{-1}$·$mA^{-2}$. We obtain a factor of 3.5 between the dose rates outside the hutch and inside the storage ring. After the gap change from 10 mm to 6.25 mm, the dose rate inside the storage ring increases with 1.13 µSv $h^{-1}$, whereas outside the optics hutch the increase is only 0.027 µSv $h^{-1}$. For these non-vacuum induced beam losses, we obtain therefore a factor of 0.024 between the dose rates outside the hutch and inside the storage ring. In this case the dose rates outside the optics hutch would be 150 times less sensitive to non-vacuum beam losses compared to vacuum induced beam losses.

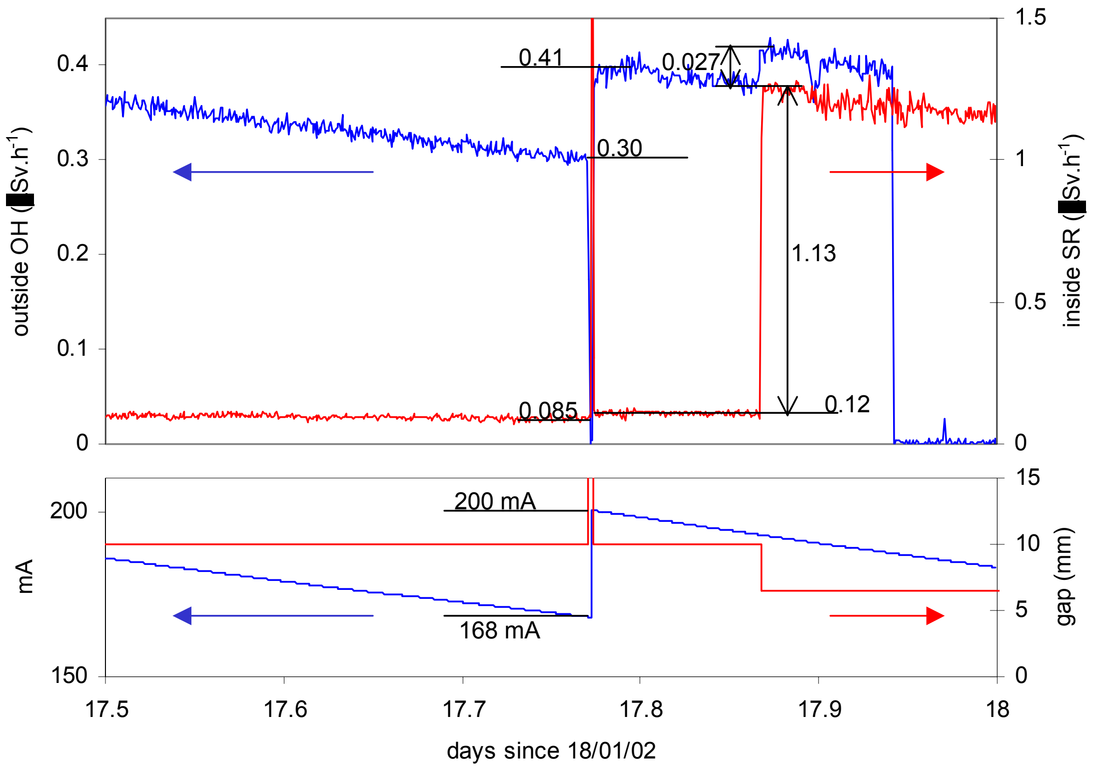


Figure 6: Comparison between vacuum and non-vacuum contributions to radiation outside the ID9 optics hutch: net dose rate outside optics hutch (blue, top), dose rate inside storage ring (red, top), stored beam (blue, bottom) and in-vacuum undulator gap (red, bottom).

Figure 7 shows the beam lifetime during the same period. The stepwise reductions in the lifetime are due to the interactions between the electron beam and the laser of the high-energy backward Compton scattering beamline (Graal). One notices, as was also discussed in reference [1], that the gap change does not alter the overall lifetime, but rather redistributes the local losses. The lifetime at 190 mA is 60 h, corresponding to a total beam loss of 8.8 $10^{-4}$ mA·$s^{-1}$ beam loss. The vacuum induced dose rate inside cell 9 corresponds to 0.108 µSv·$h^{-1}$, corresponding to a beam loss of 1.19 $10^{-5}$. mA·$s^{-1}$ when using the conversion factor of 1.1 $10^{-4}$ mA·$s^{-1}$·( µSv·$h^{-1}$)$^{-1}$ obtained in reference

[1] for the unidos beam loss monitors. The vacuum induced losses in cell 9 would therefore account for 1.35 % of the total losses. With the gap closed at 6.5 mm, an extra local beam loss of 1.24 $10^{-4}$ $mA \cdot s^{-1}$ is created in cell 9, raising the total local losses in cell 9 to 15 % of the total beam losses.

