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UK ABWR Generic Design Assessment

Generic PCSR Chapter 19 : Fuel Storage and Handling

Hitachi-GE Nuclear Energy, Ltd.

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19.1 Outline

This chapter includes the description and safety features of the fuel storage, handling, cooling and clean up of corresponding fuel storage facilities. This chapter also provides the description of preparations for refueling. Further information on the environmental considerations is included in GA91-9901-0023-00001 Demonstration of BAT [Ref-1].

New fuel bundles are brought into the Reactor Building (R/B) and after an inspection, a fuel channel is placed on each fuel bundle. These new fuel assemblies, which are waiting to be loaded into the reactor, may either be transported to the new fuel storage vault for storage or be transported and stored directly in the Spent Fuel Storage Pool (SFP).

The fuel is stored in the new fuel storage racks in the vault, which is located as close as practicable to the SFP work area to facilitate handling during fuel preparation. The New Fuel Inspection Stand is located beside the new fuel storage vault to minimize new fuel transport distance.

This chapter covers the initial storage of spent fuel in the R/B. Spent fuel removed from the reactor vessel is stored under water whilst awaiting transfer to a spent fuel processing and interim on site storage facility. The interim spent fuel storage facility is described in chapter 32. The spent fuel storage racks, which are used for this purpose, are located at the bottom of the SFP under sufficient water to provide radiological shielding. This pool water is processed through the Fuel Pool Cooling and Clean-up System (FPC) to provide cooling to the spent fuel in storage and for maintenance of fuel pool water quality.

19.2 New Fuel Storage

19.2.1 Design Basis

The new fuel storage rack for UK ABWR is designed to maintain the new fuel assemblies in a subcritical state.

The new fuel storage rack design avoids any criticality risks in the most conservative moderation conditions, assuming that new fuel assemblies are stored at the maximum storage capacity.

The new fuel storage rack is designed sufficiently strong to withstand seismic loads and other impacts by the postulated events.

The new fuel storage vault for UK ABWR has the new fuel storage racks which have appropriate storage capacity in consideration of regular fuel exchange.

The new fuel storage vault is reinforced concrete structure, which is not filled with water.

The new fuel storage vault is designed so that the clean ambient conditions are maintained.

19.2.2 Facilities Description

The new fuel storage rack, which is composed of stainless steel, prevents criticality by ensuring appropriate fuel-to-fuel distance. Normally, new fuel assemblies are stored in the rack in dry condition. It prevents criticality by a geometrically safe arrangement. The racks have the storage capacity for approximately 37 % of one full core fuel load. The design of the new fuel storage rack is such that the effective neutron multiplication factor (k_{eff}) satisfies the followings.

- $k_{eff} \leqq 0.95$, In normal operation and under any envisioned conditions, assuming the severe state such that the new fuel storage rack is filled with water.
- $k_{eff} < 1.0$, Moreover, subcriticality is maintained even when the new fuel storage rack is filled with a moisture atmosphere that theoretically achieves the highest reactivity, which is unlikely to occur in reality.

The strength of the new fuel storage rack is evaluated under the condition which maximum amount of fuel assemblies is stored, and is designed sufficiently strong to withstand seismic loads and other impacts by the postulated events.

The new fuel storage vault is made of reinforced concrete and drainage is designed to prevent the vault becoming water-filled, and it has a Heating Ventilating and Air Conditioning System (HVAC).

19.2.3 Design Evaluation

The new fuel storage rack is welded construction composed of stainless steel square pipes, and the distance between each pipe is controlled properly to prevent criticality. It prevents criticality by keeping the effective neutron multiplication factor (k_{eff}) less than the specified value in the subcriticality evaluation under the severest condition, with consideration for the shape of the rack, layout of the fuel assemblies and flood water temperature.

The rack has adequate strength by determining the thickness of its material plate which is able to withstand seismic loads and other impacts by the postulated events in the strength evaluation under the condition which maximum amount of fuel assemblies is stored.

The new fuel storage vault satisfies the required storage capacity by having more than one new fuel storage racks which is able to store approximately 37 % of one full core fuel load.

