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Analysis of the Energy Deposit in the Air by Radiation of Alpha Particles Emitted by the Water of a Spring Through the Geant4 Software

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ABSTRACT

This work presents the development of an analysis of the potential radiological risk generated by alpha particles emitted by radon-222, content in a spring water, for the population that usually swims in the place and for the people who live near this spring. This spring is located in the state of Puebla. Several measurements in the water of this place by researchers from IF-UNAM showed that it contains an average radon concentration level of 70 Bq/m^3. To evaluate this radiological risk, it has been developed a computational simulation to know the area and the height where the alpha particles deposit their energy to the medium, as well as the amount of energy that they transfer. This simulation was developed in the Geant4 scientific software and the calculations were executed in the supercomputer of the Laboratorio Nacional de Supercomputo del Sureste de Mexico of the BUAP. The results show that the energy deposit occurs within the superficial limits of the spring, between 7 and 8 meters high. This deposited is not only by the alpha particles, but also by the secondary particles that are generated by the interaction of alpha particles with the environment. Based on these results, it is confirmed that there is no radiological risk by energy deposit by alpha particles for the people.

1. Introduction

The concentration of radon-222 in the air inside homes and work spaces [1] is a matter of public safety [2], because according to different international organizations such as the United States Environmental Protection Agency (US-EPA) and The World Health Organization (OMS), radon is the second cause of lung cancer (only after snuff). In the United States, it is estimated that around 15,000 to 22,000 people die each year for an illness caused by the radon gas. For this reason, it is extremely important to quantify their levels and mitigate them when their concentration is greater than the limits recommended by the different organizations dedicated to radiation protection.

However, the situation it gets complicated if is analyze the possibility that the radon that comes from the subsoil is concentrated in the spring water and wells that are used by people for different purposes. [1]. Suffice it to say that the volume of groundwater is much greater with respect to the mass of water that is retained in the lakes and that found in the surface rivers. Therefore, radon in the water would imply a double risk for the population. On the one hand, there is the fact that radon that is emitted by water can affect the lungs of people who inhale it and, on the other hand, there is a risk that radon will enter the stomach of those people who ingest it, generating the possibility of produce stomach cancer; although the risk of contract stomach cancer from ingest water with radon is lower with respect to the risk of contract lung cancer by inhaling radon (only 11% of the population that gets cancer from radon will develop it in the stomach compared to 89% will develop in the lungs) [3]. This means that it is not enough to quantify radon in homes and work spaces, it is also important to measure their concentration levels in all the springs and wells that exist around the world before being used to irrigate crops, such as water for human consumption or for recreational activities. Table 1 presents the concentration value of radon contained in water for human consumption recommended by the US-EPA.

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Table 1. Limit value of radon concentration contained in water for human consumption recommended by the US-EPA.

Institution	Reference	Limit Radon concentration (Bq / L)
US-EPA	EPA 2006	11.1

Because water with radon, contained in a spring or in a well, can become a source of radioactive emission (depending on the level of its concentration), it is important to carry out studies that allow knowing the scope of the expansion of this radiation, in order to analyze if there is a possibility that this gas can enter through the windows of a building that is near the source of emission or to understand the radiological risk, which exists in general, to people who for some reason must stay many hours near this place. To perform this study, it is possible to develop a computational simulation that allows modeling the behavior of this radiation once it leaves the water. This simulation can focus on modeling the behavior of the gas or focusing on the behavior of the radiation by alpha particles that radon-222 emits. If it wants to know the behavior of the radiation by alpha particles, it is possible to use one of the multiple computational software that exist for this purpose, one of these software is Geant4.

