THE REQUIREMENTS FOR CONSTRUCTION OF NEW SPENT FUEL DRY STORAGE – DESIGN EXTENSION CONDITIONS APPROACH

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Abstract

Due to the stringent requirements after the Fukushima accident and due to stricter requirements arising from the new design extension conditions (DEC) requirements which have been adopted into new Slovenian nuclear legislation, the Krško NPP decided to implement the safety upgrade project (SUP). SUP also envisages the safety upgrade of spent fuel storage. The NPP decided to construct a new spent fuel dry storage (SFDS) system as this is much safer and reliable as a passive system compared to the existing spent fuel pool. The new SFDS is designed to DEC conditions in accordance with the West European Nuclear Regulators Association (WENRA) requirements from 2014. Some of design basis conditions are defined even stricter by the operator. The design and construction of the new SFDS, which will meet all specified design basis conditions, are a challenge for both; the manufacturer and the operator, who will manage the SFDS. The important upgrade of the Krško NPP's safety of spent fuel storage will be achieved with SFDS successful operation. The licensing process for SFDS started in year 2017. The design conditions for SFDS were defined by Slovenian Nuclear Safety Administration (SNSA). After the redesign of the original project, the positive opinion for the construction license was issued by SNSA in January 2019. The operation of SFDS should begin in 2021.The paper describes an outline of new DEC requirements for spent fuel dry storages, along with the example to articulate some of the Slovenian DEC requirements and how these are applied to the Krško NPP spent fuel storage.

1. INTRODUCTION

The experience from the Fukushima Daiichi accident was the main reason for introducing a new DEC approach. The DEC is dealing with the conditions more complex than those that would occur during postulated design basis accidents (DBA). The basic aim of DEC is to implement measures that are still reasonably practicable to improve the level of plant's safety [1]. It is necessary to define additional accident scenarios that are less likely than design basis accidents but to have major consequences. All the necessary modifications of the original design (safety upgrade) must be introduced to enhance the plant's capability to withstand more challenging conditions than those considered in the design basis. Additionally, an appropriate measure must be taken to ensure that the accident does not develop or to mitigate its consequences.

The DEC was fist time introduced in 2008, when WENRA published the document "Reactor Safety Reference Levels" [2, 3]. In 2014, following the Fukushima Daiichi accident, WENRA updated the safety reference levels to integrate the lessons learned from the Fukushima Daiichi accident [4]. Two categories of DEC, namely DEC A and DEC B have been introduced that time. DEC A is defined for the events for which the prevention of severe fuel damage in the reactor core or in the spent fuel storage can be achieved. DEC B is defined for conditions with severe fuel damage [1]. "A DEC event means an event or combination of events with extremely low probability and more severe consequences than design basis events. It can also include multiple failures of structures, systems and components (SSCs) in contrast to single failure postulated in the design basis" [1]. More detailed explanation of the DEC is provided in the WENRA Guidance Document "Issue F: Design Extension of Existing Reactors" [5] where WENRA defined a list of DEC initiating events.

2. REGULATORY DEC REQUIREMENTS FOR SPENT FUEL STORAGE

Immediately after issuing new WENRA reference levels, Slovenian legislation was revised in aim to incorporate the new DEC approach. The DEC definition is set in the Slovenian nuclear safety act [6]. The DEC requirements, including WENRA safety reference levels regarding spent fuel storage, are prescribed in Rules on radiation and nuclear safety factors - JV5 [7]. The new SNSA practical guideline even defines in more detail DEC approach and the relationship of DEC with plant states [8].

The basic DEC requirements for the spent fuel are defined in the JV5 as follows [1,7]:

- All possible measures have to be taken with the goal that a DEC B becomes extremely unlikely to occur for the spent fuel storage;
- Safety functions for spent fuel storage shall be fulfilled during the operational states, design basis accident and DEC A. They are sub-criticality, heat removal and confining radioactive material. Residual-heat removal shall be provided during normal operation, anticipated operational occurrences, design basis accidents and DEC A, taking into account the assumption of a single failure and the loss of off-site power. Dry storage of spent fuel shall be based primarily on the use of passive residual heat removal;
- Sufficient independent and diverse means (including necessary power and water supplies available) shall be in place to remove the residual heat from the spent fuel during DEC A, considering the assumption of the loss of off-site power. At least one of diverse means shall be effective in case of events involving external hazards more severe than design basis events;
- For the fulfilment (or reestablishment) of the safety functions, the use of mobile equipment onsite can be considered, as well as support from off-site with due consideration for the time required for it to be available. For the mobile equipment permanent connecting points accessible (from a physical and radiological point of view) under DEC shall be installed. It shall be demonstrated that systems, structures and components (SSC) including mobile equipment have the capacity and capability and are adequately qualified to perform their relevant functions for the appropriate period. The mobile equipment and the connecting points and lines shall be maintained, inspected and tested;
- The evaluation of external natural events shall consider earthquakes, flooding, extreme weather conditions, i.e. the effects of high and low temperatures, snow, ice, high winds, lightning, ice, and combinations thereof;
- The safety demonstration in relation to natural hazards shall include assessments of the design basis and DEC with the aim to identify needs and opportunities for improvement;
- For the large commercial aircraft crash to the storage facility the functionality of equipment important to safety shall be ensured during and after such an event;
- Massive collapse of building structures or consequential heavy load drops on spent fuel or other safety-related SSCs shall be prevented. Safety related SSCs shall be designed to withstand the impacts of internal and external events, including natural events which are site specific and events that are associated with human activity;
- Appropriate ventilation systems shall be provided to ensure the confinement of airborne radioactive particles during operational states, design basis accidents and DEC A;
- Adequately qualified instrumentations shall be available for DEC for determining the status of spent fuel storage and safety functions as far as required for making decisions on-site as well as off-site in case DEC B.

3. NEW SPENT FUEL DRY STORAGE AT THE KRŠKO NPP

Currently, the Krško NPP spent fuel assemblies are stored in the spent fuel pool, which is on the site. The spent fuel pool has 1709 positions in the racks to store spent fuel assemblies. Some positions are administratively prohibited or physically inaccessible for actual use. Considering the extended plant life to 2043 a total of 2282 spent fuel assemblies are expected to be stored inside the spent fuel pool.

Immediately, after Fukushima accident, the Krško NPP performed a Special Safety Review in line with the ENSREG specifications for EU Stress Tests for NPPs. Based on stress tests' results the NPP Krško prepared

operation and management restriction for the storage of spent fuel assemblies in the spent fuel pool [1]. The available storage locations in the spent fuel pool is estimated to be sufficient until 2021. Based on this fact, the proposed new spent fuel management strategy is storing the spent fuel in a new SFDS with a possibility of later reprocessing. From the technical point of view, this option is the best storage strategy for spent fuel at the moment [1].

Based on the requirements of SNSA, the Krško NPP has prepared the plant safety upgrade program. The aim of the program is upgrade the Krško NPP safety in case of severe conditions and also introduce and improve the means to successfully mitigate their consequences. The new modifications including in the safety upgrade program are grouped in three phases, part of the Phase 3 is also the construction of new SFDS. The SFDS with the belonging systems and components shall fulfil DEC conditions in accordance with DEC requirements. The general DEC requirements are set in regulations and additional ones specified by SNSA and Krško NPP (Table 1) [1,9].

TABLE 1. DESIGN BASIS CONDITIONS FOR SFDS

Environmental Condition	Design Bases	Design Extension Conditions
Earthquake	OBE=0.15g PGA SSE=0.30g PGA	0.78g PGA
Temperature	N/A	max=46.0 ºC
Tornado	N/A	yes
Extreme Wind	140 km/h	240 km/h
Glaze Ice	N/A	yes
Flooding	156.50m	157.53 m
Fire	yes	airplane crash fire
Airplane Crash	N/A	military fighter/ commercial airplane
Explosion/ pressure wave	N/A	airplane crash

3.1. Operation

The new storage building will be constructed within the Krško NPP yard with capacity for approximately 2.600 spent fuel assemblies. The Krško NPP will use a Holtec HI-STORM FW MPC Storage System for dry storage of spent nuclear fuel [1]. This storage system is certified by U.S. Nuclear Regulatory Commission. It consists of interchangeable multi-purpose canisters (MPCs) containing the spent fuel, storage overpacks (HI-STORM FW) containing MPC during storage, and transfer cask (HI-TRAC VW) containing the MPC during loading, unloading and transfer operations. The spent fuel assemblies will be stored in MPCs in up to 70 HI-STORM FW arranged in 7 x 10 matrix inside the new dry storage building.

