



Full Length Article

New simulation of the CERN Gamma Irradiation Facility (GIF++)

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ABSTRACT

The simulation of the GIF++ facility at CERN has been updated to consider the experimental area that was upgraded in 2015. A new geometry was implemented in the Geant4 simulation code to calculate dose and flux distributions in the bunker. The simulation results are compared to recent dose measurements performed by the RPC EcoGas@GIF++ Collaboration. Some differences between measurements and simulation are evidenced, which can be however accounted for by the presence of mechanical structures in the bunker that were not introduced in the simulation.

1. Introduction

The Gamma Irradiation Facility (GIF++) is a unique experimental area at CERN, where a powerful ^{137}Cs source with an activity of 11.5 TBq (as estimated in June 2024) irradiates a large area where several detectors can be tested for long-term performance studies, using the 662 keV emitted photons. A high-energy muon beam (100 GeV/c) is available from the SPS secondary H4 line. To evaluate the dose inside the bunker a detailed Geant4 [1] simulation was performed in the past [2]. Recently, due to an upgrade of the facility, a revised simulation is needed to implement the new geometry. In this paper we reported the results of the simulation and its validation using few dosimeters located in the experimental area.

2. GIF++ facility layout

Fig. 1 shows the top view layout (XZ) of the upgraded GIF++, which was extended by 8.7 meters in the upstream region, to allow more experimental set-up. The source position, the muon beam line (along the z-axis), as well as the position of the dosimeters are evidenced. Four dosimeters are available in the area, PMINA14502 and PMINA14503 provided by GIF++ group, P1 and P2 provided by RPC EcoGas@GIF++ Collaboration. Table 1 reports the coordinates values of the dosimeters relative to the source position.

Sets of adjustable filters are positioned over the two sides of the source (called respectively *upstream* (US) and *downstream* (DS)) to produce radiation fields with different attenuation factors. The filters consist of collimators and attenuators. The collimator outlets consist of two lens-shaped angular correction filters that shape the field from point to planar. The attenuation system is independent on the two

sides of the bunker. Each array of filters consists of 3×3 convex lead attenuators, which are positioned inside a steel frame. The attenuation factor, in the following referred to as ABS, can range from 1 to 46420 and can be set by selecting 27 possible combinations of filters.

3. Methods and simulation

The purpose of the study was to simulate dose and flux in the GIF++ area and to validate the results with some existing measurements.

The simulation was performed in Geant4 (version 11.2). Geometry was depicted in the Geometry Description Markup Language file (.GDML). For each of the following ABS values (1, 2.2, 3.3, 4.6, 6.9, 10, 22, 33, 46, 69, 100.) a GDML file was obtained in FreeCAD software [3]. The experimental area was divided into $5 \times 5 \times 5$ cm³ cubes.

Fig. 2 shows the gamma flux distribution inside the bunker, in the case of US and DS attenuation equal to 1 (no attenuation).

The dose D at a given (X,Y,Z) was estimated by simulating a $20 \times 20 \times 20$ cm³ tissue-like sensitive volume centered at that position. The dose rate \dot{D} was then computed accounting for the time of reference of the run, as explained in the following.

Assuming a source activity of $A = 11.5$ TBq, the reference time is $t^* = \frac{\Delta N}{A \cdot Br}$, where ΔN is the number of simulated gammas, and $Br = 0.85$ is the branching ratio for the decay chain of ^{137}Cs to 662 keV gammas. The dose rate \dot{D} is then computed as $\dot{D} = \frac{D}{t^*}$. The simulation is performed with only 10^7 gammas. To improve the accuracy of the results, the sensitive volume is divided into 8 equal cubes. The dose rate for a given sensitive volume is evaluated as the mean of the values in the associated cubes and the standard deviation is assumed as the

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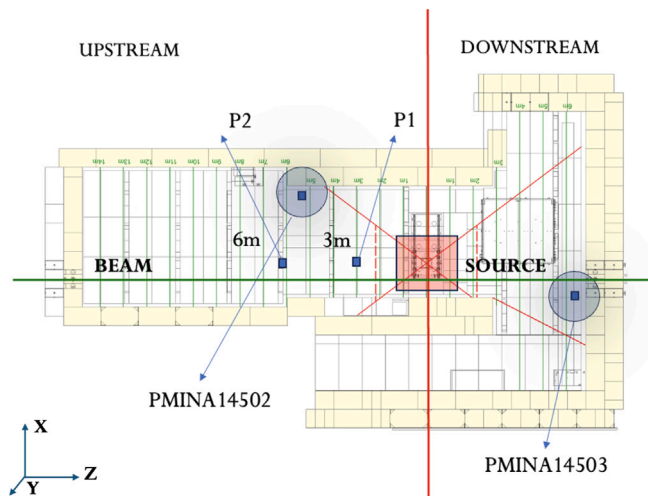


