Residence time of arctic haze aerosols using the concentrations and activity ratios of $^{210}\text{Po}$, $^{210}\text{Pb}$ and $^7\text{Be}$

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Abstract

Pollutants from mid-latitudes (mainly from Eurasia) reach the polar region through long-range atmospheric transport during winter. Due to very low precipitation in the arctic region, the pollutant-laden aerosols in the stable, and dark polar atmosphere are believed to have relatively longer residence times. The disequilibrium between the daughter products of $^{222}\text{Rn}$, in conjunction with the concentrations of $^7\text{Be}$ in arctic aerosols can be utilized to obtain information on the residence times and sources of the arctic haze. We have carried out a pilot study to explore the feasibility of determining the residence time of aerosols from the arctic haze. Towards this, we have analyzed 10 aerosol samples from two stations, Poker Flat and Eagle, Alaska for the concentrations and activity ratios of $^7\text{Be}$, $^{210}\text{Po}$, and $^{210}\text{Pb}$. The activity ratios of $^{210}\text{Po}/^{210}\text{Pb}$ varied between 0 and 0.177. The corresponding residence time obtained using the disequilibrium between the $^{210}\text{Po}$ and $^{210}\text{Pb}$, varied between 0 and 39 days. This is the first time an estimate on the residence time of aerosols from the arctic haze is determined. The $^7\text{Be}/^{210}\text{Pb}$ activity ratios varied between 2.2 and 14.0, possibly suggesting varying inputs of $^7\text{Be}$ from the upper atmosphere to the arctic atmosphere. Since long-range atmospheric transport is one of the major pathways of arctic pollution, this study has potential significance on the fate and transport of inorganic and organic atmospheric pollutants in the arctic region. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: $^{210}\text{Pb}$; $^7\text{Be}$; $^{210}\text{Po}$; Arctic haze; Residence time; Atmospheric contamination; Aerosols

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1. Introduction

Short-lived daughter products of radon-222 \((^{222}\text{Rn} \text{ half-life } = 3.84 \text{ days})\) and cosmogenic radionuclides have been used as atmospheric tracers (Lal & Peters, 1967; Lal & Suess, 1968; Poet, Moore, & Martell, 1972; Martell & Moore, 1974; Moore, Poet, & Martell, 1973, 1976; Turekian, Nozaki, & Benninger, 1977 and an excellent summary on the daughter products of \(^{222}\text{Rn}\) is given in Robbins, 1978; Graustein & Turekian, 1996). Radon-222, a daughter product in the \(^{238}\text{U}\)-decay series, is a noble gas and released from soil matrix at a constant rate. Radon-222 escape rate from the ocean surface is about 2 orders of magnitude lower than those reported for soils. The \(^{222}\text{Rn}\) emanation rate has been reported to be negligible from areas covered by glaciers and permafrost (summarized in Robbins, 1978). Thus, the concentrations of the daughter products of \(^{222}\text{Rn}\) (such as \(^{210}\text{Pb}\)) in aerosols depend on the sources of aerosols. This \(^{222}\text{Rn}\) undergoes radioactive decay in the atmosphere and produces several short-lived, particle-reactive daughter products (Fig. 1). These daughter nuclides are mainly positive ions, which become associated with polarized air or water or aerosol particles (Vohra, Subba Ramu, & Vasudeva, 1969). It was previously shown that about 90% of the natural atmospheric radioactivity was found in aerosols with radii between 0.05 and 0.5 \(\mu\)m, with an average size of 0.1 \(\mu\)m (Junge, 1963). Once these particle-reactive nuclides get attached to aerosols, the fate of these nuclides is the same as the fate of nuclide-bound aerosols, and thus, these nuclides can be utilized to obtain information on the residence time and rates of removal of aerosols (Poet et al., 1972; Moore et al., 1973).

Beryllium-7 (half-life = 55.3 days) is produced throughout the atmosphere as a product of the spallation of oxygen and nitrogen nuclei by energetic cosmic rays (Lal, Malhotra, & Peters, 1958).

