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PROCEEDINGS

Correlation between the meteorological conditions and the concentration of radionuclides in the ground layer of atmospheric air

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Abstract The main goal of this work was to find correlation between the concentrations of radionuclides in outdoor air and the meteorological conditions like: air temperature, atmospheric pressure, wind velocity and amount of precipitation. Because the sampling period of radionuclides concentrations in air was relatively long (7 days), the average levels of meteorological parameters have been calculated within the same time. Data of radionuclide concentrations and meteorological data have been analyzed in order to find statistical correlation. The regression analysis and one of the AI methods, known as neural network, were applied. In general, analysis of the gathered data does not show any strong correlation between the meteorological conditions and the concentrations of radionuclides in air. A slightly stronger correlation we found for radionuclides with relatively short half-lives. The only positive correlation has been found between the Be-7 concentration and air temperature (at the significance level $\alpha=0.05$). In our opinion, the lack of correlation was caused by a too long sampling time in measurements of radionuclides in outdoor air (a whole week). Results of the analysis received by means of the artificial neuron network are better. We were able to find certain groups of meteorological conditions, related with the corresponding concentrations of particular radionuclides in air. Preliminary measurements of radon progeny concentration support the thesis that the link between changes of meteorological parameters and concentrations of radionuclides in ambient air must exist.

Key words atmospheric air • meteorology • neural network • radionuclides

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Introduction

The aim of the investigations was to check if there is any relation between the concentrations of particular radionuclides in atmospheric air and the meteorological conditions. Measurements of radionuclide concentrations in air were performed with the application of a sampling station, type ASS-500, located in the centre of Katowice. This facility is used by the Laboratory of Radiometry in the Central Mining Institute for the collection of airborne aerosols on an FPP-15 filter in weekly periods, followed by measurements done by means of high resolution gamma spectrometry. Results of these measurements were correlated with meteorological conditions, observed at the monitoring station of the Institute of Meteorology and Water Management.

Considering that the time of sampling (about 7 days) of radionuclides from atmospheric air was relatively long, also the average values of meteorological parameters were calculated in the same periods. Such approach assumes that the average values of meteorological parameters, measured at the monitoring station, are representative for the area of the whole town.

Within the period 1991–1999 approximately 500 measurements of radionuclide concentrations have been done by sampling on a weekly basis. Concentrations of following radionuclides have been measured and calculated:

– beryllium-7, potassium-40, caesium-137, radium-226 (from March 1991 till December 1999),
– actinium-228, bismuth-214 (from the beginning of 1994 till the end 1999),
– lead-212 (January 1996 – December 1999),
– lead-210 (since April 1996 till December 1999).

To characterize meteorological conditions, the following average meteorological parameters have been measured:
– air temperature at 2 meters above ground;
– barometric pressure at ground level;
– wind velocity at 14 meters above ground;
– amount of precipitation.

Meteorological parameters were measured at the monitoring station, located in Katowice-Muchowiec.

Method of analysis

Data of radionuclide concentrations and meteorological data have been analyzed to find statistical correlation, if exists. Not only the regression analysis was applied, but also one of the AI methods, known as neural network (the network of artificial neurons). For this purpose, a network MADALINE type has been used (this is the developed network without supervising, also known as competitive learning). Such a method is also known as Kohonen network. For the application of the network essential is to teach it how to recognize groups of similar input vectors. Only a short explanation of the construction and use of such network is given below. The detailed description was published elsewhere [1, 4].

