# PRA Results and Decision Making with Uncertainty

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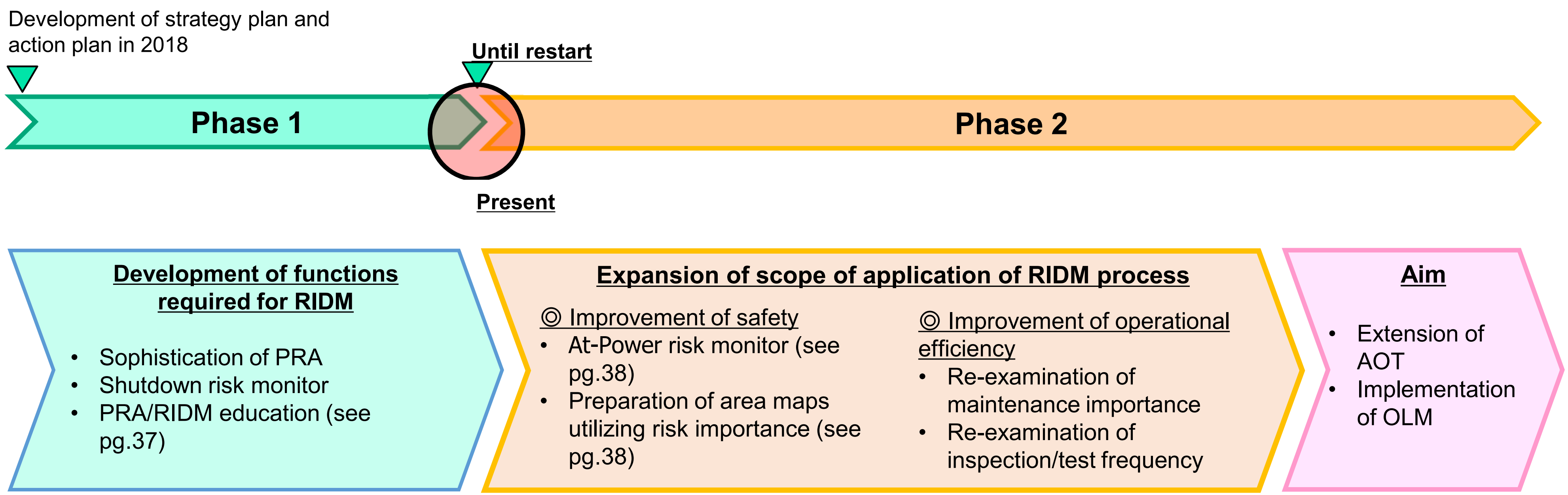
# 1. RIDM initiatives at Tohoku Electric Power
## 1.1 RIDM plan

- FEPC plans to introduce RIDM in two phases: Phase 1 (development of functions required for implementing RIDM, etc.) and Phase 2 (expansion of scope of application of the RIDM process, etc.).
- Initiatives have been taken for sophistication of PRA in Phase 1. Before moving on to Phase 2, education shall be provided on understanding and utilizing risks of Onagawa Unit 2.
- In Phase 2 after restart, studies that contribute to “improvement of safety” to ensure response to ROP shall be prioritized, followed by “improvement of operational efficiency” to realize extension of AOT and implementation of OLM which are considered by FEPC.

**Initiatives for using risk information at Tohoku Electric Power**
<Prepared based on FEPC’s RIDM strategy plan and action plan>



## 1.2 Example of development of functions required for RIDM: PRA/RIDM education

- Important matter in promoting initiatives to utilize PRA in order to safely and stably maintain, manage and operate the plant.
- Understanding that there are uncertainties, probabilistic assessment is combined with deterministic theory to re-examine operational rules, review the way of maintenance and utilize it to review improvement of safety measures.
- Regarding PRA, education is provided so that users understand that it is not a tool for measuring the level of safety by quantitatively expressing CDF and CCF.

# 1.3 Example of development of functions required for RIDM: PRA/RIDM education

■ In moving on to Phase 2 after restart, basic education shall be provided for “all station workers” and education required for the introduction and operation of the process shall be provided for “station workers related to engineering”. (sequentially provided from June 2024)

## ① PRA basic education

[Education details/objectives]

- What kind of assessments are conducted in PRA?
- What can be learned from PRA?
- How is PRA utilized?

