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AIRBORNE GAMMA SPECTROMETRIC SURVEY IN THE CHERNOBYL EXCLUSION ZONE BASED ON OKTOKOPTER UAV TYPE

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The results of field studies of radioactive contamination condition of RWTSP "Red Forest" and "Neftebaza" in the Chernobyl zone, obtained by the authors in June 2015 are represented. The technique of detection of local inhomogeneities on the soil surface without contrasting borders by airborne gamma spectrometry from the board of oktokopter UAV type is worked through. The technique of searching and contouring of hidden burial of radioactive waste is practiced.

INTRODUCTION

As a result of the Chernobyl disaster a significant amount of radioactive substances were emitted to the atmosphere that led to the radioactive contamination of large areas. The territoies directly adjacent to the Chernobyl nuclear power plant are characterized by high levels of radioactive contamination. At present these areas are characterized by a high density of surface contamination and contain the whole range of nuclear fuel radionuclides: ^{137}Cs, ^{90}Sr, ^{154}Eu, ^{155}Eu, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Am. High amount of radioactive waste temporary storage places (RWTSP) are also the secondary sources of radioactive pollution.

The RWTSP have been constructed in the years following the Chernobyl accident to prevent the further spread of radioactive substances in the environment. They contain mainly radioactive waste and soil from abandoned and demolished villages and probably some contaminated machinery and equipment used in the liquidation of accident.

There are two RWTSP types: consists of an assemblage of trenches (below-ground) and clamps (above ground). Currently clamps and trenches can be inconspicuous because of land subsidence and covering them with thick vegetation. Total number of trenches and clamps in the target areas is estimated being in the range of 800 to 1,000. Dimensions of trenches and clamps are in the range of several metres to 10s of metres in width and length. Height of clamps may be up to 2 metres (though also less), depth of trenches is probably some 2 metres.

The purpose of this research is to improve the information technology of rapid detection (search, localization, identification) and evaluation of the actual radiation situation during air reconnaissance.

To achieve formulated objectives it was necessary to solve the following tasks: to improve methods of detection of local inhomogeneities of radioactive contamination in the ground, search and contouring of hidden burials; conduct detailed exploration of defined areas for hidden burials contouring; make topographic diagram of the burials; determine the levels of radioactive contamination on the surface of the surveyed sites.

The work was performed within the project: "Investigation of radioactive waste burial and temporary storage sites in the Chernobyl Exclusion Zone". Features of created methods and tools are demonstrated on the example of the survey of areas RWTSP "Red Forest" and "Neftebaza".

EXPERIMENTAL PART

To achieve the objectives the new airborne gamma spectrometric complex (SC) "ASPEK" based on the UAV of the oktokopter type, which was developed by a team of authors in the department of nuclear phisics tecnologies of the Institute of Environmental Geochemistry of NASU, was used.

SC "ASPEK" consists of onboard and ground parts. Onboard part of the SC is intended for performing the measurements and collection of gamma radiation spectra, geographically referenced to the survey area, altitude, pressure and temperature. The ground part of SC is a computer system, which is designed for spectrometric information processing, maintenance of the database coming from the remote set, mapping of zones of radioactive contamination of the area, determination of spectral composition and the exposure dose of gamma radiation, search and determination of coordinates of point gamma radiation sources, as well as displaying, map diagrams of the radiation situation plotting, documenation of the radiation monitoring data.

Spectrometer (basic elementof measurement system) uses five blocks of gamma radiation detection BDEG-04. Detecting part of block is a scintillator, which performs on a base of NaI(Tl) crystal 63x63 mm. All spectrometers work synchronously. The signals of all detectors are summarized. This composite block has a mass of about 7.5 kg and allows to programmatically connect or disconnect each BDEG-04, depending on the required sensitivity. To eliminate the distortion of the measured distribution at high loads (high activity), the system disables the detectors sequentially. This operation is necessary to control the statistical load of the detection system (imp/sec).

With this aerogammaspectrometer surveys of RWTSP "Red Forest" and "Neftebaza" of Chernobyl exclusion zone have been conducted. The flights were performed in parallel tacks. The distance between the tacks was – 100 m, altitude – 30 m, the average speed of flight – 5 m/s. Spectrometric information was accumulated in the form of an array of “amplitude-time”, which is further was converted to the hardware spectrum. The exposure time was – 1 s. Data gridding was carried out on radio altimeter readings and GPS-receiver.

As a result of the flight after the primary measurement data processing were formed survey lines – text table with coordinate values columns in the form of latitude and longitude (WGS-84), values of the total number of pulses of gamma radiation, the number of pulses of gamma rays in the “window” of cesium-137, and column of conversion values with the count rate (counts/s) in an unit of equivalent dose μSv [1]

An example of obtained during the flight primary measurement data is shown in Figs. 1, 2.

