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Optimization of the Position of the CR-39 Polycarbonate Sheet Inside the Solid State Track Detector "Measuring Device" Through Computational Fluid Dynamics Technique

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ABSTRACT

The "measuring device" is one of the most reliable, efficient and economic indoor radon dosimeters that exist. This device was developed by the Proyecto de Aplicaciones de la Dosimetría (PAD) at the Physics Institute of UNAM (IF-UNAM) and consists of a transparent rigid plastic cup, a CR-39 polycarbonate sheet and a standard size metal clip that is used to hold the polycarbonate in the center of the cup. The cup is wrapped and covered with a low-density polyurethane protector in order to prevent the detector from being irradiated by ionizing particles found in the environment. In this work, an analysis was carried out that allowed to understand how the radon concentration on the polycarbonate sheet varies when its height is changed with respect to the base of the plastic cup, in order to understand what position increase the probability of interaction between radon and the surface of the detector. For the development of this work, four computational simulations were performed with the technique called Computational Fluid Dynamics (CFD). The results shows that as the CR-39 is positioned more closed to the base of the cup, the probability of interaction of the radon and the detector increase. Based on these results it is concluded that, when there is a limit in the time in which a measuring device can be placed in the zone where it is desired to quantify indoor radon, it is recommended to collocated the CR-39 at 1 cm with respect to the base of the cup.

1. Introduction

There are multiple techniques to detect ionizing charged particles, being track detectors one of the most used due to their effectiveness, simplicity and economic cost. Some of these techniques are the Wilson chamber, the bubble chamber, the spark chamber, photonuclear emulsions or solid-state track detectors. In this technique, when some semiconductor and insulating materials interacts with charged ionizing particles, it creates fine patterns of intense damage inside them on an atomic scale. This pattern of intense damage is called a track [1]. It was in the late 1950s and early 1960s that this phenomenon was scientifically verified and since then, an effective detection technique has been developed to create a well-established methodology for the quantification of ionizing charged particles. Today, this methodology is known as the Nuclear Track Methodology [2] (NTM). This technique is used to record α particles, protons, heavy ions and fission fragments. Therefore, they are not used if it want to detect beta particles, X-rays or gamma rays. Solid state detectors can be used to measure ionizing radiation under specific conditions, such as for calibration purposes, measurement of environmental pollutants (such as indoor radon [3]) and for parameter evaluation. Other additional advantages of this methodology are its ease of use and its low cost, as it does not need sophisticated technologies to perform the measurements, in addition to the fact that it can be used in inaccessible places [4]. Possibly, the main advantage of this methodology is the fact that tracks can remain latent in the material for a long time until they are revealed.

There are various types of materials that can be used as nuclear track detectors. In general, it can classify these materials into organic and inorganic. Among the inorganic materials that can be used are mica, quartz, obsidian, silicon glass, ruby, sapphire, apatite or olivine. Among the organic materials that can be used are cellulose acetate, cellulose nitrate, cellulose butyrate, cellulose triacetate or the

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polycarbonates. One of the most widely used polycarbonates in NTM technique for the detection of ionizing particles is CR-39 [5].

The CR-39 detector, also known by the name of allyl diglycol carbonate (ADC), is a polycarbonate belonging to the thermostable reticular plastic polymers. It was invented in 1940 by the Columbia-Southern Chemical Corporation, a subsidiary of the Pittsburgh Plate Glass Company. The name comes from the abbreviation for "Columbia Resin # 39". CR-39 is a widely used material in the ophthalmology sector for the construction of lenses and in the aeronautical industry. It is a homogeneous solid material, optically transparent and sensitive to charged particles, its sensitivity range is from 5 to 1500 KeV/μm. Its chemical composition is $C_{12}H_{18}O_7$.

In the 1980s it was discovered that the CR-39 was an efficient α particle detector [6], with a very wide response to energy (between 0.3 and 13 MeV). In addition to its excellent efficiency for particle detection, is also used for the detection of protons ($\leq$ 10 MeV) [7], heavy ions, and for neutron detection with the use of moderators [8].