1.1. The Geant4 Computer Software

Geant4 is a free software developed to perform simulations of particle interactions with matter based on the Monte Carlo statistical method [4, 5]. Geant4 is the successor of a series of programs known as "Geant", programmed by scientists and researchers of the European Organization for Nuclear Research (CERN for its acronym in French). Geant comes from the English words: geometry and tracking (geometry and tracking). Geant4 was developed in the C ++ programming language and uses a large number of physics models to simulate the interactions of particles with matter in a very wide range of energy, in fact, the program acts as a repository of scientific information because it incorporates a large amount of data on the interactions between particles, product of the results obtained in various investigations that have been carried out throughout the world over many years. The simulation tools included in this program are: the geometry of the system, the materials involved, the fundamental particles of interest, the generation of primary events, the tracking of particles through materials and electromagnetic fields, the physics processes that govern the particle interactions, the response of sensitive components of the detector, the generation of event data, the storage of events and tracks, the display of the detector and the trajectories of the particles and the capture and analysis of simulation data at different levels of detail and refinement. Geant4 is used by scientists around the world for the development of research in various areas of physics such as: high-energy physics, nuclear physics experiments, nuclear medicine, production of particles in accelerators and studies of space radiation, among many others. In this work a simulation was developed to determine the energy deposited in the air by radiation by alpha particles, emitted by radon-222 contained in a spring water located in the state of Puebla, in order to know the area and the height where this deposit is made and for Know the amount of energy that is deposited.

1.2. The Parameters in Geant4.

To develop a simulation in Geant4 it is necessary to declare certain parameters. These parameters represent all the variables that may exist within the simulation, as well as the limits that the radiation will have during its expansion and interaction with matter. These parameters are:

1. **The world.** This parameter represents the total dimensions of the environment where the whole simulation will be developed, that is, the total volume to which the particles can be expanded. Geant4 allows to create a world with the dimensions that the user requires but always with a geometric shape of a parallelepiped.
2. **The detector.** This parameter represents the dimensions of the space that will register and quantify the particles that are emitted by the radiation source, that is, the specific volume that the user places to measure the interaction of particles with matter. The world can be as large as desired, but the dimensions of the detector must always be declared within the dimensional limits of the volume that the world represents; all particles that travel beyond the detector will not be recorded and therefore will not exist in the results of the simulation. Unlike the world, the detector can acquire any geometric shape that the user requires, distinguishing between volume and phase space detectors, where the difference between both lies in the information that the user wants to obtain.
3. **The geometry.** It is the medium that interacts with the radioactive particles, it can be the environment (usually air or water), or various geometries so that the radiation has to pass through them before reaching the detector. Geant4 allows to develop all kinds of volumetric structures and materials with which the particles that are emitted from the radiation source will interact. These structures are usually developed to recreate the conditions of the simulation as real as possible. Logically these parameters will break and stop the free expansion of the particles in the medium.

4. **The source of radiation.** Also called particle gun, is the point, surface or volume from which they will be "throwing the particles".
5. **The particles.** It refers to the nature of the ionizing radiation that will interact with matter. Geant4 requires that two variables be declared to make this parameter effective: the type of particle and its energy.
6. **The number of stories.** It is the number of events that the particle gun will carry out, that is, how many particles will be thrown. Each particle and the secondary particles that are generated will compose a story.

Once these parameters have been defined, the simulation can be started. The computation time that the program will need from its execution to the delivery of the results will depend on different factors: the size of the world, the complexity of all the structures that exist within the world, the size of the detector, the number of particles sent by the source of radiation, the number and size of materials placed for interaction with the particles, the processing power of the computer, among other factors. Fortunately, in this work, it had the possibility of performing the simulation in a high-performance computer, specifically in the Laboratorio Nacional de Supercómputo del Sureste de México located in Ciudad Universitaria in the BUAP, so the time it took for the program to finish the simulation was considerably reduced.

After the simulation has finished, the results obtained must be analyzed. To perform these analyzes, another program called ROOT [6] is commonly used. ROOT is a software used for the development of large-scale scientific data analysis applications developed also by CERN researchers in the C++ programming language. With ROOT it is possible, for example, to create histograms of the simulations developed in Geant4, in order to better present the results obtained. In this work, the results obtained in Geant4 were analyzed in ROOT, the graphs obtained were also elaborated in this software.

2. Methodology and Experimentation

The natural spring, where the study was developed, presents a concrete surface that delimits its upper part, that is, while the interior of the spring is formed by a rock structure without a specific geometric shape, its surface has four walls that give it an appearance of a common pool. This fact allowed to measure the dimensions of the spring, with a flexometer, in a simple way; the dimensions obtained were 15 m long × 10 m wide. While the depth of the spring is 5 m. At the bottom of this spring there are a series of small cavities through which the water coming from the subsoil accesses, to subsequently flow freely through a stream. So that, as the water enters from the small cavities to the spring and emerges to the surface, radon also enters and emerges to the surface. In this way, the source of radiation emission in the spring is the flow of water with radon. The flow of the water was calculated by a group of geologists in previous works, reporting an approximate flow of 300 liters/second, and the measurement of the average radon concentration levels in water was developed in previous works by researchers from IF-UNAM and FCFM-BUAP. The results of these measurements revealed an average of 70 Bq/L. After entering the cavity, radon can have different destinations:

- Distribute and concentrate along the walls that make up the spring, preferably in the lower areas of the space.
- Follow the path of the stream.
- Be released to the atmosphere.

