Research activities on cryogenic safety

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

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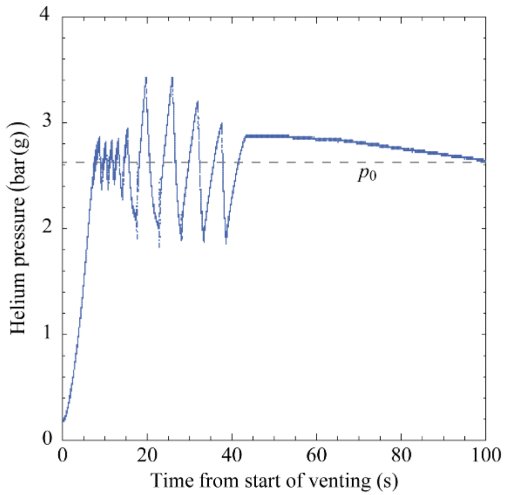

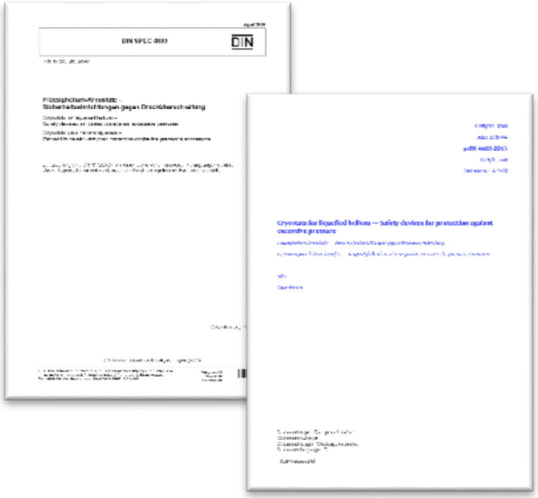

Outline

- Safety of pressure equipment – What is special in Cryogenics?
- Review of national standardization project (2010 – 2015)
- 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 $\{PS > 0.5\ \mathrm{bar(g)}\}$
  - **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 $\dot{q} \approx 40\ \mathrm{kW/m^2}$
  - Very low latent heat of helium $\rightarrow \left.\frac{\Delta h_{\mathrm{v}}}{\mathrm{L\ liquid}}\right|_{1\mathrm{bar}} (\mathrm{He} : \mathrm{N_2} : \mathrm{H_2O}) = 1 : 62 : 835$

↓

- ➢ Nearly instantaneous evaporation
- ➢ Pressure gradients in the range of $(\mathrm{bar/s})$

Quench test of a sc. solenoid (KATRIN)

What is special in LHe cryostats?

Common pressure equipment	Liquid helium cryostats
• Cryogenic storage containers	• Sc. magnet cryostats, RF cavities
• Protection against disruptive failure ➢ **Extreme** and **rare** failure scenarios	• Protection against disruptive failure ➢ **Extreme** and **rare** failure scenarios
	+ Protection against operation failure ➢ **Expected** and **frequent** failure scenarios (quenches) ➢ Need of **staging** safety levels!
	• Large number *papers*, individual *reports* and *experience* • **BUT** no systematic guideline
• Standardized task (limited complexity)	• **Complex** design task

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Examples of typical safety units

LN2 storage tank $(\approx 50.000\ \mathrm{L})$	Liquid helium cryostat $(\approx 500\ \mathrm{L})$
• Set pressure p_0 = 17 bar(g) • Two safety valves $1/2''\ (d_0 = 7\ \mathrm{mm})$ • Shuttle valve	• Safety valve DN25 at p_0 = 2 bar(g) • Two rupture disks DN65 at p_0 = 3 bar(g) • Quench gas line DN100

Source: Air Liquide

Source: KATRIN

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Safety of liquid helium cryostats

