LESSONS LEARNED FROM INTERNAL FLOOD PSAS IN KOREA

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ABSTRACT

Risk due to internal flooding has been one of the major concerns for the design and

approaches for flood protection systems, active and passive, can be considered. The approaches to flood protection design are different for each plant design, and they are

due to a flooding event is highly dependent on the flood design. The major design characteristics are 1) the location of systems that utilize sea water and their impact to other

sump which can transfer and accommodate flood water to prevent a significant flooding event. To identify and compare the effectiveness and potential vulnerability of various

plant designs, such as existing Korean PWR plants, CANDU type PHWR plants, and Korean Standard Nuclear Plants. Based on the evaluation, several design changes were

1. INTRODUCTION

The risk due to internal flooding has been one of the major concerns for the design and operation of nuclear

components within the plants. Such floods may occur, for example, as a result of the rupture or cracking of pipes or vessels containing fluids, or leakage past the glands or seals of a fluid system component that is

contribute to the frequency of core melt because of its potential for causing equipment failures that could result in initiating events and mitigating system failures.

passive, can be considered. The active flood protection system usually consists of flood level alarms, drains, sump level alarms, sump pumps, and automatic or manual isolation of the flood sources. Some

The passive flood protection system basically consists of an emergency sump and emergency drain paths. These are supplemented by water-tight barriers between safety divisions and/or surrounding individual

to mitigate the flood-induced events. The passive flood protection system is incorporated into the design of Korean Standard Nuclear Plants (KSNP).

plants' flood designs, the flood Probabilistic Safety Assessments (PSAs) have been performed for three plant designs, such as existing Korean PWR plants (900Mwe), CANDU type PHWR plants (600Mwe),

probability of coincident random equipment failure is accounted for in addition to the damage caused by the flood itself.

PSAs, 3) major findings of the flood PSAs, and 4) conclusions of this study.

2. FLOOD DESIGN DIFFERENCES BETWEEN THREE PLANT DESIGNS

ormal floor drainage, sump system, water-sealed penetrations, curbs and ramps. Also, the walls and doors act as barriers against flood

The functions of these general flood design features are as follows;

- Access ways between structures are provided with normally closed doors, some of which are designed to water-tightness standards. On the other hand, non-watertight doors with louver at the bottom are used where a free flow of water is required to prevent water buildup in the room. Doorway curbs prevent the spillage of water from minor room floods into corridors.
- Each of the major plant structures is subdivided into individual areas that are generally enclosed by reinforced concrete walls, floors, and ceilings. Redundant safety-related equipment is usually kept in separate areas or is spatially separated, thus minimizing the potential for significant damage due to water spraying or flood event.
- Inter-area penetrations are sealed with either water-tight seals or with fire seals. Although not designed to water-tightness standards, the fire seals reduce leakage, significantly.
- Level alarms of sumps and floors inform operators when flood occurs.
- Scuppers, installed in areas where rapid water buildup or a high-flow break may occur, quickly discharge large amounts of water to the outside.
- Water-sealed hatches ensure that water does not leak to a lower level. Following each opening of the hatch, the water-sealing procedure is repeated.
- Electrical cabinets and other vulnerable equipment are designed to resist sprinkler system water damage, and, where necessary, they are installed on raised pads.

In this section, the flood design differences between three plant designs are described briefly.

2.1 Flood Design For Existing Korean PWR Plants

The active flood design approach is generally incorporated in existing Korean PWR plants. Normal drainage, sump system, flood level alarms, watertight doors, water-sealed hatches, curbs and ramps are installed for protection and to mitigate flooding events [1].

Penetrations between the major structures, for example, heating, ventilating, and air conditioning (HVAC) ducts, cables, and pipe penetrations, are provided with elastomeric seals. Except for the non-Q administration/access control and switchgear building, all penetrations below the postulated flood level of their respective rooms are water-sealed. The curb height is a standard 15.2cm, but higher ones may be provided for special areas.

Most access ways have fire doors with a 0.64 - 3.8cm gap at the base. Although not watertight, these doors provide a temporary restriction to flood propagation and act as a spray barrier. Within the auxiliary building, provisions have been made for preventing a flood, originating in one Emergency Core Cooling System (ECCS) compartment, from spreading to another such compartment or to other plant areas. Each compartment has a watertight door, and special monitoring ensures that these doors are closed and locked during normal operation. All rooms are capable of withstanding the hydrostatic pressure of water expected in these volumes. Check valves and anti-siphon devices in the compartment drainage system prevent flood

alarms of sumps and floors inform operators when flood occurs.