[Effect]

- Improve sensitivity toward risks in daily work.

[Target]

- All station workers

[Example of educational materials]

### A familiar example to understand PRA

1

PRA is a method for quantitatively evaluating the frequency with which undesirable events occur. By understanding how often and to what extent "undesirable events" occur, we can make informed decisions about whether to accept these events or take measures to prevent or mitigate their occurrence and impact.
The product of the "magnitude of the impact (damage)" of such events and their "frequency of occurrence" is defined as risk, and PRA can be considered a method for quantifying risk.

Here, we will use the familiar example of "oversleeping" to illustrate how PRA can be used to assess risks and make informed decisions.

If you stay up late and get insufficient sleep, or if you drink heavily or are fatigued, resulting in poor sleep quality, you are more likely to oversleep. So, does oversleeping always occur the day after drinking heavily?

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## ② Education for introduction of RIDM process

[Education contents/objectives]

- Which accident scenarios are more likely to lead to core damage? (risk profile)
- Cases of RIDM process

[Effect]

- Promote introduction of RIDM process by station workers become proficient.

[Target]

- Station workers related to engineering

[Example of educational materials]

### 3. Results of the upgrading of the Level 1 PRA model

3

■ Core damage frequency for each initiating event

- ➢ As a result of the refined initiating events, "dependent initiating events" and the newly identified "high energy pipe rupture" have become the top-ranking initiating events.
- ➢ Scenarios leading to core damage due to the loss or isolation failure of multiple mitigating functions have been extracted as a result of these initiating events. These characteristics have been confirmed as common in BWRs.

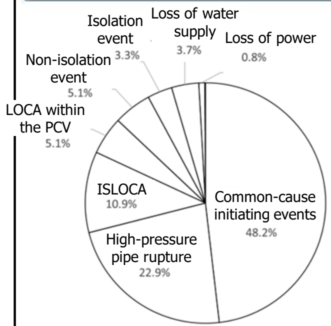


Fig. 2 Core damage frequency by initiating event

※起因事象を網羅的に抽出するために，文献調査，前兆事象分析，FMEA，保安規定の調査等を実施。従属性を有する起因事象（サポート系故障等）の追加およびLOCAの細分化などを行い，適合性審査時の16事象に対し約50事象を選定。

Tab. 2 Top initiating events and primary scenarios

| Top initiating events | Dominant scenarios | Supplementary |
|---|---|---|
| Common-cause initiating events | Loss of air-conditioning /refrigerator/recharge unit cooling + power loss +Water Filling Failure | - Increased scenarios due to detailed modelling of dependencies between frontline and support systems<br>- Room temperatures exceeding the design conditions of the installed equipment due to loss of air conditioning, etc., leading to loss of multiple mitigation functions |
| High-pressure pipe rupture (outside containment) | Breakage of main steam pipe + isolation failure | Scenarios extracted as a result of detailed modelling of equipment that loses functionality due to steam leakage as well as taking into account steam leakage outside the containment vessel |
| ISLOCA | ISLOCA +isolation failure | Same as above column. |

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# 1. RIDM initiatives at Tohoku Electric Power

## 1.4 Example of RIDM process that contributes to improvement of safety



■ In moving on to Phase 2 after restart, basic education shall be provided for “all station workers” and education required for the introduction and operation of the process shall be provided for “station workers related to engineering”. (provided from June 2024)

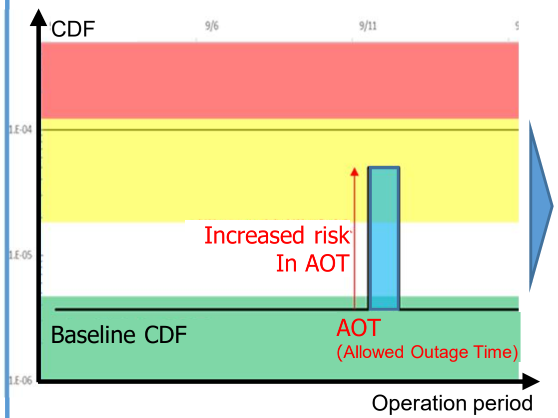
### **At-Power risk monitor** (introduced before restart)

[Implementation details]

- Monitor changes in risks during plant operation, and disseminate them to station personnel.
- If risks increase due to equipment outage, implement safety measures according to the incremental amount of risk.

