## ГЕОЛОГІЧНА ІНФОРМАТИКА

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Yuriy STARODUB[1], DSc (Phys. & Math.), Prof.
ORCID ID: 0000-0002-1947-7197
e-mail: yuriy.starodub@gmail.com

Borys MYKHALICHKO[1], DSc (Chem.), Prof.
ORCID ID: 0000-0002-5583-9992
e-mail: mykhalitchko@email.ua

Helen LAVRENYUK[1], DSc (Tech.), Assoc. Prof.
ORCID ID: 0000-0003-4509-2896
e-mail: olaw@ukr.net

Olesia KOZIONOVA[2], Engineer
ORCID ID: 0000-0002-2563-8719
e-mail: rapakivi@ukr.net

Henryk POŁCIK[3], PhD
e-mail: h.polcik@henrykpolcik.pl

Bohdan KUPLOVSKYI[4], Phd (Phys. & Math.)
ORCID ID: 0000-0002-4221-5224
e-mail: bohdan_kuplyovsky@yahoo.com

[1]L'viv State University of Life Safety, L'viv, Ukraine
[2]Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
[3]Foundry Research Institute, Kraków, Poland
[4]Subbotine Institute of Geophysics, L'viv, Ukraine

# ENVIRONMENTAL GEO-INFORMATIONAL MONITORING SYSTEM FOR THE CIVIL AND FIRE SAFETY SERVICES OF UKRAINE

*(Представлено членом редакційної колегії д-ром геол. наук, проф. С.А. Вижвою)*

**Background.** *The purpose of the work is the development of a new ecological and geo-informational system for monitoring emergency situations, which allows quick predicting the consequences of various natural and man-made hazards at the stage of preventing their occurrence. This applies to possible cases of destruction on territories where there is a threat of flooding and, accordingly, the protection of coasts, structures, roads on mountain slopes, bridges, tunnels and dams built on soils with certain geological and geophysical characteristics, as well as the occurrence and spread of fires and pollution of air, water and soil with harmful substances associated with them.*

**Methods.** *To implement the methods, available and purchased licensed software is used, creating convenient algorithms for solving practical tasks of civil protection. Information processing based on the used software packages that allow quickly processing large amounts of information, reducing the level of poor processing and data distortion.*

**Results.** *An ecological and geo-informational monitoring system has been developed, designed to ensure the coordination of actions of civil and fire protection services in order to increase the efficiency of responding to emergency situations of natural and man-made origin.*

*By conducting experiments, model results were obtained, which make possible to theoretically calculate and determine the critical permissible stress-deformed states of the soil massif in the area of engineering structures, bridge structures, to warn about the possible destruction of the massif due to excess stress and deformation under the action of loads.*

*Proposed localization of fire-hazardous zones based on satellite data. As part of the developed system for space monitoring of forest fires, satellite information is used, in particular, the AVHRR radiometer of the Terra satellite. On its basis, a temperature map of the regions of Ukraine was formed.*

**Conclusions.** *The geo-informational monitoring system was created to prevent the risks of emergency situations (including the destruction of slopes, fires, etc.) using software products, creating databases for mapping potentially dangerous objects. Its application will make it possible to assess the consequences of possible emergency situations of a natural and man-made nature and minimize their negative impact on the environment.*

*The developed geo-information system can be used to coordinate the actions of civil and fire protection services, as well as increase the efficiency of emergency and rescue measures.*

**Keywords:** *geo-information system, natural and man-made hazards, stress-deformed state of soils, fire protection technologies.*

## Background

An updating and improving environmental geo-information monitoring system to prevent emergencies of a natural and man-made nature has always been one of the priority and promising global trends. Taking into account the current military realities of our country, where the number of emergency situations of various natures is steadily increasing, the use of environmental and geo-information monitoring systems by the civil protection services of Ukraine today is strategically expedient.

The practical value of the planned results of the project for the economy and society will consist in increasing the level of safety of citizens in the field of civil defence and fire safety by using the geo-information monitoring system to solve existing environmental problems.

