Meteorological Conditions for the Variability of ^{7}Be and ^{210}Pb Concentrations in Surface Layer Air in Poland

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Abstract: The aim of this study was to determine the effect of meteorological factors on the concentration of beryllium ^{7}Be and lead ^{210}Pb in the surface layer air on background their variability due to environmental conditions. Data analysis was carried out for 13 Polish stations for the period 2005-2009. The measurement cosmogenic and terrestrial radioactivity were collected on network station type ASS-500. The analysis includes the following meteorological elements from NWS stations: temperature, precipitation, atmospheric pressure, wind speed, humidity, solar radiation and in addition number of sunspots (SSN). It was considered that these meteorological elements mainly responsible for the transport and removal processes of ^{7}Be and ^{210}Pb from the atmosphere. The study method was used correlation analysis. Because of the relatively small area of Poland, it is hard to prove the dependence of ^{7}Be activity concentration variability on the influence of such factors as geographical location or SSN. However, the activity concentration of ^{7}Be and ^{210}Pb are dependent on meteorological conditions. The inverse interaction of atmosphere stability conditions on ^{7}Be and ^{210}Pb allows one to use the $^{7}Be/^{210}Pb$ ratio as an indicator of vertical transport in the atmosphere.

Keywords: Aerosol (^{7}Be and ^{210}Pb), meteorology, radionuclides, $^{7}Be/^{210}Pb$ ratio.

1. INTRODUCTION

In the Earth – the atmosphere – outer space system, both natural and artificial radioactivity occurs. As regards origin, the former may be classified as cosmic or terrestrial radioactivity. The latter is connected with human activities. The occurrence of natural radioactivity in the surface layer of the troposphere is of high cognitive importance for understanding of the physical and chemical processes occurring in the atmosphere. Among the many radioactive substances monitored in atmospheric air in Poland, beryllium ^{7}Be and lead ^{210}Pb are elements which may be used as indicators for air mass flow and vertical interchange dynamics between the stratosphere and troposphere [1-3]. Beryllium ^{7}Be (Z=4) is a naturally occurring cosmogenic element emitting gamma radiation (0.477 MeV) and with a half-life of approx. 53.22 days. It forms mostly in spallation processes, in the lower stratosphere (~70%) and upper troposphere (~30%), as a result of a reaction of high-energy protons or neutrons, present in cosmic radiation, with light nuclei, mostly carbon ^{12}C, nitrogen ^{14}N and oxygen ^{16}O [4]. The transfer of ^{7}Be to the troposphere and the variability of its activity concentration in surface layer of atmospheric boundary layer (ABL) depend on the seasonal changes of such processes as: (1) intensity of stratosphere-troposphere air mass exchange, (2) vertical transport in the troposphere, (3) horizontal transport from temperate and subtropical latitudes to polar latitudes and the equatorial zone, (4) gravitational subsidence (dry deposition) and washing out by precipitation (wet deposition) [5]. The downflow of beryllium from the stratosphere to the troposphere occurs mostly *via* interruptions in tropopause, appearing near the of stratospheric jet-streams. The penetration of cosmogenic elements to the troposphere is most intense in spring. This is connected with a decrease of tropopause thickness or even its decay in intermediate seasons, particularly in polar latitudes. On the other hand, lead ^{210}Pb (Z=82) is a naturally occurring long-lived terrestrial element emitting gamma radiation (0.46 MeV) and with a half-life of about 22.23 years. After their formation, both ^{7}Be and ^{210}Pb readily join the atmospheric aerosols present in the Earth's atmosphere, most often with submicron diameters (accumulation mode) [6]. For the sake of different sources of origin of ^{7}Be and ^{210}Pb, the value of the $^{7}Be/^{210}Pb$ ratio may serve as indication of the height which the air mass is transported from and whether the air is of continental or marine origin; it also allows determination of the average residence time of the aerosol in the atmosphere. The activity of ^{7}Be may also be used as an indicator of the share of ozone of stratospheric origin in its total activity concentration in surface layer air [7, 8]. These issues, widely studied globally, have yielded several publications concerning Poland to a various extent [9-11] so far.

The level of ^{7}Be activity in the upper stratosphere is variable in time and space, and it also depends on the

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intensity of cosmic radiation. The activity concentration of ^{7}Be in surface layer air ABL depends on several factors, which may be classified as:

- static: geographical location;
- dynamic: solar activity, meteorological conditions including the horizontal transport and vertical exchange of air masses.

The aim of this work is to attempt the determination of the influence of meteorological aspects on the activity concentration of ^{7}Be and ^{210}Pb in surface layer air against the background of their variability resulting from the aforementioned static and dynamic factors.

2. MATERIAL AND METHODS

Measurement and observation data for the years 2005-2009 came from the following systems:

- Service for Measurements of Radioactive Contamination (SPSP) – activity concentration of beryllium ^{7}Be, lead ^{210}Pb;
- National Weather Service (NWS) – meteorological elements;
- Solar Influences Data Analysis Center (SIDC) – solar activity.

For the sake of the fact that beryllium and lead measurements and meteorological conditions measurements are carried out by various institutions, the locations of measurement stations for natural radioactivity are not always the same as the locations of measurements of weather conditions. This is why the results of the latter were assigned to the locations of natural radioactivity measurements, assuming that the meteorological conditions of the location of the radionuclide activity concentration measurement will be similar to those of the nearest meteorological station. In Poland, studies of radioactivity in the natural environment are carried out by the Central Laboratory for Radiological Protection (CLOR) and are owned by the National Atomic Energy Agency (PAA). A network of Aerosol Sampling Station type 500 (ASS-500) stations serves the purpose of early detection of radioactive contamination (Table **1**). An ASS-500 station is a device for continuous collection of samples of aerosols in the air for the purpose of detection of radioactive contamination in the air. It is manufactured by CLOR [12]. Radionuclide activity concentrations are measured in a network of laboratories equipped with high-resolution gamma ray spectrometry using a HPGe detector.

