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The Remote Radiation Monitoring of Highly Radioactive Sports in the Chornobyl Exclusion Zone

V. Burtniak[1] · Yu. Zabulonov[1] · M. Stokolos[1] · L. Bulavin[2] · V. Krasnoholovets[3]

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Abstract Innovative measuring equipment named the "GR-Smart System" has been used on-board of an octocopter to analyzing some heavily contaminated areas of the Chornobyl zone. The developed equipment enhances both the sensitivity and the probability of detection of ionizing radiation both high and low activity with limited time of observation and measurement in one single process. The equipment has allowed one to recognize small radioactive spots of high intensity among the areas abundantly contaminated with radioactive isotopes.

Keywords Chornobyl · Contamination · Nuclear waste · Radiation · Octocopter · Mapping

It is important to have detailed information about nuclear radioactive materials, their preservation and treatment especially in areas near nuclear power plants or radioactive waste disposal sites. Remote sensing of environmental pollution from an unmanned aerial vehicle (UAV) allows one to assess the level of contamination, the dynamics of the spread of contamination at a regional scale and transboundary transfer. On-board remote sensing surveying has a number of significant advantages over ground-based and space techniques, which was already demonstrated by several research teams (see, e.g. Refs. [1–8]).

Full automation of aerial vehicle exploration provides information in real time or up to thousands of times faster than land-based methods and the results obtained are characterized by a high reliability and low cost of operations.

Since 1987 the authors have designed and developed several types of airborne gamma-system "R-Navigator" that were used to assess the scale of the accident at the Chornobyl nuclear power plant and radiation mapping of areas contaminated by radioactive substances. The mentioned system completely satisfies all the demands of IAEA [9, 10].

To improve the accuracy of the localization of spatially distributed radioactive sources, new theoretical and methodological foundations for a new technology of space-time analysis of ionization radiation have been developed. This has significantly increased the sensitivity of the airborne gamma-system when looking for local sources. Besides the accuracy and speed of detection of low-level radiative materials and sources of ionizing radiation are also growing. In 1993 with the help of our "R-Navigator System" we conducted numerous surveys of the 30-km Chornobyl exclusion zone for radiation mapping of the territory, localization and delineation of areas contaminated with radioactive substances and the appropriate radioactive contamination map was recorded with an UAV.

However, at high speed and high flight altitude not all factors were taken into account of an UAV of the 1990s. It became obvious that a complex spectrum of radiation and volatility (fluctuation) of the natural background radiation

✉ V. Krasnoholovets
krasnoh@iop.kiev.ua

1 Institute of Environmental Geochemistry under National Academy of Sciences and Ministry for Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, 34-a Acad. Palladin Ave., UA-03680, Kyiv, Ukraine

