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EXPERIMENTAL STUDY OF FOAM CONCRETE AS A FIRE PROTECTION MATERIAL AND A MATERIAL CAPABLE OF ABSORBING γ-RADIATION

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An analysis of the accidents at nuclear power plants and power stations which are accompanied by high temperatures and radiation exposure of high intensity was conducted. Methodologies for identifying of fireproof ability and the determination of the absorption of γ-radiation were proposed. Requirements to experimental prototypes were presented. A fireproof performance and relaxation coefficient of γ-radiation of prototypes from foam concrete were determined. The researches of foam concrete on the subject of fire protection of metal structures and its ability to absorb γ-radiation have shown its effectiveness for its use to protect structures that are exposed to high temperatures and γ-radiation were carried out. Modern development construction encourages to usage of new materials (foamed concrete, aerated concrete, etc.), which would give an opportunity to reduce the consumption of materials and construction costs, and improve heat and ionizing protection while being eco and efficient in terms of energy saving and sufficient strength of the reactor building. The research of foam concrete held to determine the possibility of its use as a flame retardant material and material, which can absorb γ-radiant. For the experimentally and theoretical researches were developed two methods of research: for determine the ability of fire retardant foam and for determination of the absorption of γ-radiant of foamed concrete. Conducting research on the subject of fire protection foam concrete metal structures and its ability to absorb γ-radiant have shown its effectiveness and confirmed the possibility of using it in the construction of the protective membrane reactors.

Keywords: foamed concrete, fire retardant, fireproof ability, critical temperature, thermal insulation capacity, γ-radiant, protection of critical infrastructure.

Introduction. Explosions at a nuclear power plant and fossil fuel burning power station are always accompanied by high temperatures and high intensity of radioactive effects. Examples of such accidents are: Chernobyl disaster, the Fukushima Daiichi nuclear disaster and Vuhlehirska power station, which led to loss of life, big material and economic losses.

The main building materials, which are used in buildings with a high heat release and ionizing radiation (protective reactor covers of nuclear power plants, special structures (tombs, enterprises), health care centers, etc.), are concrete, reinforced concrete and heavy metal. Absolutely, one of the most difficult for the temperature operating conditions is nuclear power plants. On these facilities, from a standpoint of a temperature effects, the most vulnerable are designs of biological protection. More often biological containment buildings are the emplacement, which has a nuclear power plant and other processing equipment, which is the source of ionizing radiation.

Being in the alert condition of processing equipment protection cover must stand up to sublime heat impact, ensure the localization of its volume in all radio-active materials, which are emanating by the accident and the environment protection from ionizing radiation.

Particular attention in depletion of such objects should be given to a system of accidents prevention and emergencies (fires, etc.), which include under hardware technical area control of high-grades and other hazards, including their impact on engineering structures.

Nowadays we know different shapes and designs of containment buildings, each of those has its own advantages and disadvantages, so the choice of shielding designs should consider conditions of construction, operation and possible accidental impacts.

Modern development construction encourages to usage of new materials (foamed concrete, aerated concrete, etc.), which would give an opportunity to reduce the consumption of materials and construction costs, and improve heat and ionizing protection while being eco and efficient in terms of energy saving and sufficient strength of the reactor building.

Foamed concrete is a new generation of material, which differs from the previous type of looped system mesh, clears structuring, ability to better redistribution of loads, heat and sound insulating ability. This is achieved through the use of modern foam accordingly selected cements, additives and fillers.

Review of publications. Study [1] showed positive (light weight, good sound insulation and high performance) and negative properties (low strength, high water absorption) of foam concrete.

