# Investigation of Two-Phase Flow in Cryogenic Pressure Relief Devices

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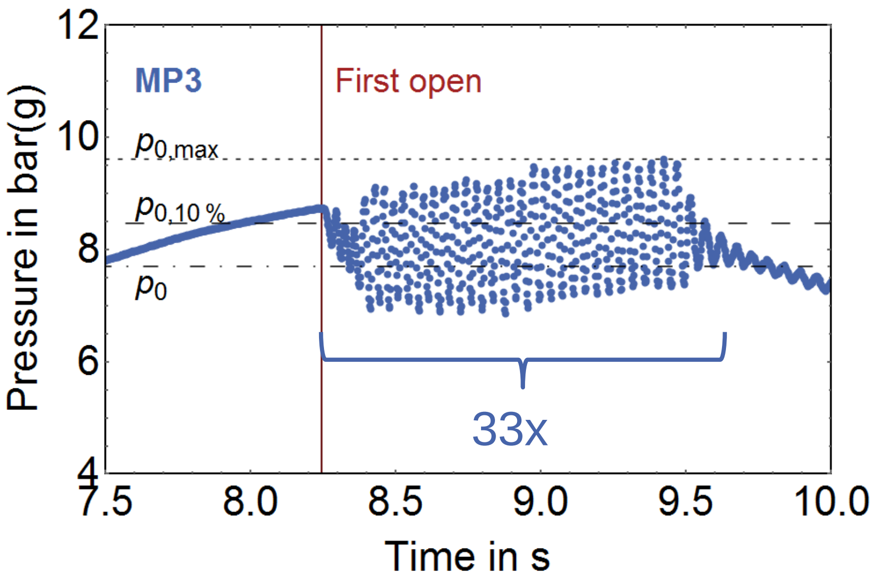
# Motivation

- Cryogenic safety test facility: PICARD
  - **Spring-loaded safety valve**
- Chattering during all experiments
  - Reduced discharge capacity
  - Possible damage of the seat




➡ **Prevent chattering**

- ➢ R&D collaboration KIT - CERN
- ➢ Thermodynamic process path and states during relieving
- ➢ Sizing of a safety valve for two-phase flow
- ➢ Conclusion and Outlook