2 Physical Faculty, Taras Shevchenko National University of Kyiv, 4b Akademika Hlushkova Ave., UA-02000, Kyiv, Ukraine

3 Institute of Physics, National Academy of Sciences, 46 Nauky St., UA-03028 Kyiv, Ukraine

Fig. 1 Trajectory and the coordinates of the route

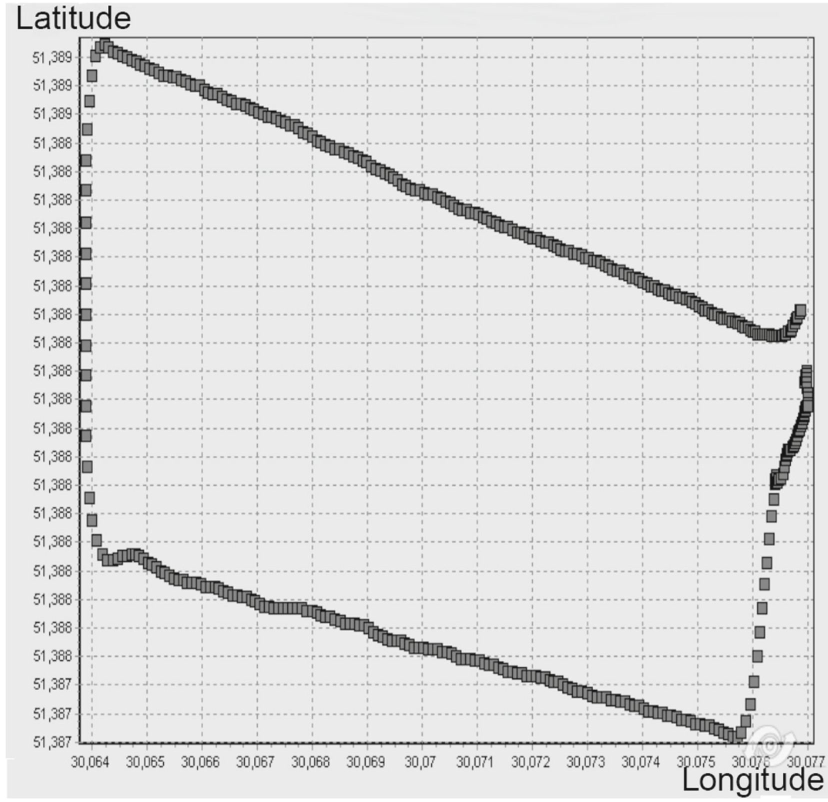
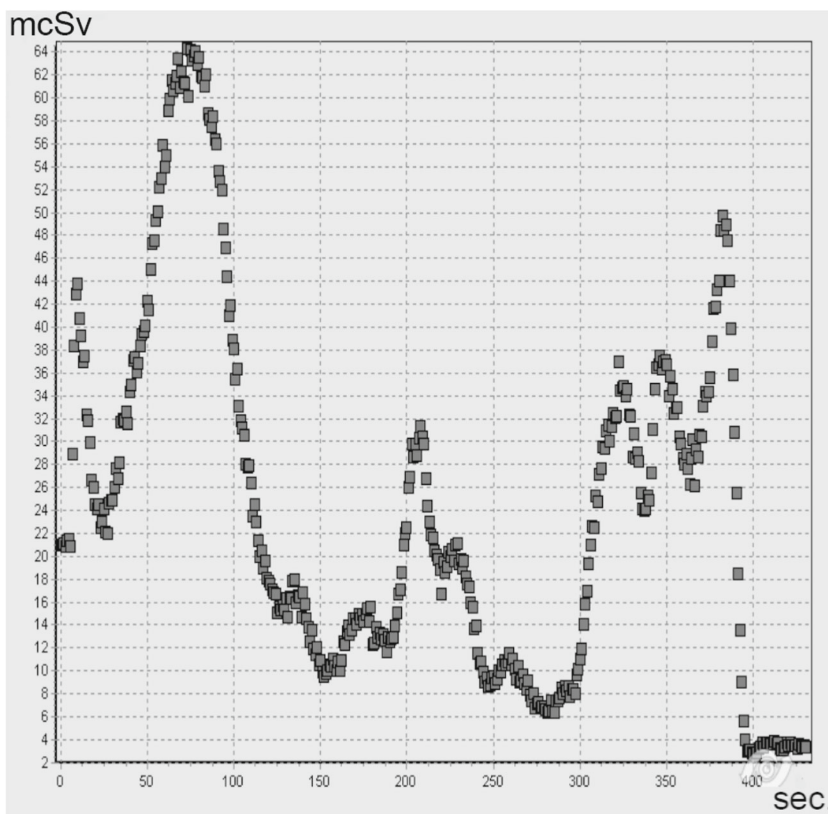


Fig. 2 Integrated gamma activity along the route



introduces serious problems in obtaining reliable data on spatially distributed radiation sources. The resulting spectral measurement data were largely noisy and blurred. The known methods of processing of such data distort the information, and this in turn decreased the accuracy in the localization of the data locations and determining the activity of the radioactive point source.

Those shortcomings including economic factors have led to the need for new measuring radiation monitoring systems embedded on UAV.

In 2016, we designed an innovative measuring system "GR-Smart System" and developed a new technology of radiation monitoring, which is based on measuring and analyzing new informative parameters characterizing the dynamic and static characteristics of non-stationary radiation fields [11]. A UAV equipped with the GR-Smart System was used to carry out remote gamma radiation sensing for mapping of some heavily contaminated areas of the Chornobyl exclusion zone.

The GR-Smart System enhanced the sensitivity of measurements, as well as the probability of detecting nuclear radiation materials and sources of ionizing radiation of low activity in real time, under uncertain and unfavorable conditions, with limited time of observation and measurement in a single process. The new measuring system has been inserted on board of an unmanned octocopter that does not require an airport. This new measuring system has substantial privileges: the flight altitude is from 5 to 3000 m; the flight speed can vary from 1 to 30 $m \cdot s^{-1}$; the sensitivity of the density of surface contamination is 0.5 $kBq \cdot m^{-2}$ (in 1993 the sensitivity was 1.5 $kBq \cdot m^{-2}$); the spatial resolution is 0.5 m (in 1993 the spatial resolution was 20–30 m). The sensitivity of dose rate now is very high, 0.8 $mcSv \cdot h^{-1}$.