The authors of [2] carried out experimental studies of the fire protection ability of foam concrete slabs for steel structures. The authors revealed the heating dependencies of the prototypes and evaluated the fire protection ability of foam concrete. In study [3], an express methodology for assessing the fire protection ability of coatings was proposed and substantiated. The essence of the methodology is to determine the fire protection ability of the coating during thermal exposure to the test sample and to determine the time until the fire resistance limit state occurs. The peculiarity of this methodology is that the test results allow to draw a conclusion about the fire protection ability of coatings without additional mathematical calculations, but depending on the coating thickness. In paper [4] the authors investigated an enclosing building structure made of structurally insulating foam concrete and showed the effectiveness of using foam concrete as a fire protection material. Famulyak Yu. at al [5] substantiated the effectiveness of cellular concrete for fire protection of standard profiles steel building structures, but the technology of its application (use) remained unjustified. In study [6] is to investigate the effect of incorporating bio-based aggregate namely oil palm shell (OPS) into lightweight form concrete in terms of strength properties and fire resistance. The authors showed that the inclusion of environmentally friendly aggregate OPS improved the fire resistance of lightweight foam concrete, which can be used as an alternative solution for non-load-bearing walls. A scientific study [7] has shown that the density of foam concrete has a major impact on the ability to insulate temperatures in a fire using a standard material preparation process. The results indicate the usefulness of foam concrete in terms of isolating fire temperatures for discontinuous partition filling that are consequently a real alternative to dedicated solutions in the field of passive fire protection. The authors [8] have shown that fire resistance and thermal conductivity increase with increasing concrete density. Obtain the required density and mechanical properties of ultralight concrete, various aggregate compositions were investigated using different components, such as plasticiser, lightweight aggregates, foaming agents and mineral admixtures. It was shown that the behaviour of ultralight concrete during a fire depends on the proportions and components of its mixture.

Considering the above, the study of foam concrete for its use as a fireproof material and a material capable of absorbing is an urgent scientific and technical task. Research on its application in the construction industry related to nuclear power plants will also be of interest.

Formulation of research purpose. The main goal of the article is investigating the fire-retardant efficiency and γ-radiant absorption capacity of foam concrete.

Methods and Research Results. The research of foam concrete held to determine the possibility of its use as a flame retardant material and material, which can absorb γ-radiant.

For the experimentally and theoretical researches were developed two methods of research:

- 1st is for determine the ability of fire retardant foam;
- 2nd is for determination of the absorption of γ-radiant of foamed concrete.

1. Determine the ability of fire retardant

1.1. Method of determining the ability of fire retardant

For the tests were used following elements:

- furnace for thermophysical checkout of compact segments of building structures and individual units of butt joints [9, 10];
- measuring equipment according to [11] and equipment for photographic and video;
- supporting structures for the installation of prototypes.

The temperature control in the furnace and in the experimental samples was carried out with thermal converter in a number of 4 units. The set consisted of chromel-alumel thermocouples, diameter of which is 0.7 mm and 1.5 mm in the amount of two pieces 2.5-3.0 m long insulated with ceramic torque. Thermal converters, diameter of 0.7 mm, were installed in the experimental samples of foam concrete to control the temperature in them, and a diameter of 1.5 mm - in the oven for temperature control in its volume, during the experiment.

Thermal converters in the furnace [12] (Fig. 1) and in the experimental samples 1 to thermotransducer of MNG-0298 (metrical noetic gage) brand which took information from the 4 thermal converters and passed it to a personal computer (PC) for recording and further processing of the results.

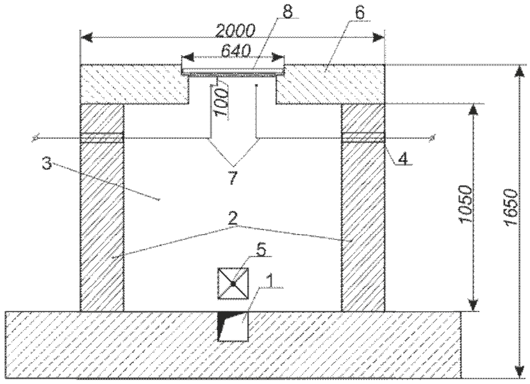

Fig. 1. Furnace for thermal and physical testing of compact segments and their individual nodes and abutting joints, where: 1-waste-gas flue; 2- furnace walls; 3- flame tube; 4-holes for thermal converters installation; 5- heating flue of flame; 6- removable top cover (reference design); 7- thermal converters of measuring the temperature in the furnace; 8-prototype

In accordance with the National Standard [13], for the samples of metallic constructions with fireproof coverages, that is tested with no-load on the sign of loss of carrying capacity (R), the maximum state for steel constructions is exceeding of temperature of metallic standard above his set temperature on 480 ^{o}C. Also, to assess the fire protection efficiency of foam concrete depending on the thickness, can be used the method presented in [14, 15].

