RADIATION DOSIMETRY WITH A TRIPLE-GEM DETECTOR

DOSIMETRÍA DE RADIACIONES CON UN DETECTOR TRIPLE-GEM

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Abstract

We studied the properties of the gaseous detector triple-GEM (triple Gas Electron Multiplier) as a dosimeter with different ionizing radiation sources used in medical applications. The detector was calibrated in energy with an Iron-55 radioactive source. We measured doses of radiation from different radioactive sources as well as from a medical portable X-ray machine, and compared them to reference values. The detector presents a linear dependence between radiation intensity and measured dose. A calibration factor of 1.13×10^4 was found, independently of the radiation source. These results allow us to conclude that the triple-GEM detector has the potential to be used as a dosimeter in medical applications.

Keywords: detectors, dosimetry, medical applications, radiation, x-rays.

Resumen

Estudiamos las propiedades del detector triple-GEM (multiplicador de gas de electrones triple) como dosímetro, con diferentes fuentes de radiación ionizante utilizadas en aplicaciones médicas. El detector fue calibrado en energía usando una fuente radiactiva de hierro-55. Se midieron las dosis de radiación de diferentes fuentes radiactivas y de un

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generador médico de rayos X, y se compararon con valores de referencia. El detector presenta una dependencia lineal entre la intensidad de la radiación y la dosis medida. Se halló un factor de calibración de 1.13×10^4, independiente de la fuente de radiación. Estos resultados nos permiten concluir que el detector triple-GEM tiene el potencial para ser utilizado como dosímetro en aplicaciones médicas.

Palabras clave: aplicaciones médicas, detectores, dosimetría, radiación, rayos X.

Introduction

One of the most successful developments in gaseous particle detectors is the gas electron multiplier (GEM) detector [1], originally made for muon detection. The operating principle of the GEM consists of micrometer-sized holes, which bend and concentrate the electric field lines in such a way that electron amplification is achieved. This detector allows for notably less aging of the gas mixture after large bouts of radiation, a wide variety of applications, mass production, flexible geometry, low noise, fast electronic signal, and improved spatial and temporal resolution [2].

The GEM detector was born in the field of large high energy physics experiments; however, it has demonstrated usefulness well beyond its intended field, in areas such as medical imaging, astrophysics, structure analysis, among others. Less work has been done to determine if the GEM detector can be reliably used as a dosimeter. Dosimeters are of great importance in medical applications in order to minimize the risk of great harm that can be caused in the human body by an excess of absorbed doses during different medical exams with ionizing radiation. However, they are usually costly, and most personal dosimeters are read once every few months. The need for an affordable, big-sized dosimeter that can be read in real time sparked the interest of this project, that aims to characterize and calibrate a GEM detector, and determine if it can be applied to medical dosimetry.

Applications in medical physics

New generation micro-pattern gas detectors (MPGD) have been successfully used in different imaging applications, in particular in radiology [3]. Several groups have been working to improve MPGD's characteristics for medical applications [4]. The GEM is the detector with the highest potential in this technology transfer, due to its advantageous characteristics [5]. GEM detectors have been used to obtain live images of a tumor, using therapeutic gamma ray beams and imaging with X-rays [6]. They have also been used in clinical imaging with the mixed technique of single photon emission computed tomography (SPECT) and computed tomography (CT). The high spatial resolution of GEMs allows the detection of radioactive tracers in small volumes, permitting the identification of cancerous cells with greater efficacy. Recently, Sauli's group at the European Organization for Nuclear Research (CERN, Conseil Européen pour la Recherche Nucléaire) was developing GEM detectors for applications in positron emission tomography (PET) [7].

These, among other applications [8–10], have demonstrated the feasibility of developing devices based on gaseous particle detectors for medical imaging. However, there is scarce information about clinical dosimetry. Preliminary results show that GEM detectors have great potential as real-time 2D dosimeters, but more work is needed [11]. A research team used a scintillating GEM detector for 2D dosimetry with alpha beams, clinical carbon beams, and proton beams, concluding that the scintillating GEM detector is promising as a dosimeter for relative 2D dose measurements in charged particle beams for radiotherapy. They also found that the detector response is linear with dose and does not present dose rate effects, being able to deal with high intensities [12]. More research needs to be done in this area, but the few results as of now prove that the GEM detector will likely be a valuable tool in medical dosimetry.