Fig. 1. Top view layout (XZ) of the experimental area. The thick red line (x-axis direction) separates the *upstream* (US) from the *downstream* (DS) regions. The thick green line (z-axis direction) represents the muon beam. The source position is shown in red, while the dosimeters, called PMINA14502 and PMINA14503, are highlighted in blue and are located respectively at $|z| = 5$ m and $|z| = 6,5$ m from the source. Additional dosimeters from the RPC EcoGas@GIF++ Collaboration, called P1 and P2, are positioned at $|z| = 3$ m and at $|z| = 6$ m, respectively from the source.

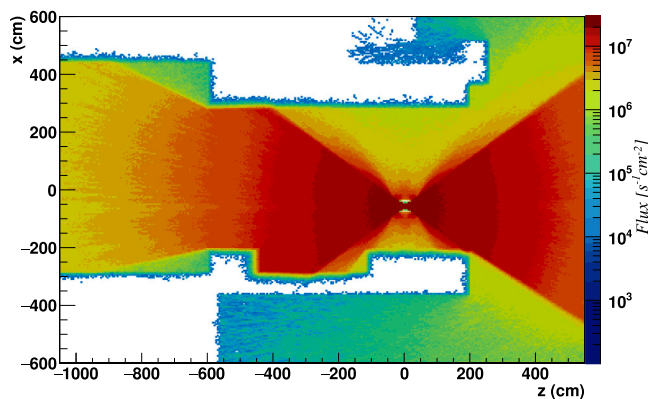


Fig. 2. Photon flux inside the bunker, centered in $z = 0$.

Table 1

Coordinates of detectors and distance respect to source.

Dosimeter	$ x(m) $	$ y(m) $	$ z(m) $	Distance (m)
PMINA14502	3	1,4	5	6
PMINA14503	2	2,3	6,5	7,2
P1	0	0	3	3
P2	0	0	6	6

error. Unfortunately, due to the limited statistics of the present work, the error bars are significantly important. A two order of magnitude increase from 10^7 to 10^9 will be needed.

4. Validation

The simulation has been preliminary validated with some existing ionization chamber monitors present in the experimental area, known as PMINA dosimeters. They consist of graphite and plastic to minimize the activation of materials of the chamber itself. They have been calibrated for the range $5 \mu\text{Sv/h}$ to 500mSv/h and the error is 5% [4]. The positions of these monitors, referred to in the following as the PMINA14502 and the PMINA14503, are shown in Fig. 1 and Table 1. They are positioned away from the detector under test so that the

line from source to dosimeter does not intercept any experimental installation.

PMINA measured instant dose rates and simulation results are compared in Figs. 3(a) and 3(b), as function of the ABS. In Fig. 3(a) ABS varies in the US region, while staying constant to 1 for DS region. In Fig. 3(b) ABS varies in the DS region, while staying constant to 1 for US region.

The RPC EcoGas@GIF++ Collaboration has performed in 2021 a dedicated campaign of dose rate measurements at location P1 and P2 (see Fig. 1) in the US region respectively at 3 m and 6 m from the source [5]. In the period of measurements, some experimental installations were interleaved between the source and the measurement dosimeters. Unfortunately, the measurements were not under our control, and we could not retrieve information on how much material budget was present during the campaign.

Comparison between RPC EcoGas@GIF++ data and simulation results are reported in Fig. 3(c) and Fig. 3(d), respectively for location P2 and location P1, as a function of the ABS value. In this case, a source activity of 12.5 TBq was accounted in the simulation, as estimated in 2021 when the measurements in P1 and P2 were taken.

By comparing Figs. 3(a) and 3(c), one finds different simulation results at the two positions where the dosimeters PMINA14502 and P2 are located, although they are at the same Euclidean distance from the source. In fact, the simulation, as already explained previously and shown in Fig. 2, considers also the filters and the collimators that shape the gamma field from point like to planar in the xy plane. Therefore, at a shorter z coordinate the simulation correctly gives a higher dose rate. This is confirmed by the measurements.

Moreover, by comparing again Figs. 3(a) and 3(c), there seems to be a better agreement between simulation and measurement in the case of PMINA14502 with respect to P2. This is due to the circumstance that the P2 dosimeter is shadowed by some interleaved material used to support detectors under test, which is not accounted in the simulation.

By comparing Figs. 3(c) and 3(d) where results are shown for dosimeters P1 and P2 (located at different distance along the z coordinate), one finds that the simulation correctly reproduces the expected $1/z^2$ behavior.