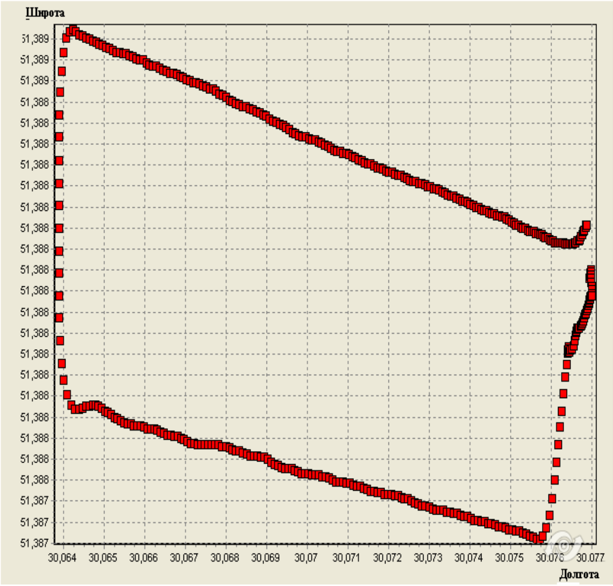

Fig. 1. Example of a survey line

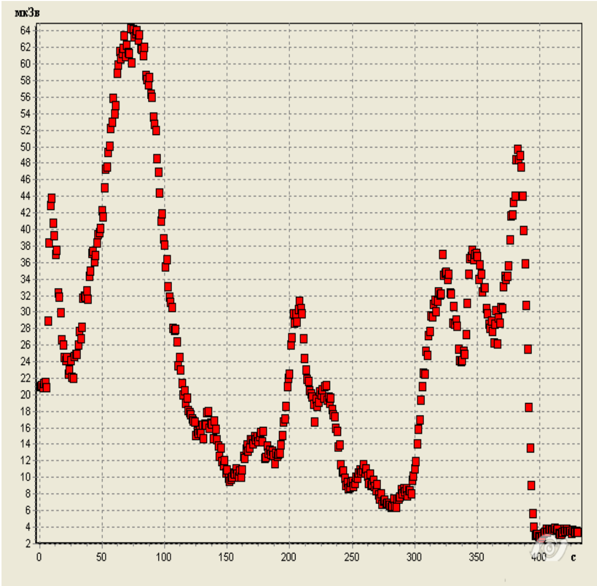

Fig. 2. Change of the integral activity on the route survey line

Original method was applied for creating maps and schemas for contaminated sites, which includes several key steps:

• initial assessment of the investigated area using GIS;

• delimitation survey and their application on the map;

• determination of the size (pitch) grid;

• map diagrams construction.

Evaluation of the territory includes:

• determination of the radiation situation on the territory under investigation from the available data;

• identifying local areas with high levels of radioactive contamination;

• preparation of various cartographic materials of the survey area.

For each conditional section of “Neftebaza”» and “Red Forest” from separated «tacks» were grouped general data files, in which longitude and latitude WGS-84 were transformed in a system of rectangular coordinates UTM WGS-84, zone 36N and additionally to the Gauss-Kruger system (Pulkovo-42, zone 6). This operation was necessary for the convenience of construction of measurement results maps and their combining with the existing topography tablets and other data at the investigated areas. In addition, the radiation intensity values were converted to surface activity normalized to the height of 1 m.

The surface activity of radionuclide R, by the data of onboard measuring, is determinated in following way

$$A_R = (n_R - n_{\Phi R}) \cdot \frac{1}{S_R}, \qquad (1)$$

where A_R – surface activity of radionuclide R; S_R - summary sensitivity of measuring channels, participated in evaluations, on determined height of flight H_f (calibration characteristic); n_R – summarycounting rate in energetic window of radionuclide R, reduced to the height H_f,; n_{cpR} - summary intensity of background radiation, by all measuring channels, in energetic window of radionuclide R.

The total sensitivity of the spectrometer S_R depends from errors in evaluations, at a calibration playgrounds with sufficient degree of accuracy, cut allows following dependence for S_R:

$$S_R = \frac{n_R^{cal} - n_{\phi R}}{A_R^{cal}}, \qquad (2)$$

where A_r^{cal} - activity value, of radionuclide R on a calibration playgrounds; n_R^{cal} - summary value of counting rate in energetic windows of radionuclide R, at changing on height H_f during the calibration.