The vault is designed to avoid becoming filled with water by having a sloping floor and locating a drain outlet at the bottom, and of the atmosphere within the vault is maintained clean using its HVAC.

19.3 Spent Fuel Storage

19.3.1 Design Basis

The spent fuel storage rack maintains the fuel assemblies in a subcritical state.

The spent fuel storage rack is designed to avoid any criticality risks in the most conservative conditions, assuming that new or spent fuel assemblies are stored at the maximum storage capacity.

The spent fuel storage rack is designed sufficiently strong to withstand seismic loads and other impacts by the postulated events.

The storage capacity of the spent fuel storage rack is capable of storing offloaded spent fuels for over 10 years plant operation and a full core offload.

The spent fuel storage rack is located within the SFP. The SFP has concrete floor and walls of adequate thickness with stainless steel liner plate, and the pool is designed with adequate water depth to provide a sufficient radiation shielding performance above the spent fuel.

The SFP prevents fuel assemblies from being exposed to air and provides cooling to the spent fuel elements.

The SFP is designed to avoid leakage.

The spent fuel storage facility is located within the R/B on the operating floor level. The spent fuel storage facility is designed so that clean ambient conditions are maintained and that the pool water temperature and quality is maintained within required limits.

19.3.2 Facilities Description

The spent fuel storage rack prevents criticality by using proper materials and a geometrically safe arrangement. That is to say the rack is made of stainless steel containing boron, and its fuel-to-fuel distance is controlled appropriately. The racks provide storage capacity for more than 300% of one full core fuel load. The design of the spent fuel storage rack is such that the effective neutron multiplication factor (k_{eff}) satisfies the followings.

- $k_{eff} \leqq 0.95$, In normal operation and under any envisioned conditions.

The strength of the spent fuel storage rack is evaluated under the condition with a maximum number of fuel assemblies stored, and it is designed with sufficient strength to withstand seismic loads and other impacts by the postulated events.

The SFP is shielded with floor and walls which are made of concrete, and also has adequate water depth to provide a sufficient radiation shielding performance above the spent fuel.

The SFP is designed so that ruptures of pipes which penetrate the pool liner or siphonic effects will not cause the pool to drain. The inner surface of the SFP is lined to prevent water leakage and to protect against damage for ensuring the SFP function. If any damage occurs to the liner which leads to leakage of the SFP water, leakage detectors and pool water level switches detect some drop in level and an alarm is provided to the operators.

The spent fuel storage facility is within the R/B and therefore the atmosphere is maintained within specified limits by the HVAC of the R/B. The SFP water is maintained at desired temperature and quality by the FPC.

19.3.3 Design Evaluation

The schematic view of Spent Fuel Storage is shown in Fig.19.3-1.

The spent fuel storage rack is composed of borated stainless steel square pipes, and the distance between each pipe is controlled properly to prevent criticality. The fuel storage rack prevents criticality by keeping the effective neutron multiplication factor (k_{eff}) less than the specified value in the subcriticality evaluation under the severest condition, with consideration for the shape of the rack, layout of the fuel assemblies and water temperature of the pool.

A strength evaluation is carried out assuming worst case conditions with the maximum number of fuel assemblies stored to ensure the spent fuel storage rack has adequate strength. The evaluation determines the required plate material thickness to withstand seismic loads. It also considers other impact loads from postulated events such as dropped loads.

The SFP satisfies the required storage capacity by having multiple spent fuel storage racks which are able to store 300% of one full core fuel load in total, with consideration for the transfer of all fuel assemblies in the reactor to the SFP plus adequate space to store spent fuel generated during 10 years operation. The SFP shields radiation with adequate thickness of concrete floor and walls and adequate water depth above spent fuel derived from shielding evaluation. The SFP prevents fuel assemblies from being exposed to air as no connecting pipes penetrate the SFP liner below the top of active fuel. In addition, leakage detectors and pool water level switch are set to provide an alarm to operators in the event of leakage and thus allow prevention of the exposure of fuel to air. The pool also prevents leakage by lining the inner surface of the SFP with stainless steel to protect against leakage and damage.

The spent fuel storage facility ambient air is maintained clean and at required temperature and humidity conditions using a HVAC, and pool water is maintained within the desired temperature and quality range by the FPC.

