# SOLAR RADIATION INFLUENCE ONTO THE SPENT NUCLEAR FUEL DRY STORAGE CONTAINER

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In the paper the solar influence on the thermal state of storage container with spent nuclear fuel is investigated by numerical simulation. Thermal simulation for the single container and for the group of containers was carried out. The daily temperature fluctuations of the concrete container surface under maximum solar influence were calculated. The absence of solar radiation influence onto the spent fuel assemblies inside storage container is shown.

PACS: 47.27.te

## INTRODUCTION

Complex safety of the Dry Spent Nuclear Fuel (SNF) Storage Facility includes thermal analysis of the main components of storage system. All factors like outer protection constructions, neighboring containers, weather etc. should be taking into account.

At the safety analysis of the dry SNF storage container, which is operated on the open-site storage facility, the heat received by a container from solar irradiance must be taken into account. This is evaluated using the IAEA recommendations [1]. It is assumed that during the daylight heat flux of solar irradiance to the horizontal surface (to the top surface of the container) equals to 800 W/m$^2$ and the one to the vertical surface (the cylindrical surface of the container) equals to 200 W/m$^2$. Traditional approach in numerical simulation of the solar influence on the containers with spent nuclear fuel consists in the setting solar heat flux onto the surfaces of containers. However, in this approach the heat flux is usually considered as constant value [2] or influence of neighboring containers and protection constructions is not taken into account [3]. Another approach at the thermal simulation consists in increasing the ambient air temperature. It was used in [4] and at the previous authors' simulations [5, 6]. Unfortunately, this approach does not give correct results due to impossibility to detect the value, which should be added to the normal ambient temperature. Therefore, both approaches are not useful for solar influence estimation at the dry spent nuclear fuel storage on the open-site facility.

The purpose of this paper is numerical unsteady simulation for detection of solar irradiance and its daily fluctuation onto the thermal state of containers with spent nuclear fuel.

## 1. PROBLEM DEFINITION

At the assessment of SNF storage containers' thermal state on the Dry SNF Storage Facility of Zaporizhska NPP it is necessary to detect the solar influence on the concrete container and on the spent fuel assemblies inside container.

The dry storage containers are operated on the open-site storage facility (Fig. 1). The most dangerous operating conditions from the thermal point of view is a summer and the longest day with the maximal solar irradiation.

Storage container was considered with assumption that all 24 spent fuel assemblies are loaded with the highest acceptable decay heat 1 kW [7] of each. Due to low decreasing of the decay heat during whole period of storage it value was not varying at calculation of the daily temperature variation.

*Fig. 1. Dry SNF Storage Facility on Zaporizhska NPP*

## 2. METHODOLOGY

The problem was considered in conjugate transient formulation with usage of the mathematical model, which is described in [6, 9].

For the detection of solar influence on the single located container the calculation area was chosen according to Fig. 2. Container is represented as a hollow cylinder. Boundary conditions are next:

– the heat flux on the inner surfaces ($B_7$, $B_8$, $B_9$). Its values are optioned from results calculated in [6] using methodology described in [8];

– the zero heat flux on $B_6$ due to low level of heat exchanging with ground;

– the atmospheric pressure and temperature on the surfaces $B_1$ – $B_5$ while taking into account the daily variation of temperature.

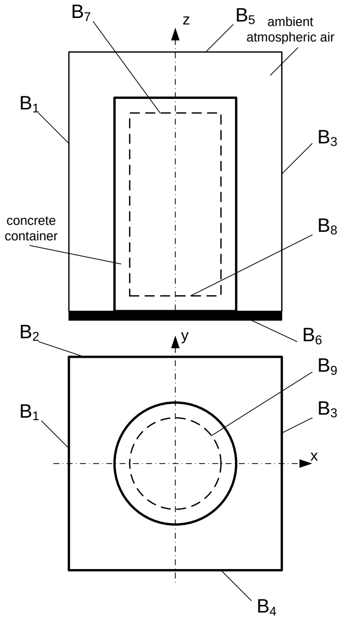


*Fig. 2. Calculation area for single container*

The temperature measurements during last 7 years were analyzed for the setting up of the daily variation of temperature. The highest temperature and its fluctuations during the longest summer day (21 June) were chosen as a boundary condition (Fig. 3).