The areas around the former Chornobyl nuclear power plant are characterized by a high density of surface contamination and contain the entire spectrum of nuclear fuel radionuclides: ^{137}Cs, ^{90}Sr, ^{154}Eu, ^{155}Eu and also isotopes of Pu, Am, etc. Immediately after the accident, two types of radioactive waste storage were introduced: trenches, which are under the ground, and piles, which are above the ground. The size of trenches and piles varies from a few meters up to 10 m in length and width. The height of a pile can

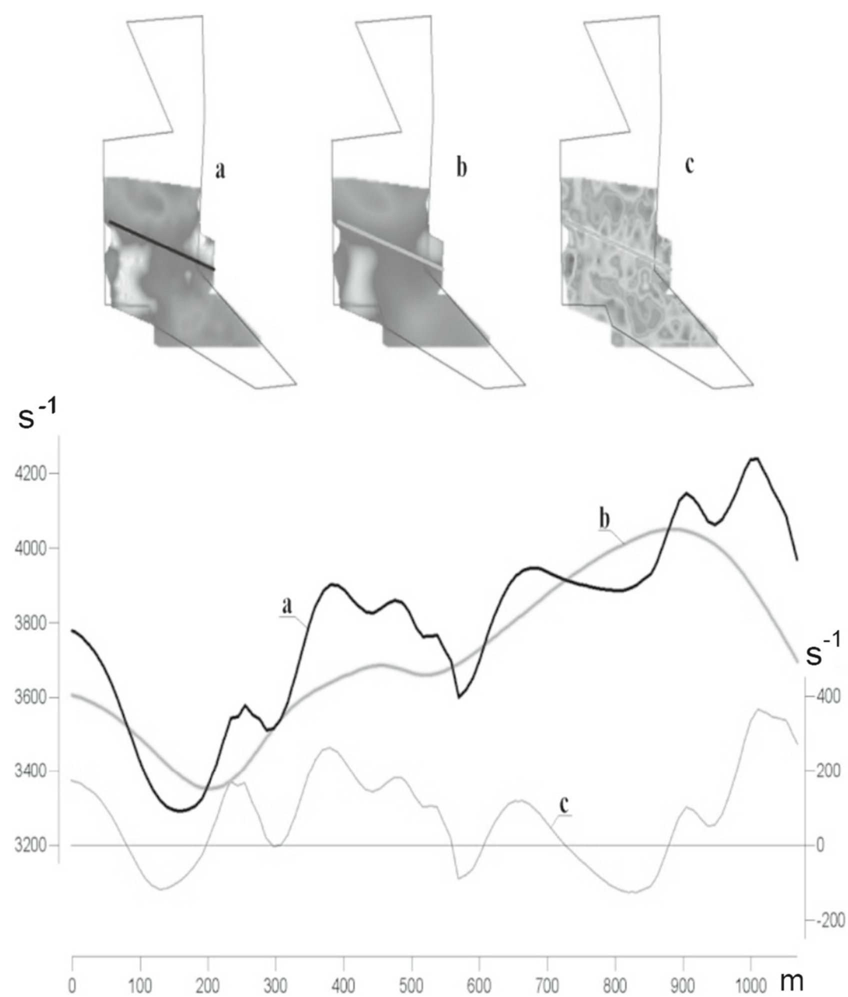


Fig. 3 Diagram of original (**a**), averaged (**b**) and the local component (**c**, c = a–b) of the field of gamma radiation in the "Red Forest" area. At the top is the position of the line of graphs on the respective maps

be up to 2 m; the trench depth is about 2 m. Currently trenches and piles are practically inconspicuous because of the subsidence of the soil and thick vegetation cover.

The GR-Smart System has been used to detect sources of high radioactivity in these waste storages. The main element of the measurement system is a spectrometer, an analyzer of gamma radiation based on NaI (Tl) scintillation detectors. The GR-Smart System has been used to investigate areas named “Oil Storage” and “Red Forest” near the 4th unit of the Chornobyl nuclear power plant exclusion zone.

