Krško NPP Spent Fuel Dry Storage Project – Technology and Implementation Overview

Vid Merljak
Krško NPP
Vrbina 12, SI-8270 Krško, Slovenia
vid.merljak@nek.si

Rok Bizjak, Andrej Kavčič
Krško NPP
Vrbina 12, SI-8270 Krško, Slovenia
rok.bizjak@nek.si, andrej.kavcic@nek.si

ABSTRACT

As a part of nuclear safety upgrade programme and to support operating lifetime extension, Krško NPP decided to implement a Spent Fuel Dry Storage system. In essence, spent fuel assemblies are transferred from actively cooled water pool to a dry storage cask, where the decay heat is removed passively by air convection. Fuel assemblies reside in a welded Multi-Purpose Canister which acts as an additional fission product barrier and are additionally protected by concrete overpacks. This dry storage system was put to service in March 2023. During the first campaign, a total of 592 fuel assemblies have been transferred to storage casks. In this paper, we present technology bases and its implementation at Krško NPP.

1 INTRODUCTION

Spent nuclear fuel (SNF) can be regarded as (a special kind of radioactive) "waste" or as a potential recyclable resource. Either way, its decay heat production must be taken into account. While recycling is not common, especially in countries without clear intention to develop closed nuclear fuel cycle, there has not been major effort to commission a SNF "waste" repository either. Rigorously regulated and relatively low in total volume, SNF is not a pressing issue. There is, however, a tendency to transfer SNF from actively cooled solutions (water pools) to passively cooled solutions (i.e., dry storage). This addresses two aspects at once: it increases nuclear safety because we do not rely anymore on continuous availability of active components (pumps, heat exchangers, electricity) – and frees up space in spent fuel pools for newer SNF with higher decay heat power. Dry storage solutions by design incorporate the ability to retrieve SNF for possible further use.

In Slovenia, dry storage of SNF was already foreseen in the Slovenian National Program on Handling of Nuclear Waste & Spent Fuel [1][2]. At first, such storage was planned to be operational after the end of original plant lifetime (2043). Following the events in 2011, resilience of nuclear power plants (NPPs) to severe (external) events was brough into focus. Safety aspects of the Krško NPP (NEK) were reassessed with one of the conclusions that Dry Storage construction should begin in 2020's as part of the current nuclear facility. A Safety Upgrade Program (SUP) was formalised, which consisted of several safety modifications, such as Alternate Residual Heat Removal system, Emergency Control Room, as well as dry storage of spent nuclear fuel. Completion of the SUP also became a Regulator's requirement for operating licence extension from 40 to 60 years. Hence first motivation for SFDS system at NEK.

There are two additional motivation factors. As it has already been mentioned reducing the heat load in spent fuel pool (SFP), which must be actively cooled, contributes to increased safety. However, a more pressing issue emerged when approaching the end of initially projected plant lifetime of 40 years, namely, the number of available locations in the spent fuel pool. SFP was not designed for entire plant lifetime. A re-racking project was carried out as early as in 2002 to change the original SFP racks with more densely packed new ones. This would suffice if re-racking was executed in its entirety. With only phase one completed (of two originally planned) SPF management grew increasingly difficult – even more with additional post-Fukushima restrictions. In fact, fuel cycle 33, which started in November 2022, would have been the last possible – if it were not for the SFDS project.

2 THE DRY STORAGE TECHNOLOGY

NEK uses the HI-STORM FW dry storage system by Holtec International [3]. The basic storage unit is a Multi-Purpose Canister (MPC), capable of holding up to 37 fuel elements (Figure 1, left; see also Figure 3). While imposing several loading constraints (such as heat load per cell & per cask total, number of damaged fuel assemblies, fuel inserts, etc.) it provides means of passive decay heat removal. It also serves as an additional fission product barrier and ensures subcriticality in all normal, abnormal, and postulated accident conditions. While licensing of dry storage buildings typically ranges between 60 and 100 years of service, MPC can also be technically licensed for final disposal (studies are ongoing).

To provide sufficient level of radiological and physical protection, the MPC is inserted into one of three overpacks (see Figure 1, right): *transfer* overpack (made of steel and lead shielding) for on-site transfer; *storage* overpack (made of steel liner and heavy-concrete shielding) for interim storage; or the steel *transport* overpacks for off-site transport.