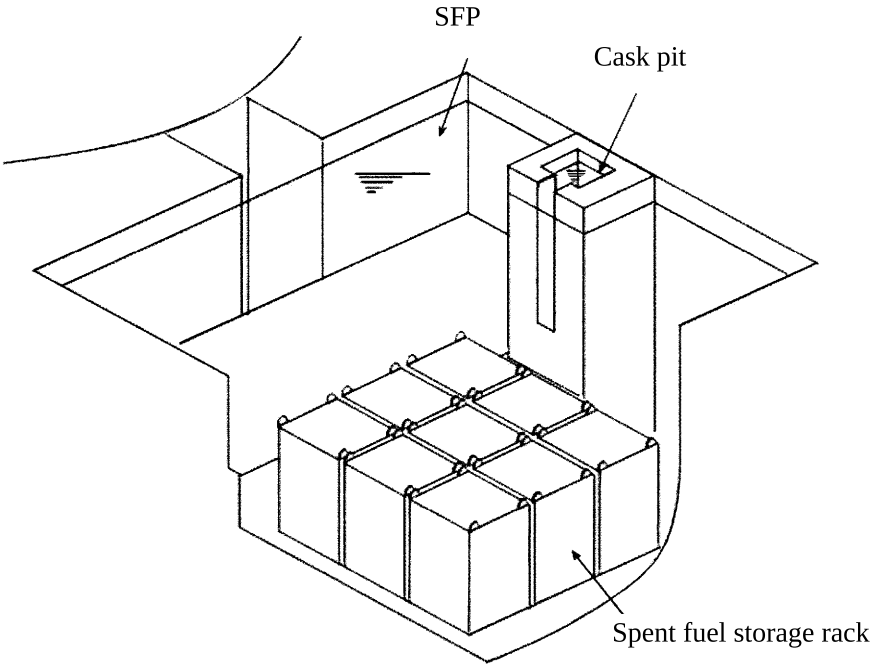

Fig.19.3-1: Schematic view of Spent Fuel Storage

19.4 Fuel Pool Cooling and Clean-up Systems

19.4.1 Design Basis

This section describes the design bases for the all systems that deliver the SFP cooling, clean-up and make-up.

19.4.1.1 Safety Functions

(1) The SFP water temperature is maintained within the designed values by removing decay heat. This normal cooling function maintains appropriate environment to store the spent fuels during normal operation and is categorised as a Category C (provisional), and components necessary to deliver the function are classified as Class 3 (provisional) according to the safety categorisation and classification of UK ABWR.

(2) The FPC maintains the quality of the water in the pool to conform the quality requirements by removing the following impurities:

-Impurities mixed in the air and contained over the pool surface.
-Impurities adhered on the surface of the fuel and components stored in the pool.
-Corrosion and fission products from the core during refueling.
-Mixing material during refueling and other operations.
-Residual chemicals used for cleaning or flushing water after pool cleaning.

This function is to mitigate a radiation exposure of workers during normal operation and categorised Category C, and the components necessary to deliver the function are classified as Class 3 according to the safety categorisation and classification of UK ABWR.
The SFP water chemistry is shown in section 23.3.

(3) The pool water level is maintained sufficiently by supplying water to prevent exposure to radiation.
This function maintains appropriate environment to store the spent fuels during normal operation and is categorised as a Category C, and components necessary to deliver the function are classified as Class 3 according to the safety categorisation and classification of UK ABWR.

(4) In the event that the cooling function of the SFP is unavailable, the Residual Heat Removal System (RHR) supplies sufficient water to maintain water level of the SFP.
From this perspective, the RHR supports the delivery of Category A safety function. In consideration that there is a sufficient time margin until loss of the water level necessary to maintain the fuel integrity, the components necessary to deliver water supply are classified as Class 2 safety components according to the safety categorisation and classification of UK ABWR.

(5) As an auxiliary make-up system, the Suppression Pool Clean-up System (SPCU), Flooding System of Specific Safety Facility (FLSS) or Flooding System of Reactor Building (FLSR) supply water to the SFP.
From this perspective, the SPCU, FLSS, FLSR support the delivery of Category B safety function, and as a secondary means against loss of cooling function, the components necessary to deliver back-up water supplying are classified as Class 3 safety components according to the safety categorisation and classification of UK ABWR.

