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AN EXPERIMENTAL STAND FOR RESEARCHING THE PROPERTIES OF SPENT FUEL ASSEMBLY DRY STORAGE

О. Корольов, М. Яценко, Д. Климчук, С. Грищенко. **Експериментальний стенд для дослідження властивостей сухого зберігання відпрацьованих тепловиділяючих збірок.** В роботі проведено аналіз сучасного стану методів зберігання відпрацьованого ядерного палива, його обробки з урахуванням знаходження палива у відпрацьованих тепловиділяючих збірках (ТВЗ). В теперішній час найбільш поширені методи пов'язані із зберіганням у контейнерах для відпрацьованих тепловиділяючих збірок з наповненням речовиною, що має високу теплопровідність. Тому експериментальні методи дослідження властивостей зберігання відпрацьованих ТВЗ у контейнерах, є перспективними. В роботі проведено дослідження в зазначених напрямках за допомогою створеного експериментального стенду. Наведено опис самого стенду та послідовність проведення експерименту, в результаті чого повинні бути отриманні необхідні експериментальні данні. А саме було визначено режими нагріву в експериментальному підігрівачі, які близькі до реальних процесів нагрівання відпрацьованих ТВЗ, що завантажуються в контейнер З цією метою був використаний лабораторний автотрансформатор потужністю 4,6 кВт. Наступним завданням було визначення часу, необхідного для виходу нагрівача на постійний режим роботи Для цього було введено поняття постійної часу процесу нагріву. Для визначення вказаного параметра було використано тепловізор FLIR ONE, а також прилади, що дозволили визначати напругу на лабораторному автотрансформаторі. Вказане дозволило визначити залежності зміни температури нагрівача від часу та напруги, також напругу підігрівача, що моделює реальні режими нагріву. В роботі наведено термографічні результати вимірювання тепловізором основних ділянок стенду. Враховуючи, що потужність нагрівача має бути близько 1,5 кВт, стенд був виконаний герметичним з контролем тиску та урахуванням реальних режимів зберігання відпрацьованих тепловиділяючих збірок, де може бути пошкодження та тріщини контейнера. В результаті проведених експериментальних досліджень було визначено оптимальні режими нагріву підігрівача.
Ключові слова: відпрацьовані ТВЗ, сухе зберігання, експериментальний стенд, лабораторний автотрансформатор, тепловізор, постійна часу

O. Koroliov, M. Yatsenko, D. Klymchuk, S. Gryshchenko. **An experimental stand for researching the properties of spent fuel assembly dry storage.** The paper analyzes the modern methods of storing spent nuclear fuel and its processing, taking into account the finding of fuel in spent fuel assemblies. Currently, the most common methods involve storage in containers for fuel assemblies filled with a substance that has a high thermal conductivity. Therefore, experimental methods of researching the storage properties of spent fuel assemblies in containers are promising. In the work, research was carried out in the indicated directions with the help of the created experimental stand. A description of the stand itself and the sequence of conducting the experiment are given, as a result of which the necessary experimental data should be obtained. Namely, the heating regimes in the experimental heater were determined, which are close to the real processes of heating spent fuel assemblies loaded into the container. For this purpose, a laboratory autotransformer with a capacity of 4.6 kW was used. The next task was to determine the time required for the heater to go into constant operation. For this purpose, the concept of constant time of the heating process was introduced. FLIR ONE thermal imager was used to determine this parameter, as well as devices that allowed to determine the voltage on the laboratory autotransformer. This made it possible to determine the dependence of the change in the temperature of the heater on time and voltage, as well as the voltage of the heater, which simulates real heating modes. The paper presents the thermographic results of thermal imager measurement of the main areas of the stand. Taking into account that the power of the heater should be about 1.5 kW, the stand was made airtight with pressure control and taking into account the real conditions of storage of spent fuel assemblies, where there may be damage and cracks in the container. As a result of the conducted experimental studies, the optimal heating modes of the heater were determined.
Keywords: spent fuel assemblies, dry storage, experimental stand, laboratory autotransformer, thermal imager, time constant