However, when it is required to measure the concentration of indoor radon it is not recommendable to place the CR-39 detector in the space to be quantified, because the material will be irradiated not only by the α particles emitted by radon-222 when it decays in polonium-218, but also by other ionizing particles that are in the environment [9]. Therefore, when observing the tracks generated in the material, it will not be possible to determine which ones were generated by α particles from ^{222}Rn and which by other charged particles. To solve this problem, researchers from the Dosimetry Applications Project (DAP) of the Physics Institute of UNAM developed a device known as a "measuring device" [10]. This device consists of a transparent rigid plastic cup with a volume of 330 ml, inside of this volume a CR-39 detector and a standard size metal clip are placed. The clip is used to freely hold and hang the detector in the center of the vessel. Finally, the vessel is wrapped and covered with a low-density polyurethane protector in order to prevent the detector from being irradiated by ionizing particles that do not belong to ^{222}Rn. Low-density polyurethane allows ^{222}Rn to enter in the interior of the vessel, but does not allow the passage of other substances that could generate other types of ionizing particles. The CR-39 used is purchased from the Lantrack® company and has dimensions of 1.8 cm high × 0.9 cm long and 750 μm wide. Each detector is identified with a number written on its surface with a laser beam and is supplied by the company with a 60 μm protective foil, in order to reduce the detector's exposure to background radiation and to protect it from damage caused for its manipulation.

It is evident that the polycarbonate is placed in the center of the cup so that its surface is irradiated evenly with respect to placing it near one of the walls of the glass, however, it is unknown if the height is a factor that could increase the probability of interaction of α particles with the polycarbonate, improving detection efficiency. Therefore, in this project it was analyzed whether it is possible to optimize the construction of this device. To develop this analysis, 4 simulations were performed using the computational fluid dynamics technique in the ANSYS FLUENT software [11]. Specifically, 4 simulations will be carried out. In each simulation the position of the height of the CR-39 within the cup will be modified. Then a mixture of ^{222}Rn-air will be emitted. Subsequently, the amount of radon that is concentrated in the surface of the CR-39 detector will be observed. Finally, it will be concluded if the height is a factor that could increase the detection efficiency of the measuring device. It is important to mention that one of these simulations will recreate the position presented by the detector in the devices armed by the DAP in the IF-UNAM.

2. Methodology

In order to solve the question described, it was decided to change the position of the CR-39 detector as follows: for the first simulation, the detector would be positioned 1 cm with respect to the base of the plastic cup. In the second simulation it would be 3 cm (position presented in the devices armed by the DAP at IF-UNAM). In the third simulation at 5 cm and in the fourth simulation at 7 cm.

To obtain a more accurate answer, it was decided to enclose the measuring device within a cylindrical concrete room (since the plastic cup has an almost cylindrical geometry, a proportional radiation is obtained over the entire surface of the measuring device). The device was placed in the center of the ceiling and a ^{222}Rn-air mixture was emitted from the floor of the room. The purpose of emanating a mixture of radon with air is to ensure that that the simulation is as close as possible to real conditions. No doors or windows were designed where the mixture could exit.

To develop the 4 simulations the following steps were carried out:

A. First, the exact dimensions of the rigid plastic cup used by the PAD IF-UNAM were measured, in order to reproduce its design in the Design Modeler module of the ANSYS software. The diameter of the base of the cup has a dimension of 5.3 cm, the diameter of the opening is 7.4 cm and the height of the cup is 10 cm. The cup has a thickness of 0.1 cm.
B. Then, the CR-39 was designed in the same module of the program, respecting the dimensions of the

polycarbonate acquired from the Lantrack® company. But unlike the particular geometry featured by the CR-39 of the company, the detector was designed with a rectangular geometry. Figure 1 shows two images, image a) shows the rigid plastic cup with the polycarbonate inside held by a clip and image b) shows the device designed in the Design Modeler module.

C. Afterwards, the cylindrical room that would enclose the measuring device was designed. With a diameter of 1 m and height of 1.1 m it can be obtain reliable results but reduce the calculation time necessary for the computer processor to execute the simulations. Figure 2 presents the measuring device inside the cylindrical room.

D. The next step was to construct the meshing of all the geometries, that is, to divide the figure into nodes so that the program can perform the corresponding calculations. Mesh construction was developed in the Mesh module of the program.

E. To perform correctly the simulation, the properties of each of the components involved in the simulation were introduced into the ANSYS FLUENT software: the CR-39 detector (special polycarbonate), the rigid plastic cup (polystyrene), the clip (steel), the wall of the cylindrical room (concrete), the ^{222}Rn and the air. Table 1 presents the properties entered in the software for each of the components used.

F. Finally, the emission conditions of the ^{222}Rn-air mixture were entered and the simulation was executed. Table 2 presents the parameters introduced in the software for the mixture.

G. All the conditions shown were repeated for the other 3 simulations, except for the height of the CR-39 with respect to the base of the plastic cup.

