Evaluation Model of Atmospheric Natural Radioactivity Considering Meteorological Variables

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This paper presents the effects of meteorological variables (atmospheric pressure, relative humidity, precipitation, wind speed and air temperature) on atmospheric natural radioactivity, using gamma dose rate and total beta activity of atmospheric aerosols and total depositions. For evaluating the relationship between meteorological variables and atmospheric natural radioactivity it was studied the variation of these variables along one year of measurements and also the correlations between meteorological variables and radioactivity measurements for each month of the year were determined. From the correlation analysis it can be clearly seen the influence of weather conditions upon atmospheric natural radioactivity.

Keywords: atmospheric radioactivity, correlations, gamma dose rate

Both natural and artificial radioactive sources are present in the environment as result of normal processes and anthropogenic activities, forming the actual radioactivity background to which population is permanently exposed [1]. Natural radiation sources provide for 85.5% of the average radiation dose received by the population and are mainly due to cosmic radiation, terrestrial radiation and radon [2].

Radon is an inert radioactive gas, which is emitted permanently by soil, in various rates, depending on the soil type. The three radioactive isotopes of radon ^{222}Rn (half-life of 3.824 days), ^{220}Rn (half-life of 55.6 s) and ^{219}Rn (half-life of 3.96 s), occur in the decay chains of ^{238}U, ^{232}Th and ^{235}U, respectively, existing in traces in the Earth's crust [1]. The population exposure to the radioactive element radon is now regarded as the most significant single contribution to human irradiation by natural sources [2, 3].

Exhalation rates of the three isotopes depend on the concentration of their precursors (^{226}Ra, ^{224}Ra and ^{223}Ra) in the ground, the meteorological conditions and the properties of the soil. The variation in exhalation rate seems to dominate the mean seasonal fluctuation of the ^{222}Rn, ^{220}Rn and ^{219}Rn concentrations.

The concentration of airborne $^{222}Rn/^{220}Rn$ progeny measured at a point above the ground depend on the radioactive decay, transport by the wind, atmospheric diffusion and exhalation from the soil. The diffusion process and exhalation rate are influenced by meteorological parameters such as atmospheric precipitations, relative humidity, atmospheric pressure, air temperature and wind speed.

The weather conditions influence the level of radiation which is directly related to the people health. This paper presents the effects of meteorological variables on atmospheric natural radioactivity, using gamma dose rate and total beta activity of atmospheric aerosols and total depositions.

Experimental part

In the paper, the natural radioactivity values presented are monthly averages obtained along one year from the row values of the atmospheric samples. The gamma dose rate values were measured with hourly frequency/day that is a total of 8760 values/year, 4 values/day of atmospheric aerosols total beta activity, that is a total of 1460 values/year and 1 value/day of atmospheric depositions total beta activity, that is a total of 365 values/year. The radioactivity values were measured, by the local Environmental Radioactivity Monitoring Station (ERMS), from Botoşani town, Romania.

The meteorological data, daily average pressure, humidity and precipitation, wind speed and temperature, were supplied by the National Meteorological Administration.

To determine the gamma dose rate absorbed in air we used a dosimeter, TIEX model, made by IFIN, equipped with Geiger Muller detector, which have a measuring range from 0.03 to 20 μGy/h and the energy range of 50-1500 keV. The detector was positioned at 1 m above the ground. The frequency of gamma dose rate readings was at each 4 s with an hourly integration. The measurement error of equipment was 15%. Data used in this paper are daily averages.

All total beta measurements of atmospheric aerosols and total depositions were performed with a low background total beta counter, equipped with a scintillation detector, ND-304 type, and a $^{90}(Sr/Y)$ reference standard. The counter background was between 0.05 and 0.1 counts per second. The statistical errors of the measurements range between 0.5 and 2%. Efficiency of the measurement ranged between 23% and 33%.

