COMPARISON OF THE PERFORMANCE OF DIFFERENT INSTRUMENTS IN THE STRAY NEUTRON FIELD AROUND THE CERN PROTON SYNCHROTRON

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INTRODUCTION

A series of measurements with active neutron detectors was performed in selected locations around the CERN PS in 2011 and 2012. The instruments employed in the campaign, both commercial units and prototypes, are used for routine measurements at CERN or employed in the Radiation Monitoring System for Environment and Safety (RAMSES)(1). The attention was focused on the potential differences in the instrument readings due to dead-time losses that are expected to affect most of the commercial units in pulsed neutron fields. The measuring locations were selected on the basis of the expected time structure of the losses in order to carry out the measurements in different stray field conditions.

During the measurement campaign the proton beams used for the fixed target physics at the Super Proton Synchrotron were extracted from the Proton Synchrotron (PS) at 14 GeV using the continuous transfer technique. In the extraction phase, comparatively large losses are observed all around the PS. These losses are due to particles scattered by the electrostatic septum used to slice the beam. Figure 1 shows a scheme of the PS complex, which is composed of 100 combined-function magnets arranged in a lattice and interleaved by 100 straight sections.

The aim of the measurements was to evaluate the response of the instrumentation in three locations where the time structure of the losses is remarkably different and then to systematically intercompare their performances in a position where the stray field is extremely pulsed and intense, i.e. where pile-up effects and dead-time losses are expected.

INSTRUMENTATION

The instruments employed were the following: two extended range rem counters (LINUS(2) and Thermo FHT 762 Wendi-2), an extended range prototype detector called LUPIN(3), available in two versions (^{3}He and BF_3), specifically conceived for applications in pulsed neutron fields, three commercial rem counters (Studsvik 2202D, Berthold LB6411 and Thermo FHT 751 BIOREM) and two customised Centronic IG5 ionisation chambers [pressurised Argon (A20) and Hydrogen type (H20)]. A detailed description of the detectors as well as of their response functions can be found in refs (4,5).

MEASUREMENTS

The measurements were carried out in the following locations (Figure 1), where, from Monte Carlo simulations, it is known that the stray radiation field is dominated by neutrons:

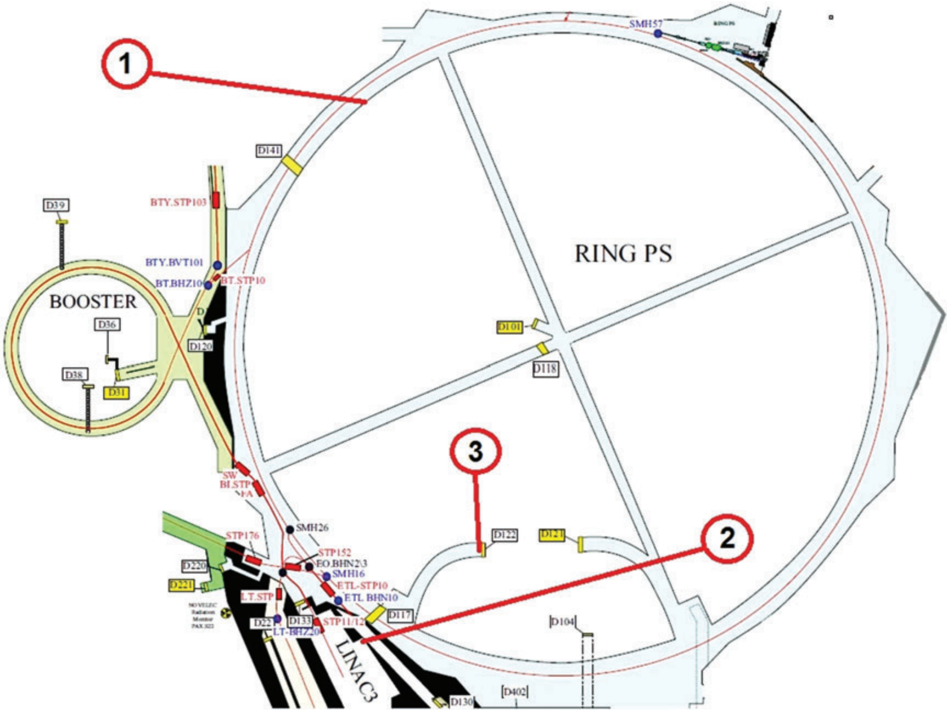

Figure 1. The PS accelerator complex. The red marks show the measuring locations discussed in the text.

