Research activities on cryogenic safety

Steffen Grohmann, Carolin Heidt, Andre Henriques (CERN), Christina Weber
European Cryogenics Days, CERN, June 9-10, 2016
Outline

- Safety of pressure equipment – What is special in Cryogenics?
- Current research activities (2015 – 2017)
- Future plans (2016 – 2019)
Safety of pressure equipment
WHAT IS SPECIAL IN CRYOGENICS?
Safety of cryogenic pressure equipment

- Cryogenic installations usually contain **pressure vessels**, subject to the European PED 2014/68/EU \( \{P_S > 0.5 \text{ bar(g)}\} \)

- **Storage containers** [static, transportable, (non-)vacuum insulated]: Dedicated standards, such as EN 13458, EN 13648, etc.

- **LHe cryostats**: No dedicated safety design standard/rule

- **LHe cryostat** conditions not covered by other standards:
  - Necessity of staging multiple safety levels
  - Large stored energies, loss of insulating vacuum
  - Inlet piping pressure drops (3 % rule) and heat loads (0.6 m rule)
  - Thermal acoustic oscillations
  - Two-phase flow
  - …
What is special in LHe cryostats?

- Process dynamics
  - Heat loads during system failure up to \( \dot{q} \approx 40 \text{ kW/m}^2 \)
  - Very low latent heat of helium \( \frac{\Delta h_v}{L_{\text{liquid}}} \rvert_{1\text{bar}} (\text{He} : \text{N}_2 : \text{H}_2\text{O}) = 1 : 62 : 835 \)
  - Nearly instantaneous evaporation
  - Pressure gradients in the range of (bar/s)

Quench test of a sc. solenoid (KATRIN)
What is special in LHe cryostats?

<table>
<thead>
<tr>
<th>Common pressure equipment</th>
<th>Liquid helium cryostats</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cryogenic storage containers</td>
<td>• Sc. magnet cryostats, RF cavities</td>
</tr>
<tr>
<td>• Protection against <strong>disruptive failure</strong></td>
<td>• Protection against <strong>disruptive failure</strong></td>
</tr>
<tr>
<td>➢ <strong>Extreme</strong> and <strong>rare</strong> failure scenarios</td>
<td>➢ <strong>Extreme</strong> and <strong>rare</strong> failure scenarios</td>
</tr>
<tr>
<td></td>
<td>+ Protection against <strong>operation failure</strong></td>
</tr>
<tr>
<td></td>
<td>➢ <strong>Expected</strong> and <strong>frequent</strong> failure scenarios (quenches)</td>
</tr>
<tr>
<td></td>
<td>➢ Need of <strong>staging</strong> safety levels!</td>
</tr>
<tr>
<td>• Standardized task (limited complexity)</td>
<td>• <strong>Complex</strong> design task</td>
</tr>
<tr>
<td></td>
<td>• Large number <em>papers</em>, individual <em>reports</em> and <em>experience</em></td>
</tr>
<tr>
<td></td>
<td>• <strong>BUT</strong> no systematic guideline</td>
</tr>
</tbody>
</table>
### Examples of typical safety units

<table>
<thead>
<tr>
<th>LN2 storage tank ($\approx 50,000$ L)</th>
<th>Liquid helium cryostat ($\approx 500$ L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Set pressure $p_0 = 17$ bar(g)</td>
<td>• Safety valve DN25 at $p_0 = 2$ bar(g)</td>
</tr>
<tr>
<td>• Two safety valves 1/2” ($d_0 = 7$ mm)</td>
<td>• Two rupture disks DN65 at $p_0 = 3$ bar(g)</td>
</tr>
<tr>
<td>• Shuttle valve</td>
<td>• Quench gas line DN100</td>
</tr>
</tbody>
</table>

Source: Air Liquide

Source: KATRIN
Safety of liquid helium cryostats

NATIONAL STANDARDIZATION PROJECT
(2010 – 2015)
## Contributions

### Industry

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blum, Lars</td>
<td>Linde Kryotechnik AG</td>
</tr>
<tr>
<td>Otte, Wolfgang</td>
<td>Air Liquide Deutschland GmbH</td>
</tr>
<tr>
<td>Reinhardt, Matthias</td>
<td>Herose GmbH</td>
</tr>
<tr>
<td>Schulenberg, Olaf</td>
<td>Goetze KG Armaturen</td>
</tr>
</tbody>
</table>

### Universities and Research Centers

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grohmann, Steffen</td>
<td>Karlsruhe Institute of Technology</td>
</tr>
<tr>
<td>Haberstroh, Christoph</td>
<td>Technical University Dresden</td>
</tr>
<tr>
<td>Heidt, Carolin</td>
<td>Karlsruhe Institute of Technology</td>
</tr>
<tr>
<td>Raccanelli, Andrea</td>
<td>Research Center Jülich GmbH</td>
</tr>
<tr>
<td>Schröder, Claus</td>
<td>GSI Gesellschaft für Schwerionenforschung mbH</td>
</tr>
<tr>
<td>Süßer, Manfred</td>
<td>Karlsruhe Institute of Technology</td>
</tr>
</tbody>
</table>