The cooling water systems that use sea water exist in the auxiliary building and control building, which

2.2 Flood Design For CANDU Type Plants

Both the passive and active flood protection design approaches are incorporated into CANDU type plants.

designed to store about 2060 m^3 of water that is used for pressure suppression in the containment following Loss Of Coolant Accident (LOCA) events, and to supply the steam generators and ECCS. The capacity of

the reactor building. During normal reactor operation, if the dousing system becomes operational due to an inadvertent dousing signal or random mechanical 'fail-open' of two dousing valves in series in one

are located above 2.6 meters inside the reactor building basement [2]. This is an example of a passive approach.

design function is not flood detection or control, but which can be adapted for that purpose. For example, the Beetles System, which is designed for detection of LOCAs, could be used for detection of increased

area to other areas. Also, the sump level alarms and other signals, such as pump discharge pressure, could be used as a method of flood detection. Various alarms and indicators are made available so that the

cause a flood may also trigger its own particular combination of alarms. For example, following a dousing system initiation, a dousing tank low level alarm will trigger early before other alarms. Another example is

service water and sump alarms. Therefore, local operator recovery actions, such as opening or closing of valves to terminate water spill or to divert the water, closing the door in a flooded area to prevent flood

protection.

The cooling water system that uses sea water exists in the service building. It was revealed in the flood

2.3 Flood Design For KSNPs

The passive flood protection system incorporated in KSNPs is based on the following design concepts [3]:

- Unlimited flood sources, i.e. sea water, are not allowed in the Primary Auxiliary Building (PAB), where most of safe shutdown equipment is located.
- The safety divisions are physically separated by water-tight barriers.
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  flood flows.

In the KSNP design, the Essential Service Water (ESW) system provides cooling water only to the

building, called the CCW HX building, which is located between the PAB and the ESW intake structure. In this design, sea water is not allowed in the PAB, where most of safe shutdown equipment is located.

protection design. There are no flow paths between division A and division B equipment in the PAB, the CCW HX building, and the ESW intake structure, with the exception of one emergency flow path at the

from one division to the other division, when the amount of flood water exceeds the capacity of the emergency sump in each division[4]. All safe shutdown equipment is installed in a compartment that is

propagation, using water-tight walls, roof, and floor slabs. Other passive flood protection devices, such as dikes or curbs, are installed to divert flood water away from the equipment, as in previous plant designs.

drainage system installed in that room. Each room has drains that will handle the potential flood capacity of the room. When the amount of flood water exceeds the capacity of the normal drainage system, the

drain path is covered by a floating cap that acts as a barrier against fire, pressure and HVAC, unless a flood occurs. The vertical type emergency drains are also designed with a vortex suppressor to ensure the

Due to the prohibition of sea water usage in the PAB, the maximum flood source in the PAB is identified to be the Refueling Water Tank inventory. To accommodate this flood source, a part of the lowest floor of the

water volume. Some safe shutdown equipment, such as high pressure safety injection pumps, shutdown cooling pumps and containment spray pumps, are located in this area, but the doors to these pump rooms

2.4 Major Flood Design Differences Between Three Plant Designs

The major design differences between the three plant designs considered here are shown in Table 1.

concept is applied. The Liquid Poison Injection System, Emergency Water Supply (EWS) system, Emergency Power Supply (EPS) system are group II systems which are backups to the group I systems.

systems fail to operate, then the group II systems can be used by the operators. In case of the PWR plants, the KSNPs incorporate a divisional concept design that divides the location of safety systems based on the

Sea water is used for cooling various heat loads in the service building of the CANDU type plants. This design presents a source of uninterruptible floods in the service building. In the PWR plants, sea water does

In the KSNPs, emergency overflow paths are installed in important areas that contain major safe shutdown equipment. But such paths are not included in the existing older PWR plants and in the CANDU type

capacity.

In the PWR plants, there is no water source in the electric power distribution system equipment room. For $_2$ gas, is utilized as a fire protection system. This design prevents the

water suppression system. However, in the CANDU type plants, there are sprinkler system and fire water hose cabinets in the electric power distribution system equipment room. Although these water suppression systems are dry-systems, they impact potential vulnerabilities in the event of floods. The fire protection system for other areas is same.

