Circulation of Radon progeny in the terrestrial atmosphere during thunderstorms

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November 23, 2022

Abstract

We describe a new phenomenon in atmospheric physics – 222Rn progeny circulation during thunderstorms. The enhancement of the natural gamma radiation during thunderstorms was measured with precise gamma ray spectrometers. Results of measurements performed at Aragats mountain in Armenia during summer 2020 demonstrate the Rn progeny lifted to the atmosphere by a near-surface electric field are returned back to the ground by rain precipitation. Thus, thunderstorms not only return negative charge to the Earth by lightning flashes but, also maintain Rn progeny circulation in the atmosphere; it this way, significantly enlarging natural gamma radiation above the Earth surface and Radon concentration in the atmosphere.

Figure1.


BICRON
ORTEC
Assembled in INDIA
CE

Figure2.

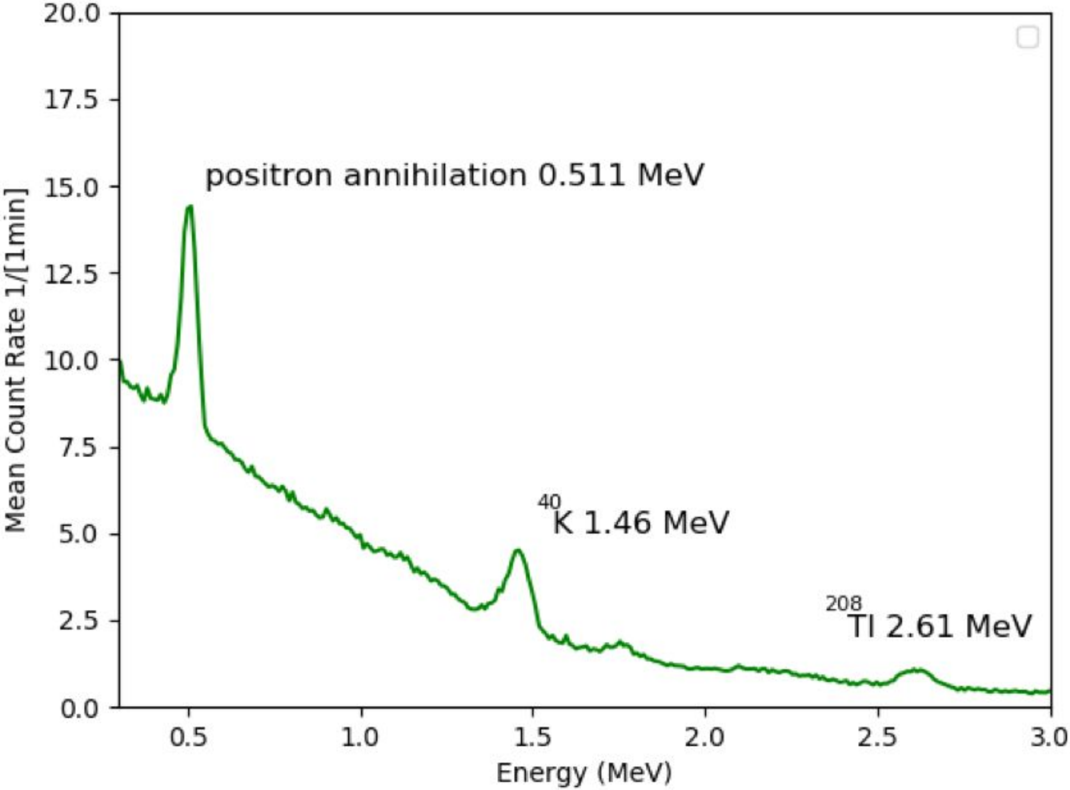

positron annihilation 0.511 MeV
^{40}K 1.46 MeV
^{208}Tl 2.61 MeV
Mean Count Rate 1/[1min]
Energy (MeV)
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Figure3.