For the development of the technological base in the civil defence units of Ukraine, it is necessary to improve software products and monitoring systems that ensure the preservation and exchange of cartographic, hydrogeological, geophysical and other data necessary for making management decisions during forecasting and responding to emergency situations. Such monitoring should include an assessment of the effectiveness of emergency and rescue measures, and should be involved in setting problems for the development and improvement of software products and technologies for their operation (Vyzhva, Vynnychenko, & Kendzera, 2008; Doltsinis, 2018; Starodub, & Havrys, 2018; Starodub et al., 2020).

To ensure reliable data exchange and the use of software methods and tools, in particular, the development and improvement of the geo-informational monitoring system, applied mathematical modelling forecast of natural and man-made dangerous threats is necessary, which together makes possible to increase the promptness of response and the effectiveness of eliminating dangerous situations. Taking this into account, there is a need to develop software methods and algorithms that, based on the use of field observations, will ensure the prediction of the consequences of emergency situations, including fires in the early stages of their discovery.

An important component of a state policy in the field of national security of any country is the protection of the population, industrial facilities, and national wealth from fires and their consequences. According to the monitoring report of the International Association of Fire and Rescue Services, in recent years in many countries of the world, including Ukraine, there has been a tendency towards the increase in the number of fires. This is due to a significant increase in temperatures, in particular in Ukraine, where the fire hazard situation is increasing due to global warming, which is especially noticeable in the summer months. This phenomenon can be seen on satellite images received at the Centre for Receiving and Processing Special Information and Control of the Navigation Field. Hence the need for satellite surveillance and monitoring of dangerous regions, especially in places where it is important to provide fire protection is necessary. The authors have previously carried out modelling and visualization of fires in space and time based on the method of spatial location of fire-hazardous zones (Havrys et al., 2023).

According to statistical data, more than 60,000 fires occur annually in Ukraine, as a result of which up to 5,000 people die and are injured, and direct and indirect material losses amount to tens of billions of dollars. Another reason for such dynamics is the rapid growth of industrial production and the use of polymer materials in various spheres of life. However, the safe use of epoxy polymers is possible only if the serious disadvantages inherent in these materials are eliminated, among which the main one is their significant fire hazard.

The creation of modern fire-resistant materials based on modified epoxy-amine composites allows solving the problem of fire protection of objects and structures to some extent. Therefore, the issue of creating a scientific basis for the development of a rational technology for obtaining metal-coordinated epoxy-amine composites with reduced fire hazard and predicting the behaviour of polymer materials based on them in fire conditions is extremely relevant (Lavrenyuk, Hamerton, & Mykhalichko, 2018; Lavrenyuk, Mykhalichko, & Parhomenko, 2019b; Lavrenyuk et al., 2020; Kochubei, Mykhalichko, & Lavrenyuk, 2022).

Another no less important task of the civil protection services is the ability to quickly assess the emergency condition of the object. Namely, in cases related to stresses and deformations of bridges, viaducts, sliding slopes of river banks, dams, etc., which may cause accidents. For this, it is important to determine the geological and geophysical parameters of the objects, in particular the available geometric and geophysical characteristics (Starodub, Havrys, & Kozionova, 2023a).

From the description of the current state of the problem, the goal and tasks of the project described in the article, consist in the creation of an ecological and geo-informational monitoring complex (system) necessary to ensure reliable data exchange using software methods and tools, in particular, applied mathematical modelling for predicting the danger of natural and man-made hazardous objects, which will collectively increase the assessment of the results of operational rescue work.

**Methods**

Analysis and forecasting of emergency situations are carried out for prompt decision-making methods.

The development of a methodology to prevent the risks of environmental emergencies by the problems of civil protection in objects and on a national scale was carried out with hierarchical and relational access to information obtained.