19.4.2 System Design Description

This section describes the design of the systems that deliver the SFP cooling, clean-up and make-up.

19.4.2.1 Overall Design and Operation

19.4.2.1.1 Normal Heat Load Operation Mode

The purpose of this mode is to cool the SFP under the normal heat load. The pool water flows out of the SFP through the skimmer weirs to the Skimmer Surge Tanks, and is then transferred by the FPC Pumps. It is filtered and cooled through the F/Ds and the FPC Heat Exchangers, The Reactor Building Cooling Water System (RCW) supplies cooling water to the FPC Heat Exchangers. The pool water is finally returned to the SFP.
One FPC Pump and one F/D unit is operated during this mode if the system is capable of maintaining the SFP water temperature sufficiently low (below 52°C) at the design flow rate (250m^3/h) given in section19.4.2.2.1.
This mode is also capable of bypassing the F/Ds.

19.4.2.1.2 Maximum Heat Load Operation Mode

In the event that more fuel is removed from the core than is normal for a refueling outage (e.g. a full core offload for inspection of the RPV internals) the SFP maximum heat load operating mode is required to remove the additional decay heat. The FPC operates in conjunction with the RHR to cool the SFP under the maximum heat load condition.

19.4.2.1.3 Make-up Function

(1) The Makeup Water Condensate System (MUWC) supplies water to the SFP from the Condensate Storage Tank (CST) to compensate evaporation, leakage from liner cracks or overflow due to any event such as earth quake.
(2) When the SFP make-up by the MUWC is unavailable due to any fault, the RHR can supply water from the Suppression Pool (S/P) and maintain the water level of the SFP.
(3) Following systems can also supply water to the SFP:
- The SPCU can supply water to the SFP and can select the water source from the CST or S/P.
- The FLSS can supply water to the SFP from water source in the Backup Building.
- The FLSR can supply water to the SFP from water source in the plant site.

19.4.2.2 Equipment Design and Operation

19.4.2.2.1 FPC Pump

(1) Configuration
Two FPC Pumps are provided in parallel and are capable of simultaneous operation.
(2) Performance
The design flow rate of the FPC Pumps is determined considering the highest of the following cases:
(i) The flow rate necessary to circulate the whole SFP water capacity twice a day.
(ii) The flow rate necessary to circulate the whole capacity of combined pools water once a day (the water contained in the SFP ~ the Reactor Well ~ the D/S Pit).

Moreover, the FPC Pumps satisfy the specifications indicated follows.

Number	2 units
Rated flow	$250m^3/h$

19.4.2.2.2 FPC Filter Demineraliser

(1) Configuration
Two F/Ds are provided in parallel and be capable of simultaneous operation

(2) Performance
FPC Filter Demineraliser is designed as follows:
Type:
Pressure precoating type with elements to preserve the precoating material incorporated inside.

Precoating material:
The precoating material is a mixture of cation and anion resin powder.

Replacement of precoating material:
The precoating material is replaced when whether the differential pressure across the F/D unit exceeds the determined value or the conductivity rate at the outlet exceeds the determined rate.

19.4.2.2.3 FPC Heat Exchanger

(1) Configuration
Two Heat Exchangers are provided in parallel on the downstream side of the F/D units in order to reduce contamination.

(2) Performance
Each Heat Exchanger is designed to remove half of the normal heat load from pool water at 52°C and with the design flow rate determined in section19.4.2.2.1 (2).

19.4.2.2.4 Skimmer Surge Tank

(1) Configuration
Two Skimmer Surge Tanks are located so that the pool water over the skimmer weirs and scuppers flows into the Skimmer Surge Tank.

(2) Performance
(i) Two Skimmer Surge Tanks are connected by a pipe between them in order to equalise their water levels.
(ii) The weir on the SFP skimmer can let the flow of the system at design flow rate and equally distribute it to each Skimmer Surge Tank.

