The PICARD Test Facility - KIT/CERN Collaboration on Cryogenic Pressure Relief Experiments

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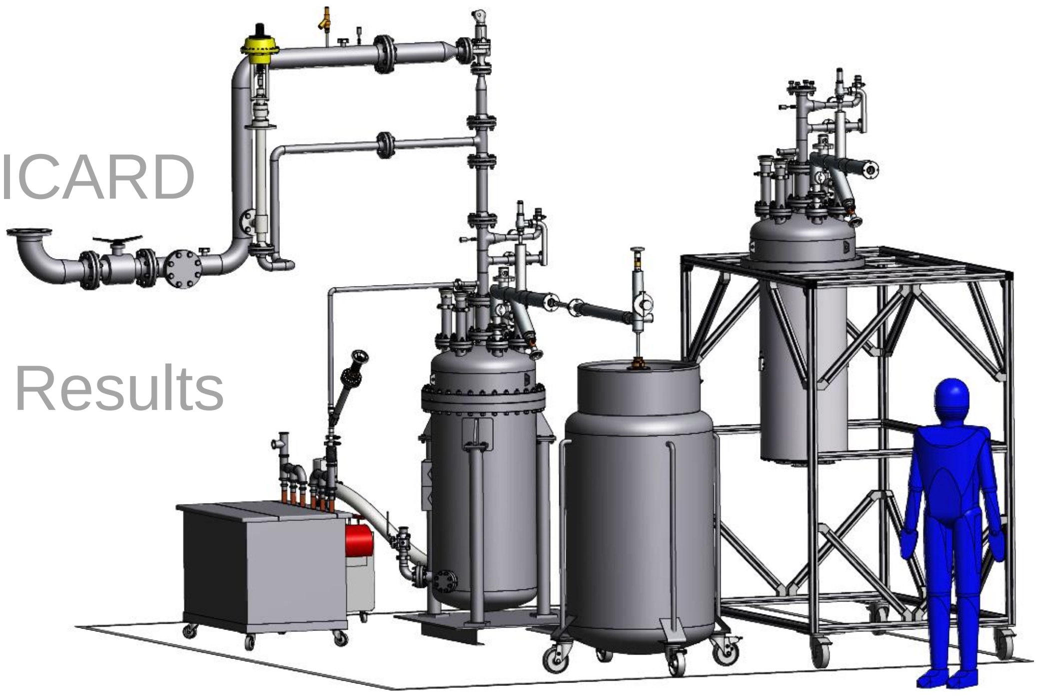
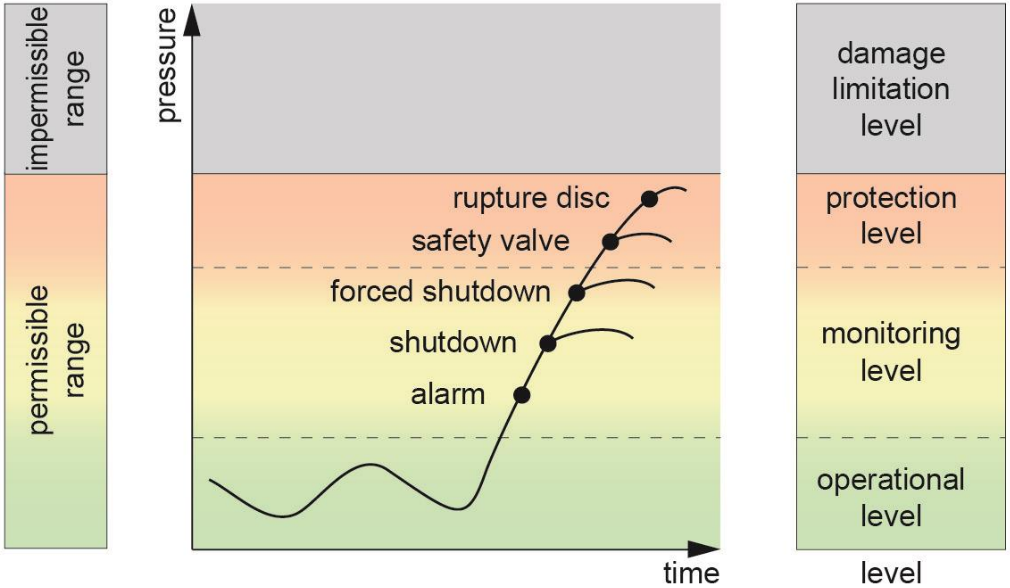
Outline

- State of the Art Helium Safety
- R&D Collaboration
- Design & Construction PICARD
- Exemplary Experimental Results
- Conclusion & Outlook



Dimensioning of cryogenic safety relief devices

- Existing models and standards (e.g. DIN EN 13648) do not consider **process dynamics** $\rightarrow \dot{q} = \mathbf{const.}$
  - Lehmann/Zahn [1]: $\dot{q}_{\max} = 3.8\ \mathrm{W/cm^2}$
  - Cavallari et al. [2]: $\dot{q}_{\max} = 4\ \mathrm{W/cm^2}$



[1] Lehmann W and Zahn G, Safety aspects for LHe cryostats and LHe containers, 1978 *Proc. Int. Cryog. Eng. Conf*. **7** 569-579

