2015 International Nuclear Atlantic Conference - INAC 2015
São Paulo, SP, Brazil, October 4-9, 2015
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-06-9**

DETERMINATION OF THE REGION OF SENSITIVITY OF A SCINTILLATOR DETECTOR NaI(Tl) (2 X 2)" SUBMERGED IN WATER

Ricardo E. de Miranda Candeiro[1], Luis E. Barreira Brandão[2], Elder M. de Souza[3]

[1] Comissão Nacional de Energia Nuclear
Distrito de Fortaleza (CNEN/DIFOR)
Av. Santos Dumont, 3610, Aldeota.
CEP: 60150-162,
Fortaleza – CE
ricardocandeiro@cnen.gov.br

[2] Instituto de Engenharia Nuclear (IEN/CNEN)
Rua Hélio de Almeida, 75, Ilha do Fundão.
CEP: 21945-970,
Rio de Janeiro – RJ
brandao@ien.gov.br

[3] Instituto de Radioproteção e Dosimetria
Av. Salvador Allende S/N, Barra da Tijuca.
CEP: 22783-127,
Rio de Janeiro - RJ
elder@ird.gov.br

ABSTRACT

This paper presents the development of a methodology used to calculate the region of sensitivity of a scintillator detector NaI (Tl) (2 x 2)" submerged in water. The procedure was based in the simulation of a radioactive cloud (radiotracer), emitting anisotropy photons, that approximate of the submerged detector. This detector will be fixed into large industrial mixing. The detector registers the increase of the number of photons, because the solid angle and concentration of radiotracer also increase. Considering the absence of data in the literature, the methodology presented has your adequacy verified indirectly with a simple geometry that consists in a circular detector and one disk source in front of the detector. The theoretical and experimental tests were used for the determination of the region of sensitivity. The Simpson integration Method was used for the solid angle calculations and Monte Carlo Method was used for the validation of the employed geometry. The two methods were compared showing an error between 1.5% and 5%. In the experimental test was employed one disk source of the ^{137}Cs, with radius of 1.2 cm and a collimated and not collimated scintillator detector NaI (Tl) (2 x 2)". The counts were registered in three different plans enabling to determine the region of sensitivity of the detector.

1. INTRODUCTION

In many tracer investigations the activity measurements are performed in large volumes of liquids or gases with homogeneously distributed dissolved tracers. When planning such work it is of great value to have possibilities for calculating the counting rate obtained as a function of the amount of tracer added to a known volume of the solvent. This is possible e.g. for tracers emitting gamma rays in "infinite" volumes under assumption of exponential absorption, which is an approximation [1, 2].

2. METHODOLOGY

The radiotracer technique is based fundamentally on experimental curves that are measured from the entry stimulus, through of the insertion in the system of a determined quantity of marked materials (radiotracer). This procedure is called stimulus-response technique, where this sign of entrance is named of stimulus, and that, after to be homogenized (due has affinity physical and chemical equal between tracer and the main stream), it acquires the same characteristics of the main stream, where through the record of the detectors of radiation is done the call response of the system [1].

Among different types of detectors used in the field of radiotracers, the commonly used are scintillation detectors NaI because of its high detection efficiency for gamma rays and be portable [3]. In general, the detectors can be positioned inside and outside of an industrial tank [4].

In this particular case, the main objective was to observe the movement of the radiotracer inside a tank through a scintillator detector submerged. The principle is that as the material will spread and mingling in half, the concentration of radioactive material will modifying the time and assuming the behavior of a “radioactive cloud” emitting radiation of anisotropic shape.

From a distance the detector will begin to register the passage of radioactive material , that even before the cloud reaches the detector, therefore, the great difficulty lies in determining to the detector sensitivity region since with the geometry it involves this type of case is complex.

2.1. Solid Angle

The correct and efficient recording of the incident photons collected by a submerged scintillator detector without collimation is of fundamental importance for the evaluation of an industrial tank and is a step that depends not only on calibration of all acquisition and measurement system, as well as geometric factors the source/system (radioactive cloud)/ detector.

As the radioactive cloud approaches the detector is a considerable increase in the registration number of incident photons, because the solid angle and the concentration of radiotracer vary. Another important factor is the density of the mean, depending on the material, the effect of absorption and scattering the liquid contribute considerably counting rate. Also the energy of the radiation emitted by the radiotracer must be considered.

