ABSTRACT

The months of October 2019 until the end of January 2020 were very rainy in São José dos Campos (23°12’S, 45°52’W) tropical Brazilian region. In the period from 10/14/2019 to 01/27/2020, the counting of gamma rays, neutrons and rainfall intensity in a tower at 25 meters high was monitored at every one-minute interval. This tower is located in a free area without electromagnetic interference from man on the site. The average rate of gamma radiation count between (0.2 – 10.0) MeV was 39,000 counts / min. The average neutron count observed was 2 neutrons / min, between 25 eV to 10.0 MeV. The amount of net rainfall in the period was 461 (mm) with variations in dry weather, fine, moderate and heavy rainfall throughout the monitored interval time. It can be seen in these measurements that the intense rains correlate very well with variations in the gamma rays and delayed of 4 to 5 days with the measured neutron intensities. This work gives possible explanations about this correlation based in same site of rainfalls, gamma and neutron observations.

Keywords: neutron, gamma rays and rainfall measurements.

I. INTRODUCTION

At the ground level interface of the Earth's surface, ionizing radiation it is composed mainly of gamma ray, soil telluric radiation, primary and secondary cosmic ray radiation [1]. However, it is difficult to separate over time the intensity of the ionizing radiation emanating from each component as the energies overlap. The telluric radiation is given by $^{238}U$, $^{235}U$, $^{40}K$ and $^{232}Th$ disintegration’s series that are constant for each region. The gamma ray and neutrons coming from radon gas arriving through the $^{238}U$ in Earth's crust disintegration to $^{226}Ra$ and $^{222}Rn$ reaching the stables isotopes $^{214}Pb$, $^{214}Po$ and $^{214}Bi$. Radioactive elements such as Uranium, Thorium and Potassium are found in almost all types of rocks, sands, soils and water [2]. The Radium $^{226}Ra$ and its decay products are responsible for a major fraction of the dose of internal emissions received by humans. $^{226}Ra$ has a half-life of 1,600 years, and decays to Radon $^{222}Rn$, which has a half-life of 3.82 days. The decay of $^{222}Rn$ is followed by successive disintegration of short half-life alpha, beta and gamma ray emitters. After decay stages, the radioactive chain ends with stable lead $^{206}Pb$. The alpha particles coming from radon gas in interaction with elements of ground level and can produce neutrons. With regard to soils and rocks, the $^{226}Ra$ is present in virtually all soils and rocks in varying amounts. Areas with high levels of background radiation found in some soils are due to geological conditions and geochemical effects and cause increased terrestrial ionizing radiation. Researches in the world, and specifically in Brazil, show these conditions. Several studies report variations throughout the day of radon concentrations. Maximum concentrations are observed in the first hours of the day and the lowest values are found late near afternoon, when concentrations are about one third of morning values [3]. The same profile is observed with the gamma ray intensity variation in the tropics region. However, it is likely that variations in concentrations in localities of gamma ray intensity are dependent on local meteorological parameters (rain, wind, pressure, temperature and cloudiness) in the gamma ray detector site [4]. Electrical discharges in low atmosphere of the region also can contribute with production of low energy gamma rayand neutrons near ground level according lightning see Figure 1 and Figure 2.
II. METHOD & MATERIAL

To monitor the gamma radiation in energy interval 200 keV to 10.0 MeV, it has been used a portable system detector composed of Sodium Iodide scintillator activated with Thallium NaI(Tl). This crystal (3” x 3”) inches (diameter and height) placed in a thin cylinder of aluminum foil and coupled with a PM (photomultiplier) with source power circuit settled in 1500 VDC and with data acquisition system provided by the company (Aware Electronics-Inc., USA)[5]. Detector and associated electronics of gamma ray were previously calibrated in ITA (Technological Institute of Aeronautics) laboratory using radioactive sources (Cs-137) and (Co-60) in terms of energy from emitted photons 662 keV and 1,17 MeV, 1,33 MeV respectively [6]. The data acquisition in terms of gamma radiation and intensity of rainfall was performed using 1-minute time interval between each measurement. This detail contributes to verify possible correlations between variation of rain intensity, and local ionizing gamma radiation.

The Ludlum Model 25311 tube Neutron Detector is designed for detection of thermal and fast neutrons (0.025 eV to 10 MeV) [7]. The neutrons are detected, not directly, but through nuclear reactions, which result in energetically charged particles such as alpha particles. In many instances, intense fields of gamma rays are also found with neutrons. Therefore, it is important to choose a method of neutron detection with the ability to discriminate against these gamma rays in the detection process. The most common reaction used in neutron detection today is: 
\[(n+3\text{He} \rightarrow 3\text{H}+1\text{H} + 0.764 \text{ MeV})\]
where both the proton H and the \(^3\text{H}\)are detected by gas-filled \(^3\text{He}\), the Ludlum Model 25311 tube. The helium-3(3He), which fills the gas proportional tube of the detector, with 1500 VDC and sensitivity:100 cpm/mrem/hr using the neutron source of (241AmBe fast neutrons) [8].

The rainfall intensity in (mm) was measured with a pluviometer (bascule/bucket) rain gauge and data logger acquisition developed in ITA according to the international recommendations. The data acquisition in terms of ionizing radiation and intensity of rainfall was performed using 1-minute time interval between each measurement [9].
Using these three tools properly calibrated for the measurements of gamma rays, neutrons and rainfall intensity, he was placed in the tower at 25 meters high for simultaneous monitoring see Figure 3.

