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WORK PACKAGE

Alternative to liquid perfluorocarbon C6F14 for mono-phase detector cooling applications at CERN

Abstract

Many mono-phase convective detector cooling applications at CERN use perfluorohexane C6F14, a strong greenhouse gas with the GWP of 9300. The purpose of the proposed work package is to evaluate the fluoroketone C6K (with GWP≈1), as a sustainable environment-friendly alternative to C6F14 for the SciFi Tracker upgrade in LHCb and other CERN projects. This activity, initiated by the CERN LHCb group (PH-LBO) and further endorsed by the CERN Detector Cooling Project, will involve chemical and radiolytical characterizations of C6K and choosing appropriate on-line purification methods for it. The time frame of this project, initially focused on low radiation dose applications, is about one year starting from March 2015. A follow-up, to validate C6K for high radiation dose applications, is foreseen.

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HISTORY OF CHANGES

REV. NO.	DATE	PAGES	DESCRIPTIONS OF THE CHANGES
0.1	2015-02-25	8	Draft
0.2	2015-03-05	10	Draft, with the style updated, Michele's corrections, deliverables updated (with more stress on purification), the active role of TE-VSC-SCC reduced to a "limited participation/support"
0.3	2015-03-11/16	16	Appendix 3 is added, with a more detailed description of the work plan, more References are added
0.4	2015-03-22	18	Minor corrections, EN-MME-MM is mentioned along with TE-VSC-SCC; Appendix A4 is added. The version discussed with TE-VSC-SCC on 23.03.2015
0.5	2015-03-24		As discussed, the WP goal made more concrete; C6K only, with the initial focus on low-rad-dose applications and the anticipated follow-up to cover high dose cases. The Appendices 3 and 4 are detached to become independent annexes

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1. INTRODUCTION

As part of its general safety policy, CERN is committed to minimize the environmental impact of the research activities [1]. One of concerns in this domain is emissions of PFCs[1], potent green-house gases (GHG), covered by the Kyoto Protocol to the UN Framwork Convention on Climat Changes, which are still being released by CERN in significant quantities. A sizable fraction of these emissions falls to C6F14 used in many detector cooling systems as a heat transfer fluid. For example, in LHCb C6F14 accounts for ~5 ktCO_2e/year, or one third of all GHG emissions by this experiment. A similar situation, even to a larger extent, is observed in other LHC experiments. The programme [2] to monitor and reduce PFC emissions at CERN is ongoing under the supervision of the CERN HSE unit. In the long run, it implies promoting environment-friendly cooling technologies for new developments, in particular for LHC detectors upgrades, and search for drop-in alternatives to C6F14 for the existing systems with irreducible coolant losses.

These issues are addressed in the LS2 LHCb upgrade project which includes a replacement of the existing Outer Tracker with a new SciFi Tracker [3] requiring a large cooling system for its silicon photo-detectors, to operate them at down to -40°C. After evaluation [4] of several candidate options, a conventional mono-phase liquid cooling technology had been adopted, with the emphasis on using of a new thermal management fluid, fluoroketone 3M™ Novec 649[2] [5], having GWP≈1 (i.e. similar to that of CO2) and, at the same time, the thermo-physical properties very similar to those of C6F14. This solution, reflected in the LHCb Tracker Upgrade TDR [3] and, recently, in the detector cooling proposal [6] for the emittance measurements at the LHC (BGV project), was supported by the thermal mock-up tests performed in 2014 by the CERN LHCb group [7]. As a coolant, C6K turned out to be quite similar to C6F14.

The idea of using C6K was endorsed by the CERN Detector Cooling Project (DCP) [8] and has attracted attention of the CERN EN-CV group – in the broader context of finding alternative(s) to GHGs in cooling applications at CERN.