If

(1) $\mathbf{x}^{(1)},...,\mathbf{x}^{(N)}$

is the sequence of vectors from the space R^m. In this particular case, the co-ordinates of the vector are the values of meteorological parameters and the concentrations of chosen radionuclides. This sequence will be further called the learned sequence, while the number of neurons in the network is denoted by letter M. For one of the input vectors $\mathbf{x}^{(k)}$, $k=1,...,N$, each neuron calculates the following value:

(2) $$e_j^{(k)} = \sum_{i=1}^{m} \mathbf{w}_i^{(j)} \mathbf{x}_i^{(k)}, j = 1,...M$$

known as the j^{th} stimulation of the k^{th} input of the neuron. Among all results, the highest value is chosen, characteristic of the strongest stimulated neuron, known also as a "winner". Let us give to it number 1. If we would like to specialize this neuron in recognition of the input k, then the weights of this vector must be improved in such a way that the next time it would "win" with greater advantage. This neuron is specialized in distinguishing of the k^{th} input and other inputs, similar to that input. It is clear that the magnitude of the stimulation is higher in case of closer congruent of the weights' vector $\mathbf{w}^{(1)}$ and input vector $\mathbf{x}^{(k)}$.

Two methods can be applied to change the weight:
– Additive method, described below by the following equation:

(3) $$\tilde{\mathbf{w}}^{(1)} = \frac{\mathbf{w}^{(1)} + \alpha \mathbf{x}^{(k)}}{\left\| \mathbf{w}^{(1)} + \alpha \mathbf{x}^{(k)} \right\|}$$

where $\mathbf{w}^{(l)}$ is an old vector of weights, while $\tilde{\mathbf{w}}^{(l)}$ is a new one for neurone 1,

– Subtractive method, in which the improvement of the weights is done accordingly to another equation

(4) $$\tilde{\mathbf{w}}^{(1)} = \mathbf{w}^{(1)} + \alpha \left(\mathbf{x}^{(k)} - \mathbf{w}^{(1)} \right)$$

In both cases the parameter a is known as the coefficient of learning.

The network is under the process of learning till the moment, when another set of input vectors does not affect any weight. Elements (vectors) of the teaching sequence are introduced to the network in the so called eras. In each era all input vectors are introduced only once to a single input. The sequence of the introduction is chosen randomly.

In the method of classification with the use of Kohonen network, no assumption is made concerning the number of neurons in the network. It may be inconvenient if the analysis of concentration is applied. If a small number of neurons appears in the network it may lead to the situation that some of them would be specialized in recognition of too many different inputs. On the other hand, if the number of neurones it too big, it is likely to happen that several neurons would be specialized in recognition of the same input.

A very essential problem appears how to choose the initial weights. If these value are chosen randomly, then some of the input vectors would not have a proper representative. Another problem is connected with the normalizing of input values for the Kohonen network. The dimension of the input vector must be eq. (1), while the co-ordinates have to be within the range <-1,1>.

We would like to use the Kohonen network for the construction of a net, which would be used for the prediction of concentration of different radionuclides in atmospheric air. As a result of the addition of Grossberg network [2], we will obtain the so called CP network (Counter Propagation).

This network works in the following way:
– The learning is supervised.
– When a particular vector is introduced in the first era, the highest stimulated neuron is chosen to send to all neurons the value 1 during the following era.
– Due to the fact that together with the input vector also the pattern of the answer has been sent, therefore, the weight vectors are corrected in such a way as to be in the closest similarity to the pattern.
– The result of the learning is an automatic catalogue with particular answers of the network. The number of elements in the catalogue cannot exceed the number of neurons in the initial layer.
– If any vector is introduced into the network, then one of the neurons is chosen as well as an appropriate pattern of the result.

Table 1. Correlation between the particular radionuclide concentrations and the chosen meteorological parameters.

Nuclide	Air temperature	Atmospheric pressure	Wind speed	Precipitation
Be-7	+	*	–	+
Ac-228	–	+	+	*
Pb-212	+	*	–	*
Bi-214	–	+	+	–
Pb-210	*	+	*	–
Cs-137	*	*	–	–
K-40	–	+	*	–

* – no significant correlation found

CP Network is more primitive (simple) in comparison with one-way networks, being in use till now. The biggest and probably the only one advantage of the CP network is the speed of learning. For the same set of data, the time of learning for CP network does not exceed several minutes, while multi-layer networks it would take several hours.

