Central Research Institute of Electric Power Industry

Application of flow testing and analysis technology to risk assessment for plant maintenance management

Shun Watanabe

Central Research Institute of Electric Power Industry

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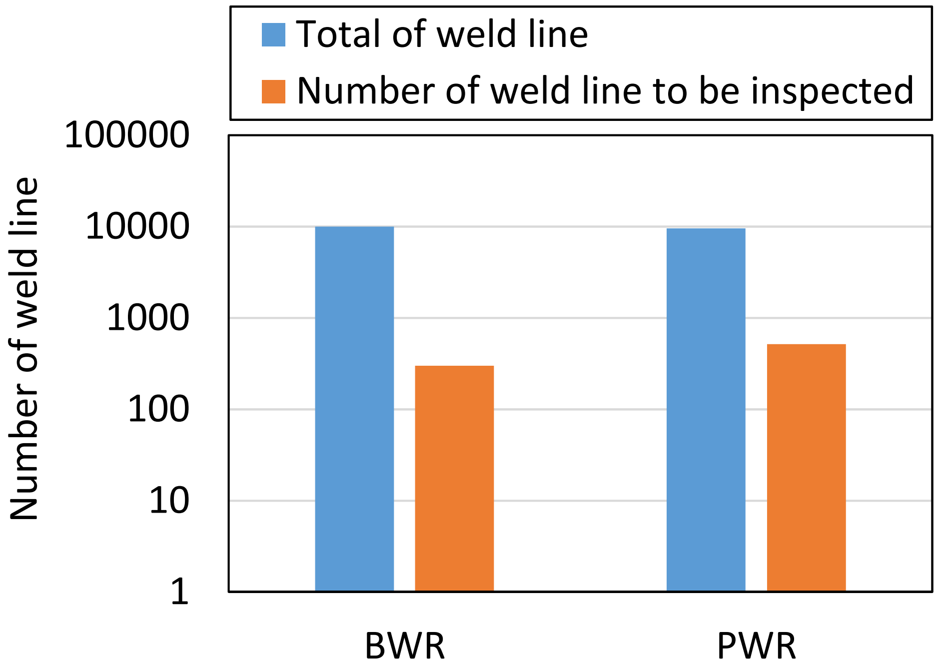
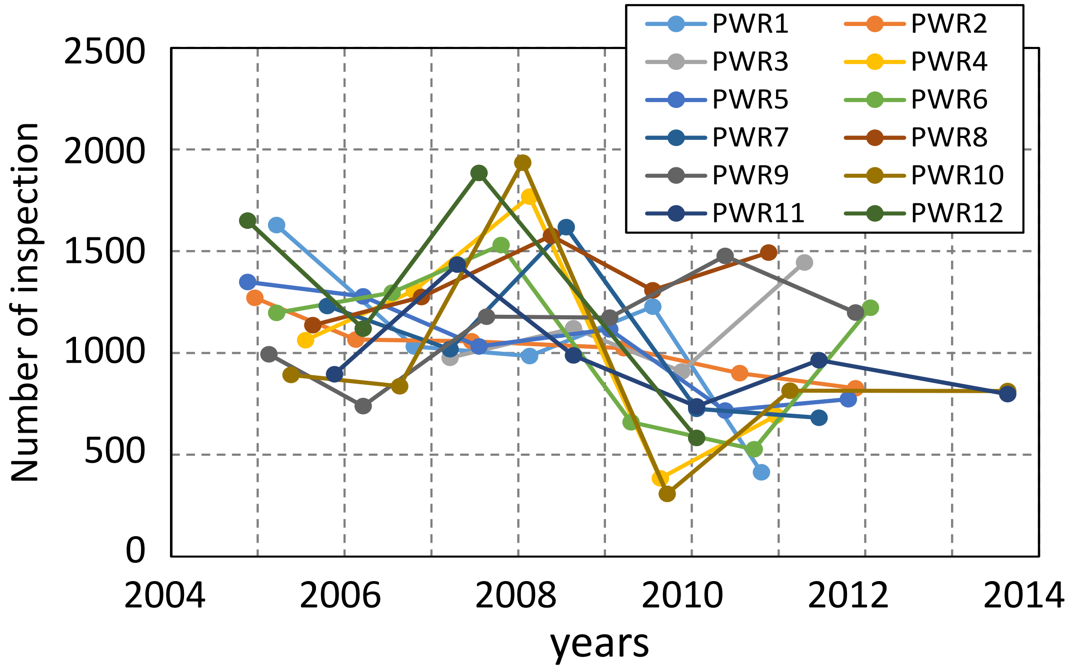
Number of inspections in JAPANESE light water reactors



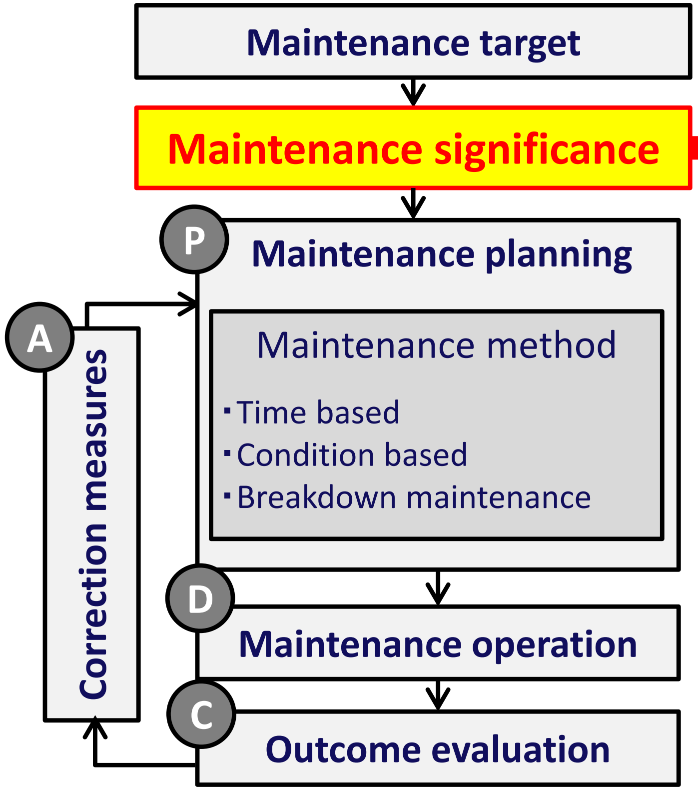
Number of inspection per 1 light water reactor*
(*Reference: "**JNES-RE-2012-0003**")