2. PURPOSE

The activity initiated by the present work package (WP), had been earlier outlined at the CERN management level [9]. In the long run, it is aimed at

- A validation of C6K for use in LHCb and other large LHC detectors, as a replacement of C6F14 in cooling applications at various temperature conditions and radiation environments. The work should include a full chemical and radiolytical characterization of C6K, relevant for the intended application. CERN has an experience of the C6F14 validation for cooling applications [10], but currently, the in-house resources for chemical analyses of fluids at CERN are very limited, therefore the new study has to be largely outsourced to one or several external laboratories.

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[1] The acronyms used in the text are explained in Appendix A1

[2] $C_6F_{12}O$, further referred to as C6K for brevity.

- establishing methods of on-line drying, degassing and purification of C6K from undesired by-products resulting from interactions within the cooling system and/or exposure to radiation[3].
- finding and evaluation of other prospective environment-friendly coolants alternative to C6F14, which appeared on the market during the last decade.

Given the very small expected radiation damage to the coolant in SciFi Tracker [11] and some other large emerging C6F14 cooling applications at CERN (like the brine cirquit of the ATLAS Thermosyphon []), it is proposed to start with a pilot study of chemical properties of C6K, especially its reactivity with liquid water (reported by the manufacturer, 3M company [12])[4]. Together with initial radiolytical characterization of C6K, *this is the subject of the present WP*. A full-scale radiological study of C6K (and other prospective liquid coolants), can be anticipated as a follow-up project.

3. DELIVERABLES

- An up-to-date market survey of different classes of commercial coolants suitable as sustainable alternatives to C6F14 for mono-phase liquid cooling applications at CERN.
- In-depth analysis of the published data about prospective fluids, taking into account their core properties as coolants (thermal conductivity, viscosity etc) and secondary aspects important for the intended application in detector cooling systems (possibility of drop-in replacement of existing GHG coolants, electrical insulation properties, compatibility with materials, radiation resistance, potential long-term chemical effects etc).
- Select and manage external agencies for *subcontracted studies* of C6K.
- As the result of these studies, acquire the knowledge on:
    a. Methods and techniques of *composition analysis* compatible with C6K; the composition of the as-provided fluid;
    b. *Reactivity with water* as function of temperature and water phase; dynamics of water intake in case of accidental direct contact of liquid water with C6K;
    c. appropriate methods of *on-line purification* (removal of moisture and the corrosive hydrolysis and radiolysis products from the circulating coolant) and if needed, *initial rectification*, see (a) above;
    d. methods of *on-line detection* of corrosive and hazardous products in the coolant, for the process control;
    e. *compatibility with metals*, resistivity of metals to the C6K hydrolysis products (mainly PFPA). The current metals of interest (in the order of decreasing relevance) are: titanium “grade 5” alloy, stainless steel, aluminium and copper;

[3] Because of greater chemical reactivity of new fluids, compared to C6F14 and other PFCs, the desiccants and acid absorbers currently used for C6F14 can be incompatible with these fluids.

[4] The cooling system design has to take into account potential secondary corrosive properties of the coolant under anomalous circumstances, e.g upon an accidental water intake in the event of breaking the cooling circuit hermeticity.

f. *radiation resistance* of the fluid to the ionizing doses of 50 and 1000 Gy and neutron fluence of 10^{12} neq/cm^2, taking into account the intended use as liquid heat transfer agent. The stress should be on such radiation-induced effects, as development of solid and undesirable (corrosive, hazardous) gaseous and liquid fractions, influence of initial impurities, the changes in viscosity and boiling point of the liquid fraction.

Commentaries on the above items and related tasks will be given in the annex(es) to the WP and the corresponding contract terms with subcontractors.