In a previous work our group has also demonstrated the viability of using a triple-GEM detector for medical dosimetry, showing its linear response for different radiation sources and intensities [13]. For this purpose, a triple-GEM detector was acquired by the

CRYOMAG research group at Universidad Nacional from CERN's RD-51 collaboration. In this work we present detailed calculations and the methodology of dosimetry calibration made for the GEM detector.

Theoretical Background

The Triple-GEM detector: GEM detectors consist of an anode, a cathode, and a GEM foil in between, as illustrated in Fig. 1. A GEM foil is a 50 μm thick insulating kapton layer covered with copper on both sides, and a grid of 50 - 100 holes per square millimeter. The holes have a diameter of 70 μm, a separation of 140 μm, and a double-conical shape [14]. The anode is covered in a two-dimensional strip readout of 256x256 detection areas that connects to the electronics, which allows for precise measurements of the location of an incoming particle. These strips are made of copper, so electrons induce a charge in them. This structure is placed inside a tight box and filled with an appropriate gas.

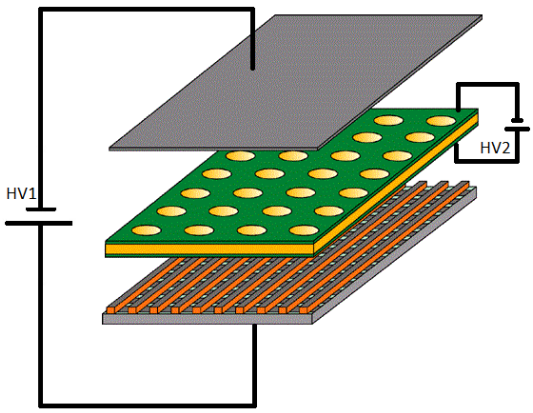

FIGURE 1. Schematic view of a single-GEM detector [1].

High voltage is applied between anode and cathode, and between both sides of the kapton foil, generating an electric field between the electrodes. Since kapton is an insulator and copper is a conductor, the electric field lines concentrate and bend inside the holes.

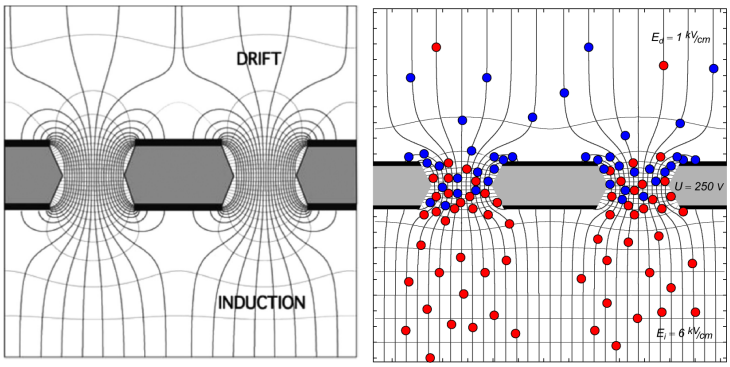

FIGURE 2. The electric field in the region of the holes of a GEM electrode [1].

When radiation, such as photons, enters the detector, it ionizes argon atoms, freeing electrons that drift towards the GEM foil following the electric field lines. Inside the holes they are strongly accelerated producing more ionizations and a cascade of secondary electrons with amplification effect. After this process, electrons continue their trajectory onto the readout pane where a signal is detected.

With a single GEM foil, the gain is approximately 100 or 200 at about 400 V [15]. However, GEM foils can be piled up on top of each other, forming double, triple, or even higher-level GEMs. Each gain is multiplied so, taking losses into account, a triple-GEM could provide a gain of 10^4 or 10^6 using relatively low voltages, so that the chance of getting sparks and therefore damaging the detector is greatly reduced. For this reason, GEM detectors are a safe, durable, and effective option for detecting ionizing radiation.

Dosimetry

In this section, we introduce the principles used to compute the radiation dose measured by a detector.
Absorbed dose is defined as the energy deposited per unit mass:

$$D = \frac{dE_{\text{abs}}}{dm} \tag{1}$$

It is measured in Joules per kilogram, or grays (Gy). This energy causes ionizations along the path of a charged incident particle, and collected charge after amplification constitutes a current pulse.