5. Conclusions

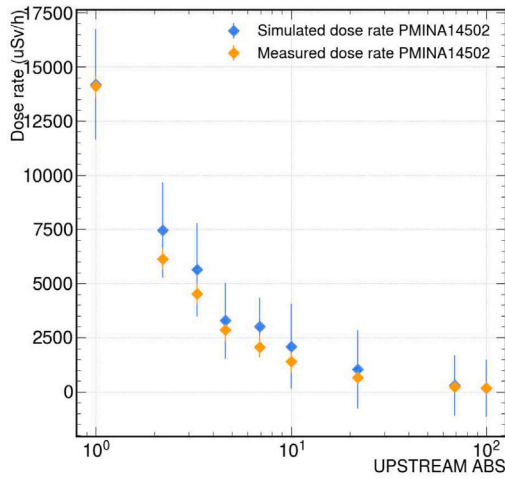
This study is a preliminary investigation of the gamma field inside the bunker of the GIF++ using Geant4 simulations. The simulated dose rate was validated using radiation protection PMINA dosimeters installed in the bunker. A further comparison was performed with measurements by the RPC EcoGas@GIF++ collaboration. In this case, some difference is evident, probably due to the effect of the mechanical structure between the source and the dosimeter, which was not accounted for in the simulation. The errors in the simulations are primarily due to poor statistics. More accurate simulations and further on-site measurements are planned.

Acknowledgments

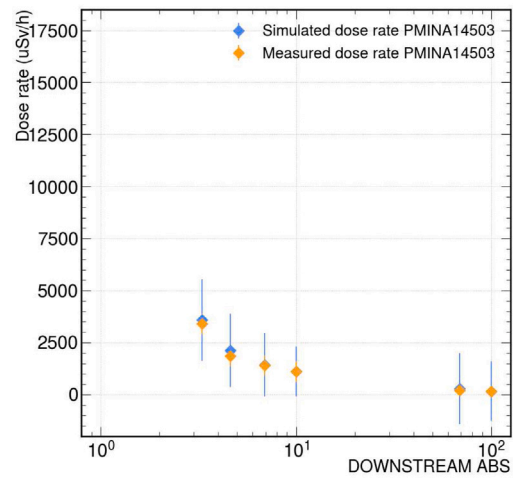
The authors are grateful to G. Pezzullo for providing the PMINA measured dose rate values, and RPC EcoGas@GIF++ Collaboration for providing their set of dose measurements, and also grateful to the GIF++ team and to Dorothea Pfeiffer.

Declaration of competing interest

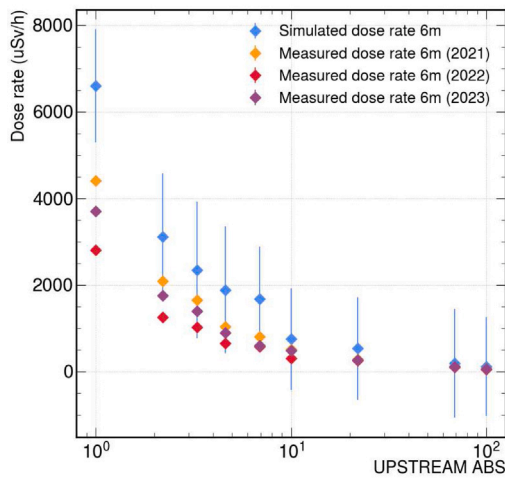
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



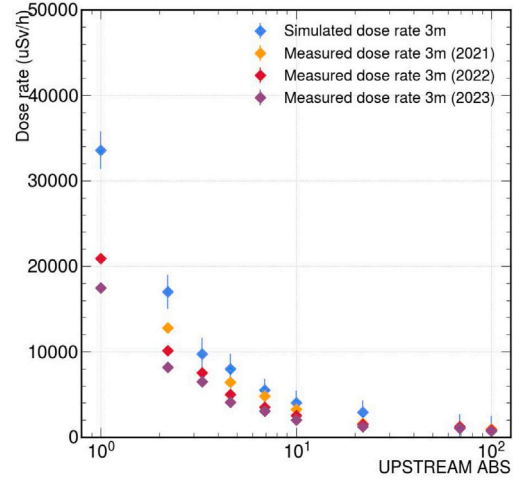
(a) Measured dose rates and simulation results as a function of ABS in the US region. The attenuation in the DS region was set to ABS equal 1.



(b) Measured dose rates and simulation results as a function of ABS in the DS region. The attenuation in the US region was set to ABS equal 1.



(c) Measured dose rates and simulation results as a function of ABS at position P2.



(d) Measured dose rates and simulation results as a function of ABS at position P1.

Fig. 3. Simulated and measured dose rates for validation.

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