The principle of measurement of atmospheric aerosols activity is based on aerosol sampling on glass fiber filters with a high retention coefficient (96 - 99%). The aspiration head is mounted at 2 m above the ground and is connected to an aerosol sampler. The sampling time was 5 h, four times a day, as follows: 02:00 – 07:00 (aspiration A1), 08:00 – 03:00 (aspiration A2), 14:00 – 19:00 (aspiration A3) and 20:00 – 01:00 (aspiration A4). The filters have been measured after 3 min from sampling, for 1000s, after 20 h, for 3000s and after 5 days, for 3000s. The first two measurements provide filter activities necessary for the

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Monitored variables	Measured interval	Average
Atmospheric precipitation [L]	0.0 – 10.0	0.6
Relative humidity [%]	46 – 100	85
Atmospheric pressure [hPa]	780.8 – 1022.4	1000.7
Air temperature [°C]	-23.3 – 26.6	8.0
Wind speed [m/s]	0.0 – 15.0	2.7
Atmospheric aerosols [Bq/m³]	0.6 – 8.1	2.3
Atmospheric deposition [Bq/m²]	0.4 – 36.1	1.2
Total gamma dose rate [μSv/h]	0.058 – 0.097	0.073

Table 1
CHARACTERIZATION IN TERMS OF ATMOSPHERIC RADIOACTIVITY AND METEOROLOGICAL VARIABLES

determination of the radon and thoron progeny concentrations and the last measurement is used to identify the presence of artificial radioactivity in the atmosphere. The errors due to the reference standard, to the flow rate determination and to the filter efficiency have a maximum estimated value of 20%.

Total atmospheric deposition samples were obtained by collecting the dust and daily rainfall using a standard collector located at 1 m above the ground. The standard collector was coated inside with a layer of polyethylene. Sampling time was 24 h , with a daily frequency, measured daily to determine the immediate total beta activity, for 1000 s.

In order to determine the dependence of atmospheric natural radioactivity on meteorological variables, Pearson's correlation coefficient [4] was used. Pearson correlation coefficient quantifies the degree of dependence of one physical measure of another physical measure, giving a value between +1 and -1 inclusive. It measures the strength and the direction of a linear relationship between two variables. The sign of the correlation coefficient indicates the relationship between the variation of two physical measures: positive values indicate that when the values for one set increases, the values for the other set also increase; negative values indicate that when the values for one set increase, values for other set decrease; values near zero means that there is a random, nonlinear relationship between the two set of variables.

Although several authors [5,6] have given different interpretation of a correlation coefficient, the criteria are arbitrary chosen and depends mostly on the context and purposes of the study.

For interpretation reasons, the following criteria was used for Pearson's correlation coefficient: uncorrelated (for a value that is between -0.09 and 0.09), low correlated (for a value that is between -0.3 and -0.1 or between 01 and 0.3), medium correlated (for a value that is between -0.5 and -0.3 or between 0.3 and 0.5) and strong correlated (for a value that is between -1.0 and -0.5 or between 0.5 and 1.0) [6].

The Person correlation coefficients were computed by means of Microsoft Office Excel using the function "PEARSON".

Results and discussions

The variation in monthly average values of meteorological variables (atmospheric precipitations, atmospheric pressure, wind speed, air temperature and relative humidity) and atmospheric deposition, atmospheric aerosols and total gamma dose rate are presented in figure 1 and figure 2.

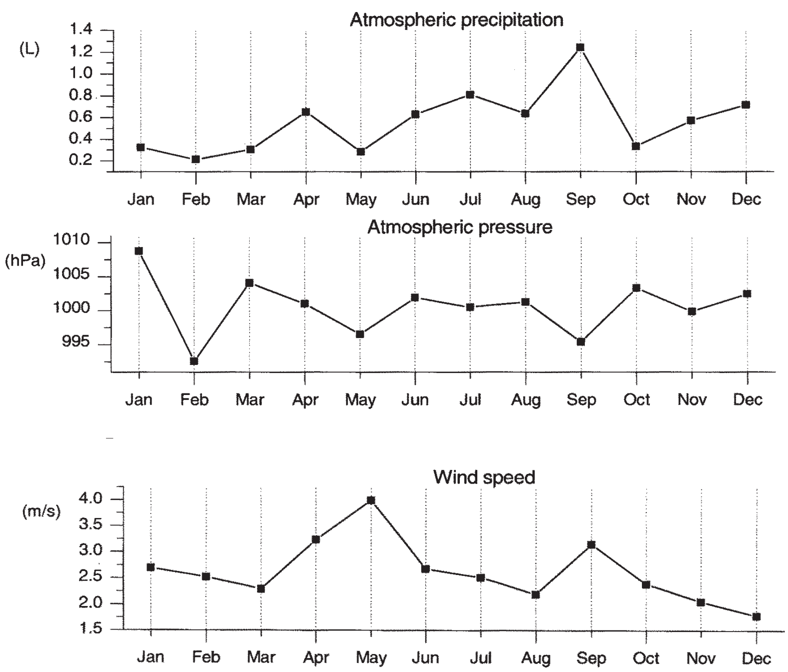
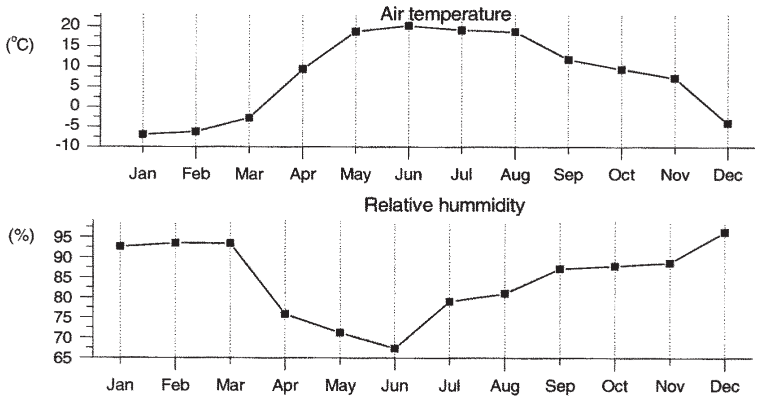


