SCIENTIFIC BASIS OF THERMAL SAFETY ANALYSIS OF DRY STORAGE OF SPENT NUCLEAR FUEL ON ZAPORIZHSKA NPP

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Abstract

Now only one Dry Storage Facility of Spent Nuclear Fuel (DSFSNF) is operated in Ukraine – facility on Zaporizhska NPP. Many different thermal investigations were done for ventilated containers of DSFSNF. In this work the generalization of scientific approaches to the thermal safety assessment are carried out. The multi-stage approach to the definition of thermal state of containers' group, single container, spent fuel assemblies and fuel rods was developed. Detailed thermal profiles of spent fuel assemblies and each fuel rod inside storage container were calculated. With usage of multi-stage approach the thermal simulations of accident conditions and influence of outer factors onto thermal state of containers were carried out. On base of obtained results the classification of accidents with channels blockage was developed and the most dangerous blockages were found. Results of thermal investigations were generalized and factors, which are influence on thermal state of containers, are detected. Method of spent nuclear fuel thermal state prediction and changes to the system of thermal monitoring were proposed.

1. INTRODUCTION

Ukraine has more than 15 years of experience to store spent nuclear fuel (SNF) of power reactors. The fuel from 6 WWER-1000 reactors of Zaporizhska NPP is stored by the dry method on the open-air platform in ventilated containers (Fig. 1).

FIG 1. Storage containers of Zaporizhska NPP.

Since 2001 when the first container with spent nuclear fuel was located on the storage platform, the thermal monitoring of the state of containers was performed. The thermal monitoring is conducted by measurement of the ventilating air temperature (Fig. 2) and in case if air heating not more than 61 degrees the operation of SNF storage container is safe [1].

FIG 2. Resistance thermometer and the place of its location in the system of thermal monitoring.

Long and safe operation of any nuclear facility such as The Dry SNF Storage Facility on Zaporizhska NPP is not possible without its scientific support. Under scientific support it is understood the deep and system analysis of physical processes during facility operation with detecting and structuring factors of influence on the state of SNF, and development of methods of effective safety control and improvement.

This paper is devoted to the analysis of the thermal processes on the dry spent nuclear fuel storage facility of Zaporizhska NPP.

2. METHODOLOGY

The specificity of containers with spent nuclear fuel does not allow to simulate directly their thermal state. Large differences between characteristic sizes (for example, height of fuel rod and its diameter) require high quality meshing, so computational time increases and need high speed computers clusters. In this case the solution could be dividing the computational area to the parts, solving thermal problems for each of it and then connecting results. The iterative methodology for the thermal state simulation is presented on Fig. 3.

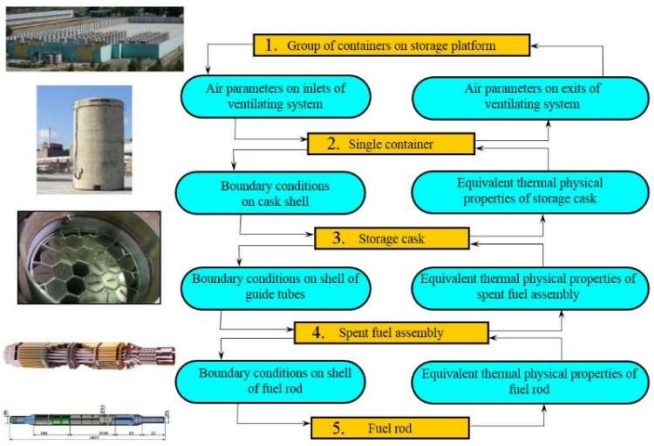


FIG.3. Iterative methodology of the SNF thermal state definition.

According to the proposed method on each level of computational domain some part of it replaced by simplified object, then detecting the boundary conditions on its surface and on the next level of computational level this part considered in detailed structure. This approach was described in detail in [2].

Verification of results which are obtained with usage described approach, was conducted by comparison of measured temperature of ventilation air in outlet vents and calculated one. The difference between these two values are not more than 3%.

3. RESULTS

Results of modelling of the thermal state of containers group with usage described approach are shown that they don't have mutual thermal influence. Heated air goes freely out of container and doesn't get into the ventilation duct of neighbouring containers (Fig. 4).

