An Indian Perspective for Transportation and Storage of Spent Fuel

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Summary

The spent fuel discharged from the reactors are temporarily stored at the reactor pool. After a certain cooling time, the spent fuel is moved to the storage locations either on or off reactor site depending on the spent fuel management strategy. As India has opted for a closed fuel cycle for its nuclear energy development, reprocessing of the spent fuel, recycling of the reprocessed plutonium and uranium and disposal of the wastes from the reprocessing operations forms the spent fuel management strategy. Since the reprocessing operations are planned to match the nuclear energy programme, storage of the spent fuel in ponds are adopted prior to reprocessing. Transport of the spent fuel to the storage locations are carried out adhering to international and national guide lines.

India is having 14 operating power reactors and three research reactors. The spent fuel from the two safeguarded BWRs are stored at-reactor (AR) storage pond. A separate wet storage facility away-from-reactor (AFR) has been designed, constructed and made operational since 1991 for additional fuel storage. Storage facilities are provided in ARs at other reactor locations to cater to 10 reactor-years of operation. A much lower capacity spent fuel storage is provided in reprocessing plants on the same lines of AR fuel storage design. Since the reprocessing operations are carried out on a need basis, to cater to the increased storage needs two new spent fuel storage facilities (SFSF) are being designed and constructed near the existing nuclear plant sites. India has mastered the technology for design, construction and operation of wet spent fuel storage facility meeting all the international standards

Wet storage of the spent fuel is the most commonly adopted mode all over the world. Recently an alternate mode viz. dry storage has also been considered. India has designed, constructed and operated lead shielded dry storage casks and is operational at one site. A dry storage cask made of concrete with stainless steel cavity was also designed for spent PHWR fuel.

Fuel transportation is subjected to highly explicit safety and security regulations, constantly updated by international and national experts. It is noted that the radioactive material transportation regulations comprise two distinct objectives.

Security or physical protection, consisting in the preventive losses, disappearances, thefts or misappropriation of nuclear materials.

Safety, which consists in controlling the irradiation, contamination and criticality hazards inherent in the transportation of radioactive materials, with a view to ensuring that man and the environment remain unaffected by the potential pollution involved.

Certain principles underline the transport regulations setup by IAEA and the universally adopted rule is that transport safety must be based on three lines of defense. Viz. the concept of a package, the reliability of transport and the efficacy of specific resources to deal with an accident.

Spent fuel transport is carried out in "type B" packages, designed to withstand severe accident conditions, simulated by tests, validated by approval certificates and subject to inspection

Introduction

Energy security is the key to the success of a nation in its forward stride and the per capita energy consumed is an index of civilization. Means of achieving this goal depends on the resources at hand and its efficient deployment. Over the years nuclear energy has evolved as a viable alternative to conventional routes of energy production.

For long-term nuclear power production, there are two fuel cycle options that are of relevance and under consideration at the present juncture, viz. the once through cycle with permanent disposal of spent fuel and the closed fuel cycle with reprocessing and recycle of uranium and plutonium. Both the options require efficient and safe waste management strategies.

The proven resources of low priced uranium are insufficient to support a long-term and meaningful contribution to India's energy demand by way of nuclear energy. Closing the nuclear fuel cycle by reprocessing the spent fuel and recycle of uranium and plutonium back into reactor systems helps in exploiting the full potential of nuclear power and maximizes the resource utilization. India is having limited resources of uranium and vast resource of thorium. In terms of fossil fuel the thorium resources are equivalent to 800 billion tonnes of coal through fast breeder reactor (FBR) and other reactor systems using thorium. The three stage Indian nuclear energy programme designed in the second half of the last century by the late Homi J. Bhabha is based on the optimum use of the available resources.

The first stage of the nuclear power programme, comprising setting up of Pressurised Heavy Water Reactors(PHWRs) and associated fuel cycle facilities is already in the commercial domain. Twelve PHWRs are operating and six PHWRs comprising a mix of 540 and 220 MWe rating are under construction. The second stage envisages the setting up of Fast Breeder Reactors(FBRs) backed up by reprocessing plants and plutonium based fuel fabrication plants. In order to multiply the fissile inventory, fast breeder reactors are necessary for our programme. A 40 MWt Fast Breeder Test reactor has been operating at the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, since attaining first criticality on 18 October 1985. Project activities of a 500 MWe Prototype Fast Breeder Reactor(PFBR) is in progress at Kalpakkam. The third stage will be based on thorium-^{233}Uranium cycle. ^{233}U is obtained by irradiation of thorium in PHWRs and FBRs.