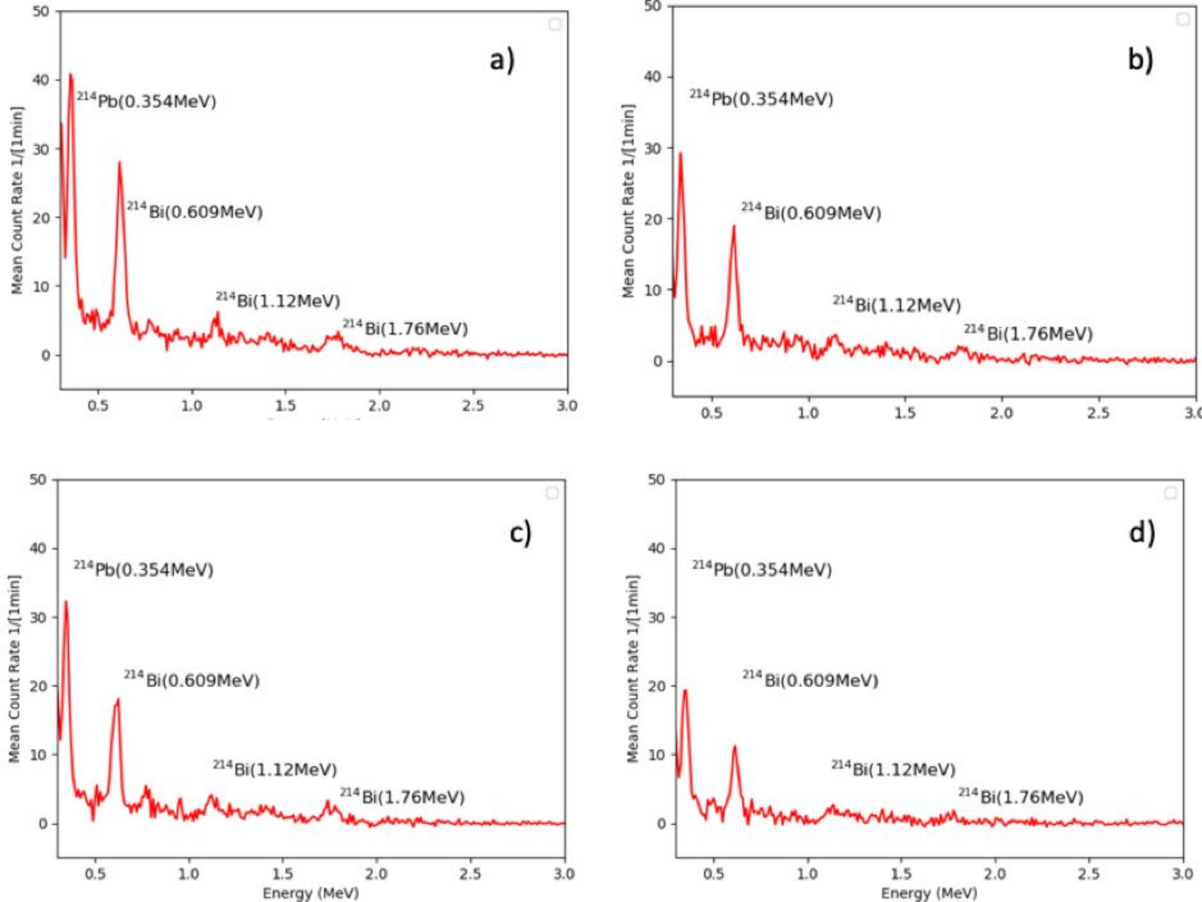
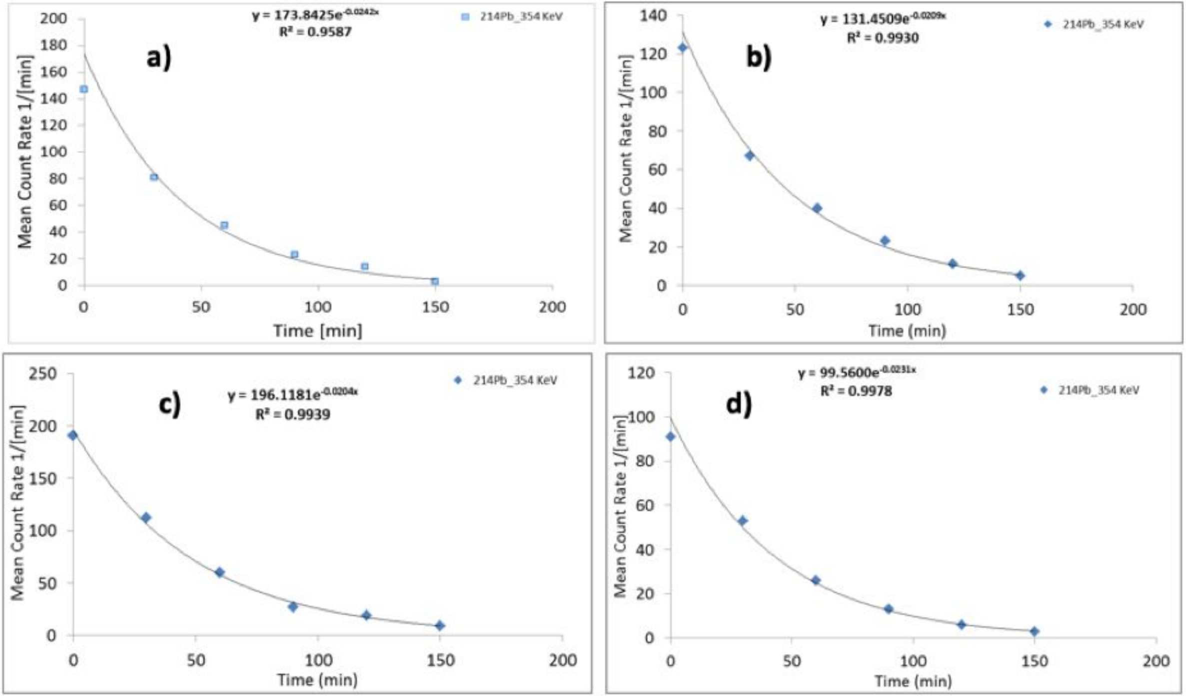