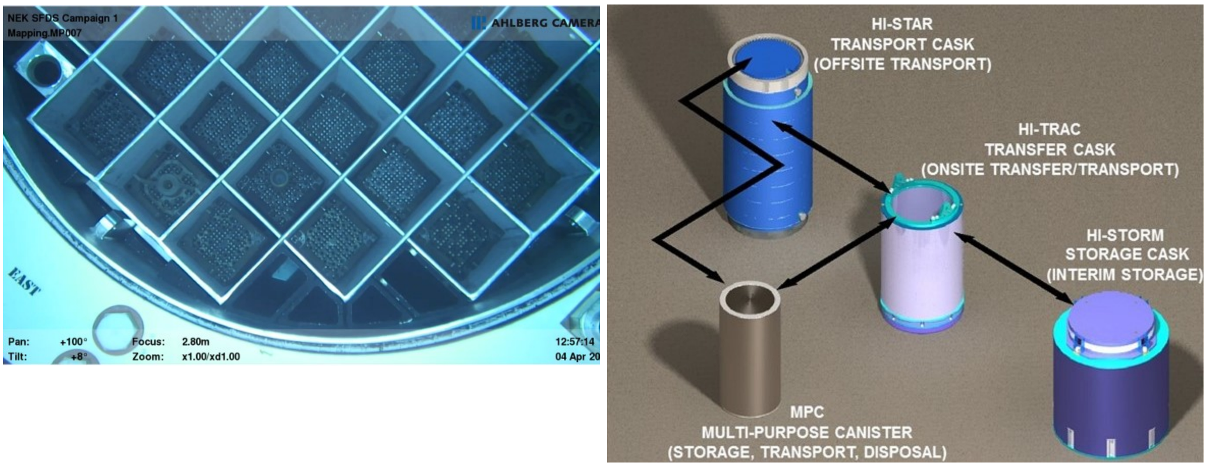

Figure 1: Partial view of MPC geometry, already loaded with spent nuclear fuel elements (left); and an illustration of MPC with its three different overpacks (right).

2.1 Dry Storage Building

As per licensed storage solution implementation of a Dry Storage Building (DSB) is not required. It has been introduced as an additional measure from NEK, following practices in the European Union. Mind that the safety of storage is still solely provided by the storage cask and that it is sufficient. The DSB acts as soft additional environmental protection and is therefore minimizing cask ageing effects due to environmental conditions.

The DSB is 70 m long and 48 m wide, with a maximum storage area capacity of 70 spent fuel casks. It features 6 m high concrete walls and a roof supported by metal construction. It is divided in three areas, namely the cask storage area, manipulation area and a small technical room (Figure 2, left and middle). The Vertical Cask Transporter (VCT) crawler used for transporting MPC with an overpack enters the building through roll-up doors to the manipulation area, while the storage area is separated by metal slide doors. 6 m walls provide structural integrity, as well as flood protection. This means that air intake for cask cooling is also 6 m above ground. Air then travels along the interior double walls down to the floor, through the storage overpacks' ventilation openings (Figure 2, right) and out of the DSB below the roof.

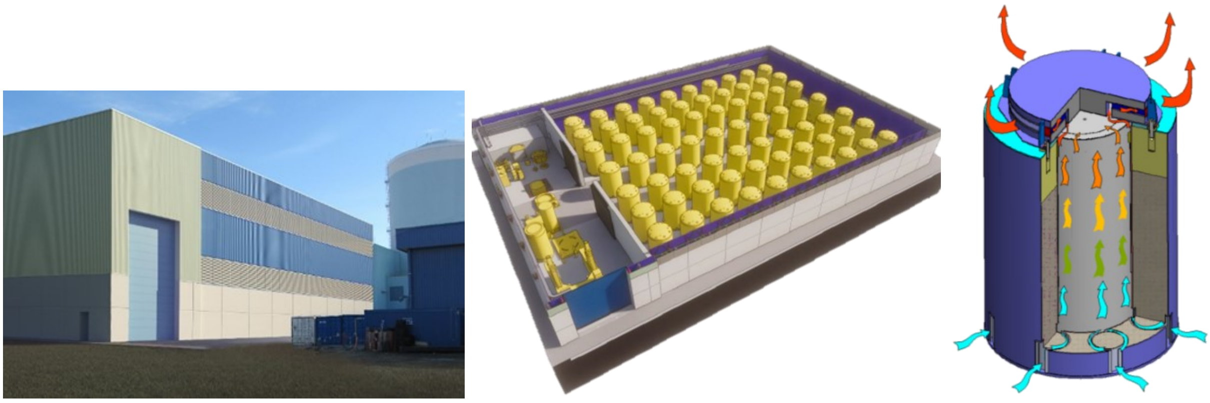

Figure 2: Dry Storage Building outside photograph (left) and cross-section image (middle); and a depiction of passive cooling of MPC inside the storage overpack (right).