Thus, depending on the geometry of the detector crystal, the geometric shape of the source and the distance between them, the sensitive region varies and the fraction of radiation emitted by the radioactive material that reaches the detector is directly proportional to the solid angle (Ω).To calculate the solid angle was considered a point source and a detector with circular face, so [5, 6, 7, 8]:

$$\Omega = \iint_A \frac{\cos\theta}{d^2}\, dA \qquad (1)$$

where:

θ - angle between the normal of the surface element and the direction of the source.
d - is the distance between the source and the surface element dA.
A - detector surface.

If the radiation source emits photons isotropically, the geometric factor (F_g) is calculated as follows:

$$F_g = \frac{\Omega}{4 \cdot \pi} \quad (2)$$

The relationship between source - detector determines the sensitivity region, and in which case the use of collimation or not, greatly influences. For example, for a collimated detector, the solid angle is reduced and as a consequence, the number of detected photons also decreases.

Any for plane or volumetric sources when the source position is not collinear with the front face of the detector, the mathematical development for calculating the solid angle is complex. This requires the use of numerical methods for solving the equation 1 [5, 6].

The identification of the highest sensitivity region for the submerged detector can be evaluated using a standard radioactive source and a detector scintillator without collimation.

For the specific case of a source in the form of circular disk of the radius, R_s, emitting isotropically, N particles/m^2.seg, being at a distance, h, away from the central axis of the circular detector of the radius, R_d, is shown a coordinate system for calculating the solid angle [6, 9].

The value of the solid angle was calculated by solving the integral equation 3 by Simpson's method and the Monte Carlo method, where through simulation were considering factors such as radius from the source, radius of the detector and the geometries associated with them.

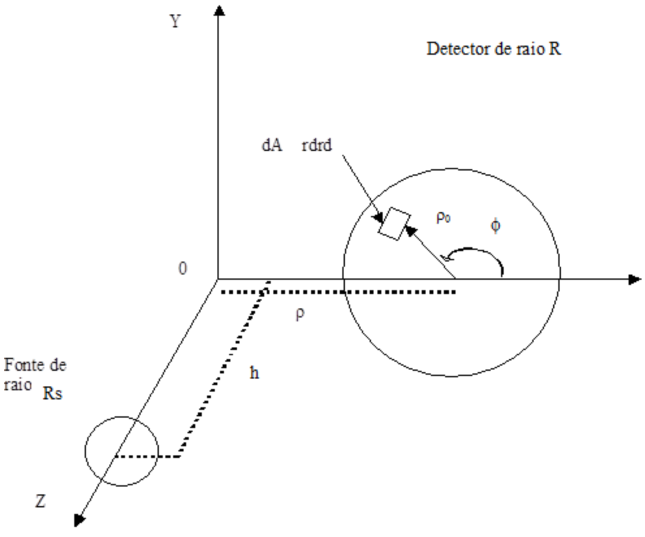

Figure 1: Solid angle subtended at a point by a circular disk.

The calculation of solid angle considering a circular source and circular detector with non-collinear axis is shown in Figure 1 and calculated in equation 3 below [5, 6]:

$$\Omega = 2\pi - \frac{4}{\pi \cdot R_S^2} \int_0^{R_S} q\,dq \int_0^{\pi} h\,d\psi \int_0^{\pi} d\phi \frac{h^2 + \rho^2 + R_d \cdot \rho \cdot \cos\phi}{h^2 + \rho^2 - \rho^2 \cdot \cos^2\phi} \cdot \left(h^2 + \rho^2 + R_d^2 + 2 \cdot R_d \cdot \rho \cdot \cos\phi\right)^{-\frac{1}{2}} \quad (3)$$

Where:

ρ_0 - distance between the center of the detector to a point on any disk area.
R_s - radius of the source in the form of circular disk.
R_d - radius of the circular detector.
ρ - distance from the center of the detector to the Cartesian axis.
h - distance from the center of the source to the Cartesian axis.

2.2. Cloud simulation radiotracer

The sensitivity region of the submerged detector was determined using a ^{137}Cs standard source positioned at different points of the separation tank in order to simulate the passage of the radioactive cloud next to scintillator detector [10].

2.2.1. Tank phase separation

A rectangular tank employed for separating liquid phases (organic/aqueous) was used to study the sensitive region of the submerged detector and mapping the displacement profile of the radioactive material [10].