The method includes the development of a new geo-information system that quickly predicts the consequences of natural and man-made emergencies at the stage of preventing their occurrence. It relates to possible cases of destruction in areas where a flooding threat is and requires protection of shores, constructions, roads on mountain slopes, built bridges, tunnels, and dams on soils with their geological and geophysical characteristics, as well as pollution of air, water, and soils by hazardous substances, and fires occurrence, etc.

In the process of the method implementation, existing and purchased licensed software (the main things are ArcGIS, ENVI, COMSOL programs) are used, and the necessary scripts are developed to use in software packages) to create convenient algorithms and solve practical problems of civil protection services.

In the case of developing layers of a geo-information system, the unique links between the data are expressed in separate layers, and in the case of supplementing such links by calling separate procedures, such layers represent the user interface. During the interactive procedure the interface moderator fills in the layers of connections between databases.

The geo-information system is created to prevent risks of emergencies (including origination of fires) using software products, in particular, the creation of databases for mapping high-risk objects, potentially dangerous objects, and water reservoirs serving as an aid in rapid response. This will contribute to the creation of orientation atlases using GPS receivers, route planning, control, track analysis, measurement, and calculations, as well as representation by users of the operational environment.

**Results**

***Geoinformation system for monitoring initiated.*** Previously, the authors proposed to create map layers by different users using the ARCGIS map editor specially designed scripts and the use of existing maps (Starodub et al., 2023c). The developments are based on the algorithm of data processing of remote sensing of the Earth using a set of software packages ARCGIS, ENVI, own development of scripts using the algorithmic language Python and programs for the packages used to process monitoring data and predict the consequences of natural and man-made emergencies.

The digital terrain model SRTM (Shuttle Radar Topography Mission) is used. The digital model of the relief is obtained by radar topographic survey of the earth's surface. The model of the territory of Ukraine is selected based on data from the official CGIAR-CSI website. Terrain database digital data – the conversion of radar data into a digital terrain model are used based on CGIAR data.

On the website of the EarthExplorer, the organization USGS "U.S. Geological Survey" available for download are hypsometric data in ArcGIS format. In the process of searching for data high-altitude data is allocated to the contours of the Ukrainian border, resulting in the SRTM model, which is presented in the database: the USGS site selects the area where it is possible to download data, to expand the list "Digital Elevation" and the SRTM terrain selected. The parts to be downloaded are selected and the necessary data is downloaded. The boundaries of regions, districts, endangered areas and other objects are obtained by creating a digital map in accordance with the technological scheme of creating digital maps based on raster maps.

To perform the described technology, the following sequence was followed: running routines (ArcMap, Catalog window), creating a folder to place the future map, copying data from a previously created DataBase folder to a folder with a future map. DataBase, which contains all the necessary and available information, makes the necessary signatures on the map (objects, symbols, indicate the scale, directions of the world of the study area) and saves (prints) information file with a map of the model of ecological and geophysical state of the territory.

***Digital models of engineering structures are used.*** The trend in the world is to solve problems related to emergencies at engineering facilities in the field of civil protection. At the same time, the task of civil protection services is to quickly assess the emergency condition of the facility. An important cause of accidents is the stress-strain state of the object. In such cases, which relate to stresses and strains concerning bridges, viaducts, landslide slopes of mountains and river banks, and dams, determination of the geological and geophysical parameters of objects, in particular, the existing geometric geophysical characteristics are important. Personal computers for calculating possible deformations and stresses in them are important (Starodub et al., 2018). The calculations are based on the theory and methodology of complex interpretation of geophysical monitoring data of dangerous geological and geophysical processes and modeling of objects by the finite element method. The approach comprises the model discretization of objects into separate rather small elements-particles in which deformations and stresses are modeled in element interaction. Digital models assess the endangered condition of objects (Lu et al., 2020; Moravej et al., 2019).

Thus, for a physical body consisting of particles with a given density, Young's modulus, Poisson's ratio; values of specific adhesion in the soil, the angle of internal friction, modeling in the environment depending on the influence of externally applied force on the object for the used Drucker-Prager model (Doltsinis, 2018) the state of the object is described as an equation finite element method:

$$KU = R,$$

where $K$ is the stiffness matrix of the object, $U$ is the vector of generalized displacement, $R$ is the vector loads on the simulated object.

