Status of a European Standard for the Protection of Helium Cryostats against Excessive Pressure

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Rembe Safety Day's, Brilon, Germany, September 17-18 2019

Motivation

- Helium **dewars** vs. helium **cryostats**

ISO 21013 – Cryogenic vessels – Pressure-relief accessories for cryogenic service

Strong influence on potential risk of excessive pressure

Helium cryostats have **active components**

- Sc. magnets
- Sc. RF cavities
- Heat exchangers
- Valves
- Flexible hoses
- Pumps

EN 1626 EN 12434 EN 24490

E.g. European
- Machine Directive 2006/24/EC
- Low-voltage Directive 2014/35/EU
- Electromagnetic Compatibility Directive 2004/108/EC
- ...


Source: http://www.fusione.enea.it

Liquid helium **dewar**

ISO 21009 (substituting EN 13458)
Cryogenic vessels –
Static vacuum insulated vessels

➡ No dedicated Standard existing that covers the conditions in helium cryostats and which is harmonized with the European PED

New working group

CEN/TC 268 - Cryogenic vessels

General | Structure | Work programme | Published Standards

CEN/TC 268 Scope

Standardization in the field of insulated vessels (vacuum or non- vacuum) for the storage and the transport of refrigerated liquefied gases ,as defined in Class 2 of "Recommendations on the Transport of dangerous goods - Model regulation" , in particular concerning the design of the vessels and their safety accessories, gas/materials compatibility, insulation performance, the operational requirements of the equipment and accessories. The one-off preparation of standards for hydrogen technologies strictly meeting the European mandate on the draft Directive deployment of alternative fuels infrastructure.

Officers

Chairperson	Dr Hervé Barthélémy
Secretary	Ms Laurie Jardel

General | Structure | Work programme | Published Standards

CEN/TC 268 Subcommittees and Working Groups

Working group	Title
CEN/TC 268/WG 1	Design
CEN/TC 268/WG 2	Compatibility, insulation, accessories
CEN/TC 268/WG 3	Operational requirements

Aim of CEN/TC 268/WG6:

New European Standard on „*Helium Cryostats – Protection against excessive pressure*“

Organizations contributing to CEN/TC 268/WG6

cen | KIT Karlsruhe Institute of Technology

- National Standardisation Bodies:

DIN | afnor GROUPE | bsi.