Number of inspection at periodic inspection in Japanese PWR*
(*Reference: **Press release** of Japanese power utilities)

- Several safety related systems were added to the plants through the process of the new regulatory requirements in Japan.
- However, the number of components to be inspected will increase even more after the plant restart. (This is already a large amount.)
- Effective measure will be required to command maintenance activities by reasonably assigning limited resource.

"Maintenance significance" in JAPANESE code



Consideration	Judgment
Classification of safety importance	Class 1, 2, 3
Risk assessment by PRA	Quantitative assessment (Core damage frequency etc.)
Supply reliability	Consideration by organizational engineered judgment **These considerations are NOT quantified.**
Operating experience	
Operational safety	
Ambient impact	

Maintenance flow and definition of maintenance significance in Japanese code*
(*Reference: "**Code for Maintenance at Nuclear Power Plants, JEAC4209**")

- The Japan Electric Association, "Code for Maintenance at Nuclear Power Plants"
- It is available for Japanese utilities to select the maintenance method according to "maintenance significance" of the object.
- Some of the maintenance significances (supply reliability, operating experience, operational safety and ambient impact) are not quantified yet.

The pipeline where "maintenance significance" is NOT effective in the present code

- The pipeline in the turbine building (**BOP : Balance of Plant**)
  - Classification of safety importance for most of these pipelines is assigned to "**class 3**" or "**non-class**".
  - It is difficult to acquire meaningful evaluation results by "the risk assessment (PRA)" because these pipelines hardly affect the core damage frequency.
  - The number of the pipelines to be inspected is still large and "time-based maintenance" is almost applied as the maintenance method.

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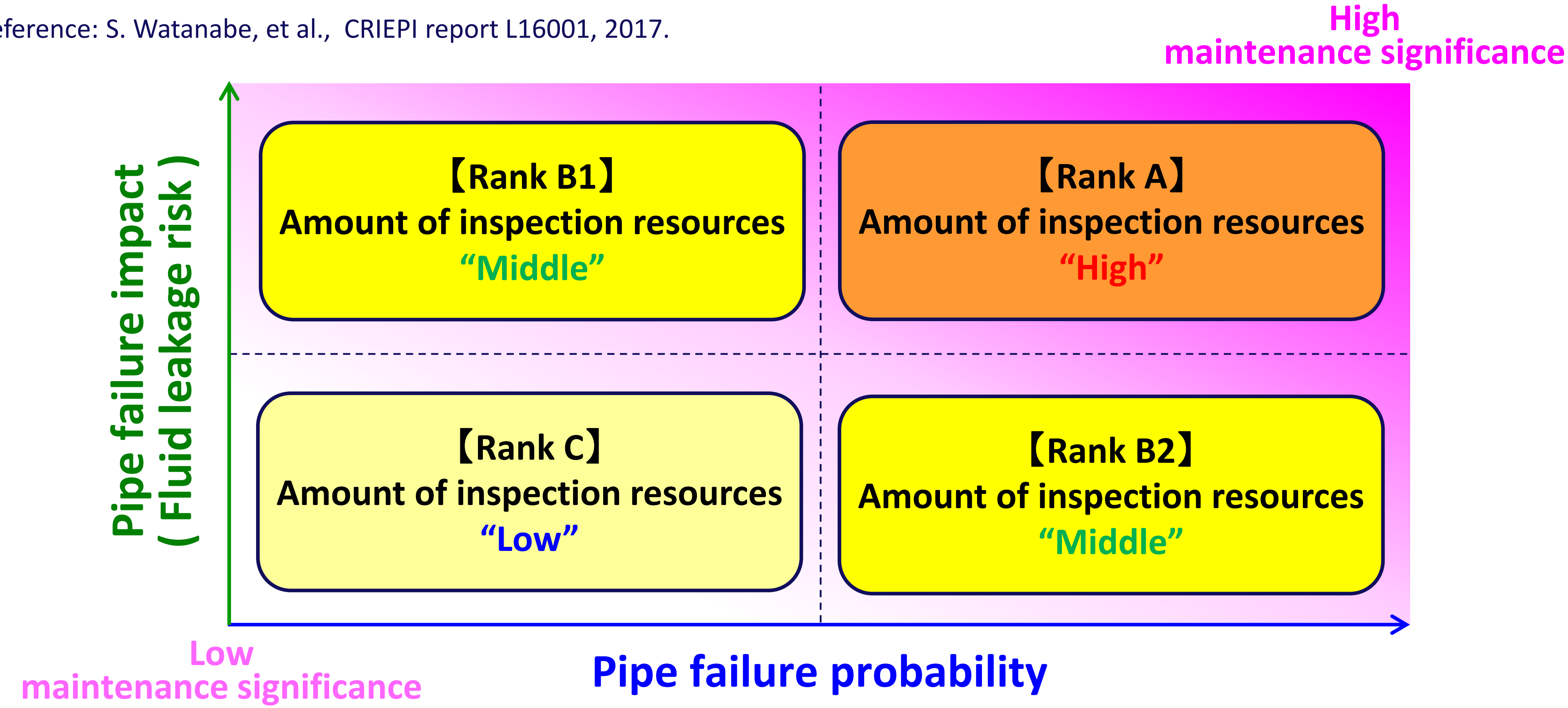
It is important to improve the maintenance framework of the BOP depending on quantification of the impact to the supply reliability and the operational safety etc. as the maintenance significance.