India is currently operating two reprocessing plants for the treatment of spent fuel from PHWRs. The reprocessing capacity is augmented in a phased manner to match the nuclear energy programme. This has resulted in the rise of spent fuel inventory and necessitated the design, construction and operation of storage facilities both at-reactor(AR) and away-from-reacto(AFR) sites prior to reprocessing. More than 30 years of operation of these facilities has given mastery over design, construction and operation of spent fuel storage facilities especially wet type meeting all the international safety standards.

In India, as the 14 power reactors are operating at different locations, the movement of spent fuel from reactor site to storage locations and reprocessing plants involve transport operations. The transport safety regulations applicable to spent fuel comply with the rules applicable to all radioactive materials, which constitute a subcategory of dangerous materials (class 7). Strict compliance to these regulations has resulted in incident free transportation of spent fuel from various locations by both rail and road for more than 25 years.

Nature of Spent Fuels and Management Strategy

Research reactors CIRUS and DHRUVA employ aluminium cald, natural uranium metallic fuel. The fuel used in Fast Breeder Test Reactor is a mixture of Pu and U carbide clad in stainless steel. TAPS-1 and 2 (BWRs), use zircaloy clad, 2.5% enriched uranium 36 pin fuel cluster and the PHWRs are fuelled with natural uranium oxide in 19 pin bundle.

The annual spent fuel arisings from the operating 12 PHWRs and 2 BWRs are shown in Table 1. Since India has adopted a closed fuel cycle on a 'reprocess to recyle mode', the storage of spent fuel prior to reprocessing forms a part of the spent fuel management policy. Fig 1. Shows the scheme of spent fuel management strategy followed in India.

Table 1.Operating Nuclear Power Plants & annual Spent Fuel Discharges

Name of Plant	Reactor type	Start of operation	Rated capacity MW(e)	Annual SF arisings tHM/a
RAPS 3 &4	PHWR	2000,2000	2x220	60
KAIGA 1&2	PHWR	2000,2000	2x220	60
KAPS 1 & 2	PHWR	1993, 1995	2x220	60
NAPS 1 & 2	PHWR	1991, 1992	2x220	60
MAPS 1 & 2	PHWR	1984, 1986	170 and 220	53
RAPS 1 & 2	PHWR	1973, 1981	100 and 200	45
TAPS 1 & 2	BWR	1969	2x160	21

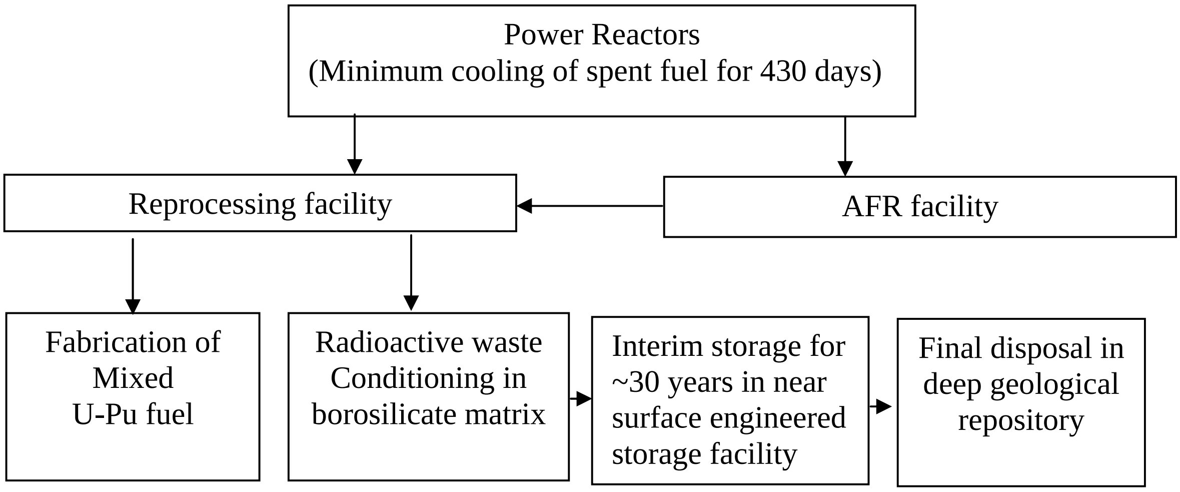

Fig. 1. Spent fuel management in India

Spent fuel Storage

(a) Wet storage of spent fuel has been the predominant mode of storage in India at various nuclear reactors and reprocessing plants.

