2024 International Nuclear Atlantic Conference – INAC 2024
Escola de Guerra Naval, Rio de Janeiro, RJ, May 6 - 10, 2024

ISBN: 978-65-594-1256-3

Atmospheric Dispersion of Rn-222 from Phosphogypsum Piles

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1. Introduction

The extraction of various minerals essential for industry and agriculture is associated with the simultaneous extraction of radionuclides from the radioactive decay chains of thorium and uranium. Some of these minerals are phosphate, tin, lead, and niobium.

Typically, mining takes place outdoors, and waste mounds left over from mineral extraction also exist, raising the potential of some radionuclides dispersing in the environment. Therefore, radionuclides from waste piles and mines can be dispersed. In this way, radionuclides can be transported by the wind over long distances and deposited on surfaces such as soil, water, or other sites, increasing radioactivity in far-off areas. As a result, there is a high risk that these radionuclides will contaminate people when they are dispersed. Hence, it is important to understand how these radioactive particles can travel in various contexts.

It is necessary to evaluate how these variables affect the estimate of radiation doses to which the affected populations will be exposed. Many variables affect the results of the dispersion and the increase in the concentration of radionuclides spread by different media and in different regions.

One of the radionuclides that can be dispersed from these waste piles is Rn-222, which, as it is a noble gas and has a half-life time for radioactive decay of 3.822 days, can be easily dispersed in the atmosphere and, consequently, be transported over long distances through dynamic air processes. In this way, the work focuses on calculating the increase in radiation and estimating the affected area in regions close to waste piles.

Therefore, based on Mazzilli et. al. [1], which presents data on the exhalation of Rn-222 from two phosphogypsum piles located in Brazil, simulations were carried out based on GFS (Global Forecast System), a NCEP (National Centers for Environmental Prediction) weather forecast model that generates data for dozens of atmospheric and land-soil variables, reanalysis data between 1948 and 2023 using HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory [2]), a tool developed by NOAA (National Oceanic and Atmospheric Administration) of the United States, normally used to simulate trajectories of pollutants in the atmosphere but which, for this study, was adapted to calculate the trajectory and concentration of Rn-222 dispersed in the atmosphere.

2. Methodology

The study site was situated within phosphogypsum piles located in Brazil, specifically in Cubatão (São Paulo, SP) and Uberaba (Minas Gerais, MG). Cubatão is positioned at 23° 50' S, 46° 23' W, while Uberaba located at 19° 58' S, 47° 52' W

For this work, similar to Pirouzmand et. al. [3], the HYSPLIT was used to calculate the trajectories of Rn-222 in the atmosphere from possible releases at Cubatão and Uberaba piles. The computational language Python was used to plot maps of dispersion and relative deposition concentrations of Rn-222 and calculate the percentage of concentration in different areas.

Based on the Rn-222 exhalation rate estimated by Mazzilli et. al. [1] of the radioactive materials present in Cubatão and Uberaba phosphogypsum, we estimate the exhalation of Rn-222 from the entire piles by the surface area. The necessary settings used to calculate the dispersion of Rn-222 in HYSPLIT were: a particle estimated diameter of 0.00012 µm, a calculated density of 0.00973 gcm^{-3} in the gast state, and a half-life time for radioactive decay of 3.822 days.

The study period was established as the entire 2018–2022 period, as reanalysis data is available with a resolution of 0.25° latitude and 0.25° longitude every hour for all days of the period. The reanalysis data used were those provided by NCEP/NCAR [4].

The period of each simulation was for each day, at an interval of 12 hours, with exhalation starting at 00 UTC and 12 UTC (Figure 1).

