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UK ABWR

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UK ABWR Generic Design Assessment

Initial Safety Case report on Spent Fuel Pool

Hitachi-GE Nuclear Energy, Ltd.

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Commercially Confidential Information (CCI):
Figure: 3.2-1 in section 3.2.2
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Acronyms

CCI: Commercially Confidential Information
CST: Condensate Storage Tank
DG: Diesel Generator
GDA: Generic Design Assessment
EDG: Emergency Diesel Generator
F/D: Filter and Demineraliser
FLSR: Flooding System of Reactor building
FLSS: Flooding system of Specific Safety system
FP: Fire Protection system
FPC: Fuel Pool Cooling and filtering (Clean-up) system
HVAC: Heating and air conditioning and cooling
LUHS: Loss of Ultimate Heat Sink
MUWC: Make-Up Water Condensate system
PI: Personal Information
PIE: Postulated Initiating Event
RCW: Reactor Building Cooling Water System
RHR; Residual Heat Removal system
RSW: Reactor Building Service Water system
SBO: Station Blackout
SFP: Spent Fuel Pool
SGTS: Stand-by Gas Treatment System
SPCU: Suppression Pool water Clean-Up system

1. Introduction

This document has been prepared as step 1 document on the initial safety case report for the spent fuel pool for the Generic Design Assessment of the UK ABWR design. This document briefly covers the safety features of the spent fuel pool design for UK ABWR.

Figure 1-1 shows schematic diagrams of the spent fuel storage system. [Ref-1]

The spent fuel storage facility in the top floor of main reactor building is composed of the spent fuel pool, spent fuel storage rack and other components. Spent fuel is stored in the grid fuel storage rack in the fuel pool. The SFP should be designed to fulfil the functions that described in 3.1.

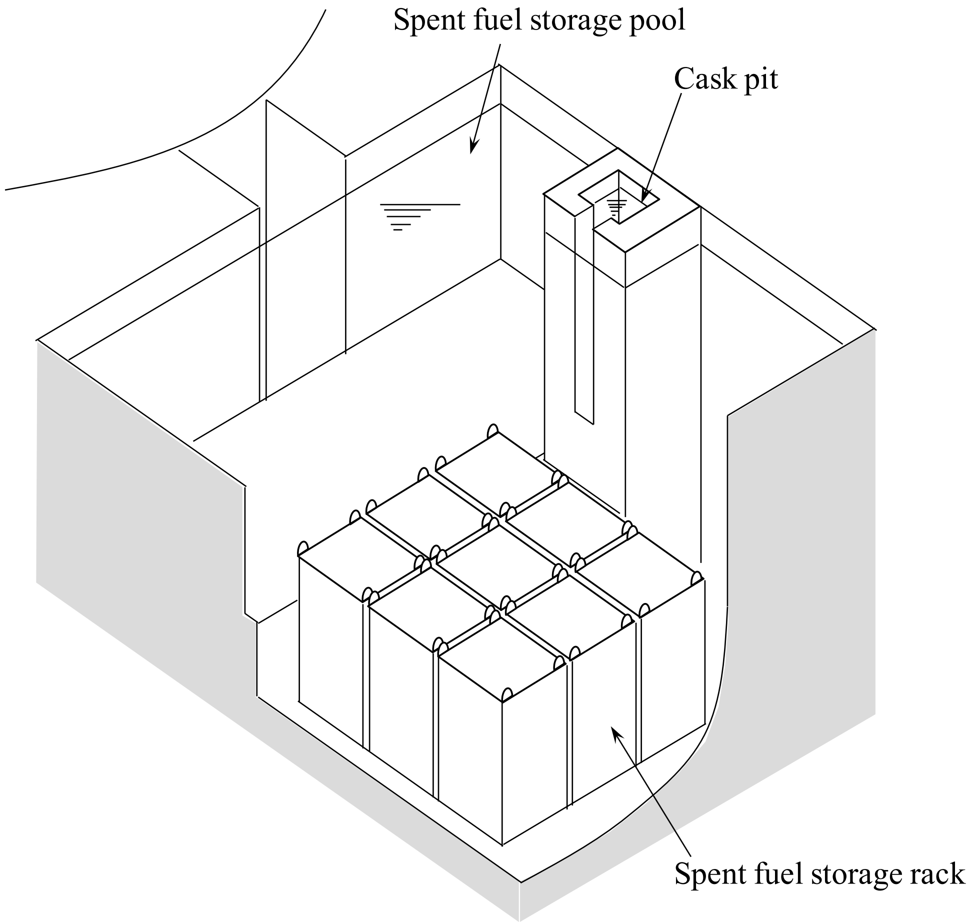

Figure 1-1 The new fuel storage system and spent fuel storage system

2. Subcriticality design in the SFP

The fuel storage system and fuel handling system is designed to prevent criticality by a geometrically safe arrangement or other appropriate means.