Operator actions to prevent or mitigate flooding events are not required in the KSNPs, but they are required in the existing older PWR plants and in the CANDU type plants. The operators are helped in monitoring and diagnosis the occurrence of flooding events by various level alarms and system malfunction signals.

Table 1 Comparison of Flood Design Differences Between Three Plant Types

Design	Existing Older PWR Plant	CANDU 6 Type PHWR Plant	KSNP
Separation Concept	Room separation	Group separation	Divisional separation
Sea water in the auxiliary or service building	Yes	Yes	No
Normal drain, curbs, ramps	Yes	Yes	Yes
Emergency drain path	No	No	Yes
Emergency sump	No	Partial (Reactor Building)	Yes
Fire protection system in electric power distribution system equipment room	Inert gas	Water	Inert gas
Flood level alarm	Yes	Yes	No
Operator action to mitigate flood event	Yes	Yes	No

3. RESULTS OF INTERNAL FLOOD PSAS

The internal flood PSAs for various plant designs in Korea were performed by same approach. After gathering the initial plant data, such as flooding sources, piping layout, location of safety-related equipment, flood protection design features, flood propagation paths, etc., the internal flooding PSA was performed in four stages, as follows;

1) Qualitative Screening Analysis
2) Quantitative Screening Analysis
3) Detailed Analysis
4) Sensitivity Analysis

First, a systematic qualitative screening of all plant areas was performed to determine in a conservative manner which flood sources may be potentially significant contributors. At the second stage, the quantitative screening analysis using event trees and fault trees was performed. At this stage, core damage frequency was assessed on the basis that all equipment, susceptible to damage in the flood area, were considered to have failed given a flood occurs or propagates to that area. The third stage included a realistic detailed analysis of the flood sources found to be potentially significant during the second stage analysis. The object here was to assess the likelihood and impact of floods of varying severity using both deterministic calculations to evaluate flood height variations with time, and probabilistic models for flood mitigation and recovery. Results of analyses from all three stages were used to evaluate flood propagation and coincident random equipment failures. Finally, sensitivity analyses to find out the impact of the assumptions and important input parameters were performed on the significant flood scenarios.

For existing, older Korean PWR plants, the flood PSA results are as follows[1];

- Control building flooding event is a significant contributor to the CDF.
- CDFs due to flooding events from the auxiliary building and turbine building are very low. (3% of control building flooding event CDF)
- Other flood scenarios are negligible.

The control building flood scenario is initiated by flooding due to breaks in the Nuclear Service Cooling Water (NSCW) lines which supply cooling water to the essential chillers and diesel generators. If flooding occurs in this area, the floodwater would accumulate in the corridor and spread into the Class 1E switchgear room via either doors left open or under the doors. The sump pumps in the control building start and the sump-level alarm is actuated. The standby NSCW pump in the faulted train also starts when the pump discharge pressure is low, and it adds to the flood flow rate. If the operator fails to isolate the flood source, failure of all equipment associated with the switchgear room would result in core damage.

In the flood PSA for the CANDU type plants, detailed analyses were performed for 8 flood areas. The results of the flood PSA for CANDU type plants are as follows [5]:

- Flooding events in the Recirculating Cooling Water (RCW) HXs room and in the condenser areas are significant contributors to plant risk (99.99%).
- Other flooding event scenarios are negligible.

If the flooding event occurs in the RCW HX room, which contains 4 RCW heat exchangers, the plant loses its service water. The major flood source in this area is Raw Service Water (RSW), i.e., unlimited sea water. If the operator can't stop the flooding event early, the flood water propagates to the Feedwater (FW) pumps area and affects the operation of the FW pumps and the auxiliary FW pump. The flooding event in this area is loss of service water and FW, and its contribution to the total CDF due to floods is 79.6%.

If the flooding event occurs in the condenser area, the plant loses its Condenser Cooling Water (CCW). The major flood source in this area is CCW and RSW, i.e., unlimited sea water. To help the operators' response to the flooding event, there are three flood level alarms in the condenser pit. Its contribution to the total CDF due to floods is 20.4%.

In the flood PSA for the KSNP, there is no significant flood scenario, and no detailed analysis was performed; i.e., all the flood scenarios were screened out at the screening analysis stage. This is a result of the specific plant design features, such as passive flood protection, divisional separation, and absence of sea water in the primary auxiliary building[3].