Table 1: Technical Characteristics of Aerosol Sampling Station ASS-500

Parameter	Characteristic
filter	Petrianov FPP-15-1.5
filter area	0.2 m^2
system drying filter	halogen radiators infrared
measuring period	weekly
air flow volume per week	50 000 – 90 000 m^3
nominal air flow	500 m^3/h (engine power 1.7 kW)
flow-meter	vortex
height of air sampling	1.5 m a.g.l.

In the area of Poland, there are 13 ASS-500 stations collecting operatively atmospheric aerosols in filters (Table **2**).

From the set of meteorological parameters measured on network stations Institute of Meteorology and Water Management NRI (NWS), the following were chosen for analysis: air temperature, total precipitation, atmospheric pressure at sea level, wind velocity, relative humidity of air and global solar radiation, assuming that these factors are responsible for both transport and the removal processes of ^{7}Be and ^{210}Pb. Global solar radiation was measured only at four stations: Gdynia, Warsaw, Torun and Lodz. Additionally, solar activity was evaluated based on the number of sunspots (SSN). As the influence of momentary meteorological conditions does not translate into instantaneous changes in beryllium and lead activity concentrations, monthly average values have been used in the analysis. In the paper, analysis of the Pearson correlation is used. All obtained coefficients of the Pearson correlation between the activity concentrations of ^{7}Be and ^{210}Pb and static and dynamic conditions are statistically important for the significance level α = 0.05.

3. RESULTS

3.1. Influence of Static Factors on the Activity Concentrations of ^{7}Be and ^{210}Pb in Surface Layer Air

Literature on the subject [see e.g. 20] indicates that dependences of beryllium ^{7}Be activity concentration on latitude, height above sea level and distance to the sea or ocean are particularly observed. The ^{7}Be content in surface layer air ABL is connected, among others, with the Earth's magnetic field, with the highest influence

Table 2: ^{7}**Be Measuring Sites in Poland Used in this Study**

Location	Geographic coordinates		Average height [m a.s.l.]	The average direct distance from the seashore [m]
	latitude φ° N	longitude λ° E		
Gdynia	54°31'	18°33'	2	1
Szczecin	53°24'	14°40'	1	56
Torun	53°1.6'	18°36'	69	149
Bialystok	53°10'	23°10'	148	275
Warszawa	52°18'	20°59.5'	82	262
Otwock-Swider	52°07'	21°15'	95	280
Zielona Gora	51°56'	15°30'	192	236
Lodz	51°47'	19°28'	180	288
Lublin	51°24'	22°50'	238	411
Wroclaw	51°06'	16°53'	120	357
Katowice	50°14'	19°02'	278	452
Krakow	50°04'	19°58'	237	480
Sanok	49°30'	22°12'	305	572

being observed in the vicinity of the equator. Therefore, the activity concentration of ^{7}Be increase with an increase in latitude. Figure **1** shows the yearly averages of ^{7}Be activity concentration for Poland vs. latitude and sampling station located in other countries. Analysis of the figure indicates that such a dependency is not observed in the area of Poland. This probably results from too small of a meridional stretch of the studied area (from approx. 49° N to approx. 55° N) and the prevalence of other activity concentration modifying factors in the surface layer air of this element. Such a dependency also does not exist in the case of lead ^{210}Pb, which is understandable considering the terrestrial origin of the metal. The average activity concentrations of ^{7}Be and ^{210}Pb in the area of Poland are comparable with the concentrations measured in stations in other countries (Table **3**).

The influence of a station's location above sea level on ^{7}Be activity concentration was then investigated, because according to the results of the studies of, among others, Duenas *et al*. [20], the dependency

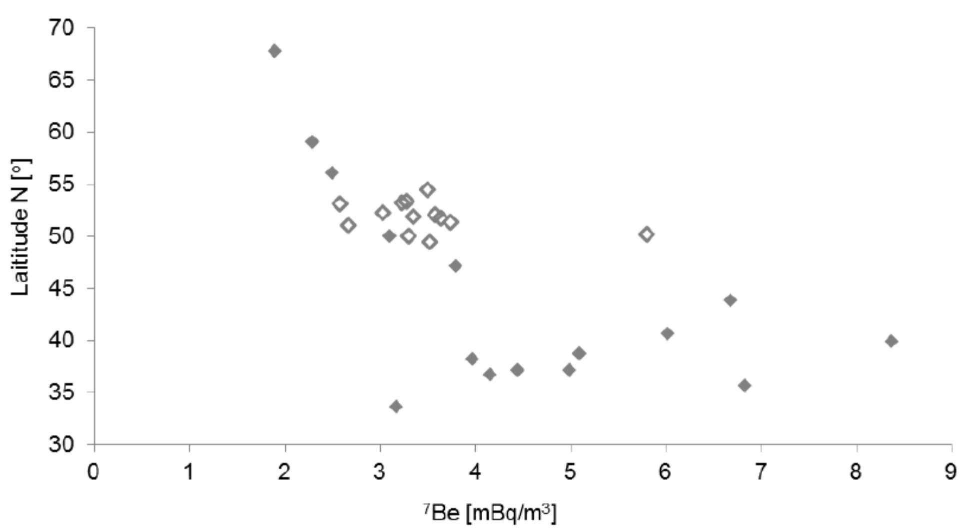

Figure 1: Long term average of ^{7}Be activity concentrations in ground level air for the northern hemisphere (33° – 68°) between 4°W and 140°E. Open diamonds correspond to data from this paper (Poland sampling stations). Filled diamonds are according to papers [13 – 21] (the order of the points on figure as in Table **3**).