[Effect]

- **Plant safety is improved by implementing** appropriate **safety measures** according to the incremental amount of risk.
- **Risks are recognized by station workers on a common scale** based on clear standards.




| Safety measures (example) |
|---|
| ・Prohibition of work |
| **・Restrictions on approaching risk-critical equipment** |
| ・Enhancement of monitoring of risk-critical equipment |
| ・Dissemination of risk information |

Operation risk monitor and safety measures (image)

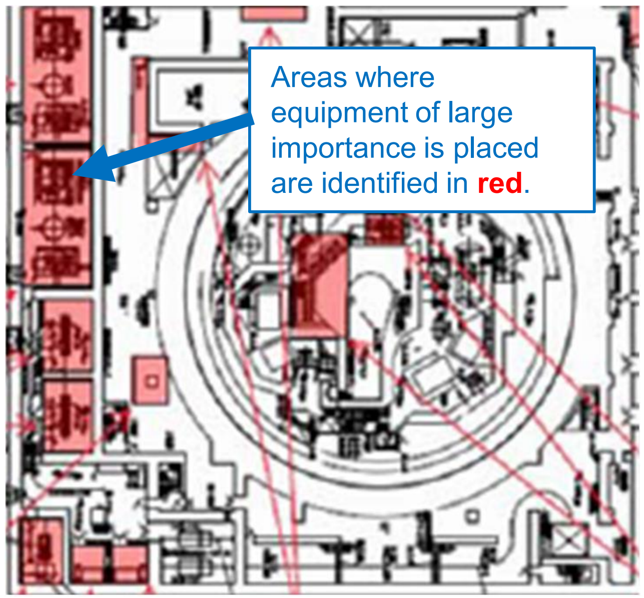
### **Preparation of area maps utilizing risk importance** (introduced by the end of FY2024)

[Implementation details]

- Develop area maps that let you visually confirm areas where risk-critical equipment is placed, and share them with station personnel (including affiliated companies).
- When working in such areas, install protection for important equipment and alert workers.

[Effect]

- **Equipment failure resulting from work is prevented by enhancing work management or protective measures in risk-critical areas.**




Area map (image)

# 2. Concept of uncertainties

## 2.1 Relationship between defense in depth and uncertainties



| Concept of defense in depth | | | |
|---|---|---|---|
| Level 1 | Prevention of abnormal operation and failures | Prevention of occurrence of abnormality and failure | Implementation of deterministic impact assessment and measures |
| Level 2 | Control of abnormal operation and detection of failures | Abnormal operational transient | |
| Level 3 | Control of accidents within the design basis | Design basis accident (DBA) | |
| Level 4 | Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents | Prevention of core damage<br>Prevention of damage of primary containment vessel | Implementation of probabilistic impact assessment and measures |
| Level 5 | Mitigation of radiological consequences of significant releases of radioactive materials | Environmental release of radioactive materials due to damage of primary containment vessel<br>Contamination of the surrounding environment | |

- In a sense, uncertainties also exist in deterministic assessment. Thus, deterministic theory ensures maintainability in the process of assessing impact (uncertainties are replaced with maintainability in assessment).
- Uncertainties exist in probabilistic risk assessment. Thus, it is necessary to recognize such uncertainties and work on refinement and sophistication.
  - In one aspect, risks may be over-evaluated on the maintenance side (reason for refinement)
  - In one aspect, potential risks may not be highlighted and recognized (reason for sophistication)

## 2.2 Relationship between uncertainties and risks as well as deterministic theory

**What is important**

Use it with the understanding that there is uncertainty. Potential risks may be overlooked when relying too much on deterministic theory, as decisions are made looking at the impact limited to matters that are known and that are recognized as risks.

**Past initiatives at Tohoku Electric Power**

Probability theory has been used understanding that there are uncertainties --- examples of use on pg.9-12

⇒ [What is unseen and overlooked in deterministic theory is assessed in PRA]

(Example)

In tsunami PRA, measures have been reviewed with an understanding that uncertainties are large.