2.2 Key Steps of the SFDS

It is important to recognise and understand the key steps of wet-to-dry SNF storage transfer. They are listed below and depicted in Figures Figure 3 – Figure 6:

1. **Cask preparation:** insert MPC into transfer overpack, check for presence of any foreign material, instal seismic restraint arms, lower into the Cask Loading Area (CLA), raise the CLA water level;
2. **Fuel loading:** load SNF into MPC while allowing time for nuclear safeguards measurement, perform video verification (fuel identification);

Figure 3: Cask preparation (left); and cask submerged in CLA, ready to load spent nuclear fuel (right).

3. **Transfer to Decontamination Area (DA):** lower CLA water level to install MPC lid, raise the MPC from water and decontaminate its surfaces, dock MPC at DA;

4. **Lid welding:** use robotic welding machine to weld the lid; perform non-destructive weld-tightness check;

Figure 4: Cask decontamination (left); and MPC lid welding (right).

5. **Drying:** drain water from MPC and exchange it for helium (to preclude exothermal hydrogen-producing reaction between zirconium cladding and water), perform Forced Helium Dehydration (FHD), backfill helium to prescribed pressure, weld the vent and drain ports, (mind that this step is the crucial point for assuring long-term MPC integrity);

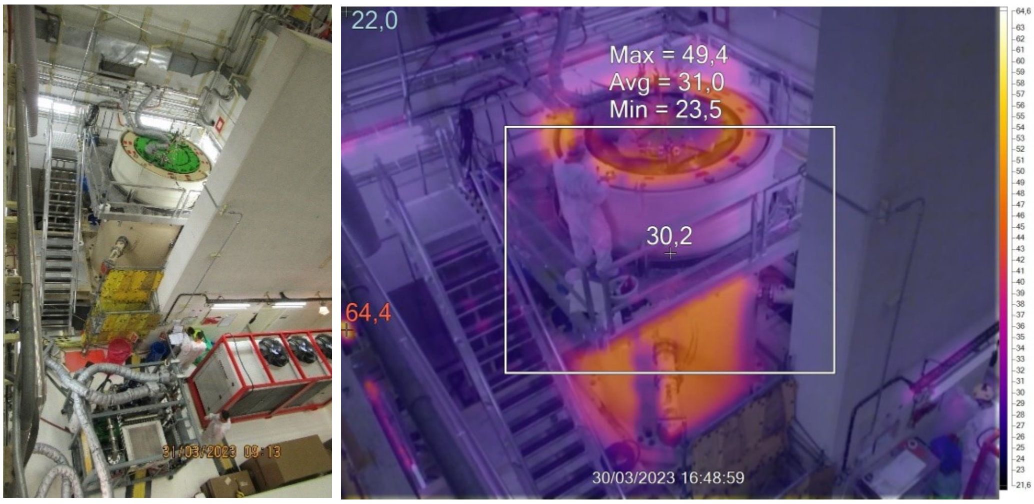

Figure 5: Forced Helium Dehydration setup (left); and an overlay thermo-vision photograph of cask at DA (right).

6. **Transfer to DSB:** lift cask from DA, lower it to a special Low-Profile Transporter, move it out of the radiologically controlled area, use the VCT crawler to transport the cask to the DSB;
7. **Change overpack:** inside DSB, at the Cask Transfer Facility, lower the MPC from transfer overpack to the storage overpack, install storage lid;
8. **Storage:** move the MPC with storage overpack to the storage area, bolt the cask to fixation rings on the floor, install temperature instrumentation, apply nuclear safeguards seals.

Figure 6: Transfer cask from Fuel Handling Building to the Dry Storage Building (left); change from transfer to storage overpack (middle); and cask at storage position (right).

