The Effect of Radioactive Aerosols on Fog Formation

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Abstract

This research study has been carried out to explore the dependence of fog formation on Radioactive aerosols. The aerosols containing radioactive nuclides are called radioactive aerosols. A large number of radioactive nuclides are present in the atmosphere among which the two most important nuclides, ^{7}Be and ^{210}Pb are considered here in this study. Results for Activity Concentrations of these radio-nuclides in air samples in clear and foggy conditions were comparatively analyzed. About 19% increase in Activity concentration for ^{210}Pb and about 23% increase in Activity Concentration for ^{7}Be was recorded during fog as compared to clear conditions. This increase in Activity Concentration during fog indicates that the presence of aerosols laden with these radio-nuclides is also one of the so many factors responsible for fog formation.

Keywords: Aerosols, Nucleation, Radio-nuclides, Activity Concentration, Fog.

Introduction

One of the most important environmental phenomena, whose effect on human beings was recognized from the early ages of mankind and which is considered to be an atmospheric hazard, is the phenomenon of fog. The impact of fog on human life has increased in the recent years due to increased air, marine and land transportation. Fog affects directly or indirectly the life of human beings. The fog droplets collect the pollutants present near ground surface. These pollutants contain toxic gasses like sulphur dioxide, ammonia, hydrochloric acid, nitrogen oxides and radioactive isotopes (natural and anthropogenic). These pollutants frequently stick to the fog droplets, posing threats to health of the people breathing in such environment. The reduced visibility caused by fog, results into economic losses due to its impact on aviation, land and marine transportation. Efforts are being made all over the world by researchers to successfully forecast fog events, and discover the ways to dissipate fog from important location like airports. (Gultepe, 2007, Lutgen and Tarbuck, 2004, Muslihuddin, 2004).

Fog in Pakistan

The frequency of fog in Pakistan has increased drastically from November to March in the recent years, and it has adversely affected Pakistan's economy because a number of flights have been cancelled on many occasions and a number of road accidents have occurred in different parts of the country because of the prevailing fog in those parts of the country. The upper parts of Punjab have been badly affected by anomalous occurrence of fog in the last decade or so. The average number of days on which fog prevails over these areas has risen above normal in the months of November–March. Lahore is an important city of Pakistan which is situated in the northern Punjab and which has and is being suffered from the worst foggy conditions in its history. Lahore is situated near Ravi River which provides enough moisture to its atmosphere. Fog occurs in Lahore almost consistently and it has implied adverse effects on the people of the region, both in direct and indirect manner. The fog which occurs in Punjab is known to be Radiation and Frontal fog. (Syed Faisal Saeed and Asma Younas, 2004).

Fig.1 shows the frequency of fog for the period (2001–2009) in Pakistan. This figure shows that the fog is mainly formed over Punjab and its adjoining areas with highest concentration over the northern Punjab. The average fog days in these areas range from 9–15 days, especially in the months of December and January.

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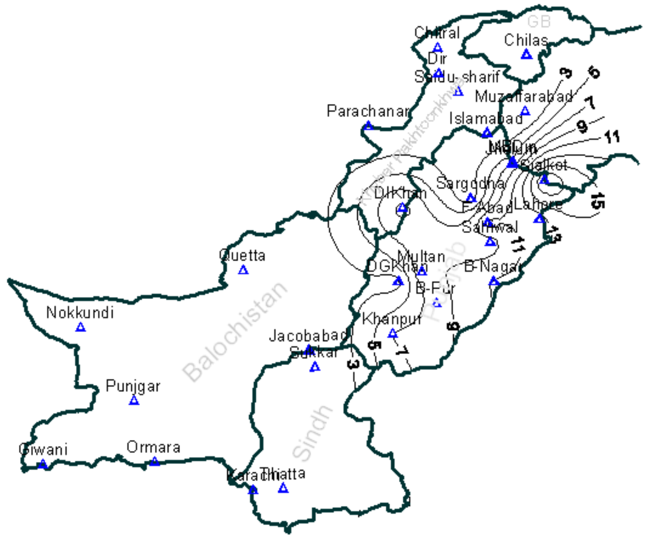

Figure 1: Mean Fog Days (2001 – 2009).

