

Relationship between the ⁷Be and O₃ in the surface layer of air in Gydnia and Warsaw (Poland)

Ewa Krajny, Leszek Osrodka

Institute of Meteorology and Water Management – National Research Institute, 01-673 Warsaw, Podlesna Street 61, Poland

Abstract

Beryllium Be appears in the surface layers of the atmospheric boundary layer (ABL) as a result of stratosphere to troposphere air mass exchange (STE). Stratosphere to troposphere air mass transport (STT) can sometimes be accompanied by the origin of stratospheric ozone (O₃). The aim of this study was to attempt to answer the question as to whether 'Be can be a good marker of stratospheric ozone origin in the concentration of ground-level ozone in the surface ABL. Eight sets of data covering the period 2002-2009 were examined: weekly concentrations of ⁷Be and hourly O₃ measured in the ground level of the atmosphere. The measuring sites were at two different locations in Poland: Gdynia and Warsaw. Both locations show the maximum ⁷Be concentration in spring and summer, and the minimum in late autumn and winter. In 2002-2009, the average concentration standard deviations of ⁷Be were 3.336 ± 1.312 mBq/m³ and 2.907 ± 0.030 mBq/m³, respectively, for Gdynia and Warsaw. The data obtained were subjected to statistical and frequency analysis (FA) in order to eliminate the periodicity the seasonal and annual variability of solar activity and to estimate the relationship between ⁷Be and O³. Keywords: beryllium (${}^{7}Be$), ozone (O_3), ${}^{7}Be/O^3$ ratio, stratospheric intrusion (SI).

1. Introduction

Galactic cosmic rays (GCRs) and solar energetic particles (SEPs) interact with the Earth's atmospheric nuclei and produce many isotopes through nuclear interactions, within a range of half-lives from several minutes to millions of years. One of them is beryllium (⁷Be), a short-lived (half-life ~53.3 days) cosmogenic gamma emitting (~477.6 keV) radionuclide. It is produced in the stratosphere (~70%) and upper troposphere (~30%) by spallation reactions of energetic protons with atmospheric oxygen O (Z=8), nitrogen N (Z=7) and carbon O (Z=6). The level of activity in the stratosphere ⁷Be is variable in time and space and depends on the

intensity of cosmic rays (CRs) and solar activity. Solar activity changes with an average cycle length of 11 years (with variations from 9 to 14 years). The greater is the intensity of the CRs, the greater the solar activity and the intensity of the solar wind. However, the solar wind weakens the intensity of the GCR component. This phenomenon should have an impact on the concentration of ⁷Be in the surface layer of the atmospheric boundary layer (ABL). The ⁷Be produced in the stratosphere comes into the troposphere by processes of air mass exchange between the troposphere and the stratosphere (STE) [1]. The main predictor controlling the seasonality of ⁷Be concentrations is the height of the tropopause, reflecting more vertical transport from upper tropospheric levels into the lower troposphere during the warm seasons than during the cold seasons. The estimated removal time in the stratosphere is much longer than the half-life of ⁷Be, suggesting that most stratospheric ⁷Be decays within the stratosphere and a large part of the surface ⁷Be is of tropospheric origin. Since most ⁷Be resides in the stratosphere, it has been used in many studies as a tracer of stratosphere to troposphere air mass transport (STT) [see e.g. 2]. Thus, air coming from the upper troposphere, and especially the stratosphere, can be identified by its enhanced ⁷Be levels. The mean residence time (MRT) of ⁷Be in the stratosphere has been reported e.g. by Thomas et al. [3] as 1 year, while the MRT in the troposphere is estimated to be approximately 25– 40 days (range 3–60 days) [4, 5, 6]. The average ⁷Be concentration in the lower stratosphere is in the range from approximately 150 to 200 mBq/m³, while in the upper troposphere air is 40-83 mBq/m³ [7, 8, 9], and surface air concentrations average a few milibecquerels per cubic metre, as widely reported in the literature [10]. The ⁷Be atoms transported from the stratosphere or formed in the troposphere, soon became attached to ambient aerosol particles in accumulation mode (from 0.07 to 2 µm, average 0.3 um) [6]. The tropospheric residence time of these aerosols can vary from a few days to a few weeks,