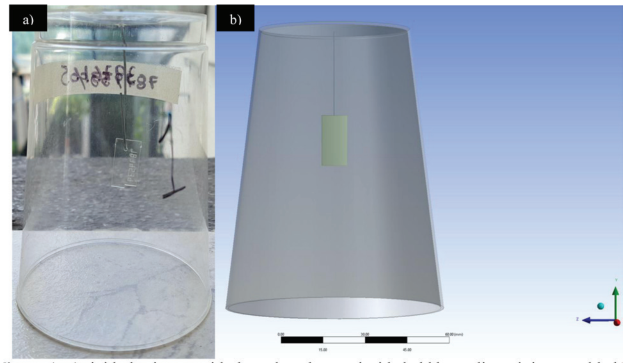

Figure 1: a) rigid plastic cup with the polycarbonate inside held by a clip as it is assembled by the PAD IF-UNAM. b) device designed in ANSYS Design Modeler module.

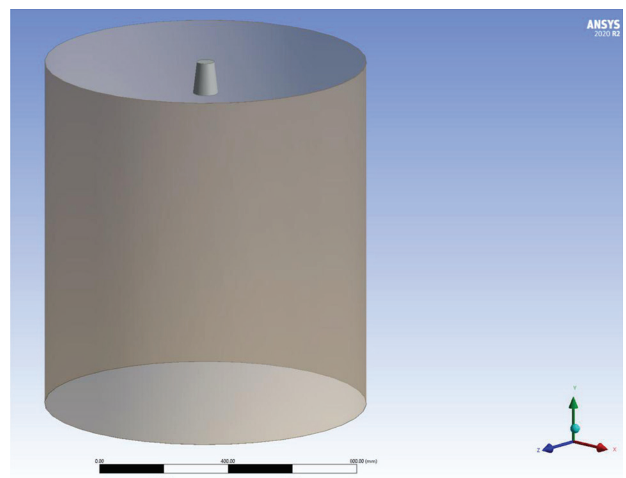

Figure 2: Measuring device inside the cylindrical room.

Table 1: Properties entered in ANSYS software for CR-39, polystyrene, steel, concrete, ^{222}Rn and air.

Property	CR-39	Polystyrene	Steel	Concrete	^{222}Rn	Air
Density (kgm^{-3})	1310	45	8030	2100	9.73	1.225
Heat capacity ($j/kg^{-1}k^{-1}$)	2302.74	1500	502.48	840	93.55	1006.43
Thermal conductivity ($w/m^{-1}k^{-1}$)	0.2091	0.033	16.27	1.4	0.0036	0.024
Viscosity ($kgm^{-1}s^{-1}$)	-	-	-	-	2.445×10^{-5}	1.789×10^{-5}
Molecular weight ($kgkmol^{-1}$)	-	-	-	-	222	28.966

Table 2: Parameters introduced in the software for the emission of ^{222}Rn-air mixture.

Parameter	Specification
Mass flow rate for a max. concentration of 1000 Bq / m^3	3.175 x 10^{-22}kg / s
Temperature of the mixture	293.15 k
Direction specification method	Normal to boundary
^{222}Rn mass fraction	0.8882
Air mass fraction	0.1118

3. Results

Figure 3 presents 4 images that show the results obtained in the simulations and corresponds to the radon concentration that the CR-39 detector registered on its surface. Image a) shows the result when the CR-39 detector was positioned 1 cm from the base of the plastic cup. Image b) when positioned at 3 cm(position presented in the devices armed by the DAP), image c) when positioned at 5 cm and image d) when positioned at 7 cm.

It is important to mention that the low radon concentrations observed in Figure 3 are due to the fact that a mass fraction of ^{222}Rn was emanated together with a mass fraction of air, so radon was rapidly attenuated and very little of this gas interacted with the detector. However, this fact allows us to observe a more realistic behavior (comparing it with the possibility of emitting only ^{222}Rn). In addition to the fact that for the purpose of this work the quantity registered by the CR-39 detectors is not important, but rather to compare these quantities between the four detectors.

As can be seen in Figure 3, the CR-39 detector that registered the highest amount of radon concentration was the one that was placed 1 cm from the base of the plastic cup and the one that received the least amount was the one that was placed at 7 cm. This means that as the detector is positioned closer to the base of the cup, the number of interactions of the CR-39´s surface with α particles from ^{222}Rn increases.

This behavior is possibly due to the fact that the radon that enters the volume of the glass is concentrated in the upper part of the container, as time passes the concentration is higher and little by little it begins to descend within the volume of the container until it begins to interact again with the surface of the polycarbonate. For this reason, the images always show a higher concentration in the upper part of the sheet. Therefore, radon gas does not interact only once with the CR-39. Also, Figure d) shows evidence that the gas can drop down to 7.5 cm.