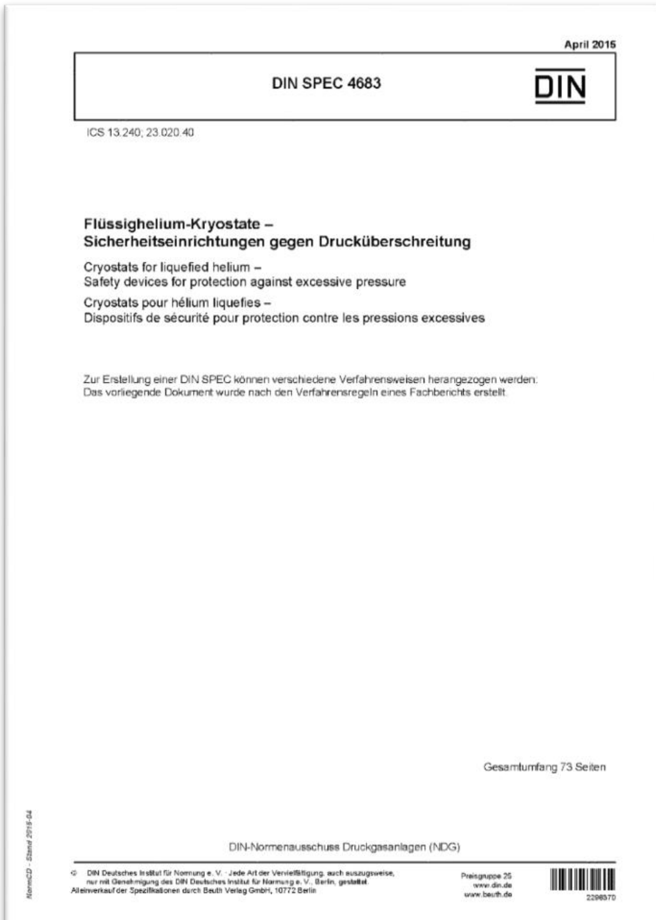
NATIONAL STANDARDIZATION PROJECT (2010 – 2015)

Contributions

Industry	
Blum, Lars	Linde Kryotechnik AG
Otte, Wolfgang	Air Liquide Deutschland GmbH
Reinhardt, Matthias	Herose GmbH
Schulenberg, Olaf	Goetze KG Armaturen
Universities and Research Centers	
Grohmann, Steffen	Karlsruhe Institute of Technology
Haberstroh, Christoph	Technical University Dresden
Heidt, Carolin	Karlsruhe Institute of Technology
Raccanelli, Andrea	Research Center Jülich GmbH
Schröder, Claus	GSI Gesellschaft für Schwerionenforschung mbH
Süßer, Manfred	Karlsruhe Institute of Technology
Organization	
Lau, Markus	German Institute for Standardization (DIN)

DIN SPEC 4683

- Publication (04/2015)


April 2015

DIN SPEC 4683 DIN

ICS 13.240; 23.020.40

Flüssighelium-Kryostate –
Sicherheitseinrichtungen gegen Drucküberschreitung

Cryostats for liquefied helium –
Safety devices for protection against excessive pressure

Cryostats pour hélium liquefies –
Dispositifs de sécurité pour protection contre les pressions excessives

Zur Erstellung einer DIN SPEC können verschiedene Verfahrensweisen herangezogen werden:
Das vorliegende Dokument wurde nach den Verfahrensregeln eines Fachberichts erstellt.

Gesamtumfang 73 Seiten

DIN-Normenausschuss Druckgasanlagen (NDG)

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NormCD - Stand 2015-04

- 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

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Safety of liquid helium cryostats

CURRENT RESEARCH ACTIVITIES (2015 – 2017)

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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

  - $V = 110\ \mathrm{L}$ inner vessel, PN16
  - Set pressures up to p_0 = 12 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