depending on meteorological conditions [11]. Thus, air coming from the upper troposphere and especially the stratosphere can be identified by its enhanced ⁷Be level. Feely et al. [1] reported that there are four factors controlling the ⁷Be seasonal variation: (a) the wet scavenging process (dry deposition plays a minor role), (b) STE, (c) the vertical atmospheric motion in the troposphere, and (d) the air mass horizontal transport from middle latitudes into high latitudes. The variations in the surface layer ⁷Be concentration generally depend on static factors, such as geographical location, and dynamic factors, such as CR variations, solar activity, cosmogenic production and in the lower troposphere, radioactive decay and meteorological conditions, including the dynamics of air mass exchange between the stratosphere and troposphere. Some studies have used the correlation between ⁷Be and ozone O₃ to quantify the contribution of stratospheric O₃ to ground level O₃ [12]. According to numerous studies which have reported the O₃ annual cycle, the two types of situation are classified into episodes of high level ozone with a maximum in summer and the ones that have a spring maximum [13]. The aim of the present paper was to study the origin and annual course ⁷Be in the near surface air at Gdynia and Warsaw during the period 2002–2009 and answer the question as to whether ⁷Be can be a good an indicator of stratospheric ozone origin in the surface layer of the ABL. The analysis was conducted for the years 2002-2009 because for this period were available full database both for ozone as well as for beryllium.

2. Material and methods

The measurement results of the radioactive contamination of the environment were collected from a network of high-volume aerosol sampling stations, type ASS-500 [14]. The Central Laboratory for Radiological Protection (CLOR) operates the network automatic State Environmental of Monitoring (PMS) in Poland and that is supervised by the National Atomic Energy Agency (PAA). The weekly activity concentrations of radionuclide beryllium ⁷Be were measured in a network of laboratories equipped with high-efficiency gamma rays spectrometry using an HPGe detector. The technical parameters of the stations ASS-500 are as

follows: filter Petrianov FPP-15-1.5 with area 0.2 m², system drying filter - halogen radiators infrared, flow-meter - vortex, air flow volume 50 000 - 90 000 m³ per week, 1.5 m a.g.l. height of air sampling. The sampling stations were located at Gdynia - a coastal city, situated at latitude 54°31'N and longitude 18°33'E, about 2 m above sea level (a.s.l.), at an average direct distance from the seashore 1 km - and at Warsaw - a continental city, situated at latitude 52°18'N and longitude 20°59.5'E, about 82 m a.s.l., at an average direct distance from the seashore of 262 km. Ozone ground-level O₃ is measured using a UV absorption spectrophotometer. The reference method for the measurement of ozone is that described in EN 1425:2005 "Ambient air quality - standard method for the measurements of concentration of ozone by ultraviolet photometry" which agrees with Directive 2008/50/EC. The monitor is located in the stationtype urban background localized in Gdynia (54°33'39''N, 18°29'36''E, 70 m a.s.l.) and Warsaw (52°13'28''N. 21°(1'8''E. 112 m a.s.l.). Ozone concentrations have been obtained within the framework of the PMS tasks and have been made available by the Main Inspectorate of Environmental Protection (GIOŚ). The ozone measurement stations were located about 8 km to the north-east and 10 km to the north from the measurement of beryllium for Gdvnia and Warsaw. respectively. database contains 1-hour ozone ground-level concentrations. Solar activity was assessed on the basis of the number of sunspots (SSN). Daily SSN data were obtained from the website Solar Influences Data Analysis Center (SIDC). The main measurement period covered the eight years from January 2002 to December 2009. All the data obtained were statistical analysis (comprehensive regression analysis) and frequency analysis (FA). were analysed for data the or monthly average values.

The concentrations of beryllium 7Be , ground-level ozone O_3 and the ratio $^7Be/_3O$ concentration, and the SSN were analysed Fast Fourier Analysis (FFA) in the period 2002–2009, together with the amplitude of the frequency of the annual and multiyear component 7Be . It was assumed that the whole analysed period was considered as an interval $[0, 2\pi]$. These points were approximated using the following trigonometric polynomial:



$$Q_n(x) = \frac{a_0}{2} + \sum_{k=1}^{n} (a_k \cos(kx) + b_k \sin(kx)) \ x \in [0, 2\pi]$$

where $a_0, ..., a_k, b_1, ..., b_n$ are real coefficient, $n \in \mathbb{N}$, n < L.

