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The Experimental WSN Network for Underground Monitoring H₂ Abundance in the Mine Atmosphere Karnasurt Mine Lovozero Layered Alkaline Intrusion

Asavin A. M.^{1*} Puha V.V.² Baskakov S.S.³ Chesalova E.I.⁴ Litvinov A.V.⁵

1. V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Moscow

2. Geological Institute Kola Scientific Centre RAS, Apatity

3. Moscow State Technical University, Moscow

4. State Geological Museum RAS, Moscow

5. National Research Nuclear University "MEPhI", Moscow

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ABSTRACT

We have developed specialized equipment based on hydrogen mini-MDM sensors and the WSN telecommunication technology for long-term monitoring of hydrogen content in the environment. Unlike existing methods, the developed equipment makes it possible to carry out measurements directly in the explosion zone with high discreteness in time. This equipment was tested at a large rare-earth deposit of the Lovozero alkaline pluton Karnasurt in the underground mining tunnel. We observed a short time impulse very high concentration of hydrogen in the atmosphere (more than 3 orders of normal atmosphere concentration). This discovery is very important because at the time of the explosion one can create abnormally high concentrations of explosive mixtures of hydrocarbon gases that can lead to accidents. The high resolving power of the our measurement equipment makes it possible in the first time in practical to determine the shape of the anomaly hydrogen of such a concentration and to calculate the volumes of hydrogen released from the rocks, at first time in the practice. The shape of the anomaly usually consists of 2-3 additional peaks of the shape - "dragon-head" like. We make an first attempt is made to explain this form of anomaly in the article. The aim of the work the estimate hydrogen emission in mining ore deposit of rare earth elements.

1. Introduction

Hydrogen is one of the most interesting trace gases found in the alkaline rocks. The emission of free hydrogen from ultrabasic rocks, associated with serpentine forming processes, is the most well-known process. However, more recently attention was paid to

high hydrogen content in alkaline rocks^[4]. The high concentration of hydrocarbon and hydrogen-hydrocarbon gases in alkaline complexes link with occluded as fluid inclusions in minerals. These fact presences in the alkaline rock of hydrocarbon gases has a number of practical implications and it is therefore important to understand their source and distribution. Under certain conditions,

**Corresponding Author:*

Asavin A. M.,

V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Moscow;

Email: aalex06@inbox.ru

combustible and exposable gas components can accumulate in the space of the underground mines. This may be a serious danger for the mining workflows and for human life and health. If you had to forecast an increase of gas emission in the mines, it is necessary to determine their spatial and time variations and a condition of their appearance. According to their mobility, gas components are very sensitive to conditions of geological environment and can be effective indicators of the dangerous and adverse geodynamic factors.

Unfortunately, hydrogen is one of the most volatile gases, and therefore, when estimating of gas emission is made by traditional methods, there is the possibility that we measure only fragment of some residual flux. We developed a specialized equipment based on MDM (semiconductors type) hydrogen sensors^[3] and used WSN (wireless sensor network) telecommunication technology for long-time monitoring of hydrogen content in the atmosphere. Unlike existing methods, the developed equipment allows to carry out measurements directly in the zone of blasting operations with high discreteness in time.

2. Methods

The basic task of work is organization of the ecological monitoring in the district of exploitation of large deposits of apatite and rare earth elements ore deposit on the base of modern WSN technologies, consisting of sensors of gas H₂, CH₄, CO₂, temperature, pressure, humidity by complex autonomous controls of telecommunications sensors network (used ZigBee protocol) (Figure 1).

Wireless sensor network monitoring (WSN) is last innovation for the industry. WSN are spatially distributed autonomous sensors to monitor physical or environmental conditions, such as gas, temperature, pressure, etc. and to cooperatively pass their data through the network to a main server location^[2]. The WSN is built of "nodes" - from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each network node has a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. The project includes the development of informational and analytical system, which includes a network of gas emission sensors and internet webpage based on modern WEB-GIS technologies. The advantages of this technology is autonomous work (to several months and more), programmable measurement of gas sensor, low cost (on one node of network), and possibility to connect to one node of supervision a several types of sensors.

Platform MeshLogic^[8] (Russian firm) software was chosen to create WSN (<http://www.meshlogic.ru/technology.html>).

