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Development of Inherently Safe Technologies for BWRs

Feb. 17, 2015

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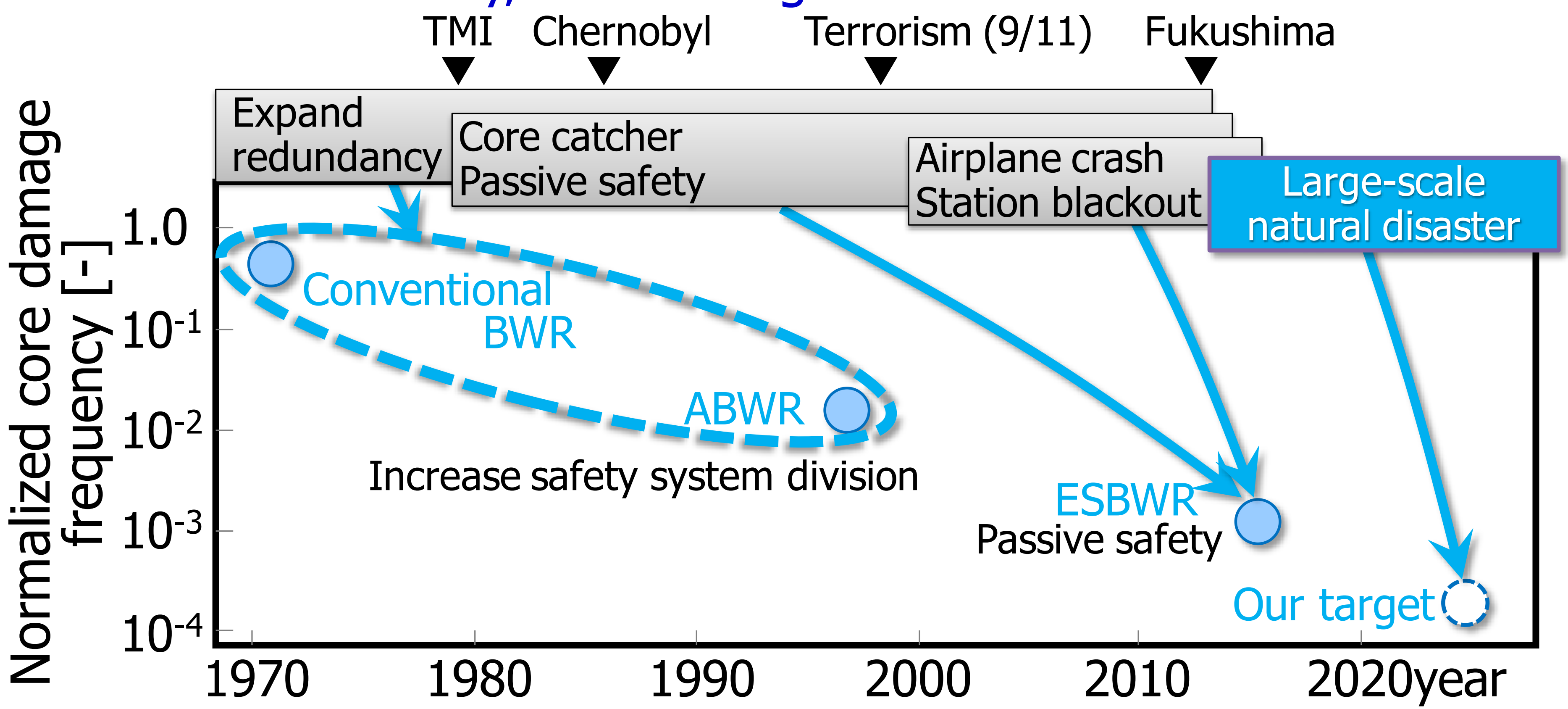
Contents

1. Background and objective

1-1 Safety improvement trends in BWRs

- Core damage frequencies have been reduced by adding or improving safety systems, considering past accidents.
- Countermeasures for large-scale natural disasters have become necessary, considering the Fukushima event.



Ref: GE Hitachi Nuclear Energy, "Safety, constructability, and operational performance of the ABWR and ESBWR designs", IAEA Technical Meeting on Technology Assessment for Embarking Countries (2013)

■ Development needs were selected considering the Fukushima event sequence.

Sequence

Tsunami & station blackout (SBO)

Cooling system stop

Core melt

Primary containment vessel failure

Hydrogen explosion

Needs

Recognition of accurate plant status

Long-term cooling system without electricity

Prevention of hydrogen explosion

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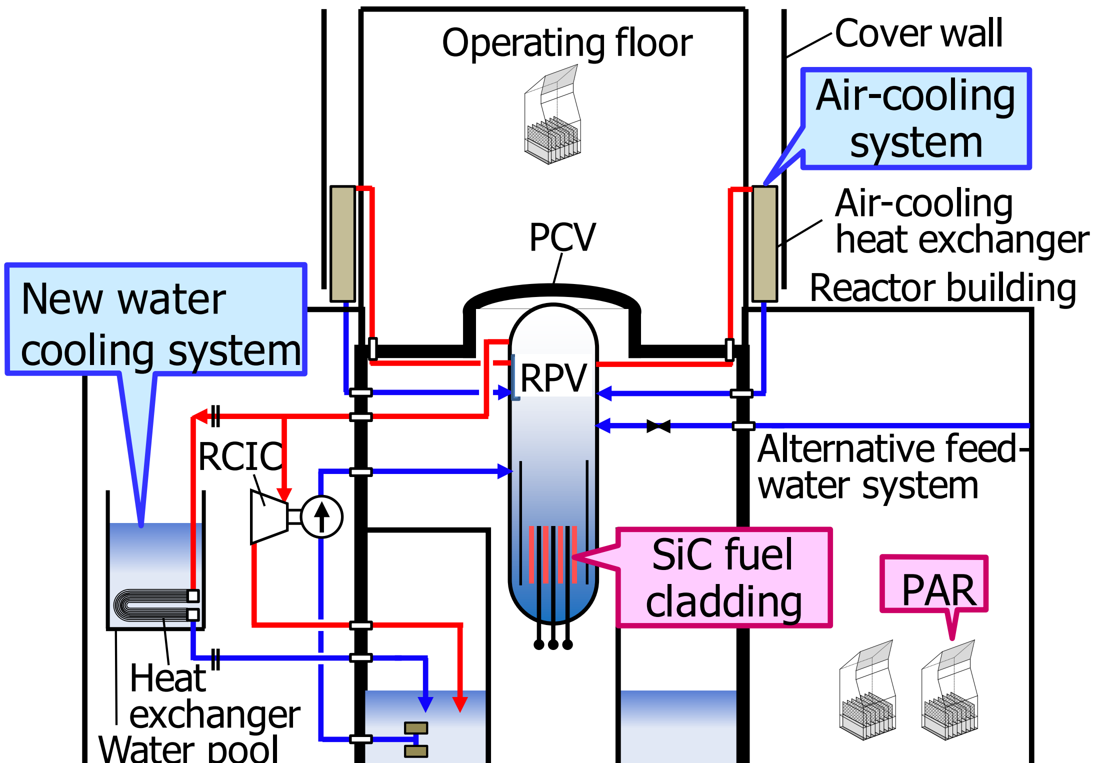
Objective:

Ensure plant safety even under a long-term station blackout or multiple failures caused by a large-scale natural disaster

- Development items regarding our innovative cooling system are mainly reported in this presentation.