Fig. 1. Monthly averages distribution for meteorological variables



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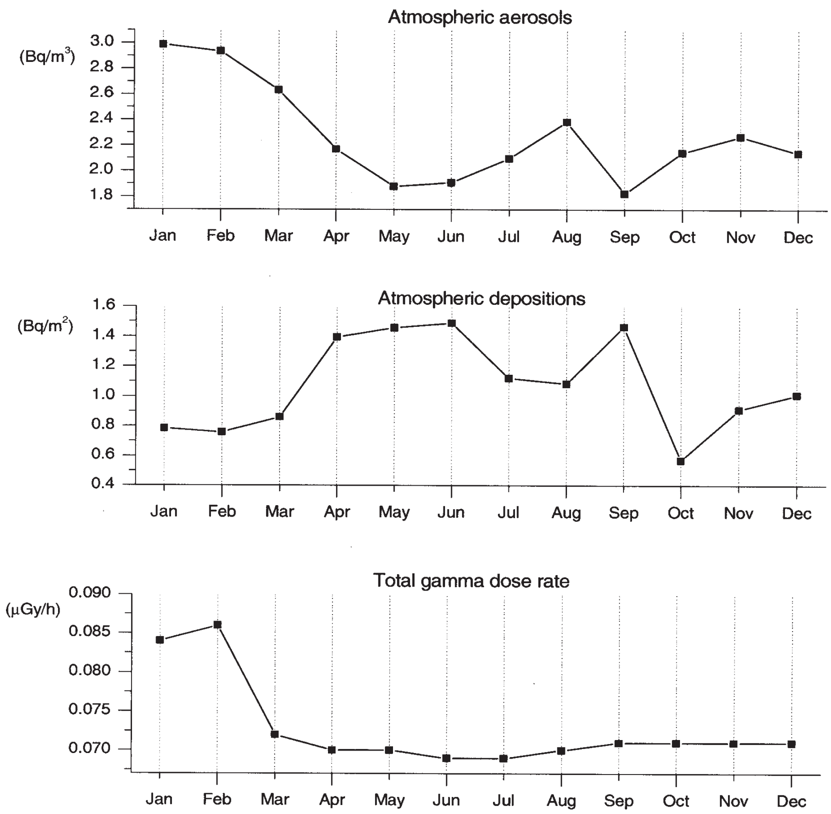

Fig. 2. Monthly averages distribution for natural radioactivity

In case of winter months it can be seen that the precipitations, air temperature and wind speed have low values, while the total gamma dose rate and total beta activity concentrations for atmospheric aerosol have maximum values due to the fact that exhalation rate of ^{222}Rn from Earth's crust is less intensified, consequently the total beta activity concentrations for atmospheric deposition are minimum, due to the fact that the precipitations are minimum.

In summer months, when the high temperatures occurs, the minimum values are obtained for the total gamma dose rate and for atmospheric aerosols concentrations due to dominant convection air currents, along with low values for wind speed and increased exhalation rate of ^{222}Rn from soil. The minimum value for total beta measurements on atmospheric aerosols and the maximum value for total beta measurements on atmospheric deposition from autumn, especially from September, can be explained by the maximum values obtained for precipitations (having as result a dust free atmosphere), an increase of wind speed, dominant factor for dust transport, and relative humidity values and low values for atmospheric pressure.

