SAFETY ISSUES OF THE DRY STORAGE OF THE SPENT NUCLEAR FUEL

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Some issues of safety of the unique in Ukraine the Dry Spent Nuclear Fuel Storage Facility are highlighted. The analysis of temperature measurements of air, which cools storage containers of the spent nuclear fuel on the dry storage platform of the Zaporizhska NPP, is carried out. Factors, which influence on thermal conditions of storage containers, are defined. The approach for solving the problem of thermal processes identification in containers on storage platform is given. The results of investigation are shown safety of dry storage on Zaporizhska NPP.

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INTRODUCTION

Temporary dry storage is the one of popular strategies of handling with spent nuclear fuel (SNF) for countries with open fuel cycle it is. This strategy has been chosen as temporary method in Ukraine until making final decision about SNF treatment. On the Zaporizhska NPP the SNF store by dry method on the open area. Therefore, the problem of the safety ensuring during all time of storage requires investigation in details [1].

The safety of the Dry Spent Nuclear Fuel Storage Facility (DSNFSF) consists of three main components – Nuclear safety, Radiation safety and Safe thermal conditions. For last field the main problem is the definition of thermal state of containers and spent fuel assemblies inside container. These results will be especially important at stage of DSNFSF operating and modernization, for control and predicting thermal state of fuel during whole period of storage.

The problem of thermal state of containers with SNF is solved by many researchers [1–3]. But, unfortunately, the analysis of external factors which are influenced on thermal state of SNF inside storage containers was not carried out. For, example, one of important factor for aboveground open storage facilities is wind. The main goal of this paper is to consider wind influence on thermal state of the ventilated storage containers with SNF of WWER-1000 reactors.

1. PROBLEM DEFINITION

At Zaporizhska NPP the storage of the SNF is carried out in ventilated concrete containers which prototype is container VSC-24 of American companies “Sierra Nuclear Corporation” and “Duce Engineering and Services” [1].

Ventilated storage container (VSC) structure is shown at Fig. 1. Twenty four spent fuel assemblies (SFA) is placed into tight cluster storage basket (TCSB). TCSB filled with inert gas (helium), which circulates in the internal space of the basket due to natural convection caused by temperature difference of hot SFA and cold casing of basket.

TCSB is placed into a concrete casing which is the radiation protection barrier and protects the basket from mechanical damages and other effects of the environment.

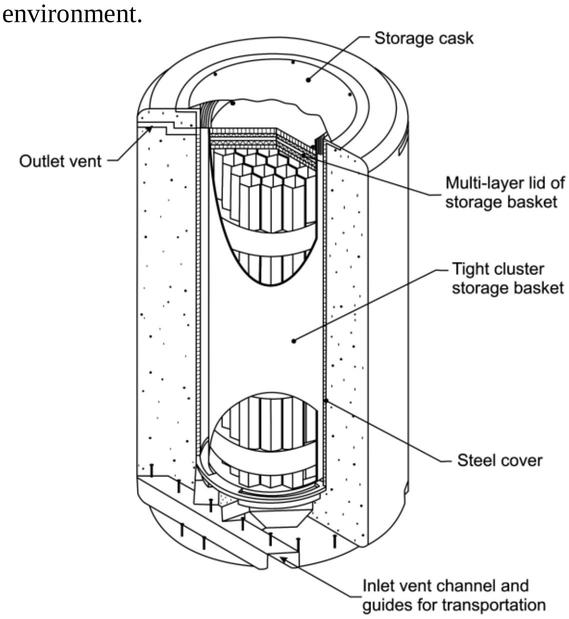

Fig. 1. Structure of ventilated container with spent nuclear fuel

Heat from basket surface is removed by natural air draft through cylindrical ventilating channel which is formed by basket casing and steel cover of concrete container casing. Heat transfer from SFA to the basket casing and from casing of TCSB to the container steel cover is carrying out by complex conductive-convective-radiative heat exchange.

Containers are located on the open barriered platform (Fig. 2), which was designed for placement of 380 ventilated containers.