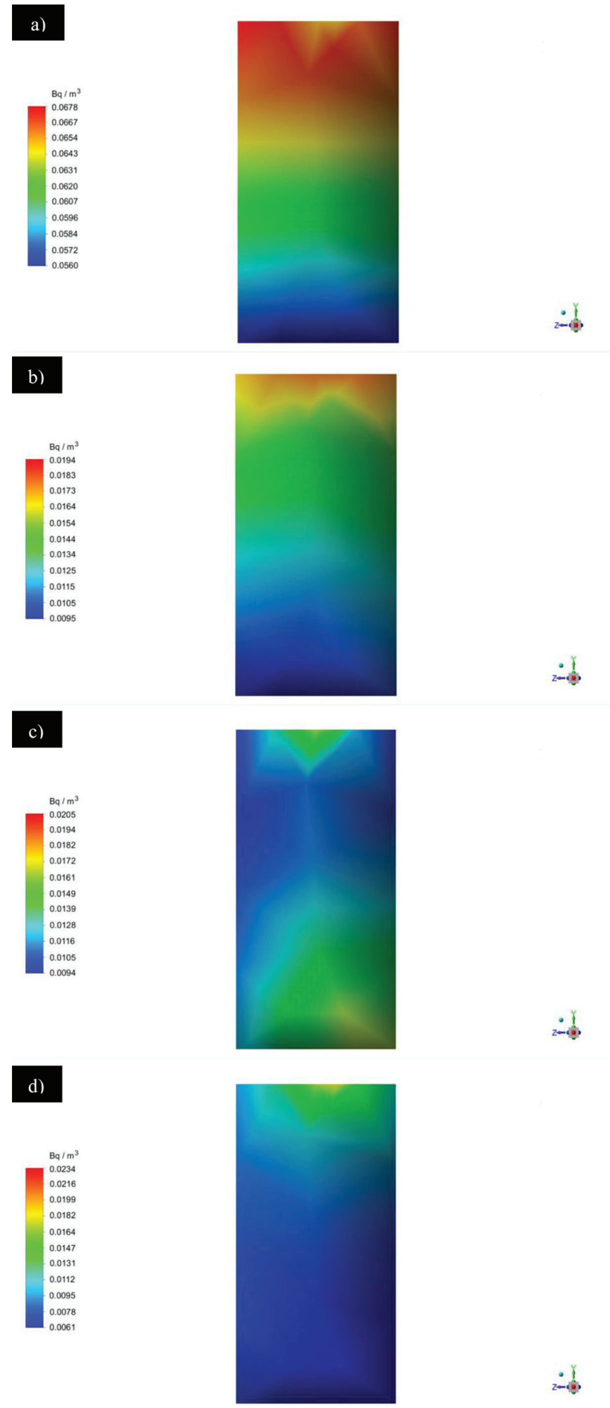

Figure 3: Radon concentration registered on the surface of each CR-39 in the 4 simulations executed, a) result when the CR-39 detector was positioned 1 cm from the base of the plastic cup, b) when positioned at 3 cm, c) when positioned at 5 cm, d) when positioned at 7 cm.

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Based on these results, it can be determined that the closer the detector is positioned to the base of the plastic cup, the greater the probability of interaction of ^{222}Rn with the CR-39. However, since the Nuclear Track Methodology is a technique that quantifies the radiation of a place from the time the detector material is exposed to ionizing particles, then, to obtain reliable results it is only necessary to increase this time of exposition. Considering this it can be stated that, if there is no a limit in the time that a measuring device will be placed to quantify ^{222}Rn, it is not necessary to modify the current position of the CR-39 (3 cm with respect to the base of the plastic cup). But if for some reason there is a time limit, it is recommended to modify the position of the CR-39 to 1 cm from the base of the cup. In this way, the probability of radioactive gas interaction with the polycarbonate surface is increased, obtaining a greater number of tracks to be counted.

Conclusion

The results obtained in the simulation show that the position of the CR-39 detector with respect to the base of the plastic cup will determine the probability of interaction of the radon gas with the surface of the detector. The closer the detector is to the base of the vessel, the greater the probability of interaction, which is why a higher concentration of radon will be recorded in the sheet. This is possibly due to the fact that as the ^{222}Rn ascend inside the vessel begins to concentrated in the upper inner part of the vessel, until after a certain time the radioactive gas begins to descend and irradiate again the surface of the detector.

It can optimize the construction of the measuring device if the CR-39 detector is placed at 1 cm with respect to the base of the plastic cup. But because this measurement technique requires that the device to remain for a certain time in the ionizing particles source to achieve adequate irradiation of the material, it is concluded that it is not necessary to modify the position of the CR-39 at the height to which the measuring device are assembled (3 cm with respect to the base of the cup). It is only recommended to decrease this position (to 1 cm with respect to the base of the cup) when there is a limit in the time in which the measuring device will be collocated inside the place to be analyzed. In this way it will be possible to increase the probability of interaction of the α particles with the surface of CR-39 and obtain a greater number of tracks to be counted.

Competing Interests

All the authors declare that they do not have any conflict of interests whatsoever.

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