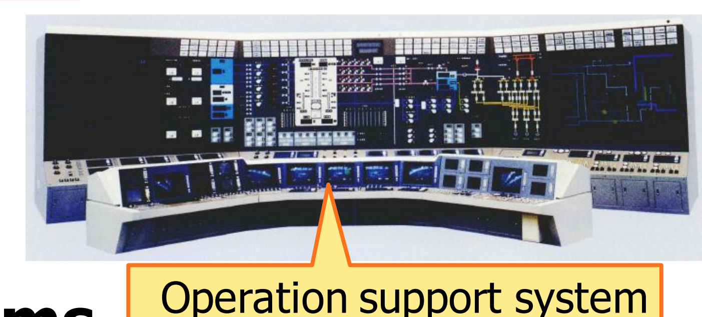


Abbreviations

IC:	Isolation Condenser
PCCS:	Passive Containment Cooling System
PAR:	Passive Autocatalytic Recombiner
PCV:	Primary Containment Vessel
RCIC:	Reactor Core Isolation Cooling
RPV:	Reactor Pressure Vessel

Innovative cooling system

Hydrogen explosion prevention system



Development items

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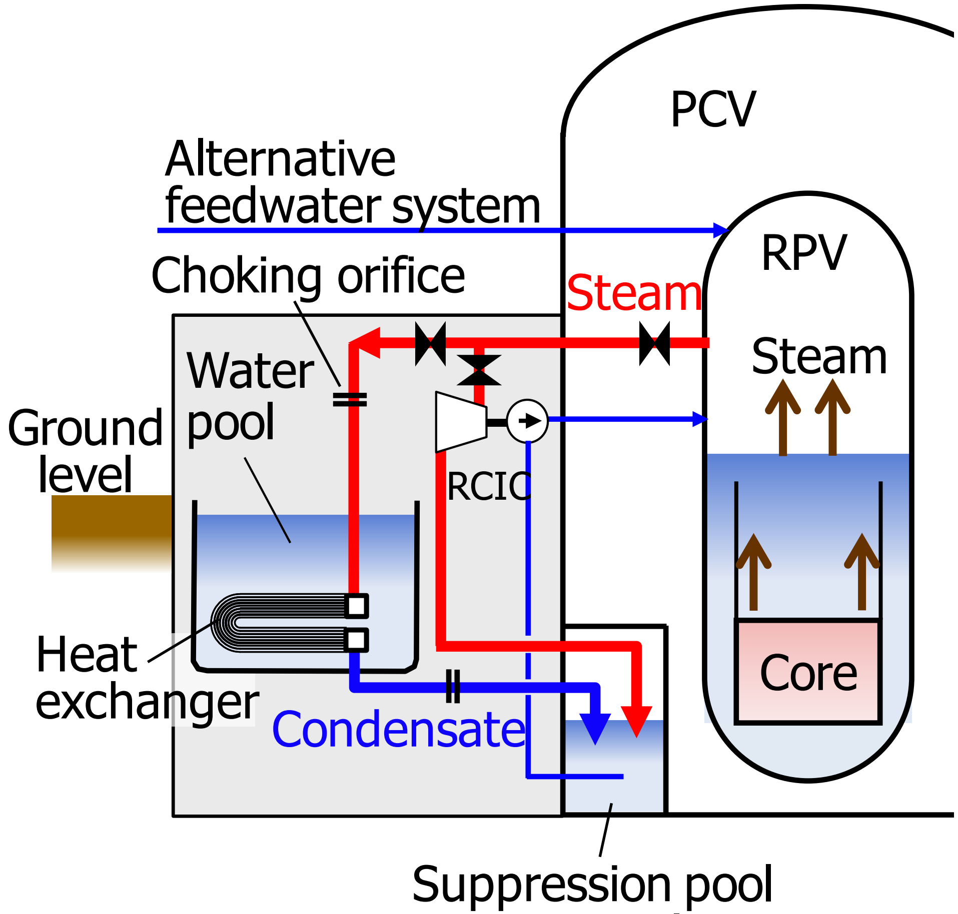
- Conventional passive water-cooling systems need a large water pool at a high elevation above the RPV.
- The system is devised to improve the seismic design of the water-cooling system.

Features of the new system

- The water pool can be located below the ground level.
- Steam generated in the RPV flows by the pressure difference between the RPV and the suppression pool.
- Water is supplied to the RPV using turbine driven system (RCIC) or an alternative feedwater system

