SPENT FUEL MANAGEMENT IN PAKISTAN NPPS, WET STORAGE TO DRY STORAGE

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Abstract

The Pakistan nuclear power generation capability is progressing rapidly. Currently five Nuclear Power Plants are in operation and two Nuclear Power Plants are under construction. Pakistan is committed towards safe, secure and sustainable management of spent fuel generated from its Nuclear Power Plants operation. The spent fuel so far generated is stored at reactor spent fuel pools under water. These spent fuel pools have limited storage capacities and are not designed to accommodate spent fuel generated from lifetime operation of Nuclear Power Plants in Pakistan. Consequently, Pakistan has decided to develop spent fuel dry storage facilities for storage of spent fuel for extended periods till ultimate decision regarding spent fuel management is taken. The paper discusses the experience of managing the spent fuel at reactor pools and development process of spent fuel dry storage facilities in Pakistan.

1. INTRODUCTION

Pakistan began its journey towards nuclear power generation in 1972 when Karachi Nuclear Power Plant (KANUPP) started its commercial operation. Since then four more NPPs at Chashma Nuclear Power Generating Station (CNPGS) have been successfully connected to national grid. Two NPPs are currently in installation and commissioning phase at Karachi and will be connected to grid in forthcoming years. Pakistan Atomic Energy Commission (PAEC) owns and operates the NPPs in Pakistan.

2. NATIONAL POLICY OF SPENT FUEL MANAGEMENT

The Government of Pakistan realizes that spent nuclear fuel is a valuable asset. Currently, the spent nuclear fuel is stored at licensed nuclear facilities. A decision regarding the fate of spent nuclear fuel will be made in due course of time by the Government of Pakistan [1].

PAEC shall be responsible for safe and secure management of spent nuclear fuel.

3. SPENT FUEL MANAGEMENT AT CNPGS

At CNPGS, four PWR type NPPs namely C-1, C-2, C-3 and C-4 are in operational phases. The reactor core of each operational NPP contain 121 fuel assemblies, out of which 40 spent fuel assemblies are replaced by fresh fuel assemblies during reactor refuelling outage planned after every 15 months.

3.1. Wet Storage at CNPGS

The spent fuel discharged from each NPP is presently stored under water in at-reactor (AR) spent fuel storage pools of fuel building. There are two spent fuel storage pools, a cask loading pit and a cask cleaning pit in fuel storage building of each NPP. The stainless steel lined, reinforced concrete spent fuel storage pools store the spent fuel in vertical racks with borated water cooling environment. Control of the storage pools water temperature during

normal operation is accomplished by circulating the pool water through heat exchanger. Purification and clarification of the pool water is by the use of filters, strainers, and an ion exchanger.

All fuel handling equipment and storage system components are designed to be operational after an Operating Basis Earthquake (OBE) or a Safe Shutdown Earthquake (SSE). Provision is made in all cases to ensure that any fuel handling operation in progress can be completed manually without any damage to the fuel assembly.

The system is designed to store the spent fuel in a subcritical array such that a Keff of less than 0.95 is maintained.

The shielding design of spent fuel storage system is sufficient to protect plant personnel from being exposed to radiation exceeding reasonably acceptable limits.

The spent fuel storage pools are sized to contain 741 spent fuel assemblies i.e. spent fuel assemblies generated from 15 outages plus one full core in case of forced unloading. Up to now, 480 (142.8 t HM), 200 (59.5 t HM) and 40 spent fuel assemblies (11.9 t HM) have been stored in spent fuel pools of C-1, C-2 and C-3 respectively. C-4 is presently in its first operating cycle and therefore, no spent fuel is generated at C-4 till now.

The design life of each NPP is 40 years and it is envisaged that about 1321 spent fuel assemblies (393 t HM) will be generated from life time operation of each NPP.

3.2. Dry Storage at CNPGS

The AR storage pools of C-1 will reach to their maximum capacity in forth coming years. The same situation will also be faced by C-2 and subsequently by C-3 and C-4. This situation necessitates the development of mechanism to shift the spent fuel from AR storage pools. Therefore, it has been decided to develop a PWR Spent Fuel Dry Storage (PDS) facility at CNPGS. The PDS facility will be constructed at the reactor site but mostly will be independent of reactor and AR storage pools. The purpose of the PDS facility is to safely transfer and store the spent fuel generated from life time operation of existing CNPGS operating units. The PDS facility is located at distance of 500 m to a maximum of 800 m away from all fuel buildings of CNPGS units. PAEC owns the PDS facility and has the overall responsibility to ensure that the facility is designed, constructed and operated without undue risk to the health and safety of the workers, public and environment.