Results and discussion

Statistical analysis

A statistical analysis of the correlation between radionuclide concentrations in atmospheric air and meteorological parameters has been done. No explicit correlation has been found but the weak one – therefore it is very difficult to say, if any changes of meteorological conditions influence the concentration of a particular radionuclide. A significant correlation between the airborne radionuclides and meteorological parameters are shown in Table 1 (at the significance level α=0.05). Radium isotope, Ra-226, is not included in the Table, because no significant correlation has been found between the concentration of that isotope and meteorological parameters. Among the parameters, taken into account in the statistical analysis, only temperature seems to have a substantial role, affecting significantly concentration of radionuclides in atmospheric air. On the other hand, solely a strong positive correlation was found between Be-7 concentration and air temperature. For concentrations of all the isotopes, a positive correlation was found with atmospheric pressure.

A slightly more significant correlation was observed for radionuclides with relatively short half-lives. Different origin of particular isotopes, due to the exhalation of radon and thoron from the soil and further decay of their progeny might cause that dependence.

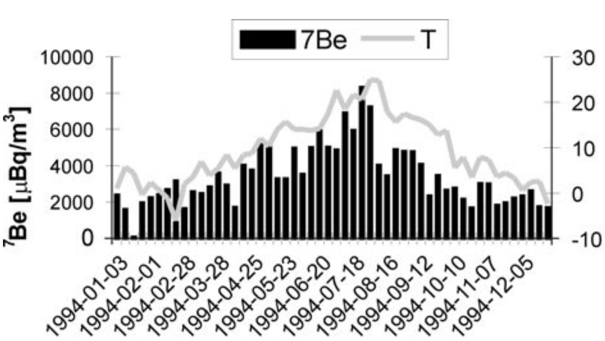

Fig. 1. Dependence of the Be-7 concentration on air temperature.

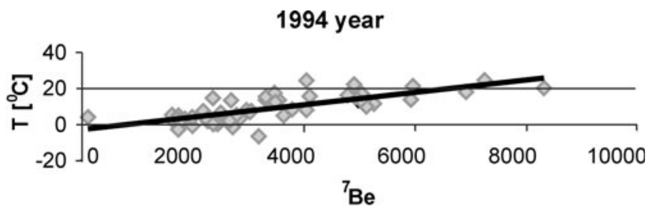

Fig. 2. Correlation between the Be-7 concentration and air temperature. Correlation coefficient = 0.74.

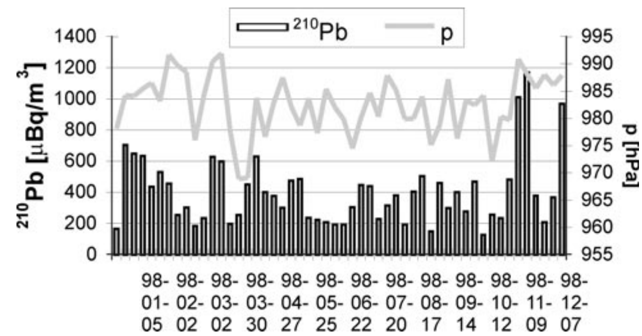

Fig. 3. Dependence of concentration of Pb-210 on the barometric pressure.

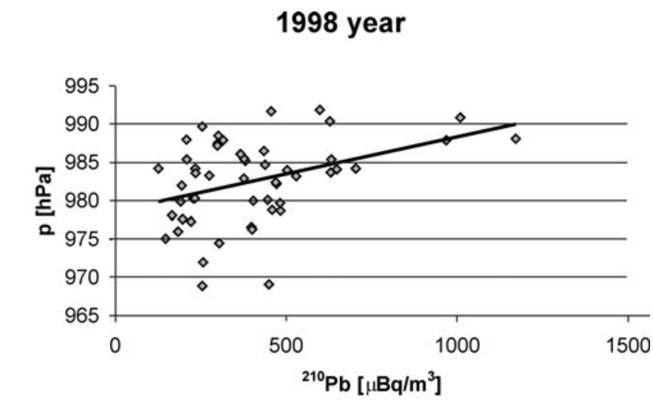

Fig. 4. Correlation between the Pb-210 concentration and barometric pressure. Correlation coefficient = 0.39.