Cavity Theory: A cavity is described as a sensitive medium of a dosimeter or detector with a volume V filled with gas and separated from the outer medium by a wall. The dose absorbed by the detector is [16]:

$$D_{det} = \frac{Q_{prim}}{\rho V} \frac{W_{gas}}{e} \tag{2}$$

where Q_{prim} is the total charge of primary ions of a single sign created inside the cavity due to the incoming radiation, ρ is the density of the gas, V the volume of the cavity, W_{gas} the average energy needed to create an ion pair in the gas, and e the electron's charge. The dose in the medium of interest (surrounding the detector's cavity) is found with a proportionality factor α, as

$$D_{med} = \alpha \cdot D_{det} \tag{3}$$

Cavity theory [16] allows us to determine the factor α. In the case of the triple-GEM, the theory that applies is the one for big cavities [17]. A large cavity is such that the dose from electrons created by photon interactions inside is much larger than the dose from secondary electrons originating outside the cavity [18]. The ratio between dose absorbed in the medium and dose absorbed in the detector for particles of energies lower than 1 MeV is:

$$\alpha = \frac{D_{med}}{D_{det}} = \frac{K_{col,med}}{K_{col,det}} = \frac{\left(\mu_{en}/\rho\right)_{med}}{\left(\mu_{en}/\rho\right)_{det}} \tag{4}$$

where K_{col} is the energy transferred [16] by collisions and μ_{en}/ρ is the photon mass attenuation coefficient.

Triple-GEM detector as a dosimeter: In order to evaluate equation 2, we find the average ionization energy of the gas mixture. For argon, this value is 26 eV per ion pair, while for CO_2 it is 33 eV

[19–21]. Therefore, the energy required to generate an electron-ion pair in the gas mixture Ar-CO_2 at a ratio of $75\,\% - 25\,\%$ is:

$$\frac{1}{W_{Ar-CO_2}} = \frac{\%Ar}{W_{Ar}} + \frac{\%CO_2}{W_{CO_2}} = \frac{0.75}{26\text{eV}} + \frac{0.25}{33\text{eV}} = \frac{1}{27.5\text{eV}} \qquad (5)$$

so $W_{Ar-CO_2} = 27.5$ eV [22].

The mass of gas can be determined from its density and the volume of the cavity. The density of argon is 1.652×10^{-3} g/cm^3, and that of carbon dioxide is 1.827×10^{-3} g/cm^3 at 18°C, giving an effective density for the gas mixture of 1.693×10^{-3} g/cm^3. The dimensions of the cavity are $10 \times 10\ cm^2$ area, and depth of 3 mm drift region, two 2 mm transfer regions, and 2 mm induction region, giving a total volume of 90 cm^3 [23]. This gives a total gas mass of 0.153×10^{-3} kg.
The lower limit of dose that can be measured is determined by the background, which must be subtracted. Background noise arises from two sources: the detector (electronic noise) and radiation from the environment.
The sensitivity of the detector, as a dosimeter, coincides with its gain G, which is reported elsewhere [13] as a function of voltage. In this work, we only mention the gain that corresponds to the chosen operating voltage.

Experimental setup and methodology

Instruments and devices: The main instruments used are described below.

- Victoreen Rad-check plus model 06-526: radiation detector
- Radioactive sources: Fe-55, Sr-90, Tl-204, Am-241
- Digital oscilloscope Lecroy - WaveSurfer 24MXs-B
- Electronic instrumentation standard NIM modules - Caen
- Picoammeter Keithley - 6485
- Portable medical X-ray generator Siemens - Polymobil 10

Methodology: We connected the 512x512 strips outputs of the triple GEM detector in parallel to get the total deposited dose. Basic characterization and determination of operating voltage and threshold voltages for pulse analysis, as well as energy calibration with an Fe-55 source were made in a previous work [13]. A summary of these results is presented in the following section.

