Tsunami PRA for Kashiwazaki-Kariwa NPP

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Abstract: The Fukushima Daiichi Nuclear Power Station was struck by the huge tsunami generated by the 2011 off the Pacific Coast of Tohoku Earthquake on March 11, 2011, and experienced a severe accident. The most important lessons learned from the accident was that the “Defense-in-depth for tsunami was insufficient”. Therefore we are implementing many safety enhancement measures for tsunami in our Kashiwazaki-Kariwa Nuclear Power Station. We performed tsunami PRA studies in order to evaluate the effectiveness of these measures for addressing tsunami. The studies was based on the guideline “The Standard of Tsunami Probabilistic Risk Assessment (PRA) for nuclear power plants”[1] issued by the Atomic Energy Society of Japan (AESJ) in February 2012. Before and after tsunami countermeasure implementation studies are being done in order to evaluate the effectiveness of the countermeasures. In this paper, the evaluation results for the case of before and after tsunami countermeasure implementation are described, and the effectiveness of the tsunami countermeasures is shown.

Keywords: Tsunami PRA, Kashiwazaki-Kariwa, Fukushima Daiichi accident

1. INTRODUCTION

On March 11, 2011, tsunami generated by the 2011 off the Pacific coast of Tohoku Earthquake hit Fukushima Daiichi Nuclear Power Station (NPS), and it caused flooding at almost all of the seaside area and the surroundings of the major buildings. Then, station blackout (SBO) and loss of ultimate heat sink (LUHS) occurred, and it resulted in severe accidents. One of the lessons leaned by this accident is “Defense-in-depth for tsunami was insufficient”. In terms of safety enhancement of nuclear power plant from this lesson, countermeasure for each layer of defense-in-depth against tsunami is enhanced in the Kashiwazaki-Kariwa NPS. In the new nuclear regulation discussed at present, it is required that external event PRA is implemented and existence of sequences other than important sequence groups designated by the Nuclear Regulation Authority is confirmed. Then, we decided to perform tsunami PRA in order to understand plant vulnerability and to check validity of deployed countermeasure against tsunami for Unit 7 (ABWR) of the Kashiwazaki-Kariwa NPS. This paper describes the evaluation result completed by applying to states before and after the implementation of the tsunami countermeasures.

2. OUTLINE OF KASHIWAZAKI-KARIWA NUCLEAR POWER STATION

The Kashiwazaki-Kariwa Nuclear Power Plant(see Fig.1) is located in Kariwa Village and Kashiwazaki city in Niigata Prefecture facing on the coast of the Japan Sea, and seven nuclear reactors (Unit 1-5: BWR5, Unit 6, 7: ABWR, a total of 8,212 MWe) are built.

Figure 1. Kashiwazaki-Kariwa NPS

The site is divided into the south side for unit 1-4 and the north side for unit 5-7, and the ground elevation is T.P. 5m (Tokyo Peil: sea-level of Tokyo Bay) at the north side, and T.P. 12m at the south side, respectively. This elevation was decided based on T.P. 3.7m as a result of tsunami height evaluation assumed by wave sources of Echigo-Takada Earthquake from past earthquake record and the related literature. Since then, Tokyo Electric Power Company (TEPCO) reevaluated the tsunami height twice. First time is when the Japan Society of Civil Engineers (JSCE) issued a new design guideline "Tsunami Assessment Method for Nuclear Power Plants in Japan"[2] in 2002. Second time is in 2006 when the latest submarine topographic data and knowledge of fault at ocean areas became available. The results were T.P.3.7m (2002) and T.P.3.3m (2006).

3. TSUNAMI PRA FOR KASHIWAZAKI- KARIWA NUCLEAR POWER STATION

In Japan, from the lesson of the Fukushima Daiichi accident, development of tsunami PRA method was accelerated immediately after the accident, and Atomic Energy Society of Japan (AESJ) issued tsunami PRA guideline in February 2012. Then, TEPCO started to perform tsunami PRA to evaluate the effectiveness of tsunami countermeasures. In the state before the implementation of tsunami countermeasures, since there is no means to prevent flooding to building and function failure of important apparatus assuming generation of tsunami exceeding the 1st floor height of building, each flooding propagation evaluation and fragility evaluation are simply performed, and the core damage frequency (CDF) for each accident sequence is calculated. The items and the contents of the tsunami PRA are described in the following subchapters.

