POSSIBLE CONSTRUCTION FEATURES OF EQUIPMENT FOR RADONOMETRY OF BOTTOM SEDIMENTS ON THE SEA SHELF DURING RESEARCH AT SHORE NPP SITES

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Abstract. Problem statement. Along with other natural gases that are freely discharged into the atmosphere in tectonic fault zones in Earth’s crust, the best-known one is the radioactive gas Radon (²²²Rn). The properties of this gas, namely inertness, short half-life period (up to 3.8 days) and availability of progeny distinguish it from other gases, such as methane, hydrogen, helium, etc. Another problem is determining the activity of tectonic faults identified by seismic exploration works in the waters near sites of future shore NPPs or those under construction. All the existing devices for offshore works were analyzed. Their advantages and disadvantages, as well as their suitability for radon research, have been revealed. Purpose of the article. In the paper, the need is substantiated to introduce radonometry for seismotectonic studies at shore NPP sites located in the sea and ocean shelf zones. Conclusions and results. As a result of analyzing the systems available for these purposes, it was deemed necessary to develop new types of devices different from the already existing ones and, for good measure, experimental prototypes. Moreover, there have been proposed their possible layout schemes. Layout schemes of specialized devices for radon research on the shelf, just as the need for such research, have been proposed and justified for the first time. Offshore radonometry conducted to identify the tectonic activity of revealed fault zones can become another additional factor that increases the operational reliability of future NPPs and, first of all, their hydraulic structures.

Keywords: NPP; shelf; radon; engineering surveys; radonometry; underwater vehicle

МОЖЛИВІ КОНСТРУКТІВНІ ОСОБЛИВОСТІ ОБЛАДНАННЯ ДЛЯ РАДОНОМЕТРІЇ ДОННИХ ОСАДІВ МОРСЬКОГО ШЕЛЬФУ ПРИ ВИШУКАННЯХ НА МАЙДАНЧИКАХ БЕРЕГОВИХ АЕС

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Anotation. Постановка проблеми. Поряд з іншими природними газами, що вільно розвантажуються в атмосферу в зонах тектонічних розломів земної кори, найбільш відомий радіоактивний радон (²²²Rn). Такі факти деревяні з виявлення активності виявлений уосіротів іншими газами, таких як метан, водень, гелій та ін. Іншою проблемою стало визначення активності майбутніх або АЕС, що будується (берегового типу). Проаналізовано всі існуючі пристрої для роботи в акваторіях. Виявлено їх переваги та недоліки, як і придатність для досліджень радону.

Висновки. В результаті аналізу існуючих систем для цих цілей визначено проблему нетривалого розробки пристроїв нового типу, розрахованого для майбутніх АЕС берегового типу, розташованих у зоні морів та океанів. Висновки. В результаті аналізу існуючих систем для цих цілей визначено проблему нетривалого розробки пристроїв нового типу, розрахованого для майбутніх АЕС берегового типу, розташованих у зоні морів та океанів. Висновки. В результаті аналізу існуючих систем для цих цілей визначено проблему нетривалого розробки пристроїв нового типу, розрахованого для майбутніх АЕС берегового типу, розташованих у зоні морів та океанів.

Ключові слова: AEC; радон; інженерні вимірювальні пристрої; підводний апарат

Formulation of the problem. Along with other natural gases that are freely discharged into the atmosphere in tectonic fault zones in Earth’s crust, the best-known one is the radioactive gas Radon (²²²Rn). The properties of this gas, namely inertness, short half-life period (up to 3.8 days) and availability of progeny distinguish it from other gases, such as methane, hydrogen, helium, etc. These properties of radon served as the basis for its use as one of the available indicators in establishing the activity rate of tectonic fault zones, especially at nuclear power plant sites [1]. During numerous field studies in the 70–80s of the last century, a direct connection was established between the intensity of radon anomalies and geodynamic processes in tectonic fault zones. This phenomenon served as the basis to start up a fundamentally new direction of applied research in the field of engineering geology: – structural geodynamic mapping (SGM) [2]. A method being similar in objectives and tasks is a method of structural thermal-and-atmospheric and hydrogeochemical investigations developed and used by the Marine Research Department of the Institute of Geological Sciences (IGS) of the National Academy of Sciences of Ukraine (NASU) [9]. Nevertheless, despite numerous facts of quite successful application of this method, radon has so far received undeservedly little attention as a possible indicator of changes in the stressed state of subsoil at sites of nuclear power plants being designed, under construction and in operation. This was especially true for measurements of radon concentrations in groundwater, where the method of measuring radon in groundwater for the purposes of geodynamic and earthquake forecast has yet to prove its value, although individual studies in this area have still been carried out [3; 4].