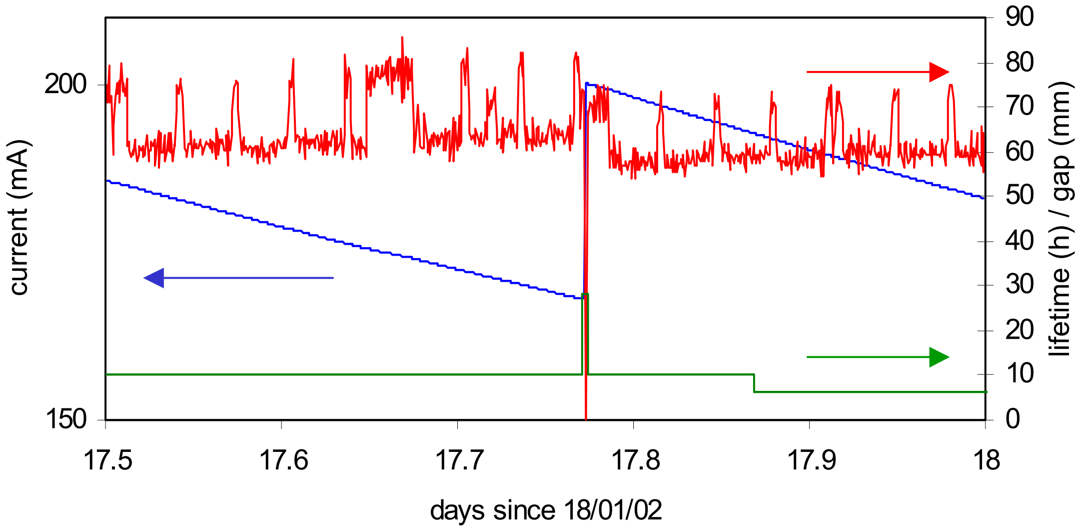


Figure 7: Stored beam (blue), lifetime (red) and ID9 in-vacuum undulator gap (green) during top-up and gap change.

## 5. Comparison between photon and neutron dose rates outside the beamlines

We have made a number of dose measurements outside the beamlines the compare the photon dose rates with neutron dose rates. Neutrons measured outside the beamlines are essentially produced by bremsstrahlung photons inside the optics hutches.

A first example is shown in figure 8. The photon dose behind the sidewall of the ID9 optics hutch was measured using a PTW 50 litre ionisation chamber and a Siemens EPD electronic dosimeter. The net integrated ambient dose equivalent is shown in the figure. The neutron dose was measured using two Apfel REMbrandt monitors, and the integrated ambient dose equivalent values are shown. We see that good agreement is found between the two photon measurements, and we see that the neutron dose is about a factor of two higher than the net photon dose. The zero increase in the integrated dose values in the middle of the period is due to the fact that the front end remained closed for several days.

A second example is shown in figure 9, concerning dose measurements outside the ID31 optics hutch. The photon dose was measured using Siemens EPD electronic dosimeters. One monitor was placed behind the 30 mm thick lead sidewall and one monitor was placed behind the 50 mm thick lead backwall. The net ambient dose equivalent H*(10) is shown in the figure. Two Apfel REMbrandt monitors were placed in the same positions.

