NEW RADIATION MONITORING SYSTEM FOR THE ESRF

P.Berkvens, P. Colomp, ESRF, Grenoble, France

Abstract

Radiation measurements around the ESRF storage ring are discussed. Using the results of these measurements a new radiation monitoring system is described which must guarantee the compliance with the new European Radiation Protection guidelines, in order to maintain the classification of the Experimental Hall at the ESRF be a non-radiation area.

1 INTRODUCTION

The Experimental Hall of the ESRF has been declared a free area in terms of Radiation Protection laws. Access to the area is restricted in the sense that people must follow the necessary safety training before entering, but people are not considered as radiation workers and personal dosimetry is not compulsory. To comply with French law we must guarantee that annual integrated doses remain below 5 mSv. On a basis of 2000 working hours per year, it means that dose rates must not exceed 2.5 µSv/h.

The reasons for choosing this policy are:

- ALARA principle: ESRF actively implements this principle by providing the necessary shielding everywhere to reduce the integrated dose for people working around the accelerators and beamlines to very low values (< 1 mSv/year).
- Personal dosimetry: with over 2000 visiting scientists per year, the organisation of a personal dosimetry would be very impractical.

We can easily prove that we respect these maximum dose limits using standard dosimeters (film badges and TLDs).

The European Directive 96/29/EURATOM of 13/05/96 defines new Radiation Protection rules which, at the latest by May 2000, must be integrated into the national laws of each member state. Two points are of particular importance in the case of the ESRF:

- The annual dose limit for the public (non-exposed people) is reduced from 5 mSv to 1 mSv/year.
- The neutron quality factor is multiplied by 2.

The ESRF wants to maintain its Radiation Protection policy in the future. From our experience gained during several years of routine operation and from extensive specific radiation measurements, we feel confident that we will meet these new limits. However the main problem will be to prove that we comply with these new limits, because the present commercial dosimeters do not allow such low values to be measured. Therefore we have started to implement a new radiation safety system.

In this paper we present:

- a selection of radiation measurements around the storage ring;
- discussion of the measured values with theory;
- presentation of the proposed radiation monitoring system

2 RADIATION MEASUREMENTS

Three types of measurements have been carried out:

- Dose rates from local beam losses during injection, to localise and quantify worst case dose rates.
- Integrated doses during normal injection and during beam losses.
- Integrated doses over several days during routine operation.

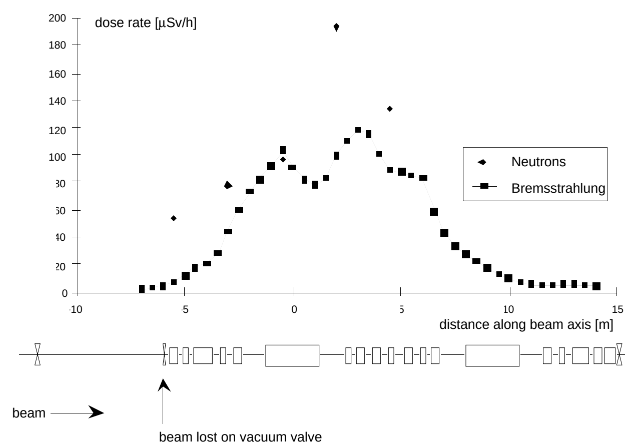

Figure 1: Dose rates outside the storage ring in case of a 6 GeV, 1 mA, 1 µs, 10 Hz beam injected and intercepted on a vacuum valve. The layout of one standard cell of the storage ring is shown.

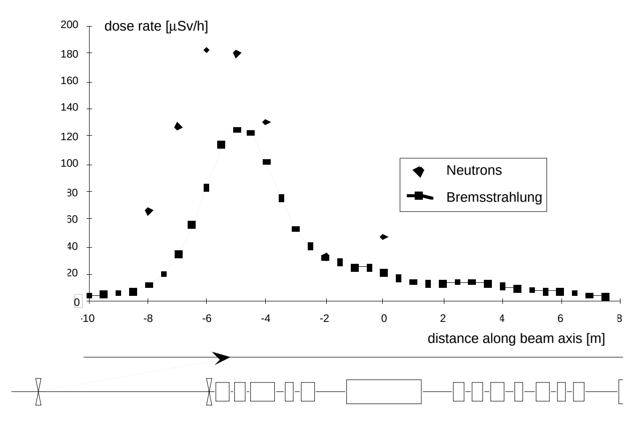

Figure 2: Dose rates outside the storage ring in case of a 6 GeV, 0.5 mA, 1 µs, 10 Hz beam injected and locally lost due to a vertical bump.