[2] Cavallari G, Gorin I, Güsewell D and Stierlin R, Pressure protection against vacuum failures on the cryostats for LEP SC cavities, 1989 *Proc. 4th Workshop on RF Superconductivity* **1** 781-803

R&D Collaboration

- On Cryogenic Pressure Relief Experiments between KIT and CERN from 12/2015 [3]
- Measurement of heat flux densities and relief flow rates in case of a breaking insulating vacuum
  - Without MLI [1,2]
  - With MLI [1]
  - With the relief point close to the critical point (EN 13648-3)
- Expansion in the two-phase area

[1] Lehmann W and Zahn G, Safety aspects for LHe cryostats and LHe containers, 1978 *Proc. Int. Cryog. Eng. Conf*. **7** 569-579
[2] Cavallari G, Gorin I, Güsewell D and Stierlin R, Pressure protection against vacuum failures on the cryostats for LEP SC cavities, 1989 *Proc. 4th Workshop on RF Superconductivity* **1** 781-803
[3] Collaborative R&D on experimental testing on cryogenic pressure relief between CERN and KIT, KE2974/KT/DGS/222C,12/2015

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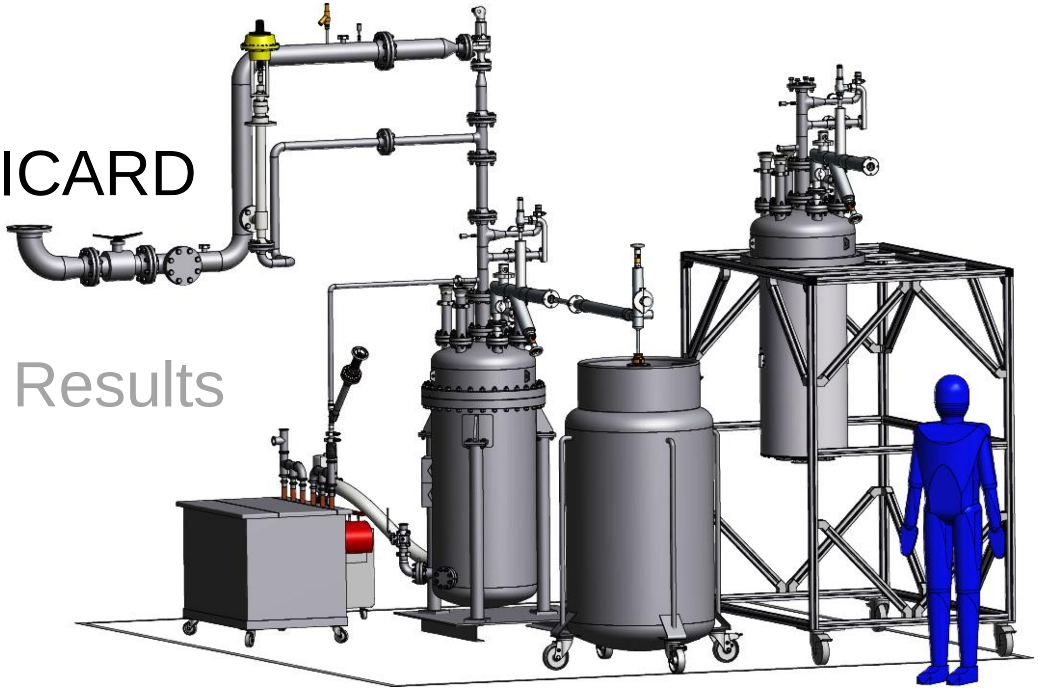