Fog and Aerosols

The aerosols present in the atmosphere act as condensation nuclei for fog droplets to form, as most of the aerosol particles are hygroscopic in nature, resulting in a large amount of water to be stuck to them. The water vapors in the atmosphere condense on these particles and hence these particles act as seeds, starting the formation of fog droplets. (Lutgen and Tarbuck, 2004, NASA Earth Observatory website). Thus an increase in the number of aerosols in the atmosphere ultimately increases the formation of fog.

^{7}Be, an isotope of Beryllium is cosmogenic in nature and is produced in the upper atmosphere as a result of spallation reaction between cosmic rays and atmospheric elements like ^{12}C, ^{16}O and ^{17}N. A peak value of ^{7}Be radioactivity exists around 10 to 20 km above ground in the atmosphere. (Papastefanou, 2008). ^{210}Pb, an isotope of Lead is the progeny of Radon (^{222}Rn), (a radioactive gas) which is produced in the decay series of Uranium (^{238}U). Both ^{210}Pb and ^{7}Be are highly particle reactive and they get rapidly attached to the atmospheric aerosols having diameters in micrometers. The aerosols containing these nuclides are called radioactive aerosols. (Zheng Xiangdong, 2005, N. Ali et al, 2011).

As for almost all of the radioactive nuclides during their production, they are positively charged ions. A charged body or particle can attract another charged body due to coulomb interaction or it can also attract a neutral body because of electrostatic induction. The aerosols present in the atmosphere can grow larger and larger in size due to acquiring other aerosols or molecules which coexist in the same location. The process of gain in aerosol particles is called nucleation. The ion induced nucleation has been studied by different researchers. **Horrak et al in 2005** studied the formation of charged particles burst during rain fall. This is an indication of ion induced nucleation. **Jan Kazil et al in 2008** studied the role of ions in the tropospheric new particle formation. The formation of molecular clusters from gas phase aerosols must be faster than its evaporation. The gas phase ions can greatly boost the nucleation process as it can suppress the evaporation process quite markedly. Thus ions are the important sources of atmospheric particles formation. **V. V. Sminov and A. V. Savchenko (2006)** verified that aerosols formation in the lower troposphere was greatly dependent on ion induced nucleation. They irradiated the dust free outdoor air by alpha rays and they observed an increase in the radiolytic aerosols mass concentration. This was an experimental proof for ion induced nucleation performed in the laboratory.

The ion induced nucleation (where the ions may be ^{210}Pb and ^{7}Be isotopes) is described in the above paragraphs. Also the role of these isotopes as atmospheric tracers, determination of aerosols residence time and deposition fluxes of aerosols laden by these nuclides in various regions of the world has been studied in different countries. No study about their role in fog formation has been found; therefore the present study is the first one in this regard. During this research project we will try to find a relation between the phenomena of fog formation and the radioactive aerosols (laden by these two nuclides).

Data and Methodology

In order to determine the relationship between radioactive aerosols and fog, 35 samples on Gelman Type A/E Glass Fiber Filters (47 mm in diameter), were taken in Lahore inside university of Punjab (31.48° N, 74.3° E). The sampling was carried out about three meter above the ground on the roof top of a building. The sampling was done with the help of a portable air sampler (F&J Model DF-AB-75L-Li). The filters were placed in polythene bags for gamma ray spectrometry. The samples were individually counted for the gamma rays of energies 46.5 keV and 477.6 keV emitted by ^{210}Pb and ^{7}Be respectively, which are present in the aerosols collected on the samples. The samples were counted for 1000 minutes each in the High Purity Germanium Detector (HPGe detector), which is N-type semi-conductor detector having resolution 2.2 keV at 1.33 MeV of ^{60}Co and relative efficiency of 52%. The data were analyzed by a computer attached to the detector by using an MCA card MCDWIN, having a commercial software Gamma-W supplied by DSG Germany.

The data of fog days for various cities of Pakistan and the daily rain data for Lahore for the period Dec–March, 2010 were obtained from Pakistan Meteorological Department.

Analysis of Results

The Activity Concentrations i.e. the gamma ray activities of the radioisotopes ^{210}Pb and ^{7}Be per unit volume of air sucked by the sampler, were calculated using the equation

$$c = \frac{Ne^{\lambda t_d}}{t \times P_\gamma \times \varepsilon_\gamma \times v}$$

Where c is the Activity Concentration which is measured in mBq/m^3 for convenience. N is the number of counts in the net area under full energy peak of gamma rays. t is the counting time of the sample in the detector, P_γ is the transition probability of isotope by gamma ray emission and ε_γ is the detector efficiency of the radionuclide at corresponding gamma ray energy. v is the volume of the air sucked by the sampler during sampling period. λ is the decay constant of each radio-nuclide and t_d is the decay time of the sample. The factor $e^{\lambda t_d}$ included in the formula is called decay correction factor. (N. Ali et al, 2010).