![Decay Scheme](Fig. 1. The decay scheme of \(^{222}\text{Rn}\).)
Due to its short mean life (≈ 76.9 d) and longer residence time of stratospheric aerosols (about one year, Kuroda, Hodges, Fry & Moore, 1962), most of the $^7$Be nuclei that are produced in the stratosphere do not readily reach the troposphere except during spring when seasonal thinning of the tropopause takes place at mid-latitudes, resulting in air exchange between stratosphere and troposphere. Since $^7$Be is of cosmogenic origin, its flux to the earth’s surface has a latitudinal dependence (Lal & Peters, 1967). Its concentration in the air increases with increasing altitude from the surface of the earth, and its atmospheric flux to the earth’s surface should be independent of local landmasses at any particular latitude (Baskaran, Coleman & Santschi, 1993).

Due to very low population density, the Arctic atmosphere is expected to be free from pollutants derived from the local sources. In contrast to the Antarctic atmosphere, the arctic atmosphere is very hazy during winter and spring. The arctic haze is derived from fossil fuel burning, industrial, and agricultural processes, by long-range transport of mid-latitude pollution products (Rahn, 1982). The build-up of the arctic haze takes place during the winter and early spring months (mainly December–April) and the aerosols in the haze are enriched in NO$_3$ and SO$_4$ along with soot, water, and organo-chlorine. This haze primarily comprised of particles that are < 2 μm in size and in patches of about 800–1300 km across, and at an altitude of less than a few km above ground (Shaw, 1995 and references cited therein). Due to very low precipitation, the removal rates of the haze are low during the periods when the haze exists (Shaw, 1991).

Earlier studies indicated that the concentration of $^{210}$Pb (half-life = 22.3 years) in Alaskan arctic aerosols reaches a maximum in winter (EML, 1979; Dibb, Meeker, Finkel, Southon, & Caffee, 1994). It is not clear if $^{210}$Pb in the arctic aerosol is entirely derived from the $^{222}$Rn that escaped locally, even though Rn escape from soil in high latitudes could be prevented by glaciers and permafrost cover (summarized in Robbins, 1978). The concentrations of $^7$Be in air samples from Barrow, Alaska showed strong seasonal variations with peak concentrations in the late winter or early spring (Feely, Larsen, & Sanderson, 1989), which coincided with the arrival of the arctic haze.

During the long-range atmospheric transport of air masses from sub-polar regions, if all the particle-reactive radionuclides produced from the decay of $^{222}$Rn during long-range atmospheric transport are scavenged from the atmosphere before reaching the arctic area, then, almost all of $^{210}$Pb and its daughter products ($^{210}$Bi, half-life = 5.01 days and $^{210}$Po, half-life = 138 days) in the arctic aerosols would be produced from the decay of $^{222}$Rn. In such a case, the disequilibrium between $^{210}$Pb and $^{210}$Po can be utilized to obtain the residence time of aerosols under the assumption that these nuclides are instantaneously removed on to aerosols after their production. It is pertinent to point out that the time span of the existence of arctic haze is only 4–5 months and is comparable to the mean-life of $^{210}$Po and hence the $^{210}$Po/$^{210}$Pb ratios can be utilized to obtain information on the residence time of aerosols from the arctic haze. Towards this, we carried out a pilot study by collecting a suite of aerosol samples from the Alaskan arctic and measured the concentrations of $^7$Be, $^{210}$Po, and $^{210}$Pb. From ancillary information on the synoptic structures associated with transport, trajectory analysis and transport modeling, along with concentrations and activity ratios of $^{210}$Pb and $^7$Be, we will be able to get better insight on the sources of air to the arctic haze. This is the first attempt to determine the residence time of aerosols collected from the arctic haze.
2. Materials and methods