Flights of the “GR-Smart” have been performed in parallel routes. The distance between two routes has been ~ 100 m and the altitude ~ 30 m with an average flight speed of ~ 5 m$\cdot$s^{-1}. The spectrometric information is accumulated in

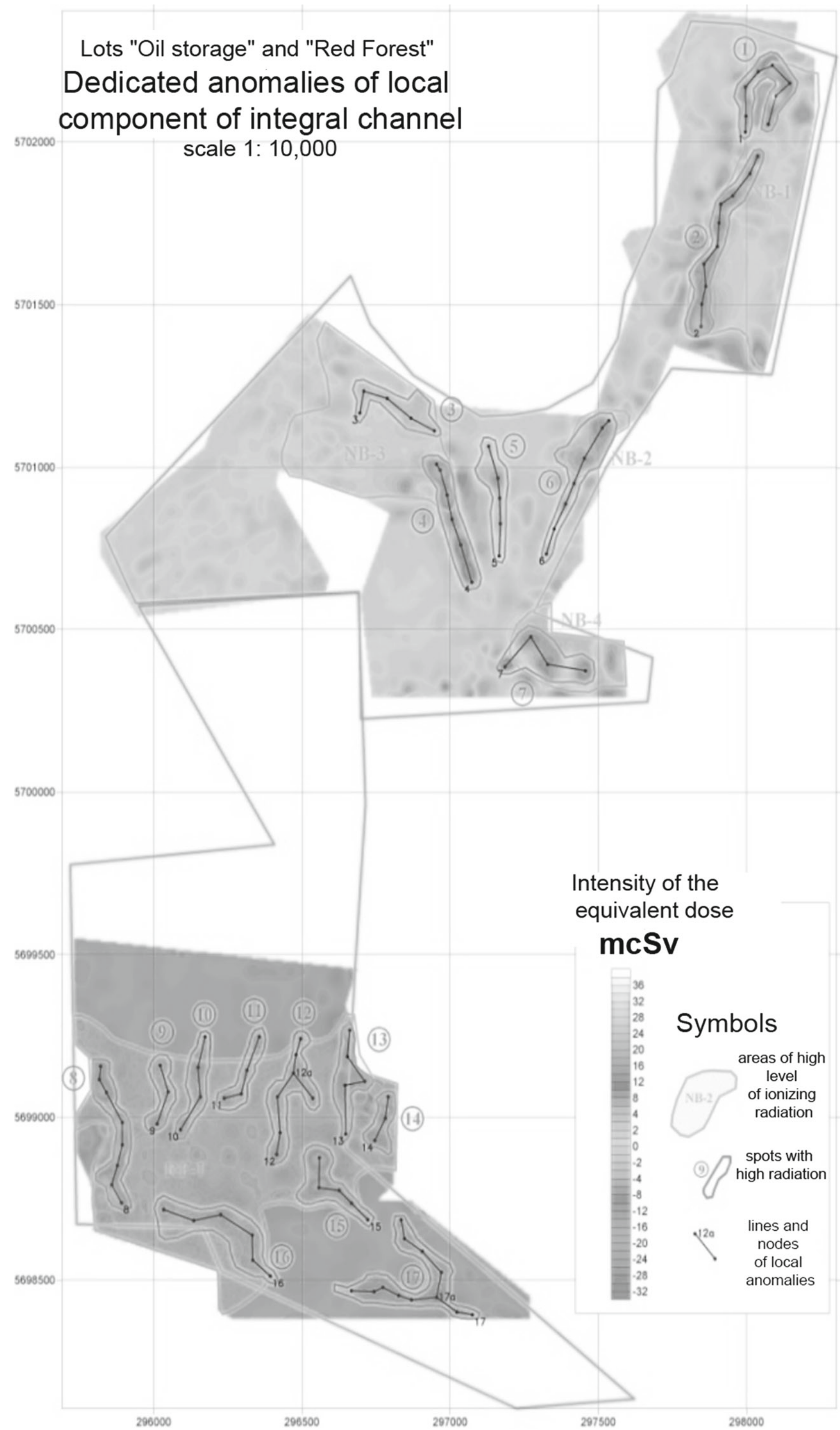


Fig. 4 Areas of high intensities revealed at the processing of data

the form of an "amplitude-time". The measured data have been plotted on the grid using radio altimeter readings and GPS-information.