3 IMPLEMENTATION

SFDS at NEK has begun on March 27th, 2023. From start to end, storing each cask took approximately one week, with some time off on Sundays. Mind that some activities for previous and next cask ran concurrently. Including five scheduled fatigue breaks (each lasting one week) the transfer of all 16 casks containing 592 fuel assemblies lasted until August 18th.

Among other factors, successful execution required coordination of many participating parties: NEK administered the project, performed nuclear fuel movement related tasks, performed decontamination work, and provided radiation protection oversight; Holtec as the main contractor performed cask handling and work related to cask technological processing, working 24/7 in two 12-hour shifts, also utilising local subcontractors; compliance with regulatory requirements was overseen by URSJV (the Slovenian Nuclear Safety Administration, SNSA, i.e., the regulator) and its authorised institutions; and finally, IAEA and European Commission (EURATOM) inspectors supervised the nuclear safeguards' aspects.

3.1 Work Organisation

Work was carefully planned well in advance and its execution was monitored with daily progress meetings. Administrative control was achieved through electronic work orders (WO): a master work order and individual works orders per cask (16 total). Each individual WO was further split into 46 operations with inter-dependencies defining possible concurrent execution or mandatory sequential work. This proved useful from at least two perspectives: anyone was able to compare the scheduled and actual start/end of an operation, and (more importantly) to see the work progress. Main Control Room (MCR) crew was regularly informed on the current cask status. They also stored values of key parameters in their digital logbook.

Holtec (not NEK) updated the work schedule twice per day – a feature both beneficial and detrimental. On one hand this ensured less interference and misinformation while preparing the schedule (beneficial to e.g., personnel constantly involved in works) and made execution as fast as possible. On the other hand, workers/inspectors needed only at specific stages of work and/or also involved in their regular assignments had to modify their planning quite often. They were, sometimes, in a sense, positioned subordinate to the contractor and its time-cost incentive.

3.2 Good Practices & Operating Experience

An example of good practice was to start the SFDS campaign with the so-called Dry Run tests, where the SFDS process was performed almost in its entirety but without nuclear fuel (see Figure 4). This served as a “real life” readiness check for both the equipment and workers. Based on this first hands-on experience we were able to implement certain improvements e.g., to procedures or at micro-organisation level. In short: Dry Runs provided valuable feedback, so we recommend that they are repeated prior to each of the SFDS campaigns.

Heavy usage of equipment, especially continuous heavy use, subjects it to failures. Risk (= probability × consequences) can also be reduced by having a contingency plan for such failures, as it was the case in SFDS project. No significant issues occurred in Campaign 1 and nuclear safety was maintained at all times. Among minor problems one could point out:

- Higher than expected filter blockage rate during Forced Helium Dehydration (due to relatively high boron concentration of SFP water, i.e., approximately $3000\ \mathrm{ppm}$) – addressed by periodic flushing.
- Tripping of the cooling unit – addressed by adjusting trip setpoints and periodic standby operation. The cooling unit turned out to be less reliable as expected.
- VCT malfunction (after safely releasing cask at its final storage position) – needed replacement of a subcomponent.
- Helium blower (shaft) broke and needed replacement. This equipment was beforehand correctly identified as important, and a spare unit was required.

There have been some cases of human errors:

- Incorrect installation of MPC lid spacers was discovered at SFDS move #3. This illustrates how independent peer checks can help prevent human error from becoming an issue.
- Need to reperform cask lid welding (incorrect welding nozzle used; again, SFDS move #3) – weld had to be excavated and reapplied. Due to prolonged time since the cask was closed and filled with water, alternate means of cask cooling needed to be established in line with procedural guidance (contingency plan).

Consequently, fatigue breaks have been re-scheduled at every three weeks instead of four weeks of work. Time delays from equipment malfunctions also resulted in additional received radiation dose, which can be seen on Figure 7 (move No. 3, 9 and 14).

Another example of a need for a contingency plan is a situation where fuel assembly replacement would be required, e.g., in case of presence of an unretrievable foreign material. Due to the aforementioned cask-loading constraints (see Sec. 2) it is not trivial to exchange fuel assemblies. In fact, fuel loading plan has been prepared months in advance of the SFDS Campaign 1 and required regulator’s approval. Therefore, NEK fuel department developed a computer tool that searches through our Fuel Assembly Register for a suitable replacement fuel assembly. Fortunately, we did not have to use it as all 592 fuel assemblies were loaded exactly as planned.