Contributions from different parties involved in this WP as listed in the table Table 1:

Group	Contribution/interaction
PH-LBO	- coordination (till December 2015), preparatory work, market survey - procurement of sample fluids (together with EN-CV) - irradiation of the samples at CERN and off-CERN centres - physical laboratory tests (heat transfer properties, compatibility with materials, viscosity etc), together with EN-CV, the DCP
EN-CV	- construction, certification and cleaning of test vessels for sample irradiation (Appendix A.1) - interaction with interested CERN groups, via the DCP - follow-up, coordination as of December 2015
Chemical laboratories	- consultancy and technical assistance (CERN TE-VSC-SCC) - chemical characterization of C6K (initial sample composition, reactivity with water, assessment of material compatibility tests performed earlier at PH-LBO) - study of water and acids removal methods compatible with C6K - study of radiolysis effects in irradiated samples

Table 1 — Task sharing between the WP participants.

4. PLANNING

The first round of studies, related to C6K chemical characterization and low-dose cooling applications, has to be completed by the end of 2015. It will be coordinated by P. Gorbounov of PH-LBO (SciFi Tracker group). Further studies (as of December 2015), dedicated to the broader implementation of the alternative coolant in the LS2 and LS3 LHC detector upgrades, will be coordinated by EN-CV. Intermediate C6K validation report will be prepared by January 2016 and the summary report C6K, including the pilot study of the C6K radiation resistance – in April 2016. The tentative planning is presented in the table Table 2. A more specific and detailed planning, taking into account the availability of subcontractors and the results of pre-irradiation studies, will be available as a separate file in the same EDMS page.

Action	Planning
Work package approval	March 2015
Early material compatibility tests	Ongoing (since December 2014)
Market survey	January–March 2015 (ongoing)
Design and production of test vessels	March-May 2015
Procurement of fluids for pre-irradiation tests	February 2015
Chemical studies (external lab)	March-December 2015
Intermediate report	December 2015-January 2016
Long-term materials compatibility study, test bench with circulation and filtration	January 2015 on
Preparation for high-dose irradiations	February 2016
Pilot radiolysis characterization	March-April 2016
Summary report	April 2016

Table 2 — Tentative planning of the WP.

5. BUDGET AND REQUIRED RESOURCES

The CERN LHCb group (PH-LBO) has already allocated ½ FTE·year to this work (P. Gorbounov, PJAS). The additional required resources through April 2016 are as follows:

- 1 FTE-year at PH-LBO for P.Gorbounov (applied physicist) – PJAS contract extension from June through Novemer2015 and subsistence from December 2015 through April 2016;
- a budget of 65 kCHF for materials (fluid samples, special containers, test bench construction, chemicals) and chemical analysis outsourcing.

We also request to secure

- a limited consultancy and technical support team by the TE-VSC-SCC_and EN-MME-MM teams, essential for interacting with the external labs and preparations for irradiations of the fluid samples.

Indirect expenses include the use of CERN irradiation facilities (CHARM, GIF++) and technical services (cleaning etc). Indirect contributions to the WP expenses are also expected from large users of PFCs at CERN, like ATLAS, CMS etc.

6. REFERENCES

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b) SiPM Cooling Workshop, 17 October 2013 https://indico.cern.ch/event/273434/

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7. a) P. Gorbounov, E. Thomas, “Thermal measurements with the SciFi read-out box mockups”, LHCb Internal Note LHCb-INT-2014-048 , in preparation;
b) P. Gorbounov, Summary Report on SiPM cooling at the 73rd LHCb week, September 2014, https://indico.cern.ch/event/335518/contribution/7/material/slides/1.pdf

8. CERN Detector Cooling Project, http://project-detector-cooling.web.cern.ch/project-detector-cooling/

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10. M.Battistin, S.Ilie, R.Setnescu, B. Teissandier “Chemical and radiolytical characterization of some perfluorocarbon fluids used as coolants for LHC experiments”:
Part 1, “Chemical characterisation” TS-Note-2006-010, EDMS 804849 https://edms.cern.ch/file/804849/1/TS-Note-2006-010.pdf ;
Part 2: “Radiolysis effects in C6F14 fluids”, TS-Note-2007-005, EDMS 642110 https://edms.cern.ch/file/842110/1/TS-Note-2007-005.pdf

11. P.Gorbounov, Assessment of the radiation damage to the coolant