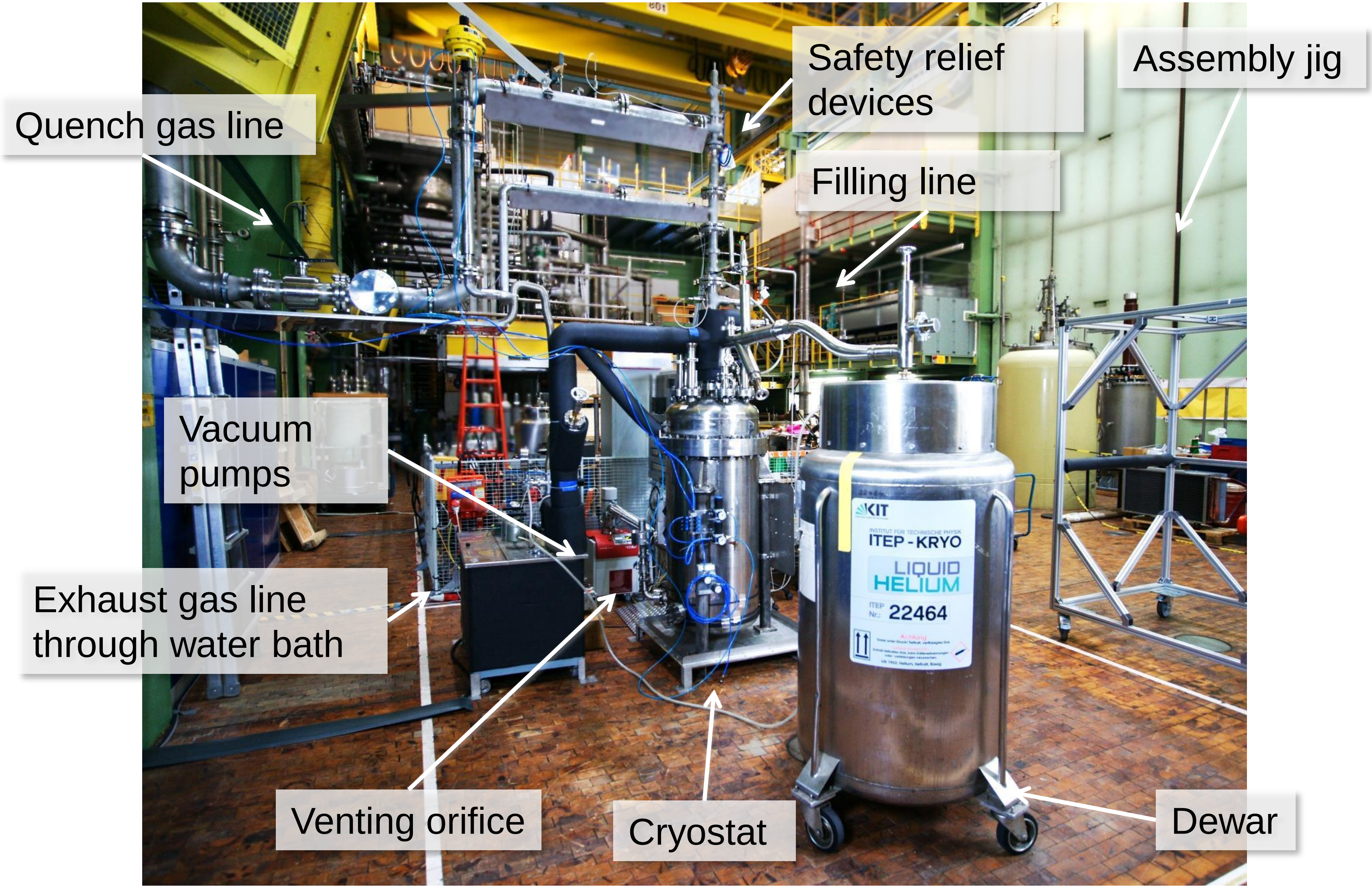
Purpose & Operating Range PICARD

- PICARD: **P**ressure **I**ncrease in **C**ryostats and **A**nalysis of **R**elief **D**evices [4]
- Broad range of safety experiments in course of R&D Collaboration

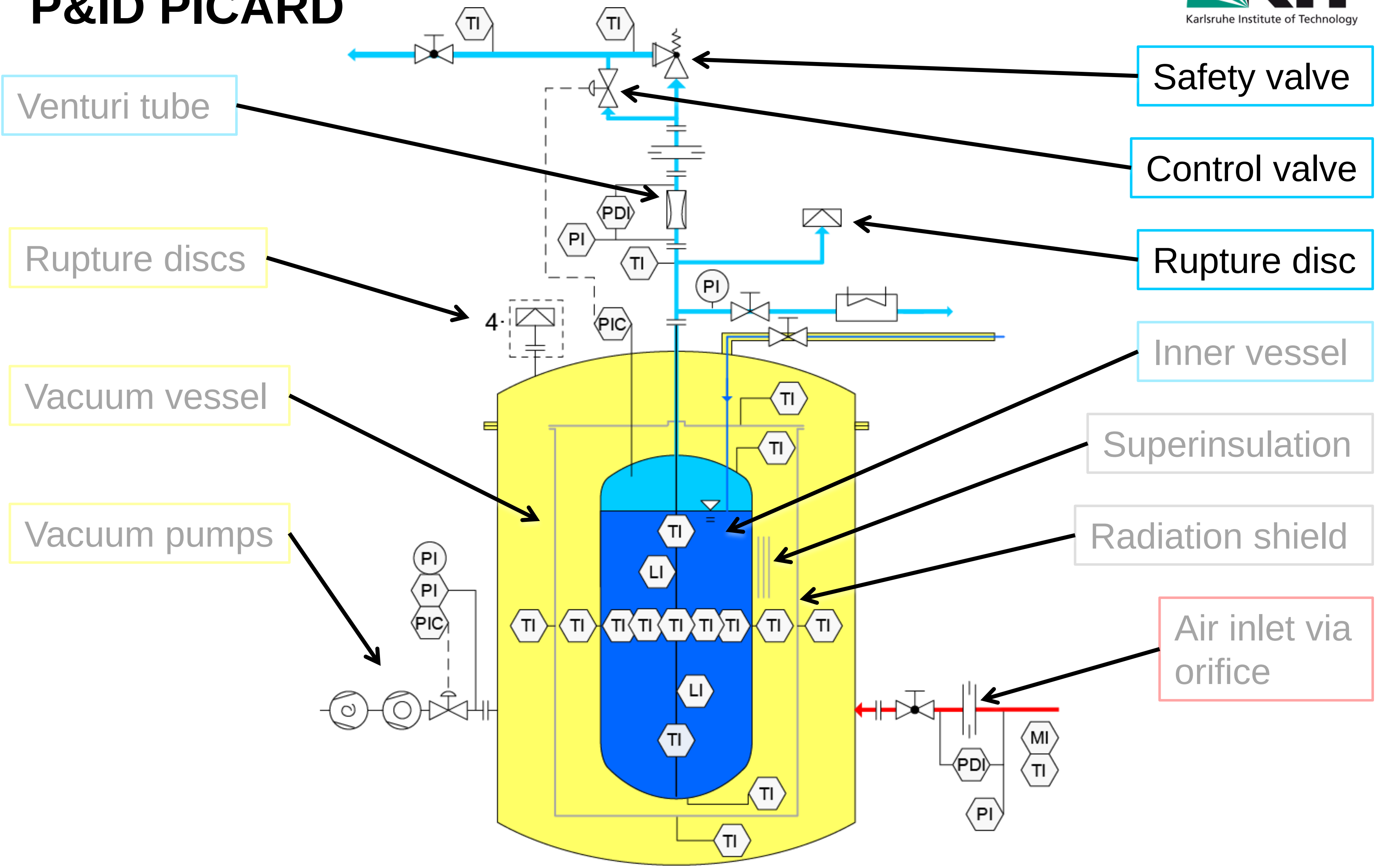
Variation of	**Range**
Venting diameter	Up to 40 mm
Liquid level	Up to 100 L LHe
Set relief pressure	Up to 12 bar(g)
Mass flow rates	Up to 4 kg/s