3.1 Tsunami Hazard Evaluation

Tsunami hazard for the Kashiwazaki-Kariwa NPS is evaluated based on "Method of Probabilistic Tsunami Hazard Analysis"[3] issued in 2009 by the JSCE. However, the occurrence frequency and the scale of earthquake, assuming linkage of the multiple faults which is the latest knowledge acquired in the 2011 off the Pacific coast of Tohoku Earthquake, are also taken into consideration.

3.1.1 Tsunami Occurrence Area Model

Regarding the tsunami occurrence area, the tsunami induced by earthquake, originated by faults which exist in the area, is determined in terms of whether they have significant influence on the tsunami hazard of the Kashiwazaki-Kariwa NPS. As a result, the following areas are selected.

1) The fault which is considered in seismic design and is identified by geological survey etc.
2) The fault which is unidentified by investigation, but indicated by an external organization (Epicenter at coast of the Niigata southwest earthquake)
3) The east edge of Japan Sea; Kashiwazaki-Kariwa NPS is considered to be affected significantly when tsunami occurs there.

Regarding these tsunami occurrence areas, the tsunami occurrence scenario is created by setting up the magnitude range and the earthquake occurrence probability.

3.1.2 Uncertainty

Random uncertainty in a numerical computation model and epistemological uncertainty regarding some issues such as existence of active fault and magnitude range etc. are considered in tsunami hazard evaluation. Epistemological uncertainty is dealt with as branch of tsunami occurrence scenario, and given weighting to each scenario. In this evaluation, the magnitude range, earthquake occurrence probability, probability of linkage, and probability distributions of random uncertainty are taken into consideration.

3.1.3 Hazard Curve

The annual probability of exceedance distribution curve is created for each tsunami occurrence scenario defined in chapter 3.1.1 and 3.1.2. Next, for each curve, with consideration for the weighting corresponding to each scenario, statistical processing is performed and hazard curve is created for weighted average as arithmetic average for weighted accumulation sum as fractal curve. As mentioned above, the tsunami hazard curve (tsunami run-up area at the north side) is shown in Fig.2. In evaluation of the state before the implementation of tsunami countermeasures, when tsunami exceeds height of the 1st floor of building, it is simply assumed that flooding in the building occurs and equipment function is lost, and it causes core damage. For example, in the evaluation of Unit 7, since the 1st floor height is T.P.12.3m, when the tsunami beyond this height strikes, it is evaluated as core damage occurs.

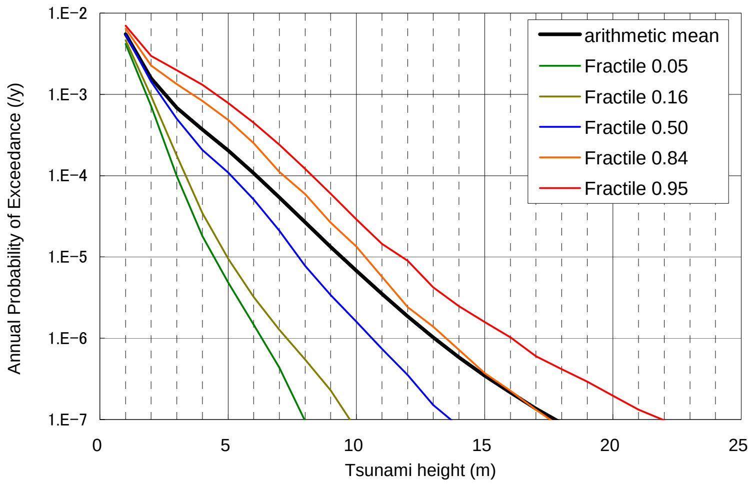

Figure 2. Tsunami Hazard Curve

3.2 Tsunami Fragility Evaluation

Regarding influence to apparatus by tsunami, damage by flooding and by tsunami wave force is considered. Regarding equipment on yard and door on outer wall of buildings such as yard tank, yard watertight door, etc., the failure probability against tsunami wave force is set by flooding depth based on tsunami run-up analysis result. Regarding equipment and door inside building, the damage probability is set by flooding propagation analysis result for building. Regarding tsunami run-up analysis, it is performed for multi case of tsunami height. For each case, fragility curve is evaluated from the equipment damage probability with consideration for the uncertainty in the flooding depth of the installation location for each equipment. The views of the main objects are shown below.

1) Embankment, tidal wall

When tsunami exceeds the height of the embankment or tidal wall, these failures are assumed.

On the other hand, in case of the tsunami less than the height, since there is sufficient resistance stress in the design, it is hard to consider to be damaged. For the reason, the height of embankment and tidal wall is set as failure-of-function limit.