a)
b)
c)
d)
^{214}Pb(0.354MeV)
^{214}Bi(0.609MeV)
^{214}Bi(1.12MeV)
^{214}Bi(1.76MeV)
Mean Count Rate 1/[1min]
Energy (MeV)

Figure4.


a)
y = 173.8425e^-0.0242x
R² = 0.9587
214Pb_354 KeV
Mean Count Rate 1/[min]
Time [min]
200
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
b)
y = 131.4509e^-0.0209x
R² = 0.9930
214Pb_354 KeV
Mean Count Rate 1/[min]
Time (min)
140
120
100
80
60
40
20
0
0
50
100
150
200
c)
y = 196.1181e^-0.0204x
R² = 0.9939
214Pb_354 KeV
Mean Count Rate 1/[min]
Time (min)
250
200
150
100
50
0
0
50
100
150
200
d)
y = 99.5600e^-0.0231x
R² = 0.9978
214Pb_354 KeV
Mean Count Rate 1/[min]
Time (min)
120
100
80
60
40
20
0
0
50
100
150
200

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Abstract

We describe a new phenomenon in atmospheric physics – 222Rn progeny circulation during thunderstorms. The enhancement of the natural gamma radiation during thunderstorms was measured with precise gamma ray spectrometers. Results of measurements performed at Aragats mountain in Armenia during summer 2020 demonstrate the Rn progeny lifted to the atmosphere by a near-surface electric field are returned backward to the ground by rain precipitation. Thus, thunderstorms not only return negative charge to the Earth by lightning flashes but, also maintain Rn progeny circulation in the atmosphere; it this way, significantly enlarging natural gamma radiation above the Earth surface and Radon concentration in the atmosphere.