[3] Collaborative R&D on experimental testing on cryogenic pressure relief between CERN and KIT, KE2974/KT/DGS/222C,12/2015
[4] Heidt, C., Schön, H., Stamm, M., Grohmann, S., Commissioning of the cryogenic safety test facility PICARD, 2015, *IOP Conf. Ser.: Mater. Sci. Eng.* **101**, 012161

Safety Test Facility PICARD



P&ID PICARD


Venturi tube
Rupture discs
Vacuum vessel
Vacuum pumps
Safety valve
Control valve
Rupture disc
Inner vessel
Superinsulation
Radiation shield
Air inlet via orifice

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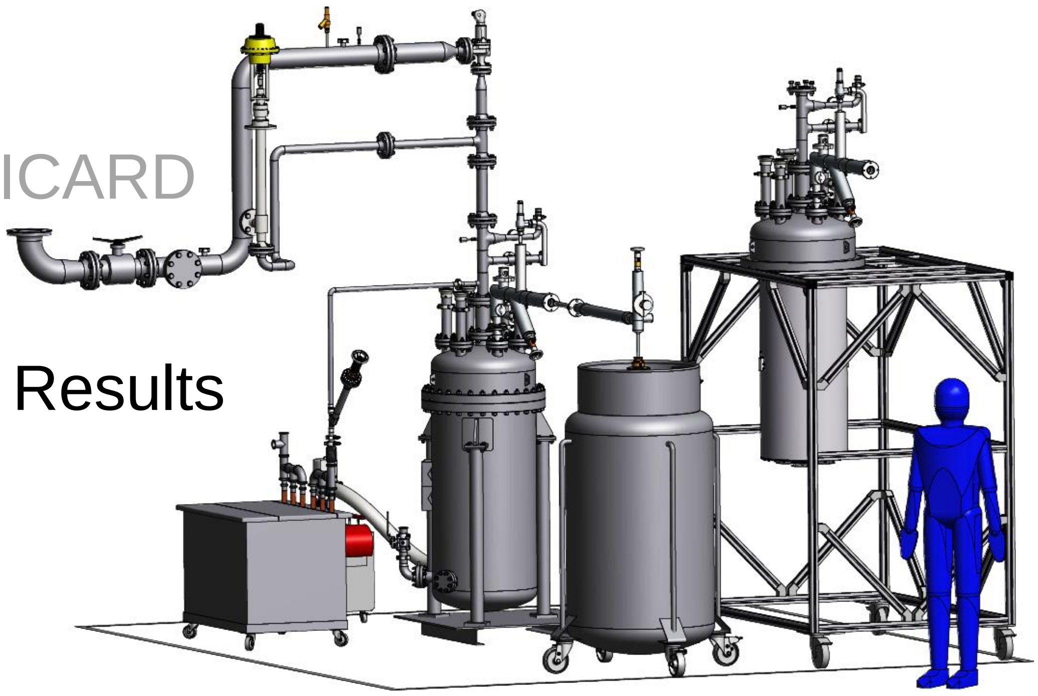
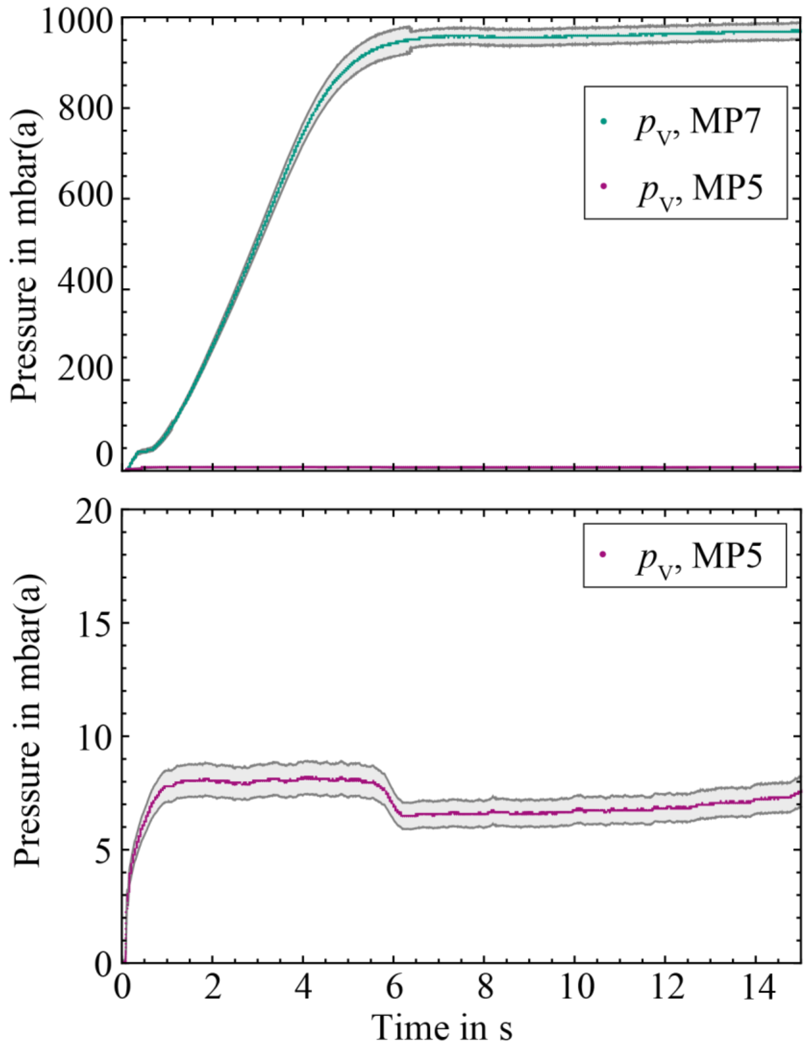


