LOCALIZATION OF MAJOR RADIONUCLIDE CONTAMINATION SOURCES IN THE CITY OF KHARKOV AND KHARKOV REGION AFTER THE CHERNOBYL ACCIDENT

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Analysis of the Chernobyl accident impact on the ecological situation in the Kharkov region and in the city of Kharkov is presented. The motion of air masses over Kharkov and the Kharkov region has been analyzed; maps of air-flow trajectories have been drawn, and the distribution of radionuclide particles in the study area after the Chernobyl accident in 1986 has been determined. The data processing technique is proposed for detecting radionuclide contamination sources.

INTRODUCTION

The study of radioactive contamination of the environment and identification of emission sources are the central problems in current research. The interest in the radiation environment reconstruction is caused by the necessity of investigating the level and consequences of radioactive contamination of the Ukraine territory as a result of the Chernobyl accident impact and the operation of industrial complex facilities.

The issue of the impact of nuclear power industry on the ecology should be considered comprehensively, with due account for the location of NPPs and other technogenic sources of contamination, both local and regional.

For ecological control over NPP releases, methods have been developed to determine the contamination source from the relationship of pollutants comprised in air (or soil) samples taken in the study area. To determine the contamination sources, mathematical methods involving the factor analysis, and resting on the inverse problem solution, are used. Given a certain number of measuring points, these methods enable one to reconstruct the parameters of contamination sources and to clear up the territorial pollution localization. For polluted air spread modeling one of the factor-analysis methods, namely the method of receptor modeling is used. The method employs chemical and physical characteristics of gases and particles, which were measured on both the source and the receptor to identify the presence of the source, and if there is any, to determine its contribution to the receptor concentration [1-3].

The aim of the present work has been to apply the developed receptor modeling technique for identifying the source of radioactive contamination of the Kharkov region from the measurements of air and soil samples taken inside Kharkov and its region after the Chernobyl accident.

1. METHODS OF POLLUTANT SOURCE IDENTIFICATION

To determine the main factors that had an impact on the radioactive air and soil contamination in the Kharkov region in 1986, the receptor modeling technique has been used. The method makes it possible to determine both the characteristics of contamination sources, and the contribution of individual sources to particular samples. The problem of localization of contamination sources themselves is solved as a result of the analysis of contaminant-transporting air mass trajectories and the analysis of fallout.

To investigate the spatial propagation of contaminants, the program HYSPLIT-4 [5] was used. The program permits modeling of the process of formation and propagation of an aerial effluent cloud from the given source. The input meteorological data required for HYSPLIT-4 were taken from the meteorological model calculations based on the in-situ measurement data.

2. CHARACTERIZATION OF THE SUBJECT OF INVESTIGATION

The Kharkov region has a high-power well-developed economic pattern. The regional industry specializes in mechanical engineering, building materials industry, gas industry, light industry, food industry, etc. In the region, there is one of the largest in Ukraine Zmiyov thermal station (ZTS), which is situated near the settlement Komsomol’skoye, 55 km away from Kharkov. Its electrical capacity at present is 2200 MW. Among most significant branches of industry, one can mention natural gas recovery and cement production.

As soon as the information on the Chernobyl accident appeared in press, the KIPT scientists began monitoring the concentration of radionuclides in the open air, and also, in the fallout in the area of Kharkov and the Kharkov region. Systematic monitoring of radiological environment in the course of May, June and July, as well as the radiation analysis permitted us to estimate average levels of alpha-, beta- and gamma-radiations [6].

3. RESEARCH RESULTS

The relationship between the Chernobyl accident and the deterioration of radiation environment in the Kharkov region and in the city of Kharkov has been investigated.

The greatest distance from the Chernobyl NPP was covered by ¹⁰⁹Ru, ¹⁰⁶Ru, ¹³¹I, ¹³³I, ¹³²Te, ¹³⁴Cs, ¹³⁷Cs.
radionuclides, and also, by radioactive inert gases as components of vapor-aerosol, gas mixtures and particles of submicron size. This just caused the formation of rather great in size radioactive “cloudings” over the territory of the majority of European countries.

During the time that has passed since the accident, not only short-lived radionuclides, but also medium-lived radionuclides have fully decayed. The dose rate of external irradiation has considerably (by several orders of magnitude) decreased. Practically, only long-lived radionuclides of cesium, strontium and transuranium elements remained in the environment [7].

