Insight from the Internal Flooding PRA For APR 1400 Plants

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An internal flooding Probabilistic Risk Assessment (PRA) is performed for Advanced Pressurized Reactor 1400(APR-1400) plant under construction. The APR-1400 plants adopted quadrant physical separation of safety related components and passive flood protection measures. Due to some limitations on the availability of the information for the plants under construction, the analyses are performed applying some conservative assumptions which cannot be obtained from the design information. The results of the flood PRA show that the risk from the internal flood is very low despite of the conservative assumptions applied. During internal and external review, two potential issues that may affect the results are identified. One is the friction factor used in the flood growth analysis and the other one is the probability of fire doors left open. Sensitivity analyses are performed to identify the impact of the issues on the review result. This paper presents the sensitivity analyses.
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I. INTRODUCTION

The APR1400 plant is designed to minimize potential flood sources within safety-related areas. As such, unlimited flood sources such as essential service water piping are not located in the auxiliary building where the safety related components are located. When a flood occurs despite of the design, the impact of flood is designed to be limited by the passive flood protection measures such as emergency overflow path, flood barriers including the flood door, and emergency sump. The layout of the auxiliary building for APR 1400 is shown as Fig. 1.

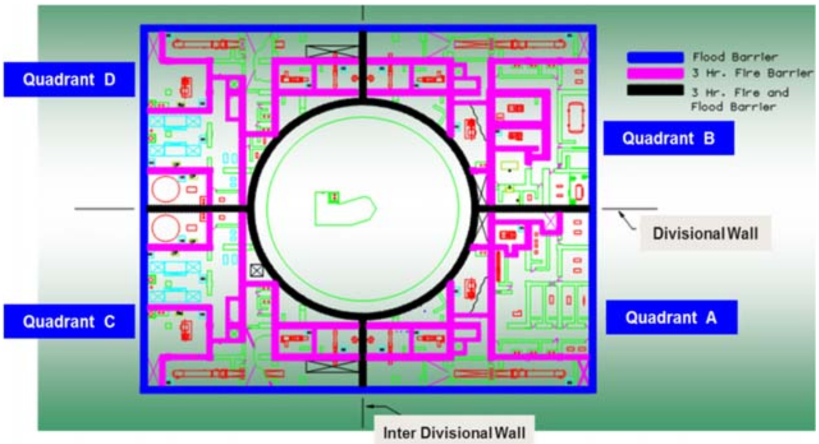

Fig. 1. Quadrant design of the auxiliary building for APR 1400

The 1st and 2nd floor of the auxiliary building, which houses the front line safety systems, is divided into quadrants. The flood barriers with a flood door provide separation between the quadrants. The flood doors are designed to withstand the water pressure from potential highest flood level and have sensors that send alarms when the doors are not closed for some designated time. The emergency overflow drains installed in each floor of the building are designed to drain any flood water in the floor to the lowest floor. The lowest floor of each quadrant does the role of emergency sump and this design confines flood water to one quadrant in most cases and up to 2nd floor in case of potential maximum flood. Thus, the equipment in the adjacent quadrants would be unaffected by any floods occurred in other quadrants if the passive flood protection measures are not failed.

The unlimited water source, i.e., essential service water (ESW), is limited to the ESW structure and Component Cooling Water (CCW) Heat Exchanger Building. Each division of the CCW Heat Exchanger building and ESW structure are separated by a concrete wall such that a flood in one division cannot propagate to the other division.

II. Bases and Assumption Applied to the Analysis

The Internal flood PRA is performed in accordance with the approach presented in the EPRI-1019194 (Ref. 1). This guidance document provides the approach intended to meet specific technical requirements of ANS/ASME Standard RA-Sa-2009 (Ref. 2).

Some of the assumptions applied to the analyses are as follows;

- In general, the PRA credited components located in the floor of flood origin are failed due to the flood.
- Critical height of electrical and I&C cabinet is 3/4 ft or 1 ft depending on the cabinet type.
- The floodable volumes are in general 50% of the total volume of the area.
- The non-watertight door including fire door is popped open outward or inward when the flood height is 1ft and 3 ft respectively.
- The probability of the left-open doors which have sensors of door status and send alarms to MCR if not closed for designated time is negligible. Considering the provisions and that the doors would be pop-opened at a specified level above, this assumption is considered not to affect the results.
- The lowest flow resistance coefficient (1.0) is applied when performing the flood growth and propagation analyses. This means that the floodwater is propagated to the lowest elevation fast. The fast flood propagation would make the PRA credited components submerged fast, which makes the available time for operator actions to isolate the flood minimum.