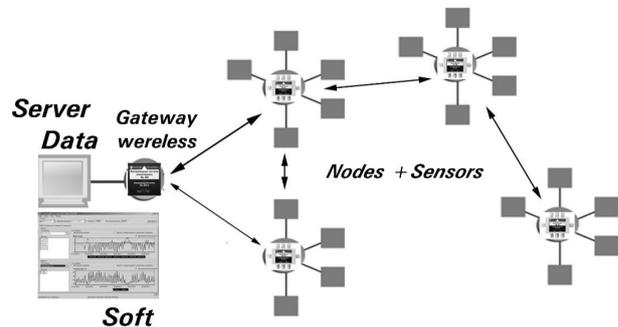


Figure 1. Principal schema WSN system. Arrow shows the direction of data exchange by radio-channel

MeshLogic standard to be distinct from other products its own network protocol stack that provides the following key benefits^[1]:

- (1) Fully homogenous network topology and algorithm of calculation position nodes in spatial;
- (2) All nodes are equal and are routers;
- (3) Self-organization, and automatic search routers;
- (4) Resistance to conflicts between nodes with simultaneously inter transmit data;
- (5) High scalability and reliability of data delivery;
- (6) Ability all the nodes to work on independent power supply.

System include special software for service monitor radio equipment and sensors tools. To transmit real-time data and store them on remote server we use GPRS cellular modem. The database was developed to collect and store online data of gas monitoring. This database provides a secure centrally administered data repository for information imported from the field data collection system.

Unique sensors have been developed for maintenance service of gas emissions monitoring. Tools were constructed in department of physics and nano system of National Research Nuclear University of Moscow Engineering Physics Nuclear Center in laboratory *Mining and examination of sensor controls on the basis of MDP structure*^[3]. Heart of gas analyzer is device D-1. Device D-1 represents sensing devices for measuring of concentrations of hydrogen, hydrogen sulphide, dioxide of nitrogen, chlorine and ammonia. The sensor fabrication technology is based on the microelectronic device fabrication technologies and the thin film laser deposition technique. A basic element is MDP (metal-dielectric-semiconductor) - structure of type Pd-Ta₂O₅-SiO₂-Si which electric

capacitance changes at interaction with gas. This layered package of the MDP condenser is heated, the molecules of gas are sorbed on the nano-layers, and as a result - the measured electrical resistance in the thermistor is directly proportional to the concentration of the sorbed gas (Figure 2). This curve is based on direct measurements of calibration mixtures of gases with known hydrogen content. Theoretical minimum level for analytical sensitivity of device concentration for H₂ - 0,02 ppm. Experimentally it is difficult to confirm, because there is not metrologically certified sources of such low concentration. Thus, it is possible to construct a calibration curve for estimating the level of a certain impurity gas from the measured electrical resistance (Figure 2). A large problem is the effect of interaction of various impurities in complex gas mixtures, changes in the properties of the MIS structure as a function of the operation time and the external conditions in the atmosphere. Each set of the MIS sensor is unique due to the high unstable laser deposition technology. All this requires individual calibration.

Figure 2 shows the calibration curves for H₂. It can be seen that the form of the functions is different for low and high concentration. Here, there are main parameters: C_{H₂} – concentration H₂ in gas mixture ppm, dC – change electrical resistance on the D-1 sensor. According this calibration curve we use 2 equations as polynomial function (1) for different parts of the curve (Table 1.).

$$C_{H_2} = A * dC^3 - B * dC^2 + C * dC + D \quad (1)$$

According to the calculated equations, we can estimate the errors in determining of gas concentration R².

Table 1. Equations parameters of different parts of the curve

Sensor N	Interval concentration for function	values of the coefficients in the polynomial equation				correlation coefficient* R2
		A	B	C	D	
85-04	0-200ppm	0.00005	-0.0024	0.3631	0	0.9998
85-04	200-5000 ppm	0.0018	-0.8977	154.52	-8976.2	1.0001

Note: *calculate in Microsoft Office Prof. Plus 2010 Excel ©

The average error of this approximating function is about 5-10 relative % of the determination of the gas concentration. If we add an additional 5% error of the signal measurement, the total error will increase to 10-15%. This is the minimum level of the error. The next problem is the definition of the zero level (the signal level when the concentration of the impurity gas is zero). We used the signal in the vacuum chamber to estimate the zero. We placed sensors into the vacuum chamber; several measurements were taken directly inside during 6-8 hours. On the graph 3 several points with a minimum signal level

reflect the vacuum conditions.