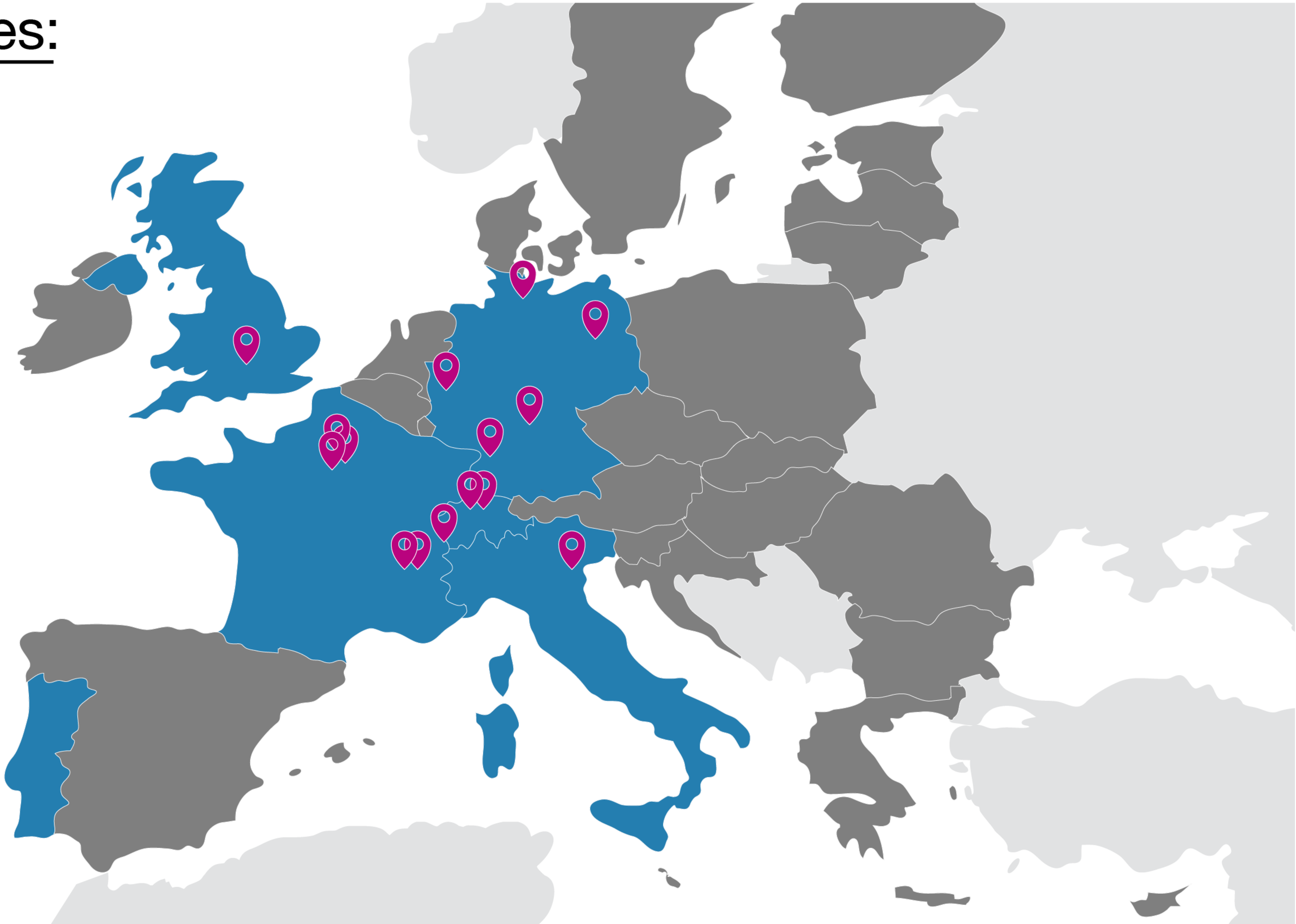
UNI ENTE ITALIANO DI NORMAZIONE | Q Instituto Português da Qualidade | SNV

- Organizations:

Air Liquide creative oxygen | BiLFINGER | cea | CERN

HEROSE | INFN | KIT Karlsruhe Institute of Technology | THE LINDE GROUP Linde

PAUL SCHERRER INSTITUT PSI | Science & Technology Facilities Council



Experts contributing to CEN/TC 268/WG6


S. Grohmann
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H. Barthélémy
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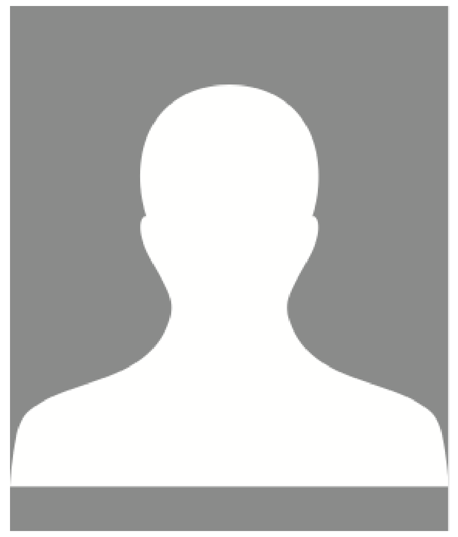
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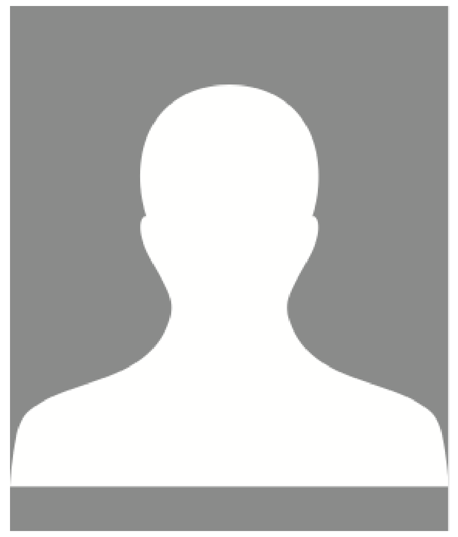
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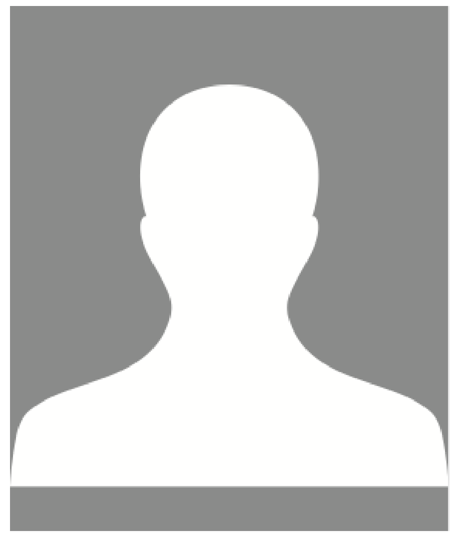
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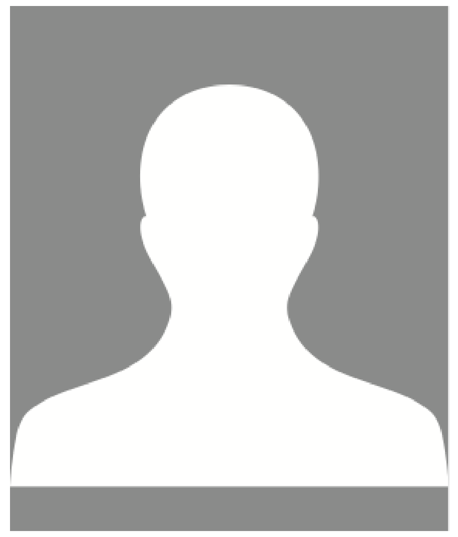
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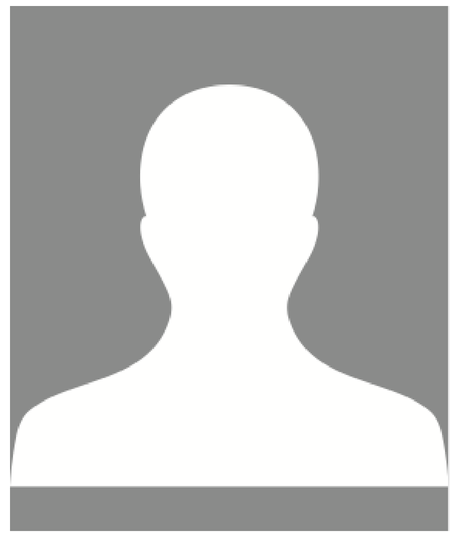
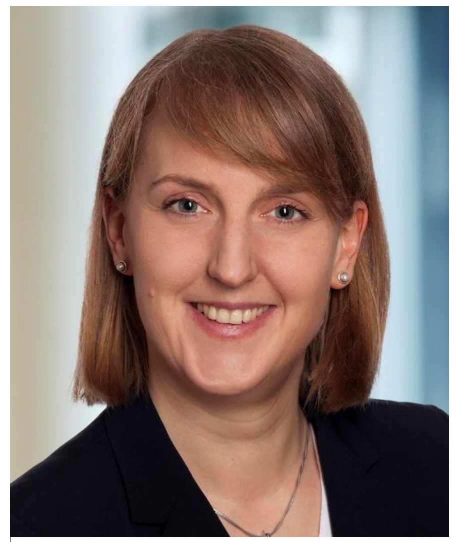