The fuel storage system is designed to assure subcriticality under any envisioned conditions even when fuel assemblies are stored at the maximum storage capacity.

The spent fuel is stored under pure water that does not include boron as an absorbing material in the spent fuel pool. A full array of loaded spent fuel racks is designed to be subcritical, by at least 5% Δk. Neutron-absorbing material (spent fuel racks) is employed as an integral part of the design to assure that the calculated k_{eff}, including biases and uncertainties, that will not exceed 0.95 under all normal and abnormal conditions.[Ref-1] Due to this configuration, subcriticality is maintained in pure water pool.

Moreover, to prevent the criticality of fuel, the fuel handling system should be designed to handle fuel assemblies one by one.

In severe accident conditions, the spent fuel heats up because of decreasing water level and this could lead to damage the fuel. Under these conditions, it is possible that the spent fuel geometry could change and affect the subcriticality. Therefore, it is important that the spent fuel heat up is prevented by making up water in the SFP to maintain the subcriticality under these circumstances.

3. Safety equipments and systems for the SFP

3.1. The function of the SFP

The SFP and related systems have the following functions.

(1) Subcritical property

Subcriticality design is described in Section 2.

(2) Cooling and clean-up function

The Fuel Pool Cooling and Clean-up System (FPC) is designed to remove the decay heat from the spent fuel stored in the SFP. The FPC is also designed to remove impurities including radioactive substances from the pool to minimise the release of radioactivity to the environs. Section 3.2 provides more detailed technical information.

(3) Emergency water cooling and makeup function

In case that SFP water cooling function fails or SFP water leakage accident occurs, alternative cooling system or makeup water systems will operate. Section 3.3 provides more detailed technical information.

(4) Storage capacity

The storage capacity of the SFP is designed to be capable of storing offloaded spent fuels for over 10 years plant operation and full core offload.

(5) Shielding

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

The fuel handling system is designed to enable spent fuel bundles to be transferred under the water, where the depth is enough to shield the radiation from the spent fuel.

(6) Preventing and monitoring leakage

The SFP is designed so that piping connections do not penetrate the SFP liner below the top of active fuels. Check valves are installed on each injection piping which leads into the SFP. The Check valves are designed to work as a device to prevent the pool water from siphoning. Moreover, if unexpected liner clacking occurs, leakage detectors and pool water level switch detect it and make alarm to the operators.

(7) Structural integrity

The fuel storage facility and fuel handling machine is designed sufficiently strong to withstand seismic loads and other impact by the postulated events. The inner surface of the SFP is lined to protect against damage and ensure the SFP function.

(8)Ventilation function

The SFP area is designed to be maintained by the controlled air from the Heating and air conditioning and cooling (HVAC) system and the exhaust air from the SFP area is treated by filters mounted on the HVAC during normal operation. If an accident occurs and radioactive materials are discharged from the SFP to inside of the operating floor, the gas is trapped in the Reactor Building, treated by the Standby Gas Treatment System (SGTS) with filtered and discharged to the atmosphere through the exhaust stack.

(9) The necessary maximum capacity of the SFP

The spent-fuel pool racks in the SFP is designed to provide storage for more than 300% of one full core fuel load.

3.2. The function of the Fuel Pool Cooling and Clean-up System (FPC)

3.2.1. Objective

The FPC treats water in the SFP that is to maintain the integrity of the spent fuel crud to maintain a fission product boundary. To achieve this, the FPC provides the following functions;

(1) The FPC cools the SFP by removing the decay heat from the spent fuel and maintains the temperature below the specified values.

(2) The FPC removes impurities by using demineraliser to maintain the water quality in conformance with the quality regulations.

3.2.2. System functions

The FPC performs the following operations to satisfy the system functions.

(1) The pool water that flowed into the Skimmer Surge Tank through the skimmer weirs and scuppers is pumped by the FPC Pumps.

(2) Miscellaneous impurities contained in the pool water are continuously demineralised and removed through the ion exchange resins in the F/Ds.

(3) The FPC Heat Exchangers maintain the pool water temperature below the design temperature.

(4) The pool water from the FPC Heat Exchangers is returned to the pool through the diffusers.

FPC line is connected with the Residual Heat Removal Systems (RHR) to operate together and maintain the SFP water temperature within the criteria during maximum heat load operation when all fuels in the core are offloaded into the SFP.