The tank shown in Figure 2, consists of two rectangular compartments, one lower (24 x 12 x 12) cm which has the function mixer. It has the fluid inlet in the inferior part and outlet in the superior part. It is connected to the second largest compartment (90 x 24 x 33) cm, designed to allow phase separation [10].

This last compartment has the output of more dense fluid in the inferior part and the lighter at the top.

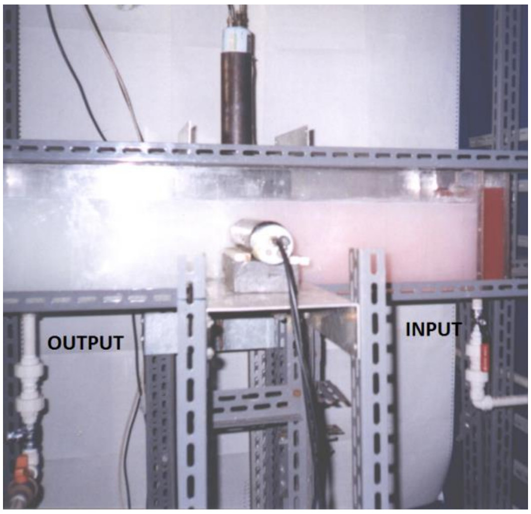

Figure 2: Tank phase separation.

2.2.2. Determination of the sensitivity region – experimental test

Some parameters were considered for simulation of the cloud such as: size and positioning between source and detector.

The experiment consisted of fixing a disk source in different positions and heights. The detector was set to 31 cm from the inlet of the tank. The division of the tank for positioning the radioactive source comprised three levels (Δy): upper, middle and lower, and each plan were fixed 12 positions (Δx), with the zero position defined as the same axis to the source and the detector. The variation, Δx, between one position and another is constant and equal to 7.75 cm. The variation, Δy, being the higher, intermediate and lower plans fixed to 6.0, 14.5 and 23.0, respectively, of the radiation detector. The position, Δz, was central to the tank, with 33 cm [10].

The Figure 3 shows the arrangement of these positions along the tank and for each position was measured background radiation, and all acquisition the total time of the measures was kept the same.

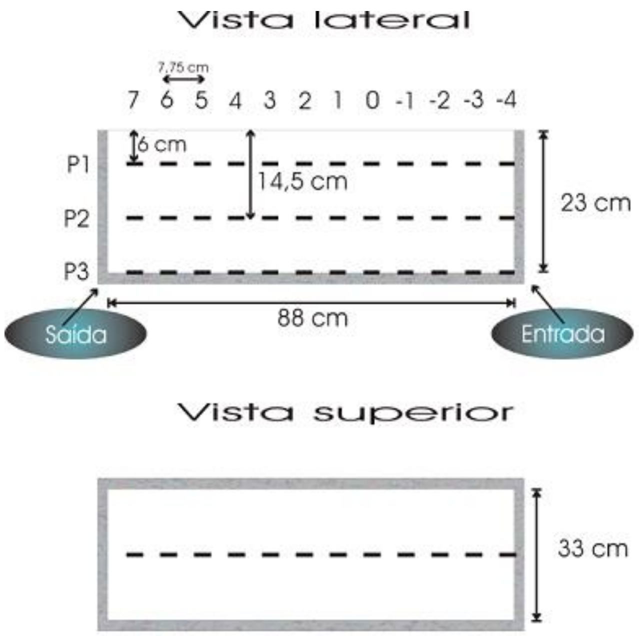

Figure 3: Position of the source along the phase separation tank

3. RESULTS AND DISCUSSION

3.1. Theoretical tests – Simpson's method and the Monte Carlo simulation

As mentioned in Section 2.1, the equation 3 was used to calculate the solid angle using Simpson's method and Monte Carlo simulation [10]. For both methods, the amount of the solid angle and shown in Figure 4, where it checks that the results are well consistent. The errors associated with the two methods ranging between 1.5 % and 5.0 %.

In Figure 4, it was observed that from position around -2 and 2 , corresponding to 20 cm from source/detector, the solid angle is very small, decreasing the number of photons recorded by the detector. From this distance the net counting rate that the background radiation level.

