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MILESTONE REPORT

LIST OF SAFETY SCENARIOS IN HELIUM CRYOSTATS

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1. INTRODUCTION

The *List of safety scenarios in helium cryostats* presented below as AMICI Milestone M5.1 has been created by experts from CEA, CERN and KIT in conjunction with their participation in the European Committee for Standardization (CEN), working group *CEN/TC 268/WG6 – Specific helium technology applications*.

The inauguration of CEN/TC 268/WG6 took place at the DIN secretariat in Berlin on July 25, 2017 with the participation 15 experts from 5 countries. The 2nd meeting of the working group took place at KIT, Karlsruhe on October 19, 2017. This meeting was attended by experts from both industry and research labs, and progress was achieved on the structure and the content of the new Standard. The new Standard will be titled *"Helium cryostats – Protection against excessive pressure"*. Therefore, the restriction to liquid helium cryostats has been removed in the description of the AMICI Milestone M5.1.

The *List of safety scenarios in helium cryostats* was derived from the baseline documents of CEN/TC 268/WG6 as well as an FMEA-like procedure established at CERN. It was agreed in a dedicated AMICI WP5.3 meeting at CERN on December 8, 2017. This list is part of Section *4 – Risk assessment* in the new Standard of CEN/TC 268/WG6, being identical with the corresponding sub-section *4.1 – Sources of excessive pressure*. The list below contains the titles and short descriptions of each scenario. The standardised requirements of each scenario are yet to be agreed among the experts in the 3rd CEN/TC 268/WG6 meeting on February 8, 2018 in Paris.

2. LIST OF SAFETY SCENARIOS IN HELIUM CRYOSTATS

No.	Title	Description
4.1.1	Loss of insulating vacuum	Helium cryostats are generally vacuum-insulated. During loss of insulating vacuum (LIV), the vacuum system is vented with atmospheric air, yielding large heat loads on the helium system due to air de-sublimation and condensation, respectively. The actual heat load depends on the optional installation of multilayer insulation (MLI) on the cryogenic surface. Loss of insulating vacuum typically defines the maximum credible incident (MCI) in helium cryostats that determines the sizing of pressure relief devices.
4.1.2	Loss of beamline vacuum	The loss of beamline vacuum by venting with atmospheric air is similar to the LIV scenario. It applies in particular to superconducting accelerator facilities, where the inner beamline surface cannot be covered with MLI in general. This yields maximum heat flux values from the vented air to the cryogenic surface. Such incident can arise from the damage of interconnection bellows between two superconducting devices in a beamline.

No.	Title	Description
4.1.3	Leak of cryogenic fluid	In this scenario, either helium from the helium system or nitrogen from a liquid nitrogen insulation system leaks into the insulating vacuum space. This causes pressure increase in both the vacuum and the cryogenic fluid systems.
4.1.4	Quench of superconducting device	A quench signifies the spontaneous transition of a superconducting device from the superconducting state to the normal conducting state. The normal conducting state implies resistive losses that are dissipated to the helium in form of Joule heating. The heat load resulting e.g. from the quench of a superconducting magnet coil induces a significant pressure increase. In some situations, quenches are triggered deliberately in order to test or protect the superconducting device.
4.1.5	Thermal acoustic oscillation	A thermal acoustic oscillation (TAO) is a resonant gas oscillation built-up under certain conditions in half-open connecting lines between a cryogenic helium reservoir and installations at ambient temperature, such as pressure gauges and pressure relief devices. TAOs cause a strong increase of the heat transport along the respective line, causing typically also ice formation at the ambient installation. In addition, the associated pressure oscillation can cause the activation of pressure relief devices.
4.1.6	Cryopumping	The cryogenic surface of a helium cryostat acts as a cryopump, on which any gas but helium is de-sublimated. Minor leaks of either ambient air or e.g. nitrogen from a nitrogen insulation system into the vacuum system do not necessarily increase the vacuum pressure, but accumulate as frost layer on the cryogenic surface throughout operation. During warm-up, the solidified gases evaporate and pressurize the vacuum system.
4.1.7	Entrapment of cryogenic fluid	The entrapment of a cryogenic fluid in a closed volume, e.g. in-between two closed valves, causes pressure increase due to ever-present heat leaks.
4.1.8	Dielectric breakdown	Electrical insulators can become conductive if the voltage applied across exceeds the breakdown voltage. Depending on the electric energy stored in the system, dielectric breakdown can either cause small electric discharge following the Paschen law, or major electric arcs in high-current installations. Major electric arcs can destroy piping and vessels of cryogenic fluid circuits, yielding pressure increase in both the fluid and the vacuum systems.

No.	Title	Description
4.1.9	Power failure	Power failure result in a lack of cooling power that compensates the heat load in cryostats during normal operation, thus causing pressure increase. In addition, power failure prevents the normal operation of control valves and other actuators.
4.1.10	Pressure surge	Pressure surge is created by a sudden fluid velocity change that causes instable conditions. The fluid velocity change can be generated by e.g. starting/stopping pumps, opening/ closing valves or reductions in line size.
4.1.11	Freezing	Ice formation can occur both inside and outside helium cryostats. For instance, hazardous freezing of nitrogen can occur due to over-filling of liquid nitrogen insulated helium bath cryostats, disabling the pressure relief of the nitrogen system. Further, freezing of remaining liquid nitrogen can occur when purging pre-cooled circuits with gaseous helium. Another problematic scenario is ice formation due to the cool-down of leaking pressure relief devices that can cause malfunction or even blockage. On the other hand, ambient air can leak through pressure relief devices of sub-atmospheric helium systems, causing internal blockage due to freezing.
4.1.12	Backflow	Backflow can occur when connecting systems of different pressure, e.g. during transfer of liquid helium from storage Dewars into cryostats. The backflow of warm gas can cause a sudden evaporation of liquid helium.
4.1.13	Other sources of excessive pressure	Other sources of pressure increase in helium cryostat include, for example, the lack of cooling due to cryoplant malfunction, human errors, control errors and non-standard operation of valves.
4.1.14	Earthquake	Earthquake scenarios typically affect the mechanical design of helium cryostats (regulated e.g. in EN 13445), rather than the design of pressure relief devices. Nevertheless, earthquakes can trigger a break of insulating and beamline vacua through cryostat displacement and damage of connecting bellows.

No.	Title	Description
4.1.15	Fire	In accordance with the Pressure Equipment Directive, the case of fire is not required to be taken into account (as a precaution) for the design of pressure relief devices, as long as there is no fire load present within the meaning of this Code. The requirement given in the Pressure Equipment Directive, Annex I, Section 2.12 for external fire refers to the damage limitation level (c.f. Annex …) and is not intended to be used for the pressure limitation in normal operation (Pressure Equipment Directive Guideline 5/2 [2]). A fire load is considered to be a combustible substance in the vicinity of a helium cryostat, which represents a potential risk to the pressure vessel in the case of fire. Due to the heat transmission in the event of a fire, hazards may arise from the fire load by the touch of flames or thermal radiation. The consideration of fire would yield excessive oversizing of pressure relief devices, causing e.g. leakage and instable operation (chatter) with reduced discharge capacity and damage of spring-loaded pressure relief valves. It is therefore recommended to prevent the risk of fire in the vicinity of helium cryostats by appropriate measures such as fire prevention, fire protection and firefighting measures.