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Procedure to optimize the solid angle for the collimation of the NaI detector used to measure the flow rate in pipelines

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ABSTRACT

The use of radiotracers in flow ducts of products from the oil and gas industry allows the measurement of installed flow meters and the knowledge of the flow profile inside the duct. The time transient method is the most used for flow measurement and measurement of flow meters and consists of recording the passage of the radioactive cloud at two different points. For the oil and gas industry it is important that the accuracy, according to the National Agency of Petroleum, Natural Gas and Biofuel (ANP) and the National Institute of Metrology, Quality and Technology (INMETRO) must be less than 0.7%, and for this value is reached, careful planning of the test is necessary. One of the critical points is the correct detector / duct geometry at the two measurement points because the quality of the result depends on the correct recording of the passage across the straight section of the radioactive cloud duct. The present work aims to analyze the effect of collimation of the detector in the process of registering the signal emitted by the radiotracer during flow in a 10"steel duct, using the Au-198 radiotracer. The analysis was carried out through computational modeling using the Simpson integration

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method, simulating the entire detector / shielding / collimation system of the front face of the 2x2 ”NaI detector and the fluid flowing in the duct was used Glycerol in turbulent flow regime. The study aims at defining the collimator opening and the optimization of the duct / detector distance and the value of the injected activity so that the registration of the displacement of the radioactive cloud allows the measurement of the flow within the limits established by the ANP standard.

Keywords: Radiotracers, Gas Industry, Microshield

1. INTRODUCTION

Radiotracers are widely used to measure the flow of liquids, gases and solids in many industrial systems. [1] This radioisotope-based technology has played an important role in various industry sectors such as petrochemicals, oil and gas, as well as effluent and plant treatment. [2]. The use of radiotracers in industrial oil transport and processing facilities allows calibration of flowmeters by measuring the average residence time of cracking columns, locating obstruction points or leakages in underground ducts, as well as investigating flow behavior [3].

Flow measurement can be performed using Residence Time Distribution (RTD) functions, which is one of the most effective analytical methodologies for studies of fluid flow in real units [6]. The radiotracer technique associated with the statistical methodology of residence time functions is one of the most suitable tools for diagnosing industrial processes, enabling the determination of the occurrence of the functioning of systems such as plumbing, deviations, shortcuts and dead volume [1,3]. This technique consists in detecting the passage of the radioactive cloud through the conduit, which when interacting with the fluid dynamics system, has its physicochemical parameters continuously modified, where the registration allows obtaining information about the flow [10,9].

The efficiency of flow measurement using the RTD technique is directly linked to the quality of data acquisition. Several parameters of the experimental arrangement may influence the detection of radiation from the radioactive cloud, such as energy and activity of the radiodracer, injection, collimation etc [7].[4] BERNE et al (2004) studied the influence of radiotracer energy on detector response using computer simulation. The authors found that several factors, including collimation, directly influence the incident radiation energy, if the detector allows to identify more relevant aspects of the flow. [5] CONSTANT-MACHADO et al (2005), states that the presence of technical difficulties in obtaining a perfectly collimated beam produces serious errors in the determination of RTDs.

When the goal is to perform flow measurement with greater accuracy, low uncertainty in the measurement of RTDs can result in unacceptable values compared to the regulatory standard for flow measurement. In Brazil, the National Petroleum Agency (ANP) together with the National Institute of Meteorology, Quality and Technology (INMETRO) indicates through Joint Resolution ANP /

INMETRO No. 1 of 10.6.2013, the necessary accuracy value for techniques and equipment used in oil and gas flow measurement. The standard states that to measure oil the uncertainty is not above 0.7%. In order to reach this value using the RTD technique, shielding optimization techniques are recommended so that the solid angle is collimated so that the oscillations at the baseline are reduced and the radiotracer pulse is as uniform as possible.Therefore, this work aims to verify the influence of the main aspects of shielding in an experimental arrangement of detection of radiotracers.

