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Technical Note

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Experimental proposal

Test of radiation protection instrumentation in HiRadMat

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Abstract

The knowledge of the response of radiation protection detectors in pulsed fields is very important, since this is a typical condition often encountered with stray radiation fields around particle accelerators at CERN and elsewhere. This document presents a proposal for testing a prototype detector and commercial instrumentation in use with the RAMSES monitoring system, due to the unique conditions that can be found in the HiRadMat facility. These tests can be extended to include instrumentation in use at other laboratories, both commercial devices and prototype units, and become an intercomparison benchmark exercise. Additional measurements include Bonner Sphere Spectrometry (BSS) measurements to verify experimentally the neutron spectra and ambient dose equivalent rates simulated by FLUKA inside HiRadMat.

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1. Scientific motivation

The need of radiation detectors capable to efficiently measure in pulsed neutron fields is attracting widespread interest in domains such as radiation protection and beam diagnostics in accelerators. Numerous investigations have focused on the development of detectors specifically designed to work in pulsed fields [1-4]. It is in fact well-known that conventional active detectors generally suffer from dead-time effects and have strong limitations in these conditions [5-6]. This is a major issue at particle accelerators including CERN machines, around which neutron and gamma pulsed fields are present due to beam losses in accelerators and beam line elements, or around targets and beam dumps.

Some of the instruments in use for routine measurements by the CERN/RP group were tested in February 2012 at the HZB (Helmholtz Zentrum) in Berlin in the framework of an intercomparison organized by the EURADOS Working Group (WG) 11. The detectors were tested in a prompt mixed radiation field. They were placed at 1 meter from a W target bombarded by a pulsed 68 MeV proton beam.

As expected, most of the instruments showed a severe underestimation of the neutron ambient dose equivalent, H*(10). Figure 1 shows the data acquired with a Studsvik rem counter of the RP group.

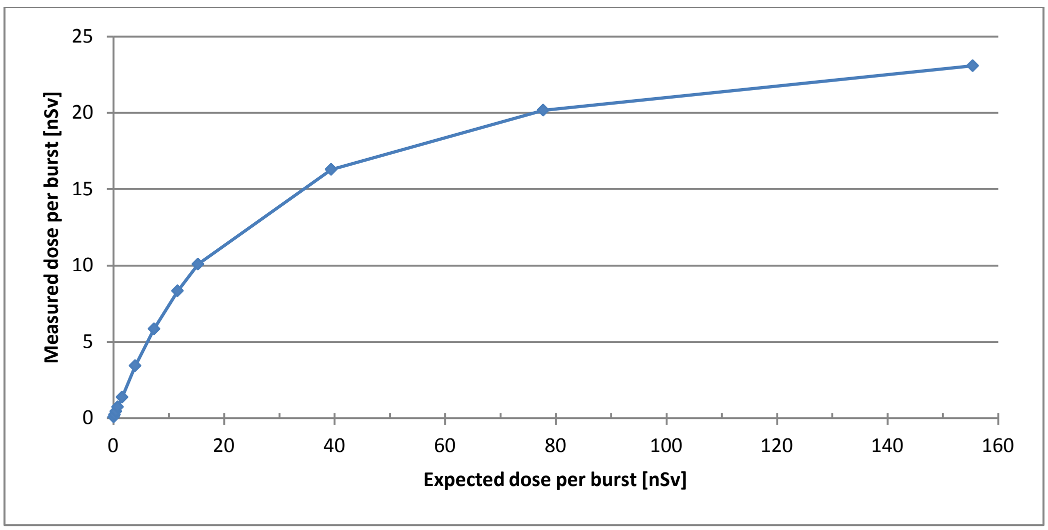

Figure 1 - Data acquired with the STUDSVIK 2202D at the HZB.

The instrument shows a good linearity up to a few nSv/burst (burst duration 1-10 μs). At 10 nSv/burst it starts underestimating the ambient dose equivalent and this underestimation becomes severe for doses higher than a few tens of nSv/burst. This same behaviour was noticed for most of the other commercial detectors tested in the same experiment.

Among the other instruments employed at the HZB, a prototype detector (LUPIN [7]) was also tested. LUPIN is a wide dynamic range neutron monitor using either a BF_3 or ^{3}He proportional counter, which operates in current mode and has a front-end electronics based on a logarithmic amplifier. This allows a measurement capability ranging over many decades of burst intensity. The results obtained in Berlin were very promising (Figure 2).