Table 3: Average Activity Concentration of ^{7}Be and ^{210}Pb in the Surface Layer Air in Poland and other Countries. SD - Standard Deviation

No.	Location (Country)	^{7}Be	^{210}Pb	Reference
		[mBq/m^3] average value ± SD (min – max)		
1.	Kiruna (Sweden)	1.9	-	[13]
2.	Grindsjoen (Sweden)	2.3	-	[13]
3.	Ljungbyhed (Sweden)	2.5	-	[13]
4.	Gdynia (Poland)	3.50 ± 1.52 (0.96 – 9.37)	0.34 ± 0.21 (0.1 – 1.49)	This work
5.	Szczecin (Poland)	3.28 ± 1.44 (0.97 – 10.71)	0.42 ± 0.36 (0.1 – 3.82)	This work
6.	Torun (Poland)	3.23 ± 1.57 (0.25 – 13.06)	0.42 ± 0.28 (0.11 – 2.39)	This work
7.	Bialystok (Poland)	2.58 ± 1.35 (0.67 – 7.81)	0.35 ± 0.25 (0.1 – 1.89)	This work
8.	Warszawa (Poland)	3.03 ± 1.34 0.52 – 7.04	0.42 ± 0.24 (0.06 – 1.69)	This work
9.	Otwock-Swider (Poland)	3.58 ± 1.62 (0.95 – 9.27)	0.52 ± 0.30 (0.13 – 1.83)	This work
10.	Zielona Gora (Poland)	3.35 ± 1.41 (0.70 – 11.56)	0.45 ± 0.36 (0.1 – 3.61)	This work
11.	Lodz (Poland)	3.64 ± 1.87 (0.56 – 15.34)	0.52 ± 0.33 (0.12 – 2.19)	This work
12.	Lublin (Poland)	3.74 ± 1.79 (0.51 – 10.74)	0.70 ± 0.39 (0.12 – 2.77)	This work
13.	Wroclaw (Poland)	2.67 ± 1.12 (0.45 – 6.44)	0.40 ± 0.12 (0.13 – 0.98)	This work
14.	Katowice (Poland)	5.80 ± 2.54 (1.03 – 13.85)	0.53 ± 0.30 (0.14 – 1.93)	This work
15.	Krakow (Poland)	3.30 ± 1.53 (0.65 – 8.26)	0.38 ± 0.22 (0.1 – 1.44)	This work
16.	Prague (Czech Republic)	3.1	-	[13]
17.	Sanok (Poland)	3.52 ± 1.50 (0.59 – 7.73)	0.52 ± 0.26 (0.15 – 1.40)	This work
18.	Dijon (France)	3.8	-	[13]
19.	Monaco (Italy)	6.69 (0.93 – 13.1)	1.13 (0.22 – 2.82)	[14]
20.	Thessaloniki (Greece)	6.02 ± 3.01 (1.2 – 14.6)	-	[15]
21.	Beijing (China)	8.39 ± 0.49	-	[16]
22.	Palermo (Italy)	5.1	-	[13]
23.	Yamagata (Japan)	3.97	-	[17]
24.	Granada (Spain)	4.45 ± 1.35	-	[18]
25.	El Arenosillo (Spain)	4.99 ± 0.19 (0.43 – 11.93)	0.57 ± 0.04 (0.06 – 2.27)	[19]
26.	Malaga (Spain)	4.16 ± 0.15 (2.5 – 6.0)	0.54 ± 0.03 (0.28 – 0.92)	[20]
27.	Qingdao (China)	6.83 ± 0.40	-	[16]
28.	Islamabad (Pakistan)	3.171 ± 0.14 (0.722 – 6.847)	0.284 ± 0.15 (0.056 – 0.761)	[21]

should be directly proportional. The higher the height above sea level, the lower the density of atmospheric air and the higher the power of cosmic radiation. However, analysis of the data did not revealed such a dependency in the studied area. Similarly as in the case of latitude influence, this probably results from the fact that height diversification of the individual measurement stations is small, and their absolute heights are close to sea level. Vertical changes in air density are small here and do not influence the beryllium ^{7}Be activity concentration significantly. Of course, such a dependency does not exist in the case of lead ^{210}Pb, too. Considering the terrestrial origin of ^{210}Pb, one should expect that its concentration in atmospheric air will be less in the coastal zone than in the interior. At the same time, the activity concentration of ^{7}Be, for the sake of its cosmogenic origin, should not depend on the distance from the sea, and it should decrease with an increase in this distance. Thus, the highest values of the $^{7}Be/^{210}Pb$ ratio should be observed in seaside regions, and the lowest values – in the area most distant from the sea. In this connection, the value of this ratio should testify to the origin of air masses. Analysis of the study results of average five-year $^{7}Be/^{210}Pb$ concentration ratios from 2005-2009 at Polish stations indicates that there is no unequivocally expressed dependency between the distance from the sea and this indicator. The range of the $^{7}Be/^{210}Pb$ ratio at Polish stations has amounted from 3.3 (Lublin) to 30.5 (Lodz), and this is comparable with other stations, such as Malaga (4.5 - 25.7), Mount Waligan, China (3 - 8), Mount Cimone, Italy (3 - 20), Belgrade (1.7 - 12.7) [16]. The lowest values were recorded in autumn and winter, and the highest values – in spring and summer. However, there is no statistically significant dependency between the distance from a sea area and the value of the $^{7}Be/^{210}Pb$ ratio. This confirms the assumption that both ^{7}Be and ^{210}Pb activity concentrations are functions of other multiple variables.