III. Potential Issues

The internal and external review identified two potential issues about the use of bases and assumptions listed above as follows;

- The flood protection design is done to prevent flood propagation from one quadrant to other quadrants. However, the flood may propagate from one quadrant to other quadrant if the door between quadrants is left open. This may affect the results significantly.
- Using the lowest flow resistance coefficient may limit the flood height at the floor where flood occurs. This may not be conservative since the flood height at the floor that the flood occurs reaches could be reached to the level that would pop-open the doors between quadrants fast. This makes the flood could propagate from one quadrant to other quadrants.

IV Sensitivity Study

Sensitivity studies were done to determine the impact of the issues listed above as follows;

IV.1 Sensitivity Analysis for Flood Height Calculation

The flood flow rate is estimated using the following equation.

$$Q = 19.65 \times D^2 \times n \times \sqrt{H/K} \qquad (1)$$

where

Q = flow rate, in gpm
d = pipe diameter, in inches
H = driving head, ft
K = flow resistance coefficient, velocity heads
n = number of drains (separate drain headers)

The K factor is typically calculated based on the physical characteristics of the drain piping such as the pipe diameter, number and angle of elbows, the length of near-horizontal piping, the type of entrance and exit, etc. (Ref. 3). Typical flood areas were selected as representative for short, medium, and long drain lines and the K factor was estimated. The calculation shows that average value of the K factor is 8.32.

To prevent overly conservative results, the other inputs that may affect the calculation are reviewed. The review suggests that the equipment occupancy fraction of 0.5 used in the analysis is overly conservative. The sample calculations done for some representative rooms shows that the maximum factor is 0.2 for corridors and 0.4 for the areas containing equipment.

Based on those described above, sensitivity analyses for four cases listed below are performed for the flooding in 5th floor of auxiliary building.

Case I) K=1, equipment occupancy factor = 0.5 (Base Case)
Case II) K =8.32, equipment occupancy factor = 0.5
Case III) K =1, equipment occupancy factor = 0.2 for corridors, 0.4 for other rooms
Case IV) K =8.32, equipment occupancy factor = 0.2 for corridors, 0.4 for other rooms