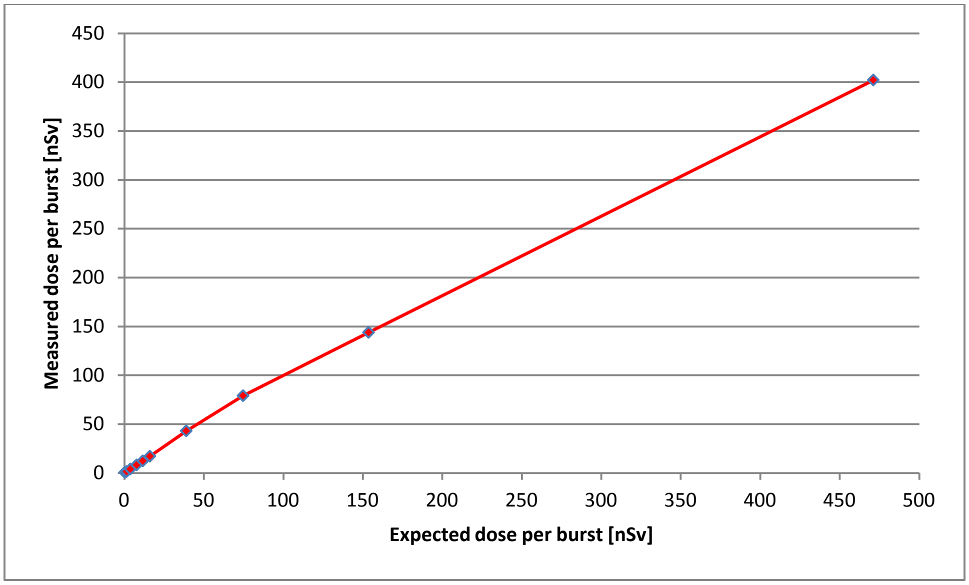

Figure 2 - Results obtained with the LUPIN prototype at the HZB

The response of the detector is almost linear up to 470 nSv/burst and the underestimation of the dose is very low. It is negligible up to 150 nSv/burst and less than 20% at 470 nSv/burst. Measurements with doses per burst higher than 470 nSv/burst were not possible due to technical constraints of the accelerator. In addition, it would have been interesting to investigate the detector behavior with narrower intensity steps, but this was not possible due to time constraints and for reasons related to the operation of the accelerator.

The CERN detectors tested in the EURADOS intercomparison were: Studsvik 2202D, Thermo BIOREM, Thermo RadEye, LINUS. The detectors used for RAMSES (the Radiation Monitoring System for the Environment and Safety [8]) could not be tested because the Hydrogen and the Argon chambers could not be shipped to Berlin. The only opportunity to test these chambers will be during a dedicated measurements campaign at CERN and HiRadMat is the best place where to perform such tests.

2. Proposal for a HiRadMat experiment

2.1. Monte Carlo simulations

FLUKA [9-10] Monte Carlo simulations were carried out to calculate the neutron field in HiRadMat [11]. A top-view of the facility is shown in Figure 3. A complete model of the tunnel structure as well as models of the beam and experimental equipment that exist in the area has been used [12] in the simulations. In the simulation scenario, a beam of protons with 440 GeV/c momentum is impinging directly on the beam dump. The ambient dose equivalent (expressed in mSv/primary) and the dose equivalent due to neutrons only, are shown in Figure 4 and Figure 5, averaged over the height of the tunnel.

