

# ***INFLUENCE OF METEOROLOGICAL ELEMENTS IN ACCIDENTS IN ENTERPRISES WITH RADIOACTIVE ELEMENTS OR DANGEROUS CHEMICAL SUBSTANCES IN BULGARIA***

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**Abstract.** In the analysis of the meteorological elements that influence the spread of radioactive particles, radioactive isotopes and dangerous chemical substances on the territory of Bulgaria, the winds and air currents that form in the airspace over Bulgaria are considered. These are the main meteorological elements that most strongly influence the change in the radioactive background. Another element that has an impact is precipitation in its various manifestations - horizontal and vertical in appearance and depending on the aggregate state of the water. Due to their negligible influence on the radiation environment, we will exclude the remaining meteorological elements from the factors forming the natural indicators of the state of the atmosphere, water and soil. Their influence in areas where there are located large enterprises working with such substances is presented.

The report examines the influence of the main factor - the movement of air masses at different altitudes in the atmosphere in the Ludogorie region and the Danube River as an area where NPPs are located in Bulgaria and Romania and which, in the event of an accident, would cause the greatest consequences. The winds in 3 cities from this region, which are located near these enterprises, are described and the corresponding analysis is made.

**Keywords:** *air flow, chemical accident, hazardous chemical substances meteorological element, nuclear accident, precipitation, radionuclide, wind.*

## INTRODUCTION

Meteorological elements may have an impact on the radioactive contamination of our environment - atmosphere, soil and water, and each indicator has a different weight in forming the radioactive background. Naturally, the strongest influence on the spread of radioactive contamination in the event of a nuclear incident, accident or terrorism is the winds at different heights from the surface of the earth's crust. In the different layers of the Earth's atmosphere, the direction and speed of air currents sometimes have radically different values. Different types of horizontal and vertical precipitation and the permeability of the atmospheric layer to the solar radiation reaching us also have an influence. The other meteorological components have a negligible influence on the distribution of radioactive rays, particles and isotopes and are therefore not the subject of this report [1], [2].

In this area are located 2 NPPs in Bulgaria and Romania and there is a selected site for the construction of another nuclear power plant. Here there are also enterprises of the chemical industry of both countries and former enterprises that are currently not working, but have worked and have raw materials or can work again. All of them can have an impact on people and our surroundings in the event of an accident. There are also many medium and small enterprises that work with hazardous substances and we

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should not ignore their influence in the event of a release of hazardous or toxic substances.

An analysis of the results of the movement of air masses in the last nearly 40 years has been made, and relevant conclusions and recommendations have been made based on them.

## II. MATERIALS AND METHODS

### *A. Influence of winds*

Wind and air currents have the strongest influence on the change of the radiation background after the occurrence of an accident in a nuclear power plant or other nuclear facilities. The direction and speed of the mean wind determine the position, extent, and degree of contamination of the radioactive cloud trail. Therefore, when assessing the radiation situation, the parameters of the air currents must always be taken into account. In the event of an accident or an increase in the radioactive background, we must constantly monitor the change in air currents, as well as inform ourselves about the possible changes that meteorologists give in their forecasts. It is also necessary to quickly collect information about the usual winds in the given area, in order to predict the direction of spread of radioactive contamination, using also local signs to determine the winds and their future development. In Bulgaria, you can use the National System for Continuous Control of the Radioactive Background at the Ministry of the Environment and the website of the National Institute of Meteorology and Hydrology at the Bulgarian Academy of Sciences, where you can see what the spread of radioactive particles will be after a certain set time and at a certain height on the earth's surface for a specific nuclear power plant from the European continent.

Wind direction and speed data allow us to solve the following tasks:

1. Determining the direction of propagation of the radioactive cloud and the scale of the radiation, as we can define it for a certain time segment;
2. Determining the time of arrival of the radioactive pollution to the designated area with the current and predicted air currents;
3. Determining the level of the assumed change in the radioactive background in a certain time range.