1. Introduction

The terrestrial atmosphere is host to various sources of electric currents and gamma radiation ranging from the fair-weather current of picoamperes to hundreds of kiloampere lightning currents. Particle fluxes range from the single particles of the ambient population of secondary cosmic rays to huge particle showers from interactions of primary high-energy proton or nuclei with terrestrial atmosphere and electron-gamma ray avalanches from the electron accelerator operated in the thundercloud. Gamma radiation from the primordial radionuclides have the half-life comparable with the age of the Earth, and they contribute significantly to natural gamma radiation (NGR) at considerably low energies (<3MeV).

Radionuclides derived from the Earth crust can influence the electrical properties of the atmosphere and can influence human illness and death rates, result in DNA alterations, and chromosomal aberrations and weakening of immunity (Hunting et al., 2020).

The static electric field in the lower atmosphere is modulated by the mobile particles carrying electrical charges, i.e. different types of hydrometeors, aerosols, small ions, and progeny of radioactive isotopes. The charge separation initiated by the updraft of moisture generates an electric field between differently charged layers emerging in the thundercloud; potential drop (voltage) in the cloud can reach hundreds of megavolts. Emerging near-surface electric field lifts charged aerosols with attached 222Rn isotope and its progeny to the atmosphere. Correspondingly, the concentration of 222Rn at surface decreases 10 times (Wilkcning et al., 1966, Roffman, 1972); the small ions and aerosols with attached 222Rn are lifted up in seconds to tens of meters due to their large mobility. These gamma emitters significantly enhance low-energy natural gamma radiation measured by spectrometers located several meters above the ground (Chilingarian, 2018, Chilingarian et al., 2019a, Chilingarian et al., 2019b). The rain returns long-lived progeny to the Earth recovering and somewhat enhancing the surface radiation (washout process, McCarthy and Parks, 1992, Barbosa et al., 2017, Fabro et al., 2016), Reuveni et al., 2017, Chilingarian et al., 2020).

We present the measurement of the gamma radiation performed on Aragats mountain, 3200 m above sea level during summer thunderstorms. We estimate the intensity of the different 222Rn progenies in the rainwater; clarify the washout process and estimate the percentage of isotopes returned by the rain to the Earth surface. For measurements, we use the precise ORTEC firm gamma spectrometer (NaI(Tl), FWHM ~7.7% at 0.6 MeV, see details in Hossain et al., 2012) surrounded with lead filters. Simulations of the cosmic radiation, radon progeny radiation, and detector response function calculation were performed with the aid of the EXPACS code (Sato, 2018).

2. Method

Gamma radiation measured on the Earth surface comes from the ground and from the atmosphere. The largest surface contribution is from gamma rays originating in the mineral grain, in their crystal lattices, and in the construction materials. The radiation is stable because the concentration of radionuclides in minerals and construction materials is constant due to long half-lives of their parent isotopes (40K, 238U, 232Th, see details in (Chilingarian et al., 2019a). Therefore, to investigate Radon progeny circulation (lifted by the near-surface electric field and returned through precipitation from rain) in the atmosphere we need to take into account and filter as much as possible this more-or-less stable contribution of the radionuclides from the surface. Gamma spectrometers are positioned on Aragats in the experimental hall which is 3 meters high and located under a metallic tilt roof of 0.6 mm thickness. By surrounding the ORTEC spectrometer with the 4-cm thick lead filter (see Fig. 1) we suppress the Radon progeny gamma radiation ≈12 times; the count rate of the spectrometer decreases from 12600 ± 112 to 1080 ± 34.

Figure 1. ORTEC firm gamma spectrometer (NaI(Tl), FWHM ~7.7% at 0.6 MeV, see details in (Hossain et al., 2012), surrounded by 4 cm thick lead filters. The spectrometer is positioned in the experimental hall on Mt Aragats (3200 m MSL) which is 3 meters high and located under a metallic tilt roof of 0.6 mm thickness.

In Fig. 2 we show the energy spectrum measured by ORTEC spectrometer for 6 hours (normalized to 1-minute count rate). Most pronounced are the positron annihilation peak (0. 511 MeV), 40K peak (1.46 MeV), and 208Tl peak (2.61 MeV). Bismuth isotopes also are present in smaller quantities, see Table 1.

