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Development of the radiation situation monitoring system based on fiber-optic sensors for pools of nuclear power plants

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Abstract. The necessity of development of the remote monitoring system of the radiation situation based on fiber-optic sensors for pools of nuclear power plants is substantiated. New method of building of communication line with fiber-optic sensor for controlling exposure dose of radioactive radiation in the large range of changes (several orders of magnitude) in remote mode is suggested. The design of sensor to provide measurements for long distance (more than 10 km from the location of the monitoring center) is developed. Functional capabilities of the fiber-optic sensor are identified. Experimental results are presented.

Keywords: fiber-optic sensor, exposure dose, fiber optic communication line, laser radiation, γ-radiation, spray pools

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Материалы конференции
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Разработка системы контроля радиоактивной обстановки на основе волоконно-оптических датчиков для водных бассейнов атомных электрических станций

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Аннотация. В статье обоснована необходимость разработки системы дистанционного контроля радиоактивной обстановки на основе волоконно-оптических датчиков для водных бассейнов АЭС. Предложена новая конструкция волоконно-оптических датчика, определены его функциональные возможности. Представлены результаты экспериментальных исследований.

Ключевые слова: волоконно-оптический датчик, экспозиционная доза, волоконно-оптическая линия связи, лазерное излучение, гамма-излучение, брызгальные бассейны

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Introduction

In the modern world, environmental degradation is constantly happening for various reasons [1–9]. This is due to both objective and subjective factors [10–16]. One such factor is related to the increasing use of radioactive materials in various fields of industry, energy, and science [17–19]. In this case nuclear power plants are the most dangerous objects [20–24]. Despite the large number of protective screens and ceilings, has increased the number of radioactive releases, the consequences of which cannot be eliminated for a long time. In addition to the reactors, the spray pools used for continuous cooling of NPP equipment pose a danger. In the case of leakage, spray pools also often become sources of releases into the atmosphere due to the ingress the liquid radioactive waste into the water. Due to the presence of a nozzles system, some of drops containing radionuclides are carried by the wind outside the spray pools. Moreover, the natural water evaporation from the pool surface also leads to a change in radiation situation in the atmosphere. So, this is the reason, why the great attention is paid to possibility if control the radiation level in pools of nuclear power plants.

The great attention is paid to possibility of remote control the radiation situation in pools of NPP. Monitoring of the radioactive radiation power is associated with several difficulties. Such control must be carried out continuously in real time Moreover, in some cases it is necessary to carry out the control in automatic mode at the distance of several kilometers from the location of the monitoring center. Most dosimetry devices cannot cope with this task. Devices often go off, and communication systems, which are used for transmitting information about radiation level to monitoring center, are out of order because of radiation accumulation [25–27]. The maintenance of such monitoring systems is rather difficult, due to the radiation accumulation on the instrument case and its functional units, which poses a great danger to humans.

One of the ways of implementation the constant control of radiation level is the use of fiber-optic sensors. But sensors developed nowadays could not provide measurements at a high D_R value due to the long-term natural relaxation of the optical fiber.

Since the exposure dose of radiation in monitoring zone can change by several orders of magnitude in a fairly short period of time, the natural relaxation of optical fiber, which is used in sensors, can take 10^6 s and more.

Moreover, it is impossible to use more powerful radiation sources in fiber-optic sensors developed nowadays (sensors based on the laser radiation polarization under the γ-radiation influence provide measurements on low powers of about 5mW). The use of more powerful radiation is not possible because of the risk of damage photosensitive layer in photodetector module. Thus, the development of the radiation situation monitoring system based on fiber-optic sensors capable of withstanding high levels of exposure dose, is extremely actual.

Materials and Methods

It is necessary to provide additional research of γ-influence on the optical fiber for develop the system of monitoring the radiation situation based on the fiber-optic sensors for pools of nuclear power plants. To provide the research we have assembled an experimental setup, which was discussed previously, as well as previously obtained experimental results [25–29]. In contrast to similar research, losses measurements were carried out both at the moment of γ-radiation influence on optical fiber, and immediately after its termination. In this case, there is no large time interval between the γ-radiation influence and the beginning of measurements.