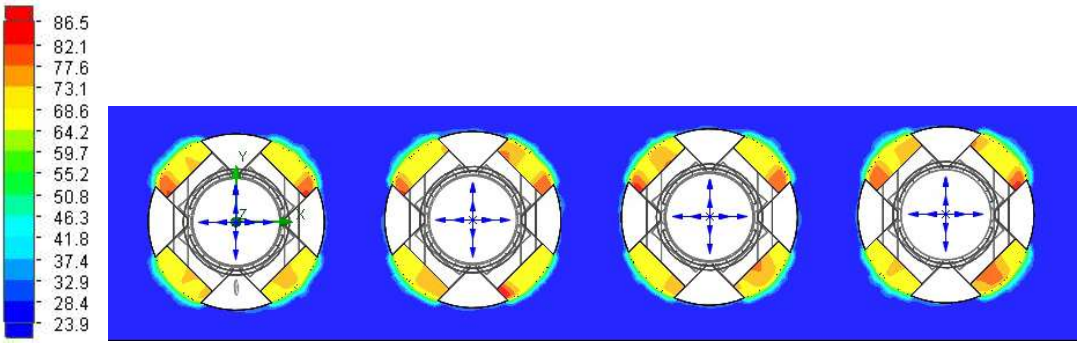
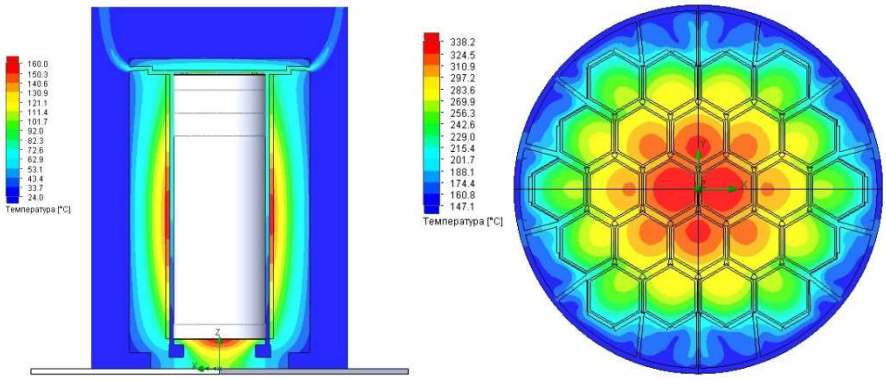


FIG.4. Temperature profile of air created by containers group.

With usage of the described approach the detailed thermal profiles of the spent nuclear fuel inside ventilated storage container were calculated. On the Fig. 5 the temperature profiles of the container and storage cask with spent fuel assemblies are presented.



a) *b)*

FIG. 5. Temperature profile of the storage container (a) and storage cask (b).

Because of operation on the open-air platform the containers with spent nuclear fuel are under influence of weather factors. One of the dangerous is wind [3] because in some conditions ventilating channels could be blocked and ventilating air flow rate will not ensure effective SNF cooling. The dependence of the maximum temperature from the direction and velocity is presented on Fig. 6.

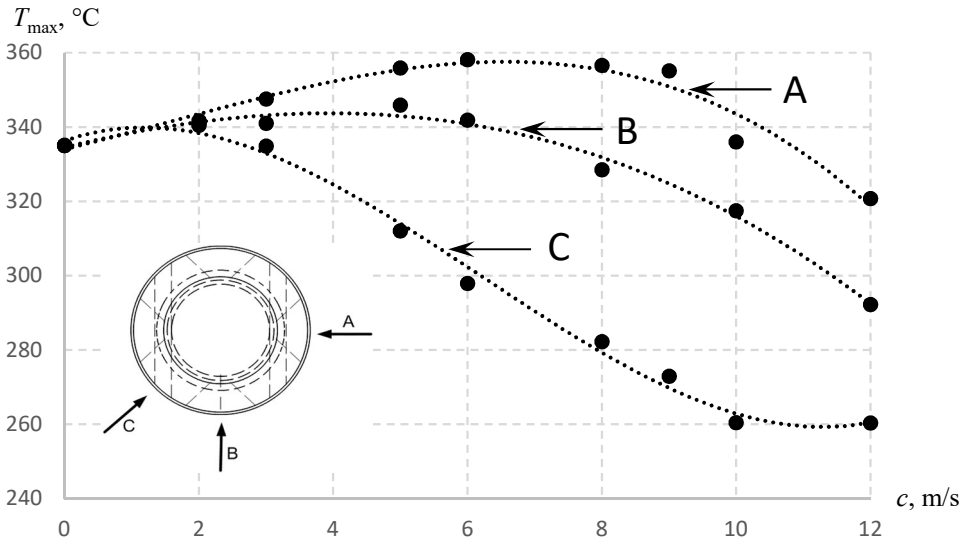


FIG. 6. Maximum temperature in storage container depending of wind direction and velocity.

Other factors of influence onto the thermal state of SNF was investigated in [4] (influence of the daily temperature fluctuations) and [5] (influence of solar irradiation). Both are not dangerous for spent nuclear fuel stored inside concrete containers.

All factors of influence on the thermal state of storage containers with SNF could be classified on basis of their character (Fig. 7). The part of these factors appears at accident conditions, other at normal operation.