(1) On Route Goward, close to SS42 (beam injection). Typical duration of the losses: 200–300 μs, smoothed by the ground shield (the street level is 6.4 m above the beam axis). Fraction of lost beam: 1–5 %. In SS42 the 1.4-GeV proton beam from the PS Booster is injected in the PS.
(2) Inside the LINAC 3 building, close to SS16 (beam extraction). Typical duration of the losses: 2.1 μs. Fraction of lost beam: maximum 1 %.
(3) At the beginning of the access tunnel to SS16 (beam extraction). Typical duration of the losses: 2.1 μs. Fraction of lost beam: 1 %. The area is located at the accelerator level, just before an interlocked door.

In addition to the losses typical of each measuring position, one has to consider that extraction losses are distributed on the overall PS and are always to be added up. These losses are due to the slicing process of the beam, which is extracted from the PS in five turns. Each of these turn lasts for 2.2 μs and the extraction losses have therefore a typical length of ~11 μs[(6)].The pulse repetition rate is 0.83 Hz, i.e. one pulse every 1.2 s.

A detailed description of the causes of the losses, as well as of the beam cycles that generate them can be found in ref. (7). The measurements were first performed in the three locations described above. A systematic intercomparison was then carried out in controlled conditions with six detectors at the beginning of the access tunnel to SS16.

Measurements in the three locations

The measurements were performed by installing the detectors in the three locations and by integrating the number of counts for a period varying between 0.5 and 6 h, according to the different $H^*(10)$ rate. The calibration factors applied to the counts were obtained in the CERN calibration laboratory with a PuBe source. The results of the measurements are shown in Table 1 with the statistical uncertainties. The uncertainty on the calibration (7 %, as reported in the calibration certificate of the source) was not taken into account since it is a correlated uncertainty. For location 3 (access tunnel to SS16) the results of the first series of measurements are not shown since they were quite contradictory due to the high $H^*(10)$ rate gradient in the area. The measurements were then repeated and the results of the systematic intercomparison are given later in the paper.

Intercomparison at the access tunnel to SS16

An intercomparison exercise was organised in at the beginning of the access tunnel to SS16 with six detectors. They were installed in six reference positions (1–6), and progressively interchanged to obtain a comparison of the responses in all the positions. The tunnel width is ∼4 m, while each position is 50 cm far from the adjacent one. Each measurement lasted 30 min and the attention focused on the integrated number of counts. The calibration factors applied were calculated by folding, when possible, the response function of the detector with the expected neutron spectrum in the area as obtained via FLUKA[8,9] Monte Carlo simulations[10] (see Figure 2).

Otherwise, the calibration factor obtained in the CERN calibration laboratory with a PuBe source was used. To normalise the results obtained in the measurements, expressed in integrated $H^*(10)$, two sources were employed: (1) the integrated proton fluence in the PS, as derived from TIMBER[11], a Java interface that allows obtaining data on the operation of the CERN accelerators in terms of setting, particle fluence and beam intensity; (2) the data, expressed in integrated $H^*(10)$, recorded by a RAMSES[1] station present in the area. The second source of normalisation is useful in the case of non-constant beam losses during the measurements; otherwise it can be used as cross-check normalisation. Tables 2 and 3 show the normalised results. The uncertainties are given as sum of two components: the statistical one and the positioning one (5 %).

Figures 3 and 4 show the plot of the results as normalised with both methods. When not visible, the uncertainty bars are smaller than the marker size.

Table 1. Results of the measurements expressed as integrated $H^*(10)$ in nSv, with uncertainties in parenthesis.