By conducting numerical experiments, model results are obtained, which makes it possible to theoretically calculate and determine the critical allowable stress-strain states of the soil mass in the vicinity of engineering structures, bridge structures, to prevent the destruction of the massif due to excess stresses and deformations under the action of loads.

An emergency situation for a soil massif with certain predetermined physical-mechanical characteristics is investigated, analyzed, localized and prevented (see fig. 1).

Information processing based on the above mentioned software packages makes it possible to quickly process large amounts of information, and reduce the level of poor processing and distortion of data.

The project analyzes methodological support of geological information systems, uses empirical research methods: predicting the possible consequences of floods and forecasting the spread of fires in the open and during man-made accidents, and as a consequence pollution due to emissions of hazardous substances and more.

As a result, the application of the proposed approach reduces the possible consequences of emergencies in the practical tasks of civil defense units.

***Geoinformation technologies for fire risk assessment***. Data are analysed and correlated for seismic (including fires associated with the destruction of buildings and gas pipelines) and explosive hazard areas where construction sites associated with natural and man-made hazards, including forest plantations, are located, which can cause fires to start and spread. Relevant research is carried out to eliminate the risk of fires in seismically hazardous areas with a special geological structure. The maps take into account the fact that seismic activity in Ukraine is mainly observed in the Carpathian and Crimean-Black Sea regions. Seismic microzoning maps are used at the design stage of important engineering structures, especially those that cause great damage to the environment in abnormal situations. In this case, the maps show an increase in the seismicity of certain areas relative to the normative values for this territory. The increase can be positive or negative, and the sign and magnitude of the increase depend on local conditions: the composition and strength of sedimentary rocks, topography, and the presence of tectonic faults. Geological-seismic microzoning is the final stage of complex studies of the territory. Data from engineering geological studies, instrumental observations of seismic fields of earthquakes, data from macroseismic surveys of the consequences of earthquakes, explosions, natural and man-made microseisms are used to construct complete maps. The results of the works are mapped on a scale of 1:10000 – 1:25000. In the presence of engineering and geological conditions that are hostile in terms of increasing the seismicity of the territory, the intensity values may exceed the background values.

Any fires detected, immediately fire prevention measures need to be taken. In this case, the parameters of the fire must be determined very accurately, as separate centres of ignition are not considered fires. In the process of monitoring, the specifics of eliminating fires in small areas are determined by the promptness of detecting fire centres and taking priority measures to extinguish them.

The fires are monitored by means of satellites, unmanned aerial vehicles (UAVs) and instrumental ground-based methods. In particular, the seismicity of the territory of Ukraine and methods for detecting and assessing forest fires using data from artificial Earth satellites are described in (Starodub et al., 2023b; Svyrydenko, Babich, & Shvidenko, 1999). Due to the use of satellite monitoring to study the fire situation in the regions, the smallest fire area that can be detected by satellite means ranges from 20 to 30 hectares with a delay from 4 to 20 hours. In practice, for effective forest firefighting, the detected fire area should be less than 1 hectare, and the fire area at the time of extinguishing should be no more than 5 hectares, which is achieved by processing reports from observation posts and available instrument observations. At the same time, satellite information is used for space-based monitoring of forest fires, in particular, the AVHRR radiometer of the Terra satellite. Further, the results are obtained using UAVs and ground-based instruments.