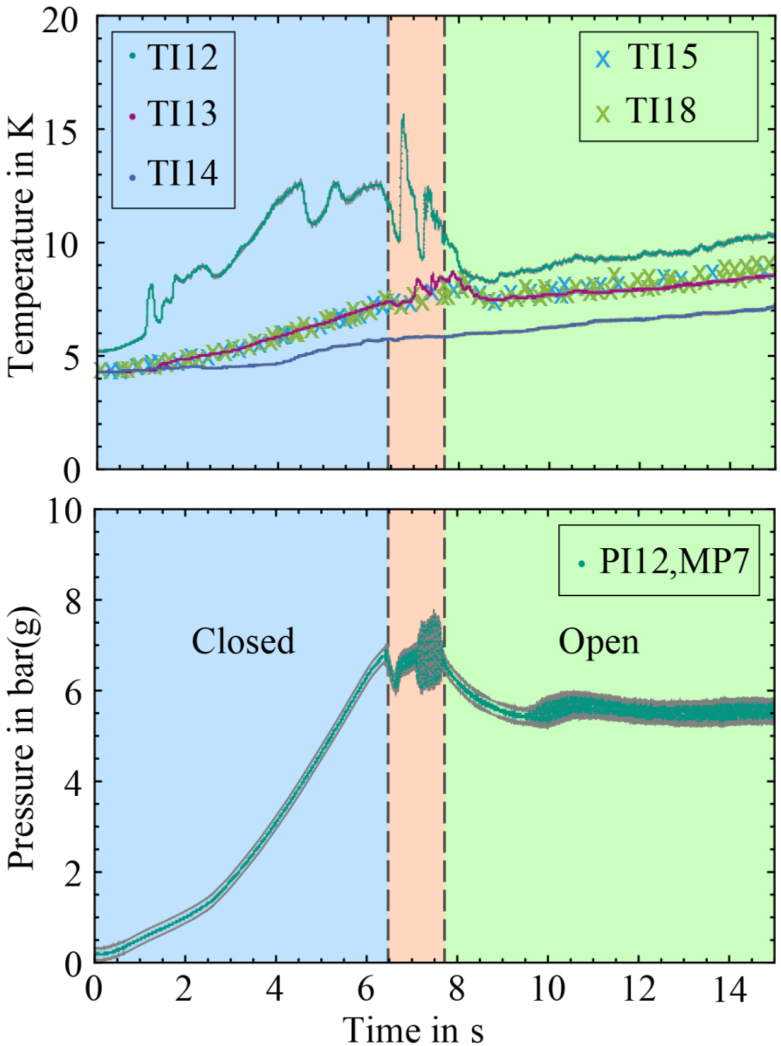
Settings of Exemplary Venting Experiments