The SFA are loaded into a basket after 5 years of storage in cooling pond. The calculated value of decay heat of single assembly is 0.909 kW [4, 5] and energy-release of each SFA is not more than 1 kW. From 2003 the spent fuel assemblies (SFA-A) with higher energy-release are used on Zaporizhska NPP. After six years of storage in cooling pond the SFA-A has energy-release

1.22 kW [4, 5]. Thus, there is a problem of storage of assemblies with energy-release more than 1 kW. Safety criteria places a limitation in 350 °C for the SNF cladding temperature inside TCSB.

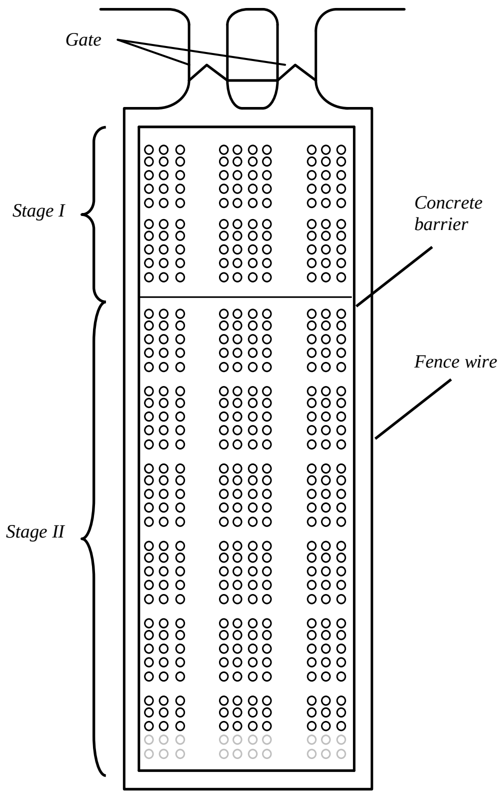

Fig. 2. The scheme of DSNFSF platform

The registration of temperature measurements on an exit from ventilating channels of the container is conducted for the monitoring of thermal state of VSC. The analysis of these measurements has allowed disclosing factors, which have an influence on thermal condition of VSC operation [6].

In calm conditions the heating of air in each channel of the container is almost identical (Fig. 3). In calm conditions for container №1 the maximal of ventilated air temperatures in channel 3 (see numbers inside the circle, Fig. 3) and minimal – in channel 2. Such distribution of temperatures remains at different values of ambient temperature (t_a). The Fig. 3 shows that heatings of ventilated air in each channel are almost equally. Differences are caused by non-uniform accommodation in basket SFA with different decay heat or local wind influence.

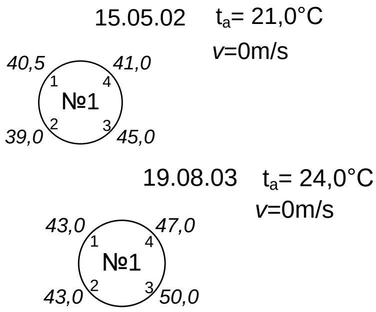

Fig. 3. Temperature measurements on exit of container ventilation channels in calm

Influence of a wind changes temperatures on an outlet from ventilating channels (Fig. 4). In the channel from windward the temperature is less than in other channels. It is caused by mixture of cold atmospheric air with heated ventilating air. The wind also causes redistribution of a cooling air stream inside VSC. The form of air motion was shown on Fig. 5. Therefore, detailed research of the wind influence on the maximum temperature in the containers is necessary.

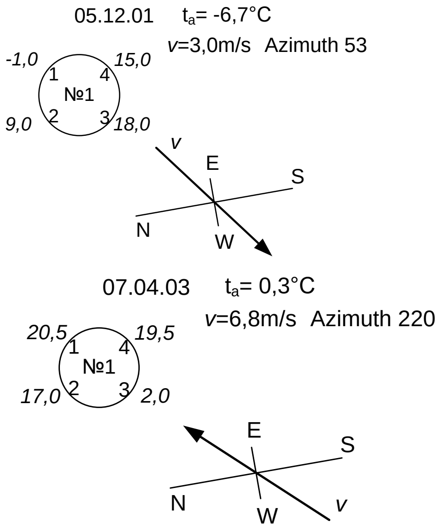

Fig. 4. Temperature measurements on exit of container ventilation channels depending on wind position

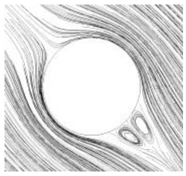

Fig. 5. The form of air motion near VSC

2. METHODOLOGY

The system of dry spent nuclear fuel storage which is used on Zaporizhska NPP is affected by strong influence of outer factors on thermal state of containers due to their operation on the open-air platform. So, during the numerical investigations of thermal processes it is necessary to consider the air moving both inside and outside of storage container.