### *B. Influence of phase transitions of water in the atmosphere*

Air humidity has a significantly weaker effect on the change of the radioactive background, but it should not be neglected as a factor for the spread of radioactive contamination [3], [4], [5].

In case of relatively heavy precipitation or fog, a decrease in pressure is observed in the front of the spread of the radioactive cloud, especially at greater distances from the place of the explosion. As the radioactive

contamination moves away from the epicenter of the event, the amount of radioactivity decreases. In explosions in medium rain (5 ml/h) or fog (0.2 g/m<sup>3</sup>), the shock wave pressure is 5–15 % lower than in normal conditions. In heavy rain (25 mm/h) or dense fog (1 g/m<sup>3</sup>), the pressure in the shock wave decreases by 15–30 %. In nuclear accidents in snowfall, the pressure in the shock wave decreases slightly and may not be taken into account in practical calculations.

Rains, to varying degrees, influence changes in the radioactive background after a nuclear accident. During the formation of the trace of the radioactive cloud, the raindrops entrain the particles of the radioactive dust and together with them fall on the earth's surface [2]. This results in:

1. Increasing the rate of settling of the radioactive cloud;
2. Increasing the degree of infection of individual small areas of the locality;
3. Stronger infection of the population, living and non-living nature [1], [6], [7].

### *C. Influence of the topography of the area*

In some cases, the topography of the area can significantly influence the nature of the spread of radioactive contamination that occurred as a result of a nuclear accident or a nuclear explosion on the surface of the earth.

On a flat area, such as the terrain with a slope of no more than 10°, the influence of the relief on the spread of radioactive contamination and the change of the radioactive background is insignificant and can be neglected. Such a character of the relief is characteristic of the central part of Southern Bulgaria, namely the Upper Thracian lowland.

Characteristic of the hilly area is the presence of hills with a height of up to 200 m and with slopes greater than 10°, ravines, slopes and other sharp folds of the area. When spreading in such an area, the front of radioactive contamination is reflected from the front (facing the accident or explosion) slopes of the hills, passes over them and to the side, enters ravines and slopes. The predominant part of Northern Bulgaria is of this type - the Danube Plain and the Ludogorie.

The increase in pressure on the front slopes of hills and ravines depends on their slope and on the intensity of the change of radioactive rays, particles and isotopes in the atmosphere and is determined by a special schedule. The pressure in the shock wave of the reverse slopes is determined by the graph. These graphs are available to the competent authorities, who are the first to fight to reduce the impact of radioactive contamination on people and infrastructure. This is characteristic of the transition from the Danube Plain to Stara Planina or the Pre-Balkans.

Behind hills and elevations with slope inclination greater than 20°, a zone of increased pressure is observed, the length of which is equal to 3–4 heights of the hill [3]. The pressure in this zone is 10-20% higher than the pressure in the passing shock wave. The front of the shock wave on the reverse slopes is slightly disturbed. The time to increase the pressure to the maximum can reach 0.01-0.05 s. At the bottom of deep depressions and ravines with steep slopes and a long length, the orientation of which coincides with the direction of propagation of the shock wave, the pressure is 10-20% higher than on the surface. This relief is characteristic of the greater part of Bulgaria, due to the presence of mountainous sections, although a large part of them are below 2000 meters above sea level.

In a mountainous area, the influence of the relief is more pronounced than in a hilly area.

#### *D. Influence of other meteorological elements*

Air density, aerosol concentration, atmospheric pressure, air and soil temperature also affect the rate of change of the natural radiation background after a nuclear accident or other action that is accompanied by radioactive radiation, but their influence is very small and therefore when determining the radiation situation, they are not taken into account. Bulgaria is located in South-Eastern Europe, it is characterized by a moderate climate and there are no anomalies in the presence of abnormal amounts of the components of the atmospheric air at different heights above the earth's surface [2], [8], [9].

