# Study on Pb-Bi Natural Circulation Phenomena

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by

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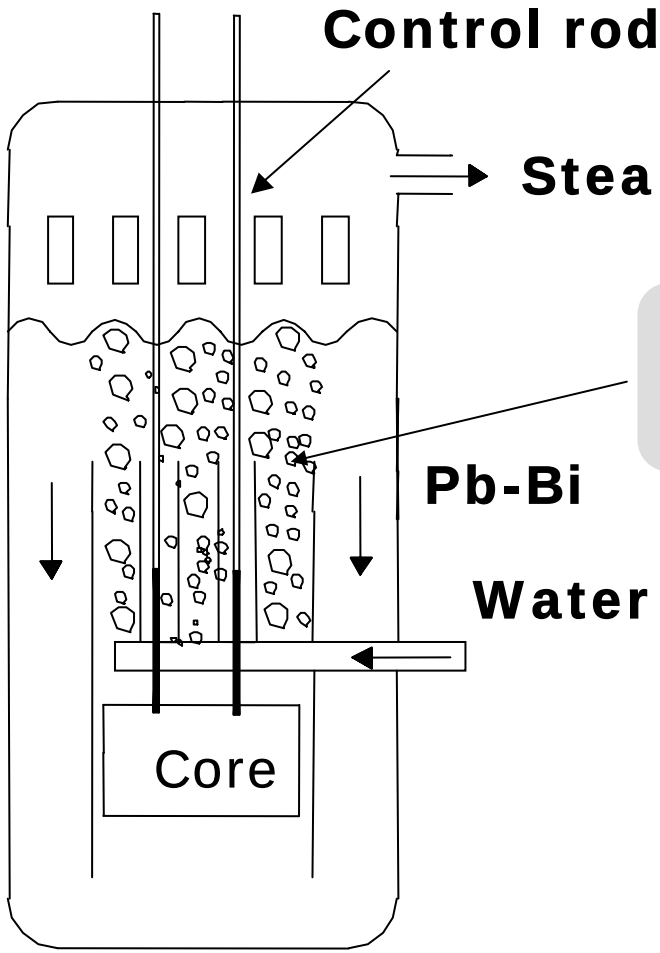
## *Contents*

1. Concept of direct contact type PFR: PBWFR
2. Experimental apparatus: Pb-Bi –water direct contact boiling two-phase flow loop
3. Experimental result of Pb-Bi natural circulation flow
4. Analysis of natural circulation
5. Conclusion

# Direct Contact Type PFR: PBWFR




**Natural Circulation**
**Direct Contact Boiling**

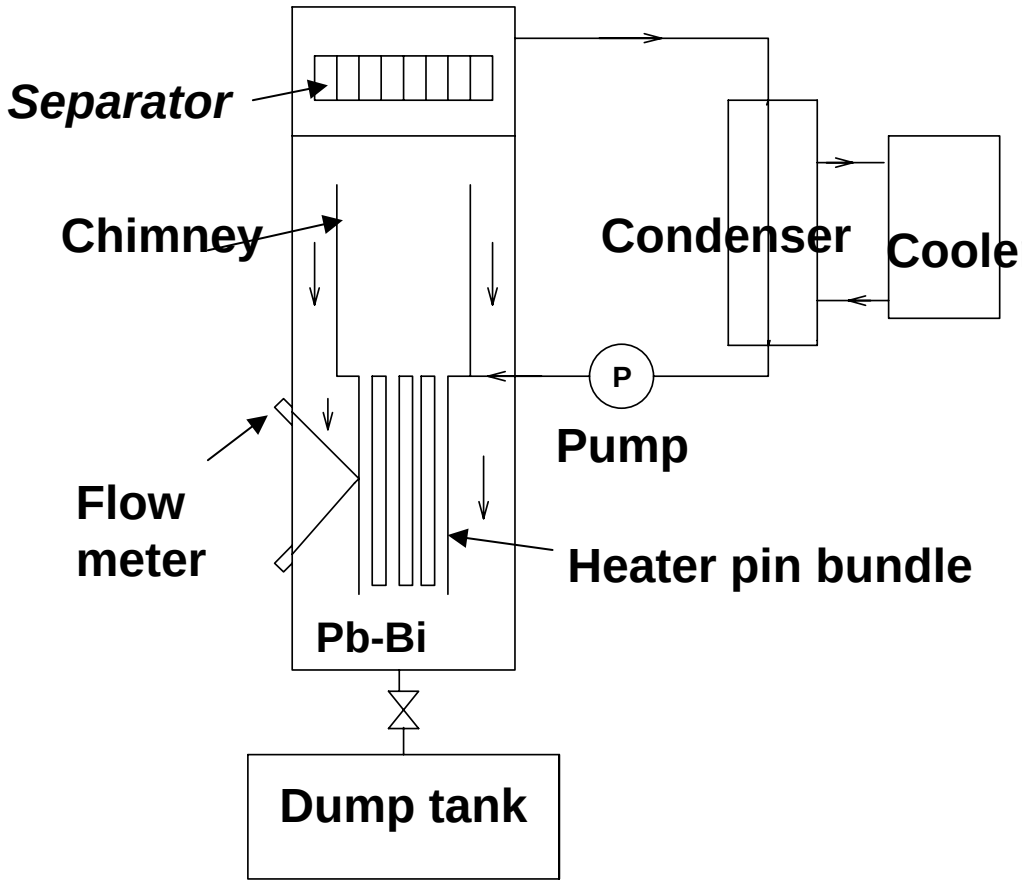
**Objective is to clarify the characteristics of Pb-Bi natural circulation**