Large volume air samples from Poker Flat (65.1 N; 147.5 W) and Eagle (65.9 N; 141.2 W) were filtered through an air filtration assembly at a typical flow rate of 1 m$^3$ min$^{-1}$. Whatman 41 cellulose fiber filter was utilized for the collection of aerosols. Although non-optimal collection efficiency of Whatman 41 filter is a well-known problem, it is reasonable to assume constant collection efficiency for $^{210}$Po and $^{210}$Pb. In such a case, problems in collection efficiency will not affect the residence time of aerosols, based on the activity ratios of $^{210}$Po/$^{210}$Pb. All the samples analyzed in this study were collected between January and March 1996. The time of collection varied between 2 and 8 days (Table 1). One half-section of the filter was digested (with 12 ml 6M HCl + 2 ml conc. HNO$_3$ + 0.8 ml conc. HF) in a microwave for 2 h. After the digestion was complete, the solution was dried and taken in dilute HCl and then transferred into a gamma counting vial. After gamma counting the vial for $^7$Be and $^{210}$Pb, the solution was further processed for polonium plating after adding $^{209}$Po spike. The details on the radiochemical processing of $^{210}$Po are given in Baskaran and Naidu (1995). Polonium was electroplated onto a silver planchet and then the planchet was counted in an alpha spectrometer. The activities of $^{210}$Po, $^{210}$Pb and $^7$Be were corrected for decay and ingrowth from the mid-time of collection to the time of counting. The errors reported are propagated errors arising from the one sigma counting uncertainty due to detector calibration and background correction.

3. Theoretical basis for the determination of the residence time of aerosols

Polonium-210, a daughter product of $^{210}$Pb, is also particle-reactive similar to $^{210}$Pb. During long-range transport of pollutants from Eurasia to the Arctic, most of the $^{210}$Po and $^{210}$Pb produced are likely removed by precipitation and unreactive gaseous $^{222}$Rn reaches the arctic area. If all the $^{210}$Pb in the sampling site in the arctic is produced from the decay of $^{222}$Rn in the air and all $^{210}$Po is derived from $^{210}$Pb (i.e., no additional sources of $^{210}$Po and $^{210}$Pb), then using a simple steady-state model, the disequilibrium between $^{210}$Po and $^{210}$Pb can be utilized to determine the residence time of the aerosols. In a well-mixed, isolated atmospheric sample where the rate of supply of radon gas is constant, the rate of change of decay product concentrations is given by

$$\frac{dN_d}{dt} = \lambda_p N_p - (\lambda_d + \lambda_r)N_d,$$

(1)

where $N_p$ and $N_d$ refer to the concentrations of parent and daughter products, and $\lambda_p$ and $\lambda_d$ are their respective reciprocal lifetimes; $\lambda_r$ is the removal rate constant. Under equilibrium conditions,

$$N_d\lambda_d/\lambda_p N_p = \lambda_d/(\lambda_d + \lambda_p).$$

(2)

In cases where the activity ratio of products are separated by an intermediate decay product, such as the ratio of $^{210}$Po to $^{210}$Pb (via $^{210}$Bi), the ratio is given by (Robbins, 1978)

$$N_{po}\lambda_{po}/N_{pb}\lambda_{pb} = \lambda_{po}\lambda_{bi}/[(\lambda_{bi} + \lambda_r)(\lambda_{po} + \lambda_r)].$$

(3)

The residence time $(=1/\lambda_r)$ can be determined from Eq. (3) using the measured activity ratios of $^{210}$Po/$^{210}$Pb. If the half-life of intermediate product (in this case, $^{210}$Bi) is short in comparison with
Table 1
Sample location, concentrations of $^{210}$Po, $^{210}$Pb and $^7$Be of the aerosols from arctic and non-arctic haze