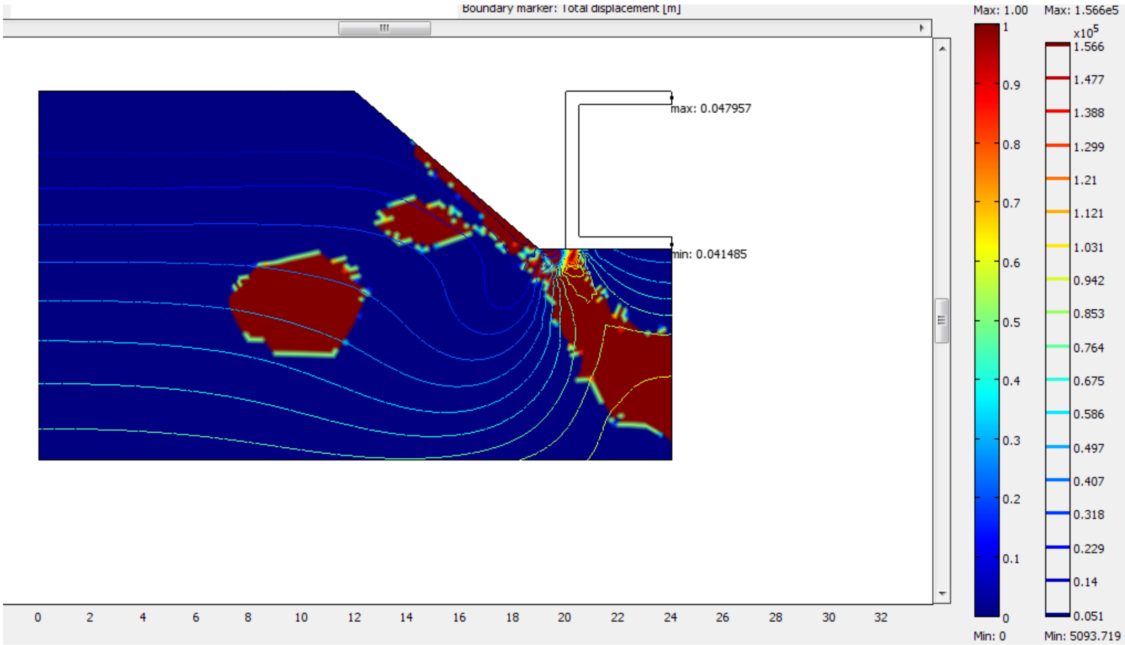


**Fig. 1. An example of simulation of the stress-strain state at the pressure effect of $5 \cdot 10^4$ N·m$^{-2}$ on the ground:**
left column – deformation, right column – stress with the same scale in horizontal and vertical directions

***Fire risk areas localization using satellite data proposed.*** The Terra satellite's 5th-channel AVHRR radiometer is used to perform space-based monitoring of forest fires. The methodology for determining fires is based on the use of radiation estimation for the 3rd, 4th, 5th channels of the AVHRR radiometer, while fires are determined by the maximum value of energy registered by the 3rd channel of the radiometer. Smoke from fires is determined by the 1st and 2nd channels of the radiometer. For more accurate identification of fires, threshold algorithms are used, which make it possible to determine the radiation temperature based on the data of the 3rd and 4th channels. As a result, a temperature map of Ukraine was obtained (fig. 2) (Starodub et al., 2013).

An analysis of temperature zones in Ukraine shows that the risks of fires in seismically active areas are increasing, resulting in a much higher incidence of forest fires. Due to the high anthropogenic load, prevention of fire spread, organization of fire extinguishing and elimination of their consequences within the forest fund is carried out in accordance with the procedure established by the State Committee of Forestry of Ukraine. Detection of forest fires within the forest fund is carried out through a set of measures. These include the presence of ground-based observation points (towers, posts, structures suitable for monitoring), patrolling of territories by forestry and fire protection units, and organization of interaction between ground and aviation services.

In order to reduce material losses and preserve non-renewable forest resources, as well as to prevent the destruction of infrastructure facilities and structures due to the spread of fires, monitoring of the possibility of fires in such areas should be carried out on an ongoing basis. Therefore, in the process of localizing fires, an important factor is to take into account the rate of flame spread, which was obtained as a result of experimental and model studies and presented in the form of a nomogram to determine the number of forces and means required to overcome the consequences of fires.

Thus, the developed geographic information system for monitoring emergencies allows civil and fire services to promptly inform about fires in natural ecosystems and at civilian facilities and buildings.