So:

$$A_R = \frac{A_R^{cal}}{n_R^{cal} - n_{\phi R}} \cdot (n_R - n_{\phi R}), \qquad (3)$$

Hence it follows, that activity of radionuclide R A_R, is are function of few variables:

$$A_R = f(A_R^{cal}, n_R^{cal}, n_{\phi R}^{cal}, n_{\phi R}), \qquad (4)$$

At the same time, n_R^{cal} and n_R is a exponential functions of flying height:

$$n_R^{cal} = N_R^{cal}(0) \cdot \exp(-\mu_R \cdot H), \qquad (5)$$

$$n_R = N_R(0) \cdot \exp(\mu_R \cdot H), \qquad (6)$$

where μ_R – a coefficient of linear attenuation with the attitude for radionuclide R_i; $N_R(0)$ – calculated spectrometer readings on the surface of the calibration platform of the radionuclide R.

Main parameters, providing influence on a measuring errors, is are temperature (t) and air pressure (P), because they significantly determinate value of air density, and as follows, value of attenuation coefficient, and indicators of onboard spectrometers during flying height changing.

Technical instructions of IAEA recommends considering influence of temperature and pressure, by bringing of measured values of heights to the uniform conditions [2]:

$$H_{\text{пр}} = H_{\text{изм}} \cdot \frac{T_0}{T_0+t} \cdot \frac{P_{\text{изм}}}{P_0}, \quad \textbf{(7)}$$

where $H_{\text{пр}}$ - given height value (m); T_o = 273 °C – absolute temperature; t – current value of temperature of air, overboard the aircraft, by Chelsium; $P_{\text{изм.}}$ – air pressure overboard of aircraft, during evaluations conduction (kPa); $P_o = 10^5$ kPa – air pressure around Earth surface; $H_{\text{изм}}$ – values of flying height, measured by measuring height channel.

The technology of computer mapping provides operation of preliminary conversion of initial observations with irregular coordinates to the data on a regular rectangular or square grid. The actual survey was done on profiles with a step ~ 5 m and length between the core ~ 100 m, so, taking into account the necessary of detailing and correctness of the constructions, as well as on the basis of trial calculations, for the final map was selected regular square with 10x10 m grid (Fig. 3).

To calculate the regular grid matrices "Kriging"-method was used as the most accurate and usable for similar purposes in almost all geographic information systems. As a result of this work, we were drawn schematic maps of pollution in the form of areal pollution with contour interval of equivalent dose of 5 μSv (Fig. 4). For schematic maps plotting and spatial analysis via GIS software ArcGIS for Desktop Basic was used [3].

To define relatively small objects with increased levels of gamma radiation, the maps of local ("high-frequency") component of the observed field with contour interval of equivalent dose of 2 μSv were plotted.

The files for these maps were obtained by subtracting from the original field of matrices of "low-frequency" component. Matrix of "low-frequency" component of the matrix were calculated by averaging the original field "sliding" window to the side of the 200 m (taking into account the distance between the profiles ~ 100 m).

The operation of averaging is to calculate from each node of the original matrix medium value of all units falling into the "window" with a predetermined size:

$$Z_{\text{cp}}(i,j) = \frac{1}{N \cdot M} \sum_{k=i-N/2}^{k=i+N/2} \sum_{l=j-M/2}^{l=j+M/2} Z(k,l), \quad (8)$$

where *i*, *j* – numbers of row, column and of the original calculation matrix; *N*, *M* – the size of the averaging "window" in the matrices nodes (see Fig. 3).

The example that illustrates the preparation of the matrix of local ("high-frequency") component is given in Fig. 4.

This technique of local anomalies highlight is widespread in applied geophysics.

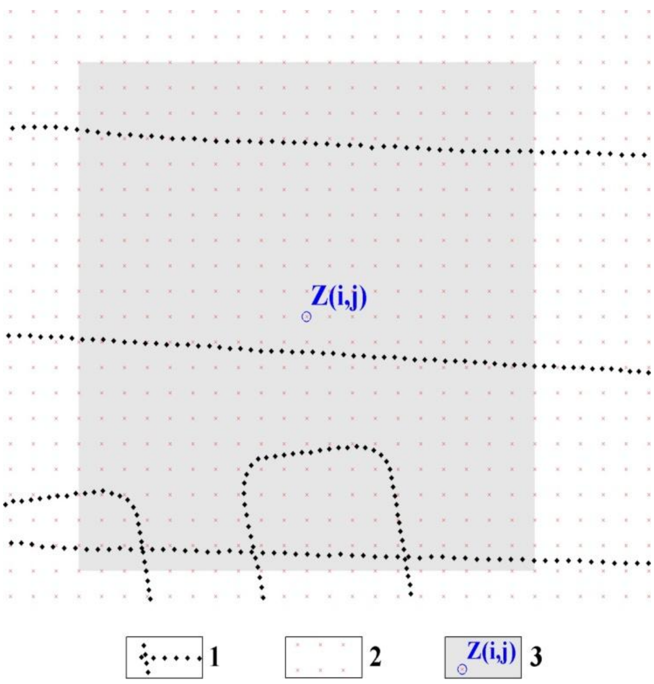

Fig. 3. Fragment of the calculated matrices.
1 – observation points, 2 – nods of settlement matrices
3 – area of averaging "sliding window" and its center