<table>
<thead>
<tr>
<th>Station</th>
<th>Date of collection (Days collected)</th>
<th>Details of the samples</th>
<th>$^{210}$Po(^b) dpm/10(^3) m(^3)</th>
<th>$^{210}$Pb dpm/10(^3) m(^3)</th>
<th>$^7$Be dpm/10(^3) m(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poker Flat-1</td>
<td>8 Jan. 1996 (8.0 d)</td>
<td>Arctic haze — air from the north and west, around Siberian high</td>
<td>9.11 ± 1.00</td>
<td>61.3 ± 0.9</td>
<td>339.3</td>
</tr>
<tr>
<td>Poker Flat-2</td>
<td>26 Feb. 1996 (2.0 d)</td>
<td>Flow from the south, passage of an east-west frontal system across Alaska</td>
<td>2.87 ± 0.49</td>
<td>49.3 ± 1.7</td>
<td>182.4</td>
</tr>
<tr>
<td>Eagle-1</td>
<td>10 Jan. 1996 (1.9 d)</td>
<td>Arctic haze — flow from the west and north</td>
<td>−0.44 ± 0.84</td>
<td>31.5 ± 2.0</td>
<td>68.7</td>
</tr>
<tr>
<td>Eagle-2</td>
<td>15 Jan. 1996 (4.0 d)</td>
<td>Low arctic haze — southern air from a low over Siberia</td>
<td>−1.5 ± 1.7</td>
<td>15.5 ± 3.2</td>
<td>85.4</td>
</tr>
<tr>
<td>Eagle-3</td>
<td>4 March 1996 (1.6 d)</td>
<td>High pressure system above Alaska, anticyclonic conditions</td>
<td>1.05 ± 0.49</td>
<td>16.5 ± 2.0</td>
<td>109.5</td>
</tr>
<tr>
<td>Eagle-4</td>
<td>6 March 1996 (2.0 d)</td>
<td>Anticyclonic conditions, some stratospheric air input</td>
<td>3.20 ± 0.23</td>
<td>18.1 ± 0.6</td>
<td>253.9</td>
</tr>
<tr>
<td>Eagle-5</td>
<td>8 March 1996 (3.5 d)</td>
<td>Arctic haze, air from the Arctic, high to the north and low to the south</td>
<td>3.55 ± 0.36</td>
<td>26.7 ± 1.4</td>
<td>159.1</td>
</tr>
<tr>
<td>Eagle-6</td>
<td>11 March 1996 (1.5 d)</td>
<td>Flow to the southwest, strongly Pacific marine air</td>
<td>1.55 ± 0.45</td>
<td>33.2 ± 2.2</td>
<td>126.8</td>
</tr>
<tr>
<td>Eagle-7</td>
<td>13 March 1996 (2.3 d)</td>
<td>Arctic haze, east-west frontal system, anticyclonic flow from the northwest</td>
<td>1.90 ± 0.27</td>
<td>22.1 ± 1.5</td>
<td>98.8</td>
</tr>
<tr>
<td>Eagle-8</td>
<td>15 March 1996 (3.0 d)</td>
<td>Arctic haze, anticyclonic flow to the northeast</td>
<td>1.90 ± 0.23</td>
<td>13.4 ± 1.5</td>
<td>152.3</td>
</tr>
</tbody>
</table>

\(^a\)The errors reported are propagated errors arising from one sigma counting uncertainty due to detector calibration and background correction.

\(^b\)The negative values of $^{210}$Po concentration is due to decay/growth corrections made on the measured $^{210}$Po values.

The aerosol residence time so that $\lambda_{Bi} \gg \lambda_r$, the activity ratio reduces to that expected if the parent ($^{210}$Pb) and granddaughter ($^{210}$Po) were not separated by an intermediate decay product. Since arctic haze lasts for about 3–4 months during winter, the aerosols also could potentially stay for much longer than the half-life of $^{210}$Bi, and in such a case, the $^{210}$Po/$^{210}$Pb ratios could be utilized to obtain the residence time of arctic haze.
4. Results and discussion

The concentrations of $^7$Be, $^{210}$Pb and $^{210}$Po on the 10 samples are given in Table 1. The concentrations of $^7$Be varied between 0.069 and 0.339 dpm m$^{-3}$, with a mean value of 0.158 dpm m$^{-3}$. Concentrations of $^{210}$Pb varied between 0.0134 and 0.0613 dpm m$^{-3}$ (mean value = 0.0288 dpm m$^{-3}$) while that of $^{210}$Po varied between below detection limit ($\sim 7 \times 10^{-5}$ dpm m$^{-3}$) and 0.00911 dpm m$^{-3}$ (mean value = 0.00251 dpm m$^{-3}$). The activity ratios of $^{210}$Po/$^{210}$Pb and $^7$Be/$^{210}$Pb varied between 0 to 0.177 (mean value = 0.085) and 2.2 and 14.0 (mean value = 6.3), respectively (Table 2).