3.2. Influence of Dynamic Factors on the Activity Concentration of ^{7}Be and ^{210}Pb in Surface Layer Air

The dynamic factors influencing changes in the activity concentration of the studied radionuclides in atmospheric air include, apart from solar activity, weather conditions, the high variability of which (in the aspects of time and space in the studied region) may be of importance for changes in their concentrations.

3.2.1. ^{7}Be and Solar Activity

As is known, the Sun influences the level of cosmic radiation in the Earth's atmosphere to a significant degree, however indirectly. The best-known indicator of solar activity is the number of sunspots. Solar activity varies in a cycle with an average duration of 11 years (with a fluctuation from 9 to 14 years). The higher the number of sunspots, the weaker the cosmic radiation in the atmosphere. The phenomenon is caused by solar wind lowering the intensity of the galactic components of cosmic radiation. Thus, during times of high solar activity, the intensity of the solar wind is also higher; therefore, the weakening effect is stronger. This should be reflected in the variability of the activity concentration of ^{7}Be as an element of cosmic origin in the surface layer ABL. Taking the above into account, a study of the relationship between the ^{7}Be concentration and the number of sunspots (Figure **2**) was carried out in a subsequent part of the paper.

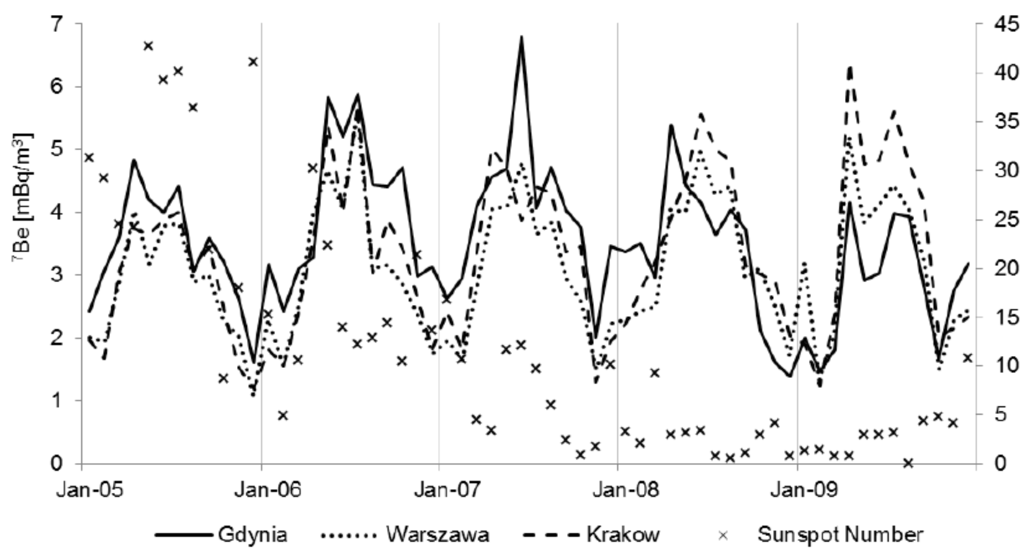

Figure 2: Average monthly activity concentrations of beryllium ^{7}Be in the surface layer air and monthly sunspots number (SSN) in the period 2005-2009.

Analysis of the results leads to the conclusion that there is no correlation between the ^{7}Be concentration and the number of sunspots observed. Pearson linear correlation coefficients (r) were negative, from –0.045 (Sanok) to –0.225 (Katowice), excluding Gdynia, where r was positive and equal to 0.095. The years 2005-2009 included two solar cycles: cycle No. 23, lasting from May 1996 to January 2008, and the current cycle - No. 24. In this year variations of beryllium ^{7}Be activity concentrations corresponding with sunspot numbers, in particular over the year 2009, a year of a particular minimum of solar activity [15], relatively higher values of ^{7}Be activity concentrations were observed.

3.2.2. ^{7}Be and Meteorological Conditions

Taking into account the fact that diversification of weather conditions in Poland is determined by seasonal changes, a yearly course of ^{7}Be activity concentration was carried out in the first place. The course of the multiple-year monthly averages of beryllium, lead concentrations and $^{7}Be/^{210}Pb$ ratio at the surface layer air for selected stations is shown in Figures **3**-**5**. During a year, the highest concentration of ^{7}Be is observed in the warm season (from April to September), with a maximum in June and July. Maximum values of the ^{7}Be concentration reach approx. 5.6 mBq/m^3 (Lublin, April) and have similar values for most of the stations. Minimum concentrations of ^{7}Be, not exceeding 2.5 mBq/m^3, are observed from November to March (cool season). A minimum value of 1.5 mBq/m^3 was recorded for December in Wroclaw.

In order to determine the influence of the individual meteorological elements on changes in the concentrations of ^{7}Be at the surface layer ABL, an analysis of the correlation of the monthly average concentration of the radionuclide with selected meteorological elements was carried out. The results of the calculations of Pearson correlation coefficients between the ^{7}Be, ^{210}Pb concentration and $^{7}Be/^{210}Pb$ ratio and the individual meteorological elements for stations intended for measurement of these chemical elements in Poland are shown in Tables **4-6**.

