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External flooding event analysis in a PWR-W with MAAP5

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ABSTRACT

The Fukushima accident has drawn attention even more to the importance of external events and loss of energy supply on safety analysis. Since 2011, several Station Blackout (SBO) analyses have been done for all type of reactors. The most post-Fukushima studies analyze a pure and straight SBO transient, but the Fukushima accident was more complex than a standard SBO. At Fukushima accident, the SBO was a consequence of an external flooding from the tsunami and occurred 40 min after an emergency shutdown (SCRAM) caused by the earthquake. The first objective of this paper is to assume the consequences of an external flooding accident in a PWR site caused by a river flood, a dam break or a tsunami, where all the plant is damaged, not only the diesel generators. The second objective is to analyze possible actions to be performed in the time between the earthquake event (that causes a SCRAM) and the external flooding arrival, which could be applicable to accidents such as dam failures or river flooding in order to avoid more severe consequences, delay the core damage and improve the accident management. The results reveal how the actuation of the different systems and equipments affect the core damage time and how some actions could delay the core damage time enough to increase the possibility of AC power recovery.

1. Introduction

One of the main lessons learned from the accident at Fukushima Daiichi was the importance of the challenge presented by the loss of the safety-related systems as a result of an external event.

In the case of Fukushima Daiichi, the prolonged loss of Alternating Current (AC) caused by the tsunami led to the loss of core and containment cooling.

Nuclear power plants present several options of electrical power supply: the main electricity grid (at least two external connections); power supply from a hydroelectric plant; supply from diesel generators; and Direct Current (DC) provided by batteries. The vulnerabilities of these options of power supplies to external events have been evaluated.

After the accident at Fukushima, European nuclear power plants developed several analyses called Stress Tests. These Stress Tests are a complementary and detailed review of the safety of nuclear power plants taking into account the events at Fukushima Daiichi. The main aspects to be reviewed included beyond-design-basis external events such as earthquakes, floods and other external events loss of AC power – Loss of Offsite Power (LOOP) and Station Blackout (SBO) – and Ultimate Heat Sink (UHS), and finally, the severe accident management capacities and mitigation of fuel damage in both, the reactor and the spent fuel pool (ENSREG, 2012).

The purpose of these tests was to identify the plants strengths and weaknesses that should be reinforced in order to improve the response of the plant against such events.

For instance, it was concluded that the main strengths of the Spanish nuclear power plants were the power supply from nearby hydroelectric plants and the protocols of Red Eléctrica Española (REE), that give priority to the power supply for nuclear plants, as well as the ability to cool the reactor in the event of power total loss by means of manual operations. On the contrary, there are areas for improvement such as the provision of portable equipments to ensure the maintenance of the safety functions (generators, pumps, batteries, etc.) and the introduction of measures to ensure the necessary controls and instrumentation in case of total loss of electrical power or the Ultimate Heat Sink. Finally periodic test of the external power supply from the nearby hydroelectric plants have to be carried out.

Besides those improvements, there are several actions planned as the strengthening of the emergency organization, creating a common emergency center, with staff and equipment ready to

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intervene at any nuclear power plant (NPP) location within 24 h and the construction of an Alternative Center Emergency Management in every site, a new building resistant to earthquakes and floods (CSN-UPM, 2012).

The design-basis analyses for nuclear plants in the United States include limitations that take margins into account with respect to the external events expected at each site. Extreme external events beyond those accounted for in the design basis are highly unlikely, but could present challenges to nuclear power plants.

To address these challenges, a study of the impact of these external events, sponsored by the Nuclear Energy Institute (NEI), was made and presented in an implementation guide (FLEX, 2012). This guide describes the processes for defining and implementing strategies that will improve the capability of nuclear plants to cope with conditions resulting from beyond-design-basis external events. The objective of this guide is to describe the process to be used by individual licensees to define and implement site specific mitigation strategies that reduce the risks associated with beyond-design-basis conditions.

Within this guide, external extreme hazards are identified and their impacts are assessed. The hazards identified were earthquakes, external flooding, severe storms with high winds, snow, ice and extreme heat or cold.

The FLEX strategies consisted of both an on-site component using equipment stored at the site and off-site components for the supply of additional materials and equipment for long-term response. Among the FLEX strategies are included: portable equipment that provides power and water to maintain the key safety functions for all reactors on site and, in addition to provide protection of such equipment to external events applicable on site. The maintenance program, testing of FLEX equipment and training of personnel are also established in the guide.