Radon that is released into the atmosphere will spread throughout the space, however, radon will be mitigated by all the trees and materials that are in the vicinity of the area and by the the air.

2.1. Parameters Declared in the Geant4 Software to Develop the Simulation.

To develop the simulation of the energy deposit of the alpha particles emitted by radon-222, the following conditions were defined in the parameters of the program:

1. **The world.** The dimensions declared of this parameter were 300.1 meters long by 300.1 meters wide and a height of 50 meters.
2. **The detector.** The geometric shape that was declared for this parameter was a parallelepiped, whose dimensions was 500 meters height by 500 meters wide and 28 meters high.
3. **The geometry.** The chosen medium with which the radioactive particles would interact once they left the spring water was air. In the simulation, no volumetric structures were built that could represent, for example, trees, houses, light poles, buildings, etc. Only the concrete surface that delimits the spring was built.
4. **The particles.** The alpha particles that emit radon-222 have an energy of 5.5 MeV. Therefore, these were the declared variables.
5. **The source of radiation.** As mentioned above, the source of radiation is the flow of water that enters through the small cavities at the bottom of the spring. While it is true that it is unknown how radon is distributed, from the moment the gas enters into the spring, it is also true that the flow flows 24 hours a day, 365 days a year. It was decided that the particles emerge freely from the surface of the spring (where the water ends, and the air begins), taking as the emission area the surface that has the spring (15 × 10 meters). This

source of radiation was positioned exactly at the center of the world and the detector.

6. **The number of stories.** It was considered that the radiation source emitted 2,419,200,000 alpha particles. The reason for having chosen this number of particles is because this amount was enough to obtain an adequate statistic to be able to observe exactly in which part of the world's volume, the radiation deposited the most part of its energy. It is important to highlight that this could be verified after performing several simulations and concluding that, no matter how much the number of particles will be increased, the trend of the behavior of the radiation was not modified.

Figure 1 presents the construction in Geant4 of the spring delimited by the concrete surfaces. In this figure it can see the water that emerges in blue color and the concrete surfaces in gray color.

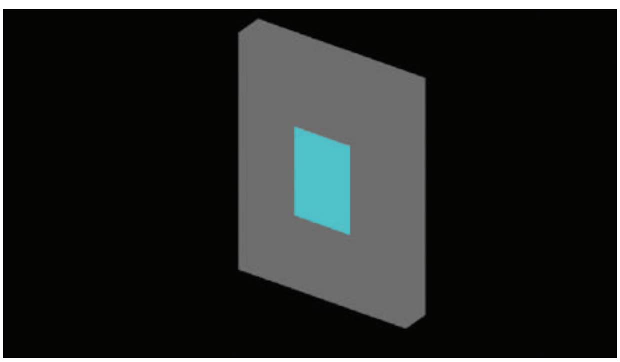

Figure 1. Construction in Geant4 of the spring delimited by the concrete surfaces.

3. Results and Discussion

Figure 2 presents a three-dimensional graph with the results obtained from the simulation developed. In this graph, the surface area of the ground is represented by the *x*, *y* axes and the height by the *z* axis. In the graph it can see squares of different colors, each square represents a deposit of energy in the air by the radiation. It is important to mention that this deposit is not only made by the alpha particles, but by all the general radiation, that is, both by the alpha particles and by all those particles that are generated as a result of the previous interaction that occurred between the alpha particles and the air (such as photons, electrons, etc.). The figure also includes a color code, where the light-yellow color represents the greatest amount of energy that the radiation deposited in the air (in MeV) and the strong blue color indicates that there was no energy deposit. The dimensions of the figure volume are in meters. In the previous figure it can be seen that the area within the world where the radiation deposited energy is very small. The figure also shows the number of frames where the detector registered a deposit: 754. This deposit was made, mainly, between 6 and 8 meters high. In order to better observe this energy deposit, an approach was made to this area. Figure 3 presents 2 graphs with different perspectives with respect to the previous graph. The first graph (a) shows the *x* and *z* axes and the second graph (b) shows the *x* and *y* axes.