1. Introduction

According to the "Joint Convention on the Safety of Spent Nuclear Fuel Management and on the Safety of Radioactive Waste Management", Ukraine undertook to comply with its provisions in the implementation of state policy in the field of nuclear energy use. In order to ensure the state policy in the field of spent nuclear fuel (SNF) management, the main areas of activity have been defined, one of which is to ensure long-term storage of SNF on the territory of Ukraine and the refusal to reprocess SNF of Ukraine's nuclear power plants at enterprises of the Russian Federation. In 2005, the American company Holtec International became the winner of the tender, with which, at the end of the same year, NAEC "Energoatom" concluded a contract for the design, licensing, construction and commis-

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sioning of the first stage of the centralized SNF storage facility. For a long time, for a number of reasons, the project was effectively frozen. In 2012, the Verkhovna Rada of Ukraine adopted a law on the construction of the SNF storage facility, which established the legal basis for the storage of SNF, the creation of a system and optimization of the SNF management structure. In 2014, the Cabinet of Ministers of Ukraine allocated 45 hectares of land in the exclusion zone for the construction of the CS SNF. In the same year, a real start was given to the construction of the storage facility. In 2015, NAEC "Energoatom" concluded with Holtec International an additional agreement to the 2005 construction contract. In 2017, NAEC "Energoatom", the financial institution of the US government Overseas Private Investment Corporation (OPIC) and the Central Storage Safety Project Trust (CSSPT, both - USA) entered into a loan agreement for the construction of the Spent Nuclear Fuel Central Storage (SNF CS). At the end of the same year, NAEK "Energoatom" began construction work. Currently, 15 PWR units (VVER) are in operation in Ukraine. Historically, Ukraine has implemented a scheme for transferring spent nuclear fuel to Russian factories in Ozersk and Zheleznogorsk for processing by chemically extracting valuable products (plutonium isotopes) for further re-introduction of these products into the fuel cycle. This scheme showed its inefficiency, and over time it was decided to abandon the export of spent fuel to the Russian Federation and to store the fuel on the territory of Ukraine. Currently, there is one VVER dry-type spent nuclear fuel storage facility in operation, and the Centralized VVER Spent Nuclear Fuel Storage Facility in the Exclusion Zone [1] is under construction. Therefore, it is necessary to study the properties of the elements of these storages.

2. Analysis of literary data and formulation of the problem

There are several approaches to the processing and storage of SNF:

– provides for the processing of SNF for the extraction of components and substances from it, the use of which is economically expedient in the future [2, 3, 4];

– provides for the processing of spent fuel with subsequent return of high-level waste to the country owning spent fuel;

– provides storage of spent fuel in a container and its disposal in deep geological formations;

– provides for long-term storage of SNF, which makes it possible to make a decision on further treatment of SNF, taking into account future technologies and economic factors.

The design decisions of nuclear power plants with reactors of the VVER-1000 type (in Ukraine, the number of operating reactors of the specified type is 13) provided for the removal of spent nuclear fuel to a stationary storage facility in other countries.

However, even during the times of the USSR, it became obvious that due to the limited capabilities of this repository, the impossibility of expanding it, as well as the lack of an opportunity to build a nuclear fuel reprocessing plant in the near future, there would be problems with maintaining the "viability" of the NPP [5, 6, 7].

Taking into account the current situation, the order of the Ministry of Energy of the USSR No. 361 of October 6, 1988 approved the project of the second stage of the Zaporizhzhia NPP, including the storage of spent nuclear fuel.

After the USSR ceased to exist, the export of spent nuclear fuel was stopped in 1993...1995. Based on the results of the analysis of the dynamics of the filling of the SNF pool, in 1993 Zaporizhzhia NPP began to search for alternative options for the storage of spent fuel.

The technology of "dry" containerized storage of SNF in reinforced concrete containers includes loading of spent fuel assemblies in the reactor pool into a steel canister with a fuel basket. The canister is sealed, and the internal space is filled with helium or other inert gas to provide heat removal from the spent fuel and prevent corrosion of the shells of fuel elements and fuel assembly elements. In turn, the steel canister is loaded into a transport container or a storage container, depending on the functionality of the container. The storage container is a massive concrete cylindrical vessel, which is placed on the storage site for 50...100 years, depending on the characteristics of the storage.