The BWRs are in operation since 1969. The storage pond at AR was initially designed to store 528 spent fuel assemblies(SFAs). Subsequently the capacity was increased to 1500 SFAs by reracking using high density racks. A separate wet storage facility, AFR has been designed constructed and made operational since 1991 for storage of 2000 SFAs extendable to 3312 SFAs. The fuel pool is 9 m (W) x 13 m (L) and 13 m (D). The depth accounts for 4.4 m fuel height, 5 m for cask height, 2.6 m for shielding and 1 m free board. Radiation shielding around the pool is provided by 1.5 m thick concrete wall. The pool is 5 m below the ground level and 8 m above ground and is lined with stainless steel 304 L plate. The concrete structure has been tested for leak tightness. A leak detection system has been provided.

RAPS 1&2 were the first two PHWRs to be commissioned in 1973 and 1981 in Rajasthan. The SFAs generated from these reactors are stored in SS trays in the spent fuel pool at the station. The capacities of the fuel pool was adequate for about 10 years full power operation. The storage capacity of the pool was increased by 30% of its original capacity by reducing the spacing between each tray and by increasing the stack height. The latest

PHWRs are being designed to have fuel pools with storage capacity of 10 reactor years.

The spent fuel is stored at reprocessing plants in underground fuel pools lined with SS plates. Their storage capacity is much less compared to fuel pools of PHWRs since they ate meant to meet operational requirements of reprocessing plants.

Figure 2. shows a spent fuel storage facility. A typical pool have a capacity of about 63 t HM of PHWR fuel. The fuel pool details are as follows :

(1) Size	: 10 m(L) x 8 m(W) x 5.2 m(D)
(2) Clear water shielding	: 3.0 m
(3) Total water volume	: 450 m^3
(4) Pool water turn over time	: 37.5 h
(5) Fuel pool lining (Stainless Steel)	: 3.2 mm

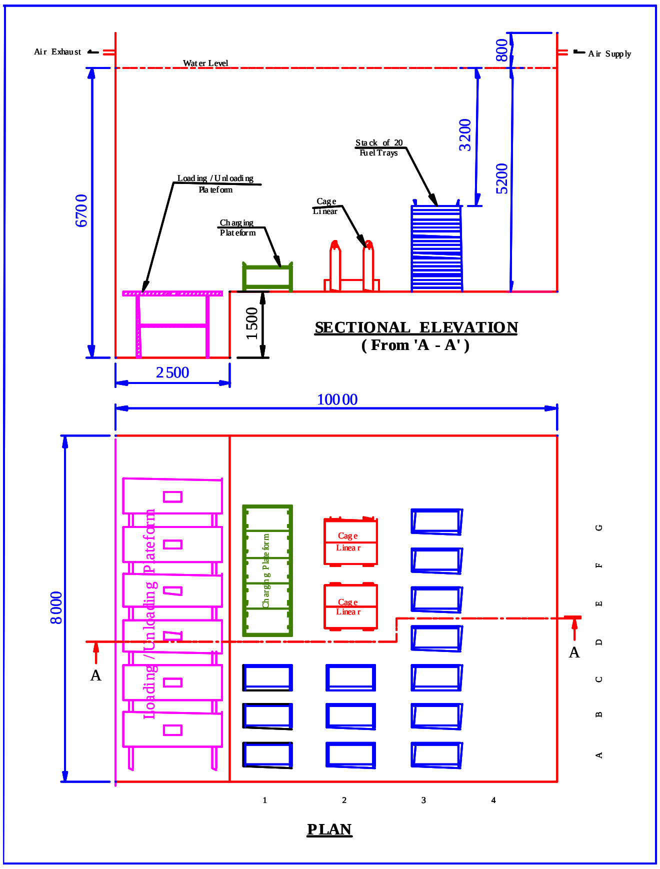

Fig. 2. Schematic Diagram of a typical spent fuel pool

The fuel pool floor has been designed for two different load bearing capacity viz., cask handling and fuel storage. The spent fuel is stored in trays in a stack of 20 trays leaving a clear water shielding of 3.0 meters. A movable bridge provided with fixed and sliding tong spans the top of the storage pool. These tongs are used for handling of the fuel under water. A seventy ton Electric Overhead Travelling (EOT) crane is used to handle the cask. A push and pull ventilation system have been adopted to minimise air born activity in the fuel handling operating area. Fig. 4. Shows the photograph of a pool at reprocessing facility.