### Organization

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lau, Markus</td>
<td>German Institute for Standardization (DIN)</td>
</tr>
</tbody>
</table>
Publication (04/2015)

Contents

- 7 chapters, 73 pages
- (1) Hazard analysis, risk assessment and safety concept
- (2) Scenarios of pressure increase
- (3) Dimensioning of safety relief devices
- (4) Design and operation of safety relief devices and safety units
- (5) Release of the working fluid
- (6) Commissioning and maintenance
- (7) Materials for safety relief devices
Safety of liquid helium cryostats

CURRENT RESEARCH ACTIVITIES
New test facility (PICARD)

- **PICARD**
- **Features**
  - Vacuum jacket PN10
  - Venting with air or nitrogen
  - Venting diameters 1…40 mm
  - Neck-cooled radiation shield
  - Optional MLI tests
  - $V = 110 \text{ L inner vessel, PN16}$
  - Set pressures up to $p_0 = 12 \text{ bar(g)}$
  - He flow rates up to 4 kg/s
  - Fluids He, N$_2$, …
  - Max. DAQ sampling rate 1 kHz
  - 30 sensors (18 TVO)
KIT – CERN collaboration

Schedule 09/2015 – 03/2017

Experimental program

1) Relief flow rates for **breaking insulating vacuum** (without and with MLI)

2) Expansion in **two-phase region** → model validation/development → determination of flow coefficients

3) Measurements with relief point close to the **critical point**

Objectives

- Validation and further development of CERN’s **Kryolize® software**
- Development of **dynamic models** for heat loads and flow rates

➢ All results will be jointly published
First experimental results

**Example**

Venting with $N_2$ through 12.5 mm orifice, 28% initial helium level, set pressure $p_0 = 2.6$ bar(g)

- I – isochoric pressure increase;
- II – chattering and pumping;
- III – relief of rest gas (simmering)

- Permissible pressure **exceeded**!
- **Oversized valve** (25%), but next smaller valve would be **too small**
- Correctly sized valve $\rightarrow$ **small incident** $\rightarrow$ oversized valve
- **General risk** of chattering/pumping?
First experimental results

Example
Venting with $N_2$ through 12.5 mm orifice, 28% initial helium level, set pressure 2.6 bar(g)

Risk for staged safety levels

<table>
<thead>
<tr>
<th>Pressure relief characteristics</th>
<th>Pressure (%–PS)</th>
<th>System characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burst pressure</td>
<td>110</td>
<td>Maximum allowable accumulation pressure without fire MAAP</td>
</tr>
<tr>
<td>Rupture disc</td>
<td>100</td>
<td>Maximum allowable working pressure MAWP</td>
</tr>
<tr>
<td>Tolerance ±10 %</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Safety margin</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Relieving pressure</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Simmer</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Re-seat pressure</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Set pressure</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Safety valve</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Tolerance ±3 %</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Operating pressure</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

The graph shows the helium pressure over time during venting, with different stages labeled as I, II, and III.
First experimental results

Example
Venting with N\textsubscript{2} through 12.5 mm orifice,
28% initial helium level, set pressure 2.6 bar(g)

- Different procedures to qualify the set pressure \(p_0\)
  - Pop action (full lift safety valves)
  - Initial audible discharge
  - Start to leak pressure (?)
  - Bubble test

- Large effect on valve performance

- Helium leak \(\rightarrow\) flow between bubble test and initial audible discharge
Safety relief devices

Focus on **cryogenic performance** of safety relief valves

1) Measurement of **leak rates** between set pressure procedures “bubble test” and “initial audible discharge” (Bachelor thesis)

2) Experiments and modelling of **two-phase flow** → determination of **discharge coefficients** (Ph.D. thesis)

3) Investigation of **stability criteria** in cooperation with CSE – Center of Safety Excellence
Safety of liquid helium cryostats

FUTURE PLANS
(2016 – 2019)
European standardization project

- Satellite meeting at European Cryogenics Days 2015 (Grenoble)
  - Agreement to advance a European standardization process

- Translation of DIN SPEC 4683 and CEA documents

- Inconsistent nomenclature in different standards!
European standardization project

- Organization of **new working group** at CEN TC/268 by DIN

**Aim**
First International Standard on safety of LHe cryostats

**Participants welcome!**
Horizon 2020 project proposal

AMICI

*Accelerator and Magnet Infrastructure for Cooperation and Innovation*

- Aim: Knowledge transfer
- Coordination: CEA Saclay
- Participation: 10 European research labs

WP5.3: Harmonization – Cryogenic safety procedures

- KIT, CEA, CERN
- Link to new WG at CEN TC/268

S. Grohmann et al. - Research activities on cryogenic safety
Cryogenic safety seminar at CERN

- **Date:** Sep 21-22, 2016
- **Aim:** Share knowledge and the challenges liked to cryogenic safety
- **Topics:**
  a) European standardization activities
  b) Pressure relief and heat load experiments
  c) Research & development
  d) Rules & regulations
  e) Safety in large/medium scale projects
  f) Risk assessment methodologies
  g) Knowledge transfer

Register @: https://indico.cern.ch/e/CryoSafety

Thank you for your attention!