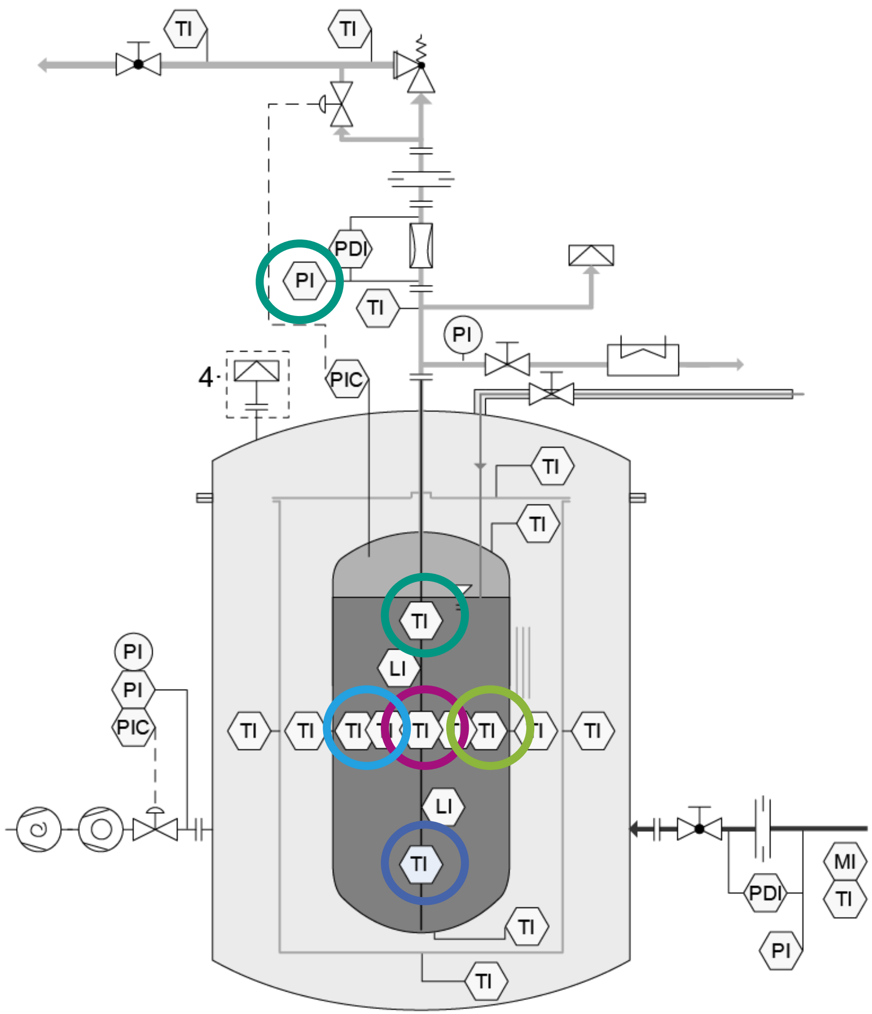
- Vacuum insulation, radiation shield
- Venting with atm. air
- Most extreme conditions

	MP7	MP5
Venting diameter	30 mm	12.5 mm
Set relief pressure	6 bar(g)	2 bar(g)
Filling level	~60%	~80%
LHe volume	66 l	103 l