Fig. 3. Spent Fuel Storage Pool at Reprocessing Facility

Design of New Spent Fuel Storage Facility

In order to cater to the increased rate of spent fuel generation need has arisen to augment the storage capacity for spent fuel. Accordingly additional spent fuel storage facilities (SFSFs) are being constructed in the vicinity of the power station and reprocessing plant. The plant layout is designed to take care of following aspects:

- Seismic events
- Maintaining the water table below the raft
- Leak detection
- External cooling provision
- Single failure proof EOT crane
- Engineered ventilation system
- DM Plant
- Provision for class III power
- Pond water polishing system

Seismic and civil structure design

The design of SFSF is based on the guidelines given in IAEA TECDOC-1250 used in safety classifications of system and components for Nuclear Fuel Cycle Facilities. These are designed for Operating Basis Earthquake (OBE). The design of pool building and other associated building is performed by using the local soil/rock data obtained through a geotechnical investigation. The design of various mechanical system and components is carried out as per the respective design codes and standards based on their safety classification and seismic categorisation. The pool structure has been designed for hydrodynamic response during seismic event to check for the stability of the structure.

The design of civil structure is carried out for a life span of 50 years. The design of the civil structures would take care of the applied bearing pressure under all load combinations, the total & differential settlements, the liquefaction effects for the sub grade below under seismic condition; the adequacy of safety factor against overturning, sliding & flotation, structural integrity, thermal loading etc.

Fuel pool

The fuel pool is designed as under ground structure on a foundation raft sitting on a hard rock strata. The cask handling and seating zone of pool are suitably located to avoid the movement of cask over the stored fuel bundles. The pool walls and raft are made of High Performance Concrete (HPC) with additional micro silica and water proofing compounds for improved leak tightness. The depth of pool is based on minimum biological shielding of 3 meter above top most tray of the stack and handling of cage during cask unloading. The radiation levels, estimated at water surface and at working level are less than 1 μSv/hr. The shielding analysis is carried out by using the ORIGIN–2 computer code for source estimation and using 2-D transport theory code DOT–3 for dose rate calculation.

Single failure proof EOT crane of 75 t capacity has been provided to handle 70 t shipping casks. The crane has sufficient safety features like double wire rope system, two rope drums, two independent brakes, VVF drive etc. A pool bridge carries out the handling of fuel storage trays and fuel bundle within the fuel pool. The pool bridge is equipped with suitable electrical hoist and tong for handling of tray and fuel bundle.

An impact absorber inside the pool is provided to take care of accidental fall of shipping cask in the pool while handling. The impact absorber would absorb the bulk of the impact energy and save the fuel pool structure. The stresses developed in the raft because of the residual energy of the fall of the cask would be well within the safe limits.

The maximum pool water temperature is limited to 40°C in normal condition and 60°C in accidental conditions. Suitable plate type heat exchangers have been provided to remove the heat generated for the spent fuel bundles. In the event of power failures, these cooling systems shall run on Class-III power supply.

Infiltration bore wells are provided around SFSF to keep the water table low enough in the local vicinity. Additional level monitoring and sampling arrangements are provided to monitor contamination of sub-soil water body as a result of highly improbable event of a breach of the pool, the lining and raft simultaneously. Schematic diagram of the layout of SFSF is given Fig. 4

The Spent fuel pool is RCC tank lined with SS 304 L plates welded on SS 304 L rectangular tubular sections embedded in concrete. On either side of the channel anchoring struts are welded in a staggered fashion. The welding of the liner plates with supporting channel is shown in Fig. 5. These tabular sections are connected to 15 NB pipe routed from the tubular grid section to the leak detection pit. All pipes are seamless SS 304 L hydro-tested and radiographed before embedding in concrete. Any accumulation of water in leak detection pit will be indicative of leakage through the liner weld. The leakage collection system is compartmentalised so that it would be possible to identify the source of leakage.