19.4.2.3 Main Support System

19.4.2.3.1 Instrumentation and Control

(1) Instrumentation

(a) The Skimmer Surge Tanks are provided with water level detection switches that control the opening and closing of the feed-water valves upon high and low water levels in the Skimmer Surge Tanks. Moreover, water level signals are warned in the Main Control Room (MCR).

(b) The SFP is provided with a water level switch to give a warning the MCR against high and low water levels. The set water level is adjustable within the skimmer weir range.
(c) A pressure switch is provided on the suction piping of each FPC Pump to provide the pump protection interlock and warning in the MCR against low suction pressure.
(d) A flow meter is provided on the discharge piping of each FPC Pump to measure the system flow rate.
(e) The SFP temperature and the FPC Heat Exchangers inlet and outlet temperatures are recorded. The temperature recorder may be shared with another system. Detection of SFP temperature is performed in the SFP and the FPC Pump suction side.
(f) Differential pressure and conductivity transmitters are provided to each F/D unit for precoat and backwashing.
(g) The pool water conductivity at the inlet and outlet of each F/D unit and the outlet of the FPC Heat Exchangers are continuously monitored and recorded. A warning is given in the MCR if the water quality exceeds the criteria.
(h) Leakage from the Refueling Bellows and the SFP Gate is detected and warned in the MCR against high leakage conditions.
(i) Leakage from the SFP liner is detected and warned in the MCR against high leakage. Leak detectors are provided for the Reactor Well and the D/S Pit as well.
(j) Signs indicating the operating status and the position of the major remotely operated valves are displayed in the MCR.

(2) Control
(a) The FPC Pumps automatically stop upon low suction pressure by the pressure switch or upon low discharge flow by the flow switch. However, these interlocks are bypassed for a determined period of time by a timer during transitional states such as FPC Pumps initiation.
(b) The system flow is controlled by the flow control valves mounted on the outlet piping of the F/Ds.

19.4.2.3.2 Power Supply System

FPC Pump motors, RHR Pump motors, motor-operated valves, instrumentation and controllers related to the delivery of the normal cooling and make-up by the RHR during fault condition are powered from the normal power source and the emergency power sources.

19.4.2.3.3 Makeup Water Condensate System

The MUWC is designed to be capable of supplying water to the SFP to compensate evaporation, leakage from liner cracks or overflow due to earthquake. Related active components are powered from the normal power source and the emergency power source.

19.4.2.3.4 Residual Heat Removal System

The RHR can work as a backup to cool the SFP under the maximum heat load condition. The RHR is a principal means to supply the SFP with sufficient makeup water to maintain the water level within the limits in the event of design basis faults.

19.4.2.3.5 Suppression Pool Clean-up System

The SPCU provides sufficient makeup water to the SFP from the CST or the S/P as a backup in the event that water supply from the RHR and MUWC are lost.

19.4.2.3.6 Flooding System of Specific Facility andFlooding System of Reactor Building

The FLSS and FLSR are also capable of supplying sufficient water to the SFP from outside of the Reactor Building as back-up systems of the MUWC, RHR and SPCU. Detail of the systems is shown in section 16.5.

19.4.2.3.7 Reactor Building Cooling Water System

The RCW supplies cooling water to the FPC Heat Exchangers. Each FPC Heat Exchanger is connected to independent and separated RCW divisions.