The radiation-induced losses were determined with using the following formula:

$$a_s = 10\log(P_{out} / P_{in}) / L, \quad (1)$$

where P_{in} is the power input into the optical fiber, P_{out} is the power output from the optical fiber, L is the length of the optical fiber.

A set of transmitting and receiving optical modules from one company was used for measurements, allowing to obtain a higher signal-to-noise ratio of the recorded optical signal at a low power of laser radiation. Modified transmitting module DMPO131-23M (company Dilaz) transmits at a wavelength λ = 1550 nm at a radiation power from 0 to 5.4 mW. Receiving optical module DFDMSH40-16M (company Dilaz) has highly sensitivity in a wavelength of 980–1550 nm. Fig.1 shows the dependences of the losses a_s in single-mode fibers with various alloying percentage from the exposure dose of γ-radiation.

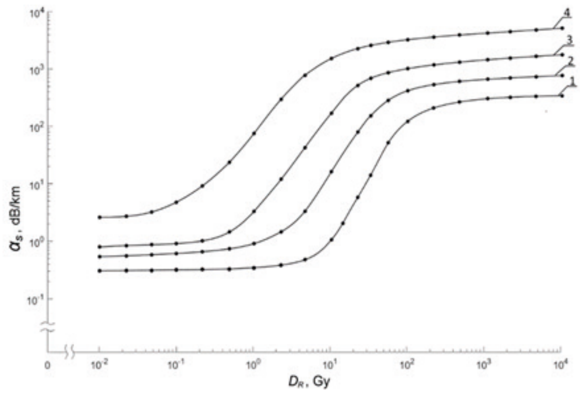

Fig. 1. Dependence of the α_s changes on irradiation dose D_R at a wavelength λ = 1550 nm on single-mode fiber with a SiO_2–GeO_2 core at T = 294.2 K

Curves *1*, *2*, *3* and *4* correspond to different alloying in %: 1.5; 4.0; 10.0 and 20.0

Analysis of the obtained results show that the velocity of color centers in optical fiber under the γ-radiation influence depends on the change in the alloying percentage. In a case of increase in alloying percentage the losses in optical fiber increase, sensitivity to changes of exposure dose of radiation. The increase of fiber optic sensitivity to D_R changes allows to register the changes in small exposure dose values, which lead to decrease of the laser radiation power at the output of FOCL by 0.2 dB.

Fig. 2 shows the research results of velocity of the optical properties recovery after γ-radiation influence.

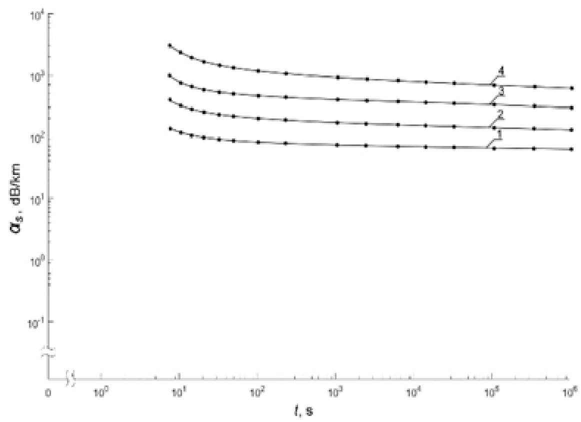

Fig. 2. Changes of losses α_s vs t at the wavelength λ = 1550 nm on single-mode fiber with SiO_2–GeO_2 core at T = 294.2 K

Curves *1*, *2*, *3* and *4* correspond to different alloying in %: 1.5; 4.0; 10.0 and 20.0

Obtained results show that with an increase of the alloying percentage of optical fiber, the relaxation velocity of color centers increases. Optical properties of fiber recovery proceeds faster

Results and Discussion

Obtained results make it possible to propose the following design of the fiber-optic sensor as the basis for the system for monitoring the radiation situation in the NPP pools. An optical fiber with 200 m long with a SiO_2-GeO_2 core with alloying 20%, which connects to an optical fiber with a pure quartz core through optical connectors. To accelerate the relaxation natural process of fiber in this design is used the previously developed method to control the *E* center formation for trunk FOCL. To test the efficiency of the proposed design, was provided the research of velocity of the optical properties recovery after γ-radiation influence with a dose of 100 G.