2. MATERIALS AND METHODS

The simulation of the experimental arrangement of this work was performed using the MicroShield computational code. MicroShield is a comprehensive gamma ray and photon / gamma shielding program. This code is widely used to design shields, estimate source energy from radiation measurements, minimize exposure to persons by signaling appropriate shielding based on dose measurement and other simulated quantities. MicroShield uses a mathematical method known as Gauss quadrature for numeric kernel-point integration in integration calculations. In this method, the source is separated into a number of kernels determined by the square order. In general, the higher the square order, the results will be more accurate [11]. In this work, an experimental arrangement commonly used in the flow measurement procedure using RTDs will be simulated. Figure 1 shows the scheme to be studied.

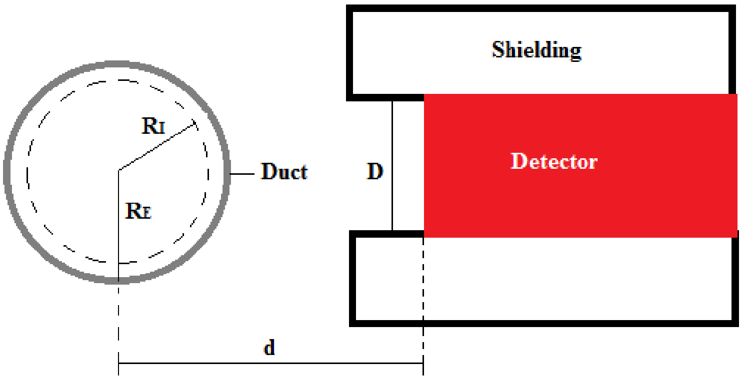

Figure 1: Experimental arrangement for detecting RTD curves, where h is the distance between the detector and the duct and D is the opening diameter of the collimation.

The simulation considered that the fluid flowing through the duct was Glycerol. Glycerol was chosen for its chemical and fluid dynamics characteristics similar to those of oil by-products of petroleum.

The detector was simulated as a point detector and it was necessary to adjust the number of photons recorded, due to the area of the scintillator. The duct was simulated consisting of PVC, with internal diameter of 5.08 cm and external diameter of 5.58 cm. The radiotracer used was Au-198, which is commonly used in oil.

The variation of h was simulated as a distance between the point detector and the duct; The variation of D (collimation) was simulated as the variation of the area of the scintillator where the photons fall. Figure 2 shows the computationally assembled scheme for evaluating the influence of distance on the number of photons detected.

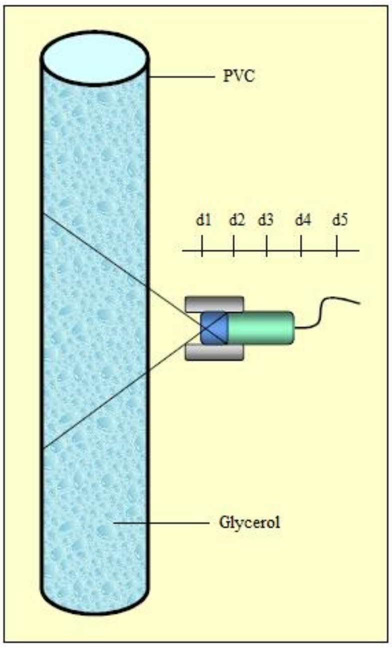

Figure 2: Illustration of the computational simulation performed: variation of detector distance at distances d1 to d5.

The computational code records the number of photons emitted by the radiotracer, which will be considered as a record of the radioactive cloud passing through the detector.

The simulation was performed considering that the baseline has an average value of 500 photons / cm^2. This value was used as a reference to distinguish the pulse generated by the passing of the radioactive cloud from the background noise. The flow of glycerol flowing through the duct was considered constant, not influencing the detection analysis. In this simulation it is assumed that the detector efficiency is equal at all points.