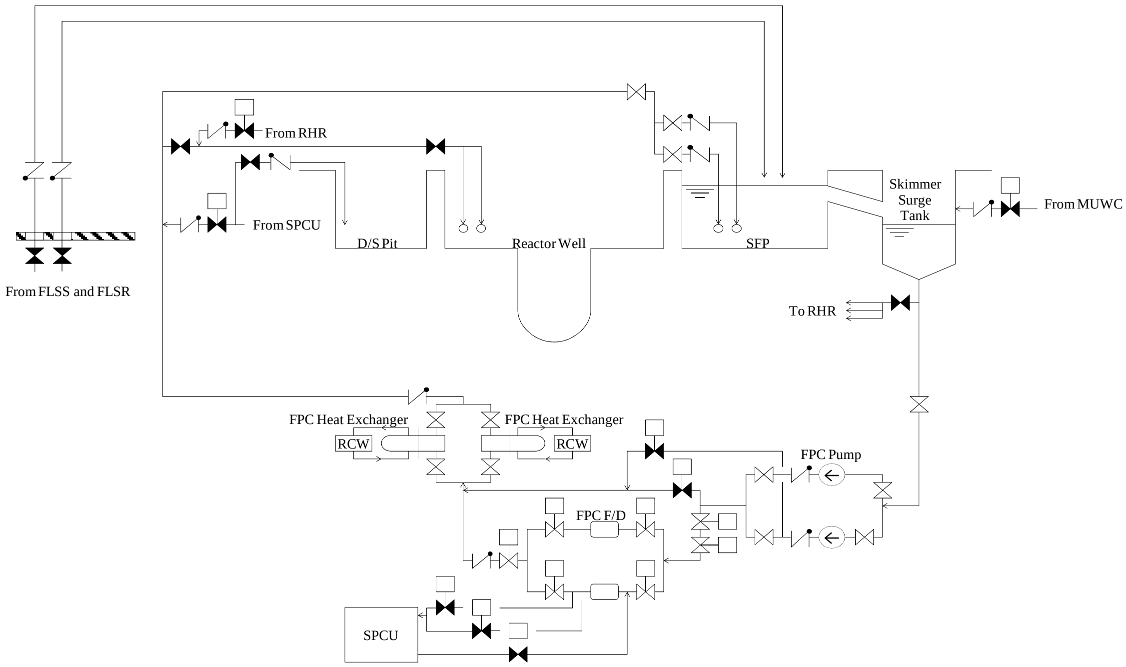

Figure 19.4-1: Outline of the Fuel Pool Cooling and Clean-up System

19.5 Fuel Handling Machine Related System

19.5.1 Design Basis

The Fuel Handling Machine (FHM) is designed to safely handle a spent fuel assembly and the Safety Functions (SFs) are as follows:

The FHM is designed to enable a spent fuel assembly to be transferred under the water, where the depth is enough to shield the radiation from the spent fuel.

The FHM is designed sufficiently strong to withstand seismic loads and other impacts by postulated events.

The FHM is designed to prevent a dropped fuel assembly during transferring operations.

Regarding dropped load, appropriate analysis is conducted to comply with target 4 of Safety Assessment Principles (SAPs). The process of the Fault Assessment is described in chapter 24, and the FHM is designed to prevent such an accident commensurate with Fault Assessment.

On the other hand, Radiation Protection is written in chapter 20. If a fuel assembly is hoisted over the limit height position, significant dose is exposed to on-site and off-site. To prevent such an accident, the FHM is appropriately designed.

19.5.2 System Description

The Reactor Building is supplied with the FHM for fuel movement and servicing, and the schematic view of the FHM is shown in Fig.19.5-1.

The FHM is a gantry crane, which spans the reactor vessel and SFP on bedded tracks in the refueling floor. A telescoping mast and grapple suspended from a trolley system is used to hoist and orient a fuel assembly for placement in the core and/or the spent fuel storage rack. The FHM also has an auxiliary hoist for in-core servicing, and Reactor Internal Pump (RIP) inspection hoist for RIP maintenance. Control of the machine is from an operator station or on the FHM.

A position indicating system and travel limit computer are provided to locate the grapple over the vessel core and prevent collision with pool obstacles. The mast grapple has a redundant load path so that no single component failure results in a fuel assembly drop.

Interlocks on the machine:

(1) prevent hoisting a fuel assembly over the vessel unless an all-control-rod-in permissive signal is present;
(2) limit vertical travel of the fuel grapple to maintain shielding over the grappled fuel during transit;
(3) prevent hoisting of a fuel assembly without grapple hook engagement and load engagement.

The FHM is designed to withstand sufficient loads such as much heavier than fuel assembly weight. The FHM grapple has redundant load path, and it is designed with a fail safe to prevent disengagement of the grapple from the fuel if it loses its air source.

19.5.3 Design Evaluation

Because the FHM is equipped with an interlock, operations such as the transfer of a spent fuel assembly from the core to the SFP and vice-versa, as well as, storage into casks can be carried out with the guaranteed necessary water depth for spent fuel shielding. Because of this, over hoisting of a fuel assembly can be prevented.