# R&D COLLABORATION

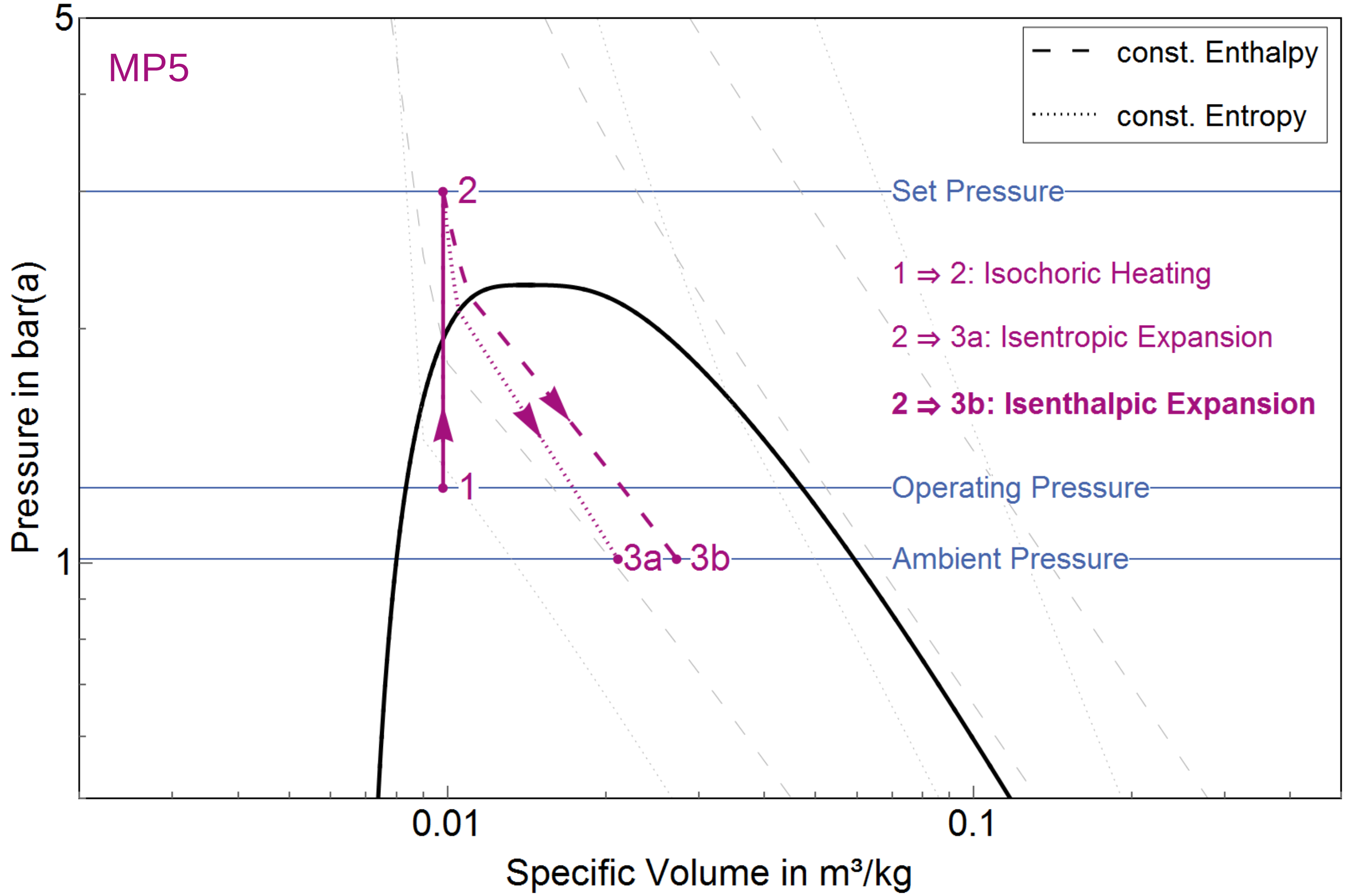
# R&D Collaboration KIT - CERN [1]

- Measurement of heat flux densities and relief flow rates after breaking insulating vacuum
  - Without multilayer insulation (MLI)
  - With MLI
  - With the relief point close to the critical point (EN 13648-3)
- Expansion in the two-phase area
  - Measurement of relief flow rates
  - Theoretical two-phase flow models for cryogenic conditions
  - Actual flow coefficients

[1] Collaborative R&D on experimental testing on cryogenic pressure relief between CERN and KIT, KE2974/KT/DGS/222C,12/2015