To introduce the matrix of the maintenance significance

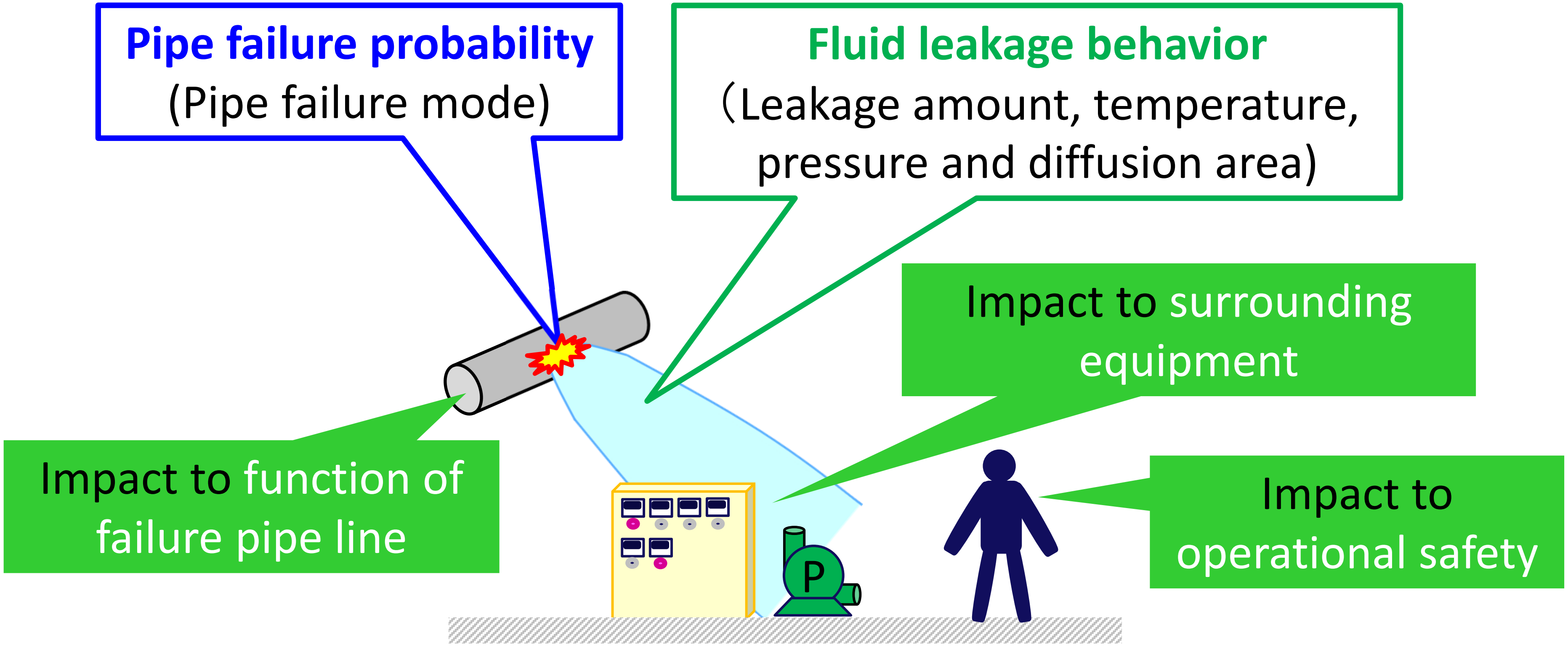
Reference: S. Watanabe, et al., CRIEPI report L16001, 2017.



- In order to quantify the maintenance significance, the matrix which defined by “pipe failure probability” and “pipe failure impact” was introduced.
- Through the matrix, the new maintenance ranking is possible to be considered for **<u>the BOP pipelines</u>** where the classification of safety importance is low. (Amount of inspection resource indicates inspection method, frequency etc.)

To quantify the parameter of the matrix

Reference: S. Watanabe, et al., CRIEPI report L16001, 2017.