Kryolize® Project

➢ All results will be jointly published

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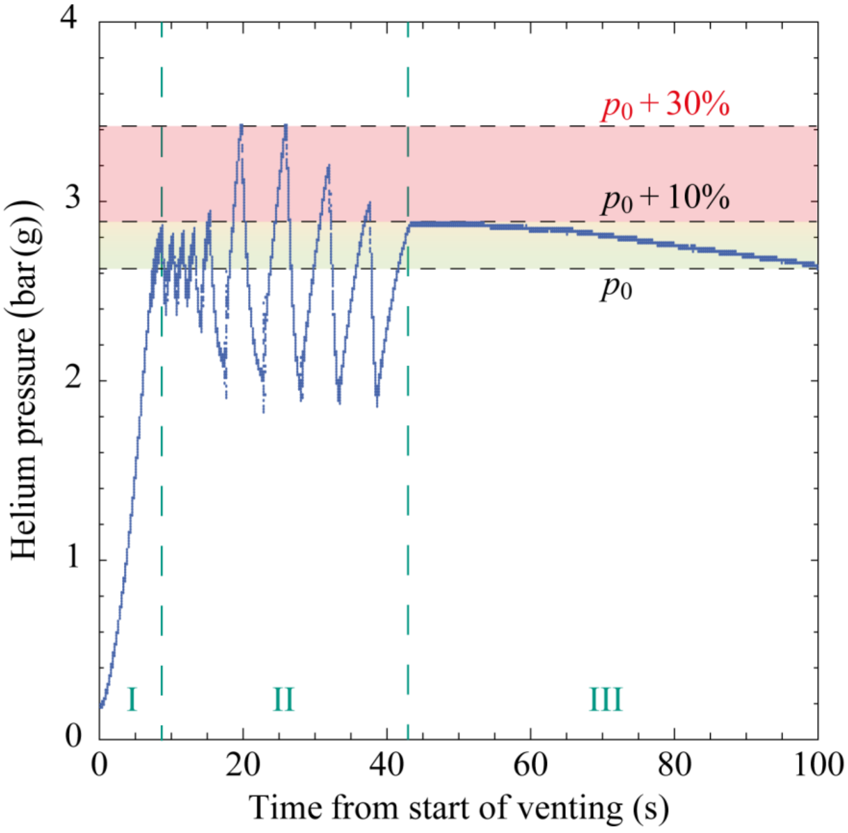
First experimental results

- 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 → **small incident** → oversized valve
- **General risk** of chattering/pumping?

First experimental results

- Example

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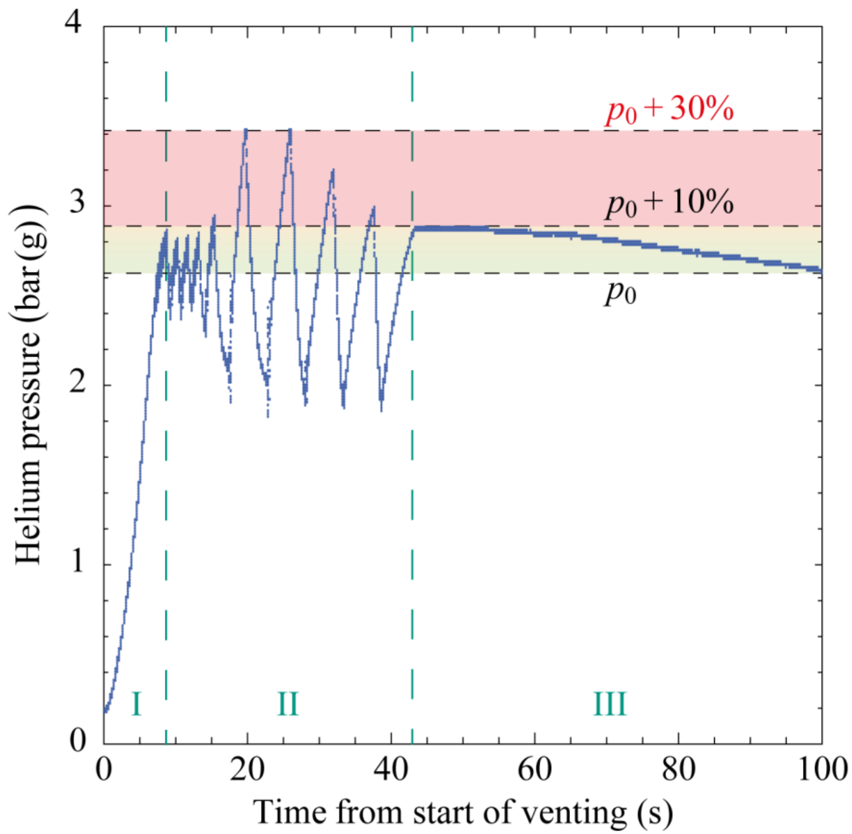
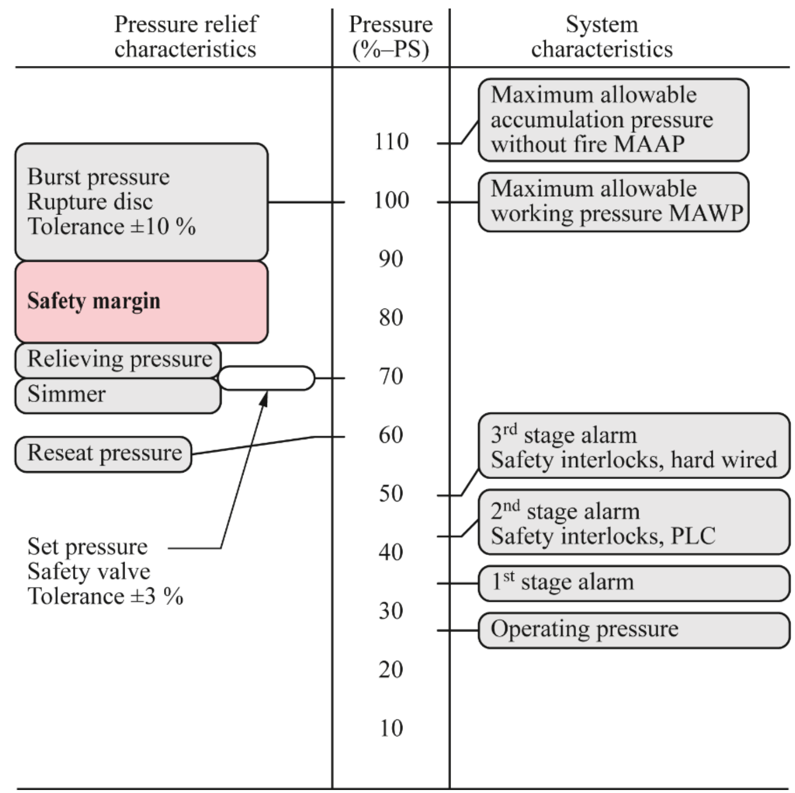
  28% initial helium level, set pressure 2.6 bar(g)