![Figure 3 - Aerial and ground view of the tower ACA and his environmental field region in São José dos Campos, SP, Brazil (23° 12’45" S, 45° 52’00" W)](image)

### III. RESULTS AND DISCUSSIONS

During the period from 10/14/2019 to 01/27/2020, 8 peaks of gamma radiation are observed, as shown in Figure 4. However, in Figure 5, the measurements of rainfall intensity show 5 peaks indicating heavy rains. Therefore, it is admitted that not only heavy rains cause an increase in the observed gamma radiation. Figure 6 shows the neutron monitoring observed every minute. The intensity during each day varies very related to weather. After 4 to 5 days of intense rain there is a significant increase in neutrons in the region. This fact can be explained by the increase of hydrogen atoms of water in the earth close to the detector that through the reaction (protons / alpha) produce neutrons. That kind of cosmogenic neutrons produced from cosmic radiation in the Earth’s atmosphere or surface is very well studied today [10].

With the soil on the wet surface conditions, the back scattering neutrons increase at the measurement site. In times of heavy rain with very humid soil, there was always an increase in neutron counts caused by interactions of cosmic rays. Also in times of dry and very hot weather, the measurements obtained show a variation and increase in neutrons, but now originated by the exhalation of radon gas from the earth's surface. Radon gas produces alpha particles that interact with the soil and produce neutrons in this energy range. For this reason, the neutron monitoring graphic is very variable in this period studied here see Figure 5.
Fig. 4 - Measures every minute of gamma radiation intensity between 10/14/2019 and 01/27/2020 showing 8 peaks of radiation increase.

Fig. 5 - Measures of rainfalls each minutes during 10/14/2019 to 01/27/2020.
Figures 4, 5, 6 show a good correlation between rainfall intensities and intensities of gamma rays during monitoring time. In the case of neutron and rainfall measurements, the correlation is good but there is also a delay of a few days as clearly seen at the end of the monitoring curve in the Figure 6.

IV. CONCLUSION

Variations in the intensities of gamma rays, neutrons and rains were monitored between 10/14/2019 to 1/27/2020 in tropical regions with only 1 minute intervals between each measurement. These measures show a good correlation between rain and gamma radiation due to the presence of radon gas in heavy rains. The correlation between rain and neutrons is due to the wet soil coming from rain and the phenomenon of neutron back scattering via cosmic rays. Also in the case of neutrons in dry times is due to exhalation of radon gas that increases the production of neutrons via interaction of alpha particles with elements of the Earth surface.

V. ACKNOWLEDGEMENTS

Thanks CNPq (National Counsel of Technological and Scientific Development) Proposal 306095/2013-0, 480407/2011-8 and 305145/ 2009-6 and CAPES (Coordination for the Improvement of Higher Education Personnel) by the fellowships grants support to the group’s researchers. To the INCT-FNA-ITA for providing instruments. The Division of Fundamental Sciences, Department of Physics - ITA - Technological Institute of Aeronautics and IAE Institute for the support of infrastructure.

REFERENCES

1. Gultom, JYT and Sulistyowati L., 2018. Strategy for Mango Candied Agro-Industry Development (Case [1] – Inacio Malmonge Martin-Environmental low energy gamma ray spectrum in São José dos Campos, Brazil region, Global Journal of Engineering Science and Researches, Vol.7, serie 1, pag. 30-37, January 2020, DOI-10.5281/zenodo.3611220.

2. N. A. Bui Van, I. M. Martin and A. Turtelli Jr. – Measurements of natural radioactivity at different atmospheric depths. RevistaGeofísica, IPGH, numero 28, enero-junio 1988, México.
3. Tameshige Tsukuda- Radon-gas monitoring by gamma-ray measurements on the ground for detecting crustal activity changes – Bull. Earth. Research Institute, University of Tokyo, vol (83), (2008), pg. 227-241, Japan.

4. Martin, I. M., Germano, J. S. E., and Takaki, T. M. (2013). ITA-DATALOGGER: Continuous Monitoring of Pressure, Relative Humidity, Temperature, Rainfall Intensity and Dose of Ionizing Radiation Near the Surface of the Earth in Sâo José dos Campos, SP, Brazil. In 65th Annual Meeting of Brazilian Science for Progress Society (SBPC), 57-62.

5. Boardman, B. J.: User’s Page. (2015). Aware Electronic Corp. Accessed in 2017. www.aw-el.com.

6. Matheus Carlos Silva, Douglas Carlos Vilela, Victor G. Migoto, Marcelo P. Gomes, Inácio M. Martin and Silvério J. Germano. In Ionizing radiation measurements using low cost instruments for teaching in college or high-school in Brazil published to Physics Education, may 2017 see http://iopscience.iop.org/journal/0031-9120.

7. Ludlum Measurements, Inc. Medical Physics, Survey Meters, 3H, Proportional Detector, USA - https://ludlums.com/products/medical-physics/category/neutron-meters.mp, accessed 08 February, 2020.

8. Federico, C.A., O. L. Gonçalez, E.S. Fonseca, I.M. Martin, L.V.E. Caldas; Neutron spectra measurements in the south Atlantic anomaly region; Radiation Measurements, vol. 45, pg. 1526-1528, 2010.

9. Inacio Malmonge Martin, Marcelo Pego Gomes & Anatoli A. Gusev, Low Energy Gamma Rays Measurements During January to February 2017 in São José dos Campos, SP, Brazil Region. International Journal of Research in Engineering & Technology, ISSN(E)2321-8843, vol. 5, Issue 3, March 2017, pag 21-26.

10. Inacio M. Martin, Variation of the Neutron Flux and Gamma Rays of Origin Cosmic as a Function of Latitude, Master Thesis, Center for Space Studies and Radiation, University de Toulouse III-Paul Sabatier, Toulouse, France, 1971. (in French).