Uncertainties here are...

Calculation of logic tree in hazard assessment

Equipment fragility

Human error, etc.

In this way, it is widely understood or often heard that uncertainties exist in various parts of PRA, but the question of whether uncertainties can be understood and used in decision making is extremely difficult.

⇒ [It cannot be simply determined that the answer is this, this is how it should be, or this is how it should be understood]

However, because there is uncertainty in any evaluation, even when making a deterministic evaluation, a conservative evaluation is performed

Even if maintainability is ensured in such deterministic theory, some things still cannot be seen.

⇒ [Operators promote use with the understanding that PRA can compensate for such areas that cannot be seen in deterministic theory]

① Vulnerable points of the plant
② Deficiencies and improvements in procedures
③ Necessity of training and education based on the size of impact of human errors
④ Time margin for decisions and operations
⑤ Clarification of maintenance-critical equipment, and suggestion of replacement frequency and inspection frequency not only based on actual failure

# 3. Past initiatives at Tohoku Electric Power

## 3.1 Multiplexing of Onagawa Unit 1 emergency cooling water system (when PRA concept was initially incorporated)

### ■ Sequence of events

- At Onagawa Unit 1, there were two independent emergency cooling water systems, but since there were no spare units installed to active components of pumps and valves within the system, reliability was enhanced by additionally installing spare units.
- The decision was made to implement this measure to multiplex emergency cooling water system (ECW/ECWS) pumps, based on the PRA results of 1994, thereby improving reliability of reactor injection functions and reducing core damage frequency.
- In April 2012, failure of emergency cooling seawater pump (A) motor occurred. At this time, system B was removed from service for being under inspection, but emergency cooling seawater pump (C), which was additionally installed following the result of PRA, automatically started up to maintain safety of the plant.
  (If the measure had not been implemented, emergency core cooling system may not have been activated (loss of residual heat removal function may have occurred))

### ■ Decision at the time

- This measure was internally discussed, since equipment not included in basic design was to be added, construction was difficult due to limited space in the room where additional pumps were to be installed, and reasonable costs were incurred. Furthermore, there was the background of insufficient understanding of PRA at the time.
- However, this decision was made based on comparison of core damage frequency with other plants and the significance of improving safety.

**Before implementing the measure**

Core damage frequency: **$1.2 \times 10^{-6}$** per reactor year

Reduction by two digits

○Core damage frequency and percentage of contribution by accident scenario, based on the PRA result of 1992-1994, is as shown in Figure 1.

○This result shows high core damage frequency compared to plants of other utilities. Since the cause was the configuration of the emergency cooling water system, pumps and valves were multiplexed in 1997. (see Figure 2 and Figure 4)

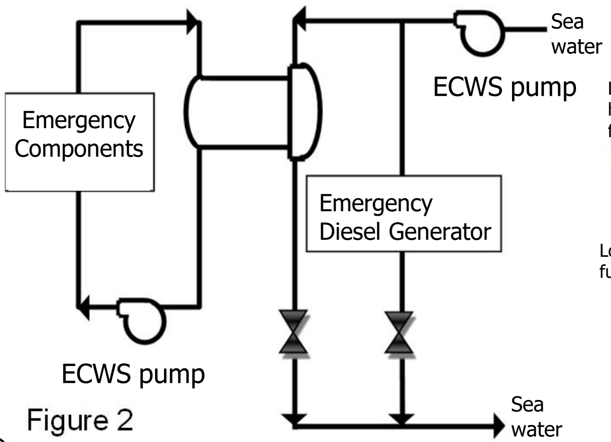
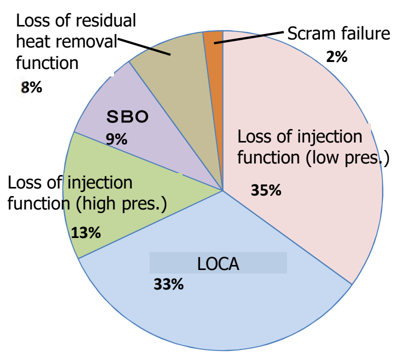