The definition of thermal fields of solid body and fields of pressure, velocity and temperature of the cooling or the heating medium at known inner and outer influences is the object of a direct conjugate heat transfer problem. The methodology of definition of thermal state of containers in various wind conditions is, in general, based on multi-stage approach, which is described in [7]. The calculation area was divided on two parts: the first one is a single container with simplified TCSB and the second one is air, which is surrounding containers' group. The domain with surrounding air was used for the definition boundary conditions for domain with single container. In this case only gas-dynamic problem was solved and, as a result, the profile of air velocity which is leaking on container was defined. For the calculation domain with a single container the conjugate heat transfer problems were solved. It's allowed to detect thermal state of container with taking into account wind influence and calculate of parameters of cooling air in the outlet vents. The mathematical model of conjugate heat transfer problem was described in detail in [7]. The one of main parameter, which was used at calculation, is the equivalent heat conductivity coefficient; it was calculated in [8].

In this paper were considered few types of problems: single container and group of containers, both are in wind conditions. For the single container three directions of wind were modelled (Fig. 6). Containers group was considered in typical wind velocity for DSNFSF region and for this storage condition few types of container placement were modelled.

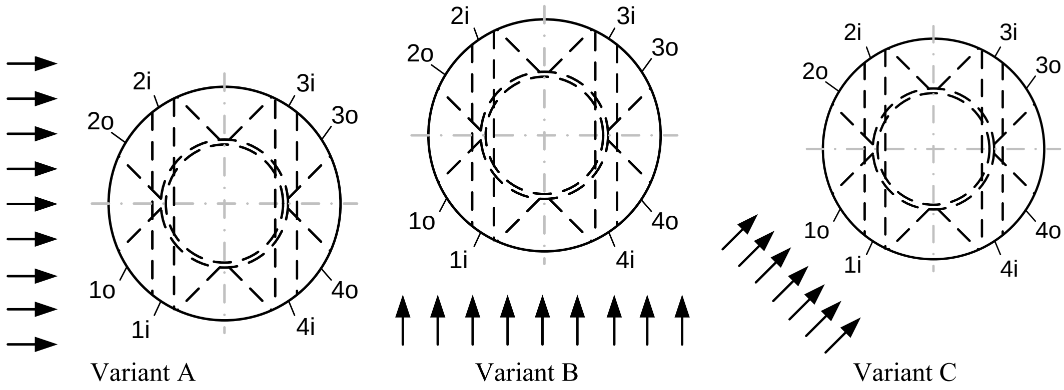

Fig. 6. Variants of wind direction (o – outlet, i – inlet ventilation channels)

3. RESULTS AND DISCUSSIONS

Results of calculations at various velocities of a wind are given in Tabl. 1.

Table 1

Maximum temperature in VSC at various velocities of a wind (t_a = 24 °C, energy-release of TCSB is 24 kW)

Wind velocity, m/s	Maximum temperature in VSC, °C		
	A	B	C
0	294.3		
1	302.5	297.2	301.5
2	317.7	304.1	304.3
3	325.6	312.7	297.7
5	305.1	318.3	288.9
10	256.8	302.9	249.1

Small velocities of a wind (about 1 m/s) render feeble influence on the maximum temperature in VSC in comparison with calm conditions. The maximum of temperature in VSC is occurred near 3 m/s wind velocity and this speed of wind are the most dangerous at storage of SNF because of blocking outlet vents. In this case there is no enough flow rate through ventilation system and decay heat not being conducted away properly. At wind (10 m/s and higher) the maximum temperature in the VSC is decreasing because the wind is strong enough and cooling air comes through ventilation system from top channels to the bottom.