At the test of non-load-bearing constructions on the loss of heat sealed ability (I), exceeding of the temperature standard on his unheated surface should occur at 180^{o}C of the original one.

In the role of a prototype was accepted 5mm thick metal plate (Fig. 2), which was applied fireproof material with foamed concrete of different thicknesses 20, 40, 60 mm. On each experimental sample was placed two thermocouples with a diameter of 0.7 mm with unheated side.

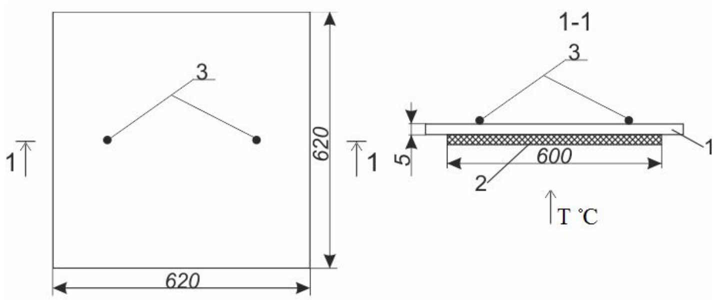

Fig. 2. The locations of the thermocouples on the sample test, where:
1- metal sheet; 2- fireproof material; 3- thermocouples with the chromel alloy type

1.2. Samples for determining the fire retardant ability

For prototypes used a metal plate (steel)-size 620x620x5 mm, coated with a layer of foam of varying thickness. Tolerance on width and length of the metal plate does not exceed ± 5 mm and thickness ± 0,5 mm.

According to the developed technology on the one side was applied layer of fireproof material thickness design. On the other side equidistant from the metal plate mounted (according to DSTU EN 1363-1:2023), two thermocouples with the chromel alloy type. From the unheated side metal plate was covered by thermally insulating mineral-wool plate according to DSTU N-P B V.1.1-29:2010, thickness of 20 ± 5 mm.

All three marks were made on samples of two samples of twins (Table 1).

Table 1

Main parameters and characteristics of prototypes

№	Brand of standard	Quantity, pieces	Brand of foam concrete, density, kg/m^3	Thickness of the foam concrete, mm
1	P-1	2	D800	20
2	P-2	2	D800	40
3	P-3	2	D800	60

For bonding foam concrete panels to metal plate was used glutinous mass «TI-1K-A», manufactured by TU U 24.6-31522416-2004. This material appeared not combustible, non-explosive and non-toxic.

Benefits of applied fireproofing adhesive mass compared to commonly used cement or mud was because of recommendation for using up to temperature 1159 °C and kept at this sufficient strength, adhesion and durability.

1.3. Determination of fireproof ability

In figures 3, 4 and 5 shows the results of averaging the temperature distribution in the furnace and a metal plate, prototype brands P-1, P-2 and P-3, during the experiment.

Temperature conditions in the furnace $T_{furnance}$ was created by using jets, which ran on diesel fuel, with air-feeding.

During the experiment, the monitoring of the critical temperature for the insulated ability for walling (Tcr_1=200ºC) and the bearing capacity of metal structures (Tcr_2=500ºC). The value of the initial temperature before the experiment was T_0 = 20 ºC.

$Tcr_2 = T_0$+480=20+480=500ºC – carrying capacity(R).

$Tcr_1 = T_0$+180=20+180=200ºC – heat sealed ability(I);

After cooling the furnace prototypes were dismantled and inspected.