### III. RESULTS AND DISCUSSION

The analysis was made on the basis of detailed statistical data on the direction and strength of the wind and air currents over the territory of Bulgaria during the last 40 years after 1985 from the database of the National Institute of Meteorology and Hydrology (NIMH) at the Bulgarian Academy of Sciences (BAS).

In addition to the daily data for the period after 2014, generalized values for the direction and strength of the winds were used, both near the border areas with neighboring countries and over the territory of our entire country. Here, data for a period of 30 years is used, which is quite sufficient to capture the trends in the change of the atmospheric masses and the adjacent water and land surfaces. I must point out that the tracking of air masses over the last 30 years only gives us the trends and the main directions of movement, but as we all know these processes are too dynamic and do not obey cyclical uniform repeatability and predictability. Therefore, at the same time as the in-depth research and data processing, we must not stop the constant monitoring of our environment and its parameters. Over the past 3 years, a change in the direction of movement of air masses has been noticed in some of the studied points, with significant values - Elhovo, General Toshevo and others. Of particular interest to us are the changes in the direction of the movement of air currents in the border regions, near which there are nuclear facilities,

and this applies most strongly to the cities along the Danube River and the region of North-Eastern Bulgaria.

This is explained by the fact of the presence of our Kozloduy NPP, the working site of the planned Belene NPP and Cerna Voda NPP on the territory of Romania, which is 40 kilometers from the border with Bulgaria.

TABLE 1. WIND FREQUENCY IN 8 DIRECTIONS AND AVERAGE SPEED IN THE CORRESPONDING DIRECTION FOR THE PERIOD 1992 - 2022 FOR THE AREA OF THE TOWN OF SILISTRA

Wind direction	N	NE	E	SE	S	SW	W	NW
with wind, %	6.2	14.1	7.1	3.8	5.9	8.2	15.6	7.6
no wind, %	9.0	20.7	10.3	5.6	8.6	11.9	22.8	11.1
V, (m/s)	4.7	4.4	2.6	2.9	3.6	3.4	3.8	3.0

Table 1 shows that the main wind direction in this region is west and northeast. Northeast of Silistra is the Cerna Voda NPP, and it is from there that 20% of the winds originate. Adding in the nearby northerly and easterly winds, it turns out that more than 40% of the winds in this area would help increase radioactive contamination in the event of a nuclear accident in our neighboring country. This is a prerequisite for us to monitor both the radiation situation around the Chrna Voda NPP, as well as the meteorological situation and, in particular, the movement of air masses in this region. Here, the wind speed must be taken into account when assessing the situation. Table 1 clearly shows that the northeast wind has the highest speed - more than 4.4 m/s, with a higher speed only the pure north wind - 4.7 m/s.

TABLE 2. WIND FREQUENCY IN 8 DIRECTIONS AND AVERAGE SPEED IN THE CORRESPONDING DIRECTION FOR 2022 FOR THE AREA OF THE TOWN OF SILISTRA

Wind direction	N	NE	E	SE	S	SW	W	NW
with wind, %	9.1	20.7	9.0	2.9	4.6	7.0	11.5	5.3
no wind, %	13.0	29.6	12.9	4.2	6.4	10.0	16.4	7.5
V, (m/s)	4.3	3.6	2.4	2.5	2.3	2.6	3.2	3.1

Table 2 shows the similar study, but taken only for the year 2022. Here the trend with the prevailing direction of the winds is even more clearly outlined - almost 30% of the days with wind it was from the northeast and when adding the north and east winds, more than half of the windy days were predominantly from Romania and more specifically from NPP. This shows us how necessary the functioning of

the systems for monitoring the radiation situation and meteorological forecasts is mainly with preventive activities.

The wind roses in other border regions of Bulgaria, which are located next to potential sources of radiation pollution, are of interest, but due to the limited volume of the report, I will present them in detail in another development. Similar are the results obtained in Svishtov, Kozloduy and Vidin, which are located along the Danube River and are respectively located east, next to and west of the Kozloduy NPP. Predominantly, the winds are westerly and are along the Danube River, with 33% being purely westerly and another 12-16% northwesterly.