JP Patent No. P05566963
EPO Patent No. 2549484

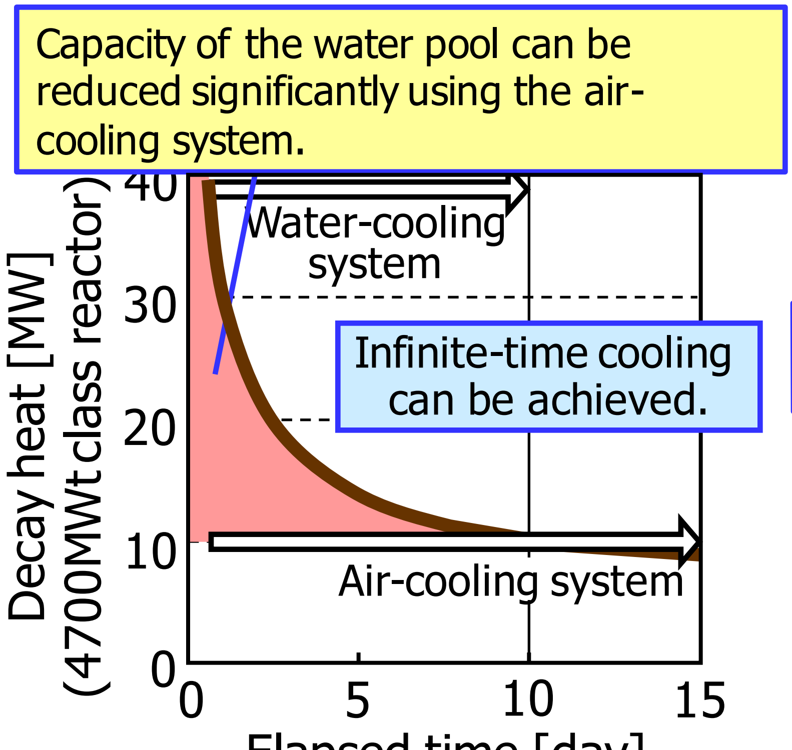


New passive water-cooling system

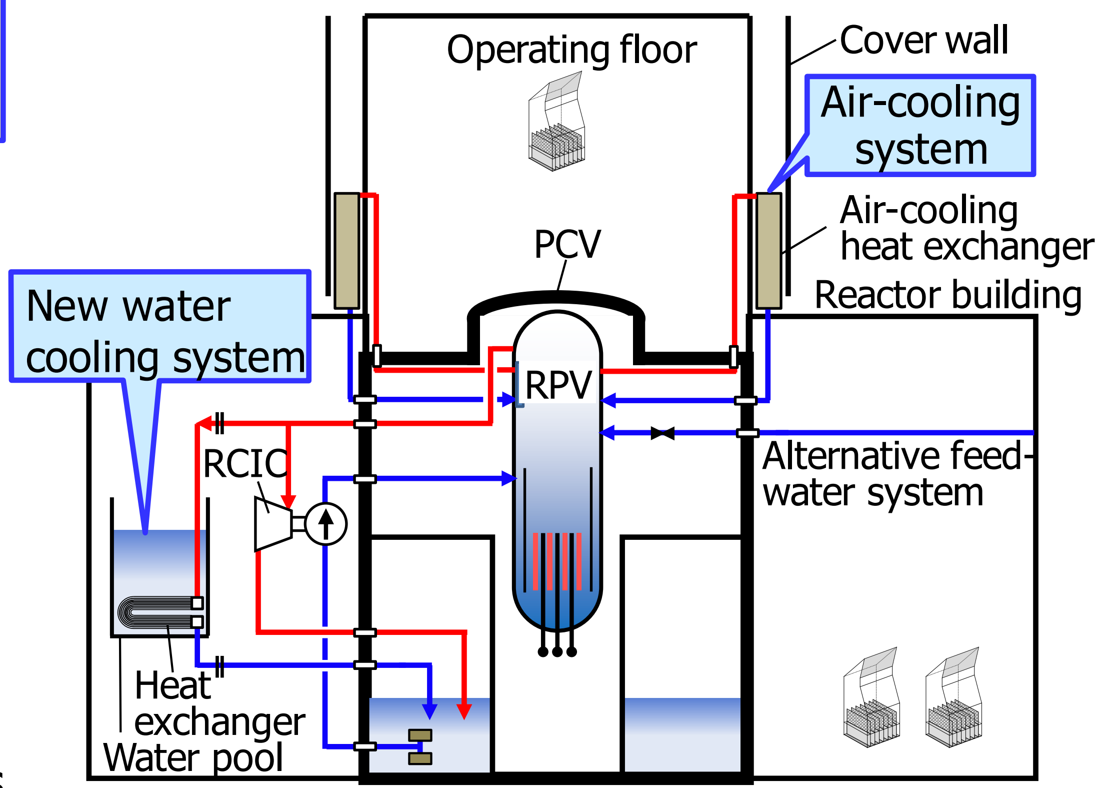
2. Overview of the development items

2-1 Innovative cooling system

- The decay heat for an initial 10 days is removed by both the water- and the air-cooling systems; then it is removed by only the air-cooling system.
- We have been developing both the water- and the air-cooling systems to realize the innovative cooling system.

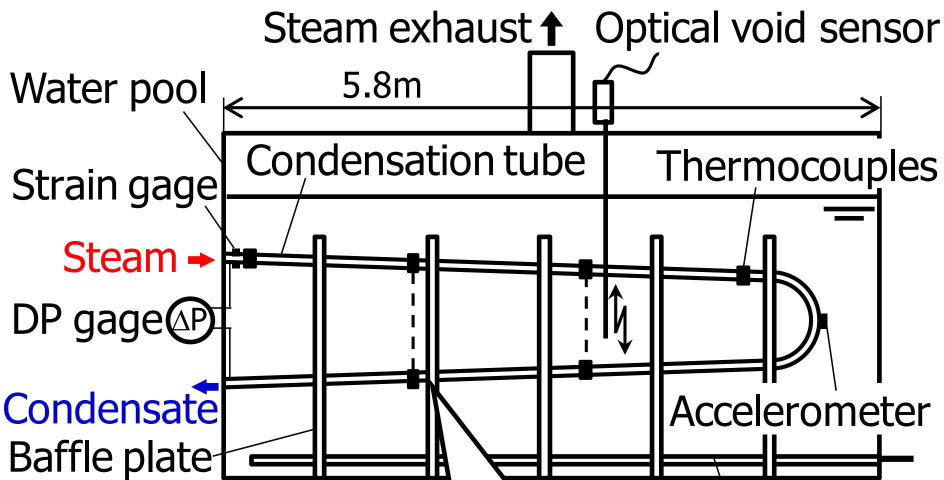


Activation period of both systems

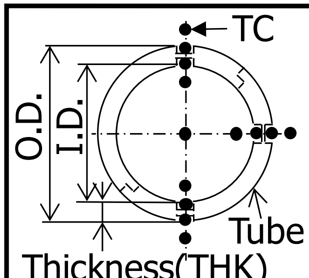


2-2 Heat transfer tests for water-cooling systems

- Heat transfer data were obtained to design the water-cooling systems, such as IC, PCCS and our new system, using a full-scale single-tube test section.
- Multiple-tube tests are also being conducted now.