An illustrative example is the storage system with a concrete container of the American firm Holtec International – HI-STORM 100. The system consists of two separate components: a multi-purpose container (MPC), a HI-STORM 100 storage module [8, 9].

MPC is a storage system for spent fuel assemblies and is a cylindrical canister with a fuel basket, a base plate, a cover, a locking ring and a body. The body is completely made of stainless steel, except for neutron absorbers and aluminum inserts used to improve heat transfer. The main components of the canister are the canister body, the base plate, the lid, the vent and drain covers, and the sealing ring. The fuel basket, which is equipped with Boral neutron absorbers, provides criticality control, removal of residual heat generation and serves as a supporting element for the fuel assemblies. MPC is loaded with nuclear fuel and filled with helium to the value of several atmospheres. The MPC is then loaded into the HI-STORM 100 and transported to an open-air storage area.

The HI-STORM 100 container provides shielding and structural protection for a multi-purpose container during storage. Its side wall consists of simple concrete sandwiched between two carbon steel shells (Fig. 1).

The concrete container has four air intakes at the bottom and four outlets at the top to allow air to circulate naturally through the cooling cavity of the multi-purpose container inside. The inner surface of the HI-STORM 100 has guide steel fins welded to the inner shell for easy loading and unloading of the MPC and providing cooling air passage.

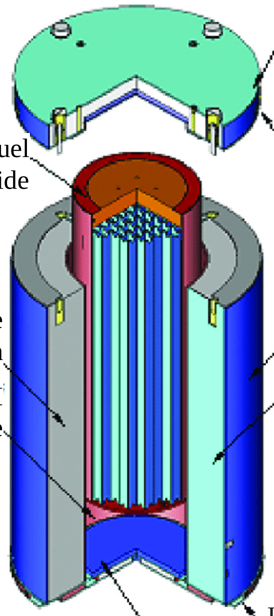

Fig. 1. Graphic representation of a HI-STORM 100 container with a multipurpose container inside

3. The purpose and objectives of the research

The main goal of the study is to simulate the real processes of storage of spent fuel in containers with fuel assemblies filled with helium, namely to obtain the key characteristics of the heater of the experimental stand.

To achieve this goal, the following tasks had to be solved:

– to build an experimental stand that simulates the real processes of storage of SNF in containers with fuel assemblies;

– to obtain the key characteristics of the heating processes of the heater in the specified stand.

4. Methods of conducting research and processing experimental data

Within the framework of the set tasks, work was carried out on the creation of an experimental stand for studying the process of heat exchange in a spent fuel storage container. As part of this work, the installation was assembled and a program of experiments was developed, including the study of normal operating conditions and emergency situations.

The installation is a pipe with a diameter of 85 mm (thickness – 5 mm) made of stainless steel of the X18H10T brand, which houses an electric heater assembled from two parts. Two flanges are installed on the ends of the pipe, the flange is attached to the upper end of the pipe with 6 M6 bolts, and the flange is welded to the lower end by argon-arc welding. The height of the assembled unit is 1440 mm. The installation is stabilized on a stand for easy access.

The diameter of the upper flange is 115 mm, the thickness in the area of attachment to the pipe is 25 mm. On the upper flange, there is a nozzle for connecting the power supply from the autotransformer, which also serves as a support segment for the heating element. Power is supplied to the heater through a special contact. On the right, there is a welded pipe for installing a pressure gauge of 16 kgf/cm^2. On the left is a welded nozzle for the installation of an experimental slit (a device used in experiments involving helium leakage). Instead of the gap, it is also envisaged to install a fitting for releasing the helium pressure. The general view of the upper part of the installation, namely the upper flange, with a nozzle for installing measuring equipment, is presented in Fig. 2.

The heater is two aluminum tubes connected together with circular fins. The maximum temperature of the heater is 200 °C. In this way, the thermophysical conditions of storage of spent nuclear fuel inside a steel container are simulated. The temperature will be measured with an infrared portable thermometer along the entire height of the outer wall of the container.

The lower segment is attached to the pipe by argon-arc welding. The heater is installed in the bottom of the lower segment by screwing it into the hole with M12 thread (Fig. 3).