Dose measurements with the triple GEM detector were compared to measurements with the Rad-check reference dosimeter. Dose measurements for the Fe-55 source were calculated with four different methods in order to determine the calibration factor. For the other radioactive sources and the X-ray generator, the most convenient of these methods was chosen. Dose measurements and the calibration procedure are presented in detail in the following section.

Results and analysis

	Optimal Value	
Parameter	**Muons**	**Fe-55**
Supply voltage	-4325V	-4200V
Threshold	1.3mV	2.0mV
Gas flow	0.3 l/min	0.3 l/min

TABLE 1. Optimal operating parameters for muons and the Fe-55 source, detailed in a separate work [13].

Summary of optimal parameters: The energy resolution of the detector is computed elsewhere [13], and resulted in 19.5 %, which is consistent with an independent reported value of 20 % [21]. The characteristic curve of the detector, presented elsewhere [13], shows a linear response, meaning it is working in the proportional region, with a gain between 10^4 and 10^6. The background current (without the Fe-55 source) has been subtracted from measured currents.

In order to calculate the number of primary electrons produced by an ionizing particle, the energy absorbed by the medium has

to be determined. To do this, the cross sections of interactions for 5.9 keV photons, from the Fe-55 source, were looked up on NIST tables [24] for the specific gas mixture used in the detector, getting for Raleigh: $\sigma_R = 1.027$ cm^2/g, Compton: $\sigma_C = 0.07718$ cm^2/g, photoelectric: $\sigma_{pe} = 208.5$ cm^2/g, and pair production: $\sigma_{pp} = 0$ cm^2/g. The photoelectric effect, being 99.5 % of the total cross section, is the dominant process; therefore, an absorbed energy of 5.9 keV can be assumed to produce primary electrons while crossing the drift region [22, 23]. This energy gives the number of primary electrons:

$$n = \frac{E_{Fe-55}}{W_{Ar-CO_2}} = \frac{5900\text{eV}}{27.5\text{eV}} \simeq 214 \tag{6}$$

where W_{Ar-CO_2} was calculated in Eq. 5. Since the detector is working in the proportional region, the size of charge pulses can be directly related to the energy of the incoming particles and absorbed dose.

Linearity

Measurements of counts vs. thickness (x) of an aluminium barrier, located between source and detector, were made in order to check the linearity of the detector's response as a function of photon intensity. Data is plotted in Fig. 3, where we can see a linear response.
According to equation 1, in order to compute the absorbed dose in the detector, we determine the absorbed energy dE using different methods, depending on the characteristics of the radiation source. The mass of gas in the detector was computed above (after equation 5), getting $dm = 0.153 \times 10^{-3}$ kg.

The Siemens portable X-ray machine can be set at tube voltages from $40 - 125$ kV, and tube current $\times$ time from $0.32 - 50$ mAs. A tube current $\times$ time of 16 mAs, a tube voltage of 73 kV, and a distance from source to detector (SOD) of 88 cm were kept constant. These values are typically used in radiology.

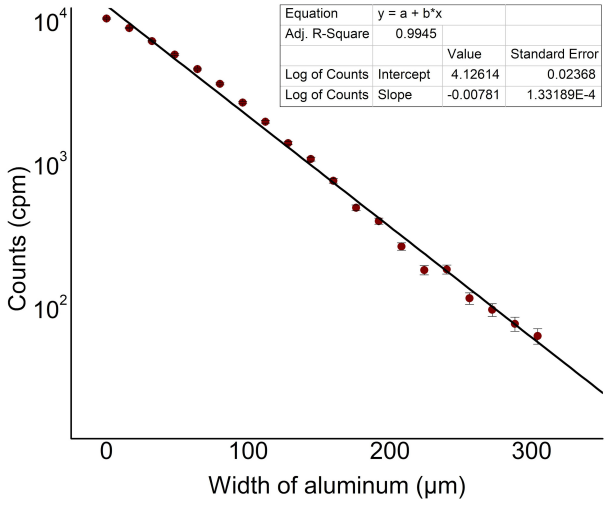

FIGURE 3. Counts vs thickness of aluminum filters (x), taken on the triple-GEM detector. It shows the linearity of the detector's response as a function of the intensity of the photon beam.

Measuring dose from the Fe-55 source

Dose from current: The current generated in the detector by the Fe-55 source was measured, and the absorbed dose was calculated with equation 2. with W given by equation 5.