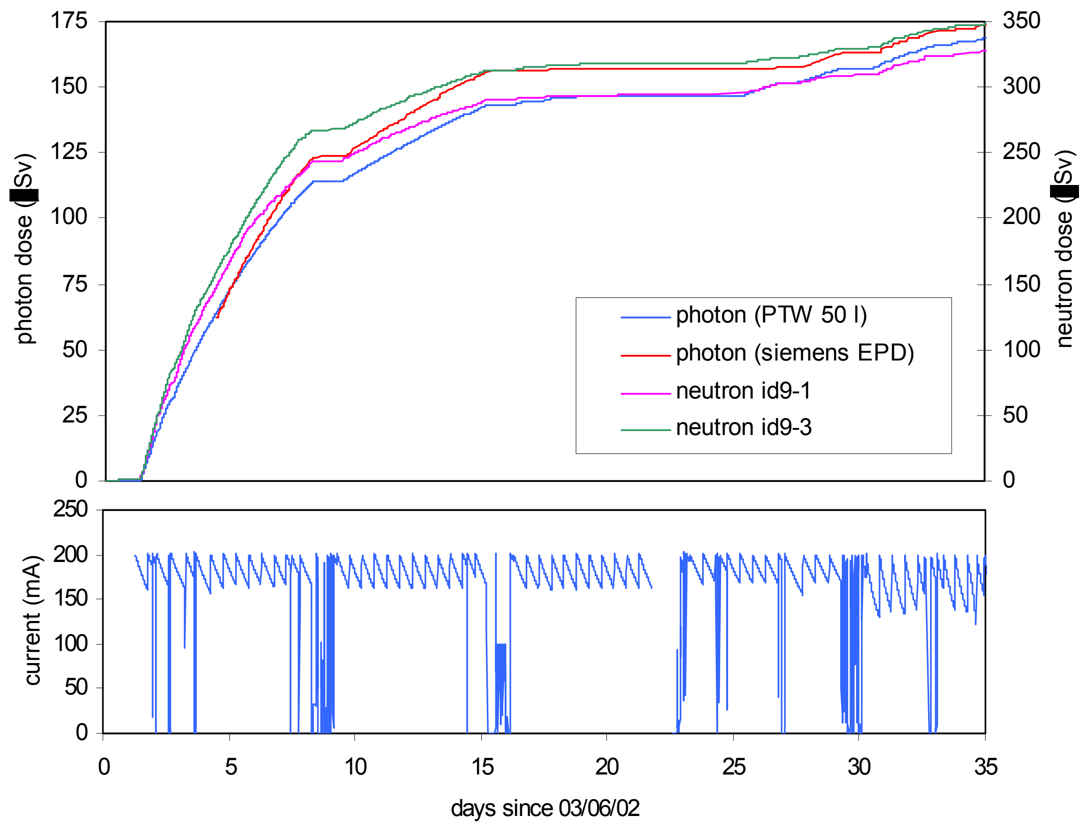


Figure 8: Neutron and photon dose outside the ID9 optics hutch during 5 weeks of operation.

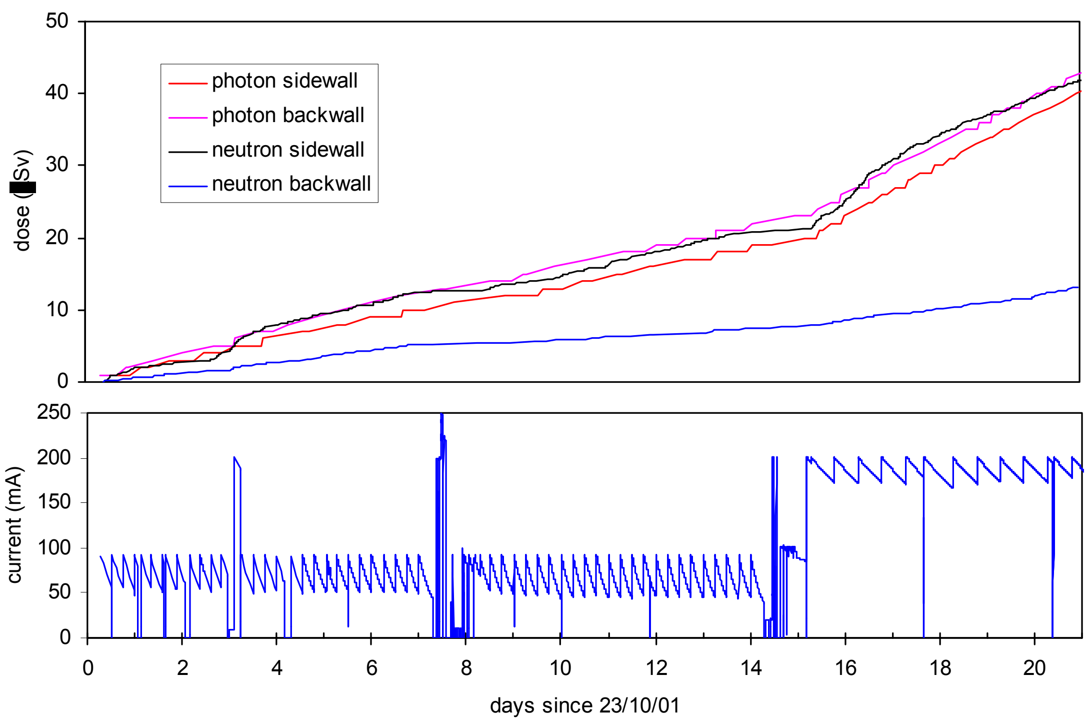


Figure 9: Neutron and photon doses measured behind the side wall and back wall of the ID31 optics hutch during 3 weeks of operation.