Route Goward (beam injection)			
LINUS	LUPIN ^{3}He	2202D	
2310 (46)	2385 (26)	1465 (38)	
LINAC 3 (beam extraction)			
LINUS	Wendi-2	LUPIN ^{3}He	LB6411
322 (17)	327 (18)	326 (9)	240 (13)

DISCUSSION

Measurements in the three locations

Table 1 shows that in location 1 (Route Goward) the results of the extended range rem counters, i.e. LINUS and LUPIN ^{3}He, are consistent within their uncertainties, while 2202D measures ∼40 % less. As expected, due to the relatively long and smoothed time structure of the beam losses, the results are not affected by dead-time losses. This is confirmed by the fact that LUPIN ^{3}He and LINUS, which work with different electronics, measure approximately the same $H^*(10)$ value. The underestimation of 2202D can be explained by its low sensitivity for neutron energies >20 MeV, while the expected neutron spectrum in the area is characterised by a peak at 80 MeV, due to the primary spallation process[7].

In location 2 (LINAC 3 building) the two categories of instruments (conventional and extended range rem counters) show different readings, as expected from their response functions. LINUS, Wendi-2 and LUPIN ^{3}He measure similar $H^*(10)$ values, which are coherent with the value obtained via FLUKA simulations, while LB6411 underestimates by 30 %. This is due to the expected neutron spectrum in the

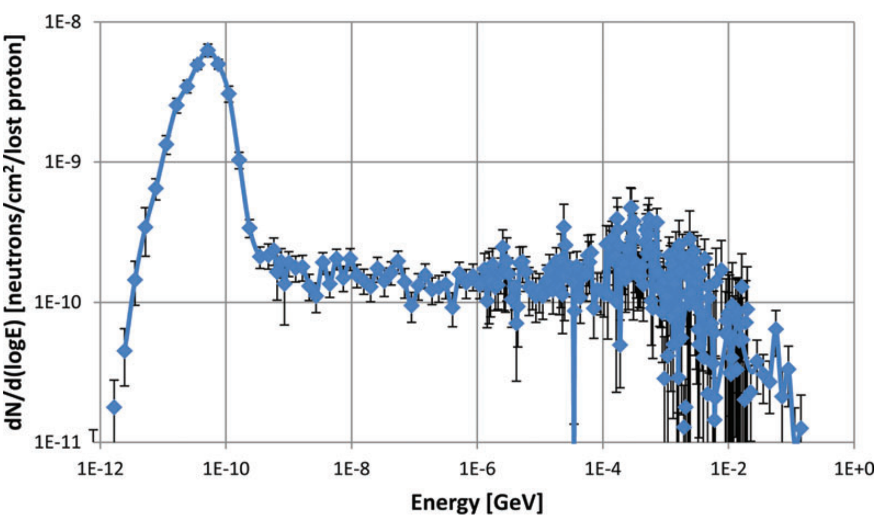

Figure 2. The plot of the neutron spectrum expected at the access tunnel to SS16 as obtained via FLUKA simulations.

Table 2. Results of the intercomparison measurements, as normalised to the $H^*(10)$ integrated by the RAMSES[1] station, expressed as absolute ratios, with uncertainties in parenthesis.

Detector	Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6
LINUS	36.0 (2.7)	39.7 (3.0)	40.6 (3.1)	36.0 (3.4)	41.6 (3.1)	38.1 (3.3)
LUPIN BF_3	104.9 (7.1)	134.2 (8.4)	149.1 (8.2)	145.9 (9.2)	139.5 (9.4)	135.7 (8.4)
H chamber	90.7 (6.1)	122.3 (8.3)	125.3 (8.8)	128.0 (9.0)	128.3 (8.3)	123.3 (8.4)
Ar chamber	97.3 (5.0)	130.6 (6.2)	147.8 (6.4)	160.1 (6.2)	154.4 (6.1)	157.1 (5.8)
BIOREM	67.2 (9.2)	90.3 (11.7)	89.8 (12.4)	86.4 (13.1)	86.6 (12.7)	83.7 (12.5)
Wendi-2	40.3 (2.7)	45.6 (3.3)	45.0 (3.4)	47.8 (3.4)	46.8 (3.3)	46.0 (3.0)

Table 3. Results of the intercomparison measurements, as normalised to the integrated proton fluence in the PS, expressed in nSv per 10^{13} protons, with uncertainties in parenthesis.