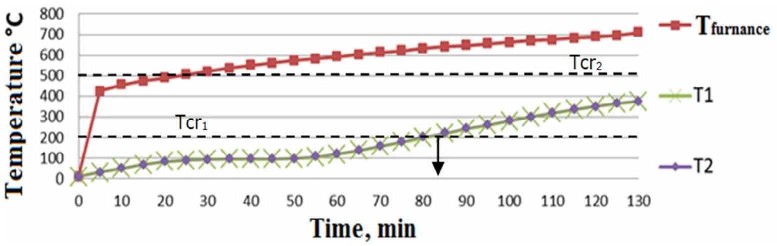

Fig. 3. The average value of warming up prototypes of P-1.1 and P-1.2

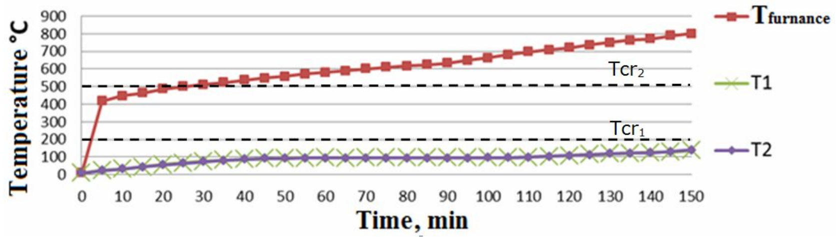

Fig. 4. The average value of warming up prototypes of P-2.1 and P-2.2

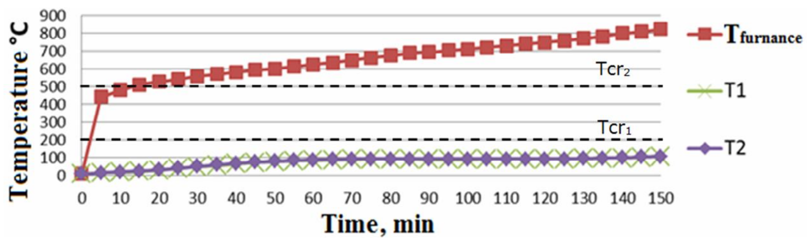

Fig. 5. The average value of warming up prototypes of P-3.1 and P-3.2

Doing analyze of the obtained averaged results (for two samples twin) studies of flame retardant properties of the test specimens were made the following conclusions:

– samples of P-1 – 20 mm thick foam concrete:
- limit of fire resistance for load capacity of at least 130 min, so R130 is ensured;
- limit of fire resistance for heat sealed ability amounted to no less than 81 minutes, it is mean that I 81 is ensured.

– samples of P-2 – 40 mm thick foam concrete:
- limit of fire resistance for load capacity of at least 150 min, so R150 is ensured;
- limit of fire resistance for heat sealed ability amounted to no less than 150 minutes, it is mean that I 150 is ensured.

– samples of P-3 – 60 mm foam concrete tile:
- limit of fire resistance for load capacity of at least 150 min, so R130 is ensured;
- limit of fire resistance for heat sealed ability amounted to no less than 150 minutes, it is mean that I 150 is ensured.

2. Determination of γ-radiant absorption of foam concrete

2.1. Methods of determination of the absorption γ-radiant

Scheme of the experimental setup is shown in Fig. 6.

Detector of γ-radiant (1) located at some distance L from the source of radiation (3). Consistently, between source (3) and detector (1) were established prototypes (2) of different types (species) of concrete and be measured for the amount of γ-radiant D_n for each type of concrete.

Based on the data, obtained during the experiment, determined the relaxation rate γ-radiant μ, which is determined from the formula:

$$D_n = D_o \times e\mu d, \quad (1)$$

where: D_o – the absorption γ-radiant without prototypes; D_n – the absorption γ-radiant n designs; μ- relaxation rate of γ-radiant; d – thickness of the sample.

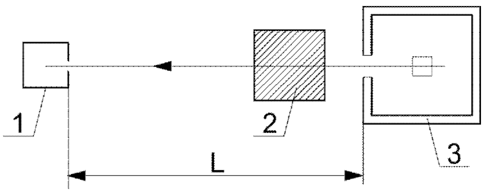

Fig. 6. Scheme of the experimental setup 1- detector of γ-radiant; 2- the sample; 3- radiating unit

2.2. Samples for the determination of the absorption of γ-radiant

Prototypes were made of foam concrete and conventional concrete the following types:

1. Foam concrete with a density of 800 kg/m^3;
2. Foam concrete with a density of 1200 kg/m^3;
3. Foam concrete with a density of 700 kg/m^3;
4. Foam concrete with a barium;
5. Fine grain concrete with a barium;
6. Fine grain concrete with a plumbum;
7. Fine grain concrete with a graphite;
8. Fine grain concrete with a density of 1800 kg/m^3.

Was determining factor weakening of γ-radiant isotope cobalt-60.

2.3. Determination of the absorption of γ-radiant

Based on the results of the studies were found relaxation rate of γ-radiant. The coefficient μ for all test specimens are given in Table 2.