The coefficients of the trigonometric polynomial that minimize the discrete least squares error are given by:

$$a_{k} = \frac{1}{L} \sum_{i=0}^{2L-1} \cos(kx_{i}) f(x_{i})$$

$$= \frac{1}{L} \sum_{i=0}^{2L-1} \cos\left(k\frac{\pi i k}{L}\right) f(x_{i})$$

$$b_{k} = \frac{1}{L} \sum_{i=0}^{2L-1} \sin f(x_{i})$$

$$= \frac{1}{L} \sum_{i=0}^{2L-1} \sin\left(k\frac{\pi i k}{L}\right) f(x_{i})$$

$$k = 0,1,2,...,n$$
(1)

 $f(x_i)$ where i = 0, ..., 2L-1 are weekly concentrations. As a result, the amplitude spectrum is calculated for a particular frequency:

$$c_k = \sqrt{a_k^2 + b_k^2},$$

where k=0, ..., 2L-1, and we can extract the component correspond to the annual variability.

3. Results

3.1 Frequency analysis

Figures 1 and 2 show the graph of the results of the frequency analysis FA for Gdynia and Warsaw.

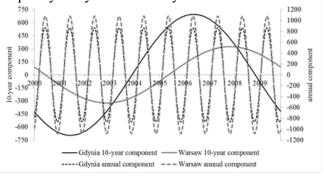
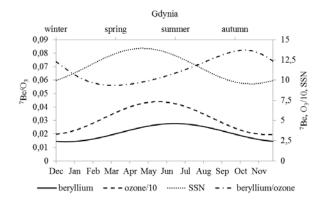


Fig. 1: Amplitude of the frequency for the annual and 10-year component of ⁷Be for Gdynia and Warsaw calculated for the period 2000–2009.

www.ijseas.com



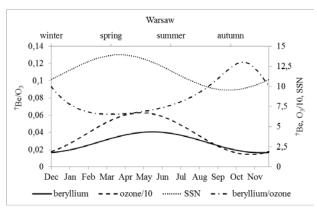


Fig. 2: Annual course amplitude of the frequency for ⁷Be, O₃, ⁷Be/O₃ and sunspot number (SSN) for Gdynia (upper figure) and Warsaw (bottom figure) calculated for the period 2000–2009 (winter: Dec, Jan. Feb, spring: Mar, Apr, May, summer: Jun, Jul, Aug, autumn: Sep, Oct, Nov).

FA confirmed the relations known from the literature:

- in general there are clearly marked variations in the annual concentrations of beryllium at both stations, the value of this component is slightly higher for Warsaw than Gdynia;
- the 10-year course of beryllium is quite significantly marked but is higher for Gdynia than Warsaw; the phase for the maximum concentration of beryllium in Warsaw is delayed by approximately 2.5 years from that of Gdynia;
- the annual course for beryllium and ozone at both stations is similar, although more pronounced for ozone;



- the maximum ozone concentration occurs in spring (April/May) and the minimum in autumn (October/November);
- the maximum beryllium concentration occurs in summer (June) and the minimum in autumn (October/November);
- the ratio of the concentrations of beryllium to ozone is highest in autumn (September/October) and lowest in spring (April);
- the annual course od SSN shows a maximum in April and a minimum in October;
- the regularity of the course concentrations of beryllium and ozone in the year indicate a significant impact of the radiation factor on the production and vertical transport of these substances.

3.2 Temporal variations of ⁷Be and O₃

The monthly average values of ⁷Be and O₃ measured at the two sites, Gdvnia and Warsaw in Poland, over the period 2002–2009 are given in Figure 3. The ⁷Be concentration is inversely correlated to the variations in SSN. ⁷Be and O₃ both show a very similar annual and seasonal cycle, wherein higher concentrations were found in Gdynia (Figures 4-7). Both data sets show the maximum in ⁷Be concentration in spring and summer, and the minimum in late autumn and winter. The average concentration deviations in 2002–2009 of ${}^{7}\text{Be}$ were 3.336±1.312 mBq/m³ and 2.907±0.030 mBq/m³, respectively for Gdynia and Warsaw. The average monthly concentrations of ⁷Be were in the range of 2.241– 4.188 mBq/m³ (Gdynia) and 1.850–3.993 mBq/m³ (Warsaw) and exhibited maximum specific activity in spring and summer and a minimum in winter. The results agree with results obtained at other locations in the world (see Table 1 for examples).