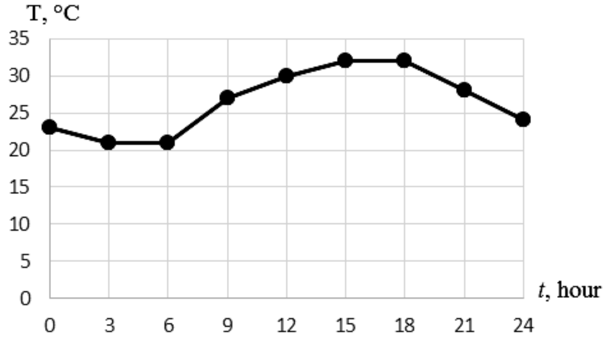


*Fig. 3. Daily variation temperature*

Solar radiation intensity was specified as a piecewise linear function:

$0{:}00 < t < 6{:}00{:}\ q = 0;$

$6{:}00 < t < 10{:}00{:}\ q = 137.5 \cdot t - 275;$

$10{:}00 < t < 14{:}00{:}\ q = 1100;$

$14{:}00 < t < 19{:}00{:}\ q = 2640 - 110 \cdot t;$

$19{:}00 < t < 24{:}00{:}\ q = 0.$

Position of the sun on the sky during the day (altitude $h$ and azimuth $A$) is calculated according to the next formulas [10]:

$$\sin h = \cos\varphi \cdot \cos\delta \cdot \cos\tau + \sin\varphi \cdot \sin\delta;$$

$$\sin A = \frac{\cos\delta \cdot \sin\tau}{\cos h},$$

where $\tau = \frac{t_{sm}}{24} \cdot 360$ – aberration of the sun from position at midday, degree; $\delta = 23{,}5 \cdot \sin\left(\frac{2\pi d}{365}\right)$ – declination of the sun, degree; $\varphi$ – latitude; $t_{\mathrm{sm}}$ – time after sun midday; $d$ – numbers of day after vernal equinox.

For the study of solar influence on the containers' group the part of storage platform with 50 containers was considered (Fig. 4). The same boundary conditions were applied but surfaces $B_1$ and $B_2$ were divided by two parts: the atmospheric pressure and the daily varying temperature on $B_{1-1}$ and $B_{3-1}$; absence of heat flux on $B_{1-2}$ and $B_{3-2}$ (parts of surfaces which corresponds to Storage Facility protection wall).