Figure 2

Figure 1




**After implementing the measure**

Core damage frequency: **$3.7 \times 10^{-8}$** per reactor year

○Core damage frequency improved as shown in the right by multiplexing pumps and valves of the emergency cooling water system. (see Figure 3)

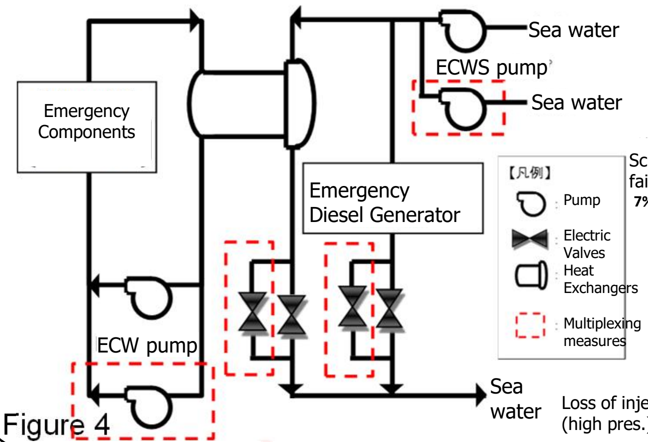
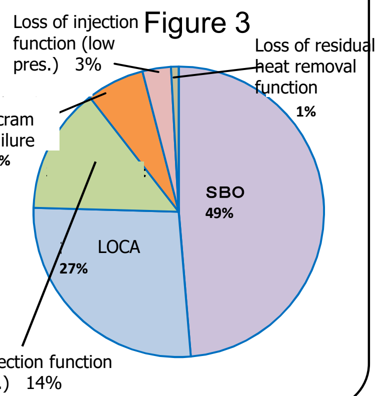



Figure 4

Figure 3



# 3. Past initiatives at Tohoku Electric Power

## 3.2 Review of measures based on Onagawa Unit 2 tsunami PRA (use of PRA in the review for conformity to the New Regulatory Requirements)

■ Sequence of events

- In Onagawa Unit 2 tsunami PRA, when O.P.+33.9m tsunami occurs, tsunami exceeds the seawall and results in flooding of the site, as shown in Figure 1.
- Initially, high ground on the sea side was initially set as the portable equipment storage area, but based on the site flooding analysis result in tsunami PRA, the location of the storage area was changed in consideration of uncertainties of flooding.
- Additionally, injection by low-pressure alternative water injection system (portable) was reviewed as response to the “accident sequence of the reactor core isolation cooling system stopping due to the safety relief valve being stuck open after station black out”, but based on the site flooding analysis result in tsunami PRA, it was changed to injection by low-pressure alternative water injection system (permanent) (DC-driven low-pressure water injection pump) in consideration of uncertainties of flooding.

■ Decision at the time

- In the internal review, it was assessed that flooding height is less than a few dozen centimeters and would not obstruct moving portable equipment, based on the site flooding analysis result in tsunami PRA. However, since uncertainties of natural phenomena (uncertainties of tsunami hazard (logic tree), flooding depth, tsunami speed) are large, and in order to ensure diversified SA equipment functions, it was decided to change the storage area and ensure injection means not with portable equipment but with permanent pumps (DC-driven low-pressure water injection pump) in the building.