Table 1: Average ⁷Be activity concentration in air in Poland and other countries.

City (Country)	⁷ Be [mBq/m ³]	Referenc e
Maryland (USA)	3.3–5	[15]
Osaka (Japan)	3–9	[16]
Kuwait (Kuwait)	0.2–14.9	[17]
Uppsala (Sweden)	0.5–9	[18]

City (Country)	⁷ Be [mBq/m ³]	Referenc e	
Detroit (USA)	1.5–9.8	[19]	
Thessaloniki (Greece)	0.47-12.7	[20]	
Belgrade (Serbia)	0.6–18.3	[21]	
Edinburgh (United Kingdom)	0.63-6.54	[22]	
Brisbane (Australia)	1.2-8.7	[23]	
Malaga (Spain)	2.5–14.9	[24]	
Barcelona (Spain)	2.4–4.7	[25]	
Islamabad (Pakistan)	1.14–3.17	[26]	
Daejeon (Korea)	1.3–7.7	[27]	
Monaco (Principality of Monaco)	0.93–13.1	[28]	
Gdynia (Poland)	0.969.37	This	
Warsaw (Poland)	0.52-7.04	work	

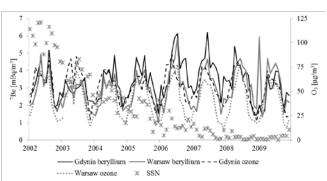


Fig. 3: Monthly average values of ⁷Be and O₃ in Gdynia and Warsaw and sunspot number (SSN) over the period 2002–2009 (data point O₃ for February 2003 in Warsaw is missing).

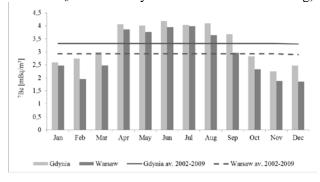




Fig. 4: Monthly average values of ⁷B in Gdynia and Warsaw in the period 2002–2009 (lines represent the average value over the examined period).

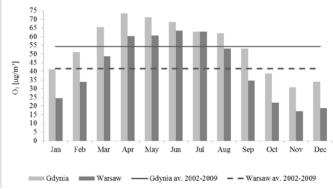


Fig. 5: Monthly average values of O₃ in Gdynia and Warsaw in the period 2002–2009 (lines represent the average value over the examined period).

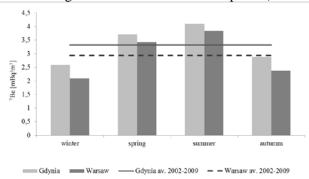


Fig. 6: Seasonal average values of ⁷Be in Gdynia and Warsaw in the period 2002–2009 (lines represent the average value over the examined period).

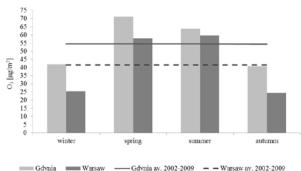


Fig. 7: Seasonal average values of O₃ in Gdynia and Warsaw in the period 2002–2009 (lines represent the average value over the examined period).

The monthly average O_3 values in the examined period were 54 $\mu g/m^3$ (Gdynia) and 42 $\mu g/m^3$ (Warsaw). The ranges of values were 19–87.7 $\mu g/m^3$ (Gdynia), and 11–79 $\mu g/m^3$ (Warsaw). The O_3 annual cycle obviously shows minima in winter and

maxima in summer. To further analyse the relationship between 7Be and O_3 , seasonal indices were calculated. Table 2 shows a monthly and seasonal index representing the ratio of the monthly average value and the overall average value for the examined period. The value index for both study sites shows a characteristic annual pattern with maximum in the summer season and minimum in the winter season.

www.ijseas.com

Table 2: Monthly and seasonal indices for ⁷Be and O₃ in Gdynia and Warsaw in the period 2002–2009.