Another problem is determining the activity of tectonic faults identified by seismic...
exploration works in the waters near sites of future shore NPPs or those under construction. That is, the matter is radon measurements in bottom sediments in the sea and ocean shelf waters above fault zones, as well as large storage reservoirs and lakes. It should be noted that according to the number of publications, radon measurements in the marine environment were actively carried out in the 60–70s of the previous century, but after that period the interest in this area decreased significantly. The problem of measuring radon in bottom sediments on the shelf for the purposes of seismotectonics, when choosing sites for nuclear power plants, is generally quite new and associated, unlike determining radon on land, with a number of objective technical difficulties, given the depth of upcoming investigations. This paper is devoted to this topic.

The purpose of the article. In the paper, the need is substantiated to introduce radonometry for seismotectonic studies at shore NPP sites located in the sea and ocean shelf zones.

Materials and Methods. Methods used at shallow depths near the coastline are described in a number of papers [5; 7; 15]. In such studies, bottom sediments are collected using a bucket sampler or a tubular gravity column, with a subsequent complex process of determining the radon concentration in pore fluid or soil particles directly on the ship or in an onshore laboratory. Certainly, such determinations are discrete and such technology is far from optimal one existing for mass determinations during surveys.

A different way was chosen by a number of researchers, in particular that for the in-situ continuous determination of radon concentrations in the water of submarine sources [6]. For example, one such system consists of a submerged module using a commercial radon sensor with a pulsed ionization chamber and gas separation membrane module to provide high accuracy and high resolution. In operating mode, water is continuously pumped through a membrane contactor, in which radon dissolved in water is degassed and balanced by a closed air circuit. The membrane physically separates water and air. Further, after dehumidification, the balanced air is directed to an active radon detector. Two back valves and a water leakage detector prevent unexpected reverse flow. The detector monitors the temperature, humidity and pressure in the inner chamber. The submerged module can be powered by either a 12V-battery or an external AC power supply via an eight-wire waterproof cable. The maximum power consumption is ~33 W when the water and air pumps are running. Once communication is established between the underwater detection unit and shore-monitoring module, no additional intervention of the operator will be required. Data collection (no more than one minute) can be programmed for any user-desired integration interval, depending on the expected radon concentration in samples. For each time step, the user receives data on radon activity, temperature, humidity and pressure, which are automatically stored in a memory device inside the shore monitoring module. Data set transmission, as well as system management, can be controlled using the Wi-Fi-based remote terminals. This experimental setup uses proprietary software to visually monitor changes in radon activity on a real-time basis from a remote laboratory located 20 km away. During the tests, the installation operated continuously over 100 hours. However, this case also touched shallow depths (up to 2.5 m), although the creators of the system claimed that it could operate at depths of up to 40 m and even be part of an autonomous underwater vehicle. In addition, the described device is a purely experimental installation, consisting of commercially available components, and moreover, requiring the presence of a coastal stationary base, which limits the offshore survey area. As it was revealed when testing, the turbid water can clog the membrane relatively quickly and, therefore, contactors typically require the rather clean water with a low concentration of suspended solids, which in itself is unlikely in near-bottom conditions, and even more in the bottom environment. To reduce the likelihood of clogging the extraction module with suspended solids while in
operation, a pre-filtration device with a 45 mm-microfilter was installed at the water inlet to the submerged module system. In some situations, it was found necessary to install a multi-stage filtration, which seriously complicates and increases the cost of a purely experimental design. Other devices of this kind were developed.