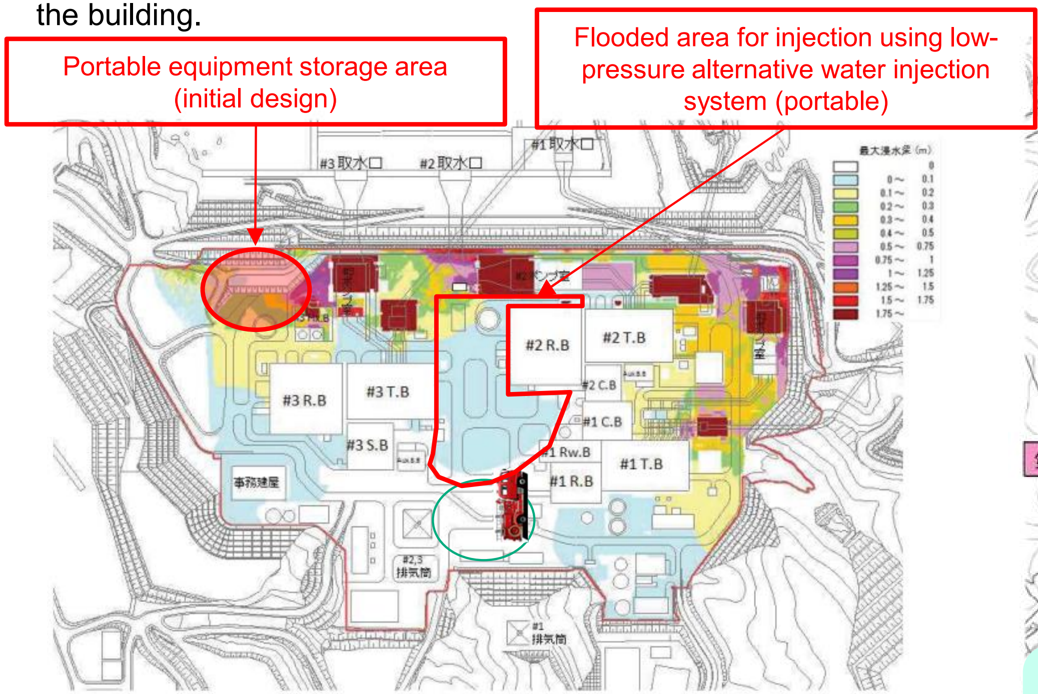
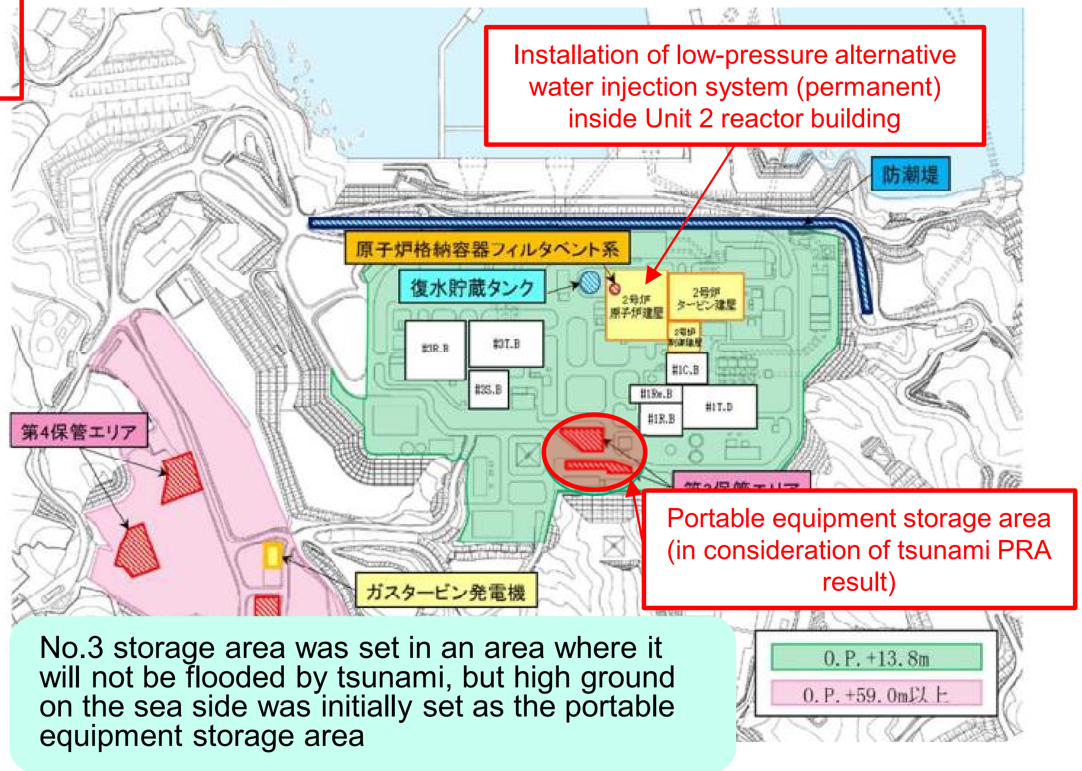



Figure 1 Distribution of maximum flooding on-site in the event of O.P.＋33.9m tsunami



# 3. Past initiatives at Tohoku Electric Power

## 3.3 Implementation of operational measures for diversification of securing of power supply (after PRA concept was established)

■ Sequence of events

・L1 internal event PRA was conducted to grasp the status of the restarted plant and further improve safety, incorporating SA equipment added for the review of conformity to the New Regulatory Requirements of Onagawa Unit 2.