tion	Gdynia		Warsaw			
uion	⁷ Be	O_3	⁷ Be	O_3		
Month						
Dec	0.7	0.6	0.6	0.4		
Dec	6	1	5	4		
Jan			0.7	0.5		
	8	5	9	8		
Feb			0.7	0.8		
	3	3	0	1.1		
Mar			0.9			
	1.2	1 2	1.2	1.3		
Apr	1.∠ 5		3			
	1.2	1.3	1.3	9 1.5		
May	1		3	5		
T	1.2	1.2	1.3	5 1.4		
	4	4	5	5 1.4		
Jul	1.1	1.1	1.3	1.4		
	7	4	0	6 1.3		
Απσ	1.1					
riug	4	4	8	0.8		
Sep	1.0			0.8		
г	6	8	7	4 0.5		
Oct				0.5		
				7 0.4		
Nov				0.4		
				ے		
			0.7	0.6		
nter						
	11	13	1.2	1.3		
ring	6	0	1	6		
	1.1	1.1	1.2	6 1.4		
nmer	8	7	8	0.6		
antum	0.8					
ullill	7	7	0	1		
	Apr May Jun Jul Aug Sep Oct	The interval of the interval o	The O ₃ Month	The O ₃ The Month		



Table 3 contains the results of the correlation between ⁷Be and O₃. The linear Pearson correlation coefficients were calculated for the whole data set and for the seasons. The calculated overall correlation coefficient between ⁷Be and O₃ is moderate for Gdynia and strong for Warsaw. The correlation is the highest for the monthly average maximum O₃. There is no very significant correlation in winter. The large correlation coefficient in autumn could indicate that ⁷Be and the maximum O₃ are regulated by the same processes. One possible explanation is the existence of the downward transport from higher altitudes. However, monthly or weekly ⁷Be allow only for limited analysis STE. Daily and hourly values of ⁷Be are more appropriate.

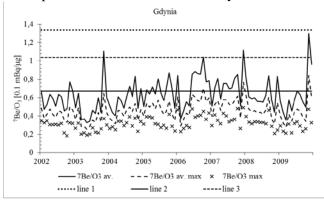
Table 3: Linear Pearson correlation coefficient of ⁷Be and O₃ (different font indicating *medium* and **large**

value).				
⁷ Be		Gdyni a	Warsaw	
Average O ₃	all	0.54	0.72	
	winter	0.33	-0.09	
	spring	0.14	0.53	
	summer	0.03	0.38	
	autumn	0.40	0.59	
Average maximum O ₃	all	0.58	0.73	
	winter	0.33	-0.07	
	spring	0.16	0.52	
	summer	0.15	0.29	
	autumn	0.48	0.67	
Maximum 1 hour O ₃	all	0.53	0.71	
	winter	0.16	-0.06	
	spring	0.15	0.43	
	summer	0.17	0.29	
	autumn	0.40	0.67	

3.3 ⁷Be/O₃ an atmospheric tracer

To identify the presence of O₃-rich stratospheric air at ground level, several studies have demonstrated the feasibility of using ⁷Be as a natural radioactivity tracer of the upper atmospheric air. In analogy with the work by Ajtic et al. [29], a same approach is here proposed for the assessment of stratospheric intrusion SI phenomenon using in situ measurements of ⁷Be and O₃. Taking into account that the descent of stratospheric air masses takes about a month, and assuming that the wet scavenging of ⁷Be and mixing

of air masses can be ignored over that period, the ⁷Be/O₃ ratios were calculated. Dutkiewicz and Husain [12] reported that the ratio of 0.2 mBq/µg gave 0.134 mBq/µg as a tropospheric ⁷Be/O₃ ratio, and the limits from Stohl et al. (2000) of 0.1 mBq/µg and 0.155 mBq/µg gave 0.067 mBq/µg and 0.104 mBq/ug, respectively. Figure 6 shows the ratios that were calculated for monthly average, monthly average maximum O₃ and monthly 1 hour maximum O_3 . Comparing the monthly average ratio (${}^7Be/O_3$) for Gdynia and Warsaw to the ratio based on Dutkiewicz and Husain [12], or Stohl [2] indicated many occurrences of stratospheric air sampling (Figure 8). The same results were obtained for the ratio ⁷Be and weekly average O₃, weekly average maximum O_3 , and weekly 1 hour maximum O_3 . Examination of the monthly or weekly Be and O₃ ratios confirmed only the possibility that the origin of stratospheric ozone is in the surface layer ABL.