2) Watertight door, general door

Regarding protection doors installed on building outer wall, fragility evaluation is conservatively performed with consideration for tsunami wave force. On the other hand, it is assumed that flow velocity of flooding propagation in building is slow enough, and fragility evaluation for the door in building is conducted for hydrostatic pressure of water accumulated in division.

3) Yard tanks (Light oil tank, pure water storage tank)

Since these tanks are on the ground, damage evaluation by tsunami wave force is performed, but evaluation for flooding and function affected by water level by submersion is also performed.

4) Fire protection system piping

Fracture evaluation is performed for bending load of piping changed by tsunami wave force. Branch piping which has high failure possibility is also taken into consideration.

5) Equipment in building (reactor core isolation cooling system (RCIC), power panel, etc.)

Flooding propagation evaluation in building is performed, and when the concerned apparatus and required support system are inundated, the function failures are assumed.

However, in evaluation of the state before the implementation of tsunami countermeasures, fragility evaluation with consideration for uncertainty is not performed, but method that the events induced by the tsunami of a certain height are deterministically evaluated is adopted.

3.3. Accident Scenario Identification

3.3.1 The state before the implementation of tsunami countermeasures

At the state before the implementation of tsunami countermeasures, it is assumed accident scenarios considering flooding according to the tsunami wave height. In addition, if the tsunami height is below the site level (T.P. 12m), it is assumed that inundation starts via maintenance hatch (T.P. 3.5m) in the heat exchanger area in the turbine building when tsunami height exceeds T.P. 3.5m. Also, it is conservatively assumed that all the buildings connected to turbine building are flooded to the tsunami height.

Tsunami height between T.P. 4.2m and T.P. 4.8m

The support system (ex. reactor cooling water system (RCW) pumps, reactor sea water system (RSW) pumps) is located in basement 1st floor of turbine building (T/B). When tsunami height exceeds T.P. 4.2m, the support system is flooded and it causes LUHS by the function failure. In addition, non-safety related metal-clad switch gear (M/C) in basement 2nd floor of T/B is also flooded.

1) Tsunami height between T.P. 4.8m and T.P. 6.5m

Emergency M/C in basement floor of reactor building (R/B) is flooded and lost its function. It causes SBO by the function failure of emergency M/C and non-safety related M/C, because it cannot be powered by off-site power and emergency diesel generators (D/Gs).

2) Tsunami height between T.P. 6.5m and T.P. 12.3m

DC power panel in the basement floor of control building (C/B) is flooded and loses its function. It causes loss of DC power.

3) Tsunami height exceeding T.P. 12.3m

Tsunami runs up to the site level, low voltage start-up transformer located at the site level is flooded and loses its function, and inundation into the main buildings occurs via entrance of each building.

3.3.2 The state after the implementation of tsunami measures

Using the results of tsunami fragility analysis as a reference, initiating events which are induced by tsunami are adopted and accident scenario analysis is conducted.

The extracted initiating events are shown below,

1) Loss of off-site power (LOPA)
   # Flooding of low voltage start-up transformer
2) Loss of function of emergency D/G
   # Flooding of emergency D/G(A,B,C) by inundation of R/B
   # Fuel transport failure by damage of light oil tank
   # Fuel transport failure by damage of fuel transport pump
   # Operation failure of emergency D/Gs operation failure by loss of support system function by T/B flooding
   # Flooding of emergency power panel room in R/B
3) Loss of ultimate heat sink
   # Loss of support system function by T/B flooding
   # Loss of support system function by D/G failure (in case of LOPA)
4) Loss of instrumentation and control system function
   # Flooding of main control room (MCR) in C/B
   # Flooding of DC power panel in C/B

3.4 Accident Sequence Evaluation

The evaluation result of the state before and after the implementation of tsunami countermeasures are described below.

3.4.1 The state before the implementation of tsunami countermeasures

Accident scenario changes according to tsunami height. So, initiating events and credited mitigation systems are changed as well.

1) Tsunami height between T.P. 4.2m and T.P. 4.8m

Initiating event is set as LUHS. In identified accident scenario, the relief valve function of SRV and RCIC are credited as mitigation systems. Event tree is shown in Figure 3. CDF for this tsunami height is calculated as 8.8E-5(/RY) and dominant sequence is TQUV (Transient with loss of all ECCS injections).