The results of the flood height calculation is shown in the Figures below

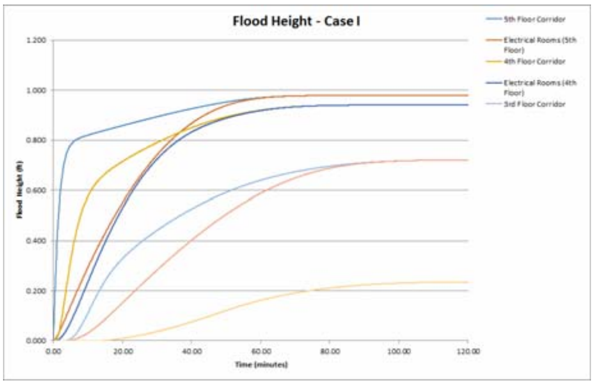

Fig. 2. Flood Height of Case I

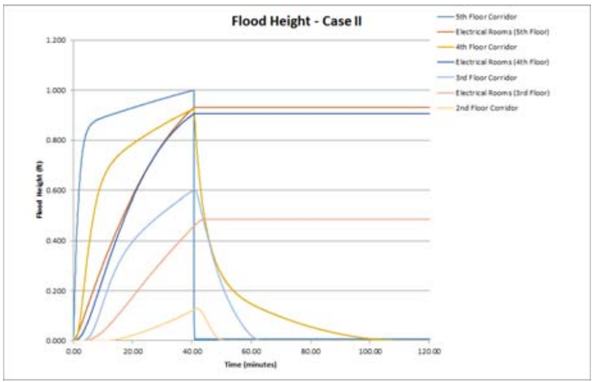

Fig. 3. Flood Height of Case II

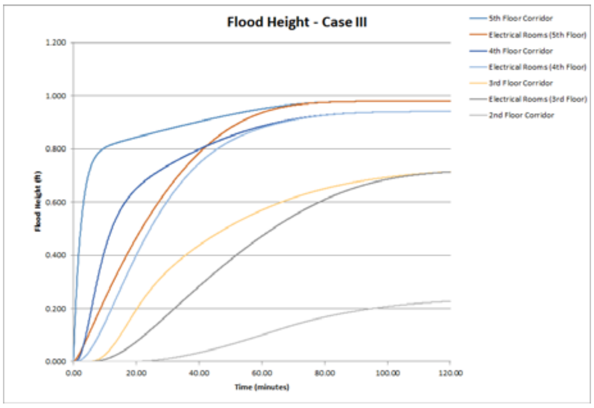

Fig. 4. Flood Height of Case III

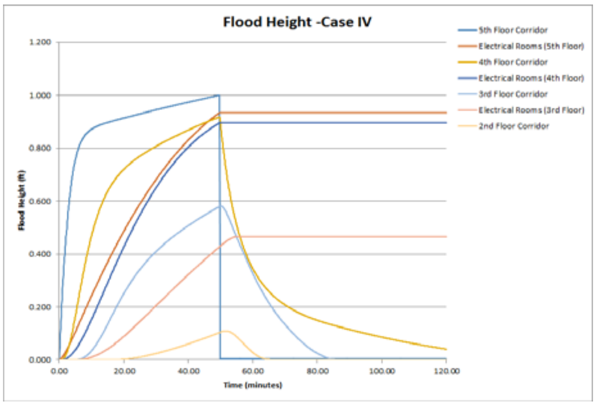

Fig. 5. Flood Height of Case IV

The maximum flood height estimated for flood areas and the below are summarized in the Table below.

Table I. Maximum Flood Height of the Cases

Flood Areas	Maximum Flood Height (inch)			
	Case I	Case II	Case III	Case IV
5th Floor Corridor	1.0	1.0	1.0	1.0
5th Floor Rooms	1.0	0.9	1.0	0.9
4th Floor Corridor	0.9	0.9	0.9	0.9
4th Floor Rooms	0.9	0.9	0.9	0.9
3rd Floor Corridor	0.7	0.6	0.7	0.6
3rd Floor Rooms	0.7	0.5	0.7	0.5
2nd Floor Corridor	0.2	0.1	0.2	0.1
1st Floor Rooms	3.4	3.4	2.3	2.3

As shown in the Table, the flood height of the 5th floor corridor is the same for all cases. The Case I shows the highest flood height for all other areas. The flood height of 1st floor room is reduced significantly in the Case III and IV. From the sensitivity calculations, it can be concluded that the resistance coefficient K does not affect the flood height much while the equipment occupancy factor could affect the flood height significantly.

IV.2. Sensitivity Analysis for Door Unavailability

A sensitivity analysis is performed considering the potential of door unavailability. In the sensitivity analysis, the floor areas in each quadrant of the auxiliary building are combined into one big flood area such as, 2nd floor Quadrant C, 3rd floor quadrant C, etc. The sensitivity analysis considers success or failure of flood isolation within 75 min. Following 4 cases for the flooding occurred in the 3rd floor, 4th floor and 5th floor of the Auxiliary Building are considered in the sensitivity analyses.

- Case 1: Flood in a Quadrant and Failure to Isolate
- Case 2: Flood in a Quadrant and Success to Isolate
- Case 3: Flood Propagated to Other Quadrants and Failure to isolate
- Case 4: Flood Propagated to Other Quadrants and Success to isolate

The results of the flood height calculation for inter-quadrant flood scenarios (Case 3 and Case 4) occurred in the 3rd floor and 5th floor are presented in the Figures below.

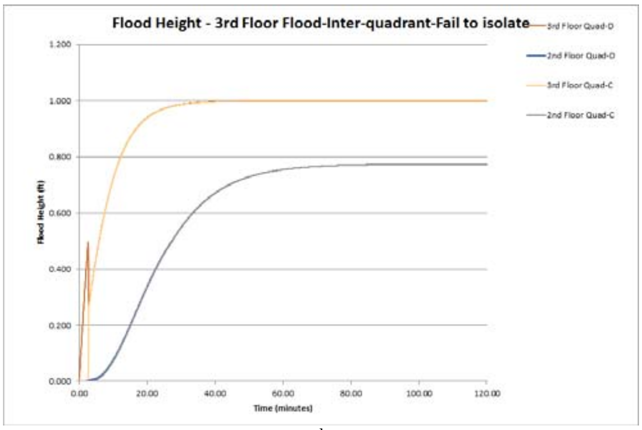

Fig. 6. Flood Height of 3rd Floor: Flood-Inter-quadrant Fail to isolate (Case 3)