A major contribution to atmospheric aerosols natural radioactivity has radon and thoron and their progeny [7]. Radon and thoron diffusion process and exhalation rate are affected by meteorological parameters [8, 9].

In order to determine the dependence of atmospheric natural radioactivity of gaseous or solid substances which form aerosols and deposition particulates on meteorological variables, Pearson's correlation coefficient [4] between sample value and different meteorological variables (atmospheric precipitations, relative humidity, atmospheric pressure, air temperature and wind speed) was calculated and presented in tables 2, 4 and 6.

Table 2 presents monthly variation of correlation coefficients between monthly averages of atmospheric aerosols total beta activity concentration and meteorological variables. From correlation analysis of monthly averages of atmospheric aerosols total beta activity concentration with the meteorological variables it was found that they are well correlated with air temperature and wind speed, both being directly responsible for the air masses movement and atmospheric aerosols activity concentrations dynamics [8, 10]. Relative humidity and pressure are generally poorly correlated with atmospheric aerosols; also the atmospheric precipitations are mostly uncorrelated. Regarding the correlation with atmospheric precipitation, October is the only month in which the medium correlation was registered, this is

Month	Atmospheric precipitations	Relative humidity	Atmospheric pressure	Air temperature	Wind speed
January	-0.09	-0.08	-0.14	-0.17	-0.49
February	0.04	0.29	0.05	-0.47	-0.41
March	-0.07	0.37	-0.18	-0.34	-0.03
April	-0.04	0.14	-0.02	0.30	-0.47
May	0.04	0.04	-0.55	0.18	-0.47
June	0.05	-0.30	-0.04	0.71	-0.65
July	0.02	0.11	-0.34	0.66	-0.61
August	-0.29	-0.12	0.22	0.43	-0.54
September	-0.03	0.05	0.28	0.41	-0.58
October	-0.36	-0.02	0.04	0.11	-0.46
November	-0.06	0.39	-0.33	0.01	0.10
December	0.27	0.29	-0.29	-0.51	-0.63

Table 2
CORRELATION COEFFICIENTS BETWEEN MONTHLY AVERAGES OF ATMOSPHERIC AEROSOLS TOTAL BETA ACTIVITY CONCENTRATION AND METEOROLOGICAL VARIABLES

Correlation	Atmospheric precipitations	Relative humidity	Atmospheric pressure	Air temperature	Wind speed
Uncorrelated (%)	75.00	33.33	33.33	8.33	8.33
Low correlated (%)	16.67	41.67	41.67	25.00	8.33
Medium correlated (%)	8.33	25.00	16.67	41.67	41.67
Strong correlated (%)	0.00	0.00	8.33	25.00	41.67

Table 3
PERCENTAGE ANALYSIS OF THE CORRELATION OF ATMOSPHERIC AEROSOLS TOTAL BETA ACTIVITY CONCENTRATION AND METEOROLOGICAL VARIABLES

Month	Atmospheric precipitations	Relative humidity	Atmospheric pressure	Air temperature	Wind speed
January	0.65	0.36	-0.53	0.36	0.20
February	0.09	0.32	-0.62	-0.22	0.40
March	0.71	0.16	-0.22	0.29	0.18
April	0.98	0.46	-0.18	-0.36	0.04
May	0.87	0.36	-0.29	-0.02	-0.24
June	0.89	0.60	-0.17	-0.01	0.04
July	0.85	0.12	-0.20	0.24	-0.15
August	0.63	0.27	-0.20	-0.17	0.14
September	0.48	0.03	0.01	0.27	-0.08
October	0.76	0.37	0.07	-0.24	0.44
November	0.66	0.32	-0.13	-0.26	0.12
December	0.73	0.09	-0.44	0.05	-0.12

Table 4
CORRELATION COEFFICIENTS BETWEEN TOTAL BETA ACTIVITY CONCENTRATION OF ATMOSPHERIC DEPOSITIONS MONTHLY AVERAGES AND METEOROLOGICAL VARIABLES

justified by the higher amount of precipitation recorded, compared with the other months of the year, and by the fact that it was the month in which occurred the most days of consecutive atmospheric precipitations.