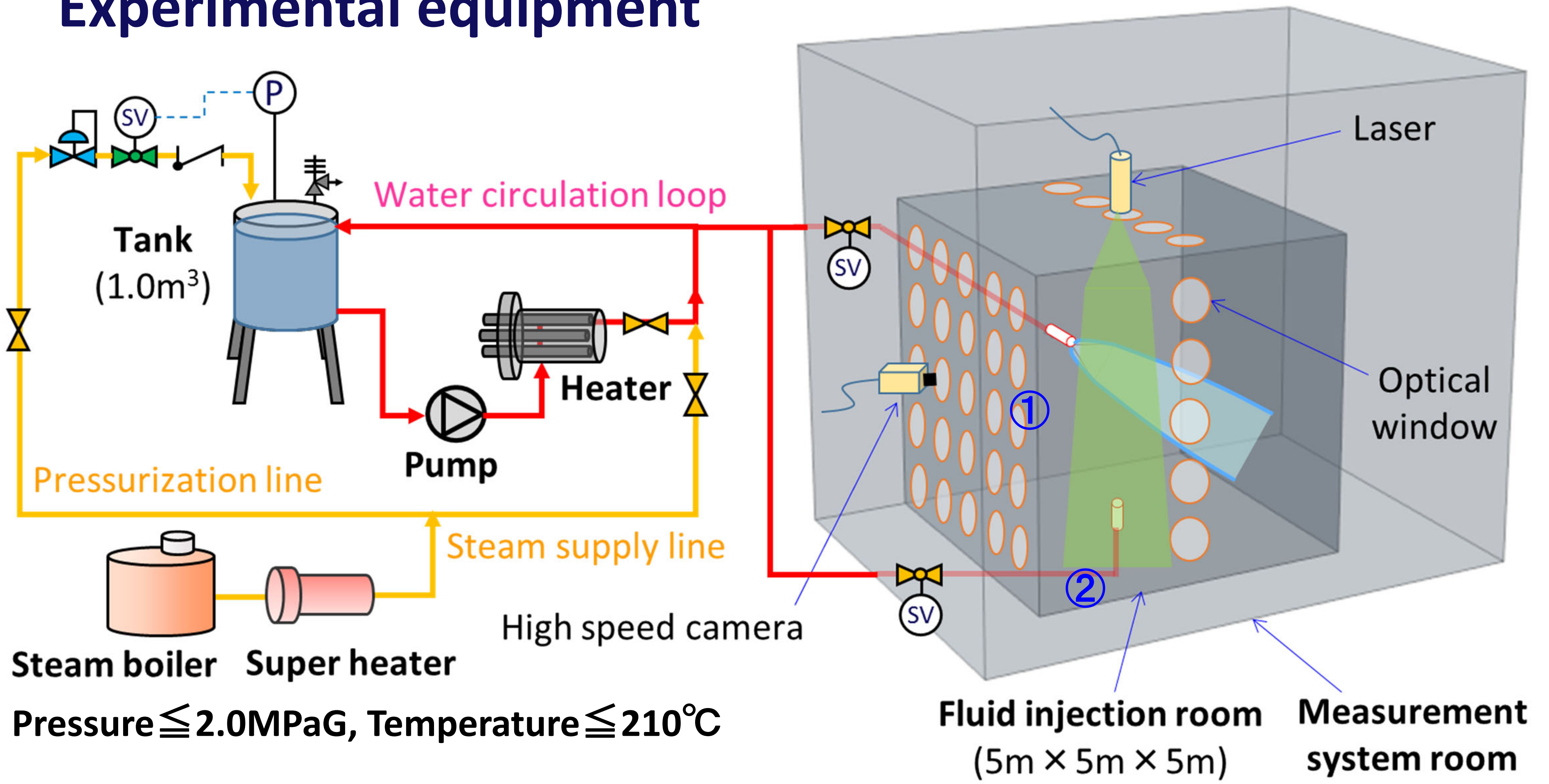
- In order to quantify "**pipe failure probability**", a variety of pipe failure mode are evaluated by using the plant database and analysis tools.
- In order to quantify "**pipe failure impact**", fluid leakage behavior due to pipe failure is evaluate by the experiment (**Main topic in this presentation**).
- And also, impact of fluid leakage to function of failure pipeline, surrounding equipment and operational safety must be considered.

Objectives in this presentation

- Optimization of maintenance management in systems with low safety significance and quantification of maintenance management risks for this purpose.
  - Quantification of the impact on maintenance management, including work safety in the event of piping damage
  - Evaluation of Pipe Damage Probability Considering Deterioration Events in Low-Class Piping

- This presentation will focus on "Quantification of Failure Effects" as a study utilizing flow testing and flow analysis.
  - Evaluation of jetting behavior and influence range by flow experiment and flow analysis
  - Work Safety Indexing Initiatives

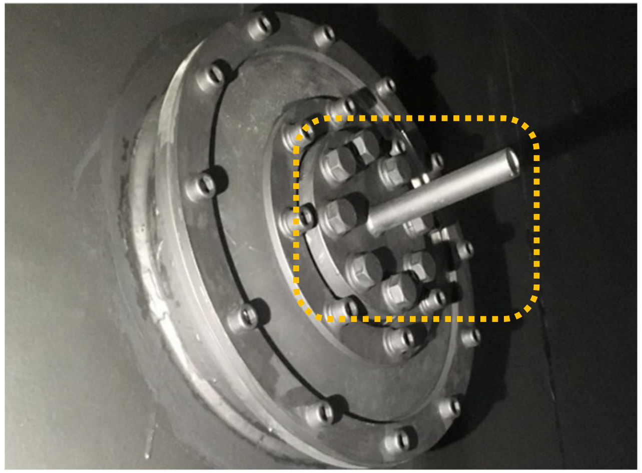
Experimental equipment



Pressure≦2.0MPaG, Temperature≦210℃

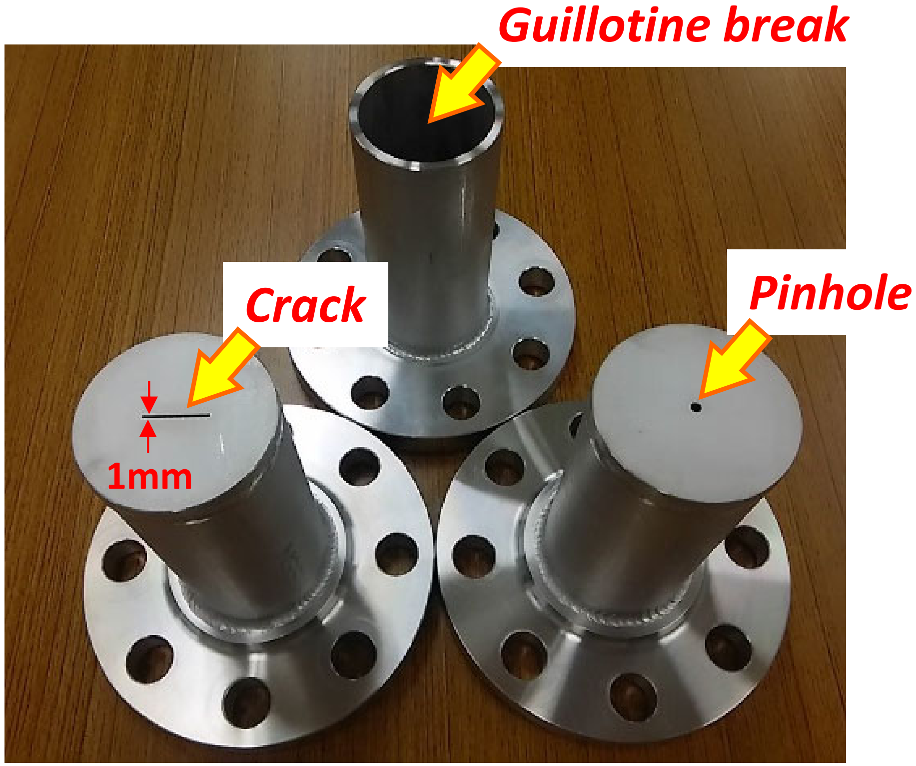
- The condition of pressure and temperature were set based on the condition of "**balance of plant (BOP)**" in Japanese NPPs.
- It is possible to inject water or steam into the fluid injection room from the horizontal nozzle (①) or the vertical nozzle (②). Flow visualization measurement is conducted by using the high-speed video camera and the laser through the optical window.