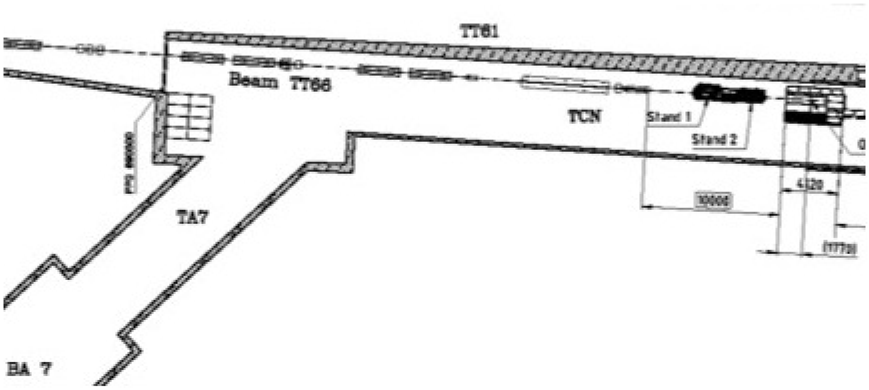

Figure 3 – Top-view of the HiRadMat facility

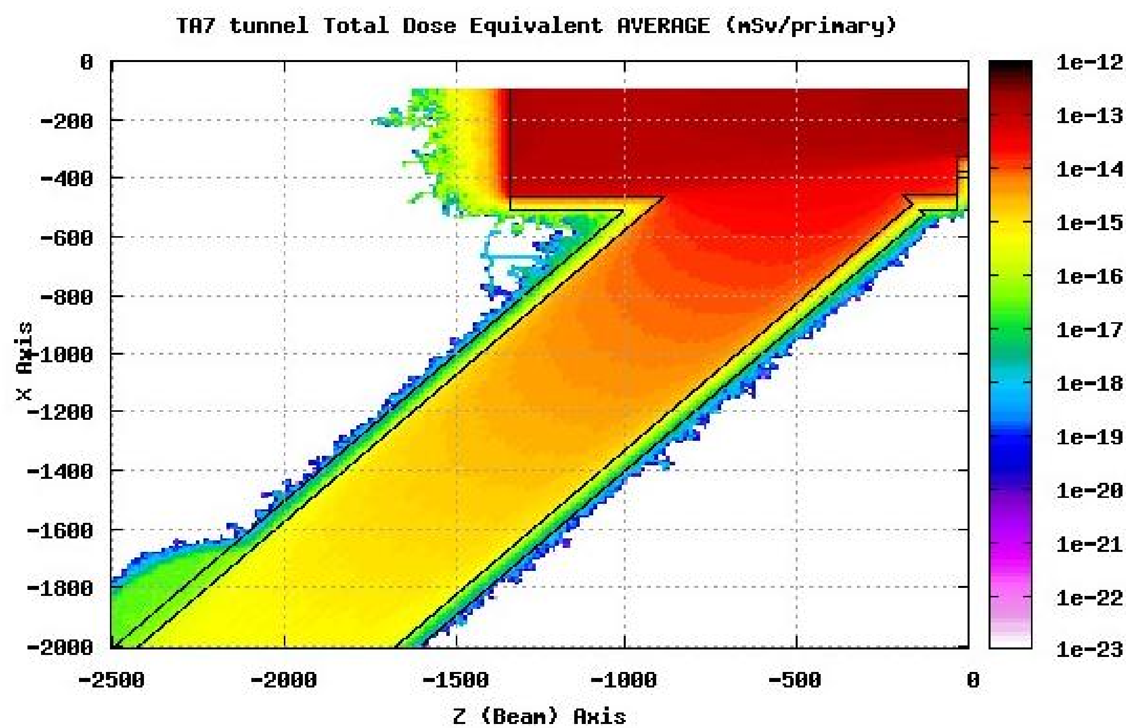

Figure 4 – Results of FLUKA simulations of the total ambient dose equivalent per primary.