Correlation analysis of monthly averages of the total beta activity concentration of atmospheric deposition with meteorological conditions (table 4) was found to be well correlated with atmospheric precipitations and relative humidity, both influencing directly the deposition rate of dust particles from the atmosphere on soil. Atmospheric deposition is poorly correlated with atmospheric pressure

Correlation	Atmospheric precipitations	Relative humidity	Atmospheric pressure	Air temperature	Wind speed
Uncorrelated (%)	8.33	16.67	16.67	25.00	25.00
Low correlated (%)	0.00	25.00	58.33	58.33	58.33
Medium correlated (%)	8.33	50.00	8.33	16.67	16.67
Strong correlated (%)	83.33	8.33	16.67	0.00	0.00

Table 5
PERCENTAGE ANALYSIS OF THE CORRELATION OF ATMOSPHERIC DEPOSITIONS TOTAL BETA ACTIVITY CONCENTRATION AND METEOROLOGICAL VARIABLES

Month	Atmospheric precipitations	Relative humidity	Atmospheric pressure	Air temperature	Wind speed
January	0.63	0.28	-0.83	0.32	0.27
February	-0.14	-0.35	0.13	0.70	-0.26
March	-0.27	-0.10	0.12	-0.64	0.34
April	-0.08	-0.31	-0.54	0.39	-0.08
May	0.14	0.52	-0.11	-0.70	-0.41
June	0.32	0.32	-0.11	-0.89	0.27
July	0.15	0.30	0.05	-0.66	0.10
August	0.70	0.48	-0.20	-0.82	0.18
September	0.55	0.72	-0.27	-0.75	0.10
October	0.57	0.64	0.22	-0.80	0.40
November	0.44	0.81	-0.36	-0.84	0.48
December	0.18	-0.26	-0.32	0.81	0.10

Table 6
CORRELATION COEFFICIENTS BETWEEN GAMMA DOSE RATE MONTHLY AVERAGES AND METEOROLOGICAL VARIABLES

Correlation	Atmospheric precipitations	Relative humidity	Atmospheric pressure	Air temperature	Wind speed
Uncorrelated (%)	8.33	0.00	8.33	0.00	8.33
Low correlated (%)	41.67	25.00	58.33	0.00	50.00
Medium correlated (%)	16.67	41.67	16.67	16.67	33.33
Strong correlated (%)	33.33	33.33	16.67	83.33	0.00

Table 7
PERCENTAGE ANALYSIS OF THE CORRELATION BETWEEN GAMMA DOSE RATE AND METEOROLOGICAL VARIABLES

and air temperature and generally uncorrelated with wind speed.

From correlation coefficient analysis between monthly averages gamma dose rate absorbed in air and meteorological variables (table 6) was found a strong correlation with air temperature and relative humidity, medium correlation with atmospheric precipitations, because of the amount of precipitation and atmospheric wash, a micro-layer of atmospheric deposition is deposited on the detectors surface (default leads to a small increase of the measured values), while pressure and wind speed are poorly correlated with atmospheric depositions.

From the correlation analysis it can be clearly seen the influence of weather conditions upon atmospheric natural radioactivity. The most influent variables on the natural radioactivity are air temperature and relative humidity, moderate influence has wind speed and precipitations and less influence in case of atmospheric pressure.

Conclusions

The experimental results obtained in this study emphasize the need for permanent monitoring of environmental radioactivity in different weather conditions in order to determine the natural background level of each type of sample. This type of information is vital in case of a potential incident / nuclear accident or radiation emergency radiation, providing prompt and reliable data on increases values of radioactivity in different media, as well as detection of the presence of artificial radioactivity in the environment. Daily monitoring of environmental radioactivity gives an indication of the changes in natural radioactivity and is the basis of real-time early warning for decision makers.

The degree of dependence of one physical measure of another physical measure was given by Pearson correlation coefficient. Basically, in case of atmosphere, the correlation coefficient indicates the degree of dependence of the concentrations of gaseous or solid (in the aerosols form) substances on the meteorological variables.

In terms of air radioactivity, a great influence is given by the soils natural radioactivity, the greater radium content from soil, the higher is the radon and thoron progeny concentration from atmospheric aerosols.

Atmospheric natural radioactivity is directly influenced by weather conditions, especially air radioactivity, while soil and vegetation radioactivity are less affected. There is an increase of global beta radioactivity values of soil and vegetation when the radionuclides are brought by atmospheric precipitation and wind speed. This means that major changes can occur to natural radioactivity only in a nuclear accident or a radiological emergency.

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