The operation of single container is not typical situation for DSNFSF on Zaporizhska NPP. So, it is necessary to detect thermal state of containers group with taking into account their mutual influence.

Firstly, the wind influence to the whole storage platform was considered. As Fig. 7 shows, containers, which are placed near the protection wall from the wind side, are under bigger wind influence than others due to forming circulation zone. But containers in the center of the storage platform could be under thermal influence of neighboring containers.

Inside containers group air flow has complex structure (Fig. 8) and atmospheric air can penetrate to the outlet vents of containers. Obviously, if air will came from outlets of neighbor container it will has influence to the thermal state and results of temperature measurement considered container.

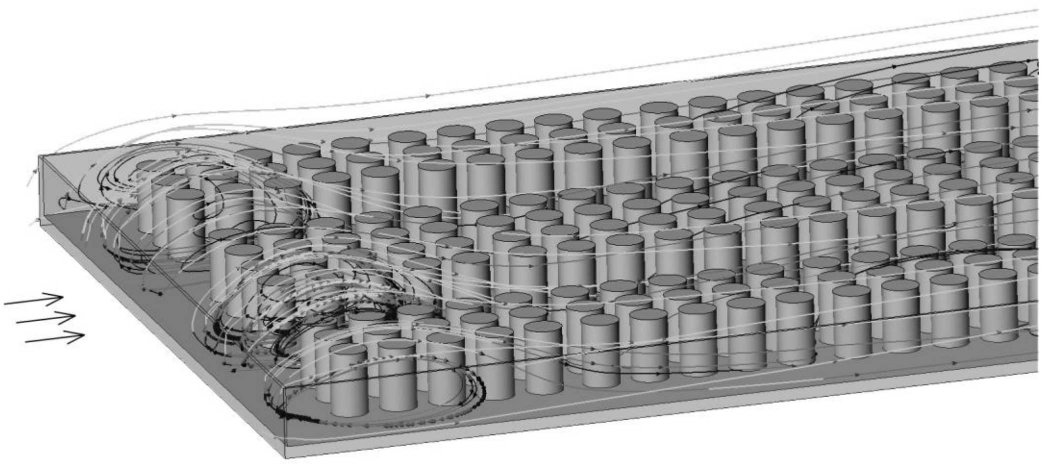

Fig. 7. Flow structure near the protection wall

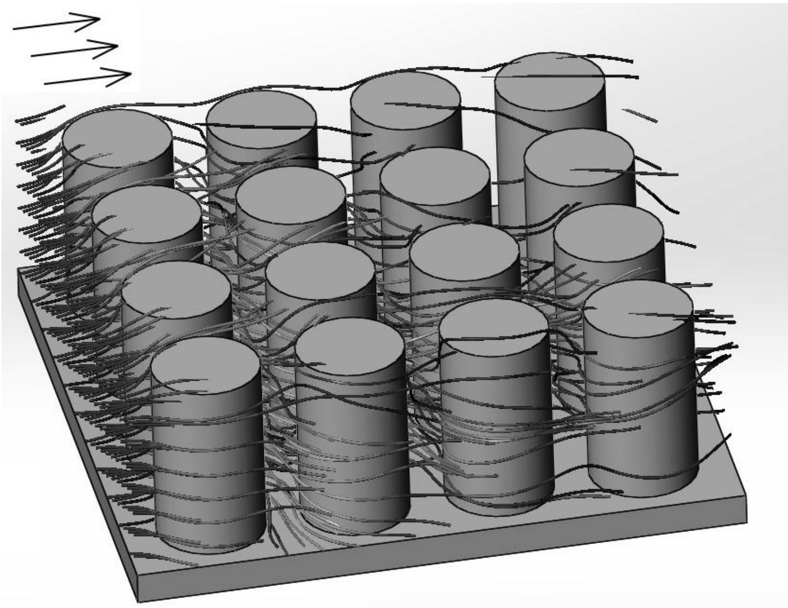

Fig. 8. Flow structure inside containers group

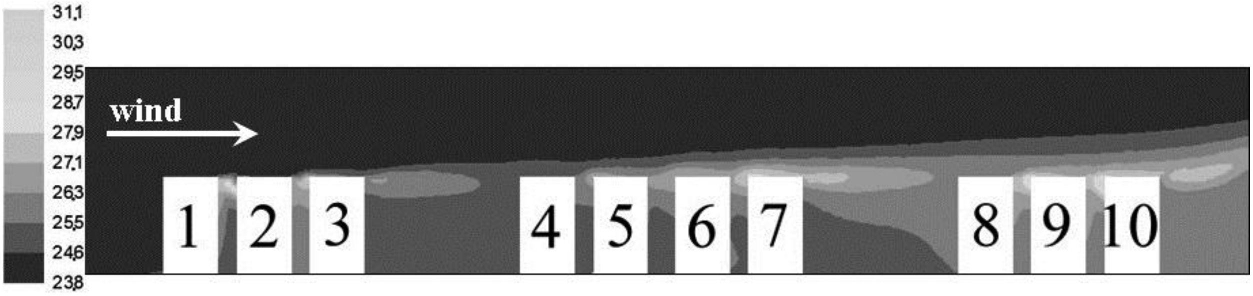

Fig. 9. Temperature of ambient air

For the line of 10 containers in wind conditions the temperature profile of ambient air is given on Fig. 9.

Results of containers' thermal state investigation, which are located in line, at wind velocity 5 m/s are given in Tabl. 2. The maximum of temperatures in each container are not more than 350 °C. Investigations are shown that at other wind velocity the maximum of temperatures in containers are not more than 350 °C also, therefore operation of DSNFSF is safe.

Table 2

Maximum temperatures in VSC, which are located in line (wind velocity 5 m/s)

Temperature of ambient air, °C	The maximum of temperature in VSC, °C									
	Container									
	1	2	3	4	5	6	7	8	9	10
24	329.3	329.1	329.1	329.7	329.6	329.6	322.6	322.6	322.6	322.6
40	345.9	345.7	345.7	346.2	346.1	346.1	338.1	338.1	338.3	338.2

CONCLUSIONS