The residence time of aerosols based on the disequilibrium between $^{210}$Po and $^{210}$Pb is given in Table 2. This residence time is based on the following assumptions:

(i) The initial concentration of $^{210}$Po is zero at the time when the aerosols reach the arctic ($^{210}$Pb concentration need not be zero for the determination of residence time using $^{210}$Po/$^{210}$Pb disequilibrium), and

(ii) The entire Po is derived from the decay of $^{210}$Pb and there is no extraneous source(s) of $^{210}$Po to the aerosols collected for this study.

If any of these two assumptions are violated, the residence times obtained from the disequilibrium between $^{210}$Po and $^{210}$Bi will be upper limits. The importance of these two assumptions are discussed in detail below.

Earlier studies based on $^{210}$Bi/$^{210}$Pb activity ratios on the residence times of aerosols for the continental United States yielded a few days while that of $^{210}$Po/$^{210}$Pb resulted in a month or more (summarized in Moore et al., 1976; Robbins, 1978). This discrepancy of residence times between $^{210}$Bi/$^{210}$Pb and $^{210}$Po/$^{210}$Pb was attributed to the additional sources of $^{210}$Po to the atmosphere, including dust storms, coal-burning power plants, forest fires, and plant exudates (Moore et al., 1976). More recently, Marley et al. (2000), have shown that the residence times for smaller size aerosols (<0.62 μm) obtained using $^{210}$Po/$^{210}$Pb activity ratios (47–57 days) are quite comparable to the residence times obtained using $^{210}$Bi/$^{210}$Pb activity ratios (42–56 days). The differences in the

Table 2
Activity ratios of $^{210}$Po/$^{210}$Pb and $^7$Be/$^{210}$Pb and residence times of aerosols from arctic and non-arctic haze

<table>
<thead>
<tr>
<th>Station</th>
<th>$^{210}$Po/$^{210}$Pb Activity ratio</th>
<th>$^7$Be/$^{210}$Pb Activity ratio</th>
<th>Age (Days)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poker Flat-1</td>
<td>0.149 ± 0.025</td>
<td>5.50</td>
<td>32 ± 5</td>
</tr>
<tr>
<td>Poker Flat-2</td>
<td>0.058 ± 0.012</td>
<td>3.69</td>
<td>11.9 ± 2.4</td>
</tr>
<tr>
<td>Eagle-1</td>
<td>−0.016 ± 0.042</td>
<td>2.17</td>
<td>−3.1 ± 8.2</td>
</tr>
<tr>
<td>Eagle-2</td>
<td>−0.011 ± 0.017</td>
<td>5.51</td>
<td>−2.2 ± 3.4</td>
</tr>
<tr>
<td>Eagle-3</td>
<td>0.063 ± 0.037</td>
<td>6.60</td>
<td>13.0 ± 7.46</td>
</tr>
<tr>
<td>Eagle-4</td>
<td>0.177 ± 0.016</td>
<td>14.0</td>
<td>38.7 ± 3.2</td>
</tr>
<tr>
<td>Eagle-5</td>
<td>0.133 ± 0.017</td>
<td>5.95</td>
<td>28.5 ± 3.5</td>
</tr>
<tr>
<td>Eagle-6</td>
<td>0.047 ± 0.016</td>
<td>3.81</td>
<td>9.5 ± 3.3</td>
</tr>
<tr>
<td>Eagle-7</td>
<td>0.086 ± 0.015</td>
<td>4.45</td>
<td>17.8 ± 3.1</td>
</tr>
<tr>
<td>Eagle-8</td>
<td>0.141 ± 0.025</td>
<td>11.3</td>
<td>30.3 ± 5.1</td>
</tr>
</tbody>
</table>

$^a$The negative residence time and $^{210}$Po concentration is due to decay/growth corrections made on the measured $^{210}$Po values. In such cases, residence time is taken to be zero.
residence times obtained using these two pairs of activity ratios become larger with the increase in the aerosol size (Marley et al., 2000). If the aerosols in the arctic haze are smaller in size, then, it is likely that the residence times that can be obtained using $^{210}\text{Bi}/^{210}\text{Pb}$ activity ratios will be comparable to the residence times reported in this paper.