In parallel with the national automated system for continuous control of the radiation gamma background in the Ministry of Environment and Water, in the National Institute of Meteorology and Hydrology at the Bulgarian Academy of Sciences, a system for forecasting the spread of radioactive contamination in the event of a major nuclear accident in the Northern Hemisphere region works on Earth, where more than 95% of the working nuclear power plants on our planet are located. This system, which is known only to some narrow specialists in the field of radiation protection, shows us in real time the distribution of air masses and their movement in time. It presents the results of the operational calculation of prognostic trajectories from certain nuclear power plants located in the region of Europe and the Northern Hemisphere. The stations are divided into groups for greater visibility of the results, and they are selected so that the movement of the atmospheric currents can be clearly seen and there is a good resolution between the individual stations. Each of the pictures shows the trajectories of the arranged NPPs, grouped into 5 groups. Three trajectories corresponding to three ejection heights start from each station:

- 100 m - red color;
- 300 m - pink color;
- 1000 m - green color.

The starting moment of each trajectory is the synoptic time (0 or 12 hours GMT), and the points that the ejected particles will reach after 12, 24, 36,.....72 hours are marked with the corresponding colored points on each trajectory. The locations of the plants are indicated by an asterisk and the numbers correspond to those in the list shown in Table 2 [2], [4].

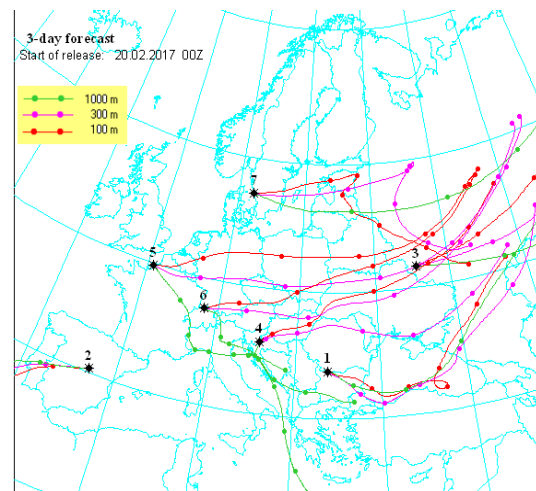
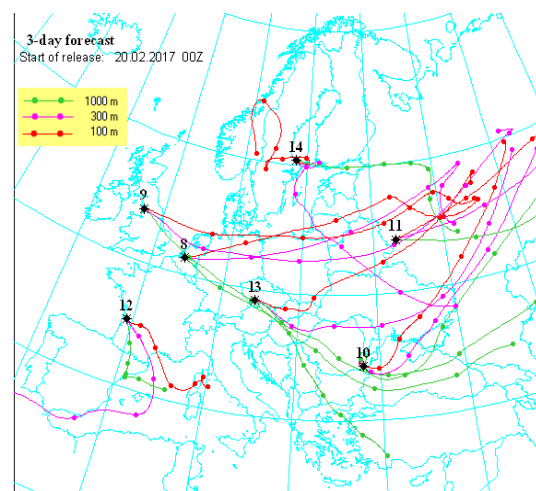


Figure 1a. Three-day forecast distribution of air currents in a suspected nuclear accident at major nuclear power plants in Europe.