In Figs. 1 to 8 concentrations of different radionuclides as a function of the chosen meteorological parameters are shown. Additionally, the analysis of Cs-137 in atmospheric air has been performed. The average values of that isotope concentration within the period 1991–1999 were taken into considerations. We found that the decrease of the ^{137}Cs concentration is faster as solely caused by its radioactive decay (Fig. 9).

The lack of significant correlation between meteorological parameters and concentrations of different radionuclides in atmospheric air found during statistical analysis, leads to the conclusion that we should check another, different approach to the problem.

Classification with the application of neural networks

During the construction of neural network, the average values of radionuclide concentrations have been used as input data. Also meteorological parameters, averaged for the same periods have been applied. All the results, gathered during 9 years of the exploitation of the sampling station ASS-500 (465 results), were used in calculations. On

Table 2. Average values of meteorological parameters, calculated for learning the sequence within the period 1991–1999.

Group		A	B	C	D	E	F	G	H	I
Number of cases		7	16	7	136	6	21	10	9	239
Parameter:										
Atmospheric pressure [hPa]	983.4	979.0±1.7	988.3±3.6	*972.2±2.5*	**987.0±6.2**	981.8±3.1	977.9±4.0	*970.6±4.0*	985.3±1.6	982.7±4.1
Wind speed [m/s]	2.6	**3.9±0.4**	**4.2±0.4**	3.0±0.2	2.4±0.7	*1.6±0.2*	**4.9±0.7**	**3.8±0.1**	**4.5±0.5**	2.1±0.6
Temperature [°C]	8.6	10.5±2.9	*0.1±3.7*	6.0±1.6	*0.0±4.2*	**17.3±2.3**	*3.7±1.8*	4.8±2.2	7.4±1.6	**14.8±4.0**
Precipitation [mm]	2.0	1.8±1.6	1.7±1.2	**3.3±1.0**	*1.0±0.9*	**9.5±0.8**	2.2±1.2	**3.1±2.0**	1.7±0.5	2.1±2.0

Table 3. Average concentration of radionuclides calculated for recognised groups in learning the sequence in comparison with the real values.

Group		A	B	C	D	E	F	G	H	I
	Number of cases	7	16	7	136	6	21	10	9	239
Radionuclide	Concentration [µBq/m^3]									
Be-7	1785	1909.5±38.4	1634.5±34.5	1582.2±26.8	*1210.3±41.2*	**2928.7±34.9**	1536.0±30.1	*1121.2±29.4*	**2219.9±19.7**	**2640.3±42.8**
K-40	17.0	**31.3±5.7**	23.1±6.0	18.0±5.6	19.7±6.2	*14.3±3.0*	**28.8±5.0**	17.6±7.6	**28.2±6.1**	15.1±6.7
Cs-137	1.1	**4.6±1.2**	1.5±1.9	1.0±1.3	1.1±2.3	*0.9±1.0*	1.4±1.7	*0.9±1.7*	**2.3±1.4**	1.2±2.5
Ra-226	11.1	**44.4±5.3**	**32.5±5.3**	16.5±7.3	16.5±7.3	*2.4±7.7*	18.4±7.6	13.5±9.4	19.9±4.7	8.0±10.3
Pb-210	221	*	**421.2±7.9**	**318.4±10.2**	213.4±10.2	**316.6±7.1**	293.4±16.2	**303.0±10.6**	323.4±11.8	299.8±14.4
Ac-228	2.3	*	3.0±1.8	**3.5±3.6**	3.0±2.2	*1.3±1.7*	**3.9±2.3**	3.0±2.5	**3.1±1.0**	1.8±1.9
Bi-214	4.8	*	5.5±2.0	**8.2±0.9**	6.5±2.9	4.6±1.1	**8.2±2.7**	6.5±2.0	4.9±2.9	*4.1±2.4*
Pb-212	6.9	*	*4.7±3.0*	*3.4±5.5*	7.2±3.7	**13.1±5.2**	7.9±3.0	*2.1±5.5*	**17.2±3.0**	**9.7±8.3**
Dust concentration	65.9	**85.2±4.2**	74.6±5.2	*58.0±4.9*	**81.0±5.6**	*52.0±4.2*	75.4±4.3	67.0±5.2	75.0±3.6	60.1±5.2