The sensing device can be used for definition of concentrations in an ambient temperatures from -30 to +40.

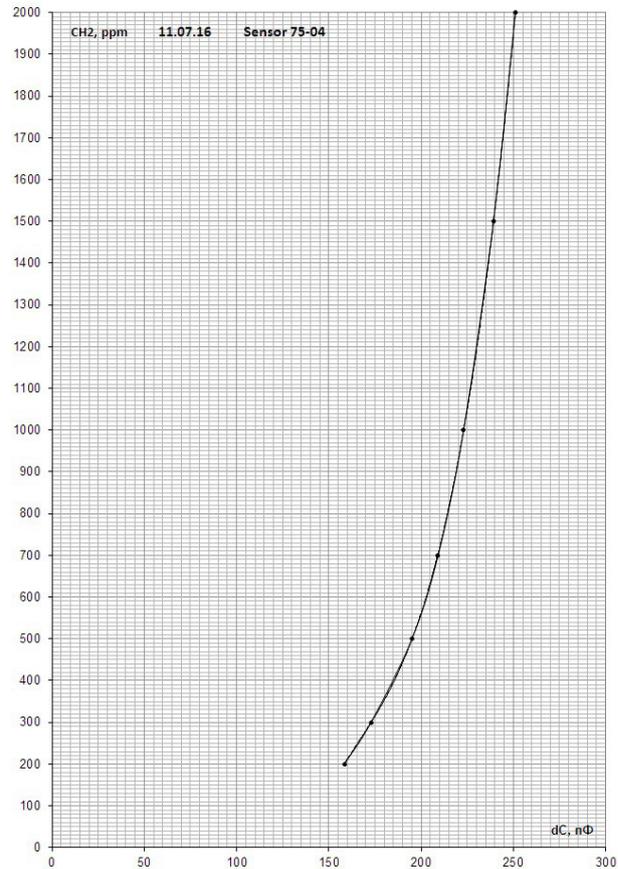


Figure 2. Calibration curve of the sensor signal (electrical resistance dC nF) as a function of H₂ concentration (ppm)

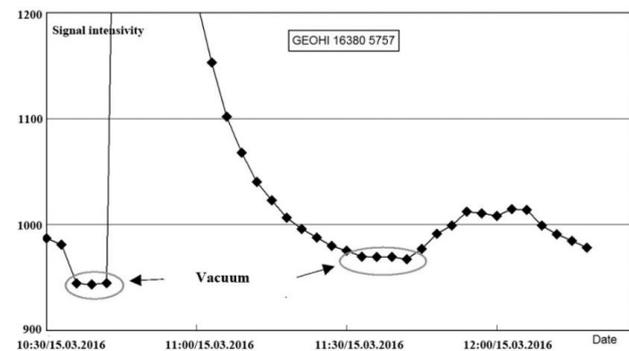


Figure 3. Graph of signal level of H₂ sensors in vacuum camera. Ellipse mark zero value

3. Results

The first technical and methodical solution was tested at the northwestern part of Lovozero massif (Kola Peninsula),

in the underground Karnasurt Mine exploiting the same name section of the rare-metal deposit. The presence of freely emitted hydrogen-hydrocarbon gases is a peculiar feature of the Lovozero rare metal deposit related to the same-name apatitic nepheline-syenite massif. A monitoring station was equipped at a tunnel drift of mines at +430-m horizon (~ 300 m below the day surface).

