Abstract. Residual energy release of VVER-1000 spent fuel was calculated with the SCALE code package for a storage period of 50-1000 years. WESTINGHOUSE (USA) and TVEL (Russia) fuel assemblies operating in the reactors of Ukrainian NPPs were considered. The calculations are provided for average geometrical, material and operating parameters of fuel assemblies. Empirical relations based on the sum of two exponential functions are proposed. They describe well the dependence of residual power release in spent fuel on the storage time from 100 to 1000 years. For the case of final disposal of spent fuel in sealed containers in geological rock formations, it is assumed that thermal radiation may be the main mechanism for heat removal from spent fuel. In this case, conservative assessments of the minimal required time of interim storage are from 100 to 200 years.

1. Introduction
In the final disposal of spent nuclear fuel, it is assumed that there will be no monitoring operations or, if any, they will be minimized. Hence, it is important to assess correctly the influence of the processes that occur in fuel on its storage parameters. One of these processes is residual power release in spent fuel.

Storage of spent nuclear fuel in sealed cavities in deep geological formations is commonly considered as the main option for its final disposal. In this case, heat removal from fuel will be very limited and even insignificant residual power release can lead to substantial fuel heat-up in the storage process. The final disposal is preceded by two stages: cooling a spent fuel in reactor pool and interim (often dry) storage. Their objective is to decrease residual heat release to an acceptable level. This paper provides preliminary assessments of the time required for cooling of spent fuel prior to its final disposal.

2. Determination of residual heat of spent fuel assemblies (cont.)
Calculations were made for reactor fuel cells of VVER-1000 under the burnup level up to 50 GWh/day/10 in 4-year fuel cycle. This cells were composed of the typical modern fuel assemblies TVE-A of Russian TVEL suppliers (Fig.1) and new fuel assemblies FA-WR of Westinghouse company (Fig.2).

The results of these calculations are shown in Fig. 3. The results demonstrate that residual heat in fuel assemblies of both types is quite close. For a period of 50-1000 years, the numerical values are described well by the following empirical dependence:

\[ P(W) = 424.4 \times 10^6 \times \left(1.4^{\alpha \times \sigma \times S} \right) \times 10^{(0.02 \times t + 0.6 \times \exp(-0.003 \times t - 0.15)),} \]

where \( t \) (years) is post-operational period.

3. Time required for interim storage of spent fuel
In the final disposal of spent fuel in closed underground compartments, thermal radiation will be the main processes of heat removal from the fuel. If fuel assemblies are arranged in several layers and there is no good thermal contact between them, heat exchange between FAAs will also mainly proceed through radiation. As a model to assess the amount of heat removed through radiation, use the well-known Stefan-Boltzmann equation for a gray body:

\[ P = \alpha \times S \left( T^4 - T^4_{amb} \right) \]

where \( \alpha \) - radiation coefficient (degree of blackness);

\( \sigma \) - Stefan-Boltzmann constant;

\( T \) - temperature of the emitting surface;

\( T_{amb} \) - temperature of the compartment wall;

\( S \) - area of the emitting surface.

According to the published data, the typical radiation coefficient of polished metals is \( \alpha = 0.3 \sim 0.7 \) [3, 4]. Using simple geometrical calculations, find \( S = 0.47 \text{ m}^2 \) - area of one FA face. Temperature of the compartment wall is assumed to be \( T_{amb} = 300 \text{ K} \). The limiting temperature of FA emitting surfaces in the storage process is accepted to be \( T_{FAmax} = 573 \text{ K} \).

4. Conclusions
Thus, for safe final disposal up to 19 fuel assemblies (3 layers) in an underground compartment 50 years is a sufficient period. For safe final disposal of 37 fuel assemblies (4 layers) in an underground compartment may require 100 years, of 61 fuel assemblies (5 layers) - 150 years and of 91 fuel assemblies may require 200 years of interim storage. Otherwise, the fuel assemblies may be overheated after sealing of the compartment and their integrity and configuration will be affected as a result.