The current at an applied voltage of -3890V was $(1.45 \pm 0.57) \times 10^{-9}$C/s. We obtain the total current produced in the detector by multiplying the measured current by a factor of four, because it comes from only one of the four strips outputs. The primary charge is calculated by dividing the total collected charge by the gain G (3.2×10^5 at that voltage), giving:

$$Q_{prim} = \frac{Q_{total}}{G} = (1.81 \pm 0.71) \times 10^{-14} \text{ C/s} \tag{7}$$

Therefore, the dose deposited in the detector per second is:

$$D_{\text{det}} = \frac{Q_{prim}}{dm}\left(\frac{W}{e}\right) = (3.26 \pm 1.28) \times 10^{-9} \text{ Gy/s} \tag{8}$$

Dose from spectrum: The spectrum of Fe-55 was measured and reported elsewhere [13]. A spectrum is a measure of the number of times an incident particle deposits a specific energy; therefore, the integral of the spectrum gives the total energy absorbed by the detector. When calibrated in energy, the size of each channel (or bin) in the spectrum was 2.63 eV. The integral of the spectrum taken at the same conditions as the energy calibration is obtained by multiplying the number of counts of each channel by 2.63 eV, and adding them all together. This gave a total energy $dE = 1.64 \times 10^9$eV, with a corresponding dose:

$$D_{\text{det}} = \frac{dE}{dm} = 1.07 \times 10^{13} \text{ eV/kg} = 1.71 \times 10^{-6} \text{ J/kg}$$

As reported in [13], the Fe-55 spectrum was taken during a five minute period, thus the dose rate is:

$$D_{\text{det}} = 5.72 \times 10^{-9} \text{ Gy/s} \tag{9}$$

Dose from oscilloscope signal: Dose can be calculated from the voltage vs. time pulses observed on the oscilloscope at the output of the detector. If these signals are divided by the input impedance of the oscilloscope (50 Ω), we obtain current pulses, which after integration give the collected charge. As done with the current method, the total charge is multiplied by four because there are four strip outputs, then divided by the gain at the voltage used (2.5×10^6) to get the charge produced by primary ionizations. The result is $Q_{prim} = 1.94 \times 10^{-16}$ C, giving the dose:

$$D = \frac{Q_{prim}}{dm}\left(\frac{W}{e}\right) = 3.49 \times 10^{-11} \text{ Gy}$$

However, since this dose comes from a single signal (a typical pulse was chosen), it is the dose per pulse. To get the dose rate, it was multiplied by the activity f of the Fe-55, which was measured under similar conditions with the Rad-check detector, resulting in 166 pulses per second. Therefore,

$$D_{\text{det}} = D_{\text{per pulse}} \times f = 5.80 \times 10^{-9} \text{ Gy/s} \tag{10}$$

Dose from source activity: A more "theoretical" way to calculate the total energy absorbed by the triple-GEM detector is to multiply the number of counts measured with the detector by the theoretical energy imparted per incident particle. The measured activity f of the Fe-55 source using the triple-GEM detector was 262 ± 16 cps, and the maximum energy absorbed by the detector for each incoming particle is 5.9 keV. Using these values, the dose is:

$$D_{\text{det}} = \frac{dE}{dm} = \frac{E_{\text{Fe-55}} \cdot f}{dm} = (1.62 \pm 0.99) \times 10^{-9} \text{ Gy/s} \qquad (11)$$

Method	**Dose rate (Gy/s)**
Current	$(3.26 \pm 1.28) \times 10^{-9}$
Spectrum	$(5.72 \pm 1.48) \times 10^{-9}$
Oscilloscope signal	$(5.79 \pm 2.11) \times 10^{-9}$
Source activity	$(1.62 \pm 0.99) \times 10^{-9}$
Weighted average	$(3.27 \pm 0.66) \times 10^{-9}$

TABLE 2. Summary of dose rates from the Fe-55 source using four different methods.