1. In this work the numerical approach for definition of thermal condition of group of containers with SNF on a storage platform is overviewed. The methodology is based on solving of conjugate heat exchange problems.

2. Placement of containers on storage platform is necessary in view of an annual wind rose to minimize influence of a wind on their thermal state. Results of investigations can be used for construction of wind protection system for containers.

3. Results of investigations can be used for construction of safety near-stations dry storages in other nuclear power plants of Ukraine or at open dry storages of the SNF in other countries.

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ПРОБЛЕМЫ БЕЗОПАСНОСТИ СУХОГО ХРАНЕНИЯ ОТРАБОТАВШЕГО ЯДЕРНОГО ТОПЛИВА

С. Алехина, А. Костиков, С. Круглов

Освещены некоторые проблемы безопасности уникального в Украине сухого хранилища отработавшего ядерного топлива. Проведен анализ температурных замеров воздуха, который охлаждает контейнеры с отработавшим ядерным топливом на площадке сухого хранения. Определены факторы, которые влияют на тепловые режимы контейнеров хранения. Предложен подход к решению задачи идентификации тепловых процессов в контейнерах на площадке хранилища. Результаты исследования показали безопасность сухого хранения топлива на Запорожской АЭС.

ПРОБЛЕМИ БЕЗПЕКИ СУХОГО ЗБЕРІГАННЯ ВІДПРАЦЬОВАНОГО ЯДЕРНОГО ПАЛИВА

С. Альохіна, А. Костіков, С. Круглов

Висвітлені деякі проблеми безпеки унікального в Україні сухого сховища відпрацьованого ядерного палива. Проведено аналіз температурних замірів повітря, що охолоджує контейнери з відпрацьованим ядерним паливом на площадці сухого зберігання. Визначені фактори, що впливають на теплові режими контейнерів зберігання. Запропоновано підхід до розв'язання задачі ідентифікації теплових процесів у контейнерах на площадці сховища. Результати дослідження показали безпеку сухого зберігання палива на Запорізькій АЕС.