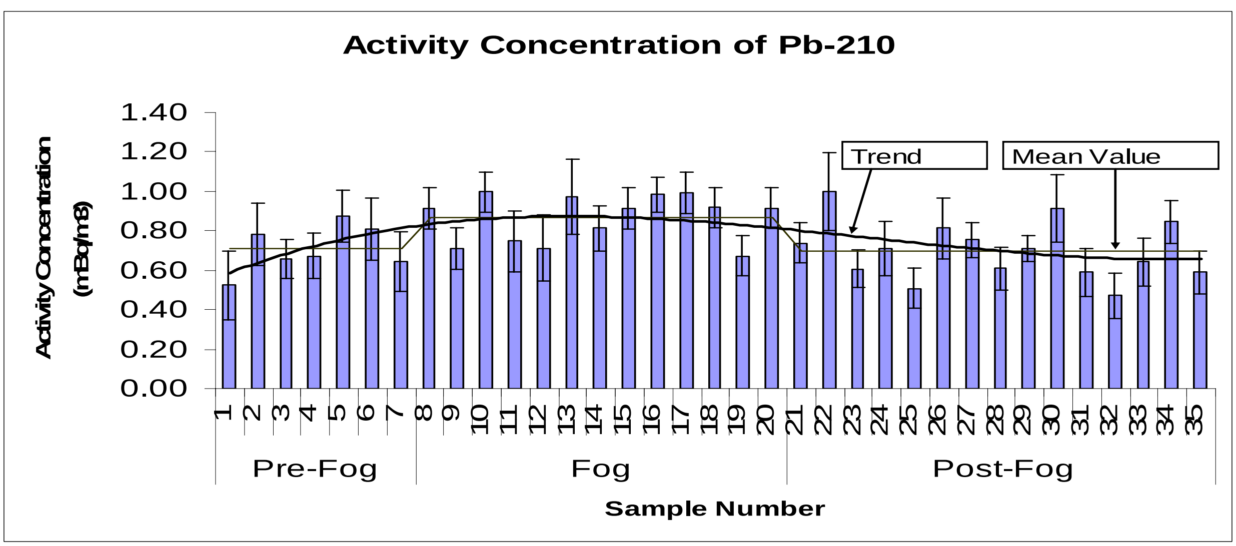

Figure 2: Activity Concentration for ^{210}Pb

Figure 2 shows Activity Concentration for ^{210}Pb. The trend line indicates an increasing trend in Activity Concentration during foggy conditions as compared to clear conditions (whether in the Pre-fog period or in the post-fog period).

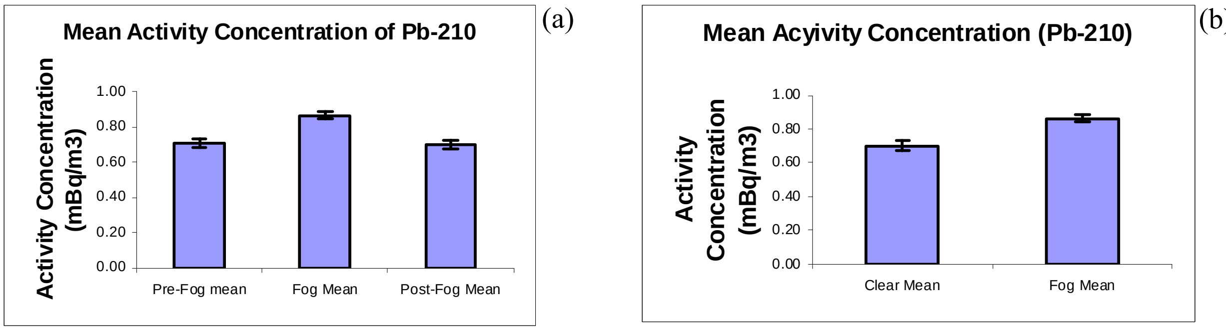

Figure 3: Mean Activity Concentration for ^{210}Pb in
(a) Pre-fog, Fog and Post-fog conditions
(b) Clear and Foggy conditions

Figure 3(a) shows Mean Activity Concentration for ^{210}Pb in the Pre-fog, Fog and Post-fog conditions. Comparing the three mean values for Activity Concentration we get about 18% change in Activity Concentration for Pre-fog and Fog conditions, about 19% change in Activity Concentration for Fog and Post-fog conditions and about 3% change in Activity Concentration for Pre-fog and Post-fog conditions. In figure 3(b) the Mean Activity Concentration in clear conditions (both Pre-fog and Post-fog conditions) and foggy conditions have been plotted. This figure shows about 19% increase in Activity Concentration during Fog as compared to the clear conditions.