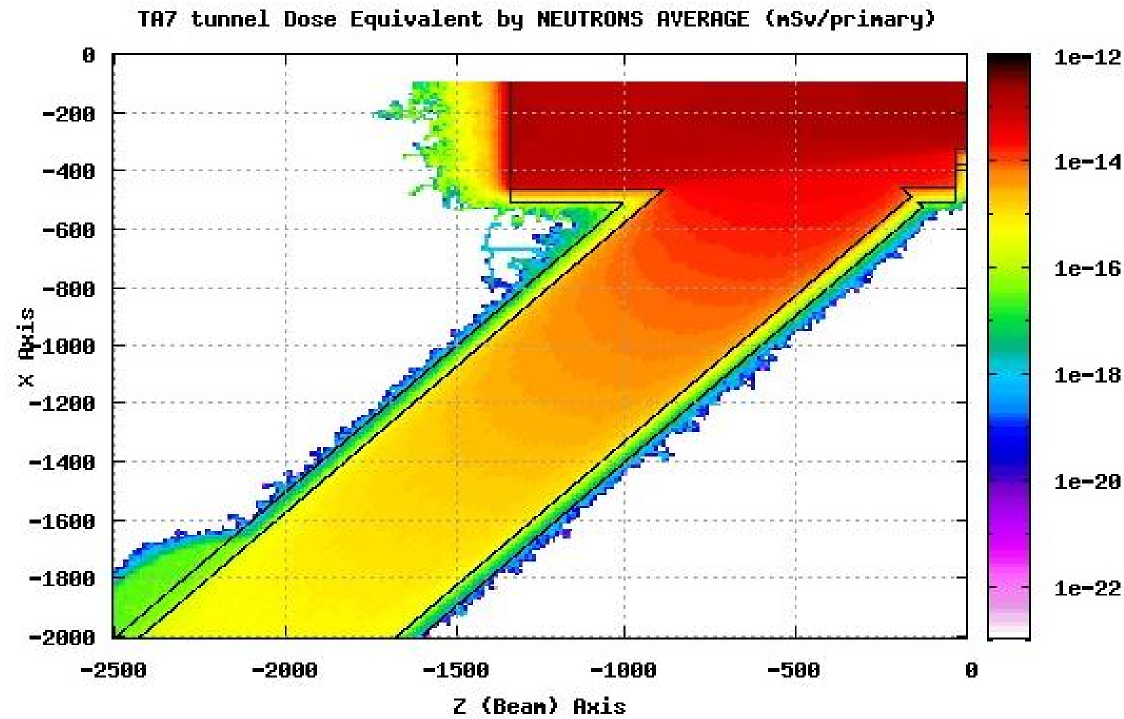

Figure 5 – Results of FLUKA simulations of the ambient dose equivalent per primary due to neutrons only

Testing the RAMSES detectors inside the HiRadMat facility would be of extreme interest due to the unique features of the neutron field in this area. In the TA7 tunnel a large area is present (according to the civil engineering plans, the average diameter of the tunnel is 5300 mm, see Figure 6) where the stray radiation field is sufficiently uniform, about 10^{-15} mSv/primary particle. Taking into account the range that can be spanned by the burst intensity (between $5 \cdot 10^{9}$ and $1.7 \cdot 10^{11}$ protons/burst), there will be the opportunity to have a dose per burst ranging from 5 to 170 nSv, which is the interval of interest for testing detectors in pulsed fields.

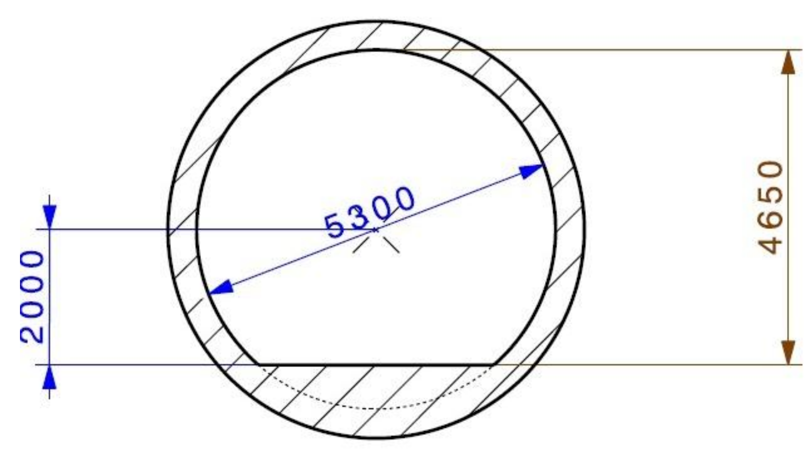

Figure 6 – Section view of the TA7 tunnel. Values are expressed in mm

Moreover, according to the beam specifications of the facility, a train of up to 288 bursts can be present in a pulse. This means that the dose per pulse could be increased step by step from 5 – 170 nSv/burst to a maximum of 1.44 – 48.96 µSv/burst, i.e. an overall variation in the range 5 nSv/burst to almost 50 µSv/burst.

This experiment would allow an investigation over a broad operational range of the instruments. For each beam intensity a few pulses would be needed to obtain good statistics. In fact, taking into account that the mean sensitivity of a detector is typically around 1 nSv/count, one can reach approximately 3% uncertainty with only 1 µSv of integrated dose. Hence the data could be collected in a relatively short time, offering the opportunity to make measurements with different detectors with limited beam time.

2.2. Tests of RAMSES detectors

It is essential for radiation protection purposes to understand the response of the monitors used in the RAMSES system to the various radiation fields. It is especially important to demonstrate that the relevant quantities like ambient dose equivalent and ambient dose equivalent rate are reliably measured even in presence of a strongly pulsed field.

Comprehensive measurements and studies took place in the past to evaluate the suitability of the detectors used for RAMSES [13-14]. Nevertheless, in those studies there was no possibility to investigate the behavior of the detectors in the overall operational range because of the lack of a reliable way to produce strongly pulsed fields with good reproducibility. In addition, no tests were made with other instruments in reference positions for comparison.

2.3. Intercomparison with other detectors

The possibility offered by HiRadMat to test the performance of active neutron instrumentation in pulsed fields is certainly of interest to other European institutions participating in EURADOS WG 11. We therefore propose to extend the measurements in order to include an intercomparison with other instruments, both commercial units and prototype/research instrumentation in use or under development in other laboratories. This would also allow a better understanding of the behavior of the various detectors in use at CERN when compared to other instrumentation either commercially available or in a research phase.