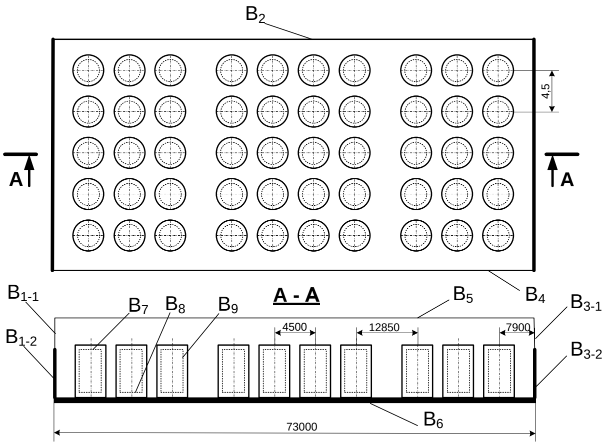


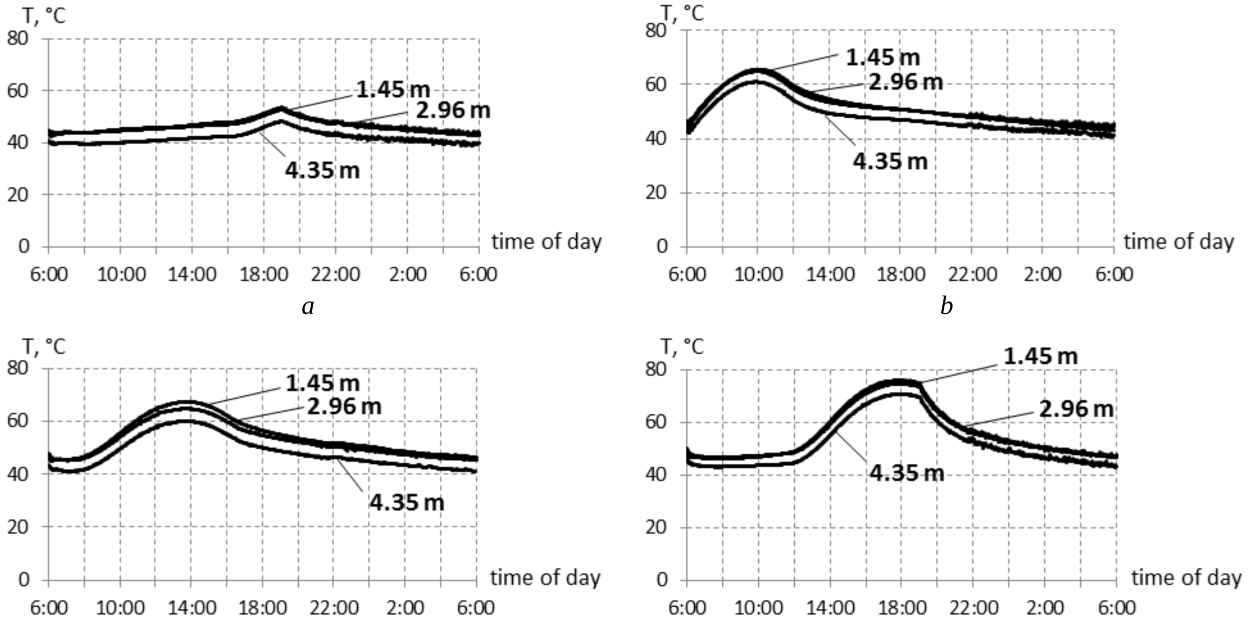
*Fig. 4. Calculation area for containers' group*

## 3. RESULTS DISCUSSION

The temperature variation on cylindrical surface of single located container depending of the side of the world and location by height from platform is presented on Fig. 5.

The lowest temperatures on container's surface are from north side where insolation is absent. It is typical for the northern hemisphere and for the latitude of storage platform location. The eastern and western part of storage container are under lower insolation than south part but the maximum temperature during the day is reached on the western side. It is caused by next factors: the western side after night cooling is heated during the first part of day due to increasing of ambient temperature; during the second part of day it is heated by solar radiation. So, eastern part has lower temperature than western side on the moment of the solar irradiance starting. Since during the light day the western and eastern parts of container got equal solar energy so temperature of western part become higher. The temperature state of southern part of container is between of these two cases because its pre-heating by increasing ambient temperature is less than western part.

The temperatures of container surface are different on height of container, which is caused by outer factors influence. The lowest temperatures are on top part of container because this part is under the influence of intensive convective flows and heat is removing quickly. The highest temperatures are in bottom part of container. It, probably, caused by stagnation regions of ambient air, which decrease of convection intensity.