Analysis of results allows one to draw the following conclusions:

- For all stations, the correlation between the activity concentration of ^{7}Be and air temperature was positive and strong. The highest correlation coefficient was observed for Krakow (0.822), and the lowest one – for Bialystok (0.431). Relatively high correlations between ^{7}Be and air temperature prove the influence of the thermal factor on the concentration of the chemical element at the surface layer air ABL. This probably results from the fact that air temperature is, in a way, an indicator of the mixing layer height in the atmosphere. At higher temperatures, occurring in the warm season, the mixing layer is higher and beryllium may freely migrate from the stratosphere.
- The high correlation of ^{7}Be with global solar radiation (from 0.701 in Torun to 0.899 in

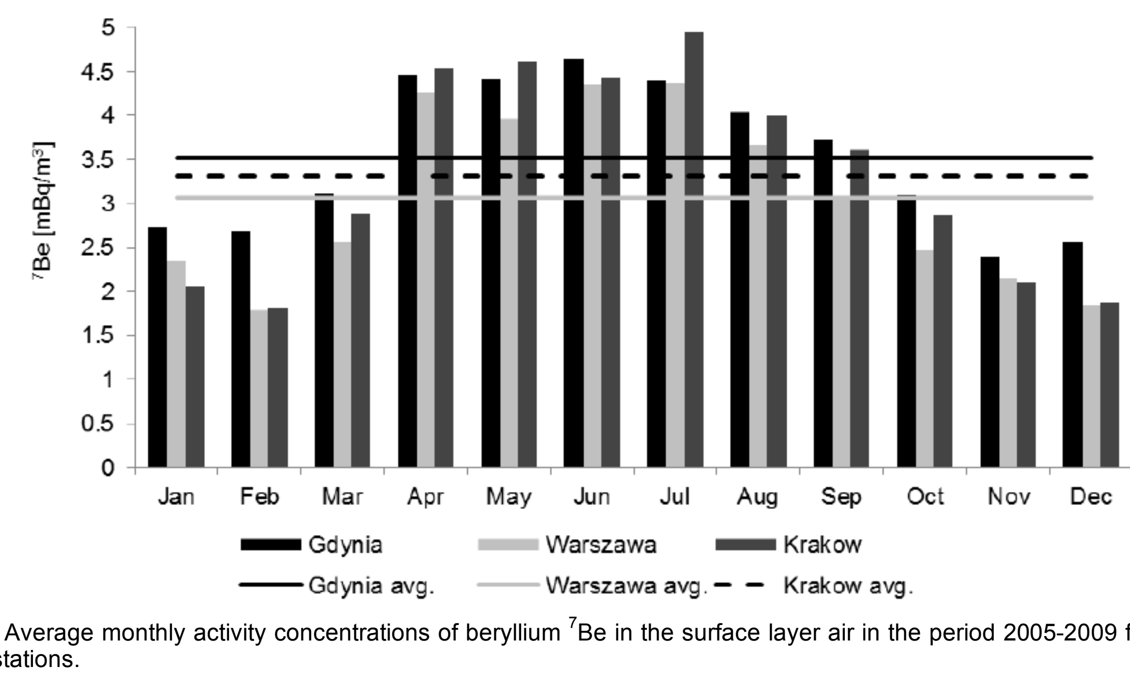

Figure 3: Average monthly activity concentrations of beryllium ^{7}Be in the surface layer air in the period 2005-2009 for the three selected stations.

Table 4: Pearson's Correlation Coefficient (Statistical Significance α = 0.05) between the Weekly Activity Concentration of ^{7}Be and ^{210}Pb and Meteorological Elements

Measuring station ^{7}Be	Correlation coefficient r						
	^{210}Pb	Global solar radiation	Air temperature	Precipitation	Atmospheric pressure	Wind speed	Relative air humidity
Gdynia	0.074	0.701	0.596	0.147	0.137	-0.415	-0.590
Szczecin	0.208		0.592	-0.014	0.222	-0.335	-0.634
Torun	-0.218	0.748	0.633	0.108	-0.014	-0.291	-0.705
Bialystok	-0.099		0.431	-0.079	0.037	-0.285	-0.739
Warszawa	-0.354	0.899	0.781	0.178	-0.105	-0.407	-0.853
Otwock-Swider	-0.310		0.758	0.178	-0.099	-0.352	-0.831
Zielona Gora	-0.125		0.694	-0.035	0.039	-0.364	-0.811
Lodz	-0.091	0.772	0.693	0.126	-0.082	-0.393	-0.671
Lublin	-0.294		0.735	0.060	-0.188	-0.530	-0.842
Wroclaw	0.258		0.756	0.222	-0.123	-0.433	-0.654
Katowice	-0.216		0.749	-0.067	-0.197	-0.306	-0.778
Krakow	-0.198		0.822	0.096	-0.222	-0.032	-0.873
Sanok	-0.294		0.753	0.058	-0.132	-0.237	-0.883

Warsaw) results not so much from the influence of solar radiation on the production of ^{7}Be, but from the influence of radiation on the formation of a thermodynamic equilibrium in the atmosphere.

- For most stations, a very weak correlation of precipitation with the activity concentrations of ^{7}Be exists, meaning that precipitation admittedly leaches particles of aerosols, on which ^{7}Be is deposited, from the atmosphere; however, this dependency is very weak or non-existent and probably results from the lengthy time periods taken for comparison (monthly values), eliminating the expected effect.