It is intended that the interim spent fuel dry storage facility provide for the safe, stable and secure storage of spent nuclear fuel before it is reprocessed or disposed of as radioactive waste. Like other engineered systems, the safe operation and maintenance of spent fuel storage facilities depends in part on adequate design and construction. The most important design features of such facilities are those, which provide the necessary assurances that spent fuel can be received, handled, stored and retrieved without undue risk to health and safety, or to the environment. To achieve these objectives, the design of spent fuel storage facilities shall incorporate features to maintain fuel subcritical, to remove spent fuel residual heat, to provide for radiation protection, and to maintain containment over the anticipated lifetime of the facilities as specified in the design specifications. The features shall also provide for all anticipated operational occurrences and design basis accidents in accordance with the design basis as approved by the Regulatory Body [2].

The PDS facility comprises of Cask Storage Hall, Container Vessel Transfer Room, Cask Storage Pad, Stack, Cask Work Shop and office building.

Cask storage hall is designed to provide safe environment and protection for concrete storage casks filled with spent fuel assemblies. The length of hall is 122 m and width is 20.5 m. The hall has a storage capacity of 124 concrete storage casks. An overhead crane of 100 tons capacity is provided for cask handling and placement operations. Aluminium louver ventilators at two levels are provided for cooling of hall interior space through passive means.

The Container Vessel Transfer Room (CVTR) is situated adjacent to cask storage hall. The purpose of this room is to shift spent fuel assemblies container vessel from Fuel Transfer Cask to Fuel Storage Cask. CVTR is constructed of high density Barite concrete. Thickness of walls and roof slabs are estimated on the basis of radiation shielding requirements. An overhead crane of 20Ton capacity is provided in CVTR. All openings in CVTR are provided with shielding graded doors and lead glass windows. A concrete stack of 21 meter height serves the purpose of release of exhaust gases from facility operations.

An office block is provided on left side of CVTR. This block consists of record rooms, store, switch room, change room etc.

A cask workshop of 30 m x 12 m size is planned near adjacent to PDS building. Casting of barite concrete in new casks will be carried out in this workshop.

The CVTR and Cask Storage Pads inside storage hall are classified as Nuclear Safety Class 3 structures and are designed and constructed in accordance with the seismic requirements for the SSE. All other structures are classified as Non-Nuclear Safety structures and are designed and constructed in accordance with Building Code of Pakistan.

3.2.1. Dry Cask System for PDS Facility

The design of a storage system starts with the site requirements, particularly cask weight or dimensional limitations, and the intended approach for ultimate retrieval of the stored fuel assemblies. Selection of the cask type, cask fabrication approach, and the materials of construction is the starting point for design and optimization [3].

Due to dimensional limitations, AR fuel building crane capacity and certain economics factors canister based dry cask storage system has been selected for PDS facility. The dry cask system for PDS facility comprises of Container Vessel (canister), Transfer Cask and Storage Cask. The system is designed to provide criticality control, containment, heat removal, shielding and all other safety requirements.

The dry cask system is designed to store spent fuel assemblies with minimum cooling time of ten years after discharge from the reactor core. Maximum discharge burnup of each fuel assembly is limited to 39.8GWd/t HM. Initial enrichment of fresh fuel assembly is less than 4%. The decay heat calculated against maximum discharge burnup and ten years cooling time is 585 Watt per spent fuel assembly [4]. Spent fuel characteristics considered for dry storage are tabulated in Table 1.

TABLE 1. FUEL CHARACTERISTICS FOR DRY STORAGE

Parameter	Value
Fuel Type	PWR 15 x 15
Initial Enrichment	<4%
Maximum Burnup	39.8 GWd/t HM
Minimum Cooling Time	10 Years
Maximum Decay Heat	585Watt/ Fuel Assembly
Gamma Source Strength/ Fuel Assembly	2.4x1015Photons/sec
Neutron Source Strength/ Fuel Assembly	3.2x108Photons/sec

Container vessel is a sealed metallic (stainless steel) container, which provides containment and criticality control. Inside container vessel a basket fabricated of Aluminium Boron Carbide based composite material will provide the neutron absorption to maintain subcriticality. Helium (He) gas at a pressure of 0.8 bars will maintain inert atmosphere. Container vessel has the capacity to contain 21 spent fuel assemblies.

A metallic transfer cask will shift the loaded container vessel from AR fuel building to PDS facility. The height of cask is 4.2 m and its outer diameter including lifting lugs is 2.5 m. Lead will be used for gamma shielding and Boron-added High Density Polyethylene (HDPE) will be used for neutron shielding. Weight of loaded transfer cask is 70 Ton approx. Surface dose rate on the exterior surface of loaded transfer cask shall be limited to less than 1.0 mSv/hr.