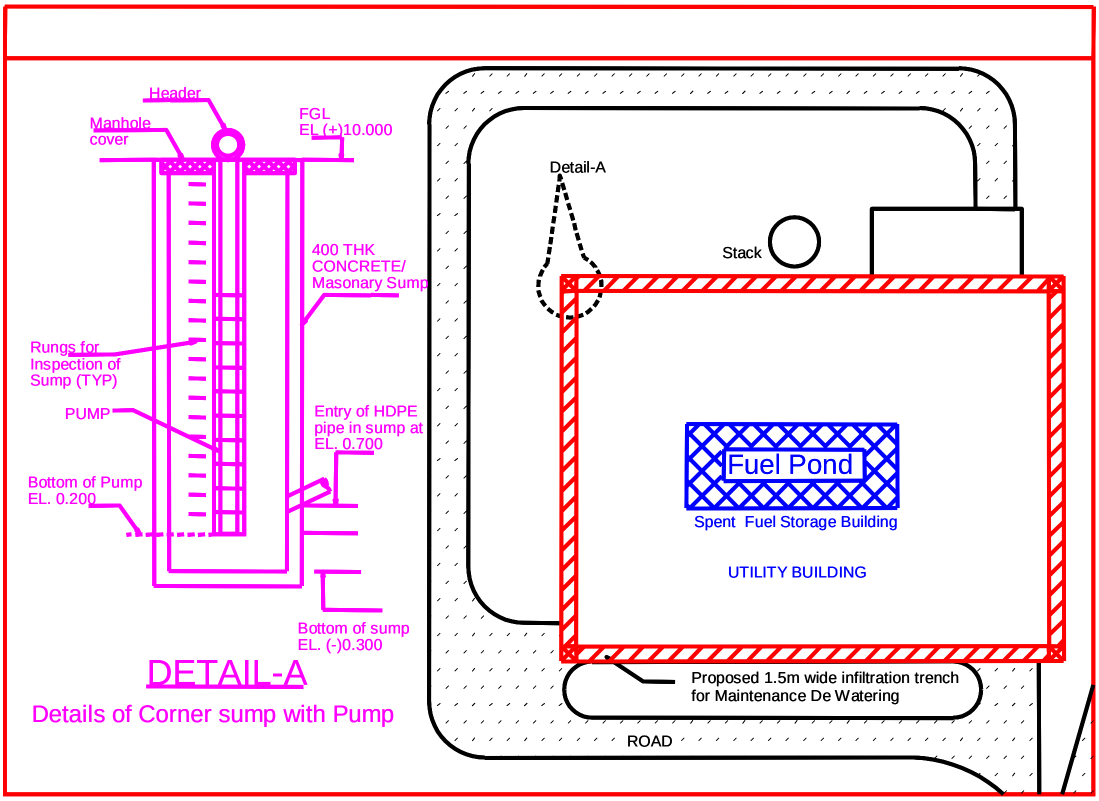

Fig. 4 Schematic diagram of the SFSF layout

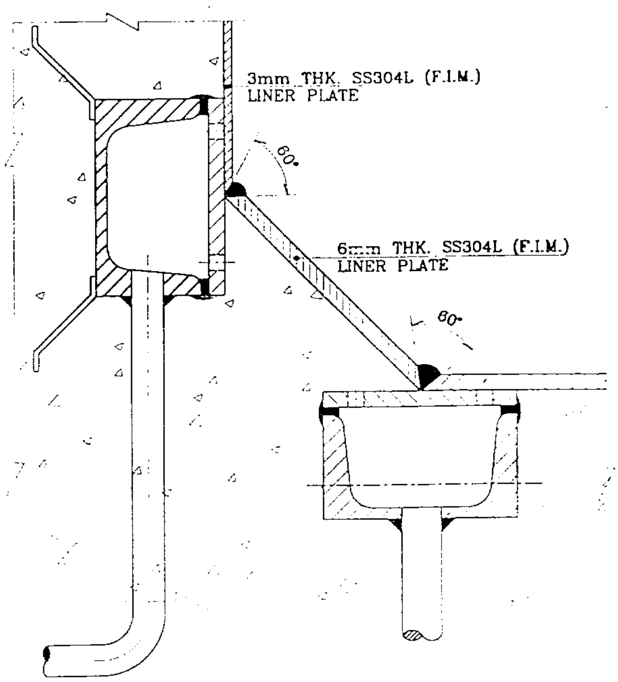

Fig. 5. Leak detection system

Operation of spent fuel storage facilities

With the present experience of spent fuel storage of BWR & PHWR fuel over a period of three decades, it has been found that wet storage is a safe method for storing zircaloy clad fuel from BWRs and PHWRs as the integrity of zircaloy clad is intact in pool environment. The pool water chemistry is maintained with pH of 6-8 and specific conductivity of less than 1 µS/cm.

In line with ALARA principle an innovative concept has been practiced for the last 10 years to maintain the chemistry of the pool water by recirculating the pool water through micro filter cation exchanger and anion exchanger. An average DF of 2 to 3 is obtained across the cation bed which is regenerated with nitric acid once in eight months and the regenerant is recycled to the process. The anion exchanger is regenerated with NaOH when the pH of the pool water falls below 6.0. the regenerant is sent to LLW as its activity is very low of the order of 10^{-5} mCi/L. A schematic diagram of the water polishing system is shown in Fig. 6.