Tsunami Height T.P.+4.2m ～T.P.+4.8m (LUHS)	SRV Open	SRV Re-Close	High Pressure Water Injection (RCIC)	No.	Accident Sequence	CDF (／RY)
LUHS	PO	PC	UR			
				1	TW	0.0E+00
				2	TQUV	8.7E-05
				3	TQUV	4.6E-07
				4	LOCA	8.8E-25
					Total	8.8E-05

Figure 3. Event Tree (Tsunami Height T.P. 4.2m～4.8m)

2) Tsunami height between T.P. 4.8m and T.P. 6.5m

Initiating event is set as LUHS and SBO. Credited mitigation system is same as 1). Event tree is shown in Figure 4. CDF for this tsunami height is calculated as 1.0E-4(/RY) and dominant sequence is TQUV.

Tsunami Height T.P.+4.8m ～T.P.+6.5m (LUHS+SBO)	SRV Open	SRV Re-Close	High Pressure Water Injection (RCIC)	No.	Accident Sequence	CDF (／RY)
LUHSSBO	PO	PC	UR			
				1	TW	0.0E+00
				2	TQUV	1.0E-04
				3	TQUV	5.3E-07
				4	LOCA	1.0E-24
					Total	1.0E-04

Figure 4. Event Tree (Tsunami Height T.P. 4.8m～6.5m)

3) Tsunami height exceeding T.P. 6.5m

Initiating event is set as LUHS, SBO and loss of DC power. No credited mitigation system is set because it is assumed loss of DC power. Event tree is shown in Figure 5. CDF for this tsunami height is calculated as 2.5E-5 (/RY) and dominant sequence is TBD(Transient with loss of all AC & DC powers).

Tsunami Height > T.P.+6.5m (LUHS+SBO)	DC Power	SRV Open	SRV Re-Close	High Pressure Water Injection (RCIC)	No.	Accident Sequence	CDF (／RY)
LUHSSBO	DC	PO	PC	UR			
					1	TB	0.0E+00
					2	TBU	0.0E+00
					3	TBP	0.0E+00
					4	LOCA	0.0E+00
					5	TBD	2.5E-05
						Total	2.5E-05

Figure 5. Event Tree (Tsunami Height >T.P. 6.5m)

Tsunami PRA result at the state before the implementation of countermeasures is shown in Figure 6. Total CDF is calculated as 2.1E-4(/RY) in average value. As for accident sequence rate, TQUV is dominant sequence accounting for 89 percentages

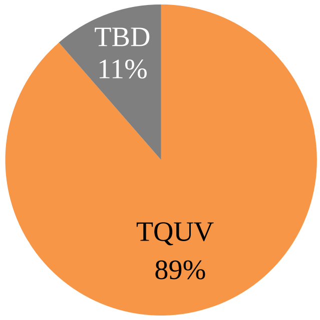

Figure 6. Tsunami PRA result
(The state before the implementation of tsunami countermeasures)

3.4.2 The state after the implementation of tsunami countermeasures

Based on the result of tsunami fragility analysis, in the accident sequence analysis, failure rate for each system, structure and component which is relevant to initiating events or equipment relevant to credited mitigation system is calculated and combination of tsunami height and damaged equipments is considered.

Regarding to the accident sequence analysis, tsunami initiating hierarchy event tree is constructed. In this event tree, yard equipments whose failure are directly connected to the initiating event are set as headings. The hierarchy event tree is shown in Figure 7. In event tree for each initiating event which is expanded from the hierarchy event tree, yard equipments which are not considered as heading is set as mitigation systems.

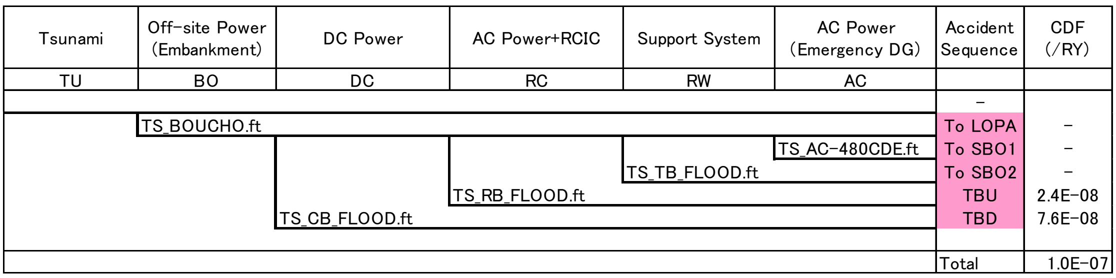

Figure7. Hierarchy Event Tree

The outline of accident sequence analysis is described below.