- Diversification of the correlation coefficients between ^{7}Be and ^{210}Pb and between ^{7}Be and atmospheric pressure probably indicates a lack of causality between these quantities.

- For all stations, negative values of the correlation coefficient between the activity concentration of ^{7}Be and wind velocity are observed. They belong within a range from –0.032 in Krakow to –0.530 in Lublin. This proves the fact that wind disperses particles of aerosol, to which beryllium is attached. At the same time, relatively large differences in values of the correlation coefficient at the individual stations may result from the large spatial variability of the wind field. This is the case when the stations for measurement of radionuclide concentrations are separated from the meteorological stations by large distances.

- There is a high negative correlation of ^{7}Be activity concentration with relative air humidity. Correlation coefficients belong within a range from –0.588 in Gdynia to –0.873 in Krakow. This relationship may be due the one hand the presence of high relative humidity during rainy weeks, which favors wet deposition of radioactive aerosols including beryllium, on the other hand may be due to the effect of atmospheric stability on the activity concentration of ^{7}Be in ground level air. High relative humidity is characteristic in Poland for the cold season (January – March, October – December). This situations occurs during the days when the greater part of the day there is the stable constant of atmosphere, which impedes of vertical transport within the troposphere.

The above thesis is confirmed by a study of the monthly course of ^{7}Be concentrations at the surface layer ABL. At all investigated stations, the highest concentrations of radionuclide are observed from April to August, i.e. in the warm season, when the unstable atmosphere equilibrium has its largest share. In the cool season, when convection is slim, there are significantly less weather conditions that favour vertical transport of beryllium from the stratosphere and the upper troposphere to the surface layer air.

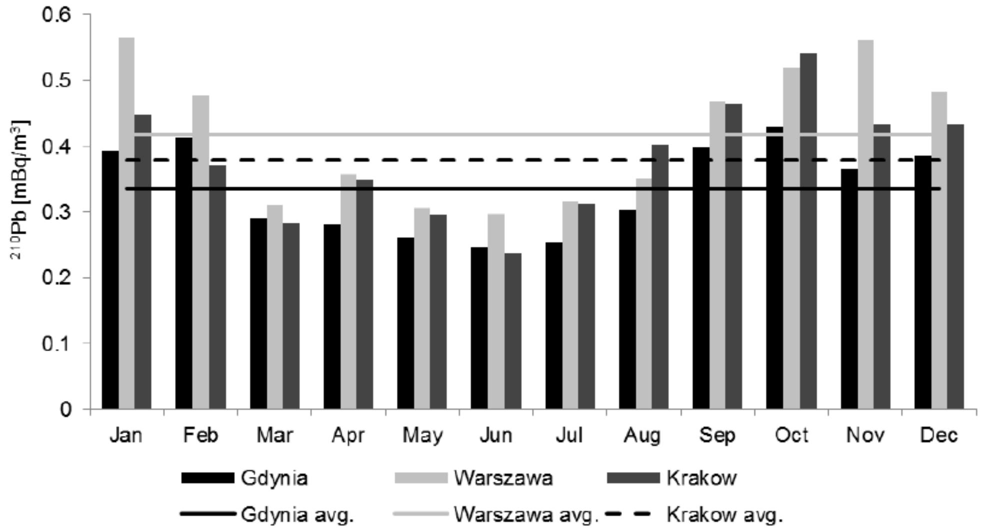

Figure 4: Average monthly activity concentrations of lead ^{210}Pb in the surface layer air in the period 2005-2009 for the three selected stations.

3.2.3. ^{210}Pb and Meteorological Conditions

Lead ^{210}Pb – a radionuclide of terrestrial origin with a high atomic mass – exhibits significantly different features. Its variability level in the surface layer of the atmosphere, caused by meteorological conditions, should be significantly lower than that of ^{7}Be. The monthly average activity concentration of ^{210}Pb exhibits an inverse course in relation to the concentration of ^{7}Be. The highest lead concentration is observed in the cool season (October-February, with a January maximum at most stations of approx. 0.6 mBq/m^3) when the prevalent constant equilibrium in the atmosphere prevents its vertical transport from the surface layer ABL to higher layers of the troposphere; the lowest activity concentration of the metal is observed in July (approx. 0.2 mBq/m^3) (Figure **4**).

A different behaviour of ^{210}Pb at the surface layer air is also confirmed by the results of a study of Pearson coefficients of the correlation between the ^{210}Pb activity concentration and the individual meteorological elements for all measurement stations of this radionuclide in Poland (Table **5**).

Table 5: Pearson's Correlation Coefficient (Statistical Significance α = 0.05) between the Weekly Activity Concentration of ^{210}Pb and Meteorological Elements

Measuring station ^{210}Pb	Correlation coefficient r					
	Global solar radiation	Air temperature	Precipitation	Atmospheric pressure	Wind speed	Relative air humidity
Gdynia	-0.371	-0.307	-0.287	0.492	-0.127	0.334
Szczecin		-0.344	-0.343	0.519	-0.107	0.345
Torun	-0.518	-0.533	-0.373	0.485	-0.206	0.490
Bialystok		-0.516	-0.312	0.377	0.161	0.283
Warszawa	-0.509	-0.481	-0.324	0.589	-0.120	0.463
Otwock-Swider		-0.511	-0.317	0.579	-0.134	0.481
Zielona Gora		-0.429	-0.392	0.563	-0.210	0.444
Lodz	-0.388	-0.386	-0.309	0.561	-0.178	0.354
Lublin		-0.433	-0.503	0.609	-0.070	0.325
Wroclaw		0.225	-0.155	0.187	-0.393	0.014
Katowice		-0.307	-0.455	0.541	-0.195	0.460
Krakow		-0.253	-0.456	0.565	-0.369	0.336
Sanok		-0.285	-0.273	0.416	-0.344	0.399