The flow velocity associated with the tracer dispersion coefficient in the medium defines the size and shape of the radioactive cloud; The solid collimation angle of the source-tube system defines the number of photons that reach the detector. Thus, all these parameters affect the variance of the mean residence time measurement. From RTD theory we have the equation (1):

$$E(t) = \frac{C(t)}{A} = \frac{C(t)}{\int_0^\infty C(t)dt} \qquad (1)$$

where C (t) is the number of incident photons. Therefore:

$$E(t) = \frac{C(t)}{\int_0^a C(t)dt} + \frac{C(t)}{\int_a^b C(t)dt} + \frac{C(t)}{\int_b^\infty C(t)dt} \qquad (2)$$

Where the value of the first term and third term of equation 2 are zero, as shown in figure 3

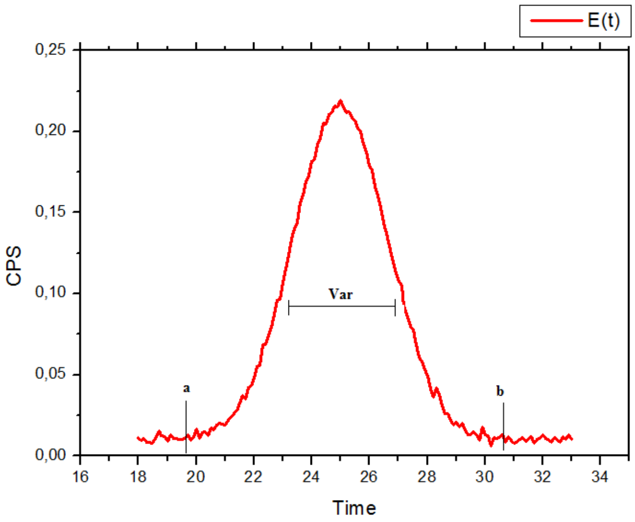

Figure 3: Representation of variance as the width at half height of curve E (t), obtained experimentally.

Thus we have from RTD theory we have the equation (3):

$$\tau = \int_0^{\infty} tE_{(t)}dt = \int_0^{a} tE_{(t)}dt + \int_a^{b} tE_{(t)}dt + \int_b^{\infty} tE_{(t)}dt \qquad (3)$$

In the lateral intervals the values are zero, and what will define are the values of a to b, which in turn is related to the dimensions of the radioactive cloud.

Figure 4 shows experimental data from Arcal Report rla 10161807551 conducted in May 2019 in Rio de Janeiro. In this constant flow test the maximum intensity decreases as the variance increases as the detector moves away from the injection point. Thus, collimation optimization is required so that at all positions the displacement of the radioactive cloud passage is recorded.

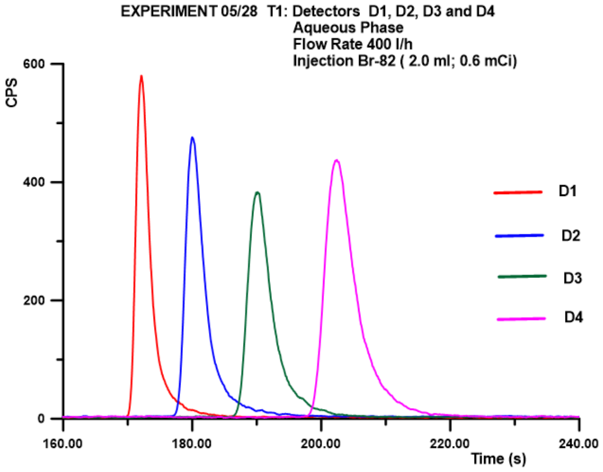

Figure 4: Variation in the number of counts with increasing distance. The result described by D4 is an unwanted increase in signal, probably due to the failure in the construction of the experimental arrangement. [8]

The influence of the value of τ is proved by verifying the equations that define flow determination, flow uncertainty and variance. However, experimentally it is noticed that the increase of τ has a less significant effect on the decrease of uncertainty when compared to the increase of the distance between detectors. The flow of a flow in a duct can be calculated by the equation 4:

$$Q = \frac{V}{\tau} \tag{4}$$

Where τ is the average residence time, given by (t2-t1) and V is the volume represented by the duct area x distance between detectors. The passage of the radioactive cloud and the visual demonstration of the mathematical concepts of flow and residence time are shown in figure 5.