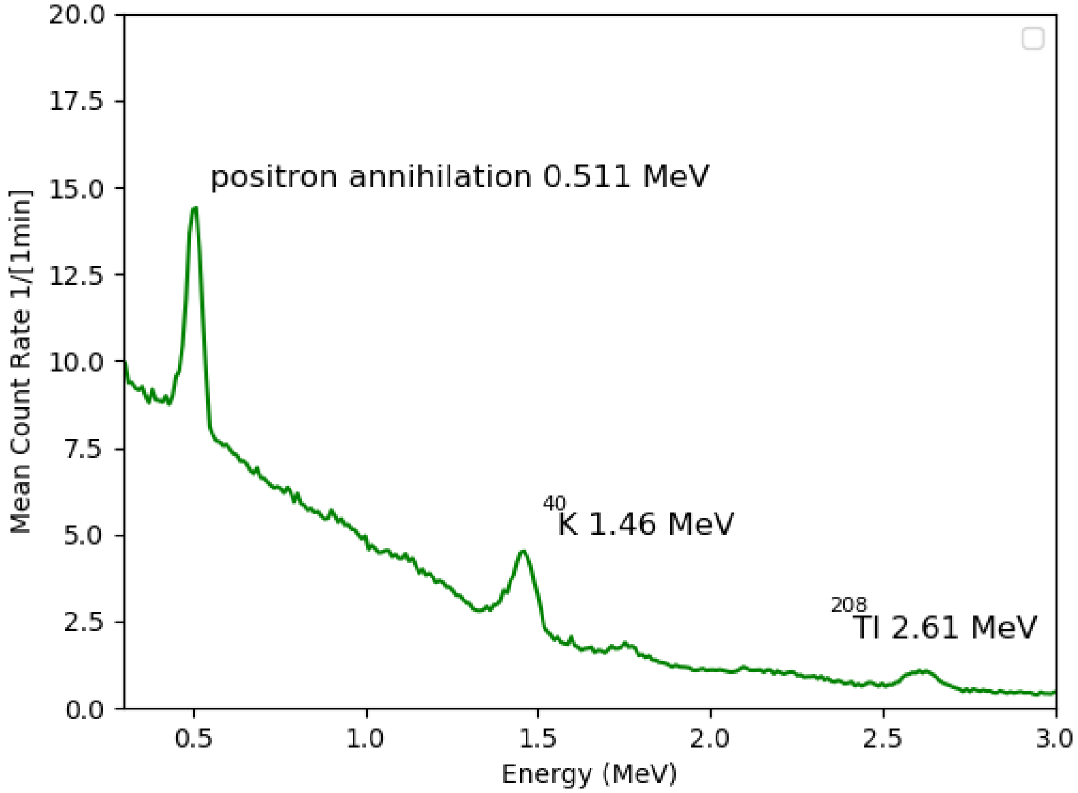

Figure 2. Energy spectra of the background measured by the ORTEC spectrometer surrounded by lead filter.

In the first column of Table I, we present the count rate of registered particles normalized to a 1-minute time span. Next is the absolute enhancement and its share of important isotopes from radon and thoron chains, potassium isotope peak, the 511 keV positron annihilation line, as well a small amount Cs-137 trace due to contamination of the ORTEC spectrometer during calibration with Cs isotope. In the last column, we show the overwhelming portion of the continuous spectrum induced by the secondary cosmic rays (CR) and Compton scattering of the gamma rays in the body of the NaI(Tl) crystal of ORTEC spectrometer.

Table 1. Composition of the background gamma radiation measured by ORTEC spectrometer surrounded from all sides by the 4-cm thick lead filter

Total intensity 0.3 -3 MeV	214Pb_354 keV	511 keV	137Cs 662 keV	214Bi 768 keV	228 Ac 911keV	214Bi 1.12 MeV	214Bi 1.76 MeV	214Bi 2.2 MeV	40K 1.46MeV	208Tl 2.6 MeV	CR and Compton scattered
912	8	31	2	4	4	3	3	3	22	4	828
100%	0.9	3.4	0.2	0.4	0.4	0.3	0.3	0.3	2.4	0.4	90.8

To measure the share of Rn progeny in the rainwater we should subtract the background spectrum from the spectrum measured during exposing rainwater to the spectrometer (see details of technique in (Chilingarian et al., 2019b). As we see in the last column of Table 1, the lead filter suppresses background down to a few percent; more than 90% of the count rate comes from the stable flux of high-energy cosmic rays penetrating the lead filter. Simulations of the detector response function with cosmic radiation, radon progeny radiation, were performed with EXPACS code (Sato, 2018) and coincide rather well with the experimentally measured count rate.