4. MAJOR FINDINGS FROM FLOOD PSAS

For existing, older Korean PWR plants, the dominant contributor from flood events is station blackout induced by the rupture of NSCW piping in the control building 80ft area. The following recommendations are considered for possible plant improvements for this flooding event[1].

- Change NSCW pump logic so that the pumps automatically stop on evidence of large rupture in the pump discharge line.
- Establish procedures for loss of essential plant monitoring and train operators in the use of these procedures.

If these two items are implemented, then the core damage frequency due to this flood scenario will be negligible.

The major findings from the flood PSA for CANDU type plant are as follows[5]:

- Well-defined procedures and well-trained operators are required

- More flood detection devices are required in significant flood areas
- Doors identified as flood barriers must be closed during the operation

The flooding event from the RCW HX room/FW pumps area and condenser areas can be stopped before equipment damage occurs, if the operator takes timely and appropriate actions. There are several indicators in these flood areas. The flooding event can be identified by the operator using the sump level signals, service water pressure and temperature signals, and condenser pit level signals. In order to achieve this reduced plant risk, the necessary operator actions must be described well in an appropriate emergency operating procedure and the operators must be properly trained in these procedures. In the sensitivity study performed in this connection, it reveals that the plant risk will be reduced to 35.1% of CDF, if the operator stops the flooding event within 15 minutes.

The failure probability of flood barriers is a significant contributor to plant risk. In the sensitivity study, it reveals that the plant risk due to flooding will be increased to 164% of CDF if the steam-tight door that is located between the condenser areas and the RCW HX room/FW pumps area is open. Thus, the steam-tight door must be closed during operation.

5. CONCLUSIONS

The approaches for flood protection design are different for each plant design, and they are highly dependent on the plant type. The flood PSA revealed that the potential plant risk due to a flooding event is highly dependent on the flood design. The major design characteristics are 1) the location of systems that utilize sea water and their impact to other safety related systems and 2) the existence of emergency overflow paths and an emergency sump which can transfer and accommodate flood water to prevent a significant flooding event.

Since the systems and/or components which utilize sea water are not installed in the auxiliary building in KSNP, there is no significant flood scenario in the KSNP flood PSA. Also, in the KSNP design, passive flood protection designs are incorporated. However, there are sea water systems in the auxiliary building or service building in the existing, older PWR plants and in the CANDU type plants. The existence of these potential flood sources is a major contributor to plant risks. The recommendations to improve plant safety are well-defined procedures, well-trained operators, installation of additional operator aids, such as level signals, moisture detectors, passive flood protection devices, etc.

If plant safety is vulnerable, the design should be changed. Thus, the applicable design changes should be incorporated in the CANDU type plants and existing, older Korean PWR plants to reduce flooding risks. However, major design changes, such as physical separation of systems which negatively affect other systems, are very difficult or impossible to implement. Thus, minor design changes, procedure improvements, and training enhancements which reduce plant risks, are considered to constitute design improvement if justified by resulting benefit. These design improvement items can be identified from PSA and/or review of other plant designs.

For CANDU type plants in Korea, design improvement activities are now being undertaken by Korea Electric Power Corporation (KEPCO), Korea Power Engineering Company (KOPEC) and Atomic Energy of Canada Limited (AECL). Also, the flood PSA will be revised to reflect these design changes. This activity will be a good model of co-operation between plant design and PSA or between international co-workers to improve plant safety.

REFERENCES

[1] "Level 1 Probabilistic Safety Assessment Report for Kori Units 3&4", KEPCO, Seoul, Korea, 1992.

[2] “Final Safety Analysis Report for Wolsong Nuclear Power Plants 2/3/4”, KEPCO, Seoul, Korea, 1995

[3] “Ulchin Units 3&4 Final Probabilistic Safety Assessment Report”, KEPCO, Seoul, Korea, 1997.

[4] “Flooding Analysis”, Design Standard DS-N-2204, KOPEC, Seoul, Korea, 1992.

[5] “Level 2 Probabilistic Safety Assessment for PHWR”, KEPRI, Taejon, Korea, 1997.

KEY WORDS

Internal Flood, Flood Design, Passive Flood Protection, Active Flood Protection, Flood PSA,