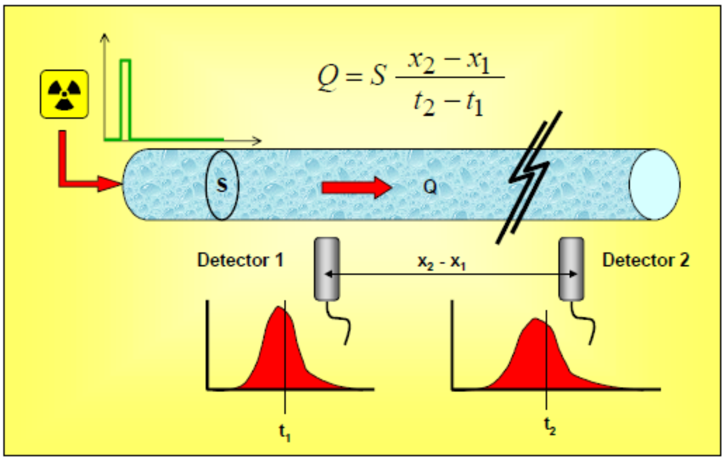

Figure 5: Radioactive cloud passage detection and radiotracer scatter visualization by "widening" the E (t) curve.

Increasing the distance from the detector to the injection point contributes to the increase in variance, which in turn leads to an increase in the calculated uncertainty. This statement can be demonstrated in equation (5) and (6).

$$\frac{\Delta Q}{Q} = \sqrt{\left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta t}{t}\right)^2} \tag{5}$$

$$\frac{\Delta Q}{Q} = \sqrt{\left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta t}{t}\right)^2} \tag{6}$$

Figure 6 experimentally demonstrates the increase in width at half height of curve E (t) due to the characteristic dispersion of the radiotracer in the fluid. This effect should not be ignored so that radioactive cloud dispersion influences flow uncertainty more significantly when compared to Δt.

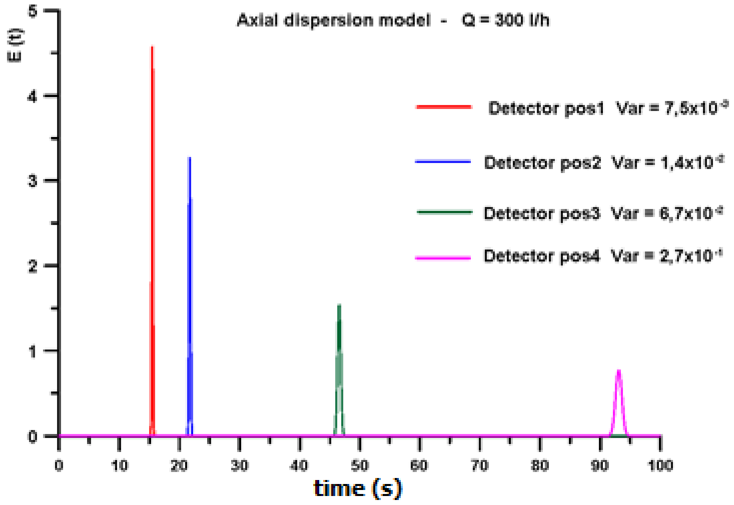

Figure 6: Width variation at half height of curve E (t) with increasing distance. Data obtained experimentally from the Radiotracers Laboratory (IEN, Brazil)[8]

3. RESULTS AND DISCUSSION

The results below refer to the variation in the number of photons collected by the detector as a function of the variation of the shield's geometric configuration. Table 1 shows the variation of the distance from the detector to the duct (d) keeping the collimation arrangement fixed. Table 2 shows the variation of detector shield collimation (D). The variation of the distance d and collimation values were performed based on the dimensions commonly used in the IEN Nuclear Energy Institute Radiotracers Laboratory. The distance and radius values ranged around 10% of the initial value.

Table 1: Variation in the number of photons with detector spacing.