Geometry parameter of the pipe opening area



Nozzles are installed at the room wall

Possible to replace

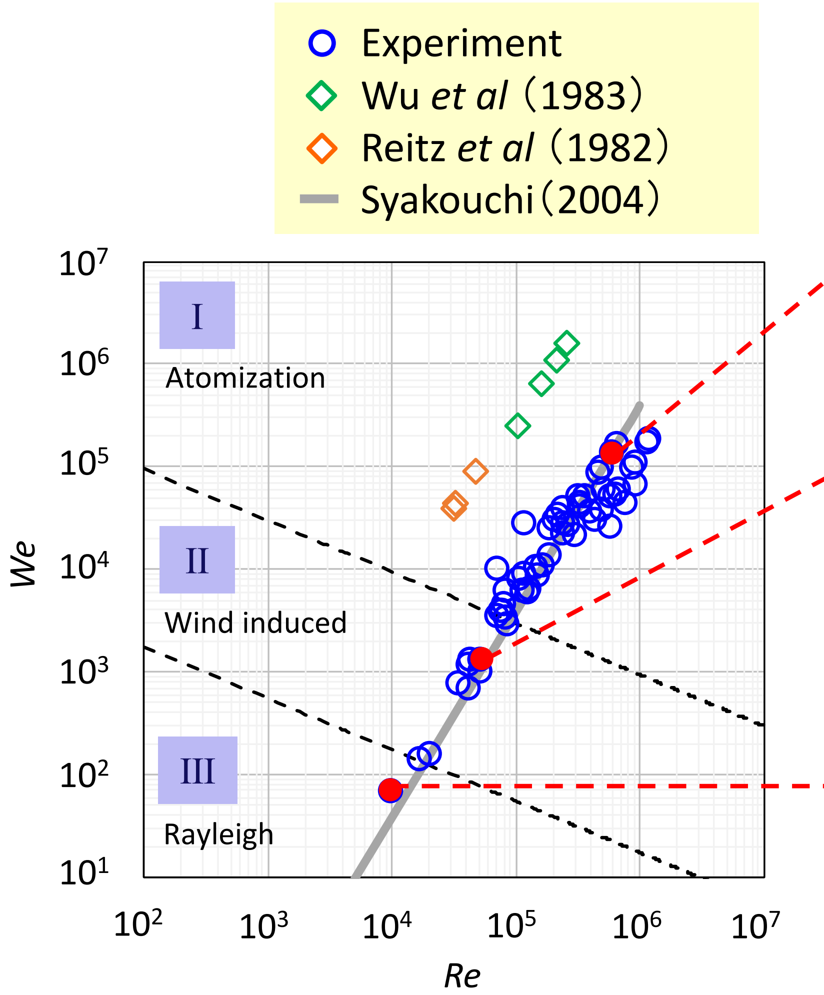


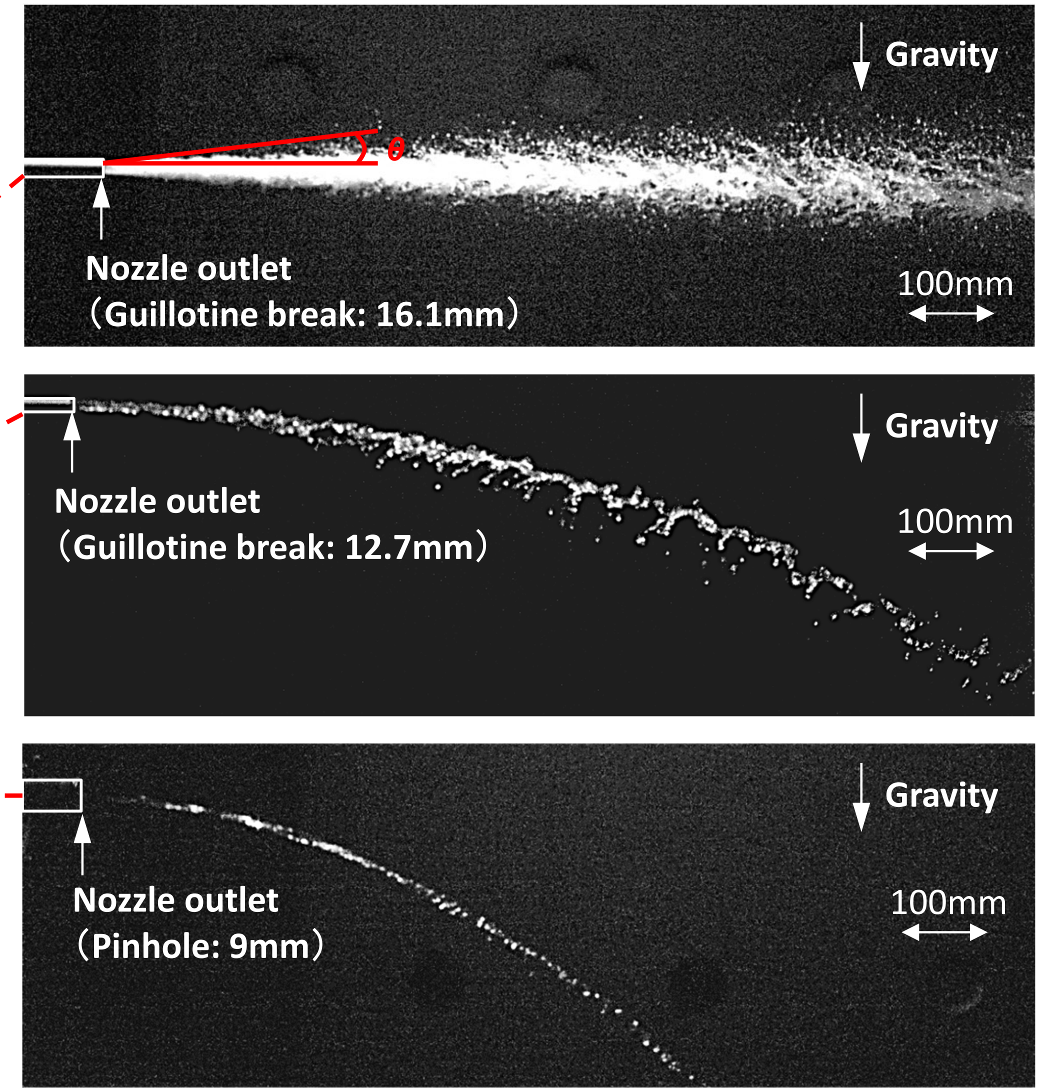
- It is possible to simulate various geometry of opening area as the pipe failure mode for 50mm and under of pipe diameter.
- In order to conduct the fluid leakage experiment, the parameter of the opening area was set to crack, pinhole and guillotine break.