R. Soika
Linde Kryotechnik


R. Vallcorba-
Carbonell, CEA


C. Weber
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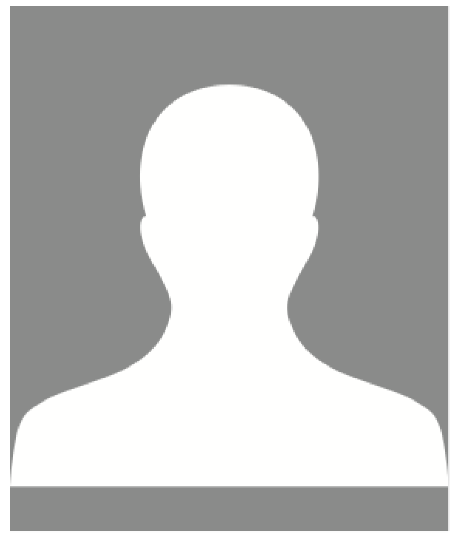
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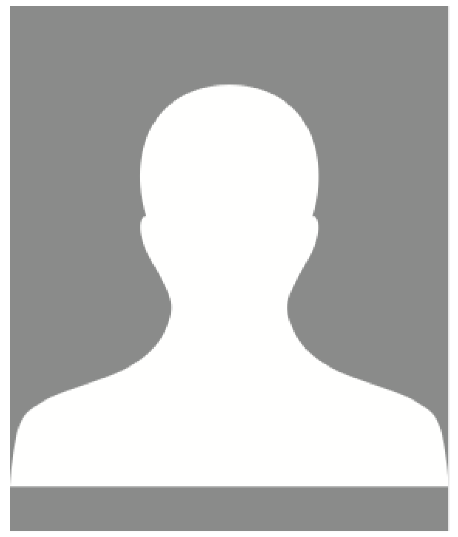
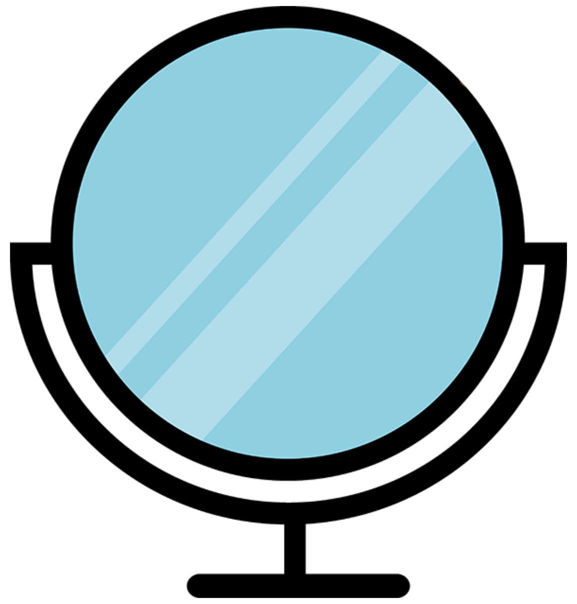

Air Liquide


C. Zoller
PSI

Scope and concept of the new Standard

- The scope includes
  - Superconducting magnet cryostats
  - Superconducting RF cavities
  - Ultra-low T refrigerator systems using ^{3}He and ^{3}He/^{4}He mixtures
  - Coldboxes of helium refrigerators and liquefiers
  - Helium distribution systems including valve boxes

- Overall concept
  - Standardization of the approach of how to obtain state-of-the-art protection
  - Specification of procedure and minimum requirements in the main part
  - Alternative/advanced methods, additional information, example solutions, exemplary measures in extensive Annex