Distance (cm)	Photons($\gamma/cm^2/s$)
5	1,90E+05
5,5	1,69E+05
6	1,52E+05
6,5	1,37E+05
7	1,23E+05

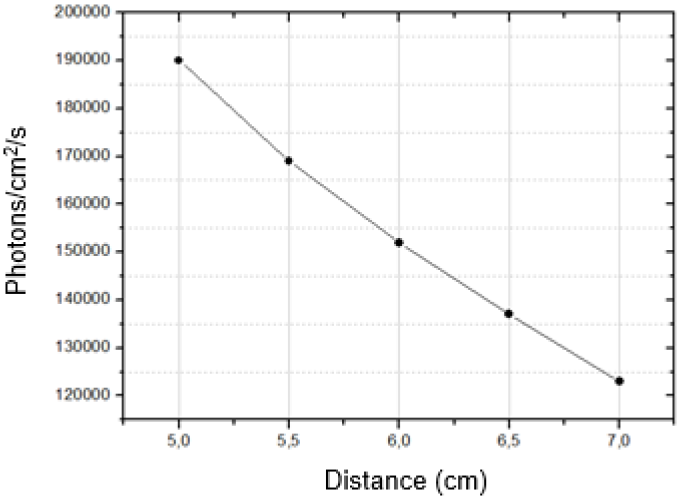

Figure 7: Graphical representation of photon number variation with detector offset.

Figure 7 and Table 1 show the decrease of photons felt by the detector detachment from the pipe. The values do not exactly obey the inverse square of distance law by the proximity of the source detector, and therefore cannot be considered as a point source.

Table 2 and Figure 8 demonstrate the increase in the number of photons when the detector area sensitive to photons. The variation in the decrease in the incidence of photon numbers is smaller when the area becomes smaller.

Table 2: Variation of photon number with decreasing solid angle

Radius Variation (cm)	Phtons($\gamma/cm^2/s$)
2,286	6,16E+05
2,032	4,86E+05
1,778	3,72E+05
1,524	2,74E+05
1,2	1,90E+05

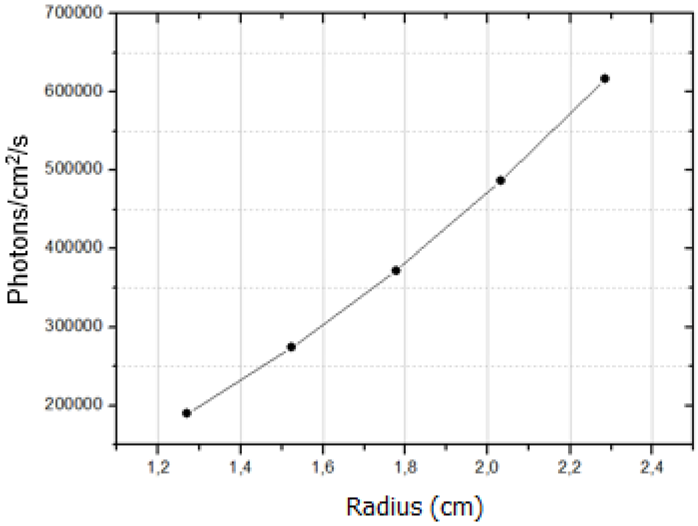

Figure 8: Graphical representation of photon number variation with decreasing solid angle

Performing a linear adjustment in the graphs of figures 7 and 8, the angular coefficient of 7 is greater than 8, making it possible to see that the incidence of photons is more affected by increasing distance than decreasing area.

It is important to note that the lack of collimation of the detector will culminate in the higher incidence of photons, however, this count will consider scattered photons, all background (BG) and any spurious radiation not coming from the source. This statement can be verified by comparing the curves in figure 9.