Some attempts have also been made to measure radon activity in situ using the underwater gamma counters based on NaI (TI) scintillators or HPGe (high-purity germanium) detectors. However, NaI (TI) applications have high background and low resolution, and HPGe systems are too expensive. There is evidence of using KATERINA-type sensor devices in water areas, which take into account the activity of radon progeny (214Pb, 214Bi) [16]. Nevertheless, the significant dimensions of devices do not yet allow them to be deepened into bottom sediments by more than a few centimeters.

It should be noted that individual elements of such modules were created in the Department of Geo-Ecology and Exploratory Research of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine. An application no. a 201509394 dd. 30.09.2015 was submitted to obtain a patent of Ukraine for one of these devices: — a bathometer-degasser (see Fig. 1). Actually, it has undergone the formal examination No. 2064/38/16 dd. 28.01.2016 [8]. However, in addition to unsolved technical problems, the seawater samples were collected and degassed for various purposes by a device developed under the guidance of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine (PDBK-2M), and this was only done from the bottom water, and not from the layer of sediments, i.e. the resulting values were initially subject to a number of disturbing factors and distortions. The device itself needed some correcting works. Notwithstanding, it is also possible to develop other design schemes (Fig. 1).

![Fig. 1. Geological complex for studying water bottoms (including additional elements: 1 — sealed body, 2, 3 — upper and lower parts of the body, 4 — rod, 5 — platform, 6 — flange, 7, 8 — upper and lower parts of the guide bushing, 9, 10 — sampler-degasser valves, 11 — cargo, 12 — pressure compensator, 13 — device for changing the sample volume, 14 — gas tap, 15 — water tap, 16 — hook kicker, 17 — water intake, 18 — filter, 19 — stock, 20 — plate rectangular-trapezoidal consoles, 21 — fixing holes, 22 — stabilizers, 23 — geological meter, 24 — bottom soil sampler, 25, 26 — shock absorber, 27 — axis, 28 — cheeks, 29 — bracket, 30 — loop, 31 — additional console, 32 — bushing, 33 — counterweight, 34 — flexible cable, 46 — tap. The photo is taken from publicly available sources](image-url)
In particular, it is a known fact that there exist two patents for similar sampling systems based on the multi-chamber syringe-type boxes: the US patent 2006090894 MПK Е21В 49/08, and the RU patent (11) 2 446 388(13) C1 (see Fig. 2, 3). However, the analysis of samples in all cases was carried out already on the surface.

**Research results.** Thus, based on the aforementioned with a view to solve problems of seismotectonics, one can talk about creating a submerged laboratory module with a sealed chamber, capable to operate at depths of up to 200 m. The module is lowered to a point either independently or from on board a research vessel (i.e., an instrument of the so-called inert type). Power supply sources are located on the platform. However, the option of supplying power via a cable from the surface cannot be ruled out. The operation of the module at the bottom can be controlled by autonomous small-sized submersible robotic platforms. The inert-type module can consist of the following basic components:

- a platform with a sealed instrument capsule and a sluice device for the forced overboard discharge (as an option) of an already studied portion of pore water at depth, and a system for pipeline purging from high-pressure air cylinders, and a system for stabilizing/reducing pressure in the capsule body, and membrane filters, and an energy supply system, and a radon-content analysis unit of selected configuration (with a pulse ionization chamber, or with the use of underwater gamma counters based on NaI (TI) scintillators, or HPGe-detectors). In the latter case, the introduction of a gamma counter into the bottom soil is possible when it is placed in the lower part of the auger column modified for marine conditions of the so-called sound procedure installation. It is also possible to appropriately use the modified commercial radon detectors, such as RAD7 (https://durridge.com) or RTM-1688 (SARAD GmbH), although there is no information about the use of these devices on underwater vehicles at sea depths of up to 200 m;