After analyzing the survey results for the amount of γ-radiant of various types of concrete can draw the following conclusions:

- effectiveness of concrete to absorb γ-radiant can be characterized by the product of the volumetric weight by a factor (without thickness);
- higher rates of easing γ-radiant than conventional concrete (in 1.3 ÷ 1.6 times) is in fine concrete with barium and plumbum;
- they are commensurate with relaxation factor of γ-radiant of super-heavy concrete (concrete heavy natural or artificial aggregates with a density of 2700 kg/m^3), which is 0.120 ÷ 0.140. It also shows that

the fine grain concrete with barium and plumbum is effective than normal concrete (in 1.6÷1.8 times) due to significantly less weight;

- other examples are the coefficients of γ-radiant on relaxation times less than normal concrete, which confirms that the lighter material is less protection against γ-radiant;
- foam concrete with a bulk weight of 1200 kg/m^3 showed relaxation rate of γ-radiant similar to fine grain concrete with graphite (bulk weight of 1800 kg/m^3), indicating its significant effectiveness in weight (1.5 times).

Table 2

The results of determine the relaxation factor γ-radiant

Type of ironed sample concrete	Volumetric weight, kg/m^3	The thickness of the sample, mm	Coefficient μ
Foam concrete	800	40	0.018÷0.021
Foam concrete	1200	40	0.030÷0.033
Foam concrete	700	40.2	0.012÷0.014
Foam concrete with a barium	800	30.5	0.001÷0.002
Fine grain concrete with a barium	1500	40.2	0.120÷0.145
Fine grain concrete with a plumbum	1700	40.5	0.121÷0.148
Fine grain concrete with a graphite	1800	40.5	0.030÷0.033
Normal concrete	1800	40	0.090÷0.100

Conclusions. A set of experimental studies has shown that foam concrete is an effective fire protection material and can be used for fire protection of steel building structures. It was found that with a foam concrete thickness of 20-60 mm, the fire resistance limit of a steel structure in terms of load-bearing capacity is 130-150 minutes and in terms of thermal insulation capacity – 80-150 minutes.

The study of γ-radiation absorption by conventional foam concrete shows that only fine-grained concrete with barium and lead has higher γ-radiation attenuation coefficients than conventional concrete (1.3÷1.6 times). They are commensurate with the γ-radiation attenuation coefficient of super heavy concrete, which is 0.120÷0.140. This also indicates that fine-grained concrete with barium and lead is more effective than super heavy concrete (1.6÷1.8 times) due to its lower weight. Studies have shown that lighter material provides less protection against γ-radiation. Foam concrete with a bulk density of 1200 kg/m^3 showed a γ-radiation attenuation coefficient similar to fine-grained concrete with graphite (with a bulk density of 1800 kg/m^3), which indicates its significant efficiency (1.5 times).

Conducting research on the subject of fire protection foam concrete metal structures and its ability to absorb γ-radiant have shown its effectiveness and confirmed the possibility of using it in the construction of the protective membrane reactors. For more detailed information in future, we will be working under computer simulation with proposed mathematical model as was showed in [16, 17].

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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ПІНОБЕТОНУ ЯК ВОГНЕЗАХИСНОГО МАТЕРІАЛУ ТА МАТЕРІАЛУ, ЗДАТНОГО АБСОРБУВАТИ γ -ВИПРОМІНЮВАННЯ