The outline of safety equipment and systems for SFP is shown in Figure 3.2-1. The safety class and safety category of above systems are set in fault study. [Ref-2][Ref-3]

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Figure 3.2-1 Schematic figure of SFP heat removing function

3.3. PIEs Identification for SFP

This table is shown indicative of postulated initiating event (PIEs) for the SFP. This will be confirmed by the fault study. The example of approaches against PIEs are described as Table 3.3-1.

Table 3.3-1 Countermeasures for SFP PIEs

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4. Safety approach for loss of cooling function

4.1. Cooling function on accidental condition

The decay heat from Spent fuel is removed by the FPC during normal operation. In order to support the SFP cooling function of the FPC, the RHR has a mode to assist the FPC by using heat exchangers and pumps in the RHR as well as injecting coolant as described in Table3.3-1. The RHR is used to supplement the FPC in the case of the maximum load condition of full core offloaded or the loss of the FPC cooling function.

The FPC is designed to maintain the water temperature below maximum allowable temperature of the SFP, even when an active equipment that composes the FPC or related systems has failed. If the SFP loses its cooling function, the SFP is supplied with water by the RHR, the SPCU, the MUWC, the fire protection system (FP), the FLSS or the FLSR. Injection lines of the FLSS and the FLSR that connect to the SFP are separated from other injection lines. The water source has diversity (RHR: S/P, SPCU: S/P or CST, MUWC: CST, FP: filtrate tank, FLSS/FLSR: Water sources inside of the plant site boundary).

The FPC Pumps, the RHR Pumps, the SPCU Pump, the FLSS Pumps are connected to the emergency power source, the FP pumps are connected to the emergency power source or diesel generator and the FLSR has dedicated mobile power source. Therefore there are numerous different ways to restore the SFP if an accident occurs. The system outline is shown in Figure 3.2-1

4.2. Time margin after loss of all cooling function

Decay heat in the SFP is much smaller than that of the reactor core. That is why a large time margin exists for accident management following loss of cooling function before the SFP water level decreases and the onset of boiling.

4.3. Boiling in the SFP

As mentioned in section 4.1 and 4.2, the SFP cooling and injection function are designed in consideration of defense in depth. Additionally, the large time margin exists for accident management. Therefore, the SFP can maintain the water level over TAF of spent fuel by these systems in most cases, and the risk of radioactive release from the SFP boiling seems to be small. The SFP water temperature and level are monitored.

In the BWRs, corrosion products released from primary structural materials deposit on the fuel surface, where they are irradiated by neutrons and become radioactive species. These species are redissolved or released into reactor water, and become radioactive ions or crud particles. Some studies have been done the deposition phenomena on the fuel surface. In these studies, heat transfer from the fuel surface to water is primarily due to evaporation of a microlayer of water that is formed between the bottom of growing bubble and the fuel surface. The bubble grows on fuel surface with heat flux, while the microlayer formed underneath the bubble. After that, the bubble leaves the fuel surface. When the bubble leaves the fuel surface, water evaporates uniformly from the surface of the microlayer. At this time, the corrosion products in water deposit solidly on fuel surface (so-called dry-out phenomena).

The amount of released crud on fuel surface due to elevation of the SFP temperature under atmospheric pressure is assumed to be small, because the crud deposited solidly on fuel surface with above the phenomena, at plant operation. However, it is difficult to evaluate quantitatively.

In addition, the crud of corrosion products such as Co-60, Co-58 and Mn-54 exist on fuel surface. Co-60 is the dominant nuclide among them for radiation exposure in ABWR, and exists in the form of non-volatile ferrite. As a result, the amount of the crud transferred to the environment above the SFP is small, in case the crud is detached from the surface of the fuel rod with steam.

If boiling occurs, there is a possibility of a few radioactive particulate being generated from crud on the fuel assemblies. This particulate is ejected into the operation deck floor atmosphere by the boiling action. In this case, release of radioactive material to the environment is decreased because the air is filtered by SGTS in the HVAC system before discharge via the stack in some cases.

4.4. Example of fault consideration

This section is indicative of example management scenario of the station black out (SBO) and loss of ultimate heat sink (LUHS)

a. Station Black Out (SBO)

The SBO is assumed that; (i)all off site power is lost because of main transformer or grid failure and (ii)all emergency AC source power is lost because all emergency diesel generators(EDGs) fail to start or continue to operate (all AC source power lost). In this fault, all AC driven components and heat exchangers using sea water are assumed to be unavailable.