***Preparation technology of composite materials with reduced combustibility.*** In order to minimize the negative consequences of emergencies, civilian and fire departments must use all the possibilities of protecting civilian objects from fire in the performance of real tasks. In this regard, the development of fire-retardant polymer composites should be considered as an engineered protection means that will reliably guarantee fire safety of civilian facilities and structures from the aggressive effects of flame.

To prevent the occurrence and spread of fires, metal-coordinated epoxy-amine composites with reduced fire risk have been developed. In addition, based on the obtained flame-retardant composite, a unique technology of fire protection of wood has been created, and wood sawdust (WS) composite material with reduced combustibility has been made.

The samples of flame retardant composites with reduced combustibility have been obtained (the direct interaction of appropriate anhydrous inorganic salt of $CuSiF_6$ with the curing agent of epoxy resins – polyethylenepolyamine (*PEPA*) and a binding agent – bisphenol A diglycidyl ether (*DGEBA*) (Lavrenyuk Parhomenko, & Mykhalichko, 2019a)). To obtain a functional composite material from wood sawdust (WS) with reduced combustibility (WS/*DGEBA/PEPA*-$CuSiF_6$), pre-dried pine sawdust is added to a previously prepared mixture of *DGEBA*, *PEPA* and $CuSiF_6$. For comparison, the original composites without a flame retardant (*DGEBA/PEPA* and WS/*DGEBA/PEPA*) were prepared by mixing the appropriate ingredients (see Table 1).

In addition, the developed flame-retardant composite (*DGEBA/PEPA*-$CuSiF_6$) was applied to the surface of wood, and the fire-protective properties of this coating were tested.

The fire hazard of the obtained epoxy-polymer and wood-sawdust composite materials was assessed by flammability, that is, by the ability of the materials to burn and spread flames. The results of experimental measurements of fire hazard indicators confirm that samples containing 66 parts by mass of CuSiF6 are more resistant to burning – they can burn only when exposed to an open flame and stop burning immediately after the flame is removed (fig. 3).

After the tests, it can be stated that the samples of DGEBA/PEPA-CuSiF6(66), as well as the developed wood-sawdust composite material WS/DGEBA/PEPA-CuSiF6, belong to the highest fire resistance category – VP-0.