Institutions and enterprises that could be interested in these measurements are those which have recently participated in the EURADOS measurement campaigns: Paul Scherrer Institut (PSI), Istituto Nazionale di Fisica Nucleare (INFN), Berthold Technologies, Institute of Atomic Energy POLATOM, Politecnico of Milano, Physikalisch Technische Bundesanstalt (PTB), Institut Radioprotection et Sûreté Nuclêaire (IRSN), Helmholtz Zentrum Berlin (HZB).

This research topic will find growing interest in the future due to the upcoming number of facilities that will use strongly pulsed fields (e.g. laser and fusion facilities).

2.4. Verification of the neutron spectra

Only results from FLUKA simulations are so far available of the neutron spectrum inside the HiRadMat facility. It will be very interesting to verify experimentally the simulated results via a series of measurements with the new active version of the Bonner Sphere Spectrometer of the CERN RP group. In fact this is the only way to carry out neutron measurements in HiRadMat, due to the fact that conventional BSS would suffer important dead-time effects and would not provide reliable results.

The measurement of the neutron spectrum could be performed in selected positions. Due to the considerable number of measurements that must be carried out in the same point to obtain a well-defined spectrum (typically 8 or 9), only one position can be planned for this purpose.

2.5. Verification of the H*(10) due to neutrons

A verification of the ambient dose equivalent due to neutrons in different positions could be performed with the LUPIN prototype. These measurements would be quite fast. Once the positions are defined, access to the HiRadMat area is only needed to move the prototype from one measurement location to the next. Each measurement would only require a few minutes. A map of the most interesting positions can be prepared beforehand and at least 10 measurements could be possible in one day.

3. Technical issues

3.1. Space and electrical requirements

No particular set-up is needed. One or two detectors will be installed at the same time inside the TA7 tunnel. They will occupy only a small fraction of the available place.

3.2. Power and cable requirements

Need of some BNC connectors (for the signal output of the instruments to be connected) and electrical plugs inside or near the TA7 tunnel. The signal coming from the detectors must be available on the surface for remote control and analysis.

3.3. Time needed for installation/removal of the instrumentation

Negligible (30 minutes to install and the same time to remove the equipment).

3.4. Safety hazards

None. Conventional electronics will be used. No activation of the detectors expected.

4. Beam request plan

Request of the slot foreseen from October 1st to October 5th. The experiments regarding the tests of RAMSES detectors and the intercomparison with other instrumentation are foreseen in the first three days of the slot. The last two days will be used for the BSS measurements and the H*(10) measurements in different locations of the facility.

4.1. First part of the slot

A possible schedule for the first three days is provided in Table 1.

Access will be needed to change the detector to be tested, after a series of measurements with all beam settings listed in Table 1. This access could require up to 30 minutes, needed to remove the detector and to put in place the next one.

Setting number	Protons per bunch	Bunches per pulse	Beam size (σ_x x σ_y) [mm x mm]	Expected dose per burst [nSv]	Number of pulses	Time between pulses [min]
Setting 1	5e9	1	2 x 2	5	40	2
Setting 2	5e9	2	2 x 2	10	20	2
Setting 3	5e9	4	2 x 2	20	10	2
Setting 4	5e9	8	2 x 2	40	5	2
Setting 5	5e9	15	2 x 2	75	5	2
Setting 6	5e9	20	2 x 2	100	2	15
Setting 7	5e9	40	2 x 2	200	2	2
Setting 8	5e9	80	2 x 2	400	2	2
Setting 9	5e9	150	2 x 2	750	2	2
Setting 10	5e9	200	2 x 2	1000	2	15
Setting 11	5e10	40	2 x 2	2000	2	2
Setting 12	5e10	80	2 x 2	4000	2	2
Setting 13	5e10	150	2 x 2	7500	2	2
Setting 14	5e10	200	2 x 2	10000	2	30

Taking into account the schedule proposed in Table 1, one must consider at least 4 hours per each detector to be tested. Due to the fact that there is plenty of space available and that the irradiation field is quite uniform in the area chosen for the measurements, in case of time constraints two detectors could be tested at the same time.

4.2. Second part of the slot

No specific control of the beam intensity is needed. A mean intensity could be chosen and let the beam operate at this intensity for most of the second part of the slot.

Access will be needed to change the Bonner spheres and to change the position of the LUPIN prototype. Each access will require no more than 10 minutes.

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