Structure of the technical part

- Risk assessment

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- Protection concepts

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- Dimensioning of pressure relief devices
- Pressure relief devices
- Substance release
- Operation of helium cryostats

Risk assessment

- Definition of 15 risk scenarios as „Sources of excessive pressure“

Loss of insulating vacuum	**Loss of beamline vacuum**	**Leak of cryogenic fluid**
Quench of sc. device	**Dielectric breakdown**	Cryopumping
Entrapment of cryogenic fluid	Thermal acoustic oscillation	Power failure
Pressure surge	Freezing	Backflow
Other sources	Earthquake	Fire

- Three phases of risk assessment
  1) Risk assessment before ordering (qualitative, HAZOP or equiv. method)
  2) Risk assessment in the design phase (quantitative, FMEA or equiv. method)
  3) Evaluation of risks by the equipment owner/employer
     - National implementations of EU Health and Safety at Work Directive 2009/104/EC

Protection concepts

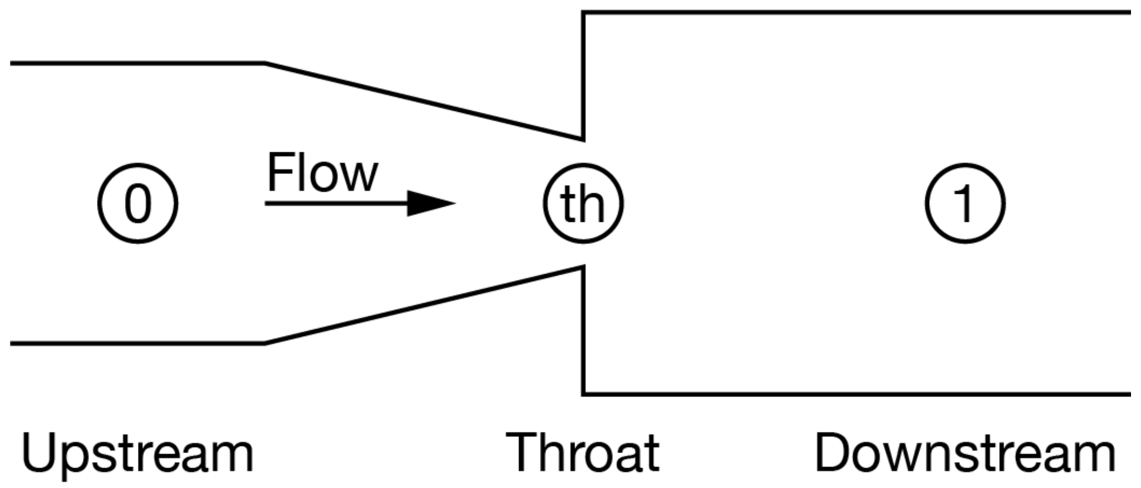
- Single-stage protection concept as minimum requirement
- Multi-stage protection concepts
  - Primary PRD completely fulfills the pressure protection at the maximum allowable pressure p_s in compliance with the PED and based on the MCI
  - Secondary PRD at either $p_0 < p_s$ or $p_0 > p_s$, either in series or in parallel
  - Particular requirements for five types of helium cryostats
    1) High-pressure superconducting magnet cryostats
    2) Low-pressure helium cryostats, such as superconducting RF cavities
    3) Sub-atmospheric helium cryostats
    4) He-II cryostats
    5) Ultra-low temperature refrigerator systems

PRD: Pressure relief device
PED: Pressure equipment directive
MCI: Maximum credible incident

Dimensioning of pressure relief devices

- The dimensioning of PRD is generally based on
  - mass-specific energy/momentum conservation + continuity equation for one-dimensional, frictionless, compressible, steady-state and adiabatic fluid flow through short nozzles (with correction factors for non-ideal behavior)

- Basic equation $$A_{th} = \frac{\dot{M}}{\rho_{th} \cdot c_{th}}$$



  - $\dot{M}$ relieving mass flow rate → from the heat load in different risk scenarios
  - ρ_{th} density in the throat
  - c_{th} velocity in the throat