* – not enough data

Results significantly higher than average values shown as bold letters, results significantly lower than the average shown as italics.

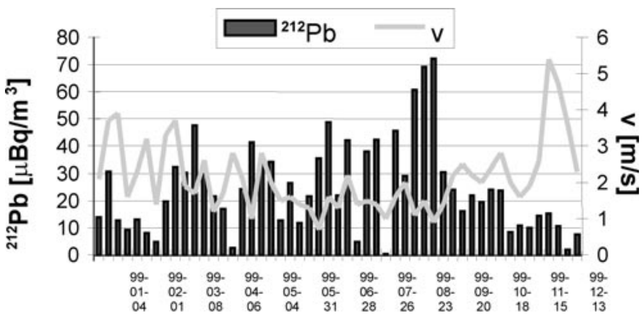

Fig. 5. Dependence of the concentration of Pb-212 on the wind speed.

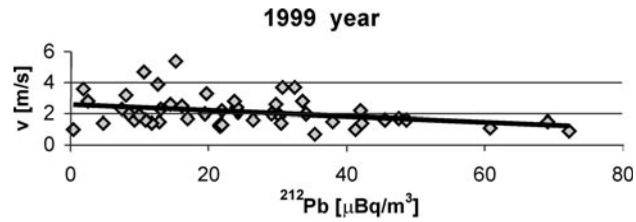

Fig. 6. Correlation between the Pb-212 concentration and wind speed. Correlation coefficient = -0.32.

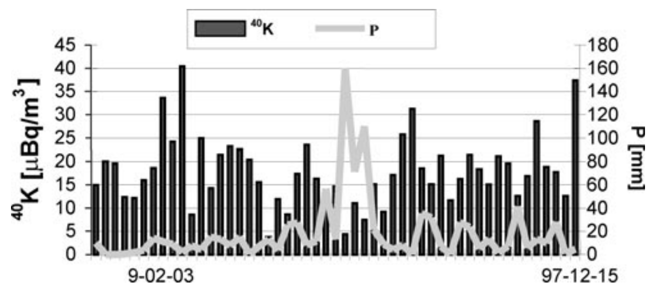

Fig. 7. Dependence of the K-40 concentration on the precipitation.

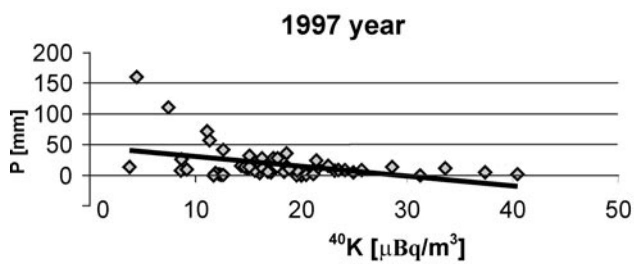

Fig. 8. Correlation between the K-40 concentration and precipitation. Correlation coefficient = -0.42.

this basis, a classifying Kohonen network was built, consisting of 20 neurons. The main goal of that approach was to specify particular agglomerations and to find a preliminary answer to the question, in which way following the meteorological parameters like wind speed, barometric pressure, temperature or precipitation, could differentiate the whole population.