- a sampling device for collecting water samples in the environment of bottom sediments (a press-in type probe with a cone tip, or a rotary auger type probe additionally equipped, if necessary, with a gamma counter). The submersible device can be either built into a sealed capsule or externally coupled with it. It must be structurally possible to collect and store the pore fluid samples at 2 horizons as a
In addition to the system for collecting and analyzing the pore water samples for radon, the platform itself can be equipped with auxiliary sensors (including a gas chromatography unit), which will significantly expand the list of recorded parameters, although it will lead to an inevitable increase in the cost of the entire system. However, a combined option is also possible, when the sampling system is installed on the platform in addition to the main CPT-equipment. A sampler for pore fluid from loose bottom sediments should initially ensure sampling from depths of at least 0.5−1 m below the reference seabed point. The converted bottom stations from LDEO and SIO Companies (USA), or ones similar to them, can also be considered as a basis.

For obvious reasons, the autonomous option will be much more complicated and expensive, because it must be additionally equipped with an ascent-submergence system, a point stabilization system, and a radar for determining the thickness of bottom sediments and their material composition, as well as an orientation system and drop weight. Moreover, there must be provided means to search for an emersed vehicle, made in the shape of a flashing beacon and/or an active radar reflector. Also, as in the inert version, it is possible to combine such a platform with other equipment-specific complexes for studying bottom sediments of marine areas [11]. The option of equipping submerged modules of both types with radon analyzers based on HPGe or other types cannot be ruled out, even despite its high cost. However, in a technical sense, this option will most likely be much easier to implement in practice.

As an intermediate option, a battery-type submersible ampulized system can be proposed. In this case, after sampling at selected points in the shelf area, ampoules filled with pore fluid rise to the surface along with the platform, or float to the surface in the certain sequence, as they are filled, with the help of additional equipment. As soon as they are delivered on board the vessel, they will immediately be sent to the laboratory for analysis. As a matter of course, the floating part...
is equipped with a detection device (a flashing light and a radio signal for direction finding).

It is certain that when using devices of both types, there is a necessity to take into account not only the topography and structure of seabed, but also the composition and thickness of bottom sediments. The presence of the silt thick mass of soupy consistency will be an obstacle to the planned measurements. In such cases, an indirect additional option for solving this problem can be the use of modules for continuous registration of radon in the near-bottom part of the shelf, located on the so-called gliders [12–14]. In particular, determining the radon content in the near-bottom part of the shelf may allow roughly outlining the tectonic disturbance at the stage of preliminary searches, especially that in the active phase, certainly if the “picture” is not distorted by gas seeps, near-bottom flows or submarines sources. However, the disadvantage of this scheme is the revealed sharp difference in the radon content within the bottom sea waters and bottom sediments.

**Scientific Novelty and Practical Significance.** When conducting surveys at shore NPP sites, it is necessary, apart from radonometry on land, to carry out works in the water area. For radonometry of the shelf zone in the aims of seismotectonics, it is necessary to have equipment of a completely different type alternatively to numerous existing installations used in oceanology and marine geology. The platform of such a device can be of either active (self-propelled) or passive type (connected to the vessel). The instrumentation can be based both on existing commercial components that are already used, and on newly created overspecialized devices. The own schemes of such devices have been proposed.

For works in water areas, it also seems necessary to make adjustments to the methodology of such research, especially with regard to determining the activity of tectonic faults by radonometry methods, if they will be identified in the study area. It is not inconceivable that the version of the universal scale of tectonic fault activity in Earth’s crust developed for land can be adjusted for the conditions of water areas.

However, there is no doubt that radonometry in water areas to identify the tectonic activity of discovered fault zones can become another additional factor that increases the safety of sites and, as a consequence, the operational reliability of both nuclear power plants under construction and those already in operation. Moreover, such research is primarily required for sites located in highly seismic regions.

**Conclusion**

When conducting surveys at shore NPP sites, it is necessary, apart from radonometry on land, to carry out works in the water area. For radonometry of the shelf zone in the aims of seismotectonics, it is necessary to have equipment of a completely different type alternatively to numerous existing installations used in oceanology and marine geology. The platform of such a device can be of either active (self-propelled) or passive type (connected to the vessel). The instrumentation can be based both on existing commercial components that are already used, and on newly created overspecialized devices. The own schemes of such devices have been proposed.

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