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Simulation of transports and concentration of radionuclides by dynamics process in the atmosphere in eventual accidents in the Angra 1 and Angra 2 Power Plants

Victor Keichi Tsutsumiuchi[1], Maria de Fátima Andrade[2], Roberto Vicente[3]

[1] victor.tsutsumiuchi@usp.br, *Av professor Lineu prestes, 2242 - IPEN/SEGRR;*

[2] maria.andrade@iag.usp.br, *Rua do Matão 1226 - IAG/USP;*

[3] mrobertovicen@gmail.com,*Av professor Lineu prestes, 2242 - IPEN/SEGRR.*

1. Introduction

A major concern about the production of electric energy from radioactive sources is the accident risk. The radionuclides used in nuclear power plants have the property of emitting high-frequency electromagnetic energy typically located in the electromagnetic spectrum between X-rays and gamma rays (γ), which can be highly harmful to live organisms, including humans, when exposed to such radioactive elements, or their subproducts.

In nuclear power plants, energy is produced by the nuclear fission process, that is, by the process of nuclear division of chemical elements generating other lighter elements. The most used element in power plants for the production of energy by the fission process is uranium dioxide (UO_2), which when bombarded by neutrons, dissociates into smaller isotopes, which, like, can emit ionizing radiation.

The conditions that can make a plant suffer accidents are diverse. Aguiar (2015) [1] cites some of the factors that can cause accidents, such as failure in the external or internal power system, failure in the refrigeration core, and failure in the ventilation system. In all these cases, there may be leakage of radioactive material out of the plant, the amount of which varies according to the degree of impact of the failure.

Although there are few cases of nuclear accidents in power plants around the world, like Chernobyl in 1988 and Fukushima Daiichi in 2011, the effects caused by released radioactive materials cannot be ignored, as they can cause damage from the moment of the accident until many years later, as the decay of some isotopes are long lived.

The Angra 1 and Angra 2 plants are the only nuclear power plants in operation in Brazil until now. Both are owned and operated by ELETROBRAS Eletronuclear and both have a pressurized water reactor (PWR, Pressurized Water Reactor), the most used type in the world (ELETRONUCLEAR, 2010) [2].

In situations of accidents in nuclear power plants, there be released of radionuclides into the atmosphere. Many of these radionuclides can be dispersed over long distances, deposited on the ground or in the oceans, and can remain for a long time due to the half-life of some radionuclides. Such nuclides can cause several damages to human health, due to their activity, dose rate, or toxicity.

Such as air pollutants, radionuclides can be carried by the wind. So models such as the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory - Draxler - 1997) developed by the NOAA (National Oceanic and Atmospheric Administration) of the United States, normally used to simulate pollutant trajectories in the atmosphere can be used to calculate where dispersed radionuclides will be carried in possible releases.

2. Methodology

The study site is the Angra do Reis Region, where Angra 1 (23°00'30"S -- 44°28'26" W) and Angra 2 (-23°00'30"S -- -44°28'26"W) are located.

For this work, similar to Pirouzmand et. al. (2018), the HYSPLIT is used to calculate the trajectories of UO_2 in the atmosphere from possible releases at Angra 1 and Angra 2 plants. The computational language R is used to plot maps of dispersion, relative deposition concentrations of UO_2 and calculate the percentage of concentration in different areas.

Based on the inventory estimated by Oliveira et al. (2020) [3] of the radioactive materials present in the Angra 1 and Angra 2 reactors; we have that UO_2 is the most abundant material in the reactors of both plants because it is the fuel material and therefore, this was the radionuclide used for the simulations of concentration in dispersion in the atmosphere. The parameters used to calculate the dispersion of UO_2 in HYSPLIT were: particle diameter of 427 µm, the density of 10.97 gcm^{-3} in the particle state, and the half-life time for radioactive decay was disregarded.

The study period was established as the entire 2019 year, as reanalysis data is available with a resolution of 0.1° latitude and 0.1° longitude every hour for all days of the year. The reanalysis data of wind used were those provided by NCEP/NCAR at <<arlftp.arlhq.noaa.gov/pub/archives/reanalysis>> lasting 72 hours from 00, 06, 12, and 18 UTC for each day of 2019.

3. Results and Discussion

From the data simulated in HYSPLIT using the reanalysis data, after being properly treated and organized in monthly tables and, making use of the openair (Caslaw, 2019) and ggplot (Wickham, 2020) library in R, trajectory and frequency maps were plotted with monthly, seasonal and annual periods for 2019, that show how the radionuclides would be loaded if the accident had happened on the day and period corresponding to the study.