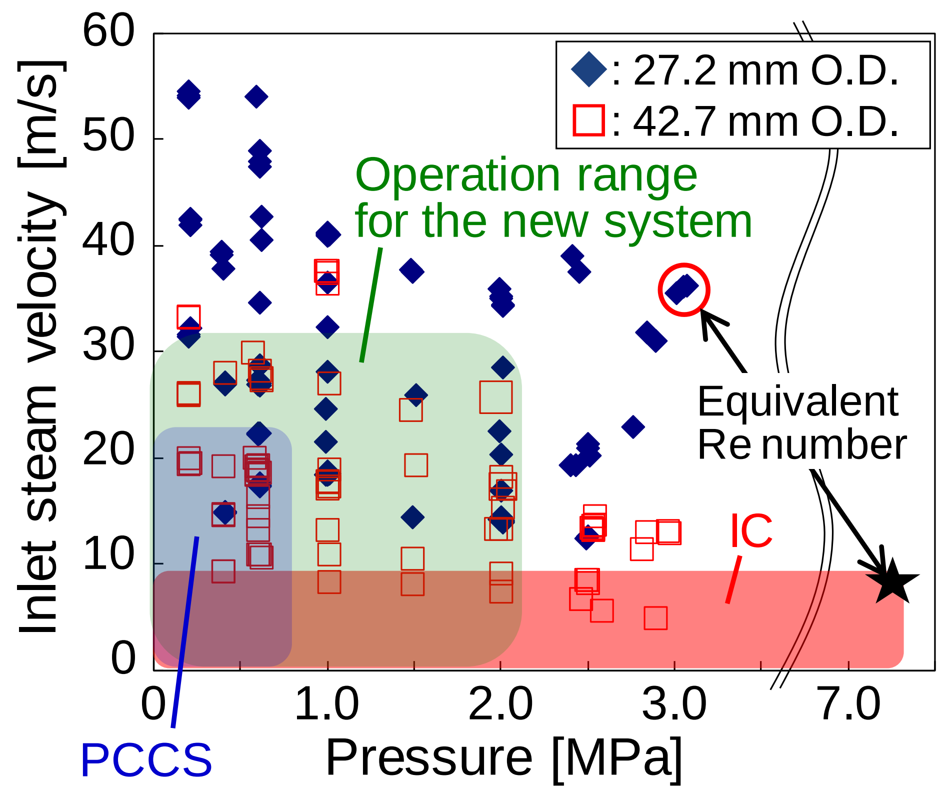


Test section



Tube type	S	M	L
I.D.(mm)	22.2	28.4	35.5
O.D.(mm)	27.2	34.0	42.7
THK(mm)	2.5	2.8	3.6

Detailed TC locations & tube size



Test condition map

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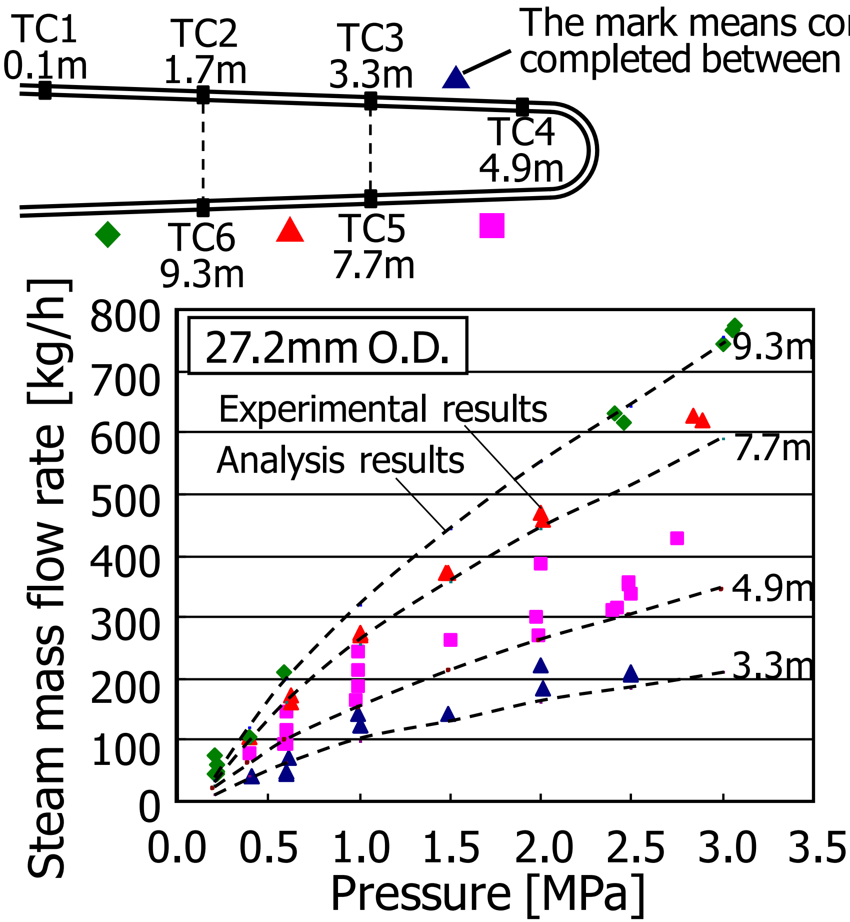
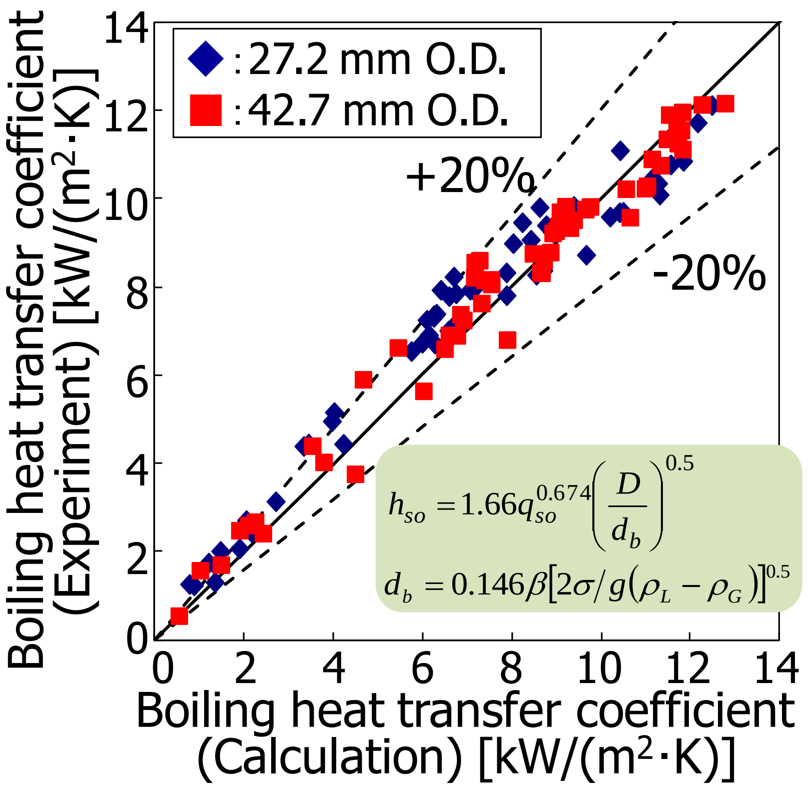
- The completed condensation length map has been made based on test results[1].
- Modified heat transfer correlations have been developed[2].