In the graphs of figure 2 it can be seen that the height where the radiation deposits the energy is at 7.5 meters height, from where the alpha particles are emitted in the simulation, and the total area where this deposit was produced It is 8 meters long and 6 meters wide. That is, if it is observed that

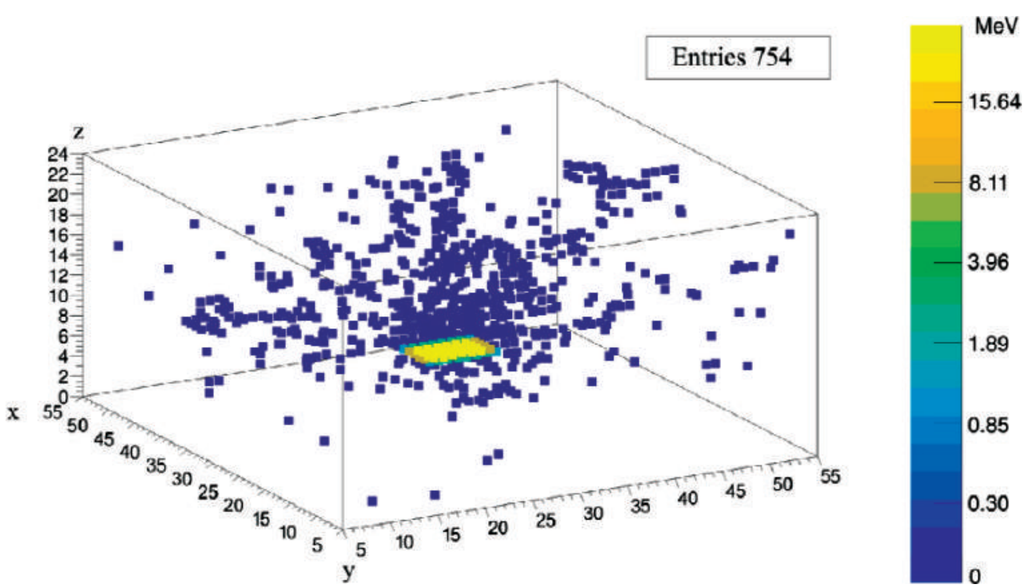

Figure 2. Three-dimensional graph of the energy deposition of radiation in the air.