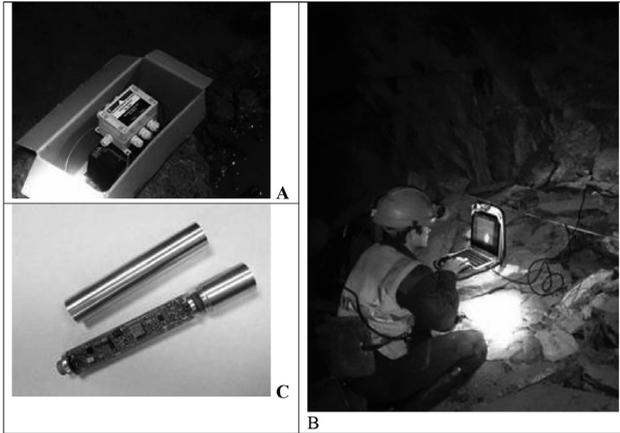


Figure 4. Appearance of WSN equipment

Note: A - The transmitting unit and the accumulator battery 12V, 18Ah; B - The author of the article downloads the current data from the hub to the laptop; C - Hydrogen sensor with removed protective case. A sensor chip and a connector for cable are visible.

Unfortunately, low temperatures in the tunnel and high measurement frequency led to a rapid discharge of autonomous power supplies. The network nodes with the power battery work autonomously approximately 2 to 3 weeks. Thus, the working scheme of the network is as follows: The sensor is in the zone closest to the explosion zone (about 20-50m); it is connected by cable to the network node; the node is equipped with sensor radio control equipment; system of data collection and transfer of information to a neighboring node and further to the central hub was established (Figure 1). There are real photos of the work operations and equipment show on Figure 4. There were 3-5 nodes in the segment of the network (Figure 5). It was done in order to duplicate the measurement near the explosion and to maximally secure the hub data collection.

The tests were carried out in two drifts (Figure 5). They are quite different of a level of water saturation condition. The maximal water flow was in the network segment of upper track number 13. This created the most unfavorable conditions for radio communication. It was the working network segment, where was the explosion events. Figure 6 shows typical patterns of hydrogen anomaly associated with explosions. Blasting operations are usually performed once a day almost at the same time. There were no explosion operations on 29 August, and there are no peaks on the graph on this day.

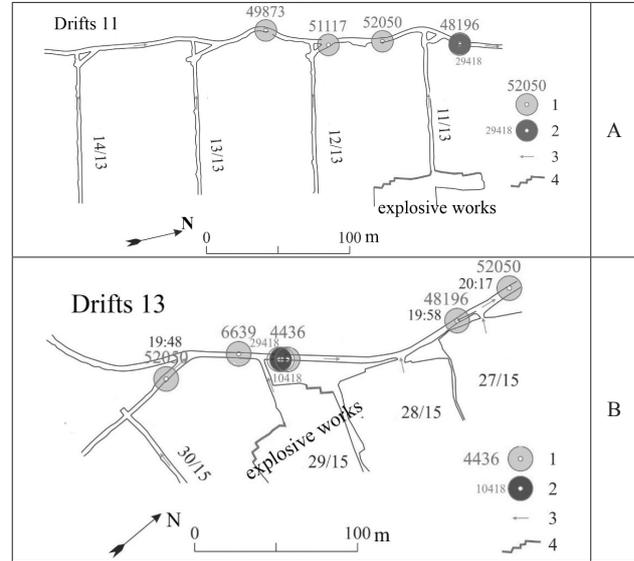


Figure 5. Location of WSN nodes (grey circle -1) in two tunnels 11 (A) and 13 (B)

Note: Grey circles on schema show node location and the dark circle (2) show gateway location. 4 - explosion zone is located. The arrow – 3, show wind flow direction.

Reduction of hydrogen content occurs quickly, because of good ventilation system. At the same time, an unexpected fact, which was established by our measurements, is the significant difference between background and peak hydrogen content. Even in our time-limited monitoring, this difference reaches to 800-1000 ppm; usually hydrogen content is changed in 12-40 times. These data indicate the possibility of dangerous hydrogen contents in the atmosphere immediately after the explosion, and the occurrence of seriously explosive and dangerous situation.

The second important observation, which no one has previously described, is that the peaks has the quite unusual form, which apparently reflects the dynamics of lithosphere hydrogen emission as a result of explosion (Figure 7). The general form is double-humped maximum curve. There is a small interval between the peaks, where the concentration sharply decreases - the “quick minimum”.