The preliminary classification is shown in Table 2, which contains also the average values of different parameters, calculated for each particular agglomeration and the number of events in each group. Finally, the network recognised 9 different agglomerations with the number of events bigger than 5 cases.

It can be clearly seen from Tables 2 and 3 that about 50% of all results are located in the agglomeration I, characterized by elevated air temperature, almost two times higher than the average value from the period 1991–1999. Other approximations of parameters in this group are similar to the real values. Elevated activities of Be-7 can be observed in agglomerations E, H and I. This fact supports a possible correlation between air temperature and concentration of Be-7 in the atmospheric air near the ground surface. For all the radionuclides the influence of wind speed is visible, but especially for the following isotopes: K-40, Cs-137, Ra-226. The concentrations of Pb-210, Ac-228, Bi-214, Pb-212 and Be-7 are somehow related with the precipitation.

Conclusions

1. The lack of strong statistical connections was found during preliminary investigations, concerning a possible correlation between the concentration of different radionuclides in atmospheric air and meteorological parameters. On the other hand, such a correlation must exist, accordingly to investigations of Rn-222 and the radon progeny concentration near the ground surface. Reports of such measurements show the influence of particular meteorological conditions (mainly wind speed) on radon progeny concentration [3, 5].
2. The probable reason of negative results of preliminary investigations was the relatively long time of sampling of radionuclides on the filter (7 days). Therefore, the sampling time should be short (24 hours) and additional monitoring of meteorological parameters must be done in the same place as sampling.
3. Analysis of the results must be carried out very carefully. Otherwise, we would be able to find indirect correlation with other parameters than the meteorological ones. For

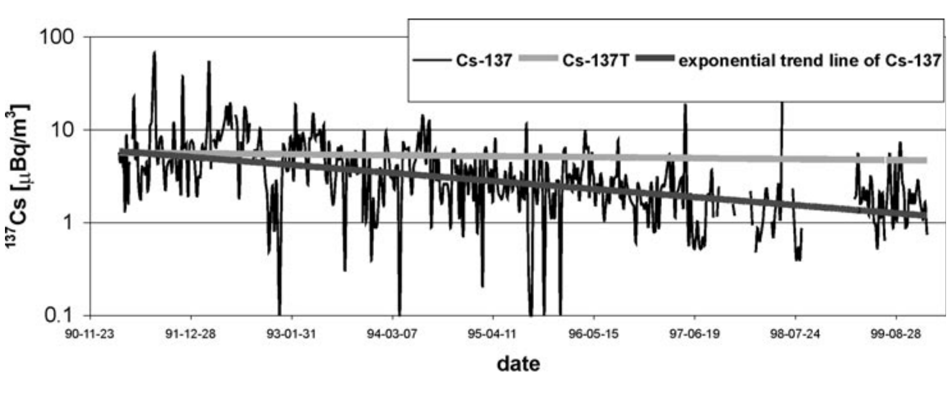

Fig. 9. Changes of Cs-137 concentration in atmospheric air (Cs-137 T – theoretical curve of the radionuclide decay).

instance, due to the heating of detached houses during winter, the dust content in air as well as the concentration of long-lived isotopes (Ra-226, Ra-228, and K-40) will be higher. Therefore, a possible correlation with air temperature is a wrong conclusion.

4. In our opinion all analyses should be done for two separate groups of radionuclides. First group should consist of primordial radioisotopes (K-40, Ra-226 etc.), whose presence in the atmosphere is connected with dust content. In the second group, cosmogenic isotopes (Be-7) as well as radon and thoron progeny (Pb-210, Pb-212 etc.) could be included. Behaviour of nuclides from both these groups is different and different may also be the influence of meteorological parameters on them.

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