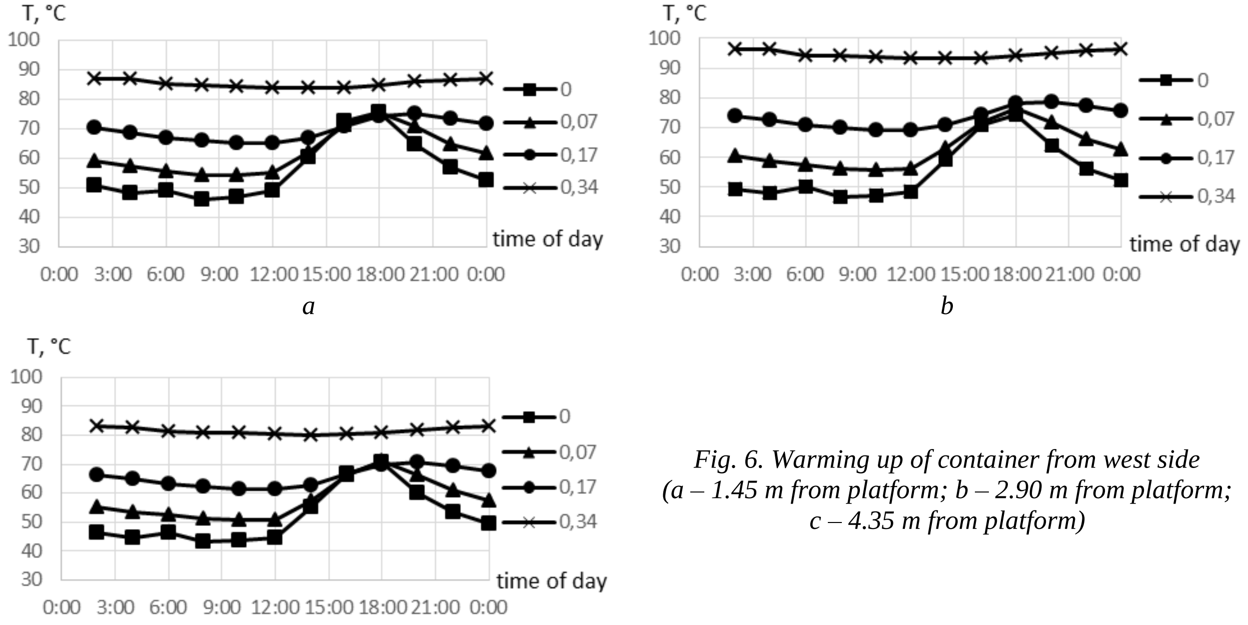
*a* *b*

*c* *d*

*Fig. 5. Container surface temperature varying with time: a – north; b – east; c – south; d – west*

Three levels (1.45, 2.90, 4.35 m from platform) on each side of container and four points (0, 0.07, 0.17, 0.34 m from container surface) on each level were selected. For these points the temperature variation in time was analyzed.

Amplitude of the daily temperature variation on the west side is the highest, so, container is warming up from the west side (Fig. 6) more than from other sides. The temperature on the surface of container is intensively varying than inside concrete shell. The temperature level inside concrete container is higher than the one on the surface and almost doesn't varying during the day, which is caused by heat flux coming from spent fuel assemblies.



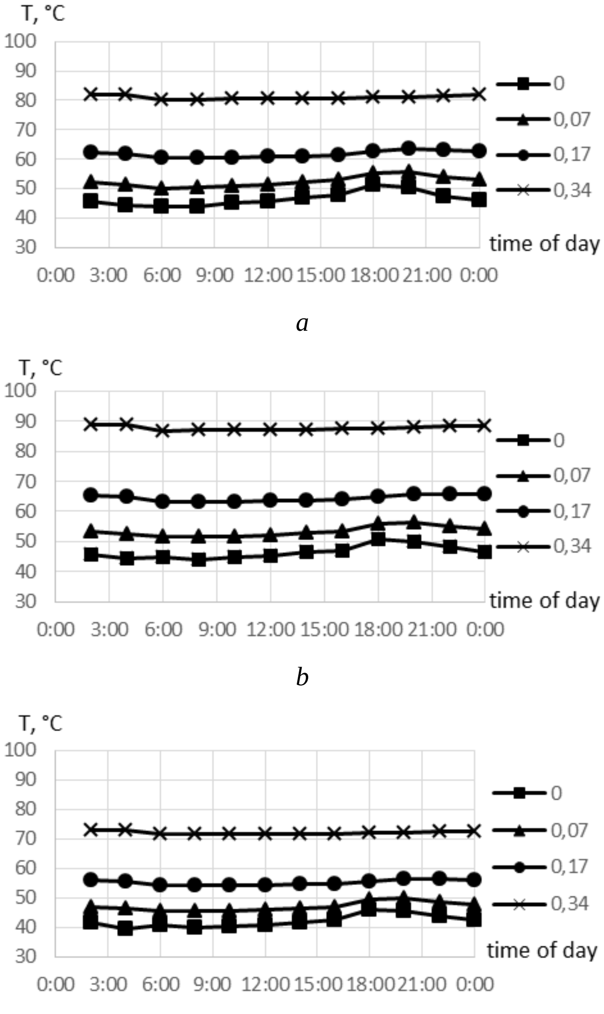
*a* *b*

*c*

*Fig. 6. Warming up of container from west side (a – 1.45 m from platform; b – 2.90 m from platform; c – 4.35 m from platform)*

For the northern side of container, which has the lowest temperatures and temperature gradient during the day, the warming up of concrete shell (Fig. 7) has the same tendency as for western side. During the day temperature varies mostly on the outer surface of container. The temperature inside concrete container stays stable.