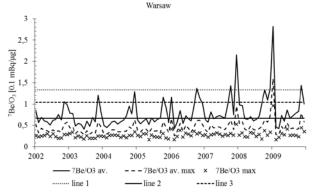


Fig. 8: Ratio of monthly mean 7Be measured in Gdynia (upper figure), Warsaw (bottom figure) and monthly average ($^7Be/O_3$ av. grey line) and monthly average maximum O_3 ($^7Be/O_3$ av. max grey dotted line) and monthly 1 hour maximum O_3 ($^7Be/O_3$ max asterisks). Line 1 represents 0.134 mBq/ μ g, calculated according to Dutkiewicz and Husain



(1979), lines 2 and 3 represent the ratio limits of 0.067 mBq/μg and 0.104 mBq/μg calculated according to Stohl et al. (2000).

To find a situation conducive to the transport of ozone from the stratosphere to the troposphere a method based on Fourier analysis was also used. The analysis of the measurement data of ozone and beryllium ⁷Be was performed by using FFA. Then, from the initial values, the component responsible for the annual cycle of ⁷Be and O₃ was subtracted. In this way, the concentrations of ⁷Be and O₃ independent of seasonal changes were obtained. In the next step, the periods in which a significantly positive deviation was noted for both O₃ and ⁷Be concentrations and in relation to their normalization courses were found. In this period, situations in which the observed ratios of the weekly concentration of ⁷Be to the weekly average maximum ozone concentration were high, were sought. Based on the analysis of synoptic and weather conditions, in particular the vertical distribution of potential temperature, relative humidity were identified, which potentially could be a phenomenon of STT. In 80% of selected cases, low relative humidity (< 20%) was identified at altitudes of about 3000 m above ground level. These situations were classified as cases of socalled "stratospheric intrusion" (SI). In the years 2002-2009 23 such cases were identified at the measuring station in Gdynia and nine cases for the station in Warsaw. The likely STE could be in June 2008 (Gdansk and Warsaw) and July 2009 (Warsaw). Most probably the situation occurred in the second ten days of July 2009. The next stage of the research will be a detailed analysis of the stratospherictropospheric phenomenon.

4. Conclusions

We can draw the following conclusions:

- ⁷Be beryl shows annual course with maximum during spring/summer season, where the concentration is higher at both sites in Gdynia and Warsaw, and agrees with the results obtained at other locations in the world, particularly locations on the same latitude.
- The correlation coefficient between ⁷Be and average O₃ generally is significant in autumn, which implies that their concentrations are driven

- by the same processes, and not very significant in winter.
- Analysis of the relationship between monthly and weekly concentrations of ⁷Be even with 1-hour ground-level ozone does not allow unambiguous identification of the contribution of stratospheric ozone in its total concentration in the surface layer of the ABL. Daily and hourly values of ⁷Be are more appropriate for this research and a more detailed study should be performed.
- Studying the monthly or weekly ⁷Be/O₃ ratio only allows the identification of potential STE situations and the appearance of the origin of stratospheric ozone in the surface layer of the ABI

In summary, ⁷Be can be one of the indicators of stratospheric ozone in the surface layer of the ABL, but on its own is not a very good indicator. As a result, on the basis of the STE, not all situations, such as satellite remote sensing, upper atmospheric sounding, back trajectories, and meteorological conditions, are then confirmed in the course of the synoptic situation. STT is a temporary phenomenon and sometimes occurs on a local level in a vertical column of atmosphere. In the study of STT phenomena, data plays an important role, the best being short-term data (hourly, daily). On the other hand, it is difficult to determine the existence of an STE situation without upper airborne observations and measurements.

Appendix

Appendixes, if needed, appear before the acknowledgment.

Acknowledgments

This study has been supported from funds for science in 2010-2013 years by the National Science Centre as the research project No. N N523 564838.

The authors gratefully acknowledge the National Atomic Energy Agency (PAA), and Central Laboratory for Radiological Protection (CLOR) for sharing data which were elaborated basing upon the investigation, conducted in the frame of the Program of the State Environmental Monitoring and financed from the funds of the National Found for Environmental Protection and Water Management.



We would like to thank SIDC (Solar Influences Data Analysis Center), Royal Warning Center of Belgium, World Data Center for used Sunspot Index in this publication (http://sidc.oma.be).