  (ρ_{th}, c_{th}:) $\dot{m}_{th}$ mass flux → two types of models

Dimensioning of pressure relief devices

- Case-specific model
  - Isentropic expansion
  - Application of isentropic relation
  - Mass flux equations:

Liquid: $\dot{m} = f(\kappa) \cdot \sqrt{2 \cdot \rho \cdot (p_0 - p_b)}$

Gaseous: $\dot{m} = f(\kappa) \cdot \sqrt{2 \cdot \rho_0 \cdot p_0}$

Two-phase: $\dot{m} = f(\omega) \cdot \sqrt{2 \cdot \rho_0 \cdot p_0}$

κ: Isentropic exponent
ω: Omega-parameter

- Homogeneous equilibrium model (HEM or G-model)
  - Isentropic expansion
  - Mass flux evaluation:

$$p_{th} = p \left| \frac{\rho(p) \cdot \sqrt{2 \cdot (h_0 - h(p))}}{dp} \right. \equiv 0$$

$$m_{th} = \rho_{th} \cdot \sqrt{2 \cdot (h_0 - h_{th})}$$

Dimensioning of pressure relief devices

- Case-specific model
  - Consistent with ISO 4126-7:2013 and ISO 21013-3:2016
  - Simpler, but more individual calculations steps
  - Definition of fluid state in the throat needed before dimensioning
  - More equations to solve, error-prone
  - Limited application range: $T_0 \leq 0.9 \cdot T_{Crit}$

    $p_0 \leq 0.5 \cdot p_{Crit}$

  - Presented in the Annex as alternative method

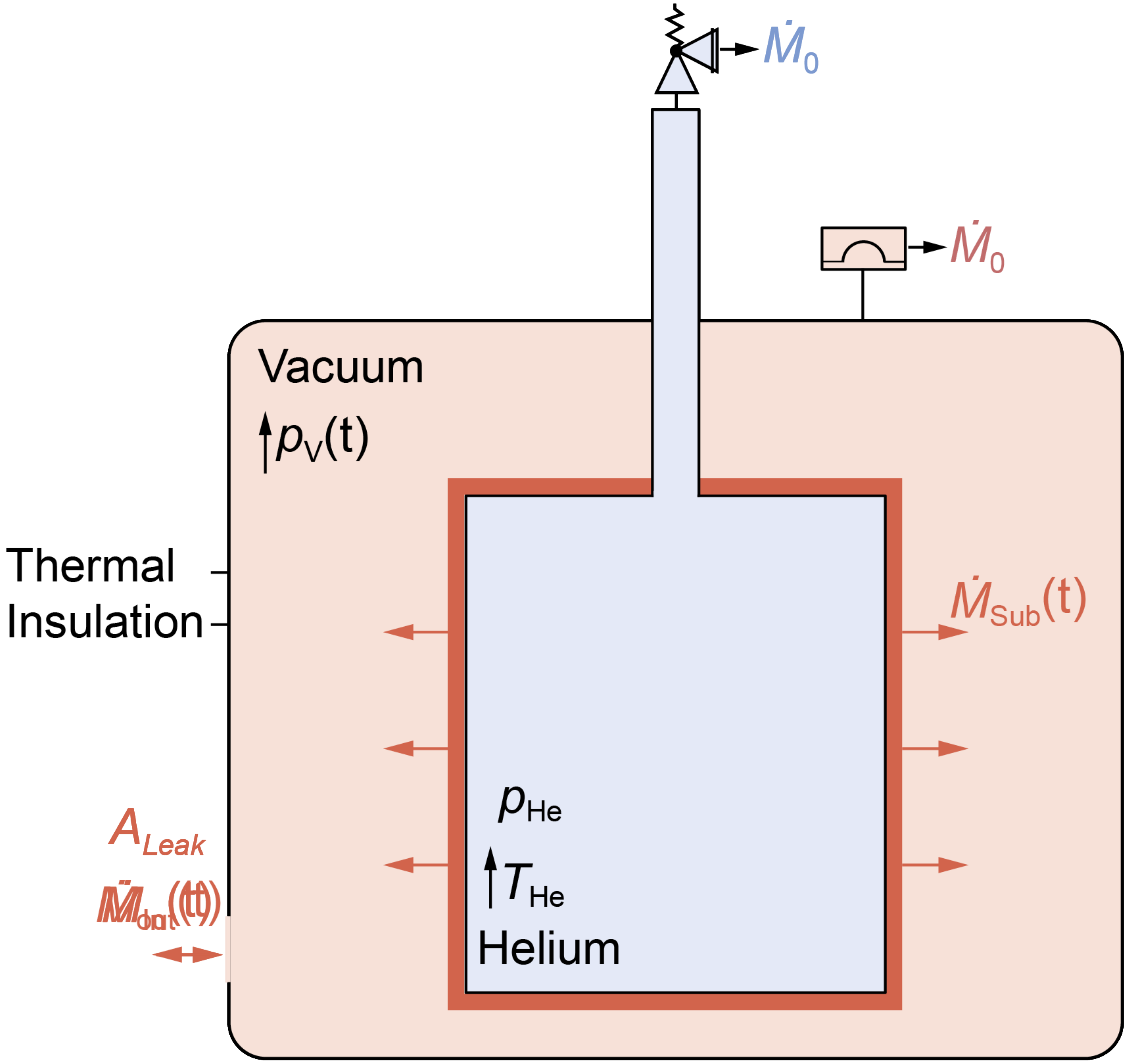
- Homogeneous equilibrium model (HEM or G-model)
  - No case definition in throat needed
  - One equation, few operations
  - Software for calculation needed (MS Excel sufficient)
  - Access to helium property data needed
  - Applied in the main part of the Standard