・Based on this PRA result, "**loss of DC/AC power supply due to increased room temperature after loss of air conditioning**" was extracted as a scenario with large contribution to core damage frequency.

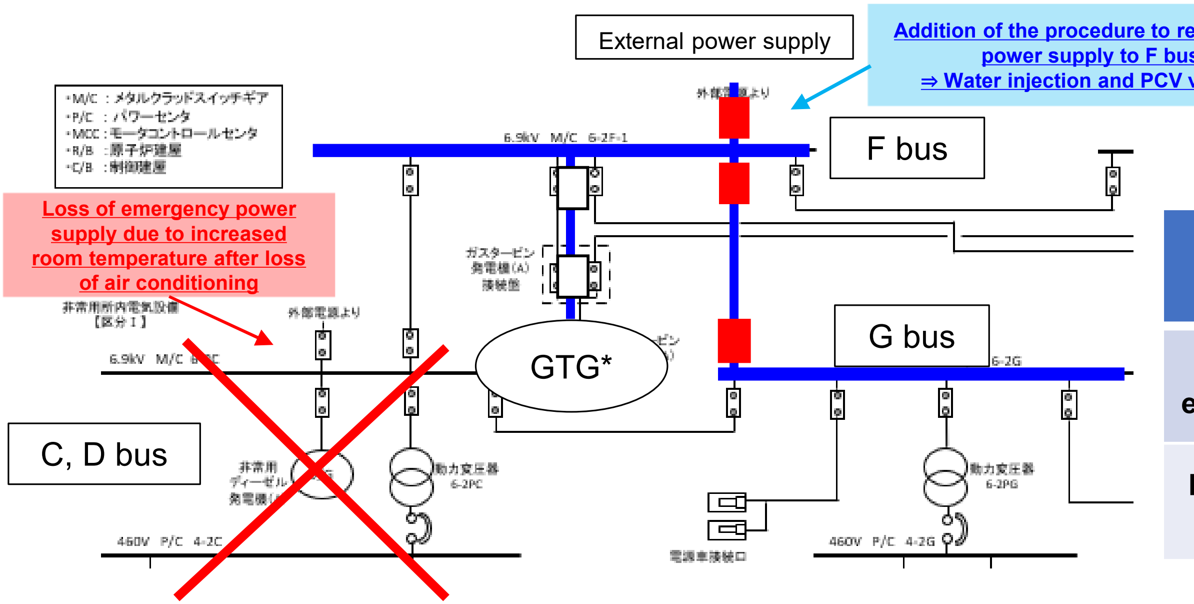
(This scenario is an operation related to "AC power switching panel operation failure" and an important operation that would double the core damage frequency if this operation is not expected)

・Analysis of factors of large contribution to core damage frequency identified that "success or failure of power reception to G bus" highly contributes to core damage frequency.

・In order to make the power reception route to the G bus redundant, addition of the procedure to "**receive power from external power supply to F bus to G bus**", in addition to power reception from GTG, was proposed to the site, and its feasibility was internally discussed. Operation of securing power supply was added to the emergency operating procedures (EOP) and incorporated into the PRA model.

■ Decision at the time

・Understanding toward PRA has deepened following the review for conformity to the New Regulatory Requirements, and there is common understanding that it is important to reduce risks for risk-critical scenarios identified from PRA upon understanding that they include uncertainties. Thus, risks identified from PRA are addressed by speedily taking measures such as re-examining operations.