When analyzing the results of the forecast movements of the air masses and the distribution of the radioactive particles as a result, it is observed that, in addition to the Kozloduy NPP and the Chernobyl NPP, which is located close to Bulgaria, at different time intervals, radioactive contamination can also occur in result of an accident at the Zaporizhzhia NPP, Ukraine; Kursk NPP, Russia; South Ukraine NPP, Ukraine; Rovno NPP, Ukraine; Paks NPP, Hungary; Leningrad NPP, Russia; Philippsberg NPP, Germany and others. The nuclear power plants are listed in descending order of possible impact on the air, water and soil of Bulgaria as a result of a radiation accident. The results of February 20 for the air currents at a height of 100, 300 and 1000 meters above sea level are shown in Fig.1. From the actual results of the movement of air masses at different altitudes, according to NIMH data, it can be seen that these processes are very dynamic and on each of the three days the impact of a possible nuclear accident in different points of Europe will be quite heterogeneous. This confirms that it is necessary to continuously monitor the radiation background, the movement of air masses and the state of the main nuclear facilities [2], [10], [11], [12].



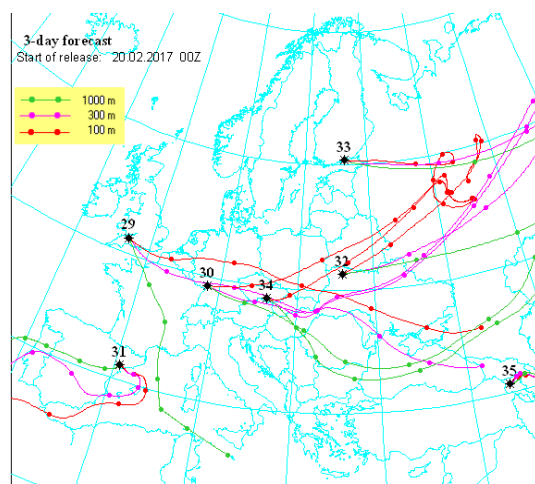
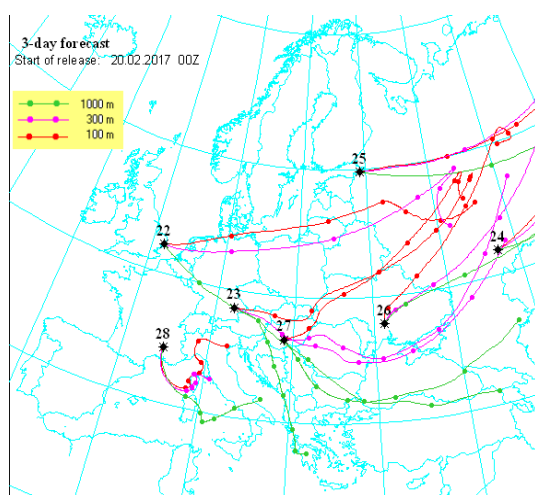
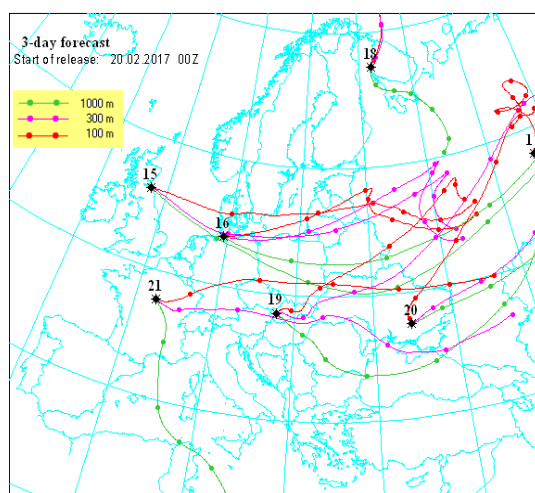


Figure 1 b, c, d, e. Three-day forecast distribution of air currents in a suspected nuclear accident at major nuclear power plants in Europe.