[1] N. Ishida et al., ICONE22-31007 (2014)
[2] H. Hosoi et al., NUTHOS10-1191 (2014)



Completed condensation length map[1]



$$h_{so} = 1.66 q_{so}^{0.674} \left(\frac{D}{d_b} \right)^{0.5}$$

$$d_b = 0.146 \beta \left[2\sigma / g(\rho_L - \rho_G) \right]^{0.5}$$

Developed heat transfer correlation[2]

2-4 Development items for air-cooling system

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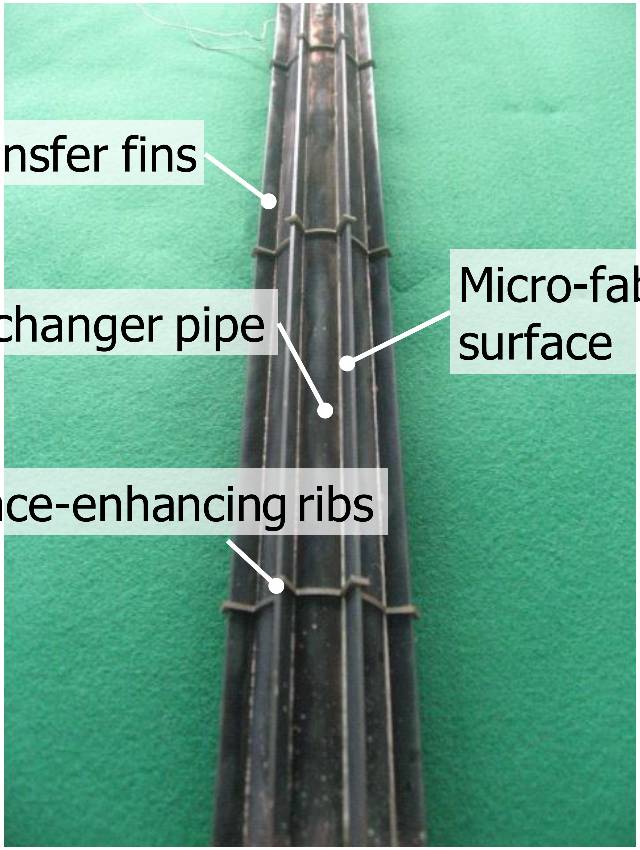
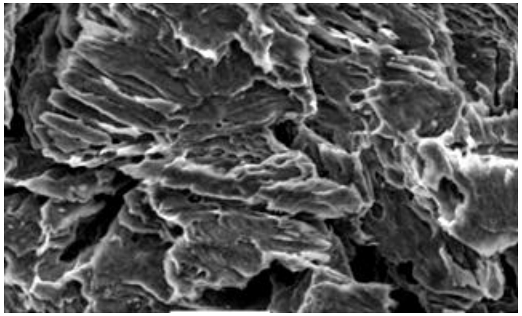
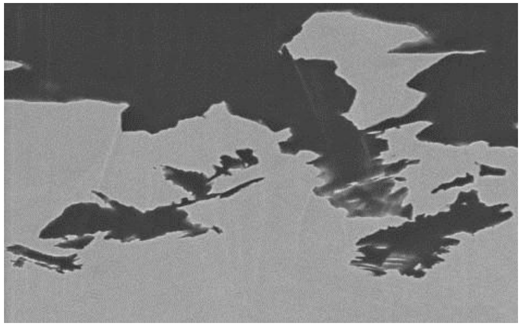
- Air-cooling enhancement technologies are key to realize the air cooling system.
- Better heat exchanger pipe has been developed.





Top view



Cross-sectional view

SEM images of micro-fabrication surface

Developed air-cooling heat exchanger pipe

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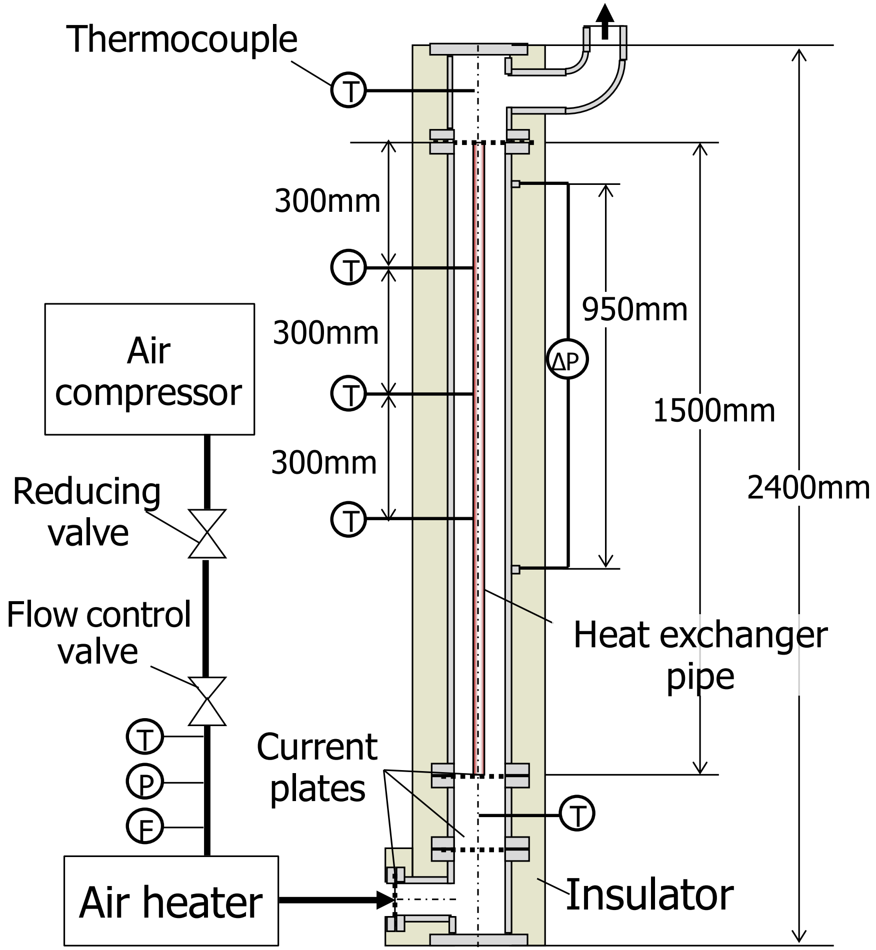
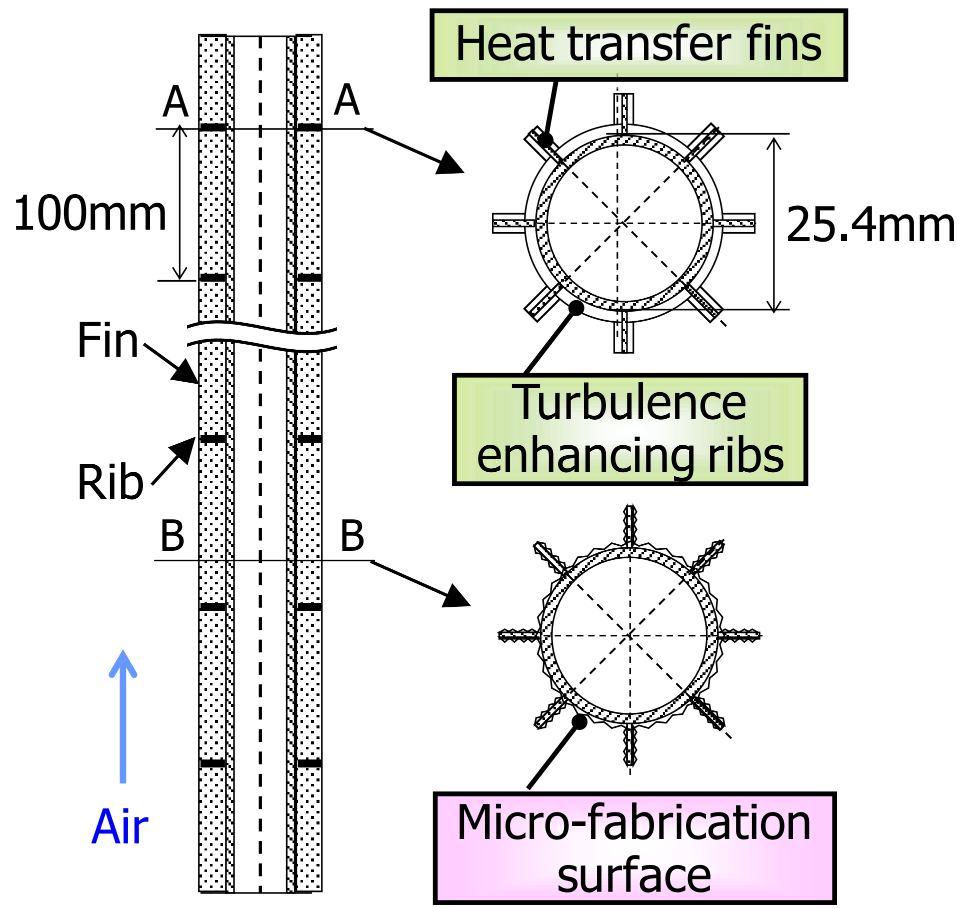
- Heat transfer tests were conducted to confirm heat transfer and pressure loss characteristics of the developed technologies.