References

- [1] H. W. Feely, R. J. Larsen, and C.G Sanderson, Factors that cause seasonal variations in beryllium-7 concentrations in surface air. Journal of Environmental Radioactivity, 9, 1968, 223-249.
- [2] A. Stohl, N. Spichtinger-Rakowsky, P. Bonasoni, H. Feldmann, M. Memmesheimer, H. E. Scheel, T. Trickl, S. Huebener, W. Ringer, and M. Mandl, The influence of stratospheric intrusions on alpine ozone concentrations, Atmospheric Environment, 34, 9, 2000, 1323-1354.
- [3] C. W. Thomas, Young, J. A., Wogman, N. A., Perkins, R. W., "The measurement and behaviour of airborne redionuclides since 1962", in Radionuclides in the Environment American Chemical Society, R. F. Gould (ed.), Washington D. C., 1970, 158-172.
- [4] R. Winkler, F. Dietl, G. Frank, Tschiersch, J., Temporal variation of ⁷Be and ²¹⁰Pb size distributions in ambient aerosol implications for chemical conversion mechanisms, Atmospheric Environment, 32(6), 1998, 983-991.
- [5] K. N.Yu, and L. Y. I. Lee, Measurements of atmospheric ⁷Be properties using high-efficiency gamma spectroscopy, Applied Radiation and Isotopes, 57, 2002, 941-946.
- [6] C. Papastefanou, Radioactive aerosols. Radioactivity in the environment – volume 12, M. S. Baxter (ed.), Elsevier, 2008.
- [7] V. A. Dutkiewicz, and L. Husain, Stratospheric and tropospheric components of ⁷Be in surface air, Journal of Geophysical Research, 90(D3), 1985, 5783-5788.
- [8] L. Kownacka, Vertical distributions of beryllium-7 and lead in the tropospheric and lower stratospheric air, Nukleonika, 47(2), 2002, 79-82.
- [9] C. E. Jordan, J. E. Dibb, and R. C. Finkel, ¹⁰Be/⁷Be tracer of atmospheric transport and stratosphere-troposphere exchange, Journal of Geophysical Research, 108(D8), 2003, 4234-4347.

[10] R. A. Brost, J. Feichter, and M. Heimsnn, Three-dimensional simulation of ⁷Be in a global climate model, Journal of Geophysical Research, 96(D12), 1991, 22423-22445.

www.ijseas.com

- [11] E. Krajny, L. Osrodka, M. Wojtylak, B. Michalik, J. Skowronek, (2001), Correlation between the meteorological conditions and the concentration of radionuclides in the ground layer of atmospheric air, Nukleonika, 46(4), 2001, 189-194.
- [12] V. A. Dutkiewicz, and L. Husain, Determination of stratospheric ozone at ground level using ⁷Be/O₃ ratios, Geophysical Research Letters, 6, 3, 1979, 171-174.
- [13] P. S. Monks, A review of the observations and origins of the spring ozone maximum, Atmospheric Environment, 34, 2000, 3545-3561.
- [14] P. Lipinski, and K. A. Isajenko, M. Biernacka, A. Żak, Integration of Polish Monitoring Networks (ASS-500 and PMS system), Nukleonika, 46(4), 2001, 143-146.
- [15] J. E. Dipp, Atmospheric deposition of Be-7 in Chesapeake Bay region, Geophysical Research Letters, 94, 1989, 2261-2265.
- [16] K. Megumi, T. Matsunami, N. Ito, S. Kiyoda, A. Mizohata, T. Asano, Factors, especially sunspot number, causing variation in surface air concentrations and deposition of ⁷Be in Osaka Japan, Geophysical Research Letters, 27, 2000, 361-364.
- [17] D. Al-Azmi, A. M. Sayed, and H. A. Yatim, Variations in ⁷Be concentrations in atmosphere of Kuwait during the period 1994-1998, Applied Radiation and Isotopes, 55, 2001, 413-417.
- [18] A. Aldahan, G. Possnert, and I. Vintersved, Atmospheric interactions at northern high latitudes from weekly Be-isotopes in surface air, Applied Radiation and Isotopes, 54(2), 2001, 345-353.
- [19] D. McNeary, and M. Baskaran, Depositional characteristics of ⁷Be and ²¹⁰Pb in south eastern Michigen, Journal of Geophysical Research, 108(D7), 2003, 4210-4224.
- [20] A. Ioannidou, M. Manolopoulou, and C. Papastefanou, Temporal changes of ⁷Be and ²¹⁰Pb concentration in surface air at temperate latitudes (40°N), Applied Radiation and Isotopes 63, 2005, 277-284.