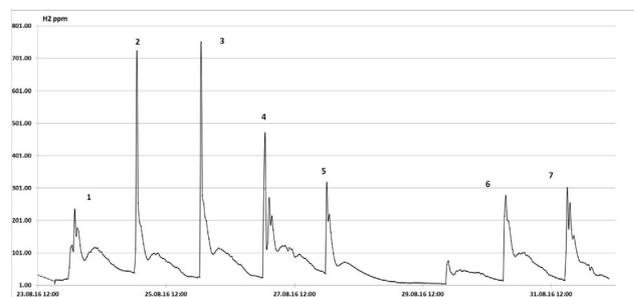


Figure 6. Time series of H₂ content in underground atmosphere of explosive zone of Karnasurt mine

At the second maximum, which is about half of the first, the concentration increases sharply, and then falls again, but at a slower rate - the “second peak”. During half hour after the explosion, the concentration drops to minimum - the “main minimum”, and then gradually decreases to a background (almost zero value) after a small increase. The quick minimum is not necessarily observed. Main minimum is observed on each anomaly of H₂ concentration.

4. Discussion

The reason of such multi-pick anomaly may result from the different sources of H₂ into the breaking rocks or multiplex source from different explosive zones. The last idea can explained identical form for 3-pick. But cannot explain “quick-minimum” and cumulative difference between anomalies. If the speed of gas wave equal air speed in tunnel the critical distance for multiplexing H₂ flow from different sources must be about 500m.

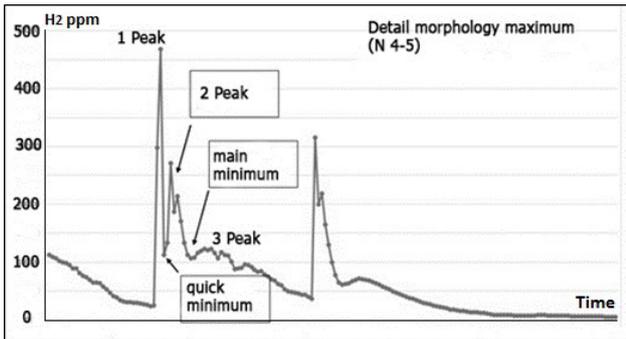


Figure 7. Typical graphical form of hydrogen content maximum associated with explosions

If real distance between different mining explosive zone >500m sensor will show unique peak of concentration on the time series graphic. From these preliminary considerations, we still keep the first point of view that the causes of the complex shape of the anomaly lay in the genetic difference of gas sources from fractured rocks.

In any case, we can calculate volume of H₂ emission corresponding for each peak and analyze relationship between them (Table 2).

However, later, with a little discontinuity in time, an additional source of hydrogen appears. What it may be? This is unlikely to be an occluded gas in the rock minerals, since its outflow will be slower due to the gradual opening of small pores or gradual seepage of gases from them.

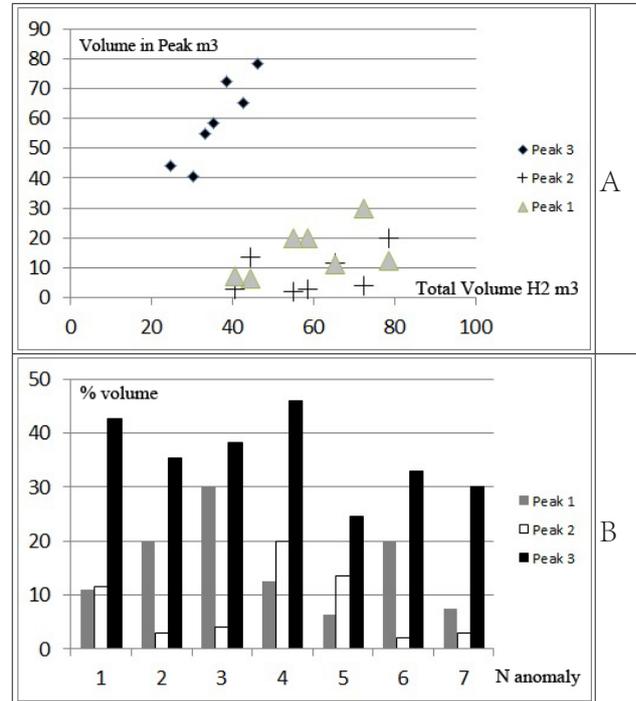


Figure 8. Relationship between total gas volume and volumes H₂ in different peaks - (A), and the histogram of the volume gas in different peaks - (B)

We assume that this is also a free crack gas, but it locate around the overburden area. These blocks of the mountain mass that were previously closed by the block are opened, pressure is released and half-open cracks give

Table 2. Volume of emission H₂ from rock after the explosion (input calculation parameters: 11.9m² gallery section, 0.7m / sec flow rate, sampling interval 10sec).

