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STUDY OF THE SOURCE-DETECTOR SYSTEM GEOMETRY USING THE MCNP-X CODE IN THE FLOWRATE MEASUREMENT WITH RADIOACTIVE TRACERS.

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ABSTRACT

The use radioactive tracers for flow rate measurement is applied to a great variety of situations, however the accuracy of the technique is highly dependent of the adequate choice of the experimental measurement conditions. To measure flow rate of fluids in ducts partially filled, is necessary to measure the fluid flow velocity and the fluid height. The flow velocity can be measured with the cross correlation function and the fluid level, with a fluid level meter system. One of the error factors when measuring flow rate, is on the correct setting of the source-detector of the fluid level meter system. The goal of the present work is to establish by mean of MCNP-X code simulations the experimental parameters to measure the fluid level [3]. The experimental tests will be realized in a flow rate system of 10 mm of diameter of acrylic tube for water and oil as fluids. The radioactive tracer to be used is the ^{82}Br and for the detection will be employed two 1” NaI(Tl) scintillator detectors, shielded with collimators of 0.5 cm and 1 cm of circular aperture diameter .

1. INTRODUCTION

One of the most important measurement in industry is the accurate detection of the flow rates of liquids, gases, and solids. The accuracy of the measurements is important due to the economical profits are closely related to the uncertainty of this measurement. There are a great variety of instruments and techniques designed to measure flow rate and the choice of one of them is not an easy task because of the several physical and chemical parameter to be to take into account. Each one has its advantages and disadvantages, and selecting a proper technique depends on its specific applications.

The nuclear techniques has the advantages that can be applied to a great variety of situations but in each case the accuracy must be considered in detail. When is measured flow rate in pipes partially filled is needed to measure the fluid flow velocity and the fluid height.The fluid flow velocity can be measured using the cross correlation function [5], equation 1, and the fluid level, which is the measuring of height of the fluid, defining the position of the interface with a level meter system consisting of an external ^{137}Cs source that is the most commonly used with a NaI(Tl) scintillator detector. The objective of this work is to establish by mean of MCNP-X code simulations the experimental parameters to measure the fluid level.

$$R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T x(t)y(t+\tau)\,dt \tag{1}$$

2. LEVEL MEASUREMENT

Measure level is defined as "the determination of the position of an existing interface between two media", where the media are liquid/gas, solid/gas, immiscible liquid/liquid. Level is simply a measuring of height, defining the position of the interface. The measure is often converted to a gravimetric or volumetric quantity. Measuring the level is a way to determine the volume fractions, eg. the gas fraction of the flow components. The void fraction is defined as the gas volume fraction divided by the total volume of the flow [1].

There are two methods to measure level, Direct method and Indirect Method. In order to measure a level of a substance, directly or indirectly the interface must be definite. For instance, the point at which water meets air in an open channel, tank or pipe. If the liquids that mix do not form clearly defined interfaces, the measure of level is a difficult task.

The direct method is simply, straightforward and economical, and it uses a direct measurement of the distance (usually height) for local indication. Indirect method of level measurement depend on the material having a physical property which can be measured and related to level.

2.1. Gamma-ray Densitometer

Nuclear radiation devices used to measure level are fundamentally densitometers and their basic components are: a radiation source and a detector with an associated electronic. When a parallel beam of monoenergetic photons with intensity I_0 strikes a target of a material of thickness t and the linear attenuation coefficient μ, the number of photons $I(t)$ emerging without having interacted in the target is given by [4]

$$I(t) = I_0.e^{-\mu t} \tag{2}$$

The intensity of the radiation also decreases with r^2 which is the distance between source an the detector. For level measurements in tanks or pipes, the number of photons detected depends upon the thickness of material between the source and the detector. To determine the fraction of volume is necessary to measure the linear attenuation coefficient on the measured volume over the cross-section of the pipe. The most common measurement configuration for single-beam gamma densitometer is shown on figure 1.