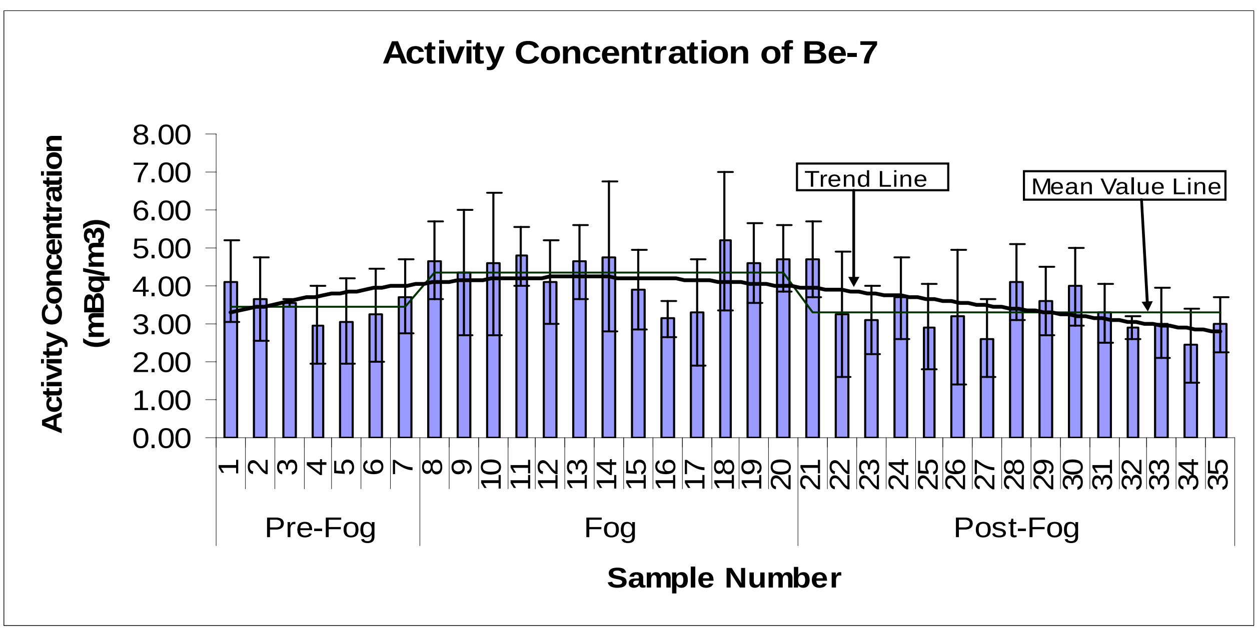

Figure 4: Activity Concentration for ^{7}Be

Figure 4 shows Activity Concentration for ^{7}Be. The trend line indicates an increasing trend in Activity Concentration during foggy conditions as compared to clear conditions (whether in the Pre-fog period or in the Post-fog period).

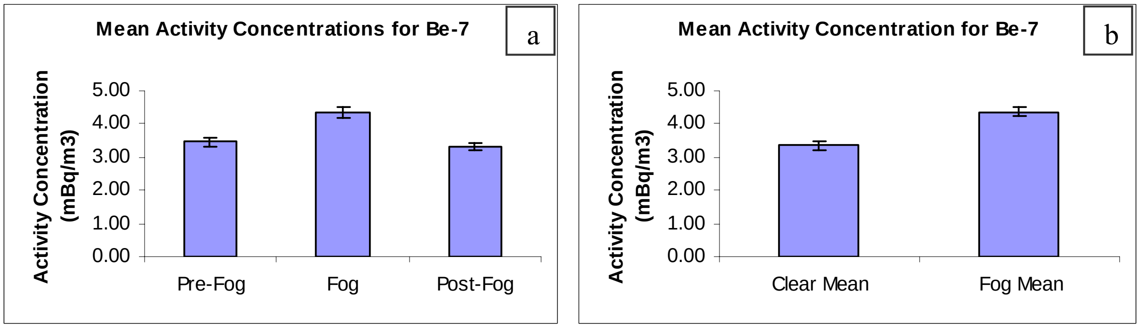

Figure 5: Mean Activity Concentration for ^{7}Be (a) Pre-fog, Fog and Post-fog conditions; (b) Clear and Foggy conditions