In PDS facility loaded container vessel will be shifted to high density Barite concrete storage cask for long term interim storage of spent fuel. The height of cask is 4.48 m and its outer diameter including lifting lugs is 3.4 m. Reinforced Barite concrete of storage cask will provide the entire necessary neutron and gamma shielding. Weight of loaded storage cask is 90 Ton approx. Surface dose rate on the exterior surface of loaded storage cask shall be limited to less than 1.0 mSv/hr.

The decay heat of spent fuel assemblies is removed from container vessel by natural draft convection. Air enters from the air inlets at cask bottom, moves upward around the container vessel and exits from air outlets at the cask top.

The safety of PDS facility resides mainly in the multiple-barrier confinement function provided by the safety related structures, systems and components and the non-dependency on active component needed for their safety functions. The casks are designed to withstand potential conditions experienced during normal or off-normal handling.

3.2.2. Transfer Process

A cask loading pit (4m x 4m) in AR fuel building will be used for shifting of spent fuel assemblies from spent fuel pools to container vessel. Adjacent to cask loading pit there is a cask cleaning pit (4m x 4m) where external decontamination of loaded transfer cask will be carried out. A cask internal conditioning system will be installed near cask cleaning pit for vacuum drying and helium gas filling in loaded container vessel. Each AR fuel building is equipped with overhead crane having lifting capacity of 75 Ton for handling of transfer cask. The spent fuel transfer process from AR fuel buildings to PDS facility is briefly described as under:

(a) Place the transfer cask in cask loading pit in AR storage pools building.
(b) Remove the cask lid and place container vessel inside transfer cask.
(c) Shift spent fuel assemblies in container vessel.
(d) Place and tight the lids of container vessel and transfer cask.
(e) Lift the transfer cask and place in cask cleaning pit.
(f) Dewater the transfer cask and wash down its exterior surface.
(g) Dry the container vessel and fill inert gas He at 0.8 bars.
(h) Perform radiation measurements and install the required instrumentation.
(i) Lift the transfer cask and place on transfer vehicle.
(j) Transfer to PDS facility and shift the transfer cask to CVTR.
(k) Place storage cask in CVTR.
(l) Remove the lids of transfer cask and storage cask.
(m) Lift the container vessel from transfer cask and shift into the storage cask.
(n) Secure the lids of transfer cask and storage cask respectively.
(o) Shift the storage cask to cask storage hall and place on the pad at the designated place.
(p) Perform radiation measurements and install the instrumentation.

4. SPENT FUEL MANAGEMENT AT KANUPP

Karachi Nuclear Power Plant (KANUPP) has been operating since 1972. The design life (30 years) of plant was completed in 2002. In order to operate the plant beyond design life, many safety upgrades were carried out at plant to acquire re-license from the regulator. The design capacity of spent fuel storage bay was also approaching to its limit of 23,760 bundles, therefore, it was decided to take steps by enhancing the storage capacity of the existing pool as short term measure and in long term an intermediate dry storage facility should be developed for interim storage of spent fuel bundles.

4.1. Wet Storage at KANUPP

At KANUPP, eleven spent fuel bundles are placed horizontally in a tray and eighteen trays are piled in a stack. A total of 120 stacks in matrix of 12 x 10 can be placed in storage bay resulting in design storage capacity of 23,760 bundles. A water thickness of 3.96m above top tray loaded with two months cooled bundles provides radiation level 30cm above water surface below 8.7E-3 mSv/hr.

4.1.1. Modification in Storage Pattern of Spent Fuel Storage Bay

The design storage capacity of spent fuel bay was completed in mid-2010. But, it was already planned to enhance the storage capacity to enable the operation by providing storage capacity to the discharged bundles as a result of plant operation beyond mid-2010.

The source term and decay heat of spent fuel bundles decreases at faster rate during initial cooling time of 10 years afterwards the rate of decrease slows down. So placing of tray having spent fuel bundles with cooling time greater than 10 years at top of each stack would require less water shield to maintain the allowable exposure above water surface. Therefore, it was planned to place 24 trays per stack to enhance the storage capacity. It was also decided to place two stacks each of 24 stacks in a High Density Tray Rack (HDTR) to provide stability. A total of sixty racks can be accommodated in KANUPP spent fuel storage bay. In this way, the storage capacity was increased by 30%. The area for storage of in-core (2266 in No.) bundles is also reserved in spent fuel bay.

4.2. Dry Storage Facility at KANUPP

Dry storage Facility for the storage of spent fuel bundles at KANUPP is an important activity of KANUPP Decommissioning Plan but now it has become a necessity for the continued operation of the plant. The storage capacity which was enhanced due to adopting HDTR system is approaching to its limit, therefore shifting of spent fuel bundles from wet storage to Dry Storage Facility is an essential requirement now.