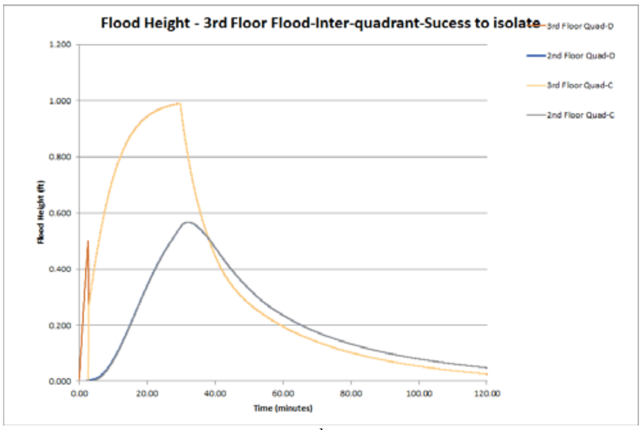

Fig. 7. Flood Height of 3rd Floor Flood-Inter-quadrant Success to isolate (Case 4)

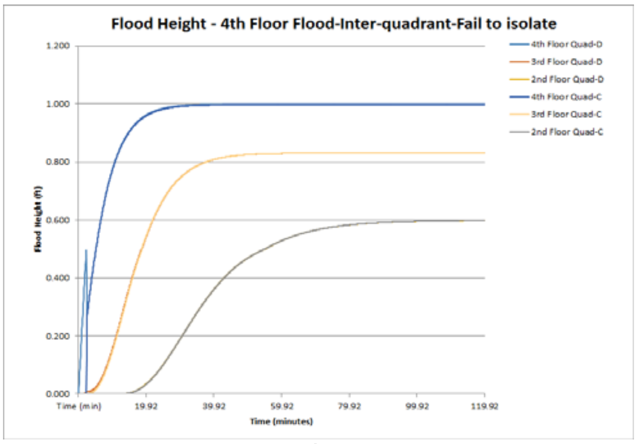

Fig. 8. Flood Height of 4th Floor Flood-Inter-quadrant Fail to isolate (Case 3)

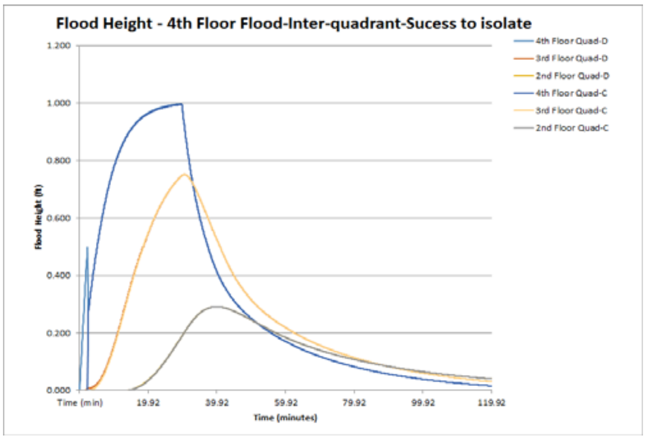

Fig. 9. Flood Height of 4th Floor Flood-Inter-quadrant Success to isolate (Case 4)

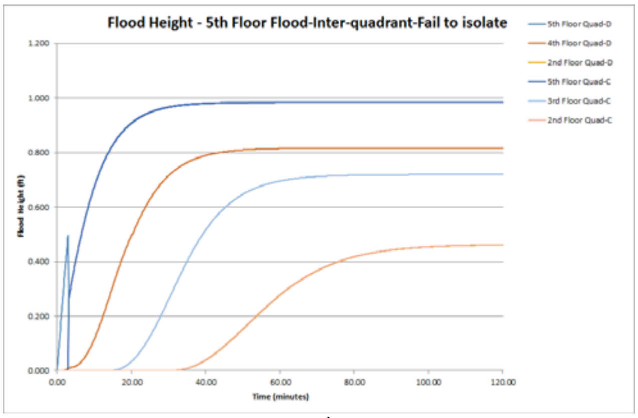

Fig. 10. Flood Height of 5th Floor Flood-Inter-quadrant Fail to isolate (Case 3)