TABLE 3. VISUALIZATION OF THE FORECAST AIR CURRENTS IN CASE OF AN ACCIDENT AT THE NPP

Map №1	Map №2	Map №3	Map №4	Map №5
1. Kozloduy, BG	8. Doeller, BE	15. Ternes, UK	22. Sisswell, UK	29. Hinkley Point, UK
2. Jose Cabreras, ES	9. Hashem, UK	16. Brockdorf, DE	23. Isar, DE	30. Philippsburg, DE
3. Kursk, RU	10. Cerna Voda, RO	17. Beloyarski, RU	24. Balakovo, RU	31. Asko, ES
4. Crush, SL	11. Smolensk, RU	18. Kola, RU	25. Leningrad, RU	32. Rivne, UA
5. Paluel, FR	12. Blaise, FR	19. Bohunice, SQ	26. South Ukraine, UA	33. Loviza, FI
6. Labshad, CH	13. Temelin, CZ	20. Zaporozhye, UA	27. Paksh, HU	34. Dukovi, CZ
7. Ringgils, SE	14. Forsmark, SE	21. Dampier, FR	28. Tricastin, FR	35. Armenia, AR

Figure 1 shows the predicted movements of air masses up to 72 hours after a possible accident in 35 plants from Europe. The points on the drawn trajectories in different colors show the location of the atmospheric particles during 12 hours or how the front will spread and what its position will be during the specified interval. The data is for 20.02., and it can be seen from the cartographic drawings that the dynamics are too great and the direction of movement is very different. This emerges even more clearly when consistently monitoring the data over time, where certain trends in the movement of air masses can be detected. Some sites that are most interesting for Bulgaria on the specified date are - Kozloduy NPP, Leibstadt NPP Switzerland, Doelr NPP Belgium, Temelin NPP Czech Republic, Paksh NPP Hungary, Dukovany NPP Slovakia and others almost in the opposite direction [5], [13], [14]. From intermediate data, inconstancy in wind directions and speeds can be observed in different parts of Europe and in Bulgaria in particular. Due to the volume of the report, I cannot present more complete data, which are available and will be summarized and presented in other reports. Data on the movement of atmospheric currents must be continuously monitored in order to be able to respond promptly in the event of possible radioactive contamination as a result of a nuclear accident in one of Europe's nuclear power plants [1], [15], [16], [17].

We must not ignore the difference in the movement of air parts at different heights from the earth's surface. The figures clearly show the differences in the direction of propagation and the length of the traveled path. This suggests that the movement of air masses at different altitudes must be known in order to react adequately. It is not enough to know only the surface winds, but it is necessary to know the movement of air masses at different heights above the earth's crust in order to be able to predict the spread of radioactive contamination and take effective preventive and follow-up actions. In view of the military actions on the territory of Ukraine in the last year, 4 nuclear

power plants, which are located on its territory, are of particular interest. Particular attention should be paid to the Zaporizhia NPP, in the immediate vicinity of which military operations are being conducted and numerous provocations have been carried out and numerous fake news have been generated. And the operation of any nuclear power plant is an extremely responsible activity and in no case should it be allowed to violate the normal technological and operational regime.

#### IV. CONCLUSIONS

1. Air currents exert the greatest influence of the meteorological elements on a possible change of the natural radioactive background and spread of radioactive particles during a nuclear accident in some of the nuclear power plants in Europe. The availability of data for previous years enables us to make predictions about possible impact and take preventive measures to limit the impact.

2. The topography of the area also has a significant influence on the natural radioactive background and its change in the case of radioactive contamination. A good knowledge of the surrounding area significantly increases the possibilities for adequate behavior and limiting the impact in the event of an accident or emergency.

3. Air currents are a very dynamic process both over time and at different heights above the earth's surface. This change must be continuously monitored in order to be able to react promptly and adequately in the event of a nuclear accident. It is desirable to use forecasts for air transformations at different heights above the earth's surface.

4. The state of the natural radioactive background over Bulgaria in different periods of time is influenced by NPPs located in different parts of Europe, but the Zaporizhia NPP, Ukraine; Kursk NPP, Russia; South Ukraine NPP, Ukraine; Rovno NPP, Ukraine; Paks NPP, Hungary; Leningrad NPP, Russia; Philipsberg NPP, Germany has the biggest impact according to data from the last 3 years. The situation around NPPs, which are located in a territory where military operations are taking place, must be monitored with great care.

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