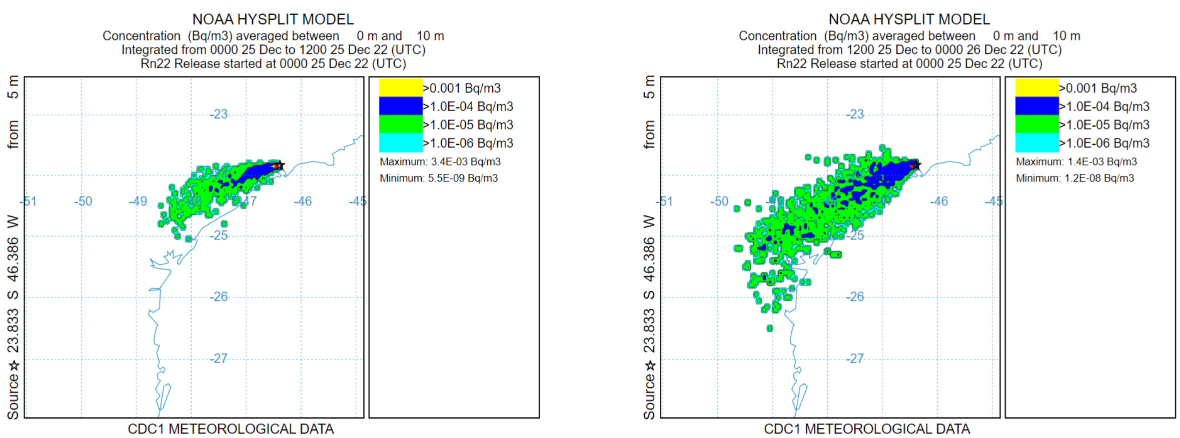

Figure 1: Cubatão Rn-222 dispersion plume at 00 UTC and 12 UTC. Source: Author.

Based on the data from Mazzilli et al. [1], the average Rn-222 exhalation in Cubatão is $0.164 \pm 0.073\, Bq\, m^2\, s^{-1}$ over an area of 160,000 m². Meanwhile, in Uberaba, the average exhalation is $0.079 \pm 0.022\, Bq\, m^2\, s^{-1}$ over an area of $1,625,000\, m^2$. Consequently, the values used in HYSPLIT for the emission rate were $26.240\, Bq\, s^{-1}$ and $128.375\, Bq\, s^{-1}$.

Subsequently, simulations were conducted using these emission rates, and annual averages of exhalation were calculated along with the five-year average concentration of Rn-222 in the atmosphere for a 10 m column.

3. Results and Discussion

With daily simulations, heat maps of the average Rn-222 dispersed from Cubatão and Uberaba were generated for each cubic meter of the atmosphere in a column of height of 10 m for the interval between 2018 and 2022, with the onset of exhalation at 00 UTC and 12 UTC for Cubatão (Figure 2) and Uberaba (Figure 3).

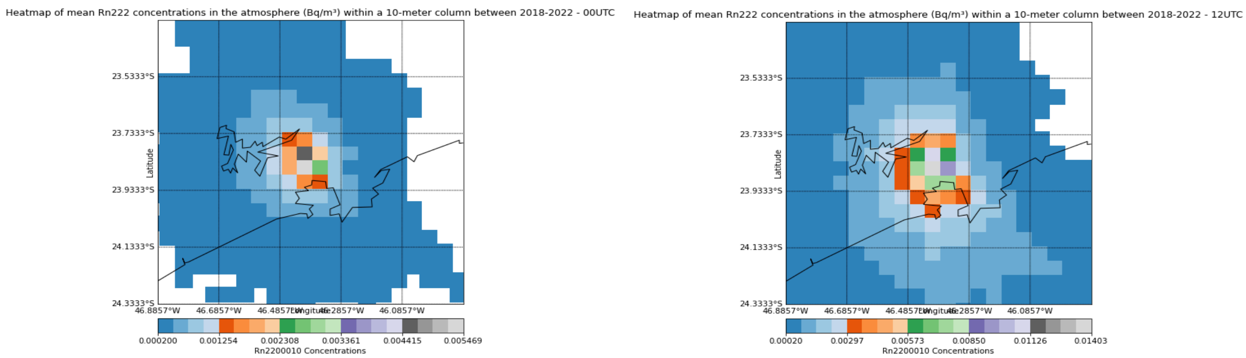

Figure 2 - Heat map of avarage Rn-222 dispersion from Cubatão with exhalation starting at 00UTC and 12UTC. Source: Author.