Pipe failure mode	Parameter
Crack (length)	10, 20, 30 and 40 mm
Pinhole	3, 6, 9, 12 and 15 mm
Guillotine break	15A, 25A, 40A and 50A

Reference: S. Watanabe, et al., CRIEPI report L16001, 2017.

Measurement of high-pressure water splash behavior



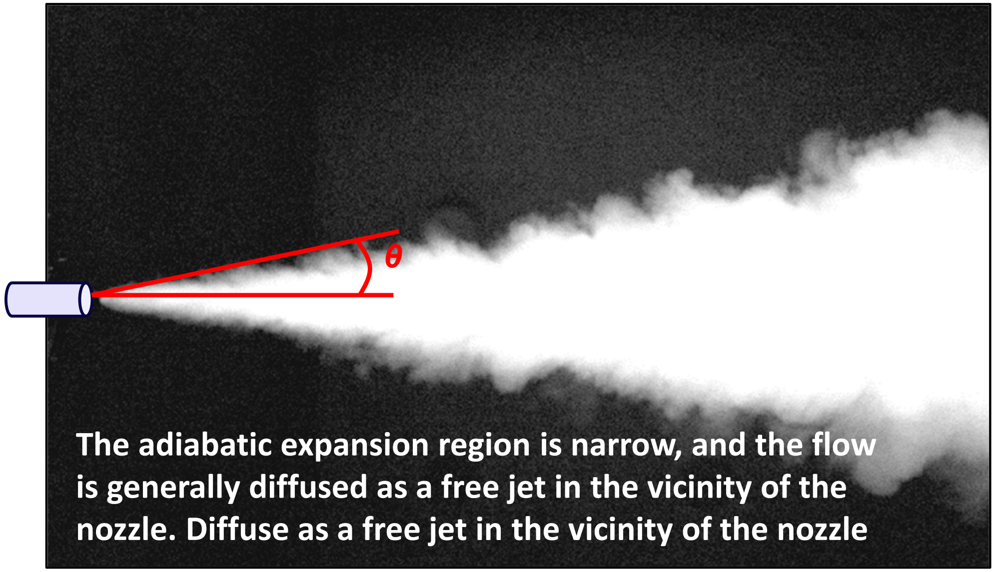


Experimental conditions and jet flow visualization results

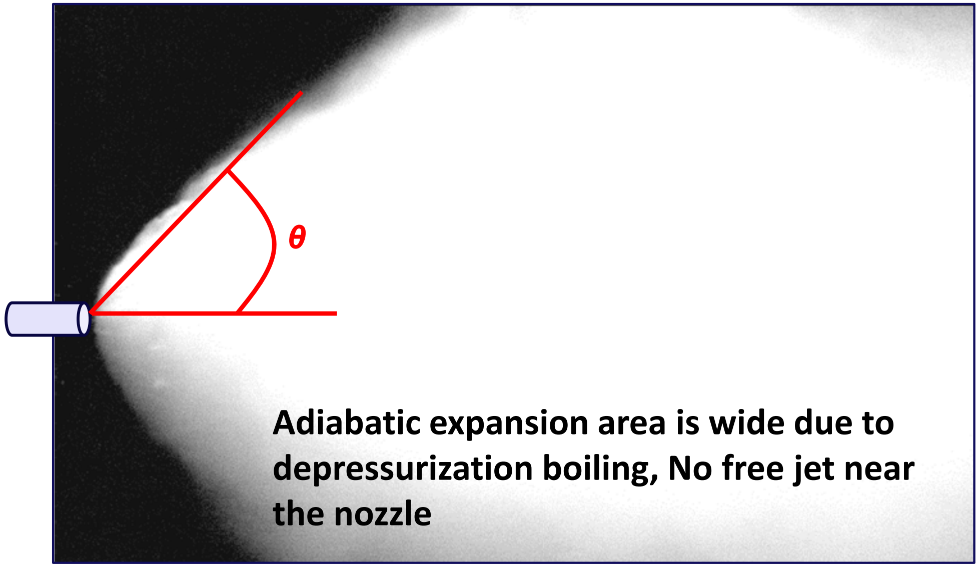
Reference: S. Watanabe, et al., Transactions of the JSME, No. 20-00109, 2020.

Measurement of dispersal behavior of high-pressure steam and flushing steam

- Visualized imaging of high-temperature, high-pressure jets
  - Steam jets have a narrow adiabatic expansion region and diffuse as a free jet near the nozzle.
  - Flushing jets* have a wider adiabatic expansion region and a wider diffusion range than steam jets. (*High-temperature water jet with phase change due to depressurization and boiling)



<u>**Steam jet spreading behavior**</u>



<u>**Flushing jet spreading behavior**</u>

Reference: T. Yuasa, et al., Transactions of the JSME, No. 22-00157, 2022.