Актуальність. Проведений аналіз аварій на атомних електростанціях та електростанціях, показав, що дані інциденти супроводжуються високими температурами та опроміненням високої інтенсивності. У аварійному стані технологічне обладнання захисної оболонки повинно забезпечувати локалізацію у своєму об’ємі усіх радіоактивних матеріалів, які виділяються при аварії, та забезпечувати захист навколишнього середовища від іонізуючого випромінювання, а також протидіяти високим температурним впливам. Сьогодні відомі різні форми і конструктивні рішення захисних оболонок, кожна з яких має свої переваги та недоліки, тому при виборі конструкцій захисних оболонок слід враховувати умови будівництва, експлуатації, та можливі аварійні впливи. Сучасне будівництво стимулює до використання нових матеріалів таких як пінобетон (газобетон), які дадуть можливість зменшити матеріаломісткість та витрати на будівництво, а також покращать тепло- та іонізуючий захист. **Мета**. Головною метою статті є дослідження вогнезахисної ефективності пінобетону та його γ-поглинальної здатності. **Основні результати.** Для досліджень було розроблено два методи: для визначення вогнезахисних властивостей пінобетону та для визначення ефективності поглинання γ-випромінювання пінобетоном. Встановлено, що вогнезахисна здатність пінобетону для сталевих конструкцій становить від 130 до 150 хв для товщини плит від 20 мм до 60 мм відповідно**.** Дослідження величини поглинання γ-випромінювання пінобетоном показали, що пінобетон з об'ємною вагою 1200 кг/м^3 має коефіцієнт послаблення γ-випромінювання аналогічний до дрібнозернистого бетону з графітом (з об’ємною вагою 1800 кг/м^3), що вказує на його значну ефективність (у 1,5 рази). **Висновки.** Комплекс експериментальних досліджень показав, що пінобетон є ефективним вогнезахисним матеріалом і може бути використаний для вогнезахисту сталевих будівельних конструкцій. Було виявлено, що при товщині пінобетону 20-60 мм межа вогнестійкості сталевої конструкції за несучою здатністю становить 130-150 хвилин, а за теплоізоляційною здатністю – 80-150 хвилин. Обґрунтовано ефективність використання пінобетону для захисту технологічного обладнання та його здатність поглинати γ-випромінювання.

Ключові слова: пінобетон, вогнезахист, вогнезахисна ефективність, критична температура, теплоізолювальна здатність, γ-випромінювання, захист критичної інфраструктури.

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EXPERIMENTAL STUDY OF FOAM CONCRETE AS A FIRE PROTECTION MATERIAL AND A MATERIAL CAPABLE OF ABSORBING γ -RADIATION

Actuality. An analysis of accidents at nuclear power plants and power plants has shown that these incidents are accompanied by high temperatures and high-intensity radiation. In an emergency situation, the technological equipment of the protective shell must ensure the localisation of all radioactive materials released during the accident within its volume, protect the environment from ionising radiation, and counteract high temperature effects. Today, there are various forms and design solutions for protective shells, each of which has its own advantages and disadvantages. Therefore, when choosing protective shell designs, it is necessary to take into account the conditions of construction, operation, and possible emergency impacts. Modern construction encourages the use of new materials such as foam concrete (aerated concrete), which will reduce material consumption and construction costs, as well as improve thermal and ionising protection. **Purpose**. The main objective of the article is to study the fire protection effectiveness of foam concrete and its γ-absorbing capacity. **Main results.** Two methods were developed for the research: to determine the fire-retardant properties of foam concrete and to determine the effectiveness of foam concrete in absorbing γ-radiation. It has been established that the fire resistance of foam concrete for steel structures ranges from 130 to 150 minutes for slab thicknesses from 20 mm to 60 mm, accordingly. Studies of the absorption of γ-radiation by foam concrete have shown that foam concrete with a bulk weight of 1200 kg/m^3 has a γ-radiation attenuation coefficient similar to that of fine-grained concrete with graphite (with a bulk weight of 1800 kg/m^3), which indicates its significant effectiveness (1,5 times). **Conclusions.** A series of experimental studies has shown that foam concrete is an effective fire-retardant material and can be used for fire protection of steel building structures. It was found that with a foam concrete thickness of 20-60 mm, the fire resistance limit of a steel structure in terms of load-bearing capacity is 130-150 minutes, and in terms of thermal insulation capacity – 80-150 minutes. The effectiveness of using foam concrete to protect technological equipment and its ability to absorb γ-radiation has been substantiated.

Keywords: foamed concrete, fire retardant, fireproof ability, critical temperature, thermal insulation capacity, γ-radiant, protection of critical infrastructure.

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У роботі обґрунтовано ефективність пінобетону як вогнезахисного матеріалу для сталевих будівельних конструкцій. Досліджено та показано, що пінобетон є здатен ефективно поглинати γ-випромінювання та може бути використаний для захисту технологічного обладнання біологічних захисних оболонок атомних електричних станцій.
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The work substantiates the effectiveness of foam concrete as a fire-resistant material for steel building structures. It has been researched and demonstrated that foam concrete is capable of effectively absorbing γ-radiation and can be used to protect the technological equipment of biological protective shells of nuclear power plants.
Fig. 6. Ref. 17.

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