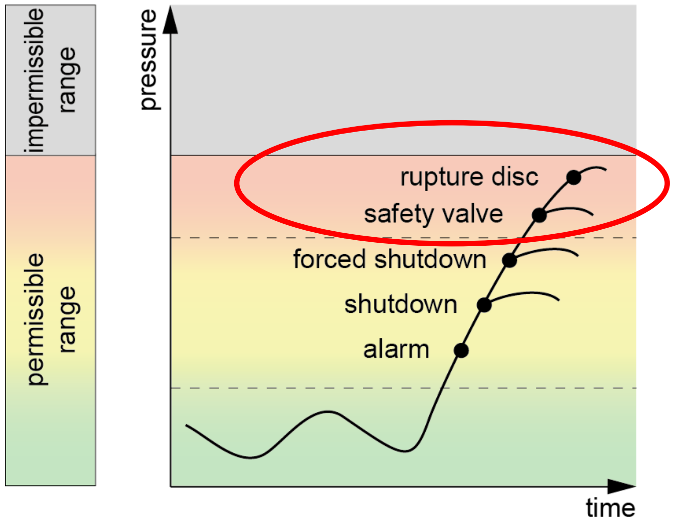


Temperature and Pressure Increase

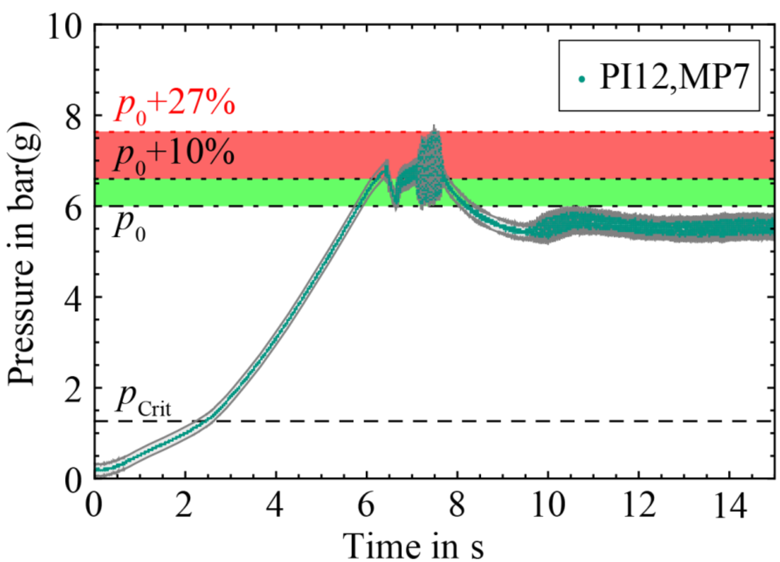


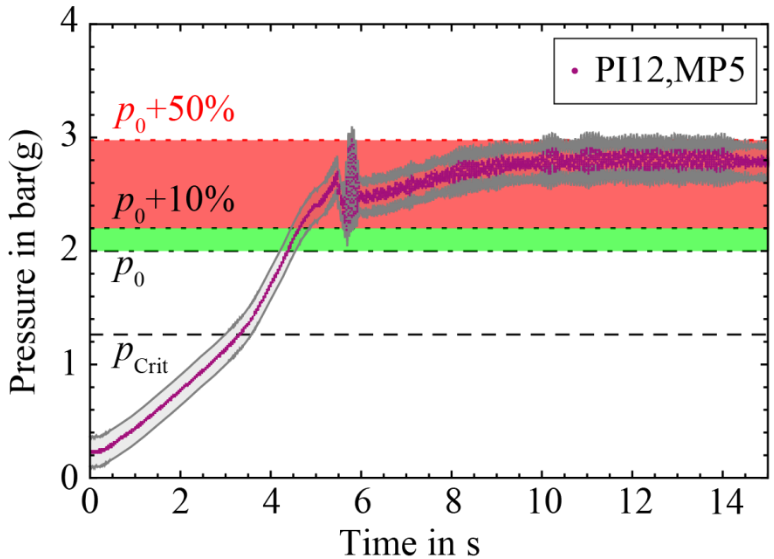


Temperature and Pressure Increase



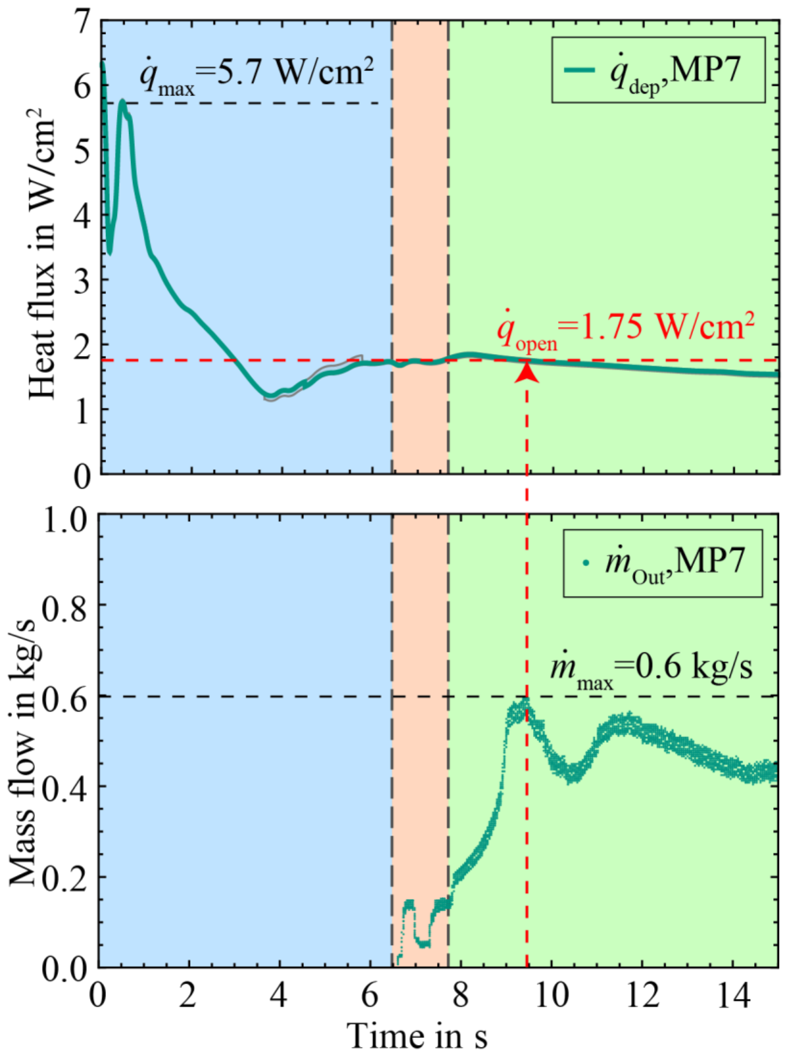
- Staged protection
  - Open system
  - Humidity
- Only safety valve
  - Plastic deformation
  - Mechanical failure





[6] DIN SPEC 4683:2015-04: *Cryostats for liquefied helium – Safety devices for protection against excessive pressure;*
[7] S. Grohmann, M. Süßer: Conceptual Design of Pressure Relief Systems for Cryogenic Application, AIP Conference Proceedings, 1573, 1581-1585

Heat Flux Density and Relief Mass Flow



- $d_{\mathrm{Vent}} = 30\ \mathrm{mm},\ p_0 = 6\ \mathrm{bar(g)}$
- Conservative calculation of heat flux by desublimation/condensation with $T_V = T_A$
- Maximum heat flux literature
  - $\dot{q}_{\mathrm{max,Lehmann}} = 3.8\ \mathrm{W/cm^2}$ [1]
  - $\dot{q}_{\mathrm{max,Cavallari}} = 4.0\ \mathrm{W/cm^2}$ [2]
  - But: $\dot{q}_{\mathrm{max,Dhuley}} = 20\ \mathrm{W/cm^2}$ [5]