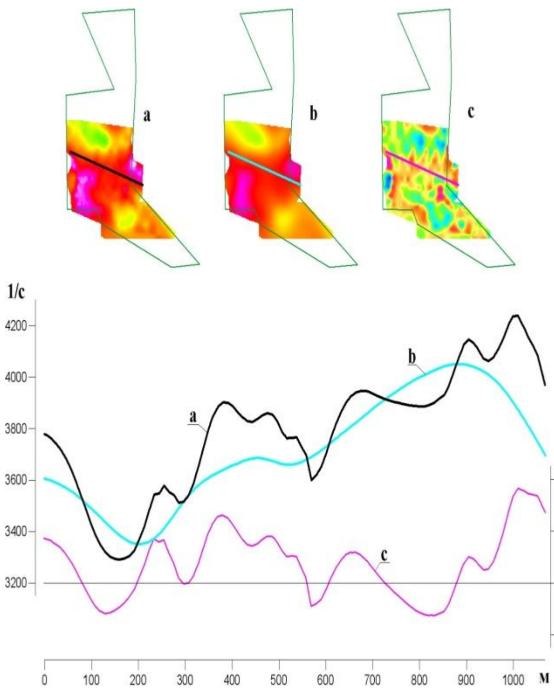

Fig. 4. Graphic of initial (a), average (b) and local component (c) of gamma radiation fields, on area "Red forest". In the top - position of the line graphs at corresponding maps

RESULTS

As a result of processing and analysis of measurement data, obtained by SC UAV "ASPEK", areas with an intensity, that exceeds the total radiation background, have been identified, their coordinates were defined (Fig. 5).