*Pb-Bi Cooled Direct Contact Boiling Water FR (PBWFR)*

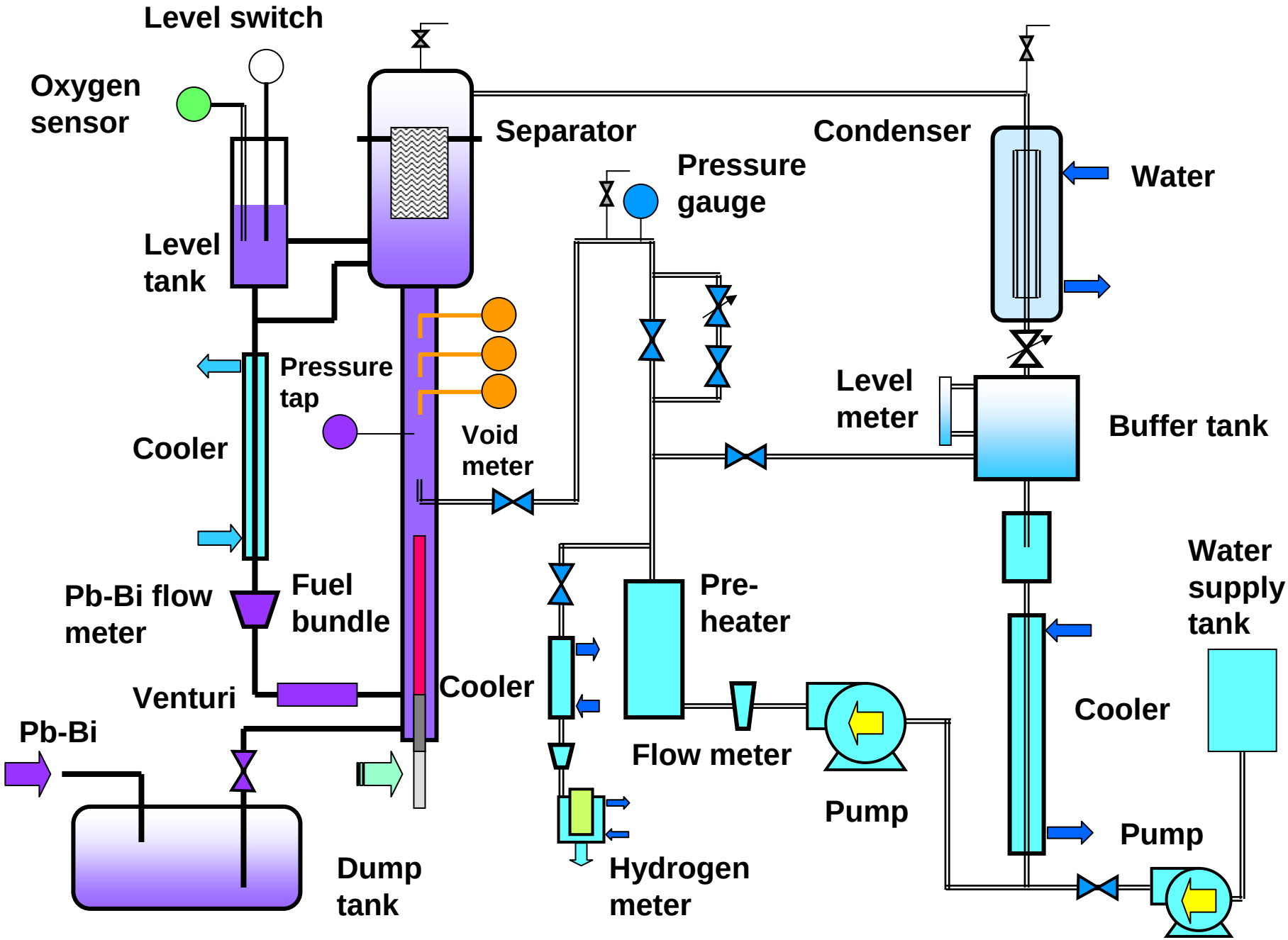
# *Experimental Apparatus for Pb-Bi and Water-Steam Flows*

**System characteristics of Pb-Bi single-phase natural circulation flow**

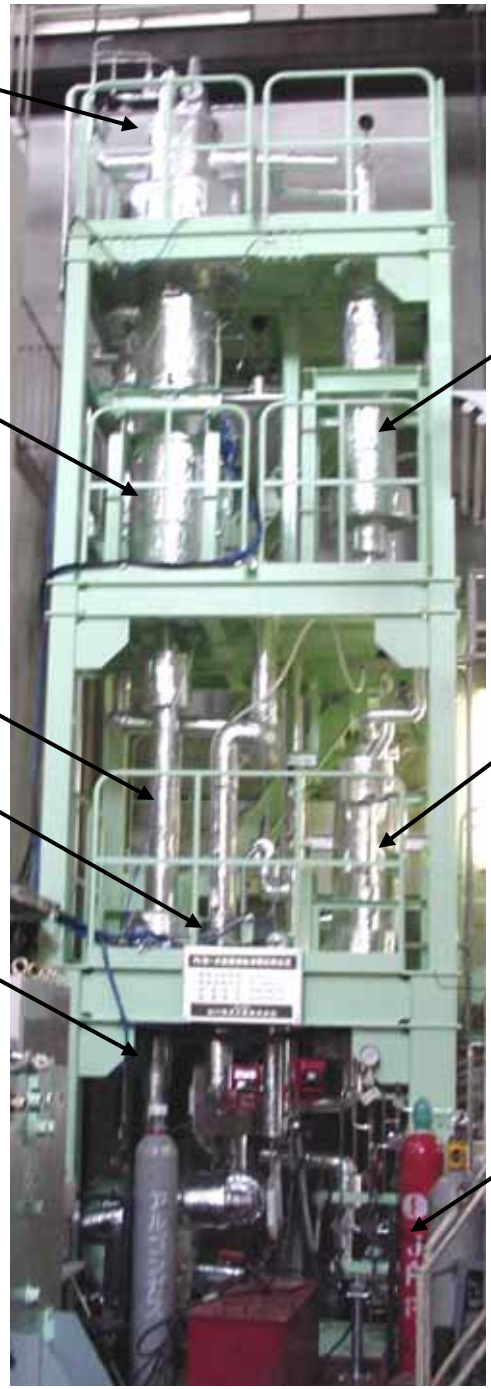
**Heater pin bundle, Chimney and Separator**



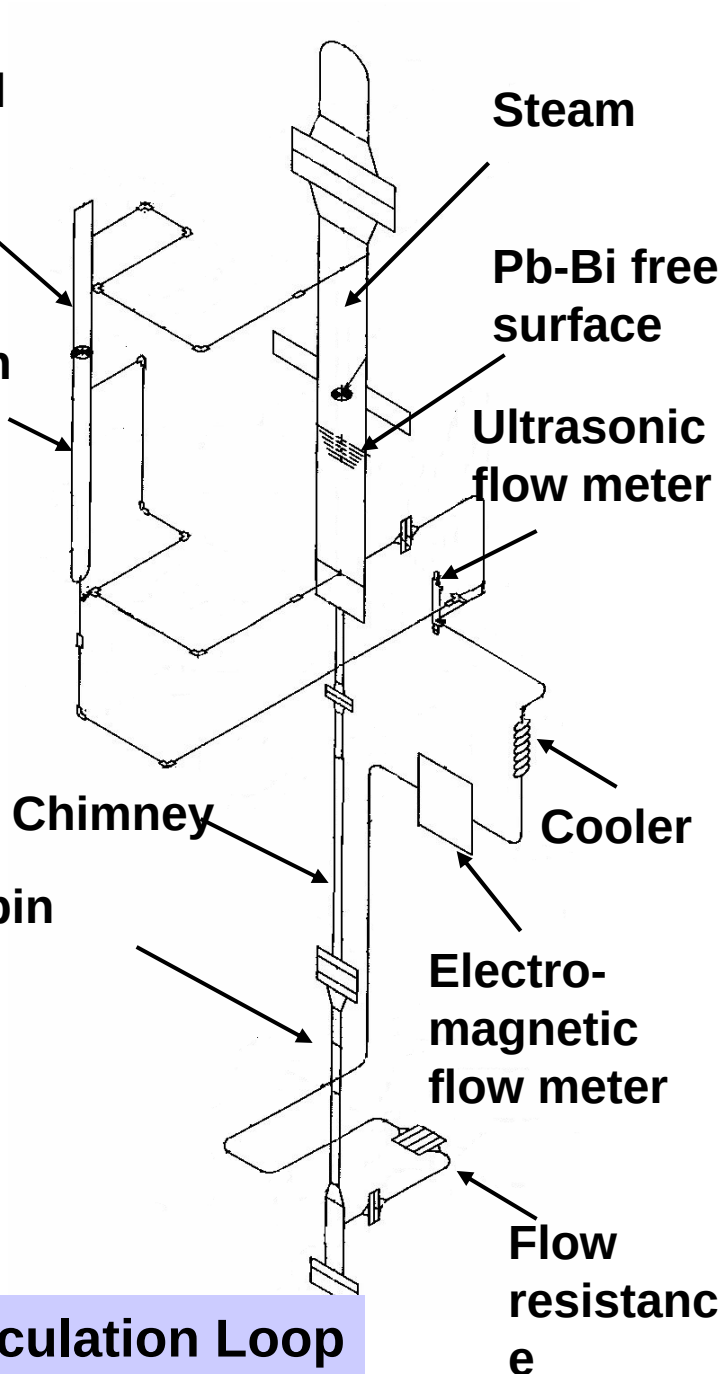

**Pb-Bi and Water-Steam Flow loops**



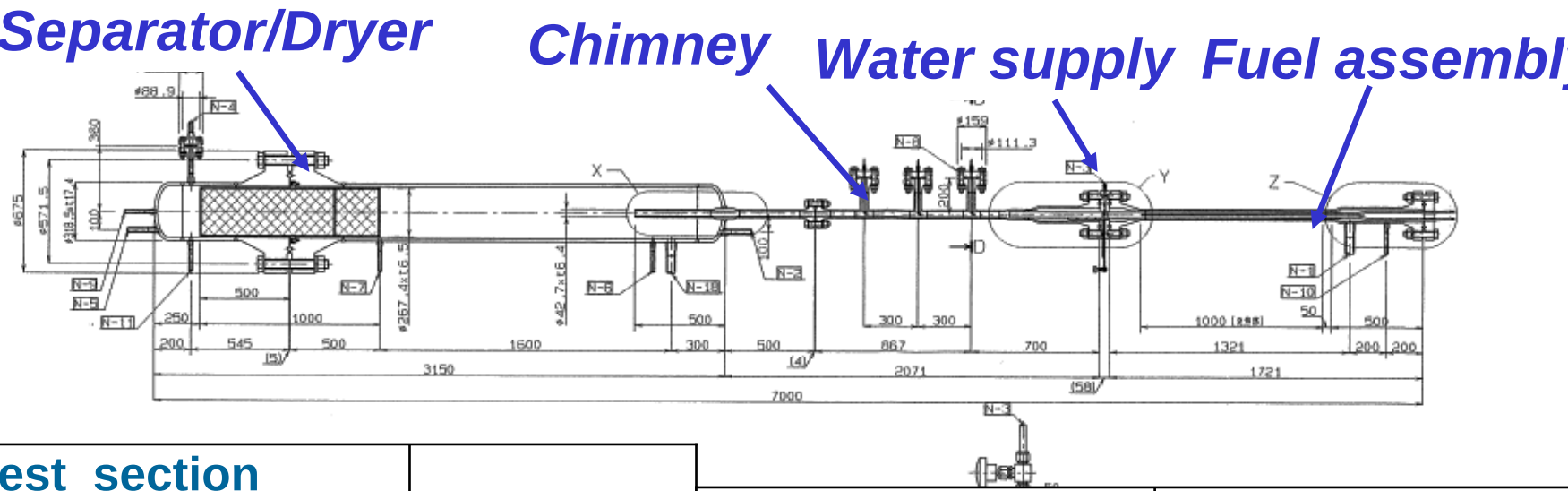

# Direct Contact Boiling Test Loop




Experimental apparatus



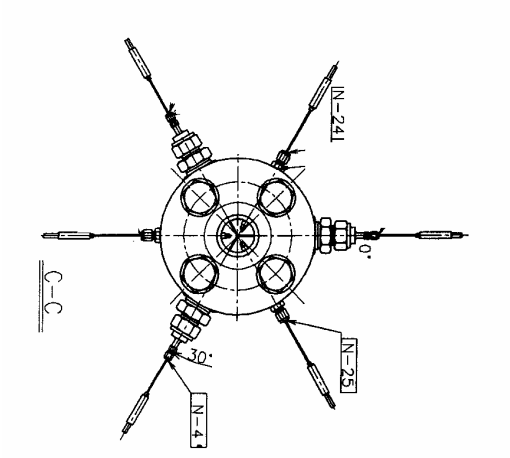

Pb-Bi Circulation Loop



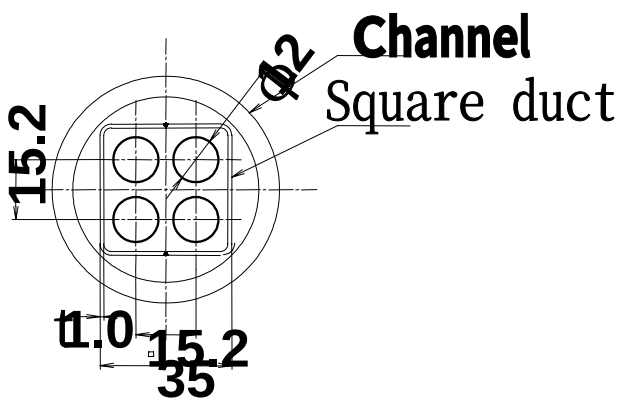

| | |
|---|---|
| **Test section** | |
| Length | 7m |
| Heater power | 133kW |
| **Pb-Bi** | |
| Inventory | 1000 kg |
| Outlet temp. | 460℃ |
| Inlet temp. | 310℃ |
| **Water loop** | |
| Inventory | 50 kg |
| Supply temp. | 220℃ |
| Steam temp. | 296℃ |
| Pressure | 7MPa |
| **Cooling power** | 133kW |

| | |
|---|---|
| **Subassembly** | |
| Length | 1.72m |
| Fuel pin | 4 / 1.65m |
| **Fuel pin** | |
| Outer dia./ Pitch | 12mm/15.9mm |
| Heater length | 1000mm |
| Power | 33.3kW x 4 |
| Cladding material | STPA24 |

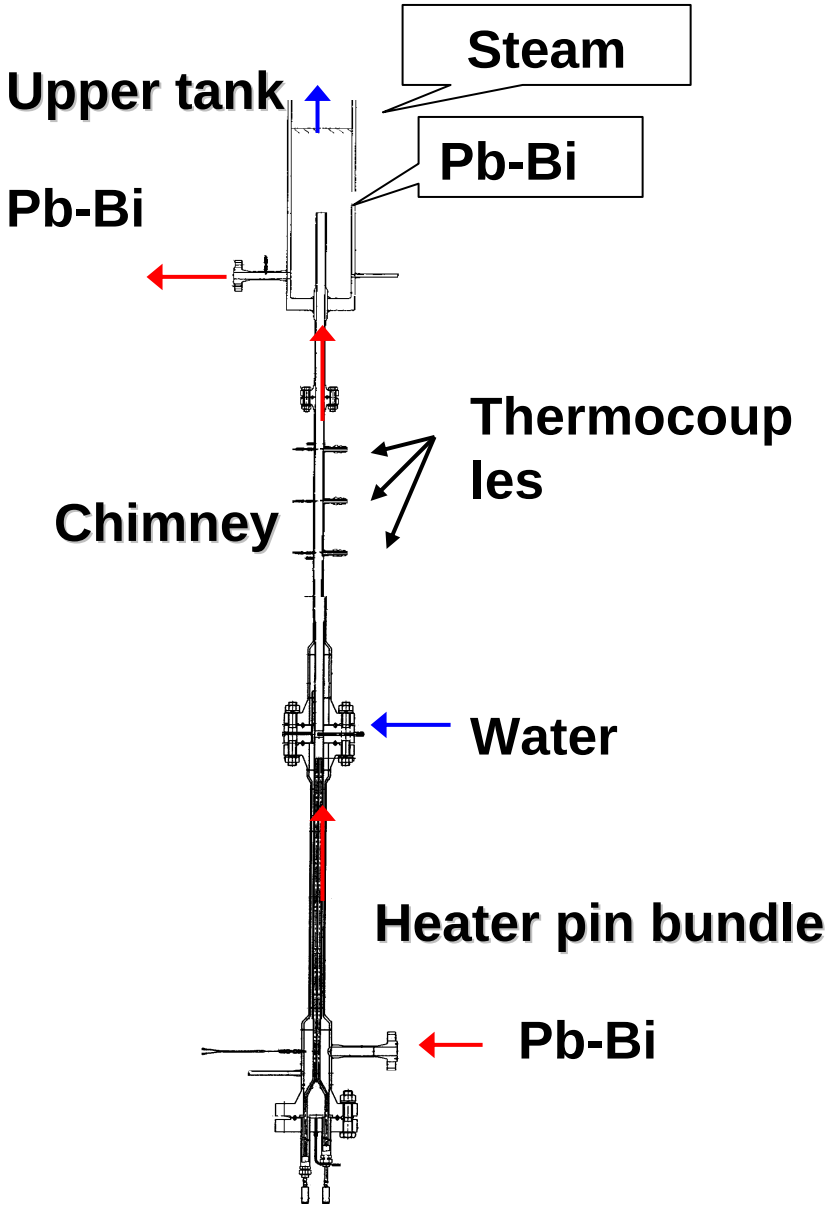
# Test section




Water supply-Pressure measurement




Heater pin bundle



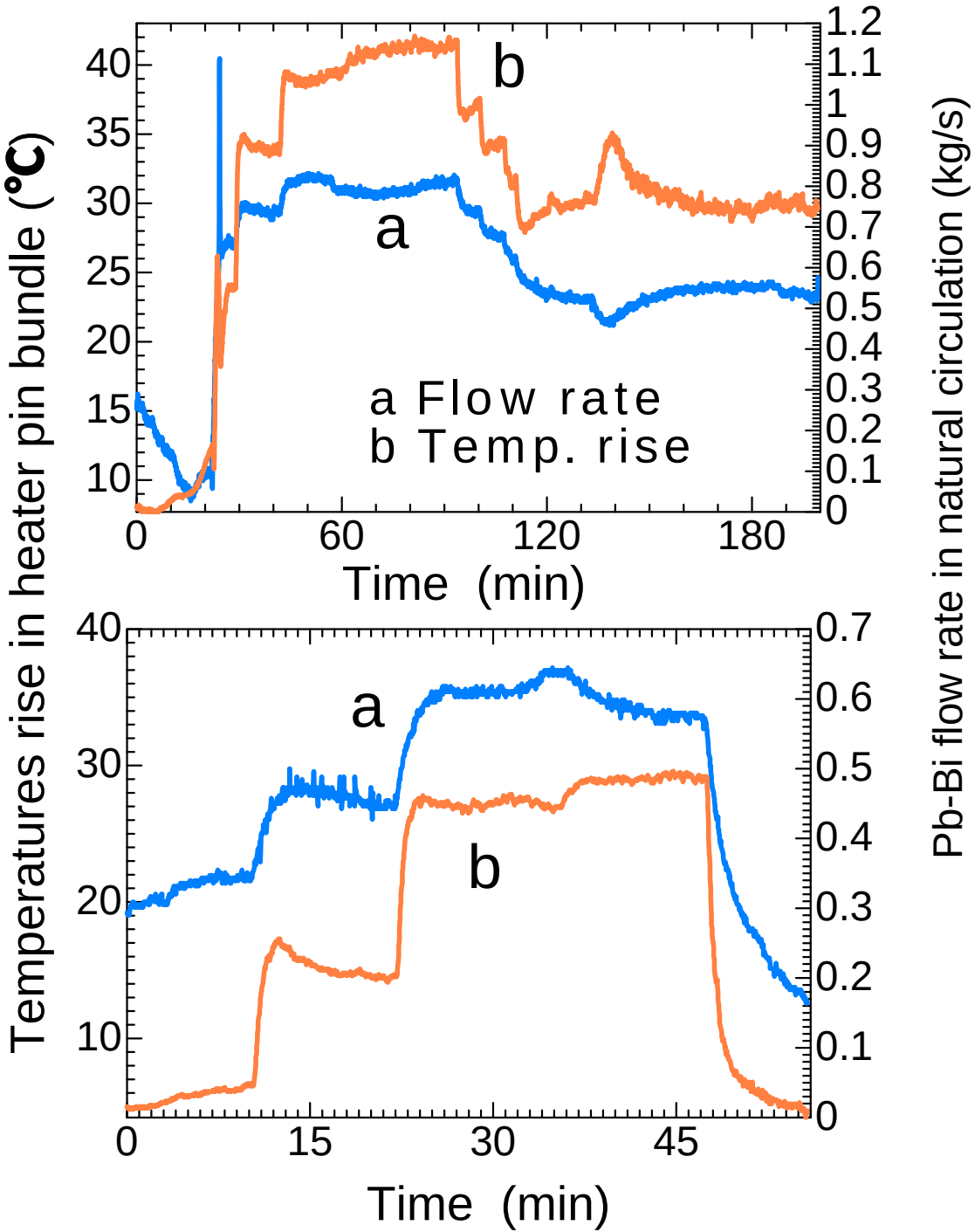
## *Controlled parameter in operation*

| Heater pin bundle | Experiment | Rated condition |
|---|---|---|
| Power (kW) | 0.038-7.7 | 133 |
| Outlet Pb-Bi temp. (℃) | 251-308 | 460 |
| Inlet Pb-Bi temp. (℃) | 243-278 | 310 |

## *Result in operation*

| | Result | Rated condition |
|---|---|---|
| Pb-Bi flow rate (L/min) | 1.5-4.8 | 36.5 |
| Temperature in chimney (℃) | 250-303 | - |

# Pb-Bi Single-phase Natural Circulation



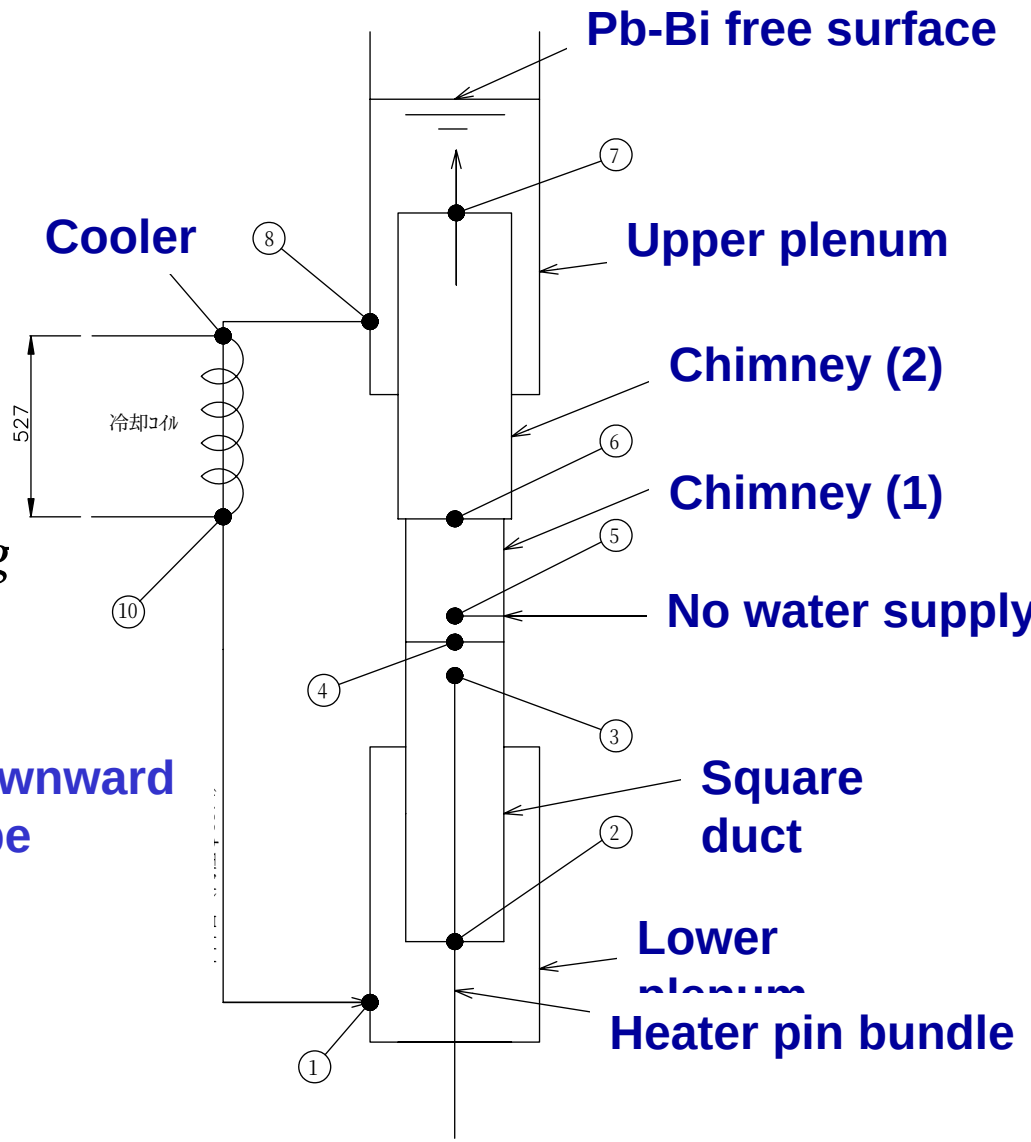
# Evaluation of flow rate in natural circulation

**Driving force of natural circulation**

$$\Delta P = \rho_{dc} h_1 g - (\rho_{dc} h_2 + \rho_3 h_3 + \rho_4 h_4 + \rho_c h_5) g$$

**Frictional pressure loss in chimney**

$$\Delta P_{L0} = \left( \varsigma + \lambda \frac{L}{D} \right) \frac{\rho}{2} \cdot V^2$$




Flow model

## Frictional loss in bare bundle

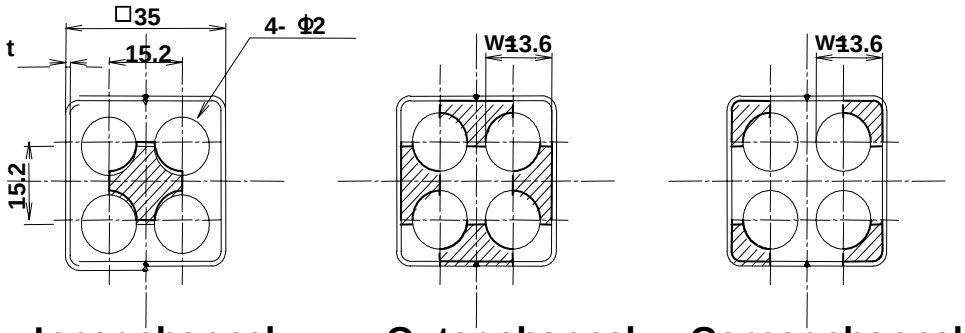
$$\Delta P_b = \frac{\rho}{2} f \frac{L}{De} V_b^2$$

**Laminar and turbulent**

$$f_L = \frac{C_L}{Re} \qquad f_T = \frac{C_T}{Re^{0.18}}$$

$$C_L, C_T = a + b_1\left(\frac{P}{D} - 1\right) + b_2\left(\frac{P}{D} - 1\right)^2$$

$$C_{fb} = De_b \left[ \sum_{i=1}^{3} S_i \left( \frac{De_i}{De_b} \right)^{\frac{m}{2-m}} \left( \frac{C'_{fi}}{De_i} \right)^{\frac{1}{m-2}} \right]^{m-2}$$




**Heater Pin Bundle**

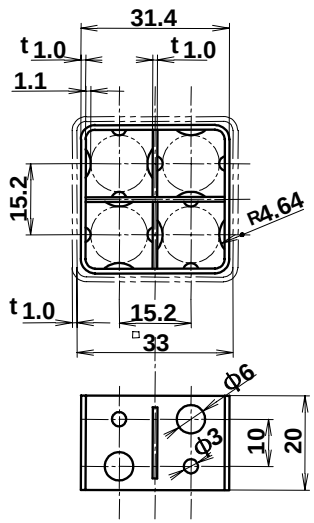
## Form loss coefficient

$$\log_{10}(C_V) = 3.018 - 0.8712 \cdot \log_{10}(\mathrm{Re}_b) + 8.688 \times 10^{-2} \cdot (\log_{10}(\mathrm{Re}_b))^2$$

## Pressure loss in Loop

$$\Delta P = \left( \varsigma + \lambda \frac{L}{D} \right) \frac{\rho}{2} \cdot V^2$$

## Honeycomb grid spacers (3 stages)

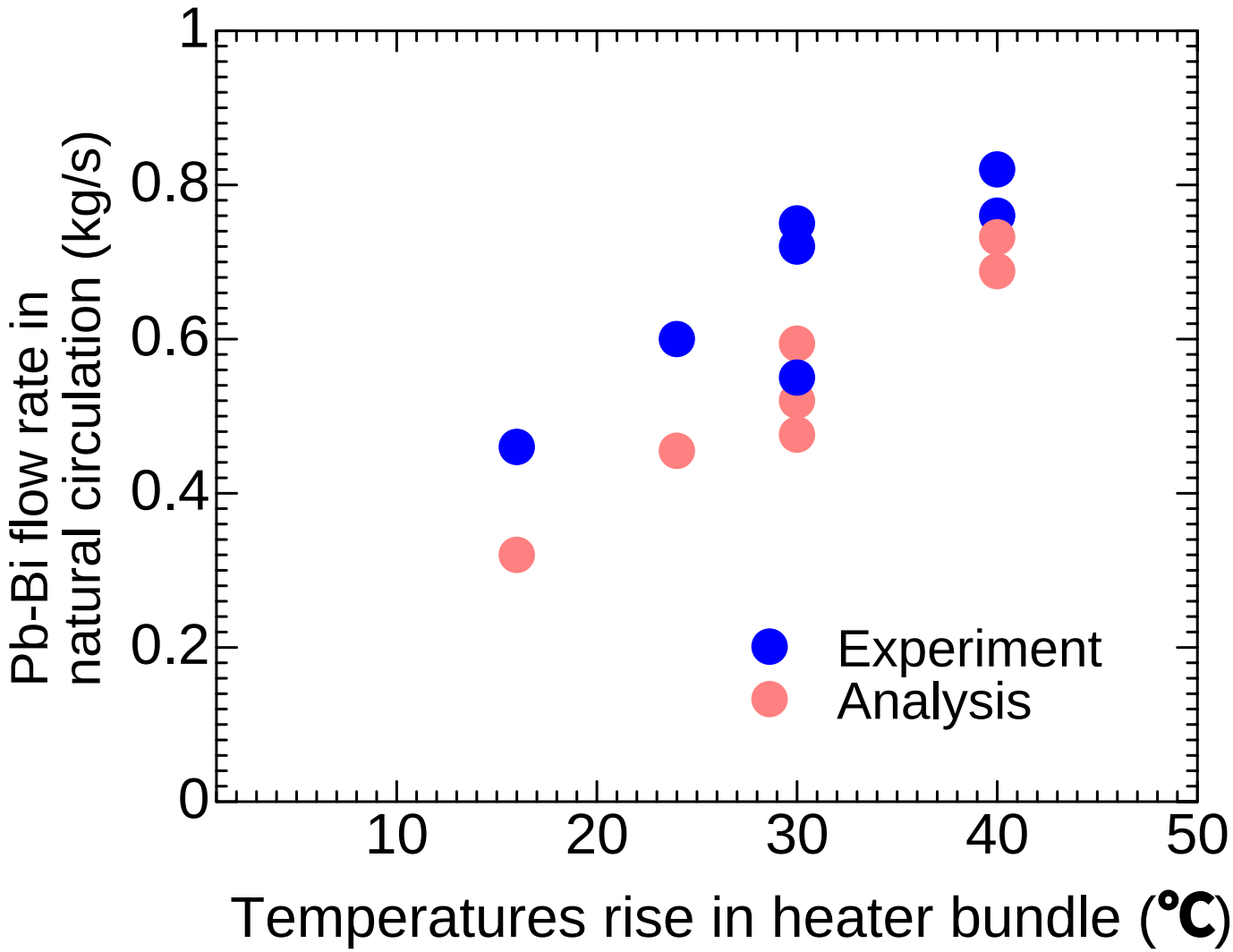



$$\Delta P_G = \frac{\rho}{2} \cdot C_V \cdot \varepsilon^2 \cdot V_b^2$$

**Area ratio**

$$\varepsilon = \frac{A_{SP}}{A}$$

# *Experimental and analytical results of flow rate in natural circulation*



# *Conclusion*

1. **Natural circulation flow was successfully achieved by heating Pb-Bi in the heater pin bundle.**

2. **Analytical result of Pb-Bi natural circulation flow rate was slightly lower than the experimental result.**