➢ Risk for staged safety levels



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First experimental results

- Example

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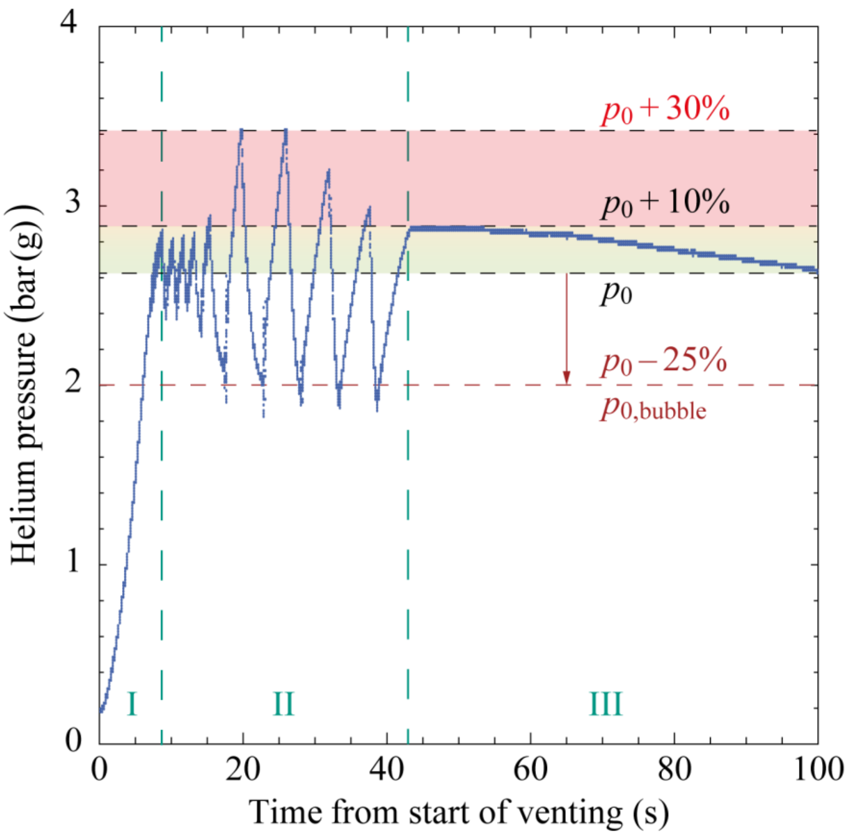