In this study, we used pulsed laser radiation with a wavelength $\lambda = 1310$ nm with a duration of 0.1 s with various powers during 10 s. The measurements were made with a laser radiation of various powers. The research results are presented in Figs. 3 and 4.

Analysis of the obtained results confirmed the possibility of increase the relaxation velocity with using the additional laser radiation. The optical properties recover in less 10 s. Moreover, as the result of the research it was found, that the optical fiber recovery proceeds faster using pulsed laser radiation, rather than continuous.

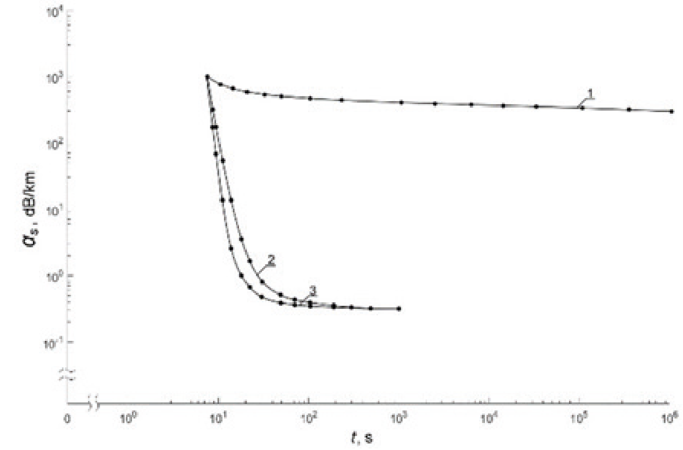

Fig. 3. Dependence of the change in losses α_s on time *t* at a wavelength $\lambda = 1550$ nm for single-mode fiber with a SiO_2-GeO_2 core (alloying 10.0 %) and polymer cladding at $T = 294.3$ K

Curves *1*, *2* and *3* correspond to different laser radiation powers at wavelength $\lambda = 1310$ nm in mW: 0; 40; 80

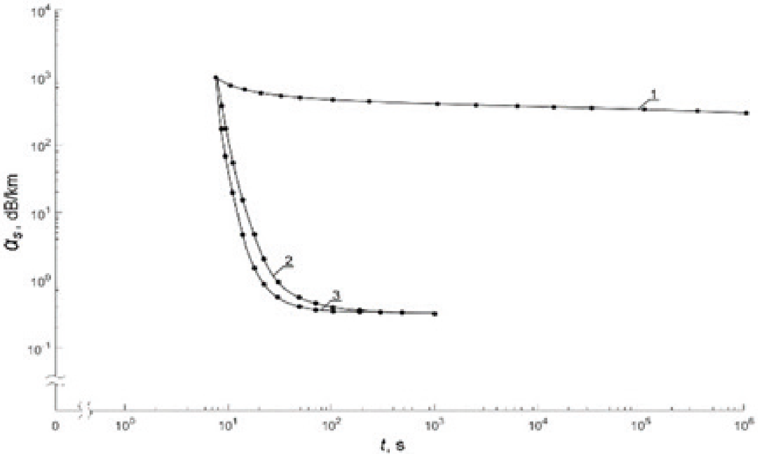

Fig. 4. Dependence of the change in losses α_s on time *t* at a wavelength $\lambda = 1550$ nm for single-mode fiber with a SiO_2-GeO_2 core (alloying 10.0 %) and polymer cladding at $T = 294.3$ K

Curves *1*, *2* and *3* correspond to different laser radiation powers at wavelength $\lambda = 1310$ nm in mW at: 0; 20; 40

Conclusion

Obtained results showed a reliable work of developed sensor in continuous mode. Using it allows to control the radiation dose from 0.1 to 1000 G in real time in NPP pools.

Moreover, the developed fiber-optic sensor for remote control of radiation situation has one feature, that differed it from the previously used. At a certain value of radiation exposure dose and power of the additional laser radiation, a static equilibrium can occur between two processes: color centers formation and their relaxation. Losses value increases for a certain period less than 1% from its initial state. In this case, fiber-optic sensor for monitoring radiation situation will be in standby mode of a radioactive release. In this case, influence of the background γ-radiation, which is also present in pools of nuclear power plants, is successfully compensated.

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