Test apparatus



Air-cooling heat exchanger pipe

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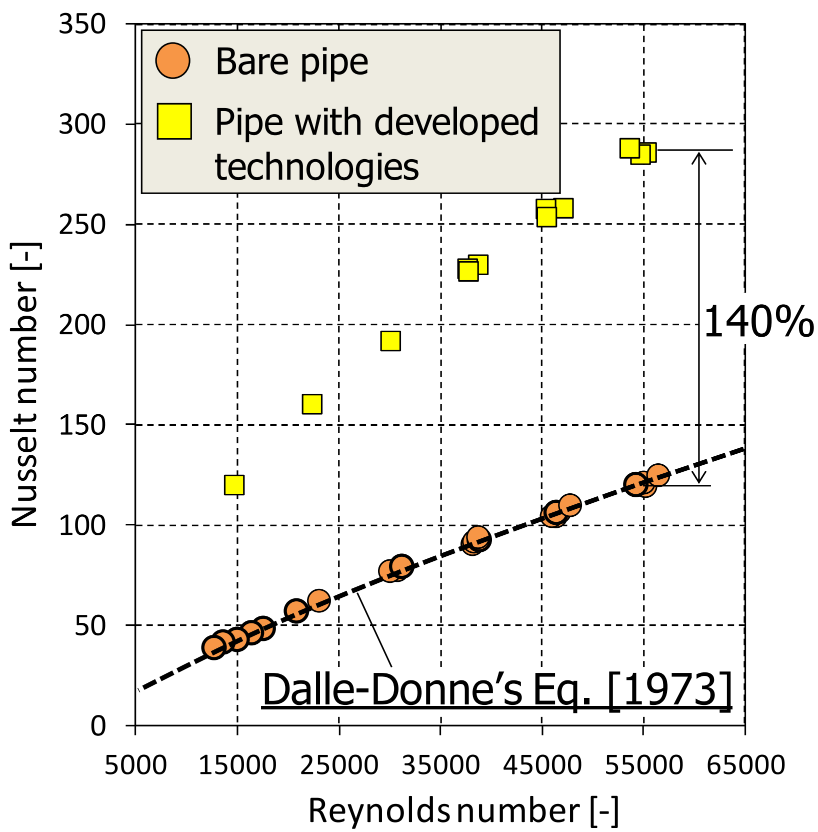
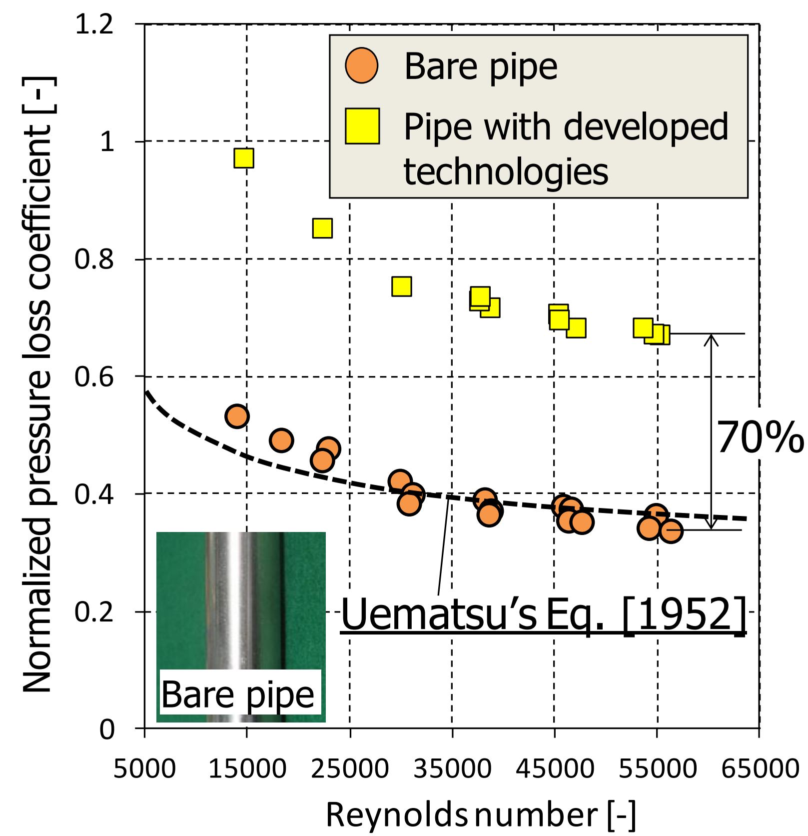
- Nu was increased 140% using the technologies[3].
- Pressure loss also increased 70% due to the fins and the ribs.

[3] N. Ishida et al., "The concept of passive cooling systems for inherently safe BWRs", ICMST-Kobe (2014)



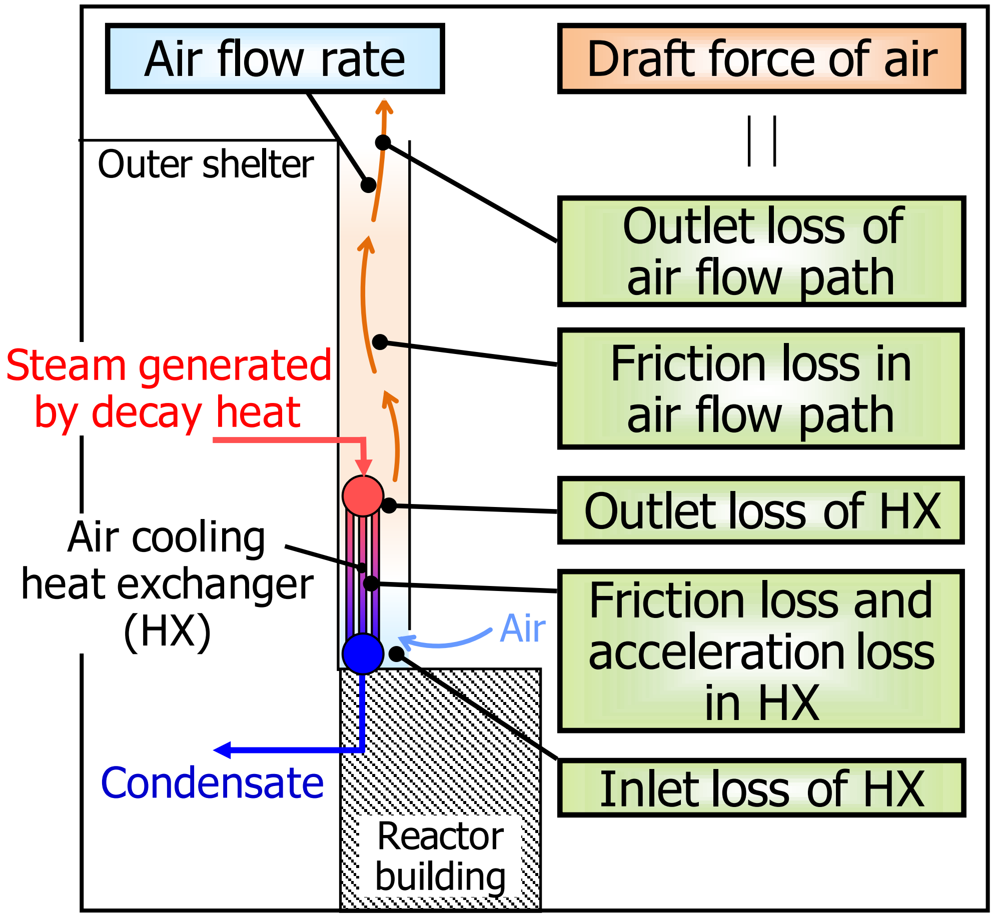
Nusselt number



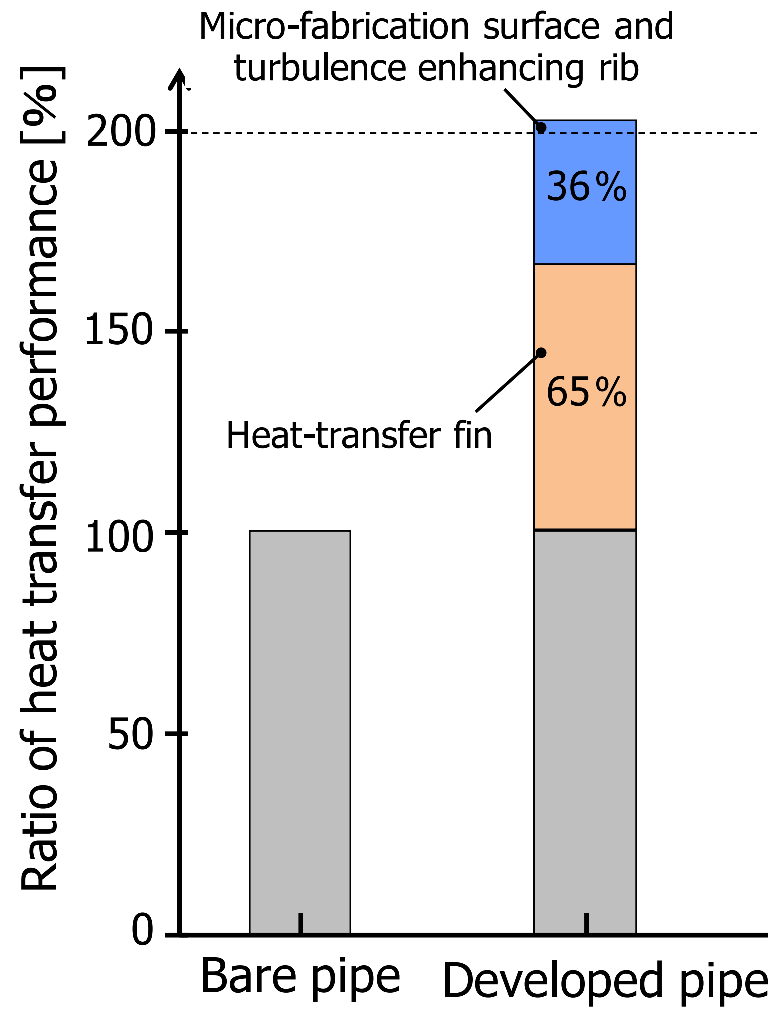
Pressure loss coefficient

2-7 Air-cooling performance in a plant

- The air-cooling performance was estimated using 1D analysis.
- Heat transfer performance increased 100%[3].



Considered factors in 1D analysis

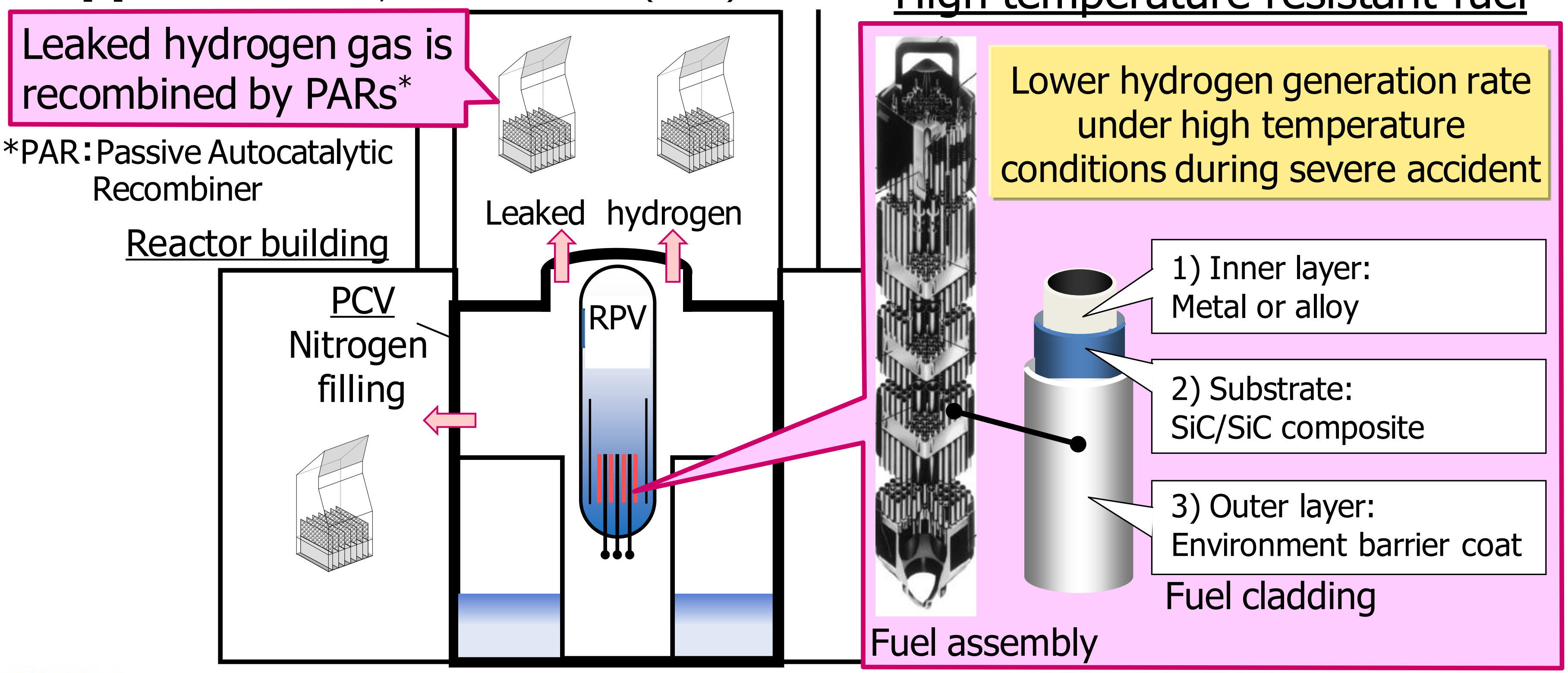


2-8 Hydrogen explosion prevention system

- Hydrogen explosion prevention system consists of using high temperature resistant (SiC) fuel cladding and PARs*.
- High temperature oxidation tests for SiC were conducted, and estimated H_2 generation using SiC fuel in a plant decreased to one-fifth or less than that using conventional zircaloy fuel[4].

[4] R. Ishibashi et al., ICONE22-31139 (2014)

High temperature resistant fuel



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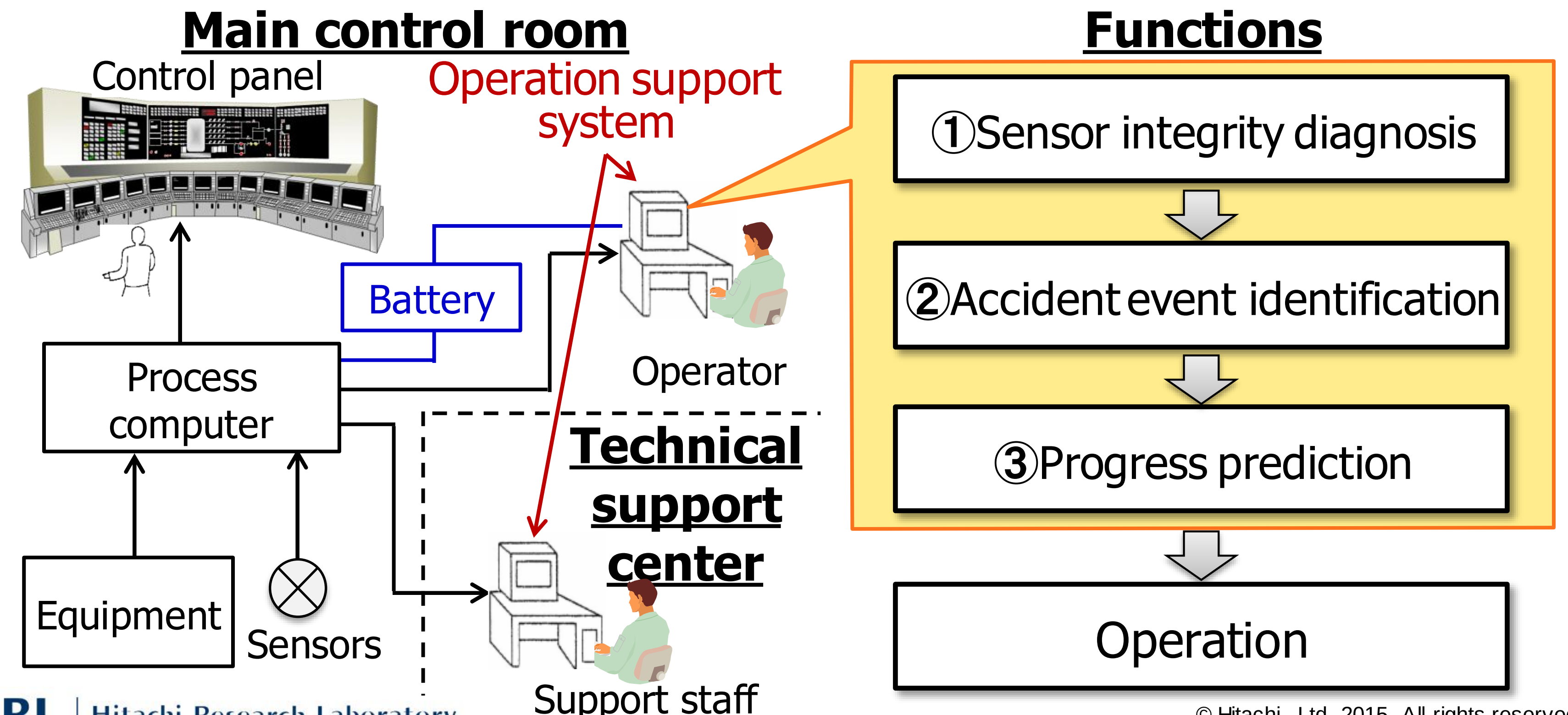
- The system covers multiple equipment failures, and it has three functions to reduce the occurrence of operators' false recognitions and human errors.
- An accident event identification method and a plant simulation code to predict event progress were developed[5].

[5] M. Kanada et al., ICONE22-31104 (2014)



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3. Conclusions

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3-1 Conclusions

- We have been developing the following inherently safe technologies for BWRs to improve plant safety during large-scale natural disasters.

  (1) Innovative cooling system
  (2) Hydrogen explosion prevention system
  (3) Operation support system

- The development items and results for the innovative cooling system were summarized in this presentation.

  - Heat transfer tests for both the water- and the air-cooling systems were conducted.
  - Heat transfer data to design the water-cooling systems were obtained over a wide range of thermal hydraulics conditions.
  - The air-cooling enhancement technologies have been developed to realize the air-cooling system.

THE END

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