- [21] D. Todorovic, D. Popovic, Djuric, G., Radenkovic, G. ⁷Be and ²¹⁰Pb concentration ratio in ground level air in Belgrade area. Journal of Environmental Radioactivity, 79, 3, 2005, 297-307.
- [22] Likuku, A. S. (2006). Factors influencing ambient concentrations of ²¹⁰Pb and ⁷Be over the city of Edinburgh (55.9°N, 03.2°W). Journal of Environmental, 87, 289-304.
- [23] C. Doering, (2007). "Measurements of the distribution and behaviour of beryllium-7 in the natural environment", Ph.D. thesis, School of Physical and Chemical Science, Queensland University of Technology, Brisbane, Australia, 2007.
- [24] C. Duenas, M. C. Fernandez, S Canete, M. Perez, ⁷Be and ²¹⁰Pb concentration ration in ground level air un Malaga (36.70N, 4.50W), Atmospheric Research, 92, 2009, 49-57.
- [25] I. Valles, A. Camach, X. Ortega, I. Serrano, S. Blazquez, S. Perez, Natural and anthropogenic radionuclides in airborne particulate samples collected in Barcelona (Spain), Journal of Environmental Radioactivity, 100(2), 2009, 102-107.
- [26] N. Ali, E. U. Khan, P. Akhter, N. U. Khattak, F. Khan, M. A. Rana, The effect of air mass origin on the ambient concentrations of ⁷Be and ²¹⁰Pb in Islamabad, Pakistan, Journal of Environmental Radioactivity, 102, 2011, 35-42.
- [27] J. S. Chae, J. I. Byun, S. A. Yim, H. Y. Choi, J. Y. Yun, J. Y., ⁷Be in ground level air in Daejeon, Korea, Radiation Protection Dosimetry, 146(1-3), 2011, 334-337.
- [28] M. K. Pham, M. Betti, H. Nies, P. P. Povinec, Temporal changes of ⁷Be, ¹³⁷Cs and ²¹⁰Pb activity concentrations in surface air at Monaco and their correlation with meteorological parameters, Journal of Environmental Radioactivity, 102, 2011, 1045-1054.
- [29] J. Ajtic, D. Todorovic, A. Flipovic, J. Nikolic, Ground level air beryllium-7 and ozone in Belgrade, Nuclear Technology & Radiation Protection, 23(2), 2008, 65-71.

First Author D.Sc. Ewa Krajny - doctor of technical sciences in the field of environmental engineering and protection (Central Mining Institute, Poland 2007), employed since 1997 in Institute of Meteorology and Water Management - National Research Institute (IMWM-NRI), at present in Department Modelling of Air Pollution; skills and expertise: atmospheric physics, boundary layer meteorology, climatology, aerosol science, air quality, air pollution modelling, remonte sensing, Earth's natural radioactivity as an indicator of atmospheric dispersion; coordinator of several research and development national and international projects, head of two projects funded by the National Science Centre; co-author of 15 international publications and 3 monographs, member of the Polish Geophysical Society, representative IMWM-NRI in the Non-Governmental International Research Network - Centre of Radon, member WG Action COST-715 I COST-633.

Second Author D.Sc. Leszek Ośródka – doctor of environmental science in the field of geography (University of Silesia, 1992), employed since 1983 in Institute of Meteorology and Water Management -National Research Institute (IMWM-NRI), head of Department Modelling of Air Pollution; skills and expertise: meteorology, climatology, climate change, atmospheric air quality, air pollution modelling. environmental meteorology, earth science and environmental management, remonte coordinator of several research and development national and international projects, head or the main contractor of several projects funded by the National Science Centre; co-author of 20 international publications and several monographs, representative IMWM-NRI in International Thematic Scientific Network for Problems of Air Pollution And Climate Change (AIRCLIM-NET), member of the working group on air quality in the Polish-Czech and Polish-German at the Ministry of Environment in Poland, member Management Committee and WG Action COST-715 I COST-633, member of International Association for Urban Climate – IAUC.