For both presented container sides on distance 0.34 m from surface the temperature does not vary. The level of temperatures is decreased in direction to the outer container surface along with increasing of the daily temperature variation. These statements are correct for eastern and southern sides too.



*a*

*b*

*c*

*Fig. 7. Warming up of container from north side (a – 1.45 m from platform; b – 2.90 m from platform; c – 4.35 m from platform)*

As results shown the largest temperature fluctuations are on the surface of containers. This fact can results microcracks in concrete containers, which were visually detected on surfaces (Fig. 8). Thermal fluctuation can decrease the container durability together with the irradiation embrittlement. It is especially dangerous in winter when ambient temperatures become lower than zero centigrade and water (melted snow, rain, mist etc.) can froze inside these microcracks.

The density of total radiation heat flux onto the surfaces of containers in the end of period of maximum solar influence (14 pm) is shown on Fig. 9. The negative values show heat flux that absorbed by surfaces (dark zones), the positive ones show heat flux that is emitted by surfaces (light zones). The largest heat comes to the horizontal surface of the storage platform. The zones, which are shaded by containers or protection wall, emitt heat. The containers' surfaces inside the group derive small solar irradiation.

The temperature of the surfaces of the components of the Dry SNF Storage Facility (Fig. 10) for the same time (14 pm) is varying between 312 K (39 ºC) and 380 K (107 ºC). The top part of containers is more heated because they are under the direct solar influence during all light day and are not shaded by protection wall or other containers. The cylindrical surfaces are less heated because other containers shade them time to time during the day and their cooling by convection are more intensive. The surface of storage platform is heated non-uniformly, their temperature varies between 22 K (49 °C) and 352 K (79 °C), the highest temperatures are in transport zones, the lowest ones are between containers.

Due to difficulties of detection of neighboring containers influence on each container in the group the conservative approach could be used. So, the shadow from other containers and protective wall could be neglected. In conservative approach (without shadows) the cylindrical surface will gather more heat and the safety requirements should be observed even in this conditions.