Dimensioning of pressure relief devices

- Relieving mass flow rate from helium vessel:
  - Calculation of the relieving mass flow rate requires heat flux
  - The new Standard defines calculation rules that yield maximum heat flux values, as a general algorithm for the variety of design solutions does not exist.
- Relieving mass flow rate from vacuum vessel
  - Vacuum vessels equipped with PRD, considered as safety-related device
  - Calculation of relieving mass flow rate via possible leak size (Bernoulli)
- Including detailed documentation, it also allows the calculation with:
  - published experimental heat flux data given for the respective conditions;
  - unpublished experimental heat flux data obtained for the particular cryostat design; or
  - numerical modelling of the processes during incidental scenarios.

> Approach on numerical modelling in Ph.D. Thesis:
> "Dynamic modelling of incidents for protection of helium cryostats against excessive pressure"

MCI: Loss of insulating vacuum

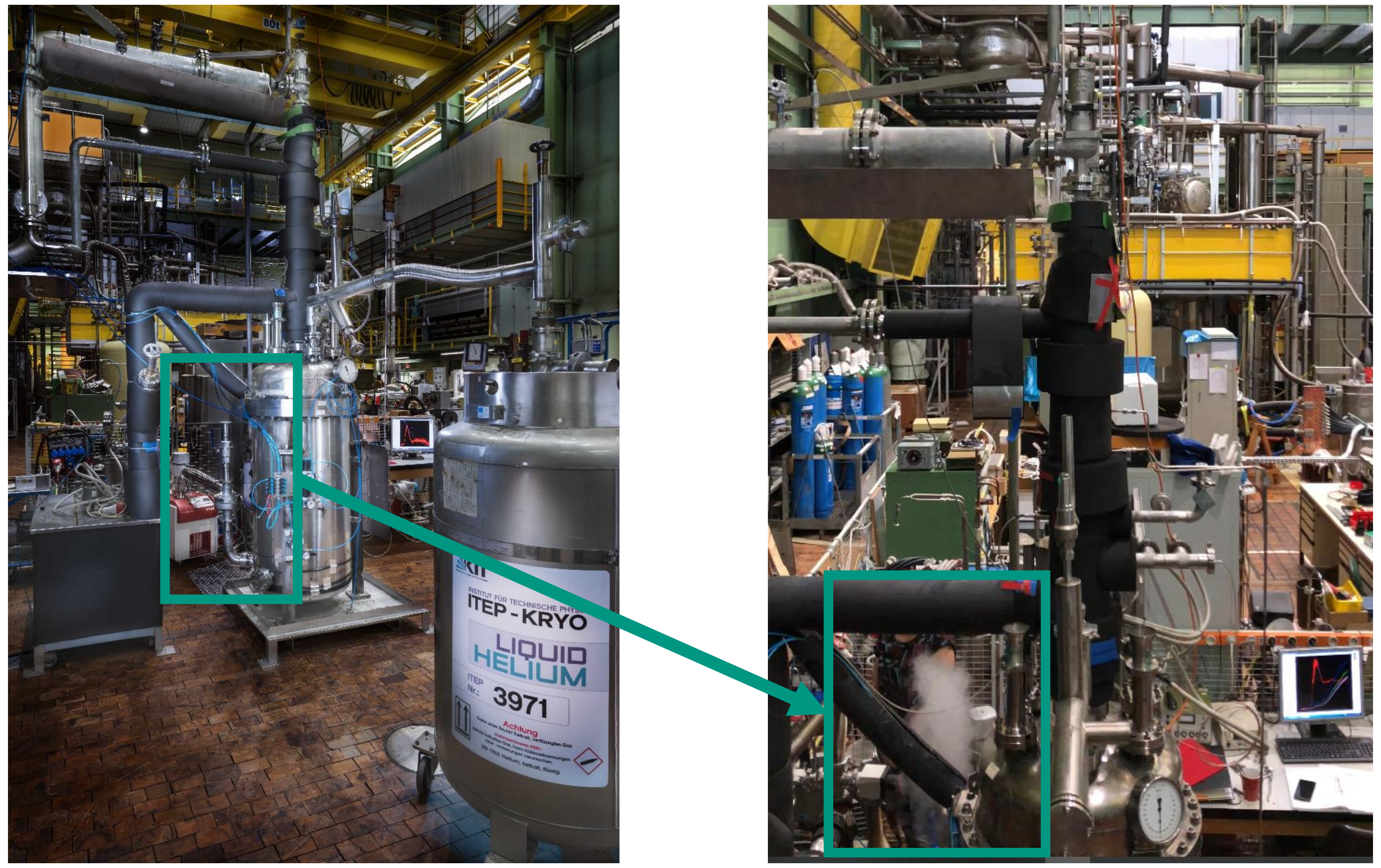


Helium vessel:

$$\dot{M}_0 = \frac{\dot{Q}}{v_0 \cdot \left(\frac{\partial h}{\partial v}\right)_{p_0}}$$

Vacuum vessel:

$$\dot{M}_0 = \dot{M}_{Sub} - \dot{M}_{out}$$



Further aspects

- Pressure relief devices
  - Emphasize on operating characteristics and tolerances particularly relevant for the combination of PRD in multi-stage protection concepts
- Substance release
  - Requirements for helium discharge lines and helium recovery systems
  - Direct helium release to the environment
- Operation of helium cryostats
  - User requirements regarding the inspection before commissioning
  - Periodic inspections and maintenance of pressure relief devices

Summary and outlook

- Foundation of new working group CEN/TC 268/WG6 in 07/2017

  „Specific helium technology applications“

- Aim: New European Standard

  „Helium cryostats – Protection against excessive pressure“

  Participating experts from 6 European countries, both from industry and research organizations

  Publication of the Standard is planned in 2020

THANK YOU FOR YOUR ATTENTION!