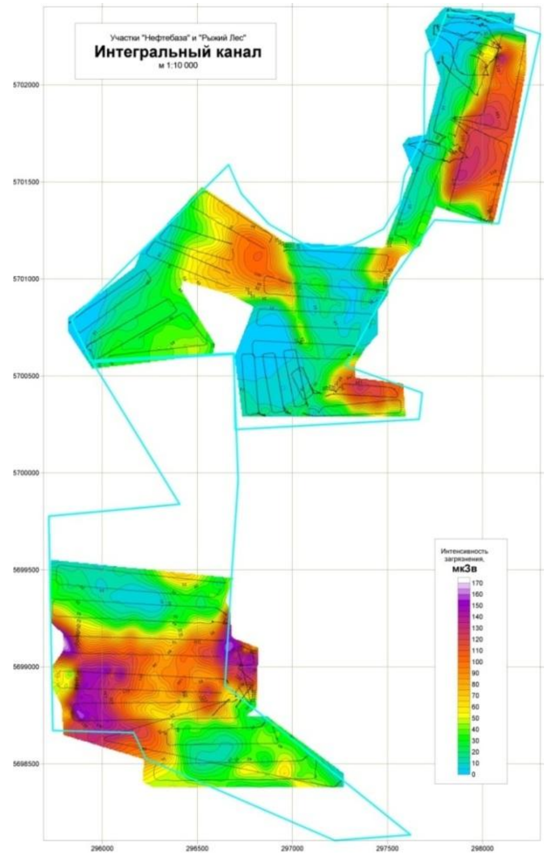

Fig. 5. The surface obtained by interpolation method

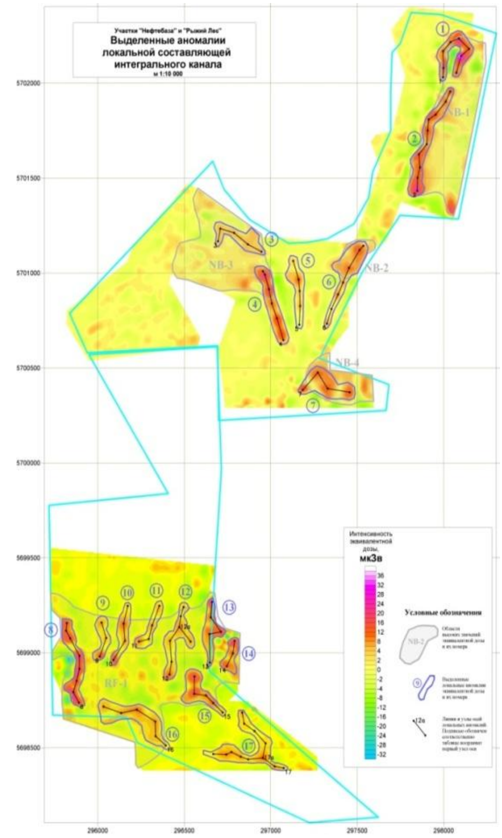

Fig. 6. Areas of high intensity, selected as a result of processing

Revealed local anomalies with high values of equivalent dose

No. of anamaly	Area	Equivalent dose, μSv	Notes
1	«Neftebaza»	18…32	–
2	«Neftebaza»	8…24	Maybe partly false because of the nature of separation technology, as located in a sharply defined border of the "regional" pollution spot
3	«Neftebaza»	4…6	
4	«Neftebaza»	12…20	It has a pronounced linearity in the plan
5	«Neftebaza»	4…10	It has a pronounced linearity in the plan
6	«Neftebaza»	4…14	It has a pronounced linearity in the plan
7	«Neftebaza»	6…14	
8	«Рыжий Лес»	12…24	Maybe partly false because of the nature of separation technology, as located in a sharply defined border of the "regional" pollution spot
9	«Red Forest»	6…14	–
10	«Red Forest»	6…16	–
11	«Red Forest»	6…8	–
12	«Red Forest»	4…8	–
13	«Red Forest»	8…18	–
14	«Red Forest»	10…22	–
15	«Red Forest»	6…18	–
16	«Red Forest»	6…10	–
17	«Red Forest»	6…10	–

The conducted researches show that the levels of radioactive contamination of the surveyed areas significantly exceed the level of background radiation.

Because of the high and thick vegetation present at the surveyed area the flights were conducted at a height of 30 m. The green "mass" of vegetation had made significant distortion into the measurement results (the intensity of the vegetation can not be taken into account during the calibration). Consequently, more accurate results of "scanning" of the earth's surface areas will be available to make only during certain time periods – in the early spring and/or late autumn (when the green cover is missing).

REFERENCES

1. Yu.L. Zabulonov, G.V. Lisichenko, N.V. Makarets. The results of model and field experiments to identify low-intensity radioactive sources [Rezultati modelnih i polevih eksperimentov po viyavleniyu nizkointensivnih istochnikov radoaktyvnogo izlucheniya]. *Collection of scientific works of Institute of modeling problems in the energy sector of NAS of Ukraine*. 2005, N 31, p. 96-100.
2. *A guide to monitoring in nuclear or radiation accidents. IAEA-TECDOC-1092/R*. IAEA, Vienna, 2002.
3. ArcGISforDesktopSoftware**.** [Electronic resource]. Access mode:http://www.esri.com/software/arcgis/about/gis-for-me.

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АЭРОГАММА-СПЕКТРОМЕТРИЧЕСКОЕ ОБСЛЕДОВАНИЕ В ЧЕРНОБЫЛЬСКОЙ ЗОНЕ ОТЧУЖДЕНИЯ НА БАЗЕ БПЛА ТИПА ОКТОКОПТЕР

Ю.Л. Забулонов, В.М. Буртняк, И.О. Золкин

Представлены результаты полевых исследований состояния радиоактивного загрязнения ПВЛРО «Рыжий лес» и «Нефтебаза» в Чернобыльской зоне, полученные авторами в июне 2015 г. Отработаны методика обнаружения локальных неоднородностей на поверхности грунта, не имеющих контрастных границ, посредством аэрогамма-спектрометрии с борта БПЛА типа октокоптер, а также методика поиска и оконтуривания скрытых захоронений радиоактивных отходов.

АЕРОГАММА-СПЕКТРОМЕТРИЧНЕ ОБСТЕЖЕННЯ В ЧОРНОБИЛЬСЬКІЙ ЗОНІ ВІДЧУЖЕННЯ НА БАЗІ БПЛА ТИПУ ОКТОКОПТЕР

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Представлені результати польових досліджень стану радіоактивного забруднення ПТЛРВ «Рудий ліс» і «Нафтобаза» в Чорнобильській зоні отримані авторами в червні 2015 г. Відпрацьована методика виявлення локальних неоднорідностей на поверхні ґрунту, що не мають контрастних границь, методом аерогамма-спектрометрії з борту БПЛА типу октокоптер. Відпрацьовані методики пошуку і оконтурювання прихованих захоронень радіоактивних відходів.