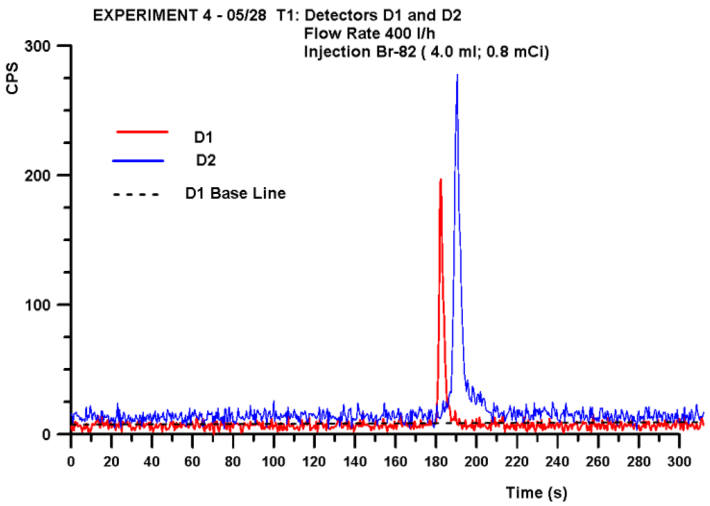

Figure 9: In blue the record of the passage of the radioactive cloud with collimation D1 in red collimation D2, where D1> D2. Significant change in baseline may be noted [8].

Therefore, when performing detector collimation, it should be noted that the number of photons should not be decreased to the extent that it is not possible to distinguish between the pulse and the background baseline. Figure 10 demonstrates that for the conditions shown in this paper, the radius should not be less than 0.05cm in order to differentiate the pulse from the BG line.

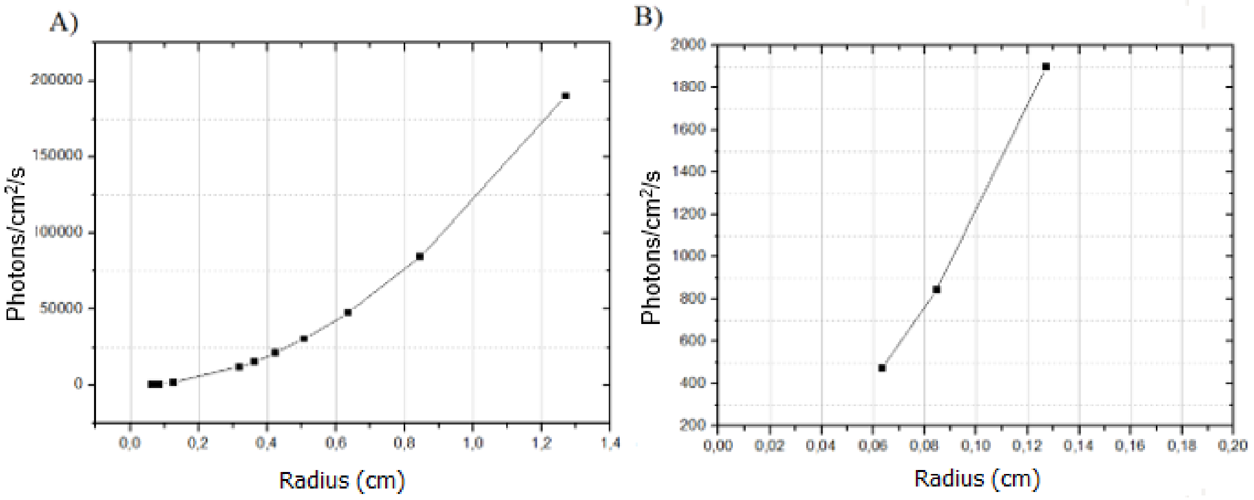

Figure 10: In A the decrease in the number of incident photons; in B enlargement of the region of the graph where the last three points are.

The collimation with a diameter value of 0.13 cm showed a large decrease in the quantity of photons indicating that the curve generated by the passage of the radioactive cloud is just above the baseline of the BG.

4. CONCLUSIONS

The previous study of the flow velocity in the duct and the choice of the ideal tracer with the appropriate dispersion coefficient for the study are important for the measurement with uncertainty values appropriate to the norm. The computer simulation demonstrated significant changes that can directly influence the uncertainty values, preventing the measurement to be below the desired limits. shielding parameters should be uniform across all detectors that will measure so that the adjustments are appropriate to the detector efficiency.

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