1) Tsunami height between T.P. 15m and T.P. 17m

Because, as shown by the fragility analysis result, the water tight doors of each building are not broken by tsunami of this height, inundation into the buildings does not occur, but the fuel transport pumps on yard are destroyed by tsunami. In this state, random failure of temporary oil transport pump which is installed thereafter is assumed. Because of this, all emergency D/Gs lose their function, and it causes the SBO.

2) Tsunami height between T.P. 17m and T.P. 18m

Because, as shown by the fragility analysis result, the water tight doors of T/B and R/B are broken by tsunami of this height, inundation into the T/B and R/B occur. Inundation into the T/B causes the flooding of support systems (ex. RCW and RSW pumps) and the loss of its function, and then LUHS occurs. Also, inundation into the R/B causes the flooding of RCIC control panel and the loss of RCIC function. Then all of the water injection function failure is occurred.

3) Tsunami height exceeding T.P. 18m

Because, as shown by the fragility analysis result, the water tight door of C/B is broken by tsunami of this height, inundation into the C/B occur, and it causes the loss of DC power (TBD).

Tsunami PRA result at the sate after the implementation of countermeasures is shown in Figure 8. Total CDF is calculated as 1.0E-7(/RY) in average value. As for accident sequence rate, TBD is dominant sequence accounting for 74 percentages in total CDF.

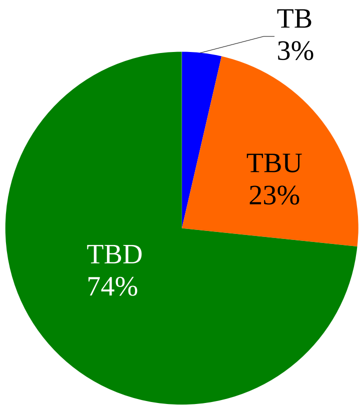

Figure 8. Tsunami PRA result
(The state after the implementation of tsunami countermeasures)

4.EFFECTIVENESS EVALUATION ABOUT THE MEASURE TAKEN IN THE KASHIWAZAKI-KARIWA NUCLEAR POWER PLANT

As stated above, in Kashiwazaki-Kariwa NPS, the various safety countermeasures is being deployed reflecting the lessons learned from the Fukushima Daiichi NPS accident. The measures against tsunami and power supply are included in the countermeasures, and the validity of these measures will be evaluated by using the tsunami PRA. Here, the validity for the implemented safety measures is qualitatively discussed from the view of TQUV and TBD which are the important accident sequences determined prior to the implementation of additional safety countermeasures. Regarding TQUV, probability of LUHS and possibility of inoperable of RCIC by submersion will decrease due to installation of embankment, tidal wall and watertight doors for important equipment rooms such as RCIC room and modification for maintenance hatch in T/B. Furthermore, when all low pressure water injection systems loses by tsunami exceeding the embankment height, water injection can be done by fire engines located at high elevations. Therefore, in the state after the implementation of the tsunami countermeasures, it can be presumed that the occurrence probability of TQUV is reduced substantially. As for TBD, probability of LOPA and inoperable possibility of DC power by submersion will also decrease due to installation of embankment and watertight doors of important equipment rooms. In addition, the enhancement of DC power supplies is implemented for storage battery extension at higher floor in the reactor building, additional established storage battery, installation of the small generator, and maintenance of the DC power supply means. Accordingly, it is presumed that the possibility of loss of DC power decreases. Therefore, the present measures can be presumed as being appropriate against the important accident sequences extracted.

5. CONCLUSION

Tsunami PRA studies for Unit 7 of Kashiwazaki-Kariwa NPS was conducted and the dominant accident scenarios that may result in core damage due to flooding were identified. The important accident sequences were evaluated as TQUV and TBD at the state before the implementation of countermeasures and CDF calculated as 2.1E-4 (/RY). This information supports qualitative assessment of the countermeasures that have been and will be implemented which indicates that these accident sequence probabilities will be decreased. Hence, the tsunami PRA was performed with the state after the implementation of tsunami countermeasures and CDF is calculated as 1.0E-7(/RY).

By comparing these two CDFs, the effectiveness of the tsunami countermeasures which are implemented in the Kashiwazaki-Kariwa NPS is confirmed. TEPCO will continue to evaluate the risks of external events including tsunami using PRA methods and enhance safety of the Kashiwazaki Kariwa NPS using such results.

References

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