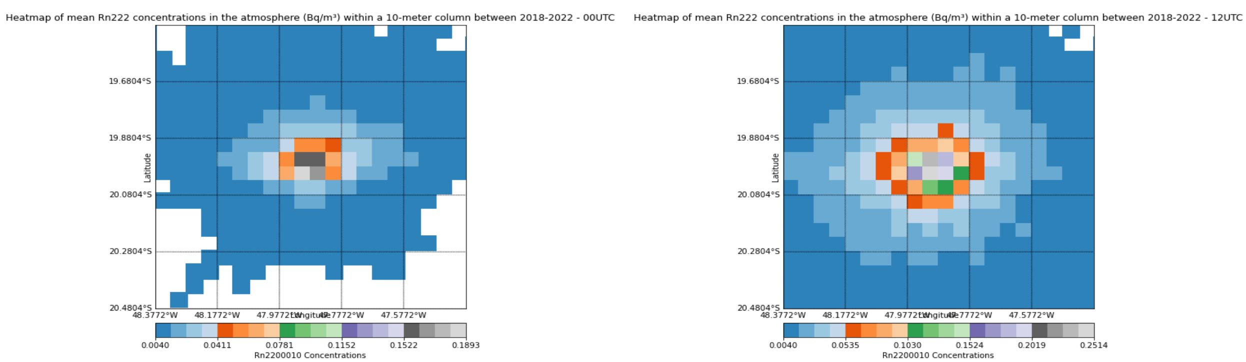

Figure 3 - Heat map of avarage Rn-222 dispersion from Uberada with exhalation starting at 00UTC and 12UTC. Source: Author.

Based on the calculated average concentration data for Rn-222, calculations were also performed to determine the regions where the radionuclides were proportionally carried (Table I). The utilization of the SW-NW-SE-NE regions allows for a comprehensive analysis of the dispersion patterns of Rn-222.

Table I - Percentage of concentration for the 4 regions from the region of Cubatão and Uberaba, with initial dispersion at 00 UTC and 12 UTC combined.

	SW	**NW**	**SE**	**NE**
Cubatão	25.84%	23.73%	29.04%	21.40%
Uberaba	29.71%	31.86%	21.67%	16.77%

It was also calculated how the volume of Rn-222 concentrates proportionally in relation to the total exhaled from the origin position of the phosphogypsum piles with the varying distances of latitude and longitude. The results for different areas are listed in the table below (Table II).

Table II - Percentage of concentration by discante the region of Cubatão and Uberaba with initial dispersion at 00 UTC and 12 UTC combined.

Radius (º Lat and Lon)	Cubatão	Uberaba
0.0 - 0.5	20.68	41.115
0.5 - 1.0	15.35	22.91
1.0 - 1.5	13.305	12.695
1.5 - 2.0	11.47	7.01
2.0 - 2.5	9.8	5.545
2.5 - 3,0	7.19	3.91
3.0 - 3.5	5.53	2.67
3.5 - 4.0	4.87	1.79
4.0 - 4.5	3.785	1.16
4.5 - 5.0	2.915	0.685
>5.0	5.105	0.51

4. Conclusions

From the reanalysis data used to conduct simulations with HYSPLIT, we observe that, for both Cubatão and Uberaba, radionuclides tend to spread to all four regions, with a slight tendency for radionuclides to be carried southeast in Cubatão and southwest and northwest in Uberaba.

We also notice that radionuclides concentrate in regions closer to the piles. Regions within 2 degrees of Latitude and Longitude have concentrations of approximately 60% and 83% of the total dispersed in Cubatão and Uberaba, respectively.

The concentration of Rn-222 in the atmosphere from the piles does not seem to pose a risk due to the low volumetric concentration, below 0.3 $Bq\, m^{-3}$ in all cases near the sites at which the radionuclides are distributed. However, it would be important to collect samples in a future experimental study to verify if the simulation calculations align with the measured values

Furthermore, in a subsequent stage of the study, it may be important to investigate how the daughter nuclides resulting from the decay of Rn-222 concentrate around the piles over time.

References

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