In Ukraine, the density of $^{137}$Cs contamination of Chernobyl origin on the contaminated territories (about 48 400 km$^2$) was registered to be higher than 37 kBq/m$^2$. More than 1.4 million of people live on these territories, mainly in rural agricultural localities. Fig. 1 shows the soil contamination with $^{137}$Cs in the northeast of Ukraine.

To determine the ecological situation in the region, air and soil radioactivity measurements were used. The measured data have pointed to the radiation situation change in the Kharkov region in the 2$^{nd}$ quarter of 1986. Four days after the accident, i.e., on 30 April, radionuclides, i.e., release products from the damaged unit, started coming to the air. A wide range of radionuclides was registered in air, in solid and liquid atmospheric fallouts. Two peaks in the activity variation with time (30 April, and 10 May) were observed. A less pronounced peak was registered on 13 May. The maximum excess of the exposure dose in air over the stationary natural radioactivity background in Kharkov was determined to be 5.3 times [6].

For determining the ecological situation in Kharkov, we have used the measured data on the volumetric activity of five radionuclides in air. The measurements were made on 28.04 to 7-06, 1986 (Table). The major radionuclides that affected the radiation environment in the study area were identified as: $^{132}$Te ($T_{1/2} = 3.26$ days), $^{106}$Ru ($T_{1/2} = 39.3$ days), $^{134}$Cs ($T_{1/2} = 2.06$ years) and $^{137}$Cs ($T_{1/2} = 30$ years), $^{134}$I ($T_{1/2} = 8.04$ days). The data were processed with the use of the program PMF v3.0.2.2 [8].

Volumetric activity of radionuclides $A_v$ in air, April-June 1986 (Bq/m$^3$)

<table>
<thead>
<tr>
<th>Date</th>
<th>$^{132}$Te</th>
<th>$^{134}$I</th>
<th>$^{106}$Ru</th>
<th>$^{134}$Cs</th>
<th>$^{137}$Cs</th>
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During active release from the reactor (from 26 April to 5 May, 1986) the wind around Chernobyl changed its direction by 360° with the result that radioactive releases (of different radionuclide composition on different days) covered a great area (Fig. 2). The travel of air masses comprising radioactive aerosols, mainly northwards and westwards from the Chernobyl NPP, contributed to a relatively more favorable radiation situation in Kharkov. The $^{131}$I concentration was determined to be 34 Bq/m$^3$, and the maximum alpha- and beta-activities in the fallouts were ~0.8 Bq/m$^2$ per day and 700 Bq/m$^2$ per day, respectively. By the end of June, these activities practically regained their stationary values, with some insignificant excesses being due to the presence of small amounts of long-lived isotopes [6].

Relying on the data obtained, we have made a spatial modeling of $^{137}$Cs and $^{131}$I distributions within the Kharkov region. The territory is restricted by the coordinates: 49.15...50.35 north latitude and 35.00...37.80 east longitude.
Fig. 2. Stages of radioactive Chernobyl release formation in the first days after the accident:
1 – 27 April, 12 h (Z time); 2 – 29 April, 12 h; 3 – 1 May, 12h; 4 – 5 May, 0 h

As a result, air-flow trajectories during the first week after the accident were determined. They confirm the fact of radionuclide intake by the Kharkov region. The map (Fig. 3.) shows the $^{137}$Cs and $^{131}$I concentrations in the Kharkov region registered from 28.04.86 to 1.05.86. The radionuclide concentrations are given in mass units.

It can be seen in the figure that the radioactive emissions for the first four days were brought to the Kharkov region, and mostly the north-eastern part of the region was subjected to contamination. This is confirmed by the studies carried out in 1986 [6].

Fig. 3. $^{137}$Cs and $^{131}$I concentrations in the air from 28.04.86, 6 h to 1.05.86 6h within the Kharkov region

Radioactive particle distribution in the air over the Kharkov region territory is depicted in Fig. 4. The radioactive particles are found in the surface layer of the atmosphere (up to 1 km). The red contour line delineates the boundaries of the Kharkov region. It can be seen that the intensity of radioactive contamination of air in this region is substantially lower in comparison with the trace tail stretching away to the Volga region and further. On evidence derived from the studies in 1986, in the period from 30 April to 1 May, the peak value of the volumetric activity of $^{131}$I in Kharkov was several times higher than the maximum allowable concentration for category B people (restricted range) [6].
Thus, on 30 April, 1986, in the city of Kharkov there was a rise in the airborne radioactivity and in the radioactivity of precipitation.