Processing of measured data allow us to form courses, i.e. text tables with columns of coordinate values in the form of latitude and longitude (WGS-84), gamma-spectra values, the number of gamma-ray pulses in the ^{137}Cs "window", as well as columns with recalculated data of the rate values (counts per second) in the unit of equivalent dose mcSv [11]. The results of the measurements obtained during a flight are shown in Figs. 1 and 2.

To determine the radiation environment for each plot of "Oil Storage" and "Red Forest", values of radiation intensity determined at a height of 30 m by the GR-Smart System should be converted to the surface activity at a height of 1 m. Computer mapping technology provides a preliminary step of the conversion of initial observations with irregular coordinate data on a regular rectangular or square grid. For the final map, taking into account the necessary detail and correctness of the constructions, as well as the basis of trial calculations, we chose a regular square grid of 10 m $\times$ 10 m. The green mass of vegetation was responsible for some distortion of the overall radiation level of measurements.

To calculate the regular grid matrices, we have used the Kriging method, which is widely utilized in almost all geographic information systems (GIS). As a result, pollution maps have been compiled in the form of areal pollution contours with a contour interval of equivalent dose of 5 mcSv (Fig. 3). To construct the maps and spatial analysis, we have used geographic information system software ArcGIS for Desktop Basic [12]. To distinguish small objects with a high level of radiation, the appropriate maps have been drawn of local ("high-frequency") components of the observed field with a contour interval equivalent dose of 2 mcSv.

The example illustrating the preparation of a local matrix component (a "high-frequency" component) is shown in Fig. 3.

The GR-Smart System has detected some isolated areas with an abnormally high intensity radioactive general background. Figure 4 shows that in the "Oil Storage" area 7 plots are detected with a high general background; namely, plots 1 to 7 with intensity from 90 to 160 mcSv. In the "Red Forest" area 10 plots are revealed with a high general background; namely, plots 8 to 17 with the intensity of 90 to 170 mcSv. The processing of data has been done by our method [13] for the detection of low-level ionizing radiation in solid, liquid or loose materials, which is base on the use of the Bayesian approach for the estimation of probabilistic parameters and a special statistical criterion, i.e. an algorithm described in detail in the quoted work.

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V. Burtniak is an IT engineer at the Department of Nuclear Physical Technologies, Institute of Environmental Geochemistry under Natl. Acad. Sci. (NAS) and Ministry for Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, Kyiv.

He is a developer of information technologies that are using at different measuring tools in particular for measuring ionisation radiation. He is co-author of dozens of research works.

Yu. Zabulonov is Dr. of Science, a corresponding member of NAS of Ukraine, the head of the Department of Nuclear Physical Technologies, Institute of Environmental Geochemistry under NAS and Ministry for Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, Kyiv. He has played an important role in the management of the aftereffects of the Chornobyl nuclear catastrophe. He is the chief architect of a system that was deployed for the measurement and treatment of radioactively contaminated people. Some of his solutions are currently used in the context of the Fukushima nuclear accident. He is specialised in "separation technologies".

During the last 10 years his professional focus has been on the recycling and purification of various kinds of waste. In 2011 he received a gold medal for his services to Ukraine in the aftermath of the Chornobyl accident and was recently awarded the Order of Saint Volodymyr for his continued services to the people of Ukraine. He is the author and co-authors of many research works, books and patents.

M. Stokolos is an electronic engineer at the Department of Nuclear Physical Technologies, Institute of Environmental Geochemistry under NAS and Ministry for Emergencies and Affairs of Population Protection from the Consequences of Chornobyl Catastrophe, Kyiv. He is a developer of electronic schemes and various measuring tools in particular for measuring ionisation radiation. He is co-author of several research works.

L. Bulavin is an academician of NAS of Ukraine. He is Doctor of Science, Professor, the head of the Department of Molecular Physics at the Physics Department of the Kyiv National Taras Shevchenko University. The head of the Department of Neutron Research Institute of Nuclear Power Plants Safety. Co- Chair of the Department of targeted training of NAS of Ukraine. He is the author and co-author of 600 papers and 12 books.

V. Krasnoholovets is PhD in a condensed matter physicist, a Senior Research Fellow at the Department of Theoretical Physics, Institute of Physics, NAS, Kyiv. His research interests are condensed matter physics, fundamental physics and applied physics. He usually arrange different experiments and provide explanation to the results obtained. He has edited several books and collections of works dealing with quantum physics and gravity. He has published over 80 research papers and recently 1 monograph titled "Structure of space and the submicroscopic deterministic concept of physics".