Detector	Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6
LINUS	9.4 (0.6)	11.6 (0.7)	10.6 (0.7)	12.4 (0.8)	10.4 (0.7)	10.9 (0.7)
LUPIN BF_3	26.3 (1.5)	34.7 (1.9)	37.0 (2.1)	36.5 (2.0)	39.6 (2.2)	31.9 (1.8)
H chamber	21.7 (1.3)	29.3 (1.7)	34.8 (2.0)	38.6 (2.2)	31.2 (1.8)	33.1 (1.9)
Ar chamber	25.8 (1.2)	36.3 (1.3)	36.2 (1.3)	37.2 (1.4)	40.2 (1.5)	43.4 (1.3)
BIOREM	19.8 (2.0)	23.0 (2.7)	23.2 (2.6)	24.8 (2.7)	26.8 (2.9)	22.0 (3.1)
Wendi-2	11.6 (0.7)	12.6 (0.7)	13.5 (0.8)	12.5 (0.7)	12.0 (0.7)	11.9 (0.7)

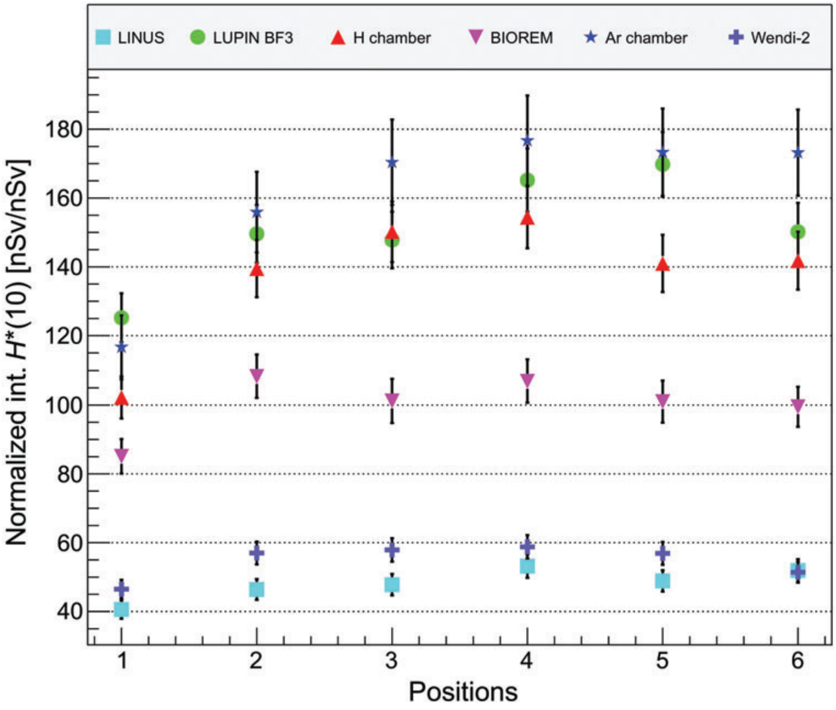

Figure 3. Results of the intercomparison, as normalised to the $H^*(10)$ integrated by the RAMSES[1] station, expressed as absolute ratios.