Additionally, to prevent dropped loads of the FHM itself, it has the strength to withstand masses sufficiently exceeding the mass of a fuel assembly as well as seismic loads and other relevant combination loads.

Furthermore, the FHM grapple is designed with double wire for retaining loads. It is designed with a fail safe that keeps a fuel assembly from coming loose from the grapple even if the air source is lost. Also, a fuel assembly cannot be hoisted unless the grapple is completely closed.

The following tests, inspections or analyses are implemented to confirm the Safety Functions of the FHM.

The FHM is confirmed to prevent hoisting a fuel assembly over the vessel unless there is an all-control-rod-in permissive signal and the interlock test is confirmed to prevent vertical travel unless there is sufficient water depth.

The FHM is confirmed to withstand loads sufficient greater than the combined load of a fuel assembly and seismic load through analysis.

The FHM is confirmed to prevent disengagement of the grapple from fuel handle if it loses its air source, and to prevent hoisting of a fuel assembly without grapple hook engagement and load engagement by performance test. In addition, The FHM is designed to prevent dropped loads through single failure, evaluated by safety evaluation.

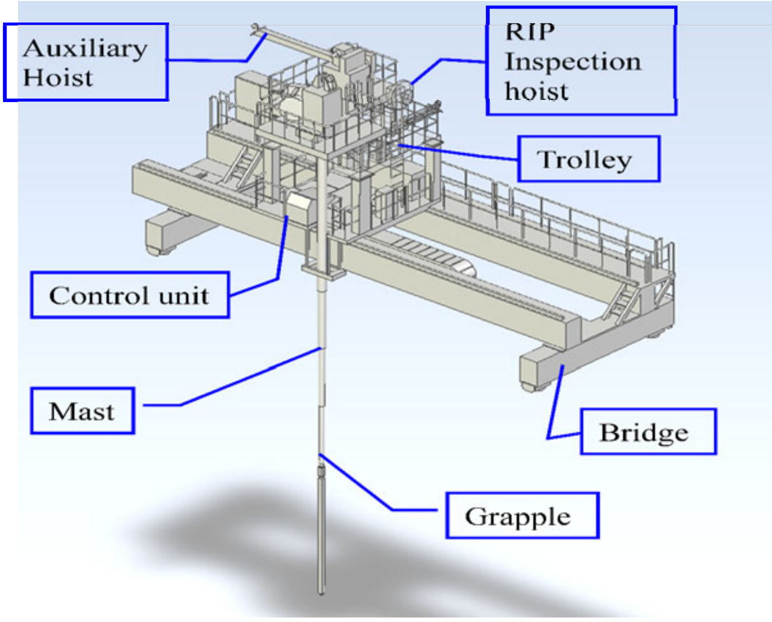

Fig.19.5-1: Schematic view of the FHM

19.6 Reactor Building Overhead Crane

19.6.1 Design Basis

The Reactor Building (R/B) Overhead Crane is designed to handle heavy loads above the refueling floor and the Safety Functions (SFs) are as follows:

The R/B Overhead Crane is designed to handle new fuel from enclosure to refueling floor, and casks containing spent fuel assemblies from the cask pit in the spent fuel pool to the enclosure with limited movement.

The R/B Overhead Crane is designed to be sufficiently strong to withstand seismic loads and other impacts by the postulated events.

19.6.2 Facilities Description

The R/B Overhead Crane does not pass over spent fuel storage rack by interlock during handling heavy load, so that prevent dropping new fuel and cask containing spent fuel assembly, thus it is equipped with redundant path of load to prevent dropping heavy load into fuel storage.

The R/B Overhead Crane is used for maintenance and fuel handling tasks. The schematic view of the R/B Overhead Crane is shown in Fig.19.6.1.

During fuel handling / servicing, the R/B Overhead Crane handles the shield plugs, drywell and reactor vessel heads, and the steam dryer / separators. The minimum crane coverage includes the R/B refueling floor laydown area, and the R/B equipment storage pit. During plant operation, the crane handles new fuel shipping containers and the spent fuel shipping casks. For these activities, the minimum crane coverage includes the new fuel storage vault, the R/B equipment hatches, and the spent fuel cask loading and washdown pits.