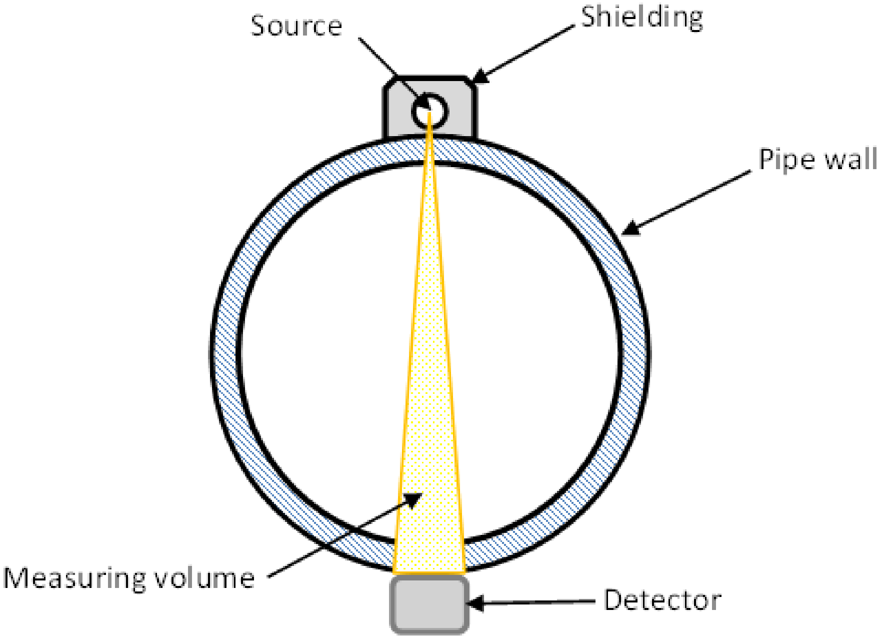

Figure 1: Cross section view of single-beam gamma densitometer with point source and detector located diametrically opposite each other

When is used a single-beam densitometer as shown on figure 1, the results will vary with the flow regime, since the measurement cross-section volume normally is less than that covered by pipe cross-section [1].

3. FLOW REGIME DEPENDENCE OF THE GAMMA RAY DENSITOMETERS

In this work are examined the fluid level only for stratified flow regime. The measurement volume depends of the collimation of the gamma ray beam and the area of the detector. The linear attenuation coefficient is the same over the cross-section. Measuring the attenuation of the gamma ray beam is possible to obtain the volume fraction of the flow.

When the detector diameter is smaller than the pipe diameter and the pipe wall is thin, and d_1 is parallel d then the volume measurement can be defined as a cone in the flow as shown in Fig. 2.

The volume fraction on the direction of the source-detector axis on the air-water interface is not symmetrical and will vary for the stratified flow, it means, that the result if the source is on top and the detector below (top-bottom configuration) will be different that for bottom-top configuration. In the top-bottom configuration and stratified flow the void fraction in the measurement volume for narrow beam can be written as [1]:

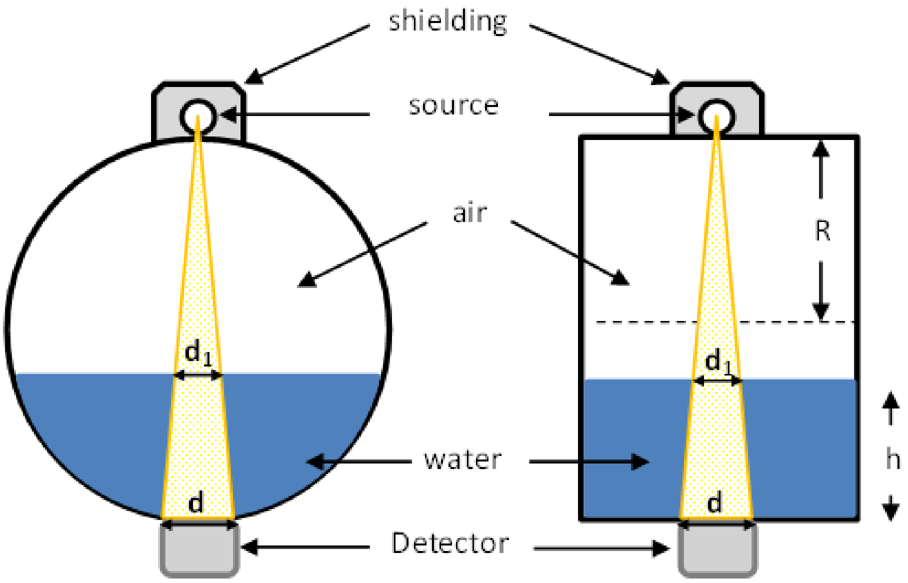

Figure 2: Cross-sectional and lateral views of stratified flow

$$\alpha_w = \frac{(2R-h)^3}{8R^3} \tag{3}$$

where h is the water level and R is the radius pipe.

The fraction volume for the bottom-top configuration is different to that top-bottom configuration and the fraction of the measurement volume is calculated for the expression:

$$\alpha_w = \frac{(2R-h)^3}{8R^3}.(h^2 + 2R.h + 4R^2) \tag{4}$$

In the case of stratified flow and a parallel beam the fraction is:

$$\alpha_w = 1 - \frac{h}{2R} \tag{5}$$

The single beam gamma-ray densitometer is based in the principle of express the volume fraction in terms of transmitted intensity which is the number of photons detected in the full energy peak in the measurement period time. The volume fraction can be calculated as [1]:

$$\alpha = \frac{ln(\frac{I_{mix}}{I_{water}})}{ln(\frac{I_{air}}{I_{water}})} \tag{6}$$

where I_{air} and I_{water}, correspond to 100% air and 100% water respectively. The results based on the equation 6 assumes that the contribution of the scattered photons detected is negligible.

4. MCNP-X CODE

The MCNP-X code is a general purpose Monte Carlo radiation transport code developed at Los Alamos National Laboratory and designed to track different types of particles (neutrons, electrons, gamma rays, etc). The code obtains the solutions of a problem simulating individual particles trajectories and recording some aspects of their average behaviour.

The probability distributions governing these events are statistically sampled to describe the total phenomenon and the sample process is based on the selection of pseudo-random numbers. The process consists of following each of many particles since emission from source until each reaches an energy threshold; the particle energy is transferred to the medium by absorption, escape, etc.

The MCNP-X code can be used as in this work to simulate the interactions of the gamma-rays with the different materials of the geometry that is been studied.

5. SIMULATIONS

This work is based on Monte Carlo simulations of a system source-detector to measure the water level in an acrylic pipe with radius of 9.5 cm.

Three cases are simulated, two for a point source, a pencil beam in which the gamma-ray beam of the source is very narrow and a second one where the gamma-ray beam is with an angle of 10 rad in relation to the vertical incident axis (cone beam). Another one case for the disc source in which the gamma-ray beam is parallel to vertical axis (parallel beam). Every one of the cases simulated was realized with 10^6 histories in the MCNP-X code. The source and the detector are placed diametrically opposite each other for every case, as shown on Fig. 3.