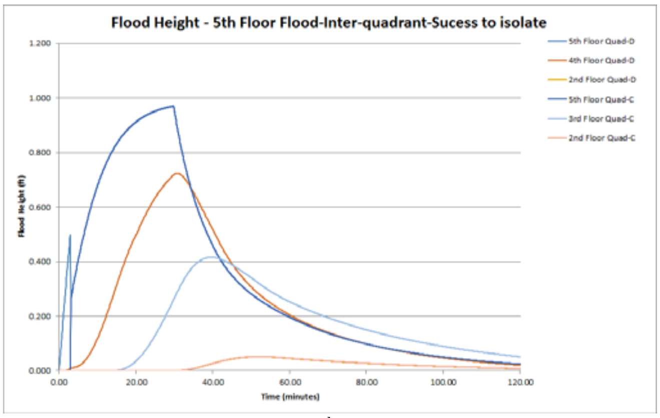

Fig. 11. Flood Height of 5th Floor Flood-Inter-quadrant Success to isolate (Case 4)

The maximum flood height estimated for the Case 3 and Case 4 is shown in the following Table

Table II. Maximum Flood Height For Case 3 and Case 4

Propagation Areas	5th Floor Flood: Case 3 (inch)	5th Floor Flood: Case 4 (inch)	4th Floor Flood: Case 3 (inch)	4th Floor Flood: Case 4 (inch)	3rd Floor Flood: Case 3 (inch)	3rd Floor Flood: Case 4 (inch)
5th Floor Quadrant-D	1.0	1.0	-	-	-	-
4th Floor Quadrant-D	0.7	0.8	1.0	1.0	-	-
3rd Floor Quadrant-D	0.4	0.7	0.8	0.8	1.0	1.0
2nd Floor Quadrant-D	0.1	0.5	0.3	0.6	0.6	0.8
5th Floor Quadrant-C	1.0	1.0	-	-	-	-
4th Floor Quadrant-C	0.7	0.8	1.0	1.0	-	-
3rd Floor Quadrant-C	0.4	0.7	0.8	0.8	1.0	1.0
2nd Floor Quadrant-C	0.1	0.5	0.3	0.6	0.6	0.8

The results of the flood height calculation show that the left-open door between the quadrants could cause flood propagation to other quadrants. The maximum flood height would be the same for both quadrants.

Incorporating the results of the flood height calculations, the CDF of the flood scenario is estimated for each of the sensitivity cases and the results are presented in the Table III below.

Table III. Estimated CDF for Sensitivity Cases

Scenario	Ratio of CDF (%) (Sensitivity Case/Base Case)	Core Damage Frequency(CDF)
3rd Floor Flood (Case 3)	253.4	>1E-08
3rd Floor Flood (Case 4)	2.6	>1E-08
4th Floor Flood (Case 3)	191.1	>1E-08
4th Floor Flood (Case 4)	0.1	>1E-08
5th Floor Flood (Case 3)	0.9	>1E-08
5th Floor Flood (Case 4)	0.02	>1E-08

As presented in the Table, the CDF from Case 4 of the 3rd and the 4th floor flood is increased significantly. The Case represents the case that the doors between the quadrants are left open and operators fail to isolate the flood before the floods propagates to other quadrants, resulting in damage of the components in the propagated quadrant. The CDF from the Case of the 5th floor flood is reduced significantly. It is due to that the flood sources in the 5th floor have limited capacity. So when the flood is spread by propagating to other quadrant, the flood height is reduced even in the quadrant of the floor that the flood originated. Thus it causes the number of components failure less than that of the base case.

V. SUMMARY

The APR-1400 plant is designed to protect the internal flood mainly by passive measures. The results of the internal flood PRA shows that the risk from the internal flood is relatively low compared to other initiating events and significantly low compared to other conventional plants. Some sensitivity analyses are performed to confirm that some assumptions applied to the analysis does not affect the results significantly. The sensitivity analyses show that the flood induced risk is not affected much on the assumptions applied. The highest increase of the CDF from different assumption is less than 1.0E-8/yr. Based on the observations, it is considered that the passive flood protection design features of APR-1400 is efficient to reduce the risk from the internal flood.

REFERENCES

1. EPRI-1091914, “Guidelines for Performance of Internal Flooding Probabilistic Risk Assessment”, Final Report, December 2009.
2. ASME/ANS RA-Sa-2009, “Addenda to ASME/ANS RA-S-2008,” American Society of Mechanical Engineers, New York, NY, American Nuclear Society, La Grange Park, IL, February 2009.
3. Crane Technical Paper 401, Flow of Fluids Through Valves, Fittings, and Pipe, 6ht printing, August, 1986.