In normal operation, decay heat from the SFP is removed by FPC systems and made up by MUWC system. In SBO, it is necessary for the SFP to make up water amount equal to that which lost by

evaporation due to decay heat. A diesel driven fire protection pump, the MUWC pump with mobile AC power source, or fire trucks is used in order for the SFP make up to continue.
In UK ABWR, a SBO event is unlikely to occur because the plant is assumed to have many routes to obtain offsite AC power source. However, in case of loss of all offsite power by unknown factor (common cause failure), it is necessary to have continuous operation of EDGs or recovery of offsite power for stable heat removal on the SFP.
Figure 4.4-1 shows the example of general event tree from loss of offsite power to SBO. [Ref-4]
For startup of the EDGs, the DC power source from batteries is needed. If the DC power source is lost, the EDGs do not start and SBO occurs.

The UK ABWR has redundant DGs. 3 independent EDGs for each safety divisions and an air-cooled DG in the back-up building, which is separately located from the reactor building. Without off-site support, these DGs can be continuously operated for 7 days. SBO occurs if the following fault happens for all EDGs;

- ✓ Failure of startup of EDGs
  - Failure of automatic startup by fault of initiation signal (Manual startup is possible)
  - Failure of startup because of a fault in the EDGs themselves
- ✓ Failure of continuous operation of EDGs
- ✓ Failure of EDG itself
- ✓ Failure of continuous operation of EDG by loss of support systems
- ✓ Failure of continuous operation of EDG by loss of fuel

If an SBO occurs, the heat removal function of the SFP is lost. Then, the pool temperature increase gradually and amount of evaporation from the pool increase too. SPCU can not be used with loss of the AC-power source. In this condition, the following coolant injection measures are available for coolant injection into the SFP:

- MUWC pumps with power supply truck
- Diesel–driven pump of fire protection system
- Pumps of fire trucks
- RHR recovered through the use of large time margin. (Not shown in figure 4.4-1)

Coolant injection with the MUWC connects to the RHR. Injection from the fire protection system also goes through MUWC injection line. Injection with fire trucks has two ways - One is a direct route to the SFP and the other goes through a fire plug.

For the design of UK ABWR, the effectiveness of each countermeasure is assessed in terms of the SFP water level and time margin considered in the event tree.

b. Loss of Ultimate Heat Sink (LUHS)

The LUHS occurs if all RSWs (Reactor Sea Water system) are lost and heat sink of cooling chain from components, or the primary loop to sea water is lost. Here, off-site power is assumed to be available. In this condition, the following coolant injection measures are available for coolant injection into the SFP.

- MUWC
- SPCU
- Fire protection system
- Fire trucks
- RHR recovered through the use of large time margin. (Not shown in figure 4.4-2)

Figure 4.4-2 shows the example of general event tree of LUHS. [Ref-4]

For the design of UK ABWR, effectiveness of each countermeasure is assessed in terms of the SFP water level and time margin considering the event tree.

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Figure 4.4-1 event tree of SBO (example)

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Figure 4.4-2 event tree of LUHS (example)

5. Seismic performance

The Seismic categorisation and classification will be described in future steps of the GDA.

6. Conclusion

Based on the description above, the SFP has enough time margins until the SFP water reaches boiling point even with the severe cases of SBO or LUHS are assumed.
Therefore, there is enough time before the top of active fuel which is uncovered due to evaporation of SFP water.

In the unlikely fault that the SFP water boils, the cruds of corrosion products such as Co-60, Co-58 and Mn-54 exist on fuel surface. Co-60 is the dominant nuclide among them for radiation exposure in ABWR, and it exists in the form of non-volatile ferrite. As a result, the amount of the crud that transferred to the environment above the SFP is small, in case the crud is detached from the surface of the fuel rod with steam. In Addition, these are filtered by venting system to decrease the radioactive particulate being discharged to the environment.

The provision of PIEs will be described in the fault study section of PCSR.

7. Reference

[Ref-1] "ABWR Design Control Document Chapter 3 Design of Structures, Components, Equipment and Systems" GE Nuclear Energy March 1997

[Ref-2] "STEP1b S2b Categorisation and Classification of Systems, Structures and Components", GA91-9901-0007-00001, XE-GD-0104, Hitachi-GE nuclear energy, LTD. December 2013

[Ref-3] "STEP1b S3b Fault Studies to Discuss Deterministic Analysis, PSA and Fault Schedule Development", GA91-9901-0009-00001, XE-GD-0105, Hitachi-GE nuclear energy, LTD. December 2013

[Ref-4] "STEP1a C3a Resilience of Design against Fukushima type Events", GA91-9901-0035-00001, Hitachi-GE nuclear energy, LTD. September 2013