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Facility design and manufacturing to measure the thermal flux on liquid hydrogen tank during vacuum breaks

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With the development of the liquid hydrogen as an energy vector, some questions about its storage safety have to be addressed. Cryogenic tanks are thermally insulated with vacuum and possibly multi-layer insulation (MLI) blankets and the loss of vacuum (LOVA) is a classical accident to be considered. The key parameter to perform the safety device sizing is the thermal flux during this kind of LOVA events. In a cryostat without MLI, Belonogov [1] measured a heat flux close to the hydrogen critical flux at a pressure just above the atmospheric pressure (9.4 W/cm²) whereas following the standard ISO 21013-3 norm the thermal flux to be used is for the result of liquid helium tank LOVA experiments performed by KIT [2]. Without MLI the thermal flux with liquid helium is 3.8 W/cm² in contradiction with the Belonogov measurement. Bibliographic review has demonstrated that available quantitative data for hydrogen are poor, the safety design sizing is then complicated. Additionally, in the MLI-equipped case, other works [3] have shown that the values indicated in the same standard with MLI seems optimistic.

In order to have a better understanding of these issues and to obtain experimental data on a broader range of storage conditions the project ESKHYMO (Enhance Safety Knowledge for Hydrogen Measurements/Modelling in cryOgenic phase) funded by France 2030 [4], has been proposed by CEA and other academic and industrial partners to work on safety questions linked to liquid hydrogen usage. Within this project a dedicate and fully instrumented liquid hydrogen test bench for the thermal flux measurement during vacuum break has to be manufactured and tested. The test facility design carried out by the DSBT and the on-going manufacturing status is presented.

The main driver for the design is the bench flexibility to be able to test different accidental scenario typically either in subcritical discharge or supercritical one, with or without additional thermal insulation (MLI or other). Two vacuum vessels have been considered, the first one around the tank and the second above the tank for the instrumentation specifically designed by the DSBT. The vacuum is broken only around the thank and kept around the instrumentation to avoid any thermally-induced influence the response of the sensors during the test. The bottom part of the tank can be changed depending on the test to perform, and above all to adjust the thermal resistance of the tank wall when the operating safety device pressure is modified. Whenever possible, the components supplied (i.e. valves, safety devices, pumps) were chosen to comply with explosive atmosphere ATEX requirements. Special attention has been devoted to operate the installation safely. Designed to be transportable to areas compatible with the use of hydrogen the setup can be operated remotely. All the components have been supplied and the cryostat is under manufacturing for a delivery in the beginning of 2026.

[1] Belonogov, A.V., et al. Heat transfer with a breakdown of the insulating vacuum in vessels with cryogenic liquids. Chem Petrol Eng 14, 243–245 (1978). https://doi.org/10.1007/BF01143860

[2] W. Lehmann et G. Zahn, « Safety Aspects for LHe Cryostats and LHe Transport Containers» in 7th Internat. Cryogenic Engineering Conf., ICEC 7, London, July 4-7, 1978

[3] C. Zoller, « Experimental Investigation and Modelling of Incidents in Liquid Helium Cryostats, » PhD thesis., KIT, Karlsruhe / Karlsruher Institut für Technologie (KIT), 2018. doi : 10.5445/IR/1000082999.

[4] https://www.pepr-hydrogene.fr/projets/eskhymo/

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