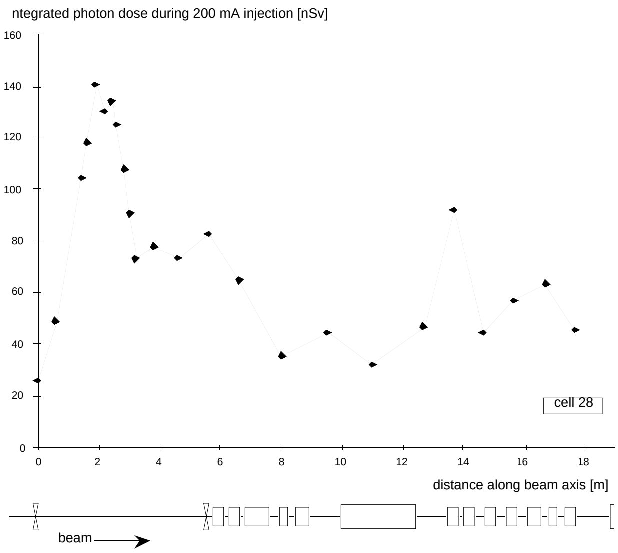

Figure 3: Integrated bremsstrahlung dose outside the storage ring for a 200 mA refill. The measurements are taken on a cell whose CV5000 vessel presents, apart from the septum, the most important horizontal limiting aperture.

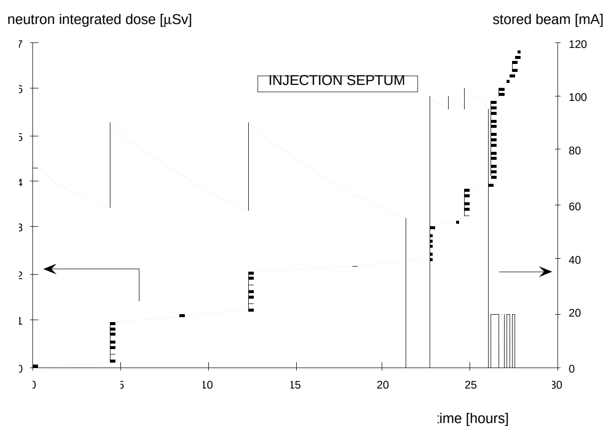

Figure 4: Integrated neutron dose outside the storage ring during 30 hours of operation. The first 21 hours correspond to User Mode Operation in 32-bunch mode (maximum current 90 mA), the last 9 hours correspond to Machine Dedicated Operation. Measurements were taken above the injection septum. One sees that the dose distribution comes essentially from injection. Note: this position corresponds to an interlocked area (no access during storage ring operation).

3 DISCUSSION

3.1 Typical dose rates outside storage ring

Figure 4 perfectly illustrates the radiation protection situation around the storage ring at the ESRF. Integrated doses are small and compliance with the new legal limits will cause no problem. However, the potential to produce much higher doses exists, and typically during Machine Dedicated Operation locally significant doses can be integrated. It is impossible to provide sufficient shielding to respect legal limits under ALL conditions, because this would require shield wall thicknesses making X-ray beamline installation impossible.

3.2 Maximum dose rates outside storage ring

Maximum dose rates outside the storage ring occur in case of local beam losses. From the measured values in figures 1 and 2, the following maximum dose rates are obtained (normalised to 1 kW beam loss).

Table 1 : Measured dose rates for local beam loss

radiation type	dose rate [mSv/h] loss on vacuum valve [normalised to 1 kW]	dose rate [mSv/h] vertical bump [normal. to 1 kW]
bremsstrahlung	2.0	5.0
all neutrons	3.2	10.0
ratio neutrons/photons	1.6	2.0

From the above values we can estimate the integrated dose that can be expected in case of a stored beam loss, in the worst case where the effective loss point would be localised in one cell, for a stored beam of 200 mA, 6 GeV (3.6 kJ):

Table 2: Integrated dose in case of beam loss

bremsstrahlung:	1.8 – 5 µSv
neutrons (Q= 10):	2.9 – 10 µSv

These values indicate that it is very important to avoid losing a stored beam locally around the storage ring. The best way to achieve this is to foresee a limiting aperture somewhere around the ring, forcing beam losses to occur on this collimator. The latter must be sufficiently shielded locally. Such a system is presently designed at the ESRF.

3.3 Comparison with theory

Source term models used in shielding calculations are based on the following formula:

$$\dot{H} = \sum_i \frac{F_{H_i} W e^{-X/\lambda_i}}{r^2}$$

with:

- $\dot{H}$ Dose equivalent rate, in $Sv \cdot h^{-1}$,
- W The primary beam loss rate, in kW,
- F_{H_i} Unshielded dose equivalent conversion factor, in $Sv \cdot h^{-1} (kW \cdot m^{-2})^{-1}$,
- X Shield wall thickness, in cm,
- λ_i Attenuation length for the ith radiation component, in cm,
- d Distance from the source to the dose point, in m.