The four methods of dose calculation produce results in the same order of magnitude and close values, as shown in table 2. However, we believe the latter (source activity) is more theoretical and less accurate, therefore gives a value farther from the other three results. All these methods have their own uncertainties, but it is satisfactory that they gave quite similar results. In principle any of these methods can be used and calibrated to obtain the absorbed dose in the detector using radioactive sources, but the most accurate seems be the one based on current measurements, since it is the most direct. In fact, this is the method used in ionization chambers. The weighted average of dose measurements in table 2 is $3.27 \pm 0.66 \times 10^{-9}$ Gy/s, which will be taken as the best measurement with the detector.

Measuring dose from other radioactive sources

Since the four methods tested with the Fe-55 radioactive source for dose measurements were validated, any of them

can actually be used; however, the best method to use in a clinical setting is the current method. Therefore, dose rates from the other three radioactive sources (Sr-90, Tl-204, and Am-241) were calculated by measuring current. A total of 200 measurements were made for each source. Measured currents were: 7.89×10^{-9} C/s (Sr-90), 1.48×10^{-9} C/s (Tl-204) and 2.09×10^{-9} C/s (Am-241) According to equations 7 and 8, we computed the dose, obtaining the results presented in table 3.

Radioactive source	**Dose rate (Gy/s)**
Fe-55	$(3.26 \pm 1.28) \times 10^{-9}$
Sr-90	$(2.27 \pm 0.44) \times 10^{-9}$
Am-241	$(0.601 \pm 0.16) \times 10^{-9}$
Tl-204	$(0.425 \pm 0.17) \times 10^{-9}$

TABLE 3. Dose rate using the current method for four radioactive sources.

As can be seen, the radioactive source that deposited the most energy into the detector was Fe-55, followed by Sr-90, then Am-241, and lastly Tl-204. According to the activities measured by the reference detector and each source's peak energy, the source that radiates the most energy is Am-241, followed by Sr-90, Tl-204, and Fe-55. However, due to the efficiency of the triple-GEM detector and its physical properties, alpha sources deposit the least percentage of their radiated energy into the detector, and gamma sources the most. In order to compare doses measured with the triple-GEM detector to those measured with the reference dosimeter, we need to convert these values to dose in air, according to equation 4.

Conversion from dose in detector to dose in air

In order to compare the doses given in the previous sections to the doses measured with the reference detector, these doses have to be converted to dose in air using equations 3 and 4, where the coefficients $(\mu_{en}/\rho)_{med}$ and $(\mu_{en}/\rho)_{det}$ are obtained from NIST tables [25]. Each element, compound, or mixture has its own coefficients, which depend on the energy of incoming photons (see table 4).

Element	μ_{en}/ρ **(cm^2/g)**
Argon	244
Carbon	10.5
Oxygen	27.0
Dry air	24.0

TABLE 4. Mass energy-absorption coefficients for relevant elements [25].

The mass energy absorption coefficient for 5.9 keV photons in the triple-GEM detector was calculated as the weighted average of the coefficients for argon, carbon, and oxygen, the components of the gas mixture:

$$(\mu_{en}/\rho)_{det} = 0.75{\cdot}(\mu_{en}/\rho)_{\mathrm{Ar}}{+}0.08{\cdot}(\mu_{en}/\rho)_{\mathrm{C}}{+}0.17{\cdot}(\mu_{en}/\rho)_{\mathrm{O}} = 186\ \mathrm{cm}^2/\mathrm{g} \tag{12}$$

Then,

$$D_{med} = \frac{(\mu_{en}/\rho)_{med}}{186\ \mathrm{cm}^2/\mathrm{g}} \times D_{det} \tag{13}$$

The dose rate deposited by the Fe-55 source in air, taking D_{det} as the average dose given in table 2, is:

$$D_{air} = \frac{24.0\ \mathrm{cm}^2/\mathrm{g}}{186\ \mathrm{cm}^2/\mathrm{g}}{\cdot}4.10{\times}10^{-9} = 5.29{\times}10^{-10}\ \mathrm{Gy\ per\ second} \tag{14}$$