3. Results

In 2020 the first rain on Aragats was in June and rain showers were only during July, which is when they fille special container in a few minutes. In Fig. 3 we show four episodes of the radiation measurements (after subtracting the background). In Table 2 we show the count rates of gamma emitters including radioactive isotopes, positron annihilation, and continuous spectrum of secondary cosmic rays (mostly muons) and gamma rays scattered in the body of the NaI crystal (continuum to the right of each spectral line).

As it was expected from previous measurements the most pronounced peaks are 214Pb and 214Bi (Chilingarian et al., 2019c, Chilingarian et al., 2019b, Chilingarian et al., 2020), and as we show in Table 2 the share of different gamma-emitting isotopes in the atmosphere measured by the same spectrometer well coincides with the spectra measured from the rainwater (see Table 2 in Chilingarian et al, 2020). Sure, the electrified atmosphere introduces changes in the particle fluxes and slightly enlarges the positron annihilation share (see Fig. 6 in Livesay et al., 2014); however, these changes are not large and do not exceed ≈1%. The potassium spectrum is very stable and does not influence the rainwater spectrum. In the last row of Table 2, we show the mean value of each gamma emitter share and error of the mean.

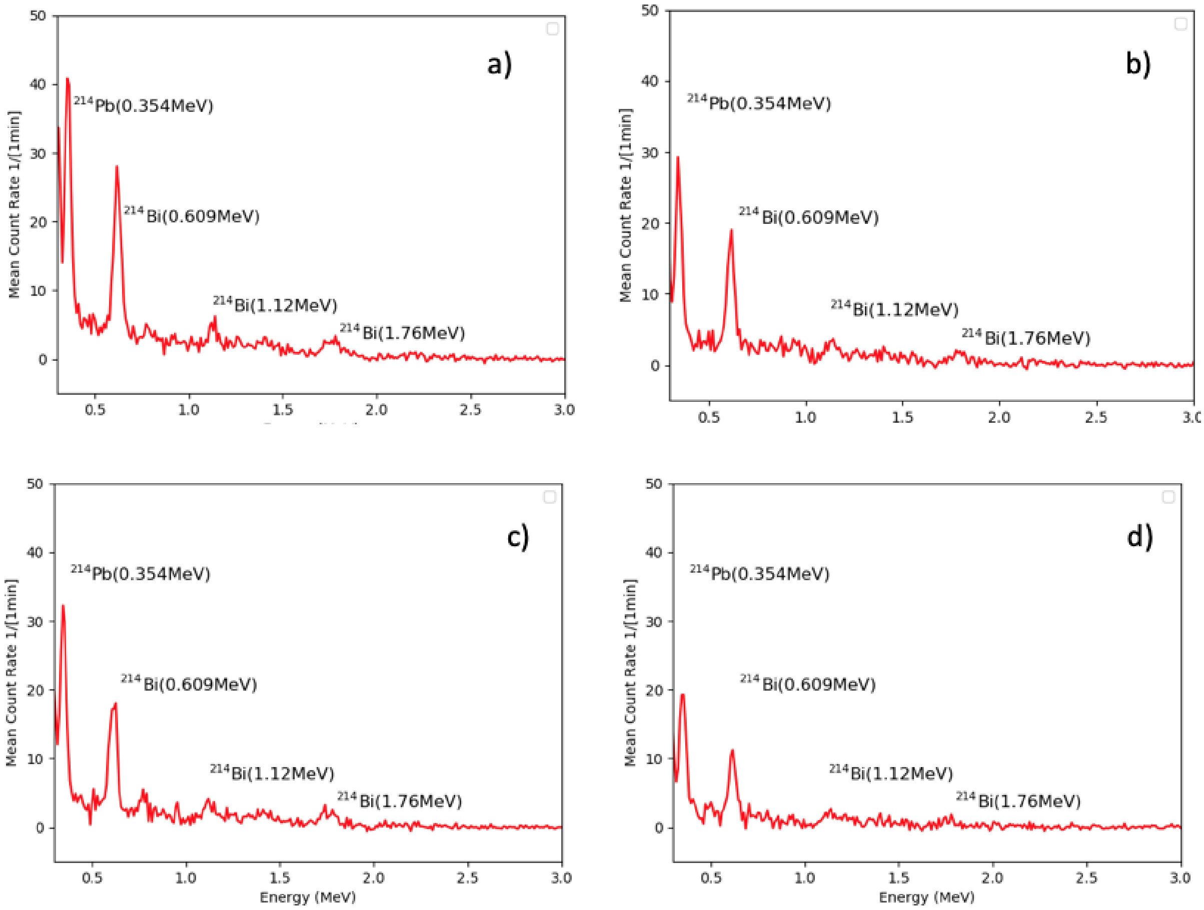