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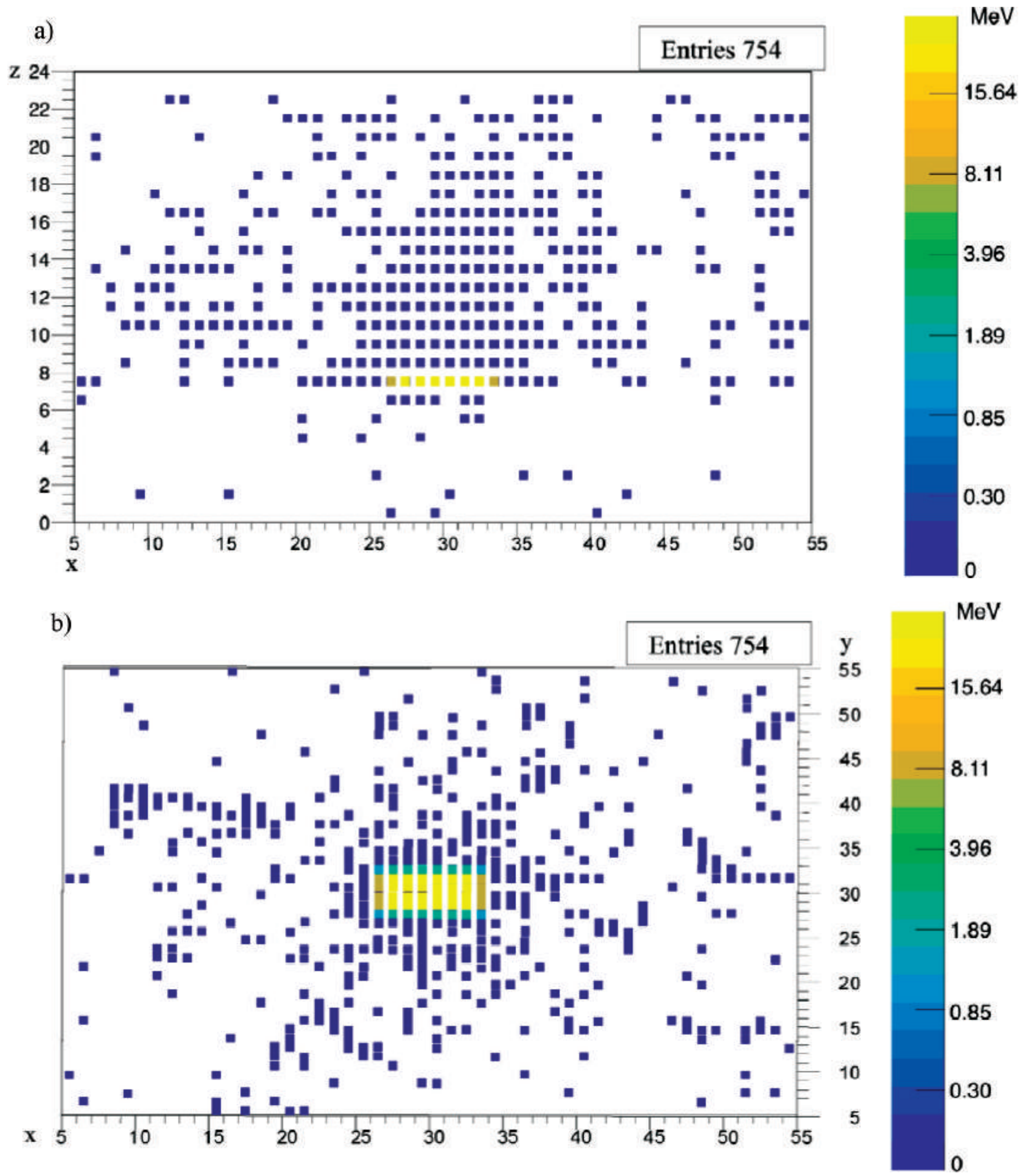

Figure 3. Two-dimensional graph of the energy deposition of radiation in the air. (a) *x* and *z* axes, (b) *x* and *y* axes.

the spring has a size of 15 × 10 m, the energy is deposited within the superficial limits of the spring. This means that the radiation, as much by alpha particles as by secondary particles, does not reach to interact and to deposit energy with the air outside the superficial limits that presents the spring. Based on these results and observing that there is no type of construction or any kind of activity that takes place in the zone where the radiation deposits its energy, it can be affirmed that there is no radiological risk by radiation of alpha particles emitted by radon-222 content in the water for the people who live in the surroundings of the spring or for the people who swim in this place.

4. Conclusions and Recomendations

The quantification of radon-222 concentration levels must not only be carried out in people's homes and workspaces, but also in the water of spring and wells used for different purposes. The risk of a concentration level greater than that recommended by the different organisms dedicated to radiological protection is greater, because this gas can not only enter and make the lungs sick of people who inhale it, but also the stomach of those people who ingested it. In addition, radiological protection mechanisms should not only focus on measuring levels of concentration in water, but also on the development of computational simulations that allow analyzing the range of gas expansion when it is emitted by water, or the zones where radiation by alpha particles interacts and deposits its energy with the air. To carry out this type of simulations, it is possible to use the multiple softwares that exist to simulate the interaction of radiation with matter, such as the Geant4 software. This work simulated the emission of alpha particles by radon-222 contained in the water of a spring, whose dimensions are $15 \times 10 \times 5$ meters, and whose radon concentration is 70 Bq/L, with the purpose of studying the zones where the radiation deposits its energy and to assess the radiological risk to which the people who live around the spring or who swim in this place are subjected. The results showed that the radiation deposits its energy at a height of 7.5 meters in height, from where the particles are emitted, and in an area that is within the surface limits of the spring. Therefore, a radiological risk generated by radiation of alpha particles in this place is ruled out. However, it is necessary to make an additional model that contemplates the expansion of radon gas, in order to have a better certainty of the low radiological risk represented by radon in the water of this spring for people.

Acknowledgements

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