Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Current Status of Study for Severe Accidents in the SFPs of CANDU Plants

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1. Introduction

SFP (Spent Fuel Pool) accidents that result in fuel degradation and, consequently radioactive release are highly unlikely. The SFP accident progression is slower in comparison to that of reactor core accidents, typically lasting days before any significant consequences occur. This slow progression enables operators to intervene and arrest the accident in its early stages, before beginning of fuel degradation and radioactive release.

In CANDU SFPs, thermo-hydraulic phenomena are expected to be significantly different from those in PWR SFPs, due to the open rack structure with horizontally aligned fuel elements. The purpose of the paper is to discuss the current status of study for severe accidents in the SFPs of CANDU plants.

2. SFPs for CANDU

The SFP at CANDU plant is typically divided into three areas – the reception bay, the storage bay, and the wet cask handling bay. The main storage bay is the largest one and fuel bundles discharged from the reactor core are stored here in low density open racks. Depending on the design, fuel bundles are stored here for about 7 to 10 years until they are cool enough to be sent and stored into dry storage facilities. The SFPs are large monolithically constructed and water-retaining double-walled structures. The walls of the SFP are typically lined with either a steel liner or a fibreglass reinforced epoxy coating. The walls are quake-proof structures and instruments are placed in the walls to detect leakage.

The size and shape of the SFPs can differ considerably between CANDU plants. The area of main SFPs can be as small as 20×12m, or as large as 34×17m and typically the depth of SFP is at least 8 m. CANDU Fuel bundle is roughly half a meter long and 10 centimeters in diameter, and 23kg in weight. They are stored in trays or modules with 24 bundles (See Figure 1). Trays are stacked on top of each other to form rack. The racks are bolted to the floor of the pool and are seismically qualified.

The SFP has cooling and purification systems which are transferring heat to the service water and removing radionuclides and general contaminants.

The instrumentation of SFPs can be grouped into five types, such as temperature, circulating system’s pressure and flow, pool water level, radiation monitoring, and indication of the position and operating status of pumps and valves [1].

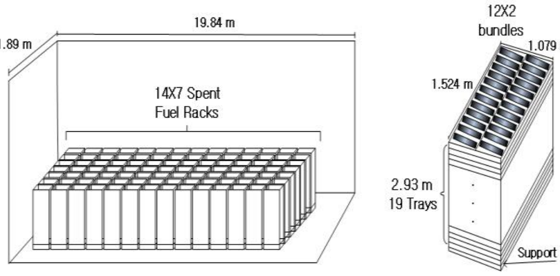

Figure 1. CANDU SFP Fuel Racks Structure and Configuration

3. Thermo-hydraulic Phenomena in CANDU SFP Accident

CANDU SFPs are monolithic structures with a double-wall design, and as a result, loss of inventory, loss of cooling, and loss of shielding are extremely unlikely to occur. The most credible events are limited loss of water inventory and a subsequent loss of cooling. In this case, the main concern is how to provide adequate makeup water to ensure that fuel bundles are maintained wet. It is also possible that fuel bundles can be overheated during the fuel transfer process to the SFP rather than in the SFP itself. Fuel drop events have also occurred, due to mishandling of fuel bundles.

2.1 Severe Accidents in CANDU SFP

It is reported that no major events have occurred in the SFPs for CANDU or other reactor types all over the world. However, the Fukushima Daiichi accident has flagged up the safety of SFPs and hence, additional measures have been undertaken to improve the SFP safety. For CANDU fuel, natural (non-enriched) uranium is used, which means that there are no criticality concerns in CANDU SFPs.

Moreover, contrary to LWR fuel, CANDU spent fuel is stored horizontally in the racks that are open to both horizontal and vertical flow. This means that the thermal-hydraulic behavior is quite different between CANDU and LWR SFPs, especially when the fuel assemblies are partly uncovered.