Unlike the earlier studies in the continental United States and other places (e.g., Moore et al., 1976), additional sources of $^{210}\text{Po}$ to our study area in the arctic are likely insignificant. From an evaluation of various sources of $^{210}\text{Po}$ to the atmosphere in the continental United States, Moore et al. (1976) estimated that the suspended soil particles could account for 53% of the additional sources of $^{210}\text{Po}$, 37% due to release from plant exudates, 3.2% from stratospheric injection, 0.8% from forest fires, and the remaining 5.8% from anthropogenic sources (including phosphate fertilizer dispersion, by-product gypsum, lead production, cement and other metal production, and fossil fuel burning). The relative importance of each of these sources to the winter arctic air is unknown; however, certain input terms during winter such as anthropogenic (in the form of phosphate fertilizer, fossil fuel burning, etc.), suspended soil particles, release from plant exudates (ability of leaf surfaces to collect and retain $^{210}\text{Pb}$ and $^{210}\text{Po}$ aerosols were reported by Moore et al., 1976) are likely negligible. During the long-range transport of aerosols from Europe and Asia through the upper atmosphere, it is likely that most of the daughter products of $^{222}\text{Rn}$ ($^{210}\text{Po}$, $^{210}\text{Bi}$, and $^{210}\text{Pb}$) are removed and only $^{222}\text{Rn}$ reaches the arctic air. Recent study by Kim, Hussain, Scudlark, and Church (2000) on the atmospheric fallout of $^{7}\text{Be}$, $^{210}\text{Pb}$ and stable Pb in the Chesapeake Bay area indicates that stable Pb is mainly transported from remote areas through the upper atmosphere while $^{210}\text{Pb}$ transport is primarily through lower atmosphere. In addition, information obtained from the satellite measurements and weather records from ships and islands have indicated that the amount of precipitation in the oceans adjoining the Arctic regions, such as North Atlantic and North Pacific, are considerably higher during winter than those in the continents. This will result in efficient removal of aerosols in the oceans (Rao, Abbott, & Theon, 1976; Rahn & McCaffrey, 1980). However, the pollutants that reach the arctic are likely transported from remote areas through the upper troposphere without much removal. When $^{222}\text{Rn}$ alone are transported to the arctic and there is no additional source of $^{210}\text{Po}$ other than from the decay of $^{210}\text{Pb}$, the residence time calculated using the $^{210}\text{Po}/^{210}\text{Pb}$ ratio would be a realistic value of the residence time of aerosols.

The residence times varied between 0 and 39 ± 3 days (Table 2). As we discussed before, earlier studies using $^{210}\text{Po}$$-^{210}\text{Pb}$ disequilibrium for the continental United States resulted in residence times of > 1 month and our values of ~ 0 days on two samples (Eagle -1 and 2) likely indicate that there are no additional sources of $^{210}\text{Po}$ to the arctic air. In half of the samples, the calculated residence time is equal to or lower than the residence time of 13 days calculated based on $^{210}\text{Bi}/^{210}\text{Pb}$ ratios for the continental United States (Poet et al., 1972). The arctic haze typically lasts for about 3–4 months during winter and if the aerosols in the haze stay for that long, then, the residence time of individual aerosol particles could vary from few days to 3–4 months. In this context, the range obtained for the residence time seems quite reasonable. It must be pointed out that the reliability of this residence time critically depends on the initial concentration of $^{210}\text{Po}$ in the incoming aerosols to the arctic region. If there were some amount of $^{210}\text{Pb}$ (but negligible amount of $^{210}\text{Po}$) present when the aerosols reach the arctic region, then, that would not affect the values of the residence time. Since we do not have any other radionuclide data on the incoming aerosols prior to coming into the arctic region, we cannot rigorously address this issue.
Similar studies in the continental United States by Mareno and Fontan (1972) and Nevissi, Beck, and Kuroda (1974) showed that the $^{210}\text{Po} / ^{210}\text{Pb}$ ratio in rain samples were high as compared to the aerosols indicating longer tropospheric aerosol residence times which also could be due to stratospheric air intrusions into the stratosphere during the passage of frontal systems (Moore et al., 1976).