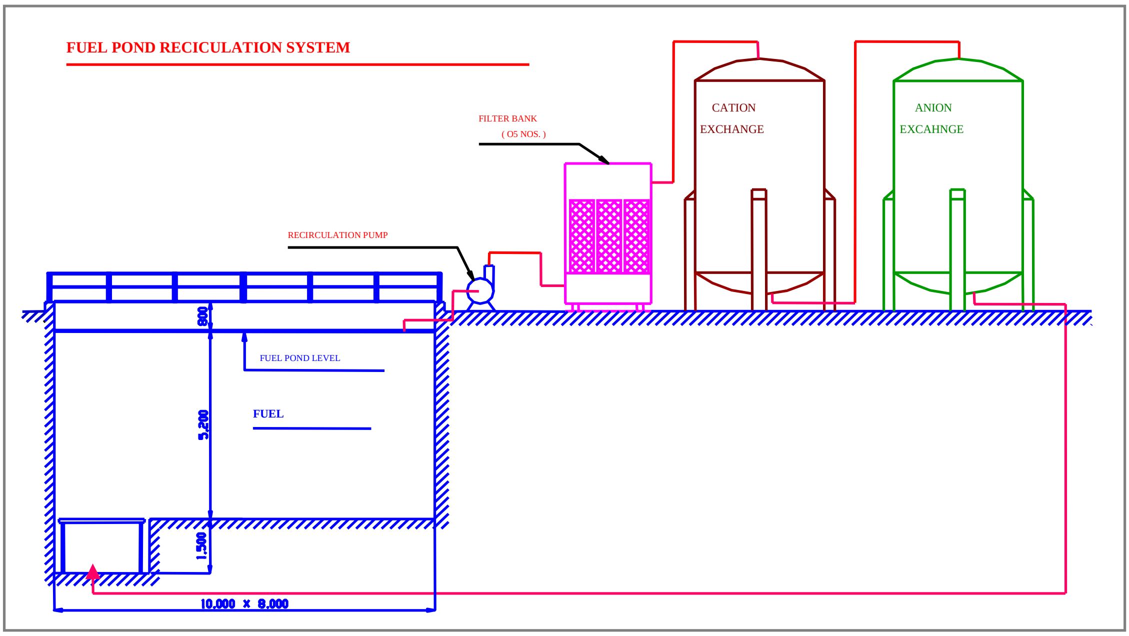

Fig. 6. Schematic diagram of the water polishing system

There is a compact filtration system, which operates under water for cleaning of pool floor for muck/debris collected during cask handling and fuel storage. The filters are remotely handled and disposed off through a lead shielded cask. The filters have 20-micron fine particles capacity and made of cellulose fibre and layers of wire mesh and silicon paper. The system is working satisfactorily with water visibility maintained at very high level (turbidity below 0.2 ppm on silica scale).

A DM water plant is also provided to meet make up water requirement of pool due to evaporation losses and for cask washings

The thermal loading of the pool has to be maintained with in stipulated limits under the operating and accidental conditions

R&D study is also being pursued for application of ultra filtration module for cleanup of pool water. Ultra filtration membrane typically have pore size in the range of 10 to 100 nanometer and work at a pressure of 1 to 10 bars. An average DF with respect to alpha and beta of 4 and 3 respectively are obtained and the turbidity of water could be brought down from 0.3 NTU to 0.1 NTU. A schematic diagram of a pilot plant using UF module is shown in Fig. 7.