Fuel burnup is the most important parameter to characterize spent fuel status. While CANDU spent fuel rods have higher burnup at their end parts, those of LWR have significantly lower burnup at their ends than in their central part, due to the different neutron flux distribution in the core. Typically, discharge burnups for CANDU fuel are about 8 MWd/kgU, compared in the range of 40 to 65 MWd/kgU for LWR fuel [1]. It is difficult to find out certain reports or studies on CANDU SFP accidents because most reports or studies on SFP are for LWR SFPs. Some studies were carried out to verify oxidation phenomena on irradiated defected CANDU fuel elements [2]. One of the results shows that a diametral increase of 4% was found to cause sheath splitting.

CANDU spent fuel bundles are stored in multiple layers of trays in the SFP. During a loss of cooling or coolant accident, the fuel bundles on the top tray which is out of the water will be heated. The heatup will gradually weaken the strength of the uncovered tray, so the total load of all the uncovered and overheated fuel bundles on the tray rests on the lower tray which is just underneath the water level. When the cumulative total load exceeds the load bearing capability of the damaged tray, the tray falls on the next underneath, transferring the entire weight to the tray just below. The process goes on with the decrease of water level, resulting in a cascade effect and a sudden collapse of the bundles and trays onto the bottom of the pool. The collapse of all the trays with bundles in the SFP could re-submerge the damaged fuel bundles temporarily and stop generating hydrogen while they are in the water.

2.2 Fuel Transfer Incident

A fuel bundle (average burnup of 5.9 MWd/kgU) was overheated in steam-air environment for a total of 5 hours during the fuel transfer to the SFP in Bruce-A Unit 4 reactor in Canada [3]. This incident occurred outside the SFP, but the phenomenology was much of the same as can be expected in SFP. The event differs from a SFP loss of coolant in several ways – it had no neighboring fuel bundles and the decay heat was higher than that of a bundle in SFP.

As a result, severe sheath oxidations were at the central bearing pads and in many cases were ballooned and distorted. Hydriding was observed in the unoxidized part of some clads. The bundle temperatures probably did not exceed 1050℃ because the sheath oxides had no columnar structure. Oxidation of the sheath inner walls and of the UO_2 was negligible, which means that the Zircaloy oxidation probably removed oxygens rapidly from the air.

2.2 Fuel Drop by Mishandling

Several incidents have occurred, where bundles or trays with bundles have been dropped. The events have proven not malignant up to date, as the dropped fuel disassembles into its elements and they have remained intact though safety analysis assumes some of them will be damaged and release fission products.

4. Discussion

In the case of LWR SFPs, the pool and the reactor core are similar in structure and configuration so that the existing severe accident codes can be used. However, as mentioned above, CANDU spent fuel is stored horizontally in the racks that are open to both horizontal and vertical flow, meaning that the conditions and the fuel configuration in the SFP are quite different from those in the CANDU reactor core. That means the existing codes for severe CANDU reactor core accidents are unfit for SFPs so that more advanced tools are required for the analysis of a severe accident at CANDU SFPs. And to conclude, no complete and comprehensive severe accident analysis tool is currently available for CANDU SFPs.

Following Fukushima accident, CANDU plants in Canada and Korea have reinforced the possible sources of cooling water and the injection methods. An additional emergency source of water, available from the lake or intake channel, has been added at some sites, enabling injection into the SFP via a series of installed flexible hosing. Although it is highly unlikely that a severe accident will occur in a SFP of CANDU plant, these measures will significantly enhance the safety of CANDU SFPs.

5. Conclusions

Unlike LWR SFP, the CANDU SFP is significantly different from the reactor core in terms of the conditions and the fuel configuration. The former is open racks type, while the latter is horizontal pressure tubes type. This difference made it difficult that CANDU SFP accident would be analyzed by the existing severe accident codes. That is why there are not many accident analyses available for CANDU SFPs and why it is hard to find new findings for CANDU SFP accident as yet. Therefore, it is recommended that a severe-accident analysis tool for CANDU SFPs be developed.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT, and Future Planning) (No. NRF-2012M2A8A4025960)

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