Figure 3. The Energy spectra of the rainwater measured by the ORTEC spectrometer covered by 4-cm thick lead filter from all sides: a) at 12:32 on 23 July ; b) at 18:27 on 23 July c) at 17:26 on 24 July; and d) at 14:16 on 1 August.

Table 2. Summary of the gamma radiation measurements from the rainwater by the ORTEC spectrometer covered by the 4-cm thick lead filter from all sides.

	Intensity 0.3 - 3 MeV	214Pb_354keV	511 keV	214Bi_609 keV	214Bi_768 keV	228Ac_911 keV	214Bi_1.12 MeV	214Bi_1.76 MeV	214Bi_2.2 MeV	CR + Compton scattered
23 July Mean Count rate [12:32-12:48] 1/min	585	147	5	109	45	26	40	32	7	174
%		25.1	0.9	18.6	7.7	4.4	6.8	5.5	1.2	29.7
23 July Mean Count rate [18:27 - 18:42] 1/min	531	123	6	102	32	43	38	23	8	156
%		23.2	1.1	19.2	6.0	8.1	7.2	4.3	1.5	29.4
24 July Mean Count rate [17:26 - 17:41] 1/min	814	191	8	161	46	41	60	42	12	253
%		23.4	1.0	19.7	5.7	5.0	7.4	5.2	1.5	31.1
01 Aug. Mean Count rate [14:16 - 14:31] 1/min	343	91	9	63	19	13	28	13	8	99
%		26.5	2.6	18.4	5.5	3.8	8.2	3.8	2.3	28.9
Mean %		**24.6 ±1.5**	**1.4 ±0.8**	**19 ± 0.6**	**6.2 ± 1**	**5.3 ± 1.9**	**7.4 ± 0.6**	**4.7 ± 0.8**	**1.6 ± 0.5**	**29.8 ± 0.9**

In Fig. 4 we present the decay curve of the most abundant 214Pb isotope. The intensity was measured every 30 minutes for a period of 15 minutes and then normalized to the 1-minute count rate. Then the measured values were fitted with the exponential function and the half-life time calculated.