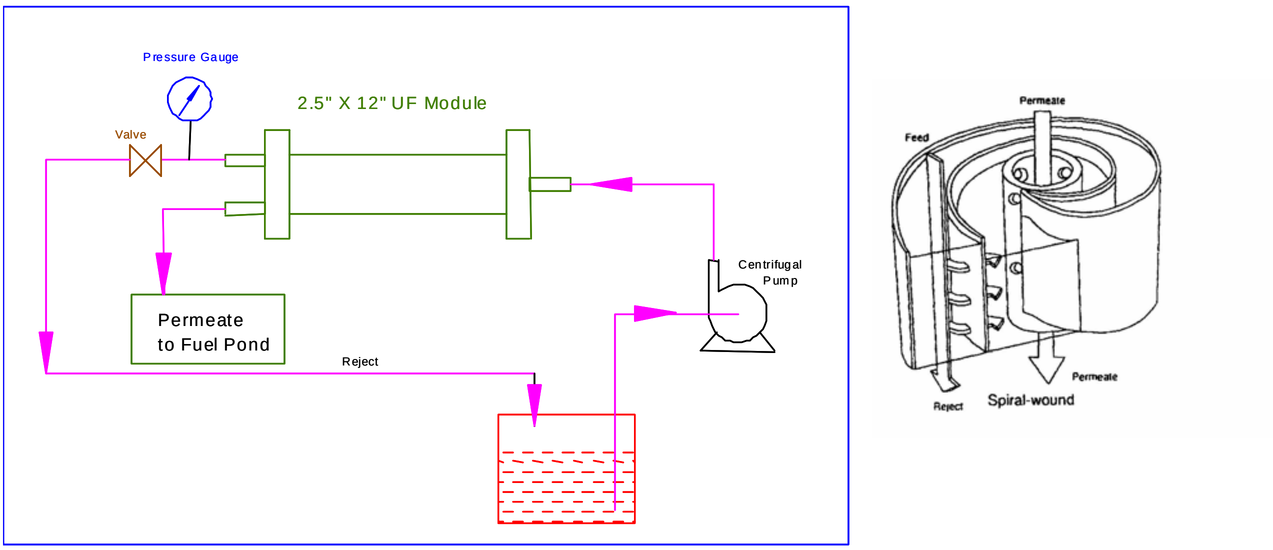

Fig. 7. UF module and the Schematic of the UF process

Dry Storage

As the dry storage casks are modular, passive, easily constructible and comparatively of low cost, these have been adopted as 'add on' system for additional storage to the fuel storage pools. Dry storage of spent fuel assemblies from BWRs at TAPS was taken up as an interim measure when the available storage capacity in the AR facility was fully utilised. The DSC is designed to store 37 BWR spent fuel assemblies with a burnup greater than 13,000 MW-d/t HM and a minimum cooling period of 10 years. Square boxes made of 3.25 mm thick SS 304 plates are used to support 37 spent fuel assemblies. These plates also act as neutron poison and keep them in subcritical condition. Four such casks are in use at TAPS without any external cooling. These DSCs also have been used for transportation of the spent fuel from the reactor pool to AFR pool.

Concrete casks have also been developed for PHWR fuel from RAPS 1 & 2 and can accommodate 220 Nos. of 10 year cooled spent fuel assemblies with a maximum burnup of 10,000 MWd/t HM. The cask has 750 mm thick reinforced concrete shielding on all sides and 850 mm at the bottom. The cask is lined with 6 mm thick steel plate both inside and outside and is designed to withstand mechanical stresses to control cracking of concrete. The total weight of the cask, when fully loaded with spent fuel assemblies, is 60 t.

Spent fuel transport

Since the reactors are located at different locations, a number of transport operations involving spent fuel movement are required to be carried out annually for either storing at the AFRs or for reprocessing operations. Fuel transportations are subjected to highly explicit safety and security regulations constantly reviewed by international and national experts. The radioactive material transportation regulations comprise two distinct objectives.

- Security or physical protection, consisting in the prevention of losses, disapperances, thefts or misappropriation of nuclear materials.
- Safety, which consists in controlling the radiation contamination and criticality hazards with a view to protect the man and the environment.

Transport safety regulations applicable to spent fuel comply with the rules applicable to all radioactive materials, which constitute a subcatagory of dangerous materials(class 7). All transport of radioactive materials with in the country is governed by guidelines by the statutory regulatory authority- the Atomic Energy Regulatory Board(AERB). The materials can be transported only in packages which are designed in accordance with standards and guidelines prescribed by AERB. These standards are based on international practices/regulations such as those drafted by IAEA.

The transport safety regulations are based on three lines of defence.

- The package consisting of the material transported and its container must be sturdy and adapted to its contents.
- Reliability of the means of transport
- The efficacy of the resources to deal with an incident or accident

Technical principles common to all packages

Package safety features should include

- Containment of the radioactive materials, to combat radilogical hazards. Eg. Surface contamination levels.
- Radiological protection, to combat radiation hazards
- Sub-criticality
- Protection against temperature related damage

The regulations then define, on the basis of the package types

- For package design, technical specifications and qualification requirements
- For package utilisation, various radiation protection, labeling and registration requirements
- For package maintenance, maintenance programme

In this frame work, spent fuel is transported in 'Type B' packages designed to withstand severe accident conditions simulated by tests validated by approval certificates and subject to inspection.

The tests under accident conditions are

- a 9 m drop test on a hard unyielding surface
- a 1 m drop on a a mild steel bar
- exposure to 800 C fire for 30 minutes

- immersion in 200 m depth water

Considerable experience has been acquired in spent fuel handling transport. In India, spent fuel transportation is carried out in specially fabricated and tested shielded cask by rail and road.