Source terms and attenuation factors, proposed by A.H. Sullivan [1], are given in the table below.

Table 3: source terms and attenuation lengths

radiation type	90 deg. source term Sv/h/(kW m^{-2})	attenuation length ordinary concrete (2.3g/cm^3) [cm]
bremsstrahlung	50	21
n < 25 MeV	10	18
n 25 – 100 MeV	1.2	28
n > 100 MeV	0.36	43

To compare calculated values with measured values we use a value for d of 2.1 m and a value for X of 100 cm of ordinary concrete [2.3 g/cm^3]:

Table 4: Comparison between measured and calculated dose rates

radiation type	dose rate [mSv/h] 1 kW local loss values predicted from model	measured dose rate [mSv/h] vertical bump [normal. to 1 kW]
bremsstrahlung	97	5
n < 25 MeV	8.8	—
n 25–100 MeV	7.6	—
n > 100 MeV	7.8	—
total neutrons	24.4	10
ratio n/γ	0.25	2

The model gives a much higher value for the bremsstrahlung dose compared to the measured value. The two reasons for this are that the model assumes high-Z material, whereas in reality only medium-Z material is present (essentially iron) and that in reality the assumption of a real point source is not met, because the losses occur more or less over half a cell. The consequence of this is that contrary to the model predictions, the neutron dose outside the shield wall outweighs the photon dose by a factor of 2 (a factor of 4 with the new quality factor!).

4 PROPOSED RADIATION SAFETY SYSTEM

The purpose of the new radiation safety system is to limit the integrated dose over 4 consecutive hours, everywhere around the storage ring tunnel, thus guaranteeing the compliance with the future radiation protection law:

$$\int_{4\text{ hours}} \dot{H}_{\gamma+N} \quad < \quad 2\,\mu\text{Sv}$$

The system has two major components. The first component is an active interlock coming from a current monitor that measures the integrated charge injected into the storage ring. The maximum charge that can be injected during 4 consecutive hours is limited such that the radiation dose outside the storage ring tunnel, under normal machine conditions, will not exceed the legal limits. If the charge limit is reached, further injection is blocked for the remainder of the 4-hour period.

From figure 3 we see that at present the maximum total dose outside the storage ring tunnel integrated during an injection of 200 mA (= 0.6 μC) is 360 nSv. To limit the dose to $2.5 \times 4 = 10$ μSv per 4 consecutive hours, we therefore at present limit the allowed injected current to 16 μC / 4 hours. In the future we will have to further limit the dose over 4 consecutive hours to a value of 2 μSv. This will be done, by on the one hand reducing the dose per injection along the tunnel (avoiding local injection losses other than on the septum and on the shielded collimator), and, if necessary, on the other, by reducing the maximum injected charge per 4 hours.

From the results in table 1, we see that even with this limit on the injected charge we could still exceed legal dose limits in case of a steering problem during injection. Therefore the second component of the new radiation safety system will be a radiation monitoring system. Every cell of the storage ring will be equipped with a bremsstrahlung monitor and a neutron monitor, providing again an interlock to the injector in case the integrated dose in one of the cells exceeds legal limits during a 4-hour period.

The main characteristic of this monitoring system is the large dynamic range which is required from the detectors. Indeed the system must allow dose integration under two extreme conditions:

- small continuous dose rates during stored beam conditions (≈ 0.1 μSv/h)
- high pulsed dose rates during injection or beam losses (several 100 Sv/h during μs pulse)

Furthermore, the neutron detector must have a large energy range (thermal to > 50 MeV), which excludes the use of most commercially available neutron monitors.

Taking these general requirements into account the following detectors have been selected for the proposed radiation monitoring system.

Bremsstrahlung will be measured using 50 litre ionisation chambers (10 litre Ar pressurised at 5 bar, connected to Unidos electrometers. This equipment has been purchased from the company PTW Freiburg. One monitor per unit cell will be installed, on the storage ring roof, behind the fist dipole.

Neutrons will be detected using superheated drop neutron detectors from Apfel Enterprises (REMbrandt model AP2001), with 12 ml SDD-100 vials with a sensitivity of 7 bubbles per μSv (neutron quality factor = 10).

REFERENCES

[1] A.H. Sullivan, "A guide to radiation and radioactivity levels near high energy-particle accelerators", Nuclear Technology Publishing, 1992.