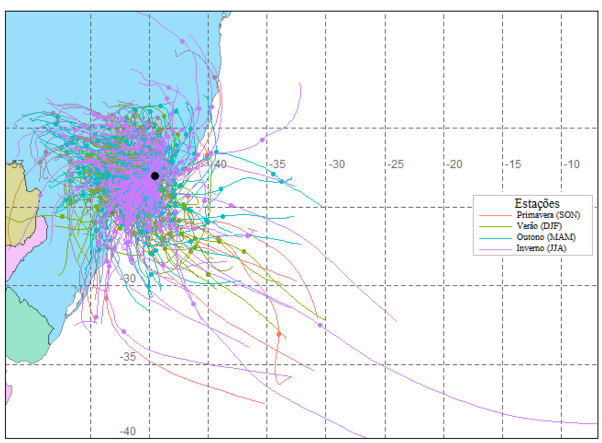

Figure 1 - Daily seasonal radionuclide trajectories identified by colors from the Angra 1 and Angra 2 plants with 72-hour dispersion for 2019 with the beginning of dispersion at 00 UTC.

Figure 1 shows that there is a tendency for radionuclides released at 00 UTC to be mostly carried to continental regions, we can also see that there is great seasonal variability in how radionuclides can be transported

To have a better understanding of where radionuclides are carried most frequently in the atmosphere, frequency maps of the trajectories simulated by HYSPLIT were made. Figure 2 shows in percentage terms the frequency with which daily trajectories of radionuclides released at 00 UTC are carried through certain regions of the map according to their initial simulation time, where it is possible to observe the most favorable trajectories for which radionuclides can be carried.

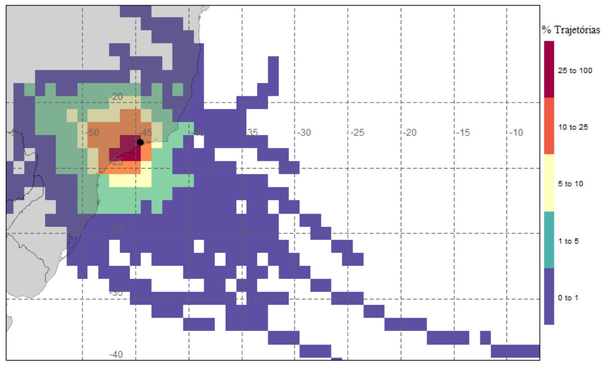

Figure 2 - Frequency map of daily trajectories calculated for 72 hours for the year 2019 with initial dispersion at 00 UTC from the Angra 1 and Angra 2 plants.

Based on the data of daily concentrations for dispersion of UO2 in the atmosphere from the power plants, concentration maps were constructed (total dispersed per cubic meter (m^{-3})), for dispersion starting at 00 UTC (Figure 3), in which the position of the plants is indicated in the white dot on the map and the grid is divided into latitude and longitude.

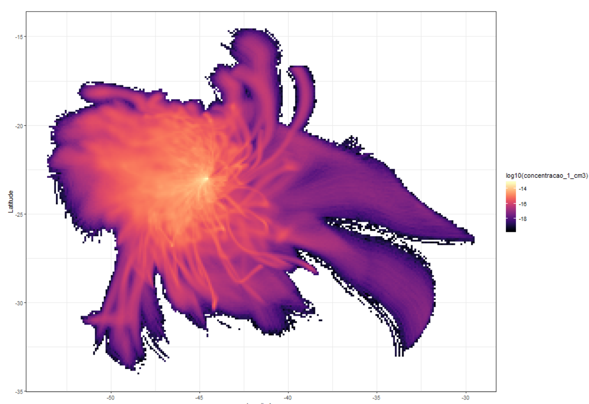

Figure 3 - Concentration log map for daily 48-hour dispersions for 2019 starting at 00 UTC from the Angra 1 and Angra 2 plants.

As in Figures 1, 2, and 3, show that radionuclides are preferentially carried between SW and NW of the power plants. That is, for continental regions. Table 1 shows the percentage where radionuclides would be carried if released at 00 UTC for an annual average.

	SW	NW	SE	NE
Year	53.1%±12.4%	29.9%±15.3%	10.2%±7.2%	6.8%±5.1%

Table 1 - Percentage of concentration for the 4 regions from the region of plants with initial dispersion at 00 UTC. Seasonal and annual averages include respective standard deviations.

4. Conclusions

From the reanalysis data used to carry out the simulations with HYSPLIT, we see a great tendency for radionuclides to be carried and to be concentrated in the southwestern and northwestern regions of the plants, regardless of the periods considered.

According to the maps of frequency of occurrence of the trajectories, it is possible to infer regions where radionuclides tend to be transported and, consequently, showing agreement with the concentration maps, is where they are concentrated.

Although there is great variability in the trajectories in which radionuclides can be carried according to the behavior of the atmosphere during the period, well illustrated in the daily trajectory maps, the study indicates most of the time, these will be carried to the regions between southwest and northwest of the plants.

The methods applied to determine the concentrations and trajectories of the radionuclides are consistent with what is observed, as the wind regime in the region is greatly influenced by the sea breeze, which leads the radionuclides to concentrate in continental regions from the transport of areas coastal areas, as observed in the work.

Acknowledgments

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