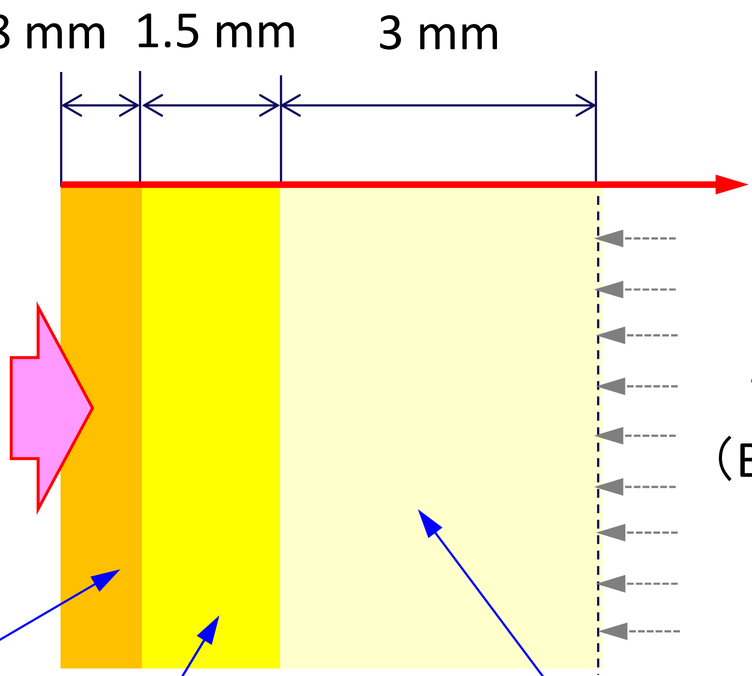
Analytical model of heat conduction in human skin

- The human body's skin consists of three layers: epidermis, dermis, and subcutaneous tissue[*1].
- Values specified in ISO13506[*2] are used for thermal conductivity and volumetric heat capacity.
- Only the skin depth direction is considered (one-dimensional model)

heat conduction equation

$$\rho c\left(\tau\frac{\partial^2 T}{\partial t^2}+\frac{\partial T}{\partial t}\right)=\kappa\frac{\partial^2 T}{\partial x^2}$$

Heat transfer coefficient $h(t)$
- Fluid temperature：50～210℃
- Room temperature：25℃



Skin depth direction x [mm]

Temperature boundary
（Body temperature：36℃）

Epidermis
- κ_1：0.616 W/m･K
- C_{v1}：4.16 MJ/m^3･K
- ρ_1：1000 kg/m^3

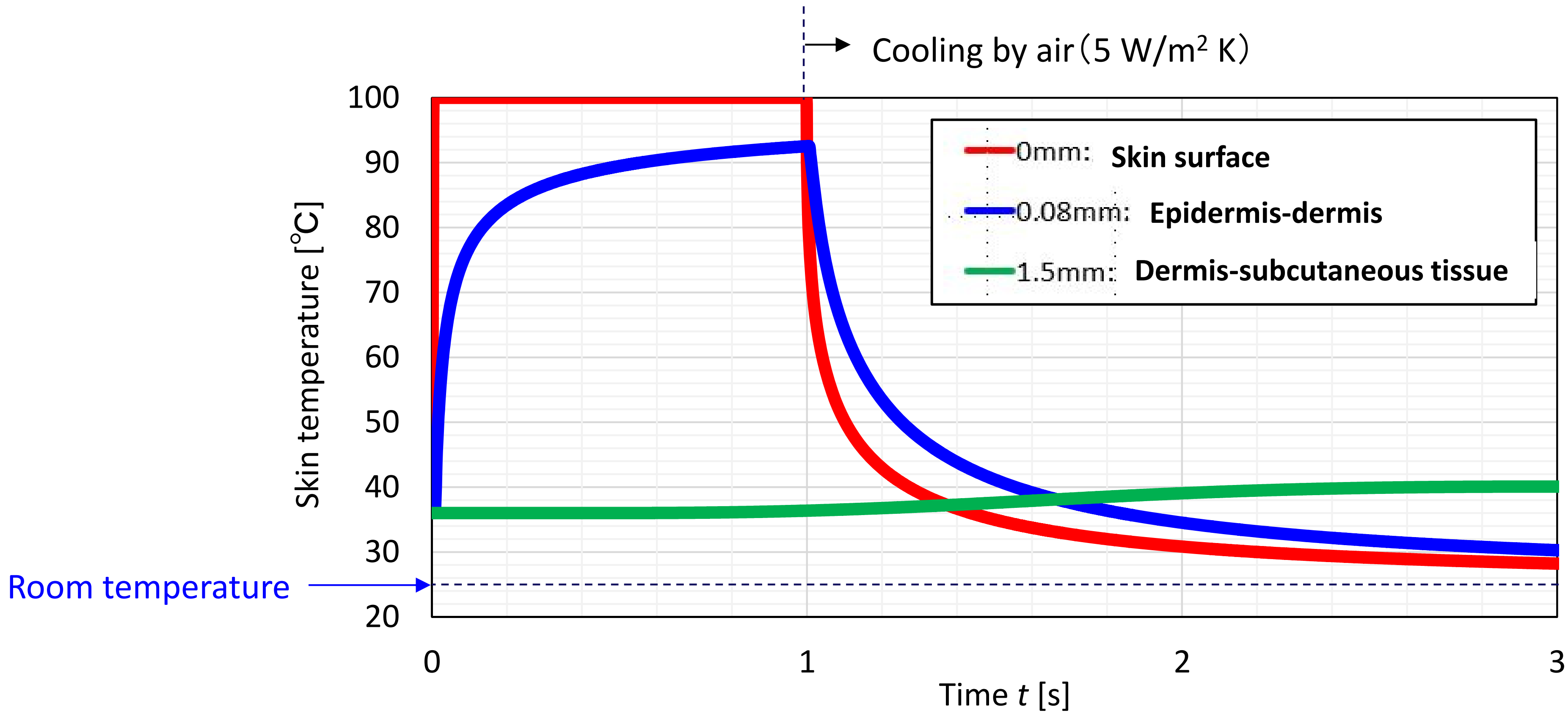
Dermis
- κ_2：0.598 W/m･K
- C_{v2}：4.02 MJ/m^3･K
- ρ_2：1000 kg/m^3

Subcutaneous fat
- κ_3：0.366 W/m･K
- C_{v3}：2.29 MJ/m^3･K
- ρ_3：1000 kg/m^3

*1：Yamada, 2018., Watanabe, 2023.　*2：ISO13506, 2017.