The transfer of spent fuel assemblies from the spent fuel pool into the SFDS is expected to be done in four campaigns. The first campaign transferring 16 overpacks (up to 592 spent fuel assemblies) is planned for the year 2021. The second campaign transferring 16 overpacks (up to 592 spent fuel assemblies) is planned for the year 2028. The third campaign transferring 12 overpacks (up to 444 spent fuel assemblies) is planned for the year 2038 and the fourth campaign transferring rest of spent fuel assemblies is planned for the year 2048.

The operating lifetime of a SFDS is at least 60 years [1]. The analyses were made to prove the stability of materials for this period or still longer. A preliminary decommissioning plan for the decommissioning of the facility was prepared, which foresees that spent fuel will be transported to the final spent fuel disposal, while the remaining material will be disposed of in the national radwaste repository.

3.2. Safety functions

According to the SNSA requirements, the new SFDS solution shall be such that the nuclear safety of the supplied spent fuel storage is enhanced in regard to passive decay removal, radioactive source reduction and criticality during the operational states, design basis accident and DEC A [1].

The criticality control features of the storage canisters are designed to maintain the effective neutron multiplication factor k_{eff} below 0.95 under all operational and accidental conditions. This maximum k_{eff} value for storage system is in accordance with criteria for nuclear criticality safety [10].

The SFDS is designed with vents to allow sufficient passive air flow for heat removal from casks inside building. The proximity of neighbouring casks and confined storage space inside the building which have adverse impact on convection and radiation heat transfer from casks are evaluated.

The confinement of radioactive materials shall be ensured for design extension conditions category A. For this purpose, the heat removal from the damaged fuel shall be ensured.

3.3. Natural hazards

In order to demonstrate safety, it is particularly important to consider the specific natural events [1]. The impact on SFDS of various natural hazards were evaluated. Possible sources of natural hazards are earthquakes, strong wind, rain, snow, glace ice, thunder/lighting, flood and extreme temperatures.

The SFDS is designed to withstand the wind load as well as the effects of tornados and missiles generated by tornados. Additionally, the system is stored inside the dry storage building which further lends protect of the stored spent fuel.

The HI STORM consist of a cylindrical vessel and lid with the outer shell and lid from carbon steel which are coated to prevent corrosion. Additionally, the system is stored inside the SFDS and is protected from rainfall. The hazard due to snow will be very insignificant. The SFDS is constructed from metallic roof. Any snow deposited on the roof of the SFDS will eventually melt down. The glace ice impact to the SFDS ventilation ports and on the cooling of the interion of SFDS is evaluated. The metallic roof and concrete wall will transfer the electricity to the ground and a lightning strike will therefore not have considerable effect on the metal part of SFDS.

The SFDS is designed against floods. Flood conditions will not have adverse effects on it. The large horizontal pad is concrete and is at an evaluation for the DEC flood level which is 157.53m. The SFDS will not sustain any damage from floods since it is constructed from metal components inside the building. Even in extreme flood events, a flood will not be able to block the inlet vent of the storage for a considerable duration.

The HI STORM is designed to maintain the temperature of the spent fuel below the peak clad temperature of the spent fuel stored inside MPC.

The SFDS is specifically design against the adverse conditions “Flood and Wind”. The individual external hazards will not impact the HI STORM FW system. The most severe combination of external hazards is that of a simultaneously occurring earthquake and flooding. The probability of more than one external hazard occurring at the same time is extremely low and effects of such event is negligible.

3.3.1. Seismic safety

The site of the Krško NPP is located in an area of moderate seismic activity, therefore seismic safety is one of the main concerns regarding the design of the new SFDS building and its SSCs. According to the Seismic Qualification Programme, the SFDS building as well as the individual fuel casks shall be designed for DEC applicable to the earthquake with peak ground acceleration (PGA) = 0.78 g; this value is approx. 30 % higher than the current specified DEC requirements (i.e. DEC designed SSCs of the NPP shall be able to withstand an earthquake with PGA = 0.6 g). This requirement conservatively affects the upper steel structure of the SFDS building as well, although it was shown in the separate analysis that the potential collapse of the upper steel structure would not unacceptably impair the integrity and/or cooling capabilities of the underlying spent fuel casks. Apart from that, the design conditions require that the individual casks shall not tip-over till the earthquake with PGA > 1.2 g occurs in order to prevent cliff edge effect – consequential loss of decay heat removal capability. To fulfil this requirement, it was decided that the individual casks would be anchored to the

foundation plate of the SFDS building. While this solution helps in stabilizing the casks during the earthquake, the anchoring elements also pose additional loads to the SFDS foundation plate.