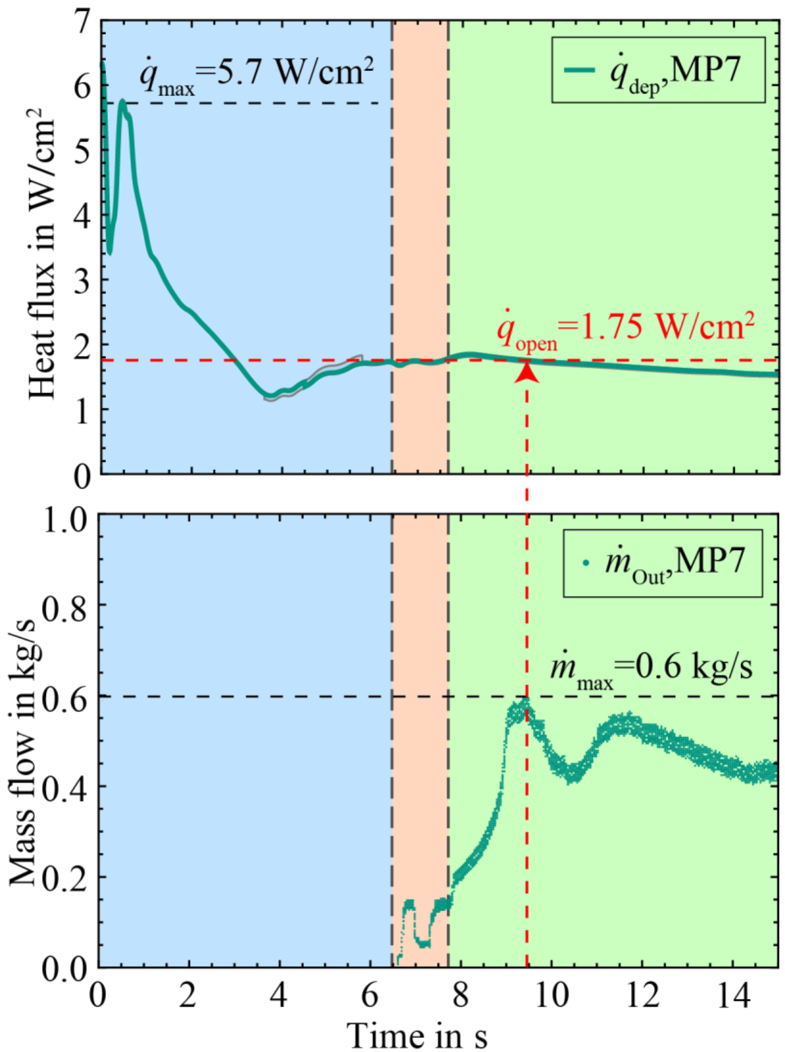
➢ $\dot{q}_{\mathrm{open}} < \dot{q}_{\mathrm{max}}$

[1] Lehmann W and Zahn G, Safety aspects for LHe cryostats and LHe containers, 1978 *Proc. Int. Cryog. Eng. Conf.* **7** 569-579

[2] Cavallari G, Gorin I, Güsewell D and Stierlin R, Pressure protection against vacuum failures on the cryostats for LEP SC cavities, 1989 *Proc. 4th Workshop on RF Superconductivity* **1** 781-803

[5] Dhuley, R and Van Sciver S, Heat transfer in a liquid helium cooled vacuum tube following sudden vacuum loss, 2015 *IOP Conf. Series: Mat. Sci. Eng.* **101** 012006

Heat Flux Density and Relief Mass Flow



- Usual dimensioning according to DIN EN 13648/ ISO 4126-7
  - with $\dot{q}_{\text{max,Cavallari}} = 4.0\ \text{W/cm}^2$ [2]:
    - $\dot{m}_{\text{Out,Cavallari}} = 1.6\ \text{kg/s}$
    - $d_{\text{SV,Cavallari}} = 22.2\ \text{mm}$
  - with $\dot{q}_{\text{open,MP7}} = 1.75\ \text{W/cm}^2$:
    - $\dot{m}_{\text{Out,MP7}} = 0.7\ \text{kg/s}$
    - $d_{\text{SV,MP7}} = 14.7\ \text{mm}$
- $\frac{A_{\text{SV,Cavallari}}}{A_{\text{SV,MP7}}} = 51\%$
- **Oversizing!**

[2] Cavallari G, Gorin I, Güsewell D and Stierlin R, Pressure protection against vacuum failures on the cryostats for LEP SC cavities, 1989 *Proc. 4th Workshop on RF Superconductivity* **1** 781-803

Conclusions

- Neglecting process dynamics can lead to **over-sizing** of safety valves
- **Unstable operation** of safety valves (*chattering, pumping*)
- **Damage** to seat of safety valve
- **Overpressures**
  - Staged pressure protection: bursting of rupture disk, **open system**
  - No staged pressure protection: **Plastic deformation**/ mechanical failure of cryostat

Outlook

- Planned experiments in course of R&D collaboration with CERN:
  - With smaller safety valve
  - With MLI
  - Pressure close to critical point
  - Additional quench of sc. magnet
- Investigation of
  - Two-phase flow
  - Safety valve behavior at cryogenic temperatures

➢ See presentation "*Investigation of Two-Phase Flow in Cryogenic Pressure Relief Devices*" by Christina Weber

Thank you for your attention!