* Power is received from GTG to F bus to G bus during SA with loss of external power supply

Figure 4 Power reception route to G bus added to procedures

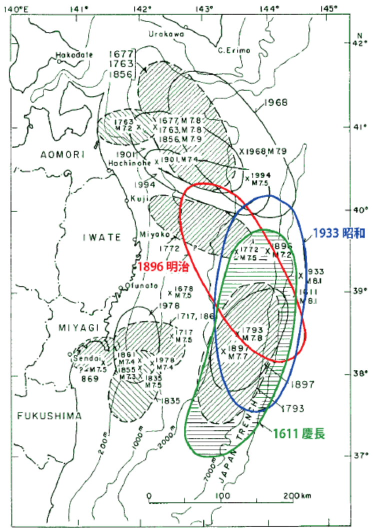
Table 1 Core damage frequency before and after adding procedures

| Assessment conditions | Core damage frequency (per reactor year) |
|---|---|
| No power reception from external power supply to G bus | $3.4\times10^{-5}$ |
| Power reception from external power supply to G bus | $3.5\times10^{-6}$ |

# 3. Past initiatives at Tohoku Electric Power

## 3.4 Decision of site height of Onagawa Nuclear Power Station (before incorporating PRA concept)

- In deciding the site height of Onagawa Nuclear Power Station, tsunami height was assumed at around 3m based on literature review and interviews with local residents.
- However, <u>the site height was decided to be 14.8m in consideration of uncertainties of tsunami height based on the observation that "tsunami could become much bigger considering the Jogan Tsunami (869) and Keicho Tsunami (1611)"</u> in the internal committee involving experts.
- Even after deciding on the site height, there is awareness (mindset) to have discussions when new knowledge is obtained, with the recognition that uncertainties of natural phenomena are large




Estimated wave source area of major tsunami that occurred off the coast of Sanriku

### Sequence of events on initially deciding on the site height

"**Assessment**" Internal committee by persons of learning and experience (from 1968)

- Record of 1896 Meiji Sanriku Tsunami and 1933 Showa Sanriku Tsunami
- Consideration of 869 Jogan Tsunami and 1611 Keicho Tsunami (literature review)
- **Assumed tsunami height is around 3m**

⇩

**"Decision" Site height determined to be "14.8m" based on expert opinions of the committee**

### Response to new knowledge

"**Assessment**" Onagawa Unit 2 Establishment Permit Application [April 1987]

- Assumed tsunami height revised **from around 3m to "9.1m"**
- Survey of impact of Jogan Tsunami (geological survey)

⇩

**"Decision" Slope reinforced up to "9.7m"**


"**Assessment**" Tsunami assessment estimate **"13.6m"** with the method of the Japan Society of Civil Engineers (February 2002)

⇩

**"Decision" <u>Confirmation of safety of the site (14.8m)</u>**

"**Assessment**" Formulation of reference tsunami **"23.1m"** in the New Regulatory Requirements (application for change of establishment February 2020)

⇩

**"Decision" <u>Establishment of seawall (29.0m)</u>**

# 4. Approach of applying PRA in various decisions

In general...

- When dealing with risks that involve "uncertainties", "conflicts with cost", "comparison with other utilities" and "difficulty of construction" are discussed.
- The range of "uncertainties" of natural hazards, such as earthquakes and tsunami, are larger than that of human errors, etc., which creates resistance to implementing measures for them.
- Such resistance to PRA results including "uncertainties" becomes large if there is lack of understanding toward PRA and makes it even more difficult to make decisions.

⇩

- It is necessary to resolve "lack of understanding of PRA" in advancing RIDM at Tohoku Electric Power.
- Therefore, understanding toward PRA and uncertainties shall be deepened by providing "PRA basic education" and "education for introduction of RIDM process", thereby "improving operational efficiency" to advance RIDM and realize extension of AOT and implementation of OLM.

# 5. Conclusion



- From past to present, Tohoku Electric Power has experienced site design based on “uncertainties” even before the use of PRA.
- However, understanding and permeation of PRA is becoming increasingly important in order to ensure and improve plant safety after restart.
- PRA is not merely a tool for measuring the level of safety by quantitatively expressing CDF and CCF. It is important to provide education to understand this.
- It is necessary to sincerely face PRA results upon recognizing that the results highlight potential risks that are not seen in deterministic assessment but that have uncertainties.
- After clarifying potential risks (scenarios) using PRA, measures can be implemented for the impact of such risks by using a deterministic approach. It is important to further instill this approach in safety regulations for the safety improvement concept to take root.