Figure 5(a) shows Mean Activity Concentration for ^{7}Be in the Pre-fog, Fog and Post-fog conditions. Comparing the three mean values for Activity Concentration we get about 23% change in Activity Concentration for Pre-fog and Fog conditions, about 24% change in Activity Concentration for Fog and Post-fog conditions and about 4% change in Activity Concentration for Pre-fog and Post-fog conditions.

In figure 5(b) the Mean Activity Concentration for ^{7}Be in clear conditions (both Pre-fog and Post-fog conditions) and foggy conditions have been plotted. This figure shows about 23% increase in Activity Concentration during Fog as compared to the clear conditions.

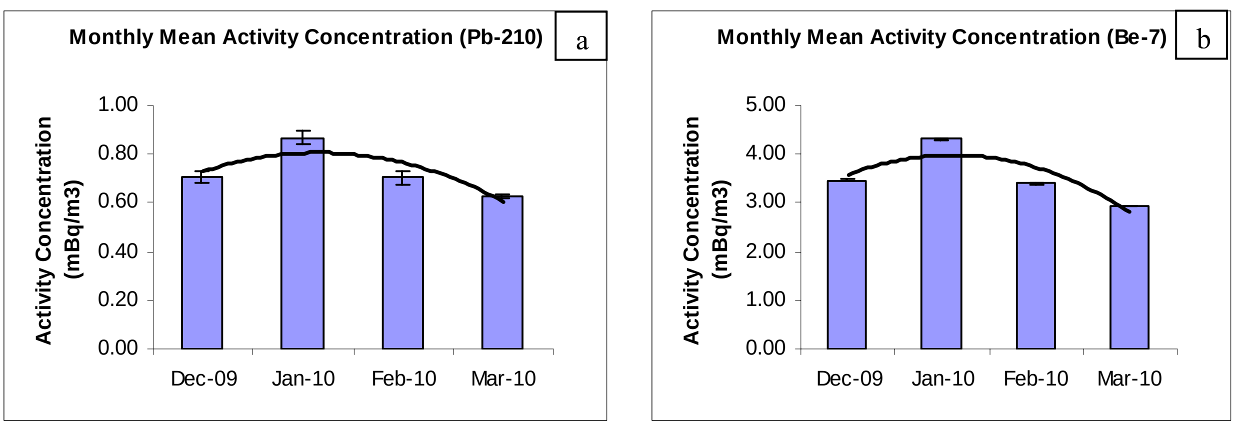

Figure 6: Monthly Mean Activity Concentrations for (a) ^{210}Pb; (b) ^{7}Be

Figure 6(a) and (b) show Monthly Activity Concentrations for ^{210}Pb and ^{7}Be. These figures also show comparatively high value for Activity Concentrations in the month of January in which most of the foggy days occurred in the site.

Discussion

Activity Concentration is a direct measure of the quantity of a radioactive nuclide in a sample. The variation in Activity Concentration reveals variation of the quantity of nuclide in the sample. This quantity varies both for ^{210}Pb and ^{7}Be in different conditions (i.e. Fog and Clear). Fig. 2 shows an increase in Activity Concentration of ^{210}Pb during foggy condition. A similar variation occurs in case of ^{7}Be as shown in Fig. 4.