Results of heat conduction analysis on human skin

- Initial skin temperature: 36 ℃, fluid temperature: 100 ℃, heat transfer coefficient: 1,000 W/m2-K
- Exposure time: 1 sec (after 1 sec, cooling by 25 ℃ air)

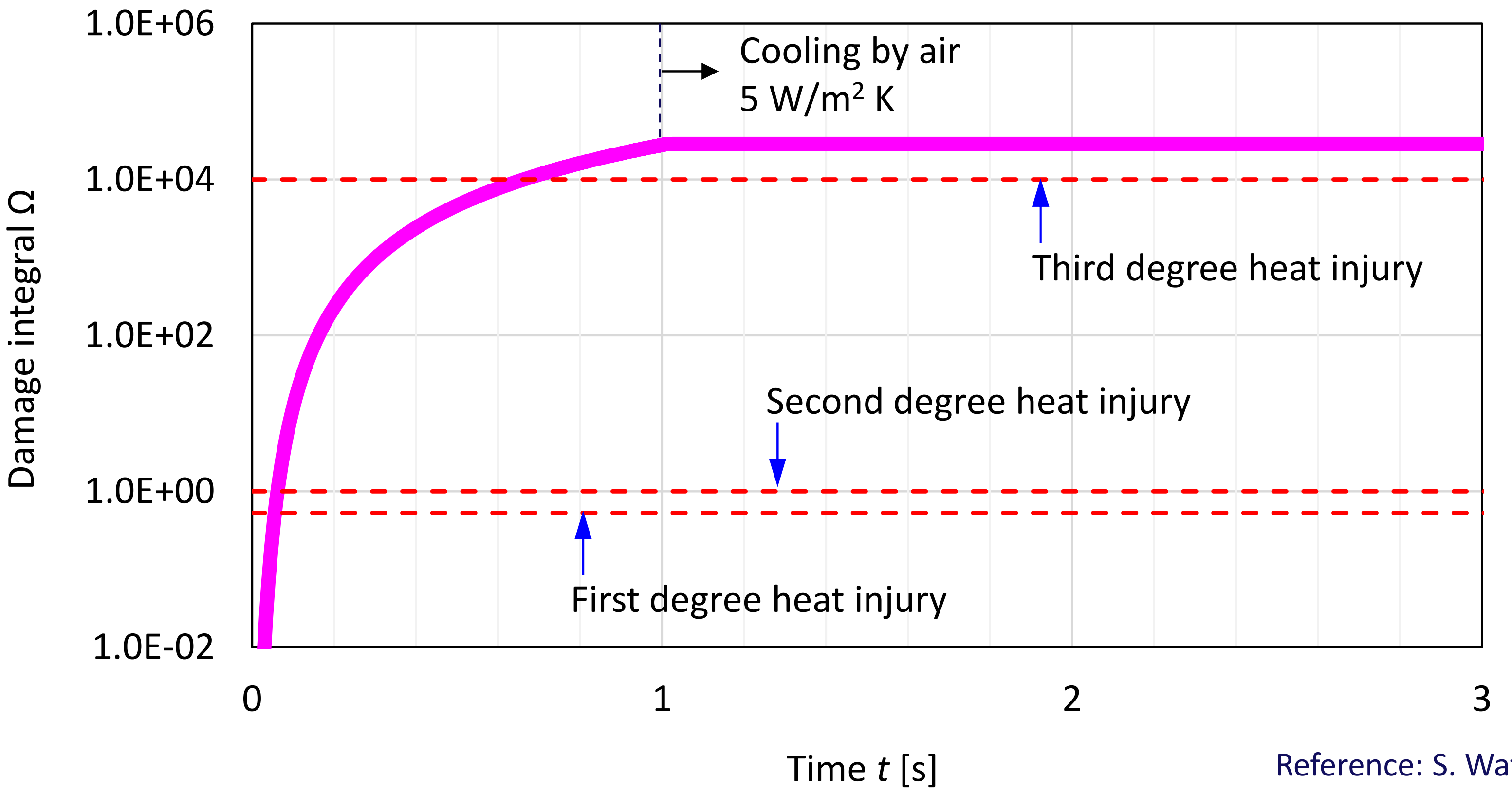


Reference: S. Watanabe, et al., 2023.

Results of burn severity evaluation

- Minor burns on the epidermis only are first-degree burns, second-degree burns reach the dermis, and third-degree burns reach the subcutaneous tissue.
- The following model equation can be used to evaluate indices related to the severity of burns.
- Ω is calculated as the integral value when T > 273.15+44 K.

$$\frac{\partial \Omega}{\partial t} = Aexp\left(-\frac{\Delta E}{RT}\right)$$



Reference: S. Watanabe, et al., 2023.

Conclusion

- In order to quantify the maintenance significance, the matrix which defined by “pipe failure probability” and “pipe failure impact” was introduced. Through the matrix, the new maintenance ranking is possible to be considered for the pipeline where the classification of safety importance is low (=BOP pipeline).
- The research project plan for the optimization of the maintenance framework of BOP in Japanese NPPs was drawn up. And the experimental facility was constructed to evaluate the fluid leakage behavior as fundamental data for “pipe failure impact”.
- By using this facility, it is able to conduct the test of the jet which leaked from various flaw geometries of the piping. And basic data related to flow leakage and diffusion from the small diameter pipe was obtained.