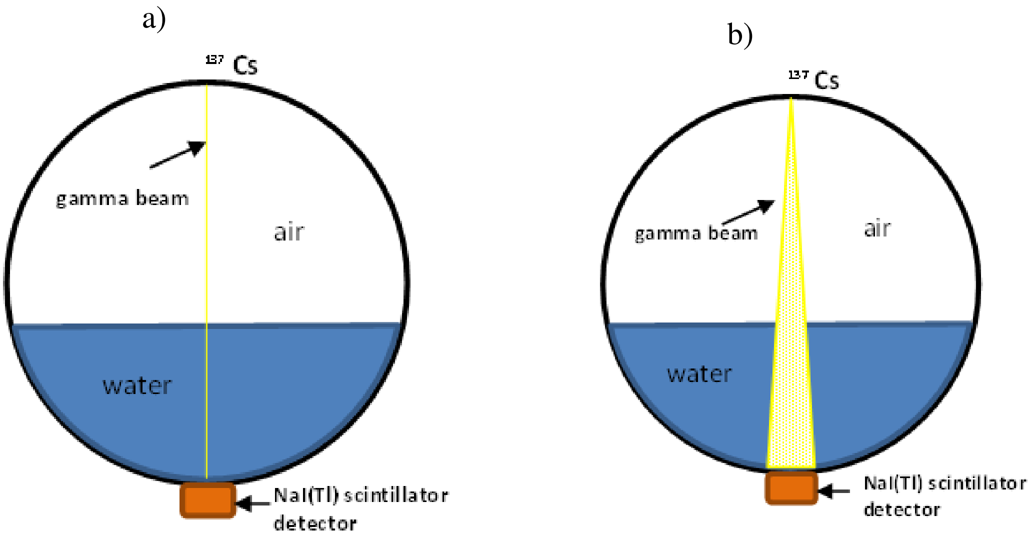

Figure 3: Basic geometries used in this work. a) Pencil Beam cross-sectional view. b) Cone Beam cross-sectional view.

For the simulations was used a ^{137}Cs source of 662 keV of energy and a modeled NaI(Tl) detector of 1”x1” [2].

5.1. Point Source (Pencil beam)

In this simulation a gamma-ray beam is very narrow and were made 17 simulations, one for each level of water, from 1cm until 17 cm. The number of counts are registered by the scintillator detector of 1”x1” in the full energy peak region of 662 keV for each level of water. All the results for this simulation are represented bellow in the figure 4:

5.2. Point Source (Cone beam)

This simulation consists as two cases before of 17 simulations for each level of water from 1 cm to 17 cm of height. In this simulation the gamma-ray beam is not a parallel one beam but it has a little aperture simulating a conical beam. The number of counts are registered by the scintillator detector of 1”x1” in the full energy peak region of 662 keV for each level of water. All the results for this simulation are represented bellow in the Fig. 4:

5.3. Disc Source (Pencil beam)

This simulation consists as the case before of 17 simulations for each level of water from 1 cm to 17 cm. This simulations were made with a disc source of 5 mm diameter. The gamma-ray beam is a parallel one as the pencil beam case. The number of counts are registered by the scintillator detector of 1”x1” in the full energy peak region of 662 keV for each level of water. All the results for this simulation are represented bellow in the Fig. 4:

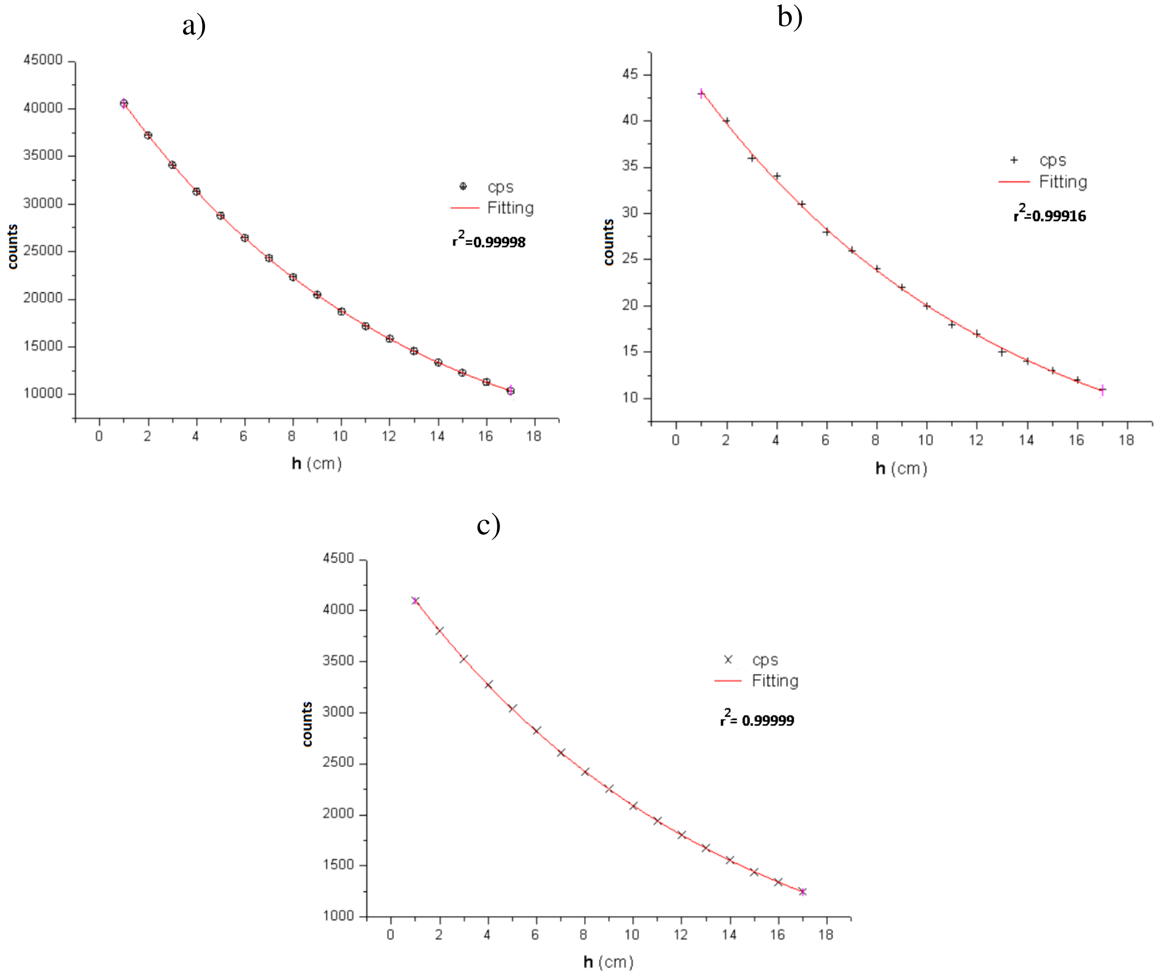

Figure 4: Counts vs water level for: a) Pencil Beam. b) Cone Beam. c) Disc source Parallel Beam. In every case the result of the exponential negative fitting r^2 is placed to the right side of the figure

6. CONCLUSIONS

The three figures has a similar behaviour, the counting decreasing with the increment of level water. The count recorded in the cone case for point source is lower than the other two cases. In this case a source with low collimation will need a higher activity. A disc source register few counts too and in the practice a source with a parallel beam is not possible to use.

This work is still running and we need to make more evaluations to reach a right source-detector system to measure fluid level.

REFERENCES

1. E. Åbro, G. A Johansen "Improved void fraction determination by means of multibeam gamma-ray attenuation measurements", *Flow Measurement and Instrumentation*, **10**, pp. 99–108, (1999).

2. C.M. Salgado, L.E. Brandão "Validation of NaI(Tl) detector's model developed with MCNP-X code", *Progress in Nuclear Energy*, **59**, pp. 19–25, (2012).
3. C.M. Salgado, L.E. Brandão "Study of volume fractions for stratified and annular regime in multiphase flows using gamma-rays and artificial neural network" , 5^{th} *International Nuclear Atlantic Conference*, Santos, SP,Brazil, (2007).
4. N. Tsoulfanidis and S. Landsberger, *Measurement and Detection of Radiation*, CRC Press, Boca Raton, Florida, United States of America (2011).
5. E.J. Avilan, V. Reis "Evaluation of cross correlation technique to measure flow in Pipes of the Oil industry", 8^{th} *International Nuclear Atlantic Conference*, Recife, PE, Brazil, (2013).