Furthermore, in the NUREG-1474 the effect of Hurricane Andrew on Turkey Point nuclear plant is analyzed. Hurricane Andrew caused a Loss of Offsite Power (LOOP) on the plant for 5 days, during which the Emergency Diesel Generators (EDGs) became operational and portable equipment was taken by helicopter to the site (NRC, 1992). The NUREG-1407 provides procedural and submittal guidance for assessing the adequacy of the safety systems of the plant against external events, such as earthquakes, tornadoes, external floods, etc. (NRC, 1991).

Other developed studies are those that analyze and evaluate the vulnerabilities of the main electricity grid to the extreme external events previously mentioned, and for example to evaluate the impact of solar storms in nuclear power plants and power grid (Barnes et al., 1991; Kappenman, 2010).

The Fukushima accident showed the massive consequences that an external flooding could cause in a nuclear power plant. Nevertheless, most part of the analyses performed before and after Fukushima was mainly focused on the pure Station Blackout (SBO) and LOOP scenarios (NRC, 2012).

The European plants Stress Tests are mainly focus on the different management solutions for the SBO (ENSREG, 2012). The external events were separately treated, using a much more deterministic perspective, and trying to give priority to the prevention of the accident more than to the management of such accident. In the case of Maanshan NPP (Taiwan), the external flooding impact of the plant site has been deeply taking into account (Taiwan Power Company, 2013).

In this paper the consequences of an external flooding event in a Pressurized Water Reactor (PWR) site are assumed, taking as hypothesis that the operational crew is aware of the flooding event 40 min before it happens, as it was in the Fukushima accident case (Sandia National Laboratory, 2012). Those 40 min are not very much time between the SCRAM and the SBO like in Maanshan NPP (Fauske & Associates, 2004), however, it could be enough to perform preventive actions. The actions supposed in this study are centered on palliate or delay the core damage. The influence of these actions is compared with the no preventive action case.

The simulations are performed with MAAP5 code (Modular Accident Analysis Program); developed by FAI for EPRI, and released in 2008, (EPRI, 2008). The reference plant selected to perform the simulation is ZION NPP, a PWR-W reactor with 4 loops and 1040 MW closed in 1998. There are some differences between Zion NPP and the most common Westinghouse reactor of three loops: three containment spray trains, and one more loop. As the thermal power is very similar for the PWR that have performed uprating, the main phenomenology is common in both reactor models for the cases that will be analyzed in this study.

There have been chosen three base cases, depending on the equipment availability. In none of these cases there are operator actions after the flooding strikes. This assumption is based on the Fukushima flooding accident due to the tsunami. When the tsunami impacted at Fukushima I NPP, nearly all instrumentation and control was unavailable, accordingly, no action could be performed from the control room after this event (TEPCO, 2011).

After the base cases, sensitivity analyses are presented. Those sensitivities analyze some critical parameters found in base cases such as the turbine driven auxiliary feedwater lifetime or the safety valves opening pressure.

The parameters selected to measure the impact of the actions in the present analysis are time to core uncovery, time to first relocation of core materials inside the vessel lower head and time to vessel failure.

2. External flooding base cases

The massive external flooding could leave inoperable the batteries which allow operating the Auxiliary Feedwater Turbine Driven Pump (AFW-TDP). In addition, the pump seals could be passive SBO-qualified Reactor Coolant Pump (RCP) ones, preventing leakages to avoid the Seal Loss of Coolant Accident (SLOCA). The base cases chosen and the main phenomena chronology are shown in Table 1.

- *Base Case 1:* No pump Seal Loss of Coolant Accident (SLOCA) and AFW-TDP not available.
- *Base Case 2:* SLOCA and AFW-TDP not available.
- *Base Case 3:* SLOCA and AFW-TDP available until 28,800 s.

In these base cases, the Fukushima Daiichi I NPP timing is taken and implemented in the MAAP5 input. Thus, while the NPP is operating at full power (reference plant, ZION NPP), the SCRAM occurs as an anticipation of an external flooding that will shortly happen. Approximately 45 min later, the external flooding arrives, inundating almost all energy devices. As a reference, in Fukushima only the diesel generator of Unit 2 was not flooded but the electrical connection between Unit 1 and 2 was, consequently the total loss of AC and DC power occurred at 2869 s for Unit 1. When the tsunami struck, almost all instrumentation became also unavailable (TEPCO,

Table 1
Main events timing of Base Cases.

	Base Case 1	Base Case 2	Base Case 3
SCRAM	200 s	200 s	200 s
SBO	2700 s	2700 s	2700 s
SLOCA	No	6100 s	6100 s
AFW-TDP available	No	No	Yes
Batteries availability	No	No	28,800 s
Core uncovery	19,504 s	17,568 s	29,663 s
Relocation of core materials	31,088 s	28,912 s	40,800 s
Vessel failure	38,245 s	35,800 s	50,193 s