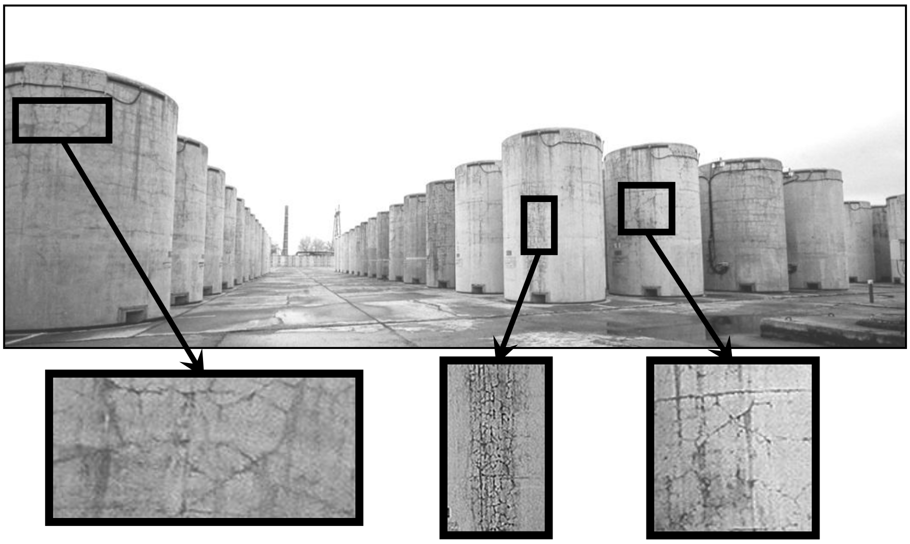


*Fig. 8. Microcracks on the surfaces of storage containers*

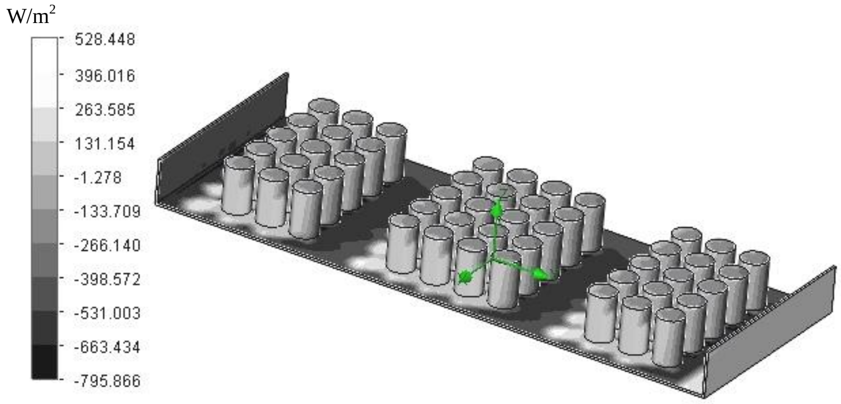


*Fig. 9. Density of the total radiation flux*

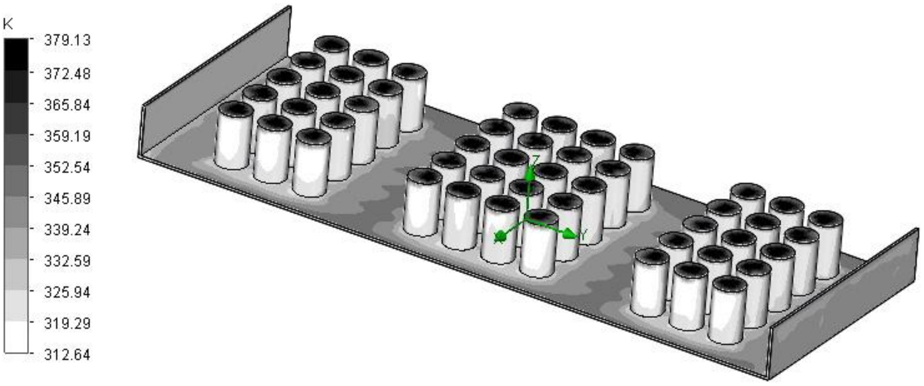


*Fig. 10. Temperature field of concrete surfaces of storage facility components*

## CONCLUSIONS

1. Results of numerical simulation are shown that solar irradiation does not have influence on spent fuel assemblies, which placed inside storage container.

2. Solar irradiance has influence on the concrete container and its value is changed by container perimeter depending on the side of the world. The largest temperature fluctuations are on the west surface of container, the lowest are on the north one.

3. Warming up of concrete container is not-uniform by thickness. Solar influence and daily ambient temperature fluctuations is observed only up to 30 cm in depth from outer container surface. Temperature fluctuations in bottom part of container are higher due to low convective heat exchange with concrete platform.

## ACKNOWLEDGMENTS

Results, which are presented in this paper, were obtained in A. Podgorny Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine (research projects K-5-40 and III-66-15) and V.N. Karazin Kharkiv National University with partial support of IAEA under CRP-20605.

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*Article received 15.03.2018*

# ВЛИЯНИЕ СОЛНЕЧНОГО ИЗЛУЧЕНИЯ НА КОНТЕЙНЕР СУХОГО ХРАНЕНИЯ ОТРАБОТАВШЕГО ЯДЕРНОГО ТОПЛИВА

***С.В. Алёхина, С.С. Капуза, А.О. Костиков***

Путем численного моделирования исследовано влияние солнечного излучения на тепловое состояние контейнера с отработавшим ядерным топливом. Тепловые исследования выполнены для отдельно расположенного контейнера и для группы контейнеров. Вычислены суточные колебания температуры бетонной поверхности контейнера при максимальной солнечной нагрузке. Показано отсутствие влияния солнечного излучения на отработавшие топливные сборки в середине контейнера хранения.

# ВПЛИВ СОНЯЧНОГО ВИПРОМІНЮВАННЯ НА КОНТЕЙНЕР СУХОГО ЗБЕРІГАННЯ ВІДПРАЦЬОВАНОГО ЯДЕРНОГО ПАЛИВА

***С.В. Альохіна, С.С. Капуза, А.О. Костіков***

Шляхом чисельного моделювання досліджено вплив сонячного випромінювання на тепловий стан контейнера з відпрацьованим ядерним паливом. Теплові дослідження виконані для окремо розташованого контейнера та для групи контейнерів. Обчислені добові коливання температури бетонної поверхні контейнера при максимальному сонячному навантаженні. Показано відсутність впливу сонячного випромінювання на відпрацьовані паливні збірки в середині контейнера зберігання.