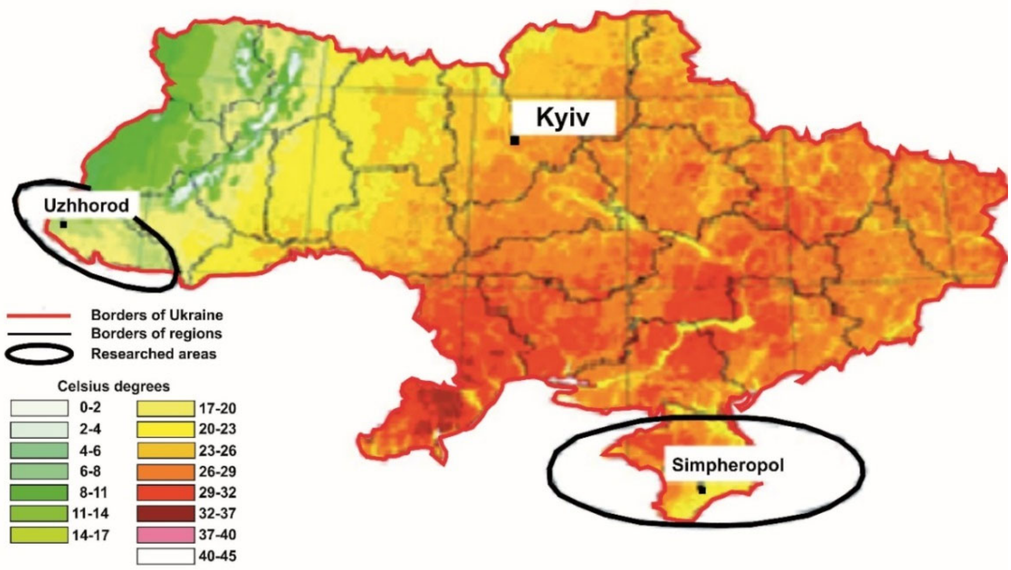


**Fig. 2. Temperature map of Ukraine modelled according to satellite data from NOAA-16 on 2012, August 7**

***Table 1***

**Stoichiometry of flame-retardant composite materials**

| **Composite** | **Ingredients (mass p.)** | | | |
|---|---|---|---|---|
| | ***DGEBA*** | ***PEPA*** | **$CuSiF_6$** | **WS** |
| *DGEBA/PEPA* | 100 | 12 | – | – |
| *BA/PEPA*-$CuSiF_6$ | 100 | 12 | 66 | – |
| WS/*DGEBA/PEPA* | 100 | 12 | – | 20 |
| WS/*DGEBA/PEPA*-$CuSiF_6$ | 100 | 12 | 66 | 20 |

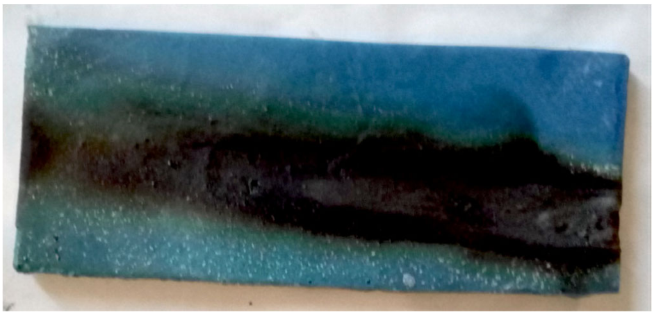

**Fig. 3. The sample of the *DGEBA/PEPA*-$CuSiF_6$ after combustibility testing**

**Discussion and conclusions**

The used environmental and geo-informational monitoring system allows to quickly identify and develop measures to eliminate natural and man-made emergencies even at the stage of their prevention. Existing and purchased licensed software was used to develop the monitoring system, which made it possible to create convenient algorithms for effectively solving practical tasks of the civil and fire-rescue services of Ukraine.

The ecological and geo-informational monitoring system should include the accounting of natural hazards and man-made loads, which will facilitate the statistical processing of data on emergency situations and fires, modeling of emergency situations in dangerous areas, as well as the study of processes of flooding, emissions and discharges of pollutants, etc. This will increase informativeness, efficiency, reliability and, as a result, the effectiveness of decision-making for the elimination and prevention of threats of a natural and man-made nature.

To prevent the occurrence and spread of fires, special products based on metal-coordinated epoxy-amine composites and a unique wood fire protection technology have been developed, which can be used to protect infrastructure objects and structures from the aggressive influence of flames.

The developed geo-information system was tested in the Kyiv, Lviv, Ivano-Frankivsk, Transcarpathian regions for the coordination of the actions of civil and fire protection services and showed an increase in the effectiveness of emergency and rescue measures when using this technique.

In the future, it is planned to produce maps for the State Emergency Situations with the help of ARCGIS, ENVI, COMSOL, PYTHON software. The developed and tested geo-informational monitoring system will be transferred to the regions of Ukraine for use by the State Emergency Service.

**Authors' contribution:** Yuriy Starodub – project administration, conceptualization, formal analysis, writing (original draft); Borys Mykhalichko – data validation, writing (revision and editing); Helen Lavrenyuk – methodology, experimental studies; Olesia Kozionova – review of publications, writing (revision and editing); Henryk Połcik – formal analysis; Bohdan Kuplovskyi – data treating, formal analysis.