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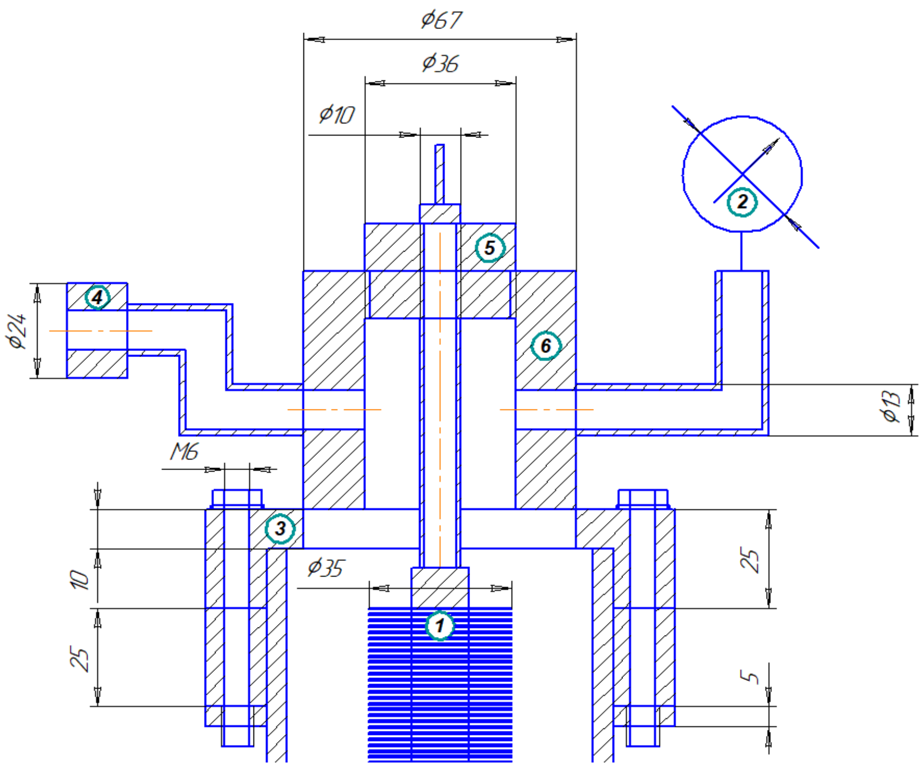


Fig. 2. The upper segment of the experimental setup (longitudinal section): *1* – electric aluminum heater, *2* – pressure gauge, *3* – upper flange (fastening to the pipe with M6 bolts), *4* – flange for installing the experimental gap, *5* – element of fastening the heater to the upper part of the flange, *6* – upper part of the flange with the nozzles of the devices

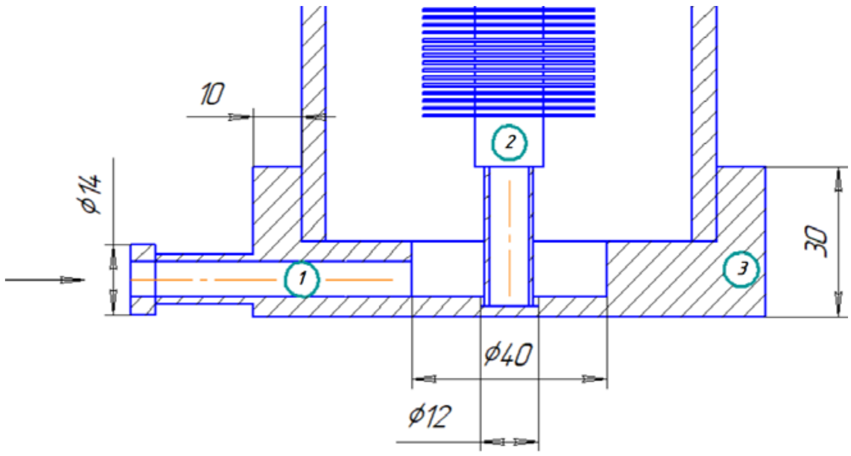


Fig. 3. The lower segment of the experimental setup (longitudinal section): *1* – helium inlet nozzle, *2* – heating element (installed in the lower flange), *3* – lower flange

A reducer will be attached to the helium inlet nozzle to change the pressure of the helium supplied to the installation. The approximate stationary pressure of helium will be *6...7* atm. Helium is planned to be supplied through a flexible pipeline from a cylinder. The general view of the installation is presented in Fig. 4.