Seismic analysis of the construction was therefore an essential step in providing important inputs for the SFDS building design. Seismic loads on the SFDS building were determined in accordance with NRC RG-1.60 [11] and Eurocode 8 [12]. The soil-structure interaction (SSI) was taken into account as well. Five different seismic accelerograms (typical for the site area) and three different soil types with regard to their shear wave velocity (best estimate, lower- and upper bound) were dealt with. This resulted in fifteen different discrete analyses of SSI in order to evaluate the dynamic response of the SFDS building and fuel casks and to find the appropriate, conservative solution (i.e. the envelope of structural response results).

The final results are:

- floor response spectra at the foundation plate and at the top of the concrete walls of the SFDS building;
- reaction forces and moments for anchoring fuel casks to the foundation plate and;
- inner forces and moments in the foundation plate.

These results were, together with other loads, used to carry out the strength analysis of the whole construction and to establish the final design of the SFDS building.

The seismic fragility analyses for cask stability and of the whole SFDS building were performed before the approval of the final design [1]. It was carried out by an independent institution (Slovenian National Building and Civil Engineering Institute) in accordance with NRC [13] and EPRI [14] guidelines. Results of the fragility analysis showed that the PGA values that correspond to 1% conditional probability of failure (High Confidence, Low Probability of Failure – HCLPF) are for the SFDS building as well as for the individual casks larger than their DEC/tip-over PGA.

3.4. Human induced hazard

The impact of an aircraft on the HI STORM system is not licenced under U.S. 10CFR72 regulation, but the aircraft crash analysis is required as DEC in accordance with JV5 regulation [7]. The impact of military fighter and large commercial airplane crash on HI-STORM FW is analysed with assumption that jet fuel will be dumped upon impact and will ignite immediately. It is demonstrated that in case of such big fire would not cause beyond limit radiological releases [1].

3.5. Dose restrictions

The regulatory requirements for dose restrictions are set very strictly. The boundaries for the dose rate on the NPP site boundary must remain unchanged despite the new SFDS will be located within the site. The limit of the dose rate on the SFDS outer wall is also prescribed for the control of radioactivity. The direct radiation from the storage measured at the site boundary should not exceed dose limit of 0.05 mSv per year and the allowed SFDS building outside wall dose rate shall not exceed 3μSv/h.

The acceptance criterion for accident condition is also prescribed. Any individual located on or beyond the nearest boundary of the controlled area may not receive from any design basis accident the more limiting of a total effective dose equivalent of 0.05 Sv.

Analyses of occupational dose rates for SFDS and site boundary as well as outside wall dose calculations were prepared. The methodology separates the dose rate calculations into two independently performed parts, namely the source term calculation and the radiation transport calculation. The results of those two parts are then combined to establish actual dose rates.

Independent evaluation of the analyses completeness and correctness was performed. Some additional independent calculations included spent fuel inventory calculations and dose rates calculations. The main findings were related to described methodology and obtained results and way the variance reduction and uncertainties were used. The conclusion was that provided margin for site boundary dose was too small and that some values/dependencies are not as expected. Revision of the project was prepared (redesign) with improved shielding design (storage cask and SFDS building) and new loading plan. The proposed design follows ALARA

principle as related to doses during loading, manipulation and storage of the casks. The dose calculations for revised project fulfils the requirements.

4. REGULATORY EXPERIENCE

The licensing process for the SFDS is on-going. In 2017, in accordance with the legislation, the SNSA issued the design conditions for new spent fuel storage [1]. During the independent project review some issues were arise and the revision of the project was prepared. Based on the proposed redesign, the SNSA reviewed and assessed the proposed project changes of the SFDS project and January 2019 issued the positive opinion for the construction license.