The reference value for this dose in air measured with the Inspector detector was $(6.6 \pm 1) \times 10^{-8}$ Gy/s, which is greater than the measurement of the triple GEM detector. However, the Inspector detector is not the best reference for an Fe-55 source, since it was calibrated with a Cs-137 source of 512keV betas and in general is meant to measure radioactivity of much higher energies. In fact, the efficiency of the Inspector detector was about 1.1 % with the Fe-55 source [13]. This means that the real dose imparted to air by the source must be about 91 times higher than that measured on the Inspector detector. If this is taken into account, the calibration coefficient for measuring dose in air with the triple-GEM detector should be:

$$\frac{D_{ref}}{D_{GEM}} = \frac{6.6 \times 10^{-8}\ \mathrm{Gy/s}}{5.29 \times 10^{-10}\ \mathrm{Gy/s}} \cdot 91 = 1.13 \times 10^4 \tag{15}$$

Measuring dose from the portable X-ray machine

Dose measurements were made with the portable X-ray generator and reference measurements were taken with a Victoreen Rad-check ionization chamber. Each measurement lasted one minute, and the background radiation was subtracted from all measurements.

Out of the four dose-measuring methods tested with the Fe-55 radioactive source, only the oscilloscope signal method proved to be reliable due to the fast response of the oscilloscope to the high photon flux delivered in each shot. The oscilloscope response to each shot appears as a long pulse containing the individual detection of each photon. No appreciable overlapping effect between individual photon pulses was observed. Dose was calculated in the same way as done with the oscilloscope method for the Fe-55 source. Doses absorbed in the detector were converted into dose absorbed in air by using equation 4, so that they can be compared to reference dose measurements taken with the Rad-check dosimeter.

Dose vs tube voltage is shown in figure 4. This data was fitted to a quadratic function, as expected according to the literature [26]. The relationship obtained is quadratic, although there is some dispersion, which reduces the R^2 value to 0.95. Dose vs tube current, shown in figure 5, was fitted to a linear function confirming that photon fluence is directly proportional to the tube current.

In figures 4 and 5 error bars correspond to the standard deviation of ten measurements taken with the same parameters. These measurements demonstrate the triple-GEM detector's capability to measure dose from X-rays with the expected relationships with peak tube voltage and tube current. Even though the variance is greater for the triple-GEM detector than for the Rad-check, this can be substantially improved with a more careful instrumentation. Although doses from the triple-GEM detector are four orders of magnitude smaller than those from the Rad-check detector. This is due to the fact that the Rad-check detector has its maximum efficiency with X-rays, and was made for that specific purpose, while the triple-GEM detector experiences higher efficiencies with cosmic

rays and radioactive sources, and was designed for detecting muons in high energy physics experiments.

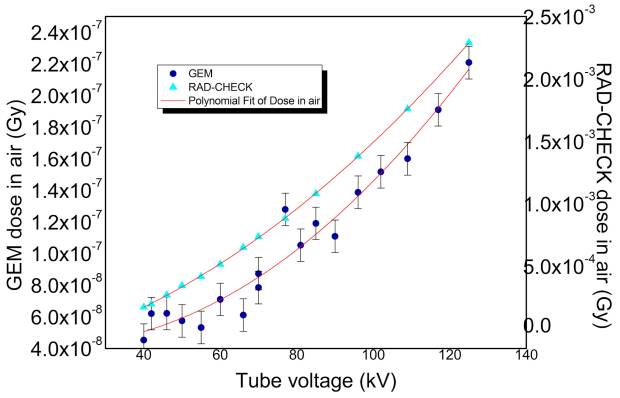

FIGURE 4. Dose in air vs tube voltage measured with the triple-GEM detector compared to the reference dosimeter. Measurements were made at a distance (SOD) of 88 cm, tube current of 16 mAs, and detector HV of -4200 V. The relationship is quadratic despite high dispersion at low voltages.

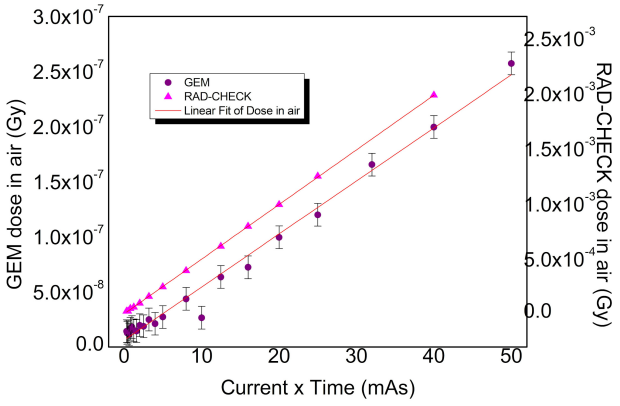

FIGURE 5. Dose in air vs tube current measured with the triple-GEM detector and the reference detector. Measurements were made at an SOD of 88 cm, peak tube voltage of 73 kVp, and detector HV of -4200 V. Both sets of data are well fitted to a linear function. The Rad-check data has an R^2 of 0.99992, while the GEM's is 0.98588.