The integrated ambient dose equivalent values are shown in figure 9. We see that in this case the photon and neutron doses on the sidewall are essentially identical, whereas on the backwall the neutron dose is about a factor of two smaller than the photon dose.

## 6. Comparison between dose rates around beamlines and dose rates around the storage ring tunnel

It is interesting to compare dose rates outside the beamlines with dose rates outside the storage ring. During the last run of 2001 we measured photon dose rates simultaneously outside the ID31 optics hutch and on the roof of the storage ring tunnel above the corresponding straight section. The location chosen for the measurement on the storage ring tunnel roof corresponds to the position where the highest dose rates are measured along the given unit cell. Both measurements were done using PTW 50 l ionisation chambers. Outside the ID31 beamline the neutron dose rate is roughly equal to the photon dose rate (see figure 9), and previous radiation measurements showed a similar situation behind the concrete shield of the storage ring.

Figure 10 shows the net photon dose rate measured outside the beamline, during a few days of typical 16-bunch operation, while figure 11 shows the net photon dose rate measured on the storage ring roof, for the same period. We see that the dose rates outside the beamline are about six times higher than the dose rates outside the storage ring. During stored beam conditions, the main dose constraint will therefore come from the beamlines.

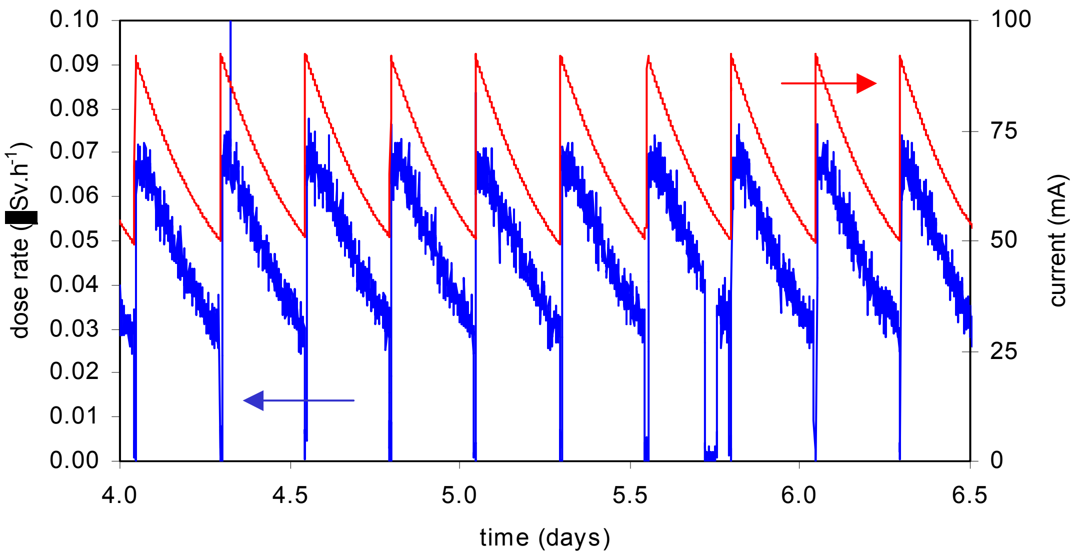


Figure 10: Photon dose rate outside the ID31 optics hutch (blue) and stored beam pattern (red) during 16-bunch operation.

During user operation the dose constraints at the ESRF will therefore primarily come from the beamlines. Outside the storage ring however, the integrated dose will come essentially from the accelerator studies. This is illustrated in figure 12, where the net integrated photon dose measured on the storage ring roof above cell 31 is shown, for the first run of 2002. We see indeed that the major part of the dose is integrated during the initial start-up period after the winter shutdown, and during the weekly machine study days during the run.