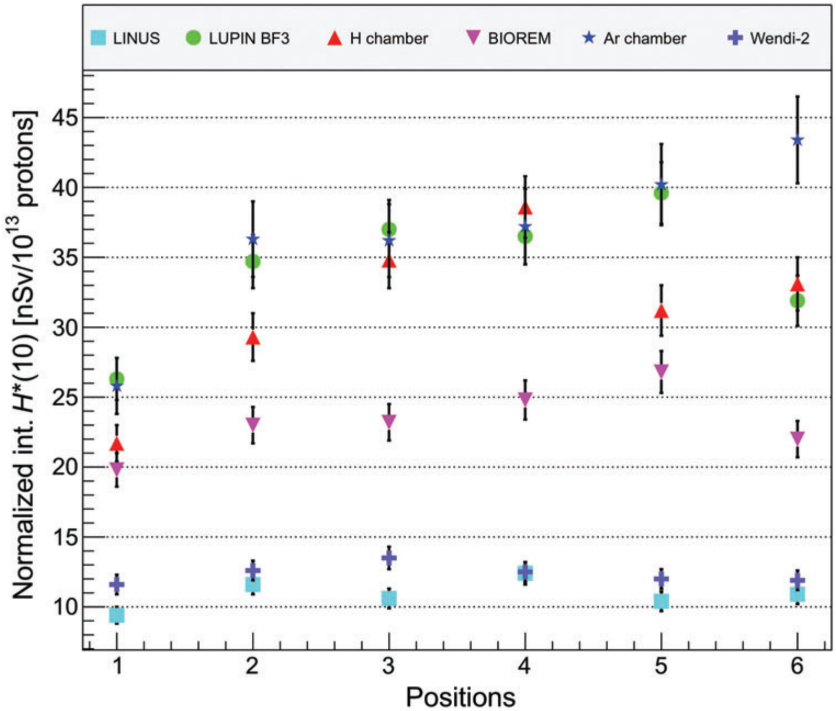

Figure 4. Results of the intercomparison, as normalised to the integrated proton fluence in the PS, expressed in nSv per 10^{13} protons.

area, whose part >20 MeV is of some importance. It can be assumed that the acquisitions were not affected by dead-time losses due to the low $H^*(10)$ rate in the area that did not produce pile up effects in the detectors.

Intercomparison at the access tunnel to SS16

From Figures 3 and 4 the detectors employed in the measurements can be divided in three classes: (1) the two ionisation chambers and LUPIN BF_3; (2) BIOREM and (3) LINUS and Wendi-2. The reading of the first three detectors agree well amongst them within the range of uncertainty and are coherent with what expected from FLUKA simulations (i.e. 20–40 nSv per 10^{13} protons); the BIOREM underestimates by 30 %; the last class of detectors underestimates by 65 %. This is explained by dead-time losses, which are higher in the last classes of detectors, characterised by a dead-time of ~2 µs, while the BIOREM has a dead-time of ~1 µs.

It can also be noticed that there is a slight difference in the measured $H^*(10)$ values between the six reference positions, which is a confirmation of the high $H^*(10)$ rate gradient in the area. From the comparison between the two plots one can also see that the data normalised to the $H^*(10)$ integrated by the RAMSES[1] station are much more stable than the data normalised to the PS proton fluence. This is probably due to the fact that the fraction of lost beam did not stay constant during the measurements.

CONCLUSIONS

The analysis of the results obtained in the three locations and during the intercomparison at the access tunnel to SS16 shows that:

(1) conventional rem counters (Berthold LB6411 and Studsvik 2202D) underestimate $H^*(10)$ by ~30 % with respect to the extended range rem counters and the FLUKA expected value, due to their low sensitivity for neutron energies >20 MeV, when exposed in locations where the beam losses in the PS produce high-energy stray fields;
(2) extended range rem counters (LUPIN, LINUS and Wendi-2) agree well amongst them and with the FLUKA expected $H^*(10)$ value when exposed in a non-pulsed high-energy stray field;
(3) all the rem counters apart from the LUPIN (LINUS, Wendi-2, BIOREM) showed important dead-time losses when exposed to pulsed neutron stray fields that lead to a consistent underestimation

of $H^*(10)$, from 30 % up to 65%. This is due to dead-time losses that are higher in the detectors characterised by a higher dead-time;

(4) ionisation chambers readings agree with the range of uncertainty and with the FLUKA predictions. These detectors are not affected by dead-time losses and their reliability is high even when employed in an intense pulsed neutron field;

(5) LUPIN showed results coherent with the $H^*(10)$ values as obtained via FLUKA simulations and did not show underestimation of $H^*(10)$ in all the measurement locations, proving its ability to efficiently withstand very intense pulsed fields.

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