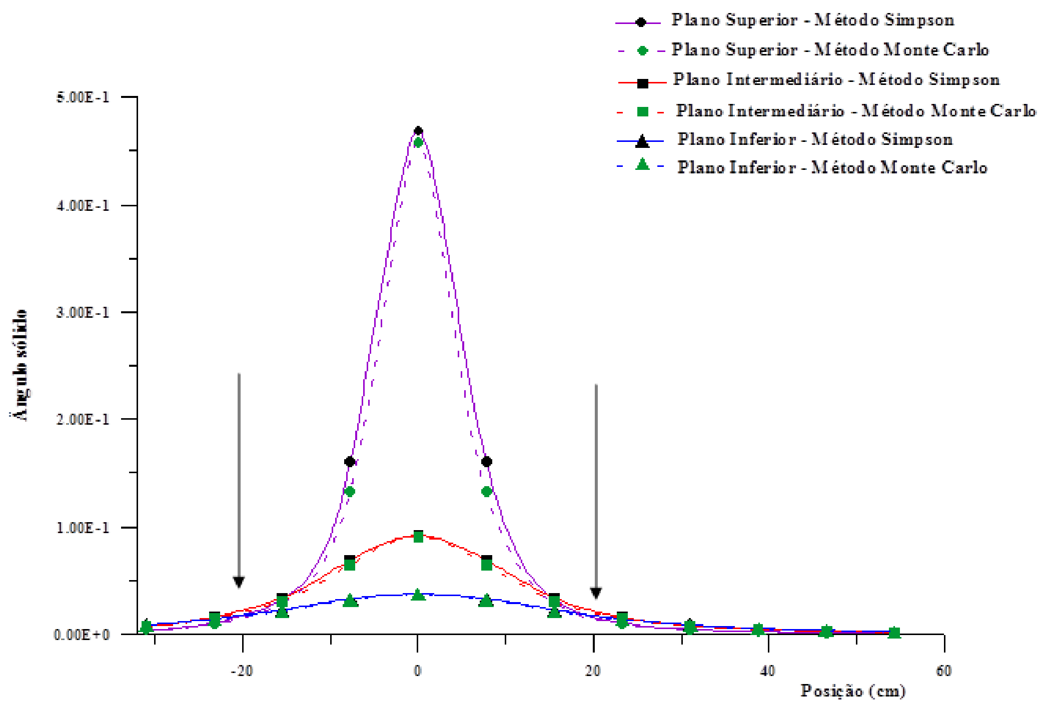

Figure 4: Solid angles of the plans: upper, intermediate and lower; calculated by the Simpson's method and Monte Carlo simulation.

In real situations, for a detector without a collimator, the registered number of incident photons will be greater than in the case of a collimated detector, because as the scintillator crystal is fully exposed.

3.2. Solid angle calculation and determination of sensitivity region of the detector

To determine the sensitivity region of the submerged detector measurements were performed with a ^{137}Cs sealed source (E_{γ} = 662 keV), in form circular disk of the radius 1.2 cm and scintillator detector NaI, (2 x 2)", with and without collimation. The net count rates, recorded at each point of different planes, enabled the building of the curves determining the sensitive region to record photons as a function of source/detector system geometry.

As shown in Figure 5, in all plans, the net count rate for the not collimated detector is greater than a collimated detector, because there is an increase in the solid angle resulting in enlargement of the sensitive area of the detector. So for the two geometries source/detector, the sensitivity region of the registration of photons is around positions -3 and 3, this is equivalent to approximately (23 ± 0.5) cm distance between source/detector in the three plans.