4.2.1. Limitations in the Design of Storage Cask

KANUPP was designed in late sixty's, therefore much considerations for the transfer of spent fuel bundles was not given at the time of design of wet storage. A cask loading area (2.4m x 2.4m), decontamination area (2.6m x 3.7m) was provided adjacent to the KANUPP spent fuel storage area (7.6m x 12.5m). The design capacity of crane is only 25 Ton.

4.2.2. Transfer Process

An inspection area of 5.5m x 5.2m is provided which will be used for the loading of spent fuel bundles in basket and storage cask. The tray loaded with spent fuel bundles will be tilted vertically allowing to pick spent fuel bundles vertically and placed in steel basket. Two baskets will be placed in each cask. The cask will then be shifted to Decontamination pit for decontamination, drying and dose rate monitoring. The cask will then be lifted from storage bay decontamination area with the help of a crane (25 T) and placed over a transfer vehicle for the transfer of cask to storage building about 400 m from KANUPP Reactor Building.

4.2.3. Dry Cask System

The dry cask system of KANUPP comprises of barite concrete cask and basket. The diameter and height of cask is 1.78 m and 2.15 m respectively. Shielding thickness is 47.2 cm. Weight of empty cask is 16.0 Ton and of loaded cask will be 18.25 Ton approx. 54 spent fuel bundles will be stored in one basket and two baskets will be placed in a storage cask made up of barite concrete. Surface dose rate on the exterior surface of loaded storage cask shall be limited to less than 1.0 mSv/hr.

The dry cask system is designed to store 108 spent fuel bundles in a single cask. Burnup of each spent fuel bundle is 9 GWd/t HM. The minimum cooling time required to all the spent fuel bundles before shifting into the cask is ten-year.

5. LICENSING OF DRY STORAGE FACILITIES

Pakistan Nuclear Regulatory Authority (PNRA) is the competent and independent nuclear regulatory body and is responsible for licensing of nuclear installations in Pakistan.

All activities including design, manufacturing, construction, installation of dry storage facilities shall be conducted in accordance with the applicable codes and standards.

For PDS Facility at CNPGS, PAEC has applied for a Site Specific License. The Preliminary Safety Analysis Report (PSAR) of the facility is submitted to PNRA and presently is under review stage. PAEC will submit PSAR of dry cask to PNRA for permission of prototype manufacturing.

For KANUPP Spent Fuel Dry Storage Facility, PAEC has applied for a General License. The safety analysis report of the cask has been approved and manufacturing & testing of prototype cask has also been completed. Design approval of the cask by PNRA is under process.

6. IAEA SAFEGUARDS

CNPGS and KANUPP fuel is already under IAEA surveillance. The intention to develop dry storage facilities at KANUPP and CNPGS were communicated to IAEA during preliminary design stages of respective facilities. The provisions for IAEA requirements have been considered during designing of casks.

7. CURRENT STATUS OF DRY STORAGE DEVELOPMENT

At CNPGS, the construction work of PDS facility is in progress. Currently one dry storage building is being constructed and in future two more building will be constructed. Casks prototype manufacturing will be started after review and approval of casks PSAR.

At KANUPP, the construction work of dry storage building is completed. Manufacturing & testing of prototype cask has also been successfully completed with PNRA. Manufacturing of dry casks is planned in near future after design approval and issuance of certificate of compliance by PNRA.

8. CONCLUSIONS

By the development of dry storage facilities at CNPGS and KANUPP, the storage capacities will be enhanced to store spent fuel generated from lifetime operations of operating NPPs in Pakistan. The experience and technical expertise gained by PAEC during design, development and operation of these facilities will be beneficial for developing the same for upcoming NPPs.

Dry storage is now a proven technique employed worldwide for safe and secure storage of spent fuel for extended periods. Therefore, dry storage facilities will provide safe, secure and reliable storage of spent fuel for Pakistan till availability of reprocessing or disposal facility.

REFERENCES

[1] PAKISTAN NUCLEAR REGULATORY AUTHORITY, National Policy on the Safe Management of Radioactive Waste, Decommissioning and Spent Nuclear Fuel in Islamic Republic of Pakistan, RWP-01/2018, PNRA, Islamabad (2018).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of Spent Fuel Storage Facilities, IAEA Safety Series No 116, IAEA, Vienna (1994).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Optimization Strategies for Cask Design and Container Loading in Long Term Spent Fuel Storage, IAEA-TECDOC-1523, IAEA, Vienna (2006).

[4] SALIM, Z., SANAULLAH, Decay Heat Calculation for a Fuel Assembly with Operating and Maximum Discharge Burnup with 5 Years and 10 Years Cooling Time, CNPGS, Chashma, 2014.