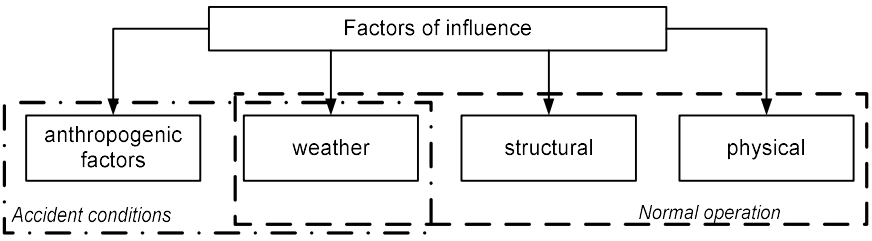


FIG. 7. Classification of the factors which have influence on the thermals state of SNF.

The physical factor of influence (decay heat) and weather factor (temperature of atmospheric air) must be taken into account at calculation (prediction) of the maximum temperature inside storage container. On base of results of numerical simulation the dependence of the maximum temperature in storage container from decay heat (Q) and temperature of atmospheric air (T_a) will be next:

$$T_{\max} = 26.96 + 0.74T_a + 0.014Q - 0.0036T_a^2 - 1.141\cdot 10^{-7}Q^2 + 1.07\cdot 10^{-5}T_aQ, \quad (1)$$

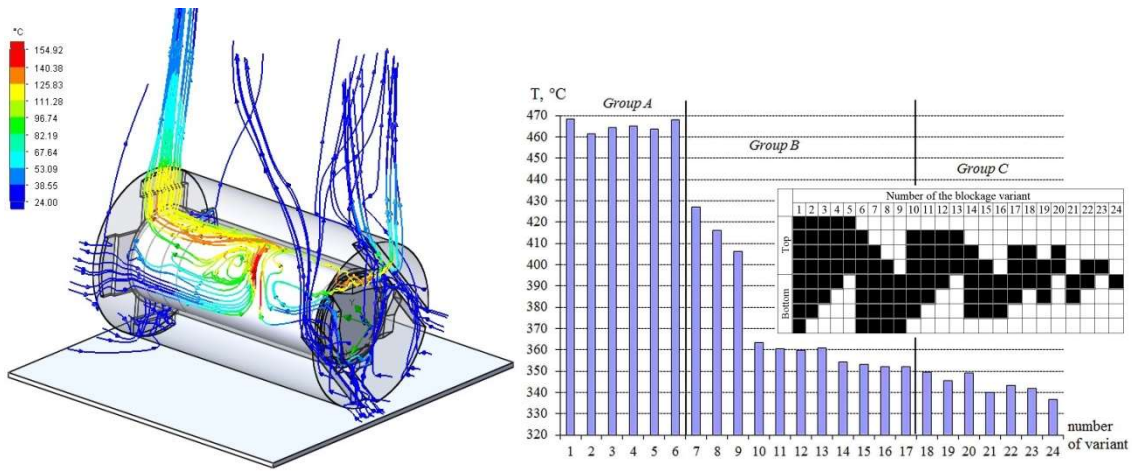
and temperature of the ventilated air (T_{exit}) could be calculated by next formula:

$$T_{exit} = 8.13 + 0.8694T_a + 0.002Q - 0.00085T_a^2 - 1.432\cdot 10^{-8}Q^2 + 6.116\cdot 10^{-6}T_aQ. \quad (2)$$

This dependence is reasonable to be used at thermal monitoring of SNF storage for control measured parameters. It is especially actual during the last years of storage when decay heat of SNF is low and thermal criteria for air heating will not be reached. So, the measured temperature of ventilating air must be compared with calculated temperature of ventilating air with purpose to detect air heating increasing and probable accident.

Thermal analysis of storage containers with spent nuclear fuel under accident conditions is important part of safety analysis of storage facility. Some accidents usually don't analyze carefully from the "thermal point of view" due to low probability of it or absence dangerous effects. Under scientific support of storage facility on Zaporizhska NPP wide range accidents were considered and results were generalized. Obviously the loss of cooling for the dry storage containers will be the most dangerous accident from the "thermal" point of view. It could be at ventilation duct blockage or at over-project working conditions.

At the container falling down and blockage of the all outlet vents are the highest temperatures (FIG. 8). Container cooling is conducted by natural circulation, so if ventilating air couldn't freely go outlet the temperature of SNF is the highest and this accident almost the same as loss of cooling conditions by it results.



a) *b)*

FIG. 8. Flow structure at container falling down and maximum temperatures at the ventilation duct blockage.

4. CONCLUSIONS

Scientific support is important part of SNF storage facility operation. Thermal simulations were done for the dry storage containers of the Zaporizhska NPP. Obtained results are important at the safety analysis and allow to develop safety assessment process on scientific base with taking into account physical nature of processes.

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