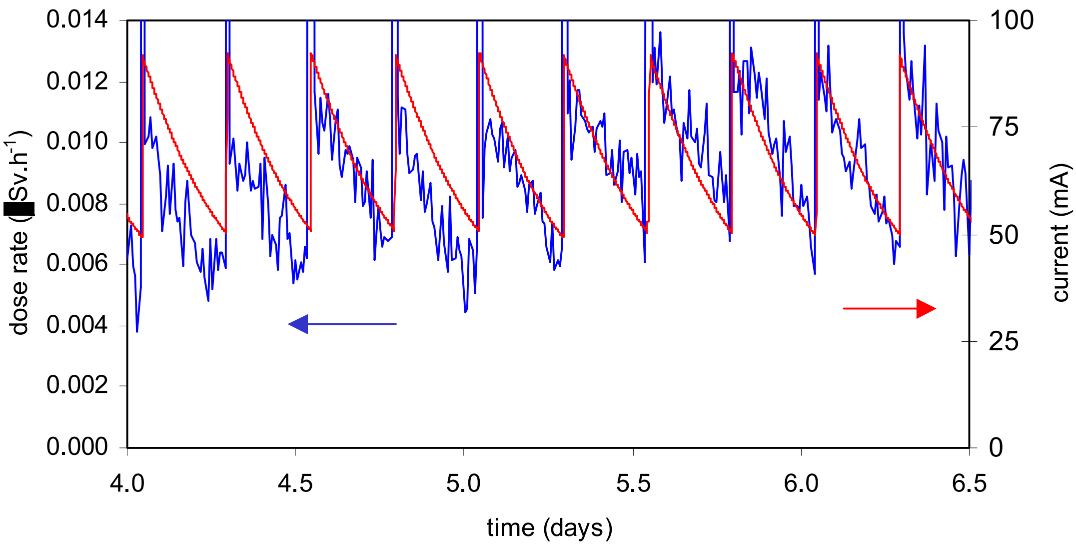


Figure 11: Photon dose rate above storage ring roof (blue) and stored beam pattern (red) during 16-bunch operation.

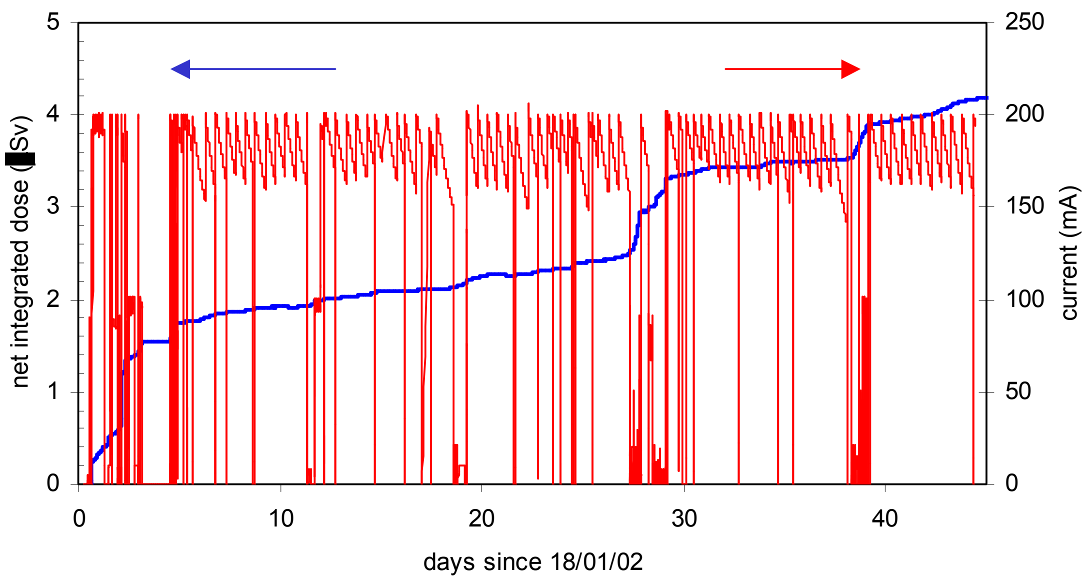


Figure 12: Net integrated photon dose above storage ring roof (blue) and stored beam pattern (red) during the 1st run of 2002.

## 7. Summary

The upgrade of the shielding of the optics hutches of the ID beamlines at the ESRF, together with the improved vacuum conditions in the straight section, due to the NEG coating of the 5 m long ID vacuum vessels, allow the operation of these beamlines, while respecting the new European radiation protection regulations. New ID vacuum vessels are characterised on the Machine/Safety diagnostics beamline using on-axis bremsstrahlung measurements. Afterwards, a minimum of reconditioning of the vacuum vessel on the actual straight section is required before the beamline can operate. Despite the improved vacuum conditions in the storage ring straight sections, photon dose measurements outside the beamlines show that dose rates are essentially determined by scattered gas-bremsstrahlung. Neutron dose rates outside the optics hutches can no longer be neglected, due to the reduction of photon dose rates with the increased lead thickness of the hutch walls. Therefore, if in the future a further shielding upgrade would be necessary, neutron shielding should be considered. Finally, during user operation the main dose constraints will come from the beamlines, rather than from the storage ring, where machine studies cause the major contribution to the integrated dose.

## References

[1] P. Berkvens & P. Colomp, Measurements of radiation levels inside the ESRF storage ring