Spent fuel from TAPS is transported to AFR storage facility by road in stainless steel clad and lead shielded cask of 70 t. Shipment of PHWR spent fuel from SF from RAPS/MAPS to reprocessing facility is carried out by rail and road.

The cask designed to handle at any one time 220 bundles of CANDU fuel (corresponding to about 3200 kg of UO_2) irradiated to an average 6700 MWd/t and cooled for 120 days. The over all dimensions of the cask are 3270 L x 2440 W x 2230 H mm. The cask cavity dimensions of the cask are 1600 L x 1220 H x 1220 D mm. The cask weighs 63,000 kg and is provided with four lifting trunnions. The spent fuel bundles are housed in a single cage stacked in two columns, each housing 110 assemblies (10 x 11). Shielding equivalent to 280 mm of lead has been provided to give a dose rate of about 32 mr/hr on the shield. The cask is provided with level indicator, thermo-couple for measuring the coolant temperature and vent lines. The vent is provided with off-gas filter.

The cask is designed for transport in wet condition with external means of removing heat. The cask is also provided with fins (6 mm thick, 150 mm high and 76 mm apart) for heat transfer and the external surface is clad with stainless steel to facilitate decontamination. The hear removal capacity is 75 kW. Schematic diagram of the shipping cask is shown in Fig.8.

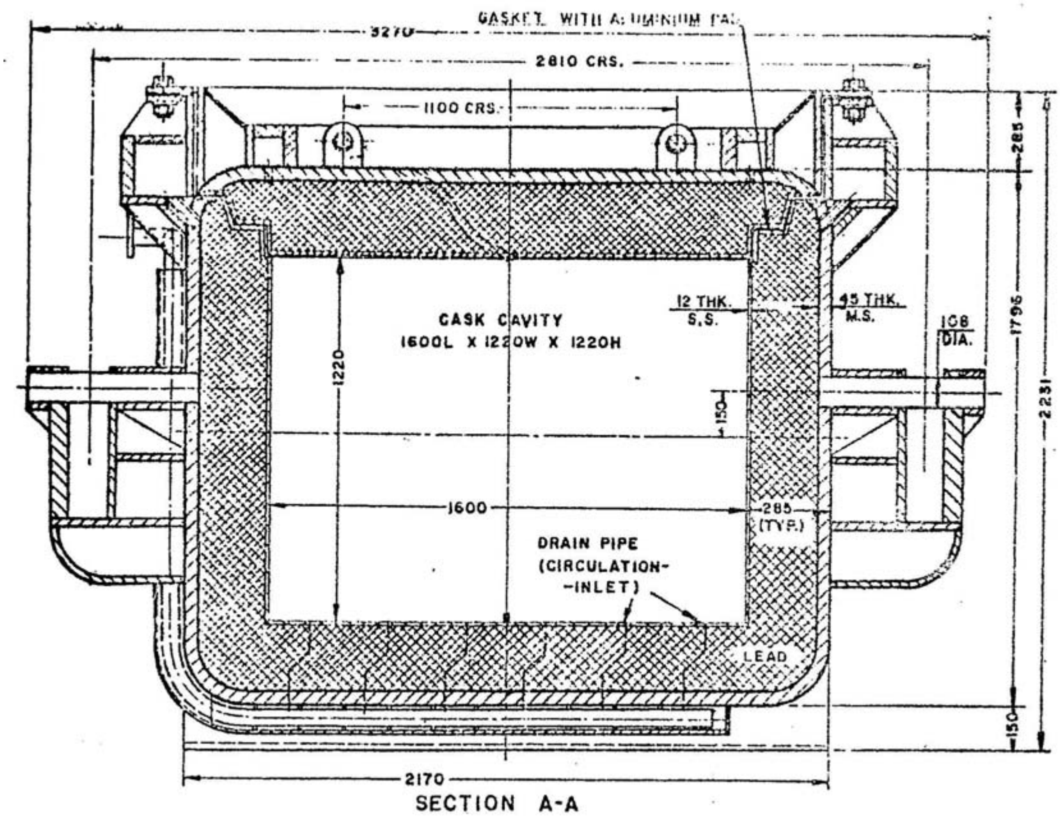

Fig. 8. Design Features of the PHWR Spent fuel transport Cask

Fig. 9 Shows the photograph of the trailer loaded with the transportation cask.

Fig. 9. Transportation Cask on trailer

Conclusions

1. Operation of wet spent fuel storage facilities for more than three decades has given mastery in design, construction and maintenance of these facilities meeting the national and international specifications.

2. Limited experience is gained in the design of dry storage facilities.

3. Incident free cross country transportation of spent fuel transportation could be carried out complying with national and international regulations.