In accordance with DEC approach, the new SFDS design based on regulatory requirements while some of design basis conditions are defined even stricter by the operator. DEC for long term spent fuel storage will be implemented in Krško NPP for the first time. The design and construction of the new SFDS are a challenge for both the manufacturer and the operator. The nuclear industry does not yet have a well-established practice for such demanding projects.

The SFDS licensing is also a challenge for Slovenian regulator. The presented regulatory experience shows that in this novel work the regulator and operator could not rely on international practice and were therefore forced to define and approve original solutions. In this development process the role of authorized technical support organisation (TSO) is also very important, since TSO's independent evaluation triggered the redesign of the original SFDS project.

The prerequisite for successful implementation of new project is knowledgeable TSOs which independently evaluate the project, an appropriately qualified regulatory body staff and appropriate knowledge level of the operator. The cooperation between all those involved in the licensing process in all phases (design, construction, commissioning, operation) is essential.

Future activities for the SFDS are licensing in accordance with Nuclear safety act [6]. The TSOs shall prepare the independent expert opinions to support the licensing process of the SNSA. The SNSA approval for operation is expected in 2019 and construction can begin and the first spent fuel transfer from the spent fuel pool into the SFDS is planned for 2021 [1].

5. CONCLUSION

Due to operation and management restriction applied at the Krško NPP after Fukushima Daiichi accident and extended lifetime to the year 2043, the additional storage capabilities to store spent fuel assemblies are needed. As there no permanent spent fuel storage location known on the world, the Krško NPP decided to use the new SFDS for spent fuel storage. The SFDS is technical solution which is safer and more reliable system compared to classical spent fuel pool, mainly due to its passive colling of the spent nuclear fuel [1].

In order to demonstrate SFDS safety, it is particularly important to consider the external and internal hazards. The effect of an earthquake on the SFDS was accurately analysed. The analyses show that the SFDS withstands effects of various external hazards.

The design and construction of the new SFDS shall meet all specified design basis conditions and this is a challenge for the manufacturer, operator and SNSA as well. The licencing process is underway. The SFDS is to be completed by the year 2021 and this is also one of a prerequisites for the extension of the Krško NPP lifetime beyond the original 40 years of operational lifetime.

REFERENCES

[1] PERŠIČ, A., at al., New Safety Requirements for Power Reactor Spent Fuel Storage, Proceedings of the 27th International Conference Nuclear Energy for New Europe, Portorož, Slovenia, (2018).

[2] CIMEŠA, S., at al., Transposition Challenges of New WENRA Requirements into Slovenian Regulation, Proceedings of the 24th International Conference Nuclear Energy for New Europe, Portorož, Slovenia, (2015).

[3] WENRA Reactor Safety Reference Levels, WENRA RHWG, (2008).

[4] WENRA, Safety Reference Levels for Existing Reactors, WENRA RHWG, (2014).

[5] WENRA, Guidance Document Issue F: Design Extension of Existing Reactors, (2014).

[6] Ionising Radiation Protection and Nuclear Safety Act, ZVISJV-1, Official Gazette RS No. 74/2015 (2015).
[7] Rules on Radiation and Nuclear Safety Factors, JV5, Official Gazette RS No. 74/16 (2016).
[8] SNSA Practical Guidelines PS 1.06, Definition of Plant States, available at http://www.ursjv.gov.si/si/zakonodaja_in_dokumenti/prakticne_smernice_ursjv/ (in Slovenian) (Accessed 2019).
[9] NPP Krško Safety Upgrade Project Design Inputs and Interfaces, Rev. 8., (2016).
[10] US NRC 10 CFR 72.124, Criteria for nuclear criticality safety.
[11] Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants", Revision , (1973).
[12] EN 1998-1:2004, Eurocode 8: Design of Structures for Earthquake Resistance - Part 1:General Rules, Seismic Actions and Rules for Buildings, 2004.
[13] NUREG/CR-2300, PRA Procedure Guide. US NRC, 1983.
[14] KENNEDY, R.P., REED, J., Methodology for Developing Seismic Fragilities. EPRI TR-103959, Electric Power Research Institute, Palo Alto (1994).
[15] PERŠIČ, A., Design Extension Conditions for Spent Fuel Storage, Proceedings of the 12th International Conference of the Croatian Nuclear Society, Zadar, Croatia (2018).