- **Different procedures** to qualify the **set pressure** p_0
  - Pop action (full lift safety valves)
  - Initial audible discharge
  - Start to leak pressure (?)
  - Bubble test
- Large effect on valve performance
- Helium **leak** → ***flow*** between *bubble test* and *initial audible discharge*

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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

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Safety of liquid helium cryostats

FUTURE PLANS
(2016 – 2019)

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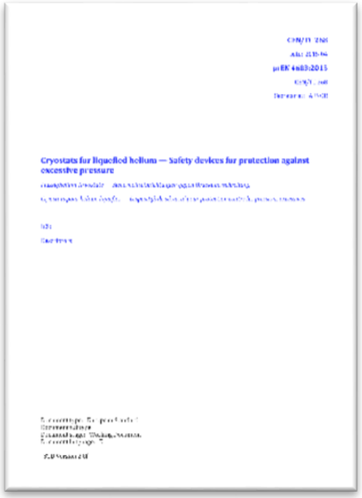
European standardization project

- Satellite meeting at European Cryogenics Days 2015 (Grenoble)
  - ➢ Agreement to advance a **European standardization process**
- Translation of **DIN SPEC 4683** and **CEA documents**

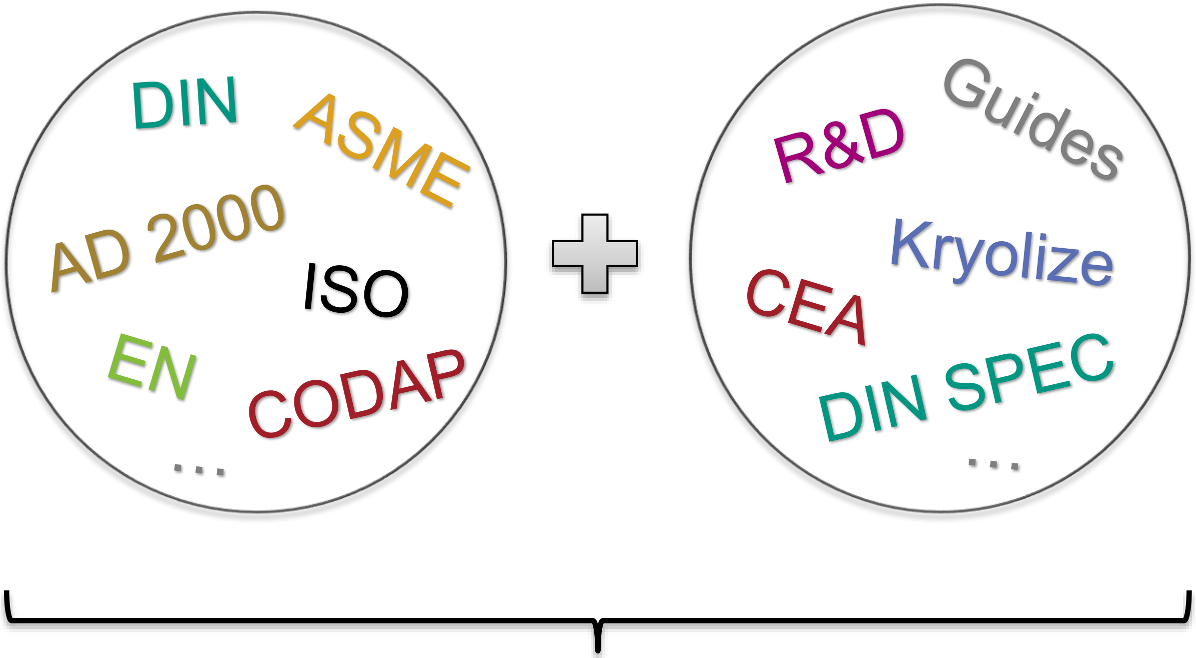

DIN SPEC 4683
DIN
Flüssighelium-Kryostate –
Sicherheitseinrichtungen gegen Drucküberschreitung


Cryostats for liquefied helium — Safety devices for protection against excessive pressure

  - ➢ Inconsistent **nomenclature** in different standards!
  - ➢ **Different definitions** of **set pressure** in ISO 4126 (2013), API 520 (2014) and ASME PTC 25 (2014)

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!

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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

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!

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