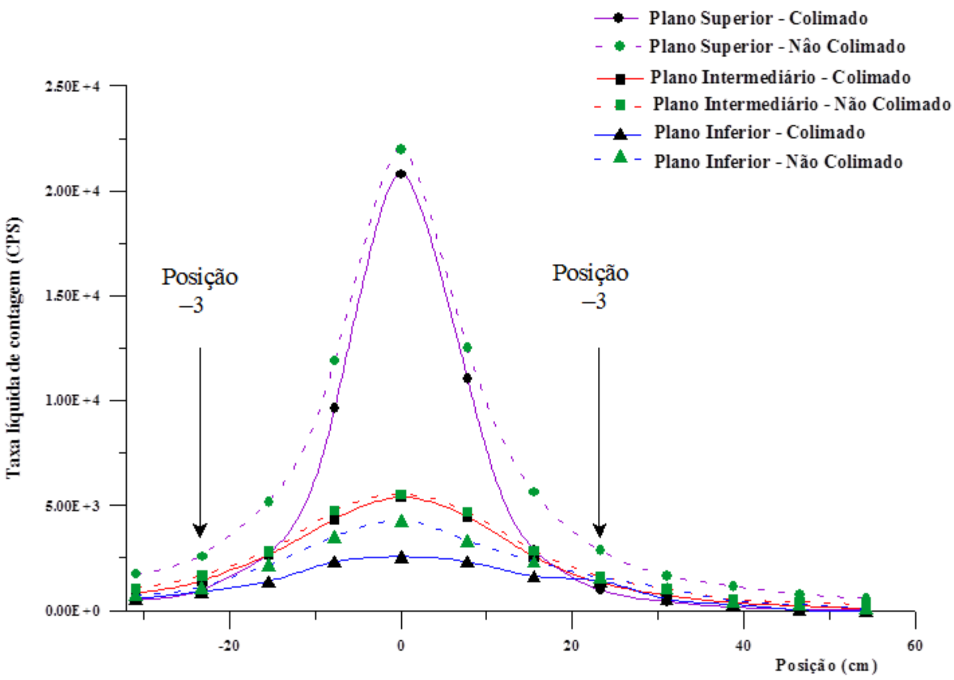

Figure 5: Curves related to the sensitivity regions for the collimated and non collimated detector in the positions 1, 2 and 3.

4. CONCLUSIONS

Despite the sensitivity of regions are nearby, there are differences between the two. As an example, assume a system in which there is canalization, the cloud radioactive with a specific geometric distribution, has a higher record of photons in the areas around to the detector, which corresponds to the superior plane, but if there is a concentrated fraction of radioactive material canalized in a lower plane, the intensity of photons will also be high, this complicates the analysis of the responses recorded by the detector not collimated.

Through the results obtained by simulation was possible to build the submerged unit containing within a scintillator detector.

The submerged unit was used in the displacement profile study of an industrial tank and was efficient with respect to the registration of the movement of the radiotracer, according to their sensitivity region.

ACKNOWLEDGMENTS

The authors would like to thank the Institute of Nuclear Engineering for their collaboration, specifically the laboratories of radiotracers, Cyclotron division.

REFERENCES

1. [1] CHOLETTE, A., CLOUTIER, L. “Mixing Efficiency Determinations for Continuous Flow Systems”, *The Canadian Journal of Chemical Engineering*, **Vol. 37**, pp. 105-112, (1959).

2. Revista BRASIL NUCLEAR “Fontes Radioativas Garantem a Qualidade dos Processos Industriais” n. 25, ano 9, pp. 24-25, Jun-Ago (2002).
3. KNOLL, G.F., *Radiation Detection and Measurement*. 2 ed, John Wiley & Sons, (1989).
4. TUGRUL, A.B. “A New Approach for Calculating the Geometry Factor for Flow Measurements with Radioactive Tracers”, *Kerntechnik*, Vol. **60**, pp. 265-266, (1995).
5. OBLOZINSKY, P., RIBANSKY, I. “The Solid Angle at a Disk Source by a Non-Parallel Disk Detector”, *Nucl. Instrum. And Meth.* **Vol. 94**, pp. 187-188, (1971).
6. CARVALHO, M. R., SOARES, A. J. “Determinação do Fator Geométrico em Monitores de Gases Radioativos”, *Revista de Física Aplicada e Instrumentação,* **Vol. 11**, n.2, pp. 65-70, junho, (1996).
7. GARDNER, R, P., CARNESALE, A. “The Solid Angle Subtended at a Point by a Circular Disk”, *Nuclear Instruments and Methods,* **Vol. 73**, pp. 228-230, (1969).
8. TSOULFANIDIS, N., *Measurement and Detection of Radiation*. McGraw-Hill Int. Edit, (1983).
9. RUBY, L., RECHEN, J. B. “A simpler Approach to the Geometrical Efficiency of a Parallel-Disk Source and Detector System”, *Nucl. Instrum. And Meth.* **Vol. 58**, pp. 345-346, (1968).
10. R.E.M. Candeiro, *Medida de Tempo de Residência em Tanques Industriais, usando uma Unidade Estanque para Detector Estanque Submerso*. Tese de Mestrado, COPPE/UFRJ, Rio de Janeiro, Brasil (2003).