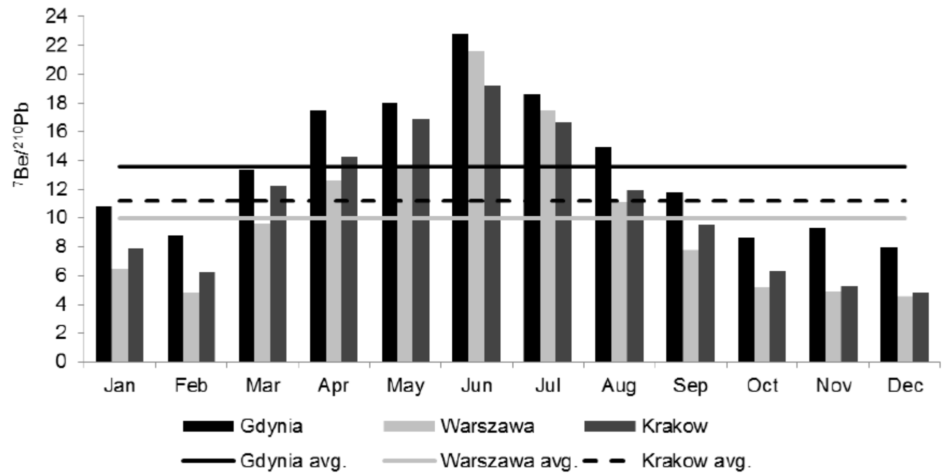

Figure 5: Average monthly ratio ^{7}Be/^{210}Pb in the surface layer air in the period 2005-2009 for the three selected stations.

The analysis carried out shows that the activity concentration of ^{210}Pb depends most strongly on the value of the atmospheric pressure. The correlation coefficients are in this case positive for all stations, and they range from 0.187 in Wroclaw to 0.609 in Lublin. This means that in systems of high atmospheric pressure, which are characterised by high stability of the atmosphere particularly in the cool half of the year, the concentration of ^{210}Pb is higher than in cyclonal systems. The other meteorological elements studied influence the concentration of lead in a less distinct way. All the correlations are negative, apart from a weak positive correlation with relative air humidity.

3.2.4. Ratio ^{7}Be/^{210}Pb

The inverse courses of the monthly averages of ^{7}Be and ^{210}Pb and their relationship with the dynamics of vertical air transport allow for the use of the ratio of their activity concentrations as an indicator for the efficiency of mixing in the atmosphere. During a yearly course, the highest values of this indicator are observed in summer, being a consequence of the aforementioned yearly course of ^{7}Be and ^{210}Pb concentrations, resulting from the differences in the course of thermodynamic conditions of the lower atmosphere (Figure **5**).

The value of the indicator is positively correlated with air temperature, and the correlation coefficient, determined based on the values of monthly averages, varies depending on the measurement station, from 0.145 in Lublin to 0.681 in Krakow (Table **6**). However, the values of the correlation coefficient of these variables are decidedly lower than in the case of the

Table 6: Pearson's Correlation Coefficient (Statistical Significance α = 0.05) between the Weekly Activity Concentration of ^{7}Be/ ^{210}Pb and Meteorological Elements

Measuring station ^{7}Be/^{210}Pb	Correlation coefficient r					
	Global solar radiation	Air temperature	Precipitation	Atmospheric pressure	Wind speed	Relative air humidity
Gdynia	0.716	0.524	0.327	-0.214	-0.142	-0.676
Szczecin		0.654	0.335	-0.264	-0.023	-0.706
Torun	0.757	0.653	0.329	-0.283	0.025	-0.705
Bialystok		0.512	0.111	0.047	-0.314	-0.492
Warszawa	0.699	0.552	0.179	-0.224	-0.149	-0.636
Otwock-Swider		0.363	0.178	-0.144	-0.041	-0.277
Zielona Gora		0.645	0.325	-0.373	0.005	-0.740
Lodz	0.385	0.373	0.230	-0.177	-0.070	-0.358
Lublin		0.145	-0.107	0.007	-0.106	-0.392
Wroclaw		0.563	0.239	-0.168	-0.148	-0.636
Katowice		0.520	0.332	-0.312	-0.068	-0.567
Krakow		0.681	0.377	-0.402	0.152	-0.760
Sanok		0.504	0.087	-0.092	0.070	-0.684