In 1991, the NSC KIPT team performed measurements of equivalent gamma-radiation dose rates at a height of 1 m, above and below ground in the city of Kharkov and in the Kharkov region; and also, the soil contamination with $^{137}$Cs in the region was measured [9].

The measurements brought the following results. The average equivalent dose rate, measured in the soil at a depth of 2 to 5 cm around the periphery of the city, was determined to be $(0.139 \pm 0.1) \mu$Sv/h. The soil contamination with $^{137}$Cs was mainly contributed by both stratospheric fallouts of nuclear burst products and Chernobyl NPP contaminant fallouts. Prior to the Chernobyl accident, the soil contamination within Kharkov and its region was estimated to be about $0.22$ Bq/cm$^2$. The Chernobyl NPP accident caused a 4-fold increase in the average soil contamination of the city [9].

The analysis of the measured equivalent dose rates in the soil has shown that in the Kharkov region there are several localities displaying a relatively high radioactivity. This is the locality between the towns of Zmiyov, Chuguyev and Balakleya; the locality between the towns of Izyum and Barvenkovo; the south-western part of the Kharkov region, and also all the territory close to the northern boundary of the region.

The Zmievskaya thermal power plant (TPP), which is located between the towns of Zmiyov and Balakleya, is another contributor to the radiation background buildup.

The black coal-fired TPPs produce one third of all contaminants in the surface layer of the atmosphere. Their releases comprise the components having toxic effects on human health. These are sulphur dioxide, nitrogen oxides, carbon oxides, and also, coal fly ash. The ash of dry coal has displayed the presence of heavy elements and microelements, which are characterized by noncarcinogenic (Co, V, Cu, Zn, Ni) and carcinogenic (Cr, Ni, Cd, As, Be) effects, and also, natural radionuclides ($^{226}$Ra, $^{210}$Pb, $^{208}$Th) [10].

The soil, most severely contaminated with $^{137}$Cs, is found on the territory between the towns of Zmiyov, Chuguyev, Balakleya, and in the locality being to the north-eastward from Kharkov (Fig. 5). The enhanced dose rates in soil were detected just on the same territories. It should be also noted that there are six localities, the contamination of which ranges from 0.15 to 0.3 Bq/cm$^2$. This points to the fact that in some parts of the region there were practically no fallouts of $^{137}$Cs in 1986.
Thus, the main radionuclides and contamination sources that had an impact on the radiation environment in the study area were found out; air-flow trajectories inside the Kharkov region were determined, as well as maps of $^{137}$Cs and $^{131}$I radionuclide propagation after the Chernobyl accident of 1986 were drawn. The treatment of the data obtained has suggested the conclusion that the radionuclide content in the free air of the city of Kharkov and the Kharkov region increased as a result of the Chernobyl NPP accident.

CONCLUSIONS

Analysis of radionuclide propagation inside Ukraine during the first week after the Chernobyl NPP accident, as well as the analysis of the accident impact on the ecological situation in the Kharkov region have been presented. The main radionuclides and contamination sources have been identified.

The spatial distribution of contaminants on the territory of the Kharkov region in 1986 has been reconstructed, and the fact has been confirmed that the Chernobyl NPP accident had caused a several-fold increase in the radionuclide content in both the atmospheric air and the soil of the given region. It has been shown that there is the locality with enhanced radioactivity being due to Zmiyov TPP operation.

The present investigation is the validation of the method of contamination source identification from the measurements of radionuclide concentration and the analysis of air-mass trajectories in the study area.

REFERENCES


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Представлен аналіз впливу чорнобильської аварії на екологічну ситуацію в Харківській області та м. Харкові. Проведено аналіз руху повітряних мас на території м. Харкова та області, отримано карти траєкторій повітряних потоків і розподіл частинок радіонуклідів після аварії на Чорнобильській АЕС у районі дослідження в 1986 р. Пропонується методика обробки даних з виявлення джерел забруднення радіонуклідами.