The R/B Overhead Crane is interlocked to prevent movement of heavy loads over the spent fuel storage portion of the spent fuel storage pool. The hoisting and braking system of the R/B Overhead Crane are redundant. The R/B Overhead Crane has a lifting capacity greater than or equal to the heaviest expected load.

19.6.3 Design Evaluation

The R/B Overhead Crane has limited movement during the handling of new fuel from enclosure to refueling floor, or cask containing spent fuel assembly from SFP to enclosure, and the minimum crane coverage includes the R/B refueling floor laydown area, and the R/B equipment storage pit.

The R/B Overhead Crane has a lifting capacity greater than or equal to the heaviest expected load to withstand seismic load and the other impacts by the postulated event.

The R/B Overhead Crane is interlocked to prevent movement of heavy loads over the spent fuel storage portion of the spent fuel storage pool to prevent dropping heavy load into fuel storage.

The R/B Overhead Crane is designed so that the hoisting and braking system are redundant to prevent dropping load. In addition, the hook of main hoist is held with double wired cable.

The following tests, inspections or analyses are implemented to confirm the Safety Functions of the R/B Overhead Crane.

In the fuel transport mode, depending on the Overhead Crane operating range, the fact that auxiliary hoist transport from the enclosure to the refueling floor and main hoist transport from the fuel storage pool cask pit to the enclosure are included in the range is confirmed.

The R/B Overhead Crane is confirmed through analysis to withstand the seismic load and other impacts by the postulated events such as greater than or equal to heaviest expected load.

The R/B Overhead Crane is tested to have limited movement that cannot pass over spent fuel storage rack and spent fuel pool during handling heavy load by interlock test.

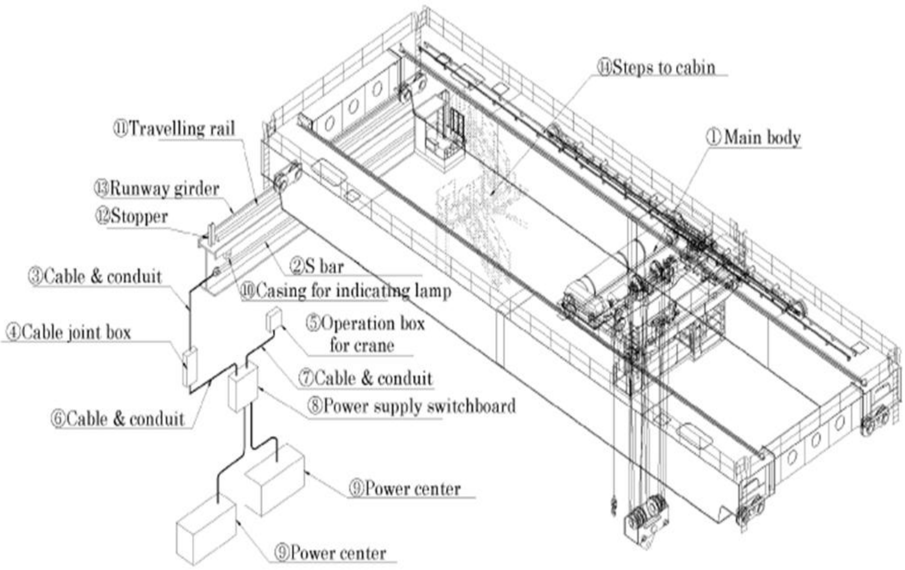

Fig.19.6-1: Schematic view of R/B Overhead Crane

19.7 Refueling Preparation

19.7.1 Fuel Handling Tasks

Fuel handling facility is equipped with Fuel Preparation Machine and New Fuel Inspection Stand. Fuel Preparation Machine installed on the spent fuel pool wall handles fuel channel under the water and serves inspection of fuel assembly.

New Fuel Inspection Stand installed at operating floor supports new fuel assembly which served visual inspection over whole length.

19.8 References

[Ref-1] "Demonstration of BAT" (GA91-9901-0023-00001, Rev.D, Hitachi-GE Nuclear Energy, Ltd)