The stand receives power from a laboratory autotransformer with a capacity of 4.6 kW with a set voltage of 100, 160 and 220 V. Independent devices were used as voltage meters. Direct measurement of temperature was carried out by an XA thermocouple and recorded by a MASTECH device. The device allows you to measure temperatures up to 200 °C with an accuracy of 0.1 degrees.

To increase the accuracy of measurement, FLIR ONE thermal imager [10] was used, which served to control the temperature and was connected to a mobile phone.

Fig. 4. Experimental stand. General view and upper nozzle

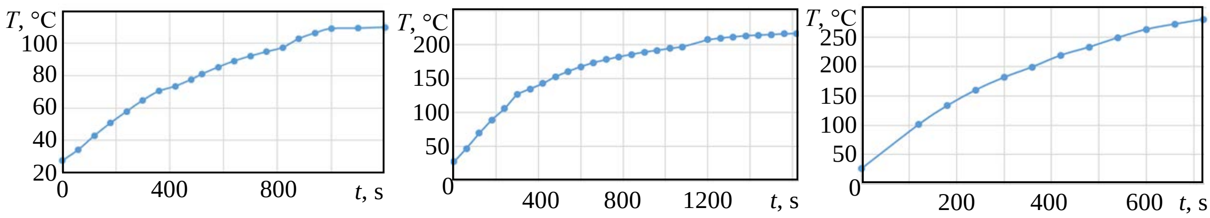
The supply voltage was measured by a MASTECH multivoltmeter. The voltage on the laboratory autotransformer was set with a voltmeter and then the experiment was conducted. Measuring devices are presented in Fig. 5.

Fig. 5. Laboratory autotransformer, MASTECH multivoltmeter, multimeter, FLIR ONE thermal imager

5. Results of experimental bench research

One of the main tasks of setting up the stand was to create such a power of the heater that would correspond to the power of fuel assemblies.

The second task was to determine the time constant of the heater to determine the time when the stand enters the measurement mode. For this purpose, the necessary voltage was set on the laboratory autotransformer, the heater was turned on, and after 60 seconds the temperature of the heater was fixed. Below are the graphs of the heating process (Fig. 6).



a *b* *c*

Fig. 6. Graphs of changes in the temperature of the heater depending on time and voltage: at a voltage of 100 V (*a*); 160 V (*b*); 220 V (*c*)

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The graphs show that the time constant of the heater was 540...560 seconds, that is, about 9 minutes. By heating, you can also judge the voltage applied to the heater. Obviously, it should not exceed 100 V.

Thermal imager data show that the surface temperature is unevenly distributed even on the heater itself, but within acceptable limits for the purposes of the experiment (Fig. 7).

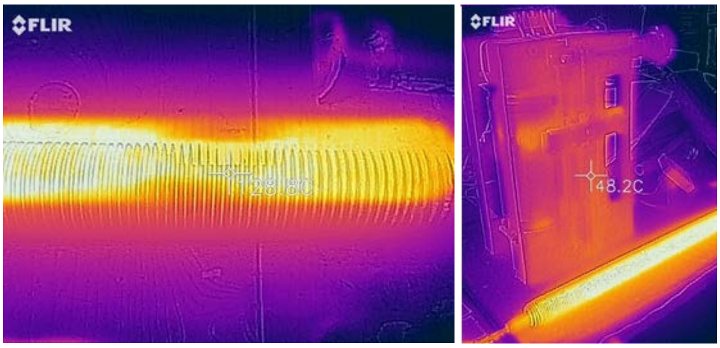

Fig. 7. Results of measuring the heating process with a FLIR thermal imager ONE

Conclusions

The paper analyzes the current state of spent nuclear fuel storage methods, its processing, taking into account the finding of fuel in spent fuel assemblies.

In accordance with the research objectives, an experimental stand was developed, the purpose of which is to study the modes of storage of spent fuel assemblies in containers filled with helium. A description of the stand itself and the sequence of the experiment are given.

As a result of the experimental studies, the optimal heating modes of the heater were determined, which simulates the temperature regime in the container for storing spent fuel assemblies. The time constant is 540...560 seconds, while the voltage does not exceed 100 V.

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