3.3 Radiological Impacts

Radiological impacts on workers were monitored throughout the entire campaign. Official data shows that the highest individual exposure was $2.56\ \mathrm{mSv}$, while the average dose of all personnel involved in the SFDS project was $0.31\ \mathrm{mSv}$ (more precisely, $1.33\ \mathrm{mSv}$ on average for Holtec’s and its subcontractors’ crew, and $0.07\ \mathrm{mSv}$ on average for all others, including NEK staff). Projected and actual collective dose per cask is depicted in Figure 7.

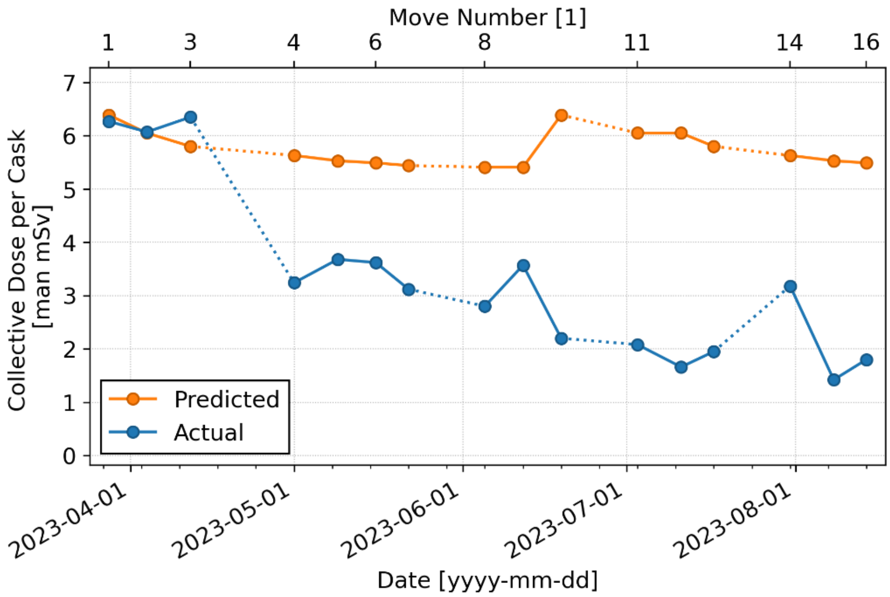

Figure 7: Projected and actual collective dose per cask. Dotted lines represent fatigue breaks. Time delays from equipment malfunctions can also be seen as increased dose (move No. 3, 9 and 14).

Starting from $6.3\ \mathrm{man\ mSv}$, a sharp drop in actual collective dose per cask can be seen after the third cask, which can be attributed to a decree stating that since workers have obtained enough experience by then, they shall not be present solely for training purposes anymore. Consequent further decrease in actual dose is due to two factors. Firstly, with more experience certain stages of work could be performed in less time; and secondly, additional radiation shielding was installed, including neutron shielding/moderating boards. Therefore, with all three radiation protection principles (distance, time, shielding) employed the received collective dose fell below $2\ \mathrm{man\ mSv}$ per cask.

4 CONCLUSION

From March to August 2023 the Krško NPP transferred 592 spent fuel assemblies from wet to dry storage. The basic dry storage unit is Holtec's Multi-Purpose Canister, each holding up to 37 fuel assemblies and serving as an additional fission product barrier. These casks are inserted into storage overpacks and stored in a Dry Storage Building. The transfers were completed without any serious issues or challenges to nuclear safety. There were, however, some equipment malfunctions that resulted in time delays. Radiation levels were monitored continually, and individual doses remained well below regulatory limits. Successful completion of Spent Fuel Dry Storage Campaign 1 completes the Safety Upgrade Program and thus fulfils the last regulatory requirement for plant lifetime extension to 60 years (till 2043).

REFERENCES

[1] Resolucija o nacionalnem programu ravnanja z radioaktivnimi odpadki in izrabljenim gorivom za obdobje 2016–2025 (ReNPRRO16–25).

[2] Resolucija o nacionalnem programu ravnanja z radioaktivnimi odpadki in izrabljenim gorivom za obdobje 2023–2032 (ReNPROIG23–32). Uradni list RS, št. 14/2023 z dne 3. 2. 2023.

[3] US NRC Certificate of Compliance for Spent Fuel Storage Casks, No. 1032, Amendment No. 2, HI-STORM FW MPC Storage System.