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**Юрій СТАРОДУБ[1], д-р фіз.-мат. наук, проф.**
**ORCID ID: 0000-0002-1947-7197**
**e-mail: george_starodub@yahoo.com**

**Борис МИХАЛІЧКО[1], д-р хім. наук, проф.**
**ORCID ID: 0000-0002-5583-9992**
**e-mail: mykhalitchko@email.ua**

**Олена ЛАВРЕНЮК[1], д-р техн. наук, доц.**
**ORCID ID: 0000-0003-4509-2896**
**e-mail: olaw@ukr.net**

**Олеся КОЗІОНОВА[2], інж.**
**ORCID ID: 0000-0002-2563-8719**
**e-mail: rapakivi@ukr.net**

**Генрик ПОЛЬЧИК[3], д-р філософії**
**e-mail: h.polcik@henrykpolcik.pl**

**Богдан КУПЛЬОВСЬКИЙ[4], канд. фіз.-мат. наук**
**ORCID ID: 0000-0002-4221-5224**
**e-mail: bohdan_kuplyovsky@yahoo.com**

**[1]Львівський державний університет безпеки життєдіяльності, Львів, Україна**
**[2]Київський національний університет імені Тараса Шевченка, Київ, Україна**
**[3]Науково-дослідний інститут ливарного виробництва, Краків, Польща**
**[4]Інститут геофізики ім. С. І. Субботіна, Київ, Україна**

## ЕКОЛОГО-ГЕОІНФОРМАЦІЙНА СИСТЕМИ МОНІТОРИНГУ ДЛЯ СЛУЖБ ЦИВІЛЬНОЇ ТА ПОЖЕЖНОЇ БЕЗПЕКИ УКРАЇНИ

**В с т у п .** ***Метою роботи є розробка нової еколого-геоінформаційної системи моніторингу надзвичайних ситуацій, яка дає змогу оперативно прогнозувати наслідки різних природних і техногенних небезпек на етапі запобігання їх виникненню. Це стосується можливих випадків руйнування на територіях, де існує загроза підтоплення і, відповідно, захисту берегів, споруд, доріг на гірських схилах, мостів, тунелів і дамб, побудованих на ґрунтах з певними геолого-геофізичними характеристиками, а також виникнення і поширення пожеж і пов'язаного з ними забруднення повітря, води і ґрунту шкідливими речовинами.***

**Методи.** ***Для реалізації методу використовується наявне та придбане ліцензійне програмне забезпечення, створення зручних алгоритмів для вирішення практичних завдань цивільного захисту. Обробка інформації на основі використаних програмних пакетів дає змогу швидко опрацьовувати великі обсяги інформації, зменшити рівень неякісної обробки та спотворення даних.***

**Результати.** ***Розроблено еколого-геоінформаційну систему моніторингу, призначену для забезпечення координації дій служб цивільного та пожежного захисту з метою підвищення ефективності реагування на надзвичайні ситуації природного та техногенного походження.***

***Шляхом проведення експериментів отримано модельні результати, що дають змогу теоретично розрахувати та визначити критично допустимі напружено-деформовані стани масиву ґрунту в районі інженерних споруд, мостових споруд, попередити про можливе руйнування масиву внаслідок перевищення напруги і деформації під дією навантажень.***

***Запропоновано локалізацію пожежонебезпечних зон за супутниковими даними. У рамках розробленої системи для космічного моніторингу лісових пожеж використовується супутникова інформація, зокрема радіометр AVHRR супутника Terra. На її основі сформовано температурну карту регіонів України.***

**Висновки.** ***Геоінформаційна система моніторингу створена з метою запобігання ризикам виникнення надзвичайних ситуацій (у тому числі руйнування схилів, виникнення пожеж тощо) з використанням програмних продуктів, створення баз даних для картографування потенційно небезпечних об'єктів. Її застосування дозволить оцінити наслідки можливих надзвичайних ситуацій природного та техногенного характеру та мінімізувати їх негативний вплив на довкілля.***

***Розроблена геоінформаційна система може бути використана для координації дій служб цивільної та пожежної охорони, а також підвищення ефективності аварійно-рятувальних заходів.***

**Ключові слова:** ***геоінформаційна система моніторингу, природні і техногенні небезпеки, напружено-деформований стан ґрунтів, технології вогнезахисту.***

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