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Assessment of the behavior of spent nuclear fuel in Ukraine

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Abstract. Before June 2023 the Zaporizhzhya Nuclear Power Plant, which is the largest nuclear facility in Europe, had suffered a complete loss of external power seven times since the beginning of the Russian invasion. This forced it to rely on emergency diesel generators to guarantee the safety and security functions of the plant, such as reactor cooling. From that, it appears of meaningful importance to evaluate the performance of all its nuclear facilities, among which the building where the spent fuel storage pool (SFP) is located, to assess what consequences anomalous/abnormal or accident events may determine.

Contrary to dry storage, the dry cask/packaging system is stored on open concrete pads within a protected area of the plant site; the wet storage requires a hydraulic environment such as the water pools where SF is safely stored. The hydraulic effluent and the physical containment barriers act as confinement and shielding, guaranteeing safety criteria are fulfilled.

In this preliminary study, the attention is thus paid to the SFP; for this reason, a description of its behavior and filling status must be provided. Since 2001, spent nuclear fuel (SNF) from 6 VVER (water–water energy reactor)-1000 units has been stored in the dry storage facility at the Zaporizhzhya Nuclear Power Plant. This means that, despite radioactive decay, the total activity of such inventory may exceed 30 times that of the fourth damaged Chornobyl unit at the time of the accident, and this is due to long-lived actinides (2×10^{19} Bq), ^{137}Cs (1×10^{19} Bq) and ^{90}Sr (9×10^{18} Bq). Continued damage caused by a missile attack on the SFP (e.g., cyclic, dynamic, and thermal loadings) may increase the risk of loss of integrity, because, as it is widely known, concrete has low resistance under tension. In this assessment, an evaluation, therefore, the radiological risk is addressed. For such an evaluation, it is considered that an SFP in VVER-1000 is designed to store 687 fuel assemblies and 670 in VVER-440. When it is half full, which is the case for 15 Ukrainian units, it will store about 2200 t U, containing up to 1×10^{19} Bq of ^{137}Cs, 7×10^{18} Bq of ^{90}Sr and 1×10^{19} Bq of TUE. Moreover, if it is considered that the spent fuel pool represented the Achilles' heel of the nuclear power plant during the 2011 Fukushima accident, it appears quite obvious that there is a need to evaluate the threat associated with the SF storage condition in order to prevent the occurrence of a new severe accident or other challenging situations that the armed conflict has created and may create. The results of the analysis of the Zaporizhzhya Nuclear Power Plant behavior suggest firstly that the plant was/is subjected to high stresses its structures may not withstand for a long time. Secondly, damages may impact SFP instrumentation, which is used for monitoring, for example, radiation or hydrogen formation, leading to loss of control of the SFP facility. Further, it is shown that to prevent the global nuclear threat, nuclear safety and security systems must be maintained and upgraded with at least the introduction of new technical and environmental devices.

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