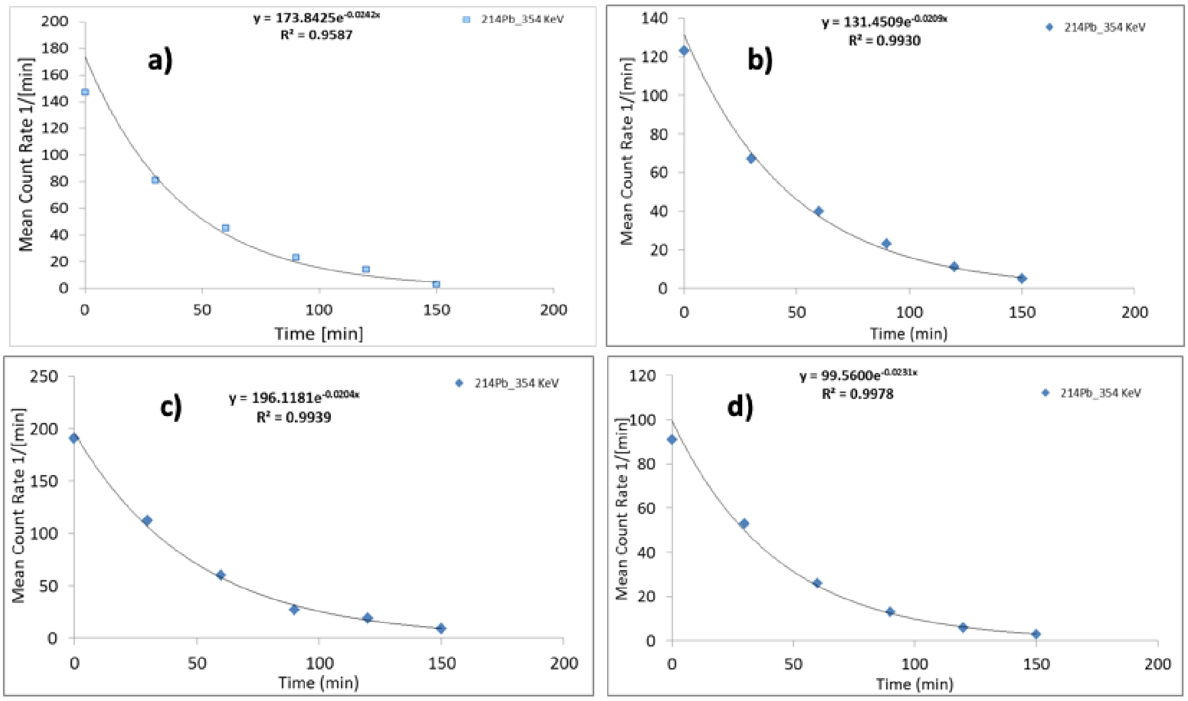

Figure 4. The exponential fit of the decay of the 214Pb isotope. The intensity of the 354 keV line was measured each half-of-hour during 150 minutes of measurements. Solid line – the exponential fit.

The derived mean value of the 214Pb (354 keV) isotope half-life time (31.4 ±2.5min) is larger than the real value of half-life time (26.8 min.). This shows that the collected rainwater contains the 222Rn isotope and it continues to decay giving additional Pb-214 isotope, and in this way enlarging its half-life time. It means than rain washout not only gamma emitters (mostly Bismuth isotopes) but also 222Rn itself.

4. Conclusions

We measured the gamma radiation of 222Rn progeny during thunderstorms by precise gamma spectrometers located within the lead filter. The gamma radiation was measured from the rainwater collected during 4 summer storms on Aragats. The concentration the most abundant gamma emitters in the rainwater 214Pb, 214Bi(609keV), 214Bi(1.12 MeV) was 25.3 ± 0.8%, 19.5 ± 1%, and 7.5 ± 0.2% in the first minute of the exposing of the rainwater to the ORTEC spectrometer. In the last, 150-th minute of exposition, the concentration of these isotopes changed to 13.5 ± 0.7%, 25.6 ± 1.8%, and 17.1 ± 2.8% accordingly. The overall composition of the 222Rn progeny in rainwater coincides well with one recovered from the registered gamma radiation of the atmospheric origin. Thus, near-surface electric field lifts the 222Rn and its progeny up in the atmosphere and the rain return it backward in this way providing the circulation of the radioactive isotopes and enlarging surface radioactivity during thunderstorms.

ACKNOWLEDGMENTS

We thank the staff of the Aragats Space Environmental Center for safeguarding the operation of experimental facilities on Aragats. The data for this study is available on the WEB page of

the Cosmic Ray Division (CRD) of the Yerevan Physics Institute, http://adei.crd.yerphi.am/adei.

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