The calibration function was found by plotting dose values taken with the GEM and reference detectors at the same parameters, and comparing both sets of data, as shown in figure 6. The relationship

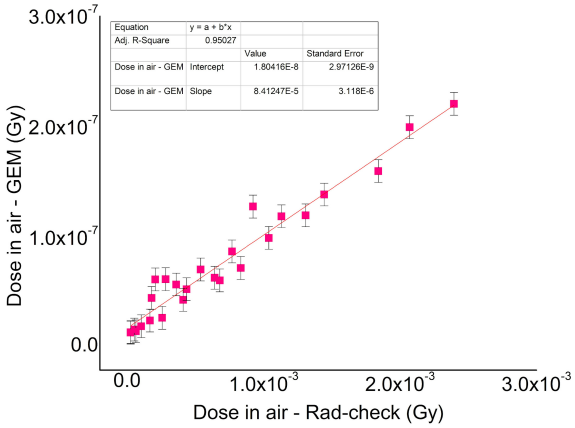

FIGURE 6. Dose in air as measured with the triple-GEM detector compared to reference dose measured with the Rad-check ionization chamber. The linear fit provides the calibration function that allows to correct dose measurement done with the triple-GEM detector with the calibration coefficient 1.13×10^4. The horizontal error bars are too small to be visible in the graph because of the high precision of the Rad-check detector.

between doses measured on the triple-GEM detector and reference doses is linear, therefore a single calibration coefficient is needed to correct the triple-GEM measurements. The linear fit done in Fig. 6 gave the relationship:

$$\text{Dose} = 1.13 \times 10^4 \cdot \text{Measured Dose} - 1.71 \times 10^{-4} \qquad (16)$$

Because the y-intercept is so small, it can be said that the calibration coefficient for the triple-GEM detector is 1.13×10^4. Despite that, there is a relatively big variance in the data. This linear relationship proves that the triple-GEM detector is useful for measuring dose. With future instrumentation improvements it has the potential of becoming a very accurate dosimeter.

Surprisingly, this is exactly the same calibration coefficient found for the Fe-55 source in equation 15. The fact that this result is the same for two different radiation sources is very promising, and means that no matter the type or energy of the incident radiation, at least for the sources used in this work, the absorbed dose in air can be measured with the triple-GEM detector by multiplying it by 1.13×10^4.

Conclusions and future work

The triple-GEM detector is promising for dose measurements, since a proportionality constant was found that calibrates it to get the correct dose, for different radioactive sources or an X-ray shot at a wide range of a tube current and voltage values. Even though the uncertainties are not that low, we demonstrated that the triple-GEM detector measures dose equally well for all the radiation sources and energies tested.

Because triple-GEM detectors have countless advantages such as flexible geometries, large detection areas, pixel readout panels, low noise, the possibility of mass production, and are relatively inexpensive, using them as dosimeters is an interesting proposal.

Additionally, triple-GEM detectors have the possibility of using a pixelated readout board with good spatial resolution, which would allow users to make 2D dose maps. To adapt the detector to dosimetry, more appropriate electronics and devices for a clinical environment have to be implemented.

Now that it was proven that the triple-GEM detector works satisfactorily in measuring doses, its behavior could be studied with different gas mixes that are more practical and common in clinical settings, such as purified air. Additionally, it could be very valuable to test the response of the triple-GEM detector as a dosimeter with radioactive sources of higher energies, such as the ones used in nuclear medicine, radiotherapy, and brachytherapy. We expect it will perform equally well, since it was developed to work at high energies. In this work we have satisfactorily proved that the triple-GEM detector not only works well for the high energy physics applications for which it was designed, but also for countless other applications, and particularly for medical physics.

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