5. Concentrations of $^7\text{Be}$ and use of $^7\text{Be} / ^{210}\text{Pb}$ activity ratio as atmospheric tracer

The $^7\text{Be}$ concentration in six aerosol samples from Eagle station collected between a period of two weeks varied between 0.099 and 0.254 dpm m$^{-3}$, with a mean value of 0.150 dpm m$^{-3}$. The concentrations of $^7\text{Be}$ in aerosols are primarily controlled by three factors: (1) variations in the amount of precipitation which causes the change in the deposition fluxes as well as air concentrations of $^7\text{Be}$; (2) changes in the stratosphere–troposphere exchange during late winter and early spring seasons; and (3) variations in the amount of $^7\text{Be}$ brought by long-range transport. Since the production source functions of $^{210}\text{Pb}$ and $^7\text{Be}$ are distinctly different, a relatively high correlation between the concentrations of $^7\text{Be}$ and $^{210}\text{Pb}$ will provide information on the atmospheric removal behavior of these nuclides as well as information whether these two radionuclides can be used as independent atmospheric tracers (Todd, Wong, Olsen, & Larsen, 1989; Baskaran et al., 1993; Baskaran, 1995). The $^7\text{Be} / ^{210}\text{Pb}$ activity ratios varied over a factor of 6 in the arctic aerosol samples while a factor of 15 has been reported in the precipitation samples from Galveston (Baskaran et al., 1993).

The concentrations of $^7\text{Be}$ plotted against $^{210}\text{Pb}$ in all the aerosol filter samples (Fig. 2) indicate that there is a positive correlation between the two ($r = 0.63$, $P < 0.1$). However, when one data point is removed from the linear fit, there is no significant correlation. A strong positive correlation between the bulk depositional fluxes of $^7\text{Be}$ and $^{210}\text{Pb}$ (in rainfall) was observed for several places suggesting that the atmospheric removal behavior of $^7\text{Be}$ and $^{210}\text{Pb}$ are relatively similar and that these two nuclides cannot be used as two independent atmospheric tracers (Todd et al., 1989; Baskaran et al., 1993). From a synthesis of all the earlier published data on the bulk depositional fluxes of $^7\text{Be}$ and $^{210}\text{Pb}$, Baskaran et al. (1993) concluded that in most of the continental and coastal stations, $^7\text{Be}$ and $^{210}\text{Pb}$ cannot be used as two independent atmospheric tracers and only in

Fig. 2. Concentration of $^{210}\text{Pb}$ are plotted against $^7\text{Be}$ concentrations in the aerosol samples collected from the Arctic.
oceanic and a few coastal stations, do \(^{7}\)Be and \(^{210}\)Pb fluxes seem to vary independently. In those places where there is a correlation between the bulk depositional fluxes of these two nuclides, \(^{7}\)Be and \(^{210}\)Pb cannot be used as independent air mass tracers. Our data is limited and hence we are unable to address this issue from our pilot data set if these tracers can be used as independent atmospheric tracers. More extensive database from several stations in the arctic will enable us to address the issues on the sources and transport of arctic aerosols.

6. Conclusions

From a limited number of samples, we can draw the following conclusions:

(i) The activity ratios of \(^{210}\)Po/\(^{210}\)Pb in arctic aerosol samples varied between 0 and 0.177 corresponding to a range of residence times between \(\sim 0\) and 39 days. This range of values is in contrast with earlier studies for the continental US where additional sources of \(^{210}\)Po were attributed to the longer residence time. Thus, it appears that there may not be any additional sources of \(^{210}\)Po to the arctic and most of the \(^{210}\)Po to the study area is derived from the decay of \(^{210}\)Pb present in the arctic air.

(ii) There appears to be correlation between \(^{7}\)Be and \(^{210}\)Pb, possibly suggesting that these tracers cannot be used as independent atmospheric tracers. More extensive study from the beginning till the disappearance of the arctic haze will enable us to determine the usefulness of \(^{210}\)Po/\(^{210}\)Pb and \(^{210}\)Bi/\(^{210}\)Pb disequilibria for the residence times of arctic haze. In addition, such studies will also help to elucidate various sources of air to the arctic region.

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