The graphs for Mean Monthly Activity Concentration in Fig. 6(a) for ^{210}Pb and Fig. 6(b) for ^{7}Be also show a clear demarcation in Activity Concentration in the month of January 2010 in which foggy days occurred during sampling process. A much clear outcome we get from the results is that shown in the Fig. 3(b) for ^{210}Pb and Fig. 5(b) for ^{7}Be. These figures show Mean Activity Concentration for both nuclides in clear and foggy conditions. Fig. 3(b) shows about 19% increase in Activity Concentration of ^{210}Pb in foggy condition as compared to the clear conditions. While the same result is shown for ^{7}Be in Fig. 5(b) giving about 23% increase in Activity Concentration during foggy conditions. Figures 3(a) and 5(a) represent Mean Activity Concentration for Pre-fog, Fog and Post-fog conditions for ^{210}Pb and ^{7}Be respectively. Comparing these mean values for Activity Concentrations we get about 18% increase in Activity Concentration in fog as compare to Pre-fog conditions in the case of ^{210}Pb and about 23% increase in case of ^{7}Be. For Fog and Post-fog Comparison we get about 19% decrease in case of ^{210}Pb and about 24% decrease in case of ^{7}Be. Comparison of Pre-fog and Post-fog Activity Concentrations gives about 4% decrease in case of ^{7}Be and about 3% decrease in case of ^{210}Pb. This decrease in Activity Concentrations is due to the rain which occurred in the months of February and March in the Post-fog conditions. This rain resulted in wet deposition of the aerosols present in the atmosphere and consequently the quantity of radioactive nuclides in the atmosphere dropped and a reduction in their Activity Concentration occurred. The Figure. 7 shows daily rain recorded by Pakistan Meteorological Department from December 2009 to March 2010 in Lahore.

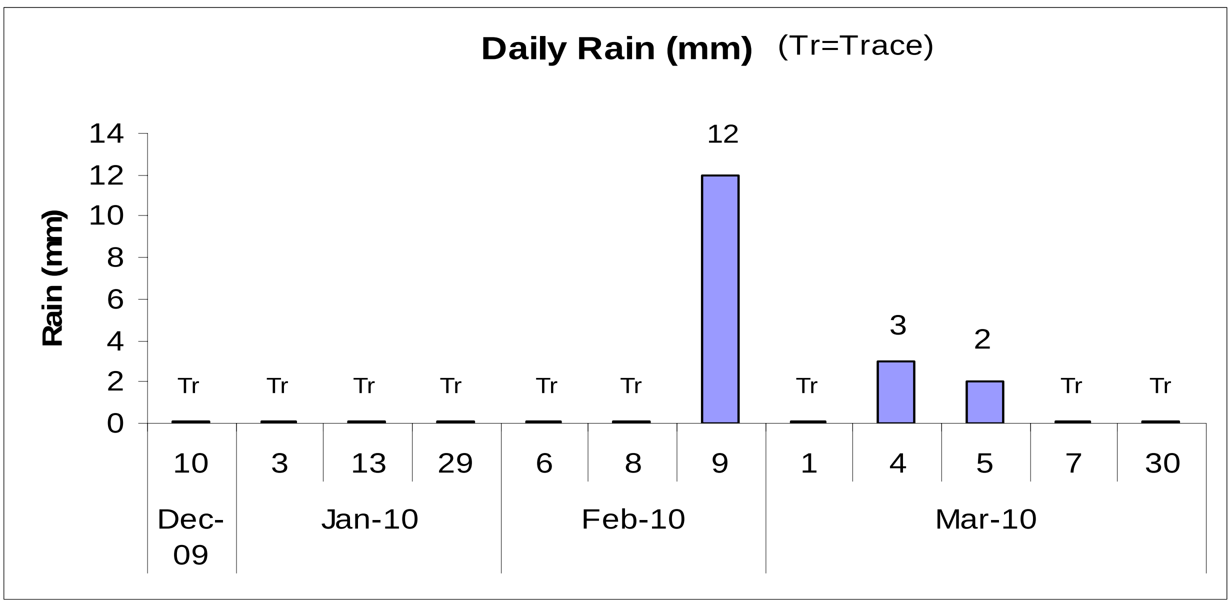

Figure 7: Daily Rainfall amounts recorded in Lahore during the sampling period (Dec–March).

Conclusion

As mentioned in the preceding text that both ^{7}Be and ^{210}Pb are positively charged nuclides as they are generated. This property causes them to associate with atmospheric aerosols, which are the precursors for the formation of fog provided other conditions (e.g. high relative humidity, low temperature and mild wind) are fulfilled. Their positive charge enhances their hygroscopicity. These aerosols, because of their positive charge get associated with polar molecules like water in the atmosphere, and hence they act as condensation nuclei for fog droplets to form. This is the fact that more and more condensation occurs on aerosol particles which results into the formation of fog. Thus it is concluded that the presence of these radio-nuclides in atmospheric aerosols can increase their seeding capability and more fog can form in the atmosphere. Therefore the presence of radioactive aerosols is also one of the so many factors responsible for fog formation.

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