№ maximum on Figure 6.	Square maximum on the total graphic (c.u.)			Duration sec.			Volume H ₂ m ³		
	1 peak	2 peak	3 peak	1 peak	2 peak	3 peak	1 peak	2 peak	3 peak
1	10840	10790	67500	10840	10790	67500	11	11.6	42.6
2	17980		70140	17980		70140	23		35.3
3	18040		66540	18040		66540	34		38.3
4	5390	14380	64860	5390	14380	64860	12.4	20	46
5	3530	12580	70190	3530	12580	70190	6.4	13.4	24.5
6	16130		66650	16130		66650	22		33
7	5330	53980		5330	53980		7.4	33.11	

a new peak - the “second peak” that we fix.

Interpretation of the revealed pattern of gas flow distribution requires further research, but even now some assumptions can be made. It is obvious that the first peak corresponds to the most mobile gas component. This gas located in the liberated cracks and large pores of the blasted rock mass [5]. This most mobile part is immediately thrown into the mine space and gives a sharp 1-peak maximum release. The 3-peak, gradually slowly falls to the background value. It may be due to the slow expiration of gases from inclusions. A more gradual decrease in concentration indicates a slow outflow of gases, which may be explained by the gradual decrepitation of inclusions in the minerals. Although the outflow is more smooth, the total volume is also sufficiently large. We calculate this volume as the area under the curve after the “main minimum”. As can be seen from Table 1, we failed to make a precise separation of the peaks for all the anomalies.

Often a “fast-minimum” is not allocated, so 1- and 2-peaks are summed. In general, the 2-peak is usually much smaller than the first, although for example in the fifth anomaly the ratio is reversed. Sometimes there is a situation when the “main minimum” is not manifested. In this case we unite 2 and 3 peaks. For interpretation of our limited obtained data, we can construct the histograms (Figure6). On this chart we try to see the relation between total volume of anomaly H_2 and parts of H_2 connected with different peaks. We can see that total volume correlate with H_2 3-peak, but there is no any correlation with quick gas from 1-2 peaks. The share of fast gas in the total volume is approximately 30-50%.

These are interesting estimates because it turns out that very large quantities of gas were not previously taken into account in calculations or were randomly included as abnormal deviations. The advent of high-resolution monitoring tools can reveal new aspect of the behavior of high volatile gases.

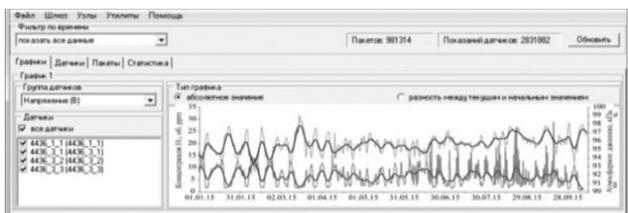


Figure 9. Software interface of wireless gateway. The graphs of H_2 (lower line) and atmosphere pressure (upper line) – demonstrated inverse correlation

Analyzing this factors in time series of hydrogen concentrations obtained in about a year with the previous works by flicker-noise spectroscopy has revealed the set of resonance about frequencies: one maximum on 7 months, one maximum during 2 months and 2 maximums

about 1 months and lesser. Less than month period has revealed the next set of resonance: 2 maximums about one day, and 3 maximum about half day periods [7].

Possibility some of them are connected with the Earth’s rotation and solar period [6]. Our preliminary analysis of a temporal series of H_2 emission at the Lovozero deposit does not confirm these suggestions. In our opinion H_2 dynamics depending mainly on meteorological factors.

5. Conclusions

This work is the first experiment in technical decision for long-term monitoring of gas emission on the base of WSN, the high-sensitive sensors of hydrogen, software and equipment attended with a transmitter network. In addition to scientific task, this monitoring system also allows to monitor an explosive situation in mines as a result of high concentration of explosive gas mixtures.

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