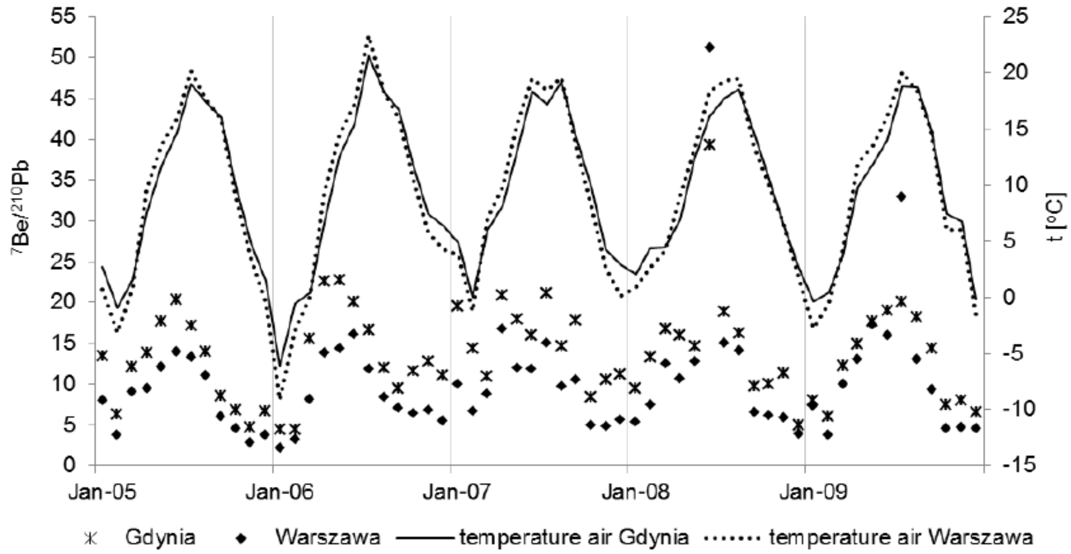

Figure 6: Average monthly ratio ^{7}Be/^{210}Pb and air temperature in the surface layer air in the period 2005-2009 for the two selected stations.

correlation coefficient between the beryllium activity concentration and air temperature.

In the course of the monthly averages of the indicator in time, non-typical situations – significant deviations of the indicator value from the normal course (Figure **6**) – draw attention.

Situations similar to the aforementioned non-typical situations were noticed by Ajtic *et al*. [7], who explained their occurrence with the effect of so-called stratospheric intrusions. However, the issue requires further studies: obtaining, among others, diurnal and better instantaneous activity concentrations of these chemical elements. In the spatial distribution of the indicator, the high diversification of its value at various measurement stations prompts contemplation. This probably results from a diversification in geological conditions at the individual stations, influencing the intensity of ^{210}Pb emanation. Correlation of the indicator with other meteorological elements (excluding relative air humidity, having a negative correlation with the indicator, from –0.277 for Otwock-Swierk to –0.760 for Krakow) is slight and significantly lower than the correlation of meteorological conditions with the concentrations of ^{7}Be.

4. DISCUSSION

The obtained results of studies of the influence of geophysical and meteorological conditions on activity concentrations of ^{7}Be and ^{210}Pb at the surface layer ABL indicate a multifactorial character of the dependence. The influence of static conditions (solar activity, latitude, height above sea level, distance to large water bodies) on the concentration of ^{7}Be, reported in literature, is hard to notice in the case of the area of Poland. This is probably connected with a relatively small diversification of these elements (when compared to the global scale) and, therefore, a similar influence of the cosmogenic factors that depend on them (magnetic field, cosmic radiation). Also, the proposition on the influence of solar activity on the variability of this chemical element in Poland has not been confirmed. Of course, this does not indicate the lack of its action, but it leads to the possibility to omit this factor as less important in further considerations. This means that under the conditions of regions located along medium latitudes, having a small meridional stretch, small vertical diversification and not too large distances from sea regions, including Poland, the main factors influencing the variability of the ^{7}Be activity concentration and the ^{7}Be/^{210}Pb ratio are the dynamic factors defined above. The studies carried out also confirm the argument that dynamic factors influence changes in ^{7}Be concentrations more strongly than those of ^{210}Pb. Although ^{7}Be production does not depend on the season, its deposition depends on seasonal changes in atmospheric processes. Transport from the upper atmosphere to surface layer air is connected with several factors, mainly the stratosphere-troposphere exchange of air masses and vertical and horizontal transfers. As the vertical exchange of air masses is much more intense in the warm season, this explains the occurrence of maximum activity concentrations of beryllium ^{7}Be at the surface layer ABL in summer.

This results from the different origin of both radionuclides and their different atomic masses. However, thanks to vastly different responses to the dynamic factors, investigations of interrelations between both radionuclides, including the $^{7}Be/^{210}Pb$ ratio, may be helpful in evaluation of the vertical exchange of air masses.

Among the studied dynamic factors, global solar radiation, temperature and air humidity are of highest importance for the variability of ^{7}Be concentrations at the surface layer air. These factors are direct indicators of the thermodynamic properties of the atmosphere. The higher the solar radiation and air temperature, and the lower the relative humidity – and the more unstable the thermodynamic properties of the atmosphere, the higher the mixing layer is located and the larger the probability of vertical ^{7}Be transport. Such situations occur in the warm season, from April to October.

Analysis of the results also enabled identification of non-typical situations. In cases when the $^{7}Be/^{210}Pb$ activity concentration ratio deviates significantly *in plus* from the typical yearly course, in the month when the phenomenon is observed, one may suspect the occurrence of episodes of so-called stratospheric intrusions (Figure **6**).

5. CONCLUSIONS

a) Because of the relatively small area of Poland, it is hard to prove the dependence of ^{7}Be activity concentration variability on the influence of such factors as geographical location or solar activity.

b) However, the activity concentration of ^{7}Be and, to a lesser degree, the concentration of ^{210}Pb are dependent on meteorological conditions. The most important role is played here by factors that determine the conditions of thermal-dynamic atmosphere stability (air temperature, wind velocity, air humidity, global solar radiation) and precipitation. Nevertheless, for the sake of the multi-element and non-linear character of the dependence, apart from simple methods of correlation analysis, elements of multifactorial analysis should be used for more precise investigation of their influence.

c) The inverse interaction of atmosphere stability conditions on ^{7}Be and ^{210}Pb allows one to use the $^{7}Be/^{210}Pb$ ratio as an indicator of vertical transport in the atmosphere. High values of this factor may indicate the occurrence of so-called stratospheric intrusions.

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