# PROCESS PATH DURING RELIEVING

# Process Path





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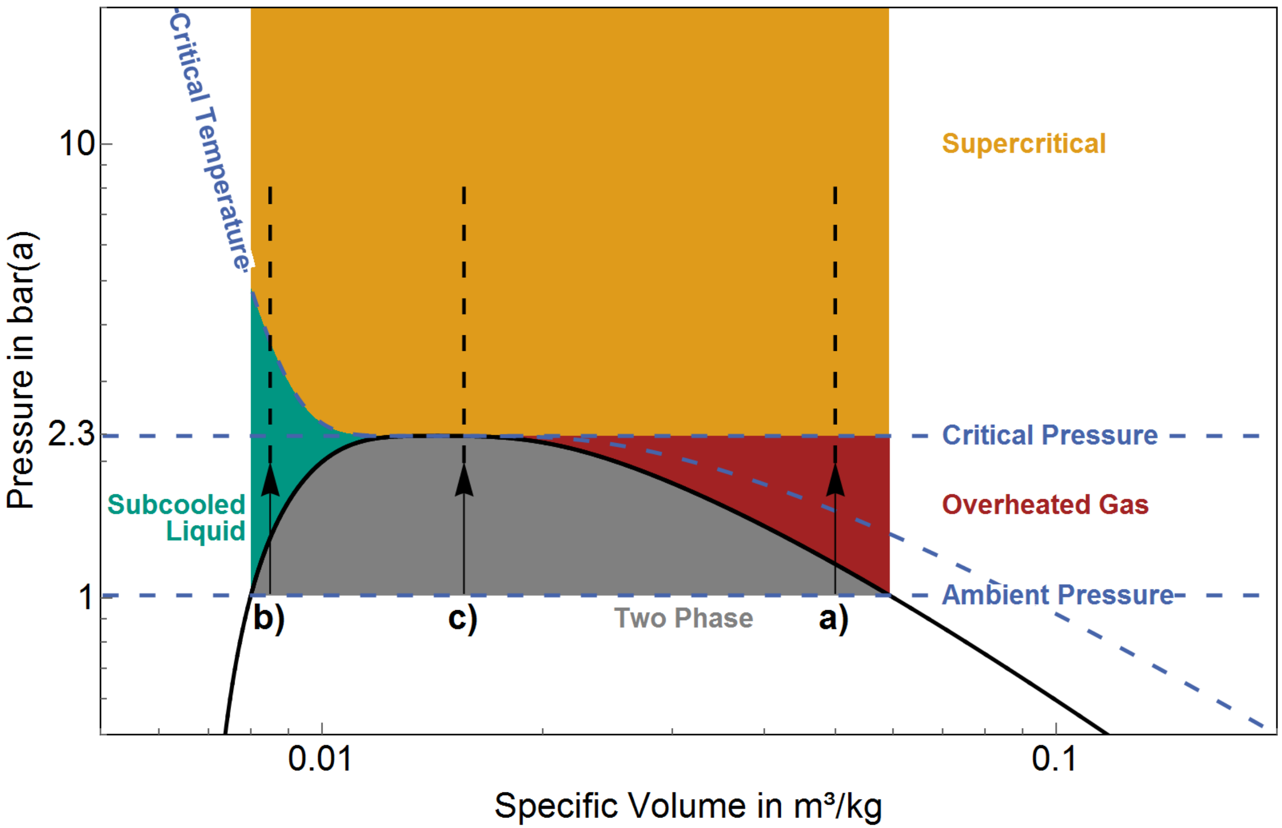
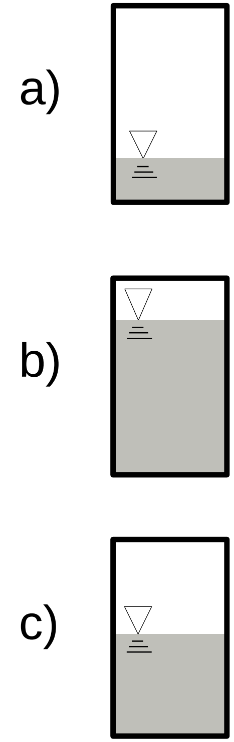
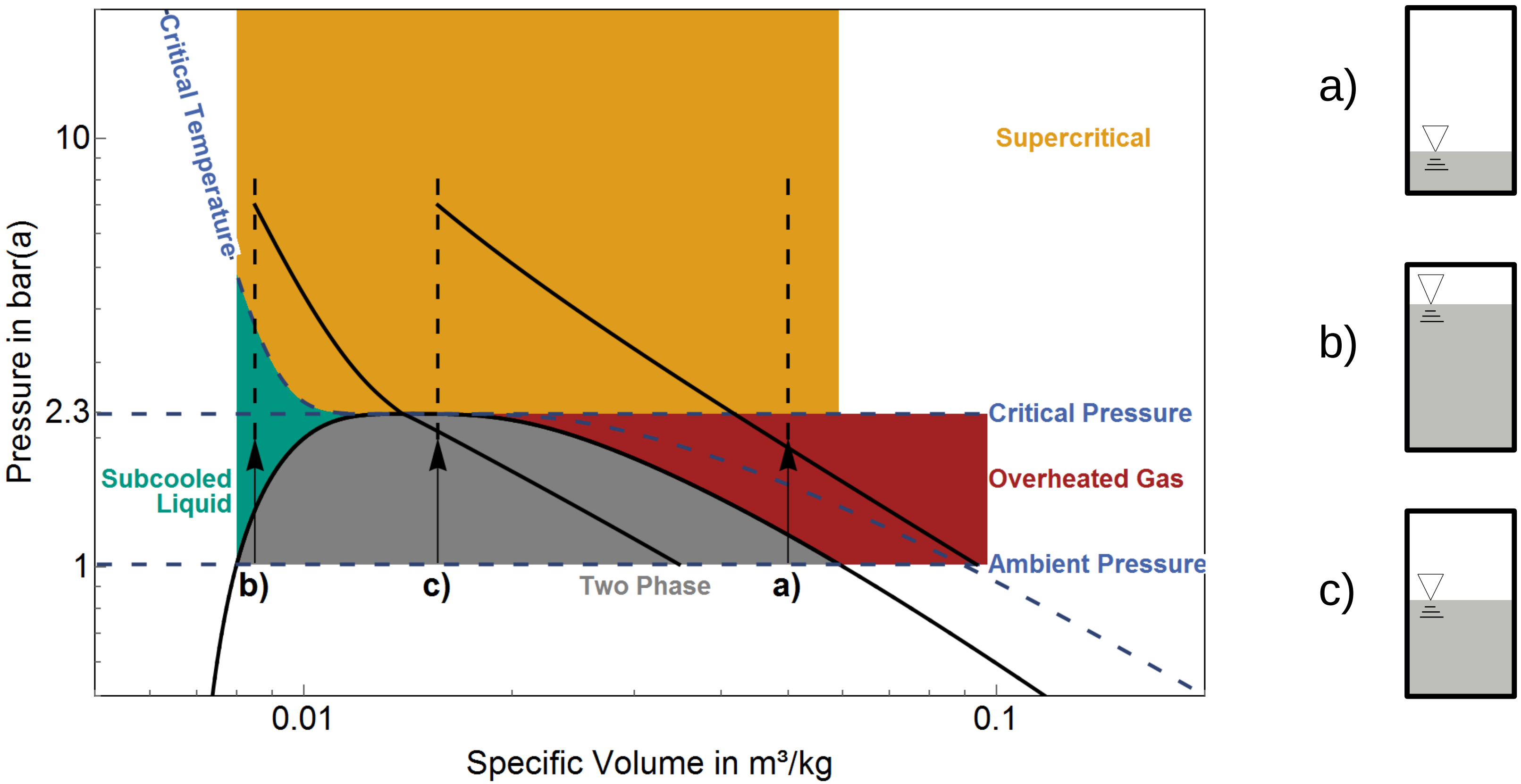
# Inlet Conditions




- 4 inlet conditions possible
  - Overheated Gas
  - Subcooled Liquid
  - Two-Phase
  - **Supercritical Fluid**

# Outlet Conditions




- 2 outlet conditions possible
  - **Two Phase**
  - Overheated Gas

→ supercritical inlet flow and expansion into two phase region

# SIZING FOR TWO-PHASE FLOW

# Sizing of Safety Valves

- Area safety valve [1,2]: $A = \dfrac{\dot{m}_{id}\sqrt{v_0}}{K_{dr}\,\Psi\,\sqrt{2 \cdot p_0}}$

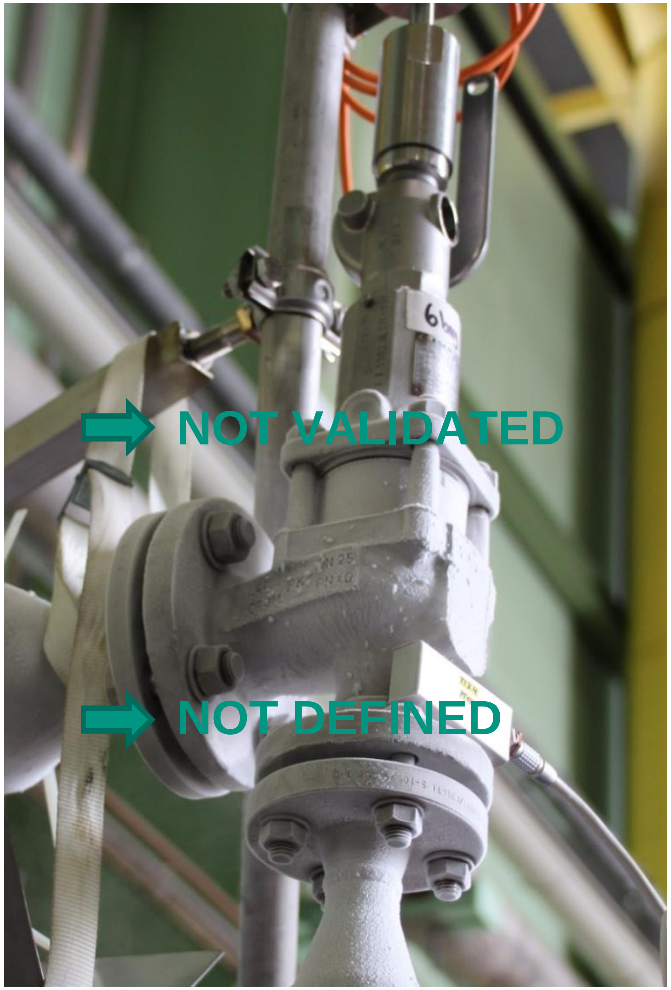
  - $p_0, v_0$: Inlet conditions
  - $\dot{m}_{id}$: Ideal discharge mass flow [3]
  - $\Psi$ : Discharge function
  - $K_{dr}$: Discharge coefficient


[1] ISO 4126-7, *Safety devices for protection against excessive overpressure - Part 7 Common Data*, 2013 [German Version].
[2] AD 2000-A2, *Sicherheitseinrichtungen gegen Drucküberschreitung – Sicherheitsventile –*.
[3] DIN EN 13648-3, *Cryogenic vessels – Safety devices for protection against excessive pressure*.

# Discharge Function $\Psi$

- Single-phase [1]: $\Psi_{1ph} = f(\kappa)$
- Two-phase [4,5]: $\Psi_{2ph} = f(\omega)$
  $\omega$*: compressibility factor*
- API 520 [4]:
  - Using homogeneous equilibrium model
  - $\omega = f(\text{inlet conditions})$
- ISO 4126-10 [5]:
  - Using homogeneous non-equilibrium model
  - No supercritical inlet considered
  - Only valid for: $p_r = \frac{p_{max}}{p_{crit}} \leq 0.5$

➡ For helium: $p_{max}$ **≤ 0.14 bar(g)**




[1] ISO 4126-7, *Safety devices for protection against excessive overpressure - Part 7 Common Data*, 2013 [German Version].
[4] API Standard 520, *Sizing, Selection, and Installation of Pressure-Relieving Devices*, 2014.
[5] ISO 4126-10, *Safety devices for protection against excessive overpressure - Part 7 Sizing of safety valves for gas/liquid two phase flow*, 2010.

# Sizing of Safety Valves

- Area safety valve [1,2]: $A = \frac{\dot{m}_{id} \sqrt{v_0}}{K_{dr} \, \Psi \, \sqrt{2 \cdot p_0}}$
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# Discharge Coefficient $K_{dr}$

- Definition: $$K_{dr} = \frac{\dot{m}}{\dot{m}_{id}}$$

  - Experiment: PICARD
  - Theory: Different models based on

    **a)** Thermodynamics: $K_{dr} = f(p_0, x_0)$ [5,6]

    **b)** Fluiddynamics: $K_{dr} = f(\eta_{crit})$ [7,8]


[5] LEUNG, J.C. A theory on the discharge coefficient for safety relief valve. *Journal of Loss Prevention in the Process Industries,* 2004, **17**(4), 301-313.
[6] LENZING, T. et. al. Prediction of the maximum full lift safety valve two-phase flow capacity [online]. *Journal of Loss Prevention in the Process Industries,* 1998, **11**(5), 307-321.
[7] DARBY, R. On two-phase frozen and flashing flows in safety relief values [online]. *Journal of Loss Prevention in the Process Industries,* 2004, **17**(4), 255-259.
[8] SALLET, D.W. Thermal Hydraulics of Valves for Nuclear Application. *NUCLEAR SCIENCE AND ENGINEERING,* 1984, 220-244.

# Discharge Coefficient $K_{dr}$

- Exemplary sizing with API [4] calulation:

| $K_{dr}$-Method | $K_{dr}$ / - | $d_i$ / mm | $A_{2ph}$ / $A_g$ |
|---|---|---|---|
| *API* [4] | 0.85 | 40.9 | 0.99 |
| *Leung* [5] | 0.67 | 46.1 | 1.26 |
| *Lenzing* [6] | 0.56 | 50.2 | 1.50 |
| *Darby* [7] | 0.70 | 45.0 | 1.20 |
| *Sallet* [8] | 0.65 | 46.8 | 1.30 |

a) (Leung, Lenzing) b) (Darby, Sallet)

**a)** Thermodynamic models **b)** Fluiddynamic models

➡ **Further investigation needed**


[4] API Standard 520, *Sizing, Selection, and Installation of Pressure-Relieving Devices*, 2014.
[5] LEUNG, J.C. A theory on the discharge coefficient for safety relief valve. *Journal of Loss Prevention in the Process Industries,* 2004, **17**(4), 301-313.
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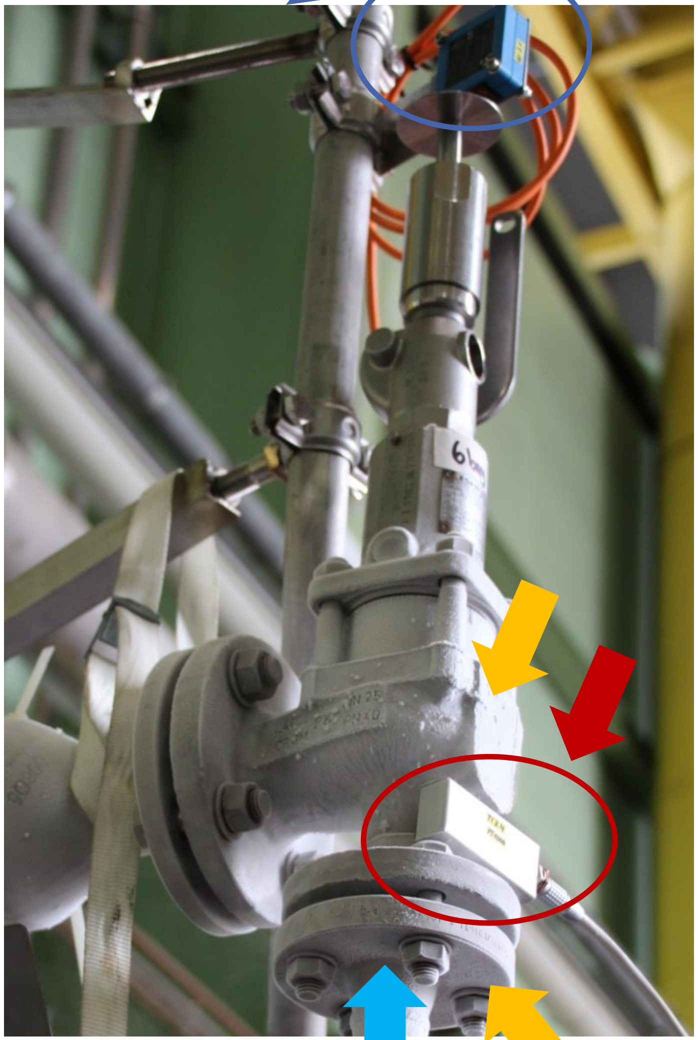
# CONCLUSION & OUTLOOK

# Conclusion & Outlook

- No validated helium two phase flow model available in literature
- Approaches:
  - Validate API calculation
  - Measurement of $K_{dr}$
  - Calculate supercritical speed of sound
  - Consider nucleation during expansion
  - Investigate pressure oscillations

➡ **More data needed**

- Already done:
  - Proximity and temperature sensor installed
- Planned
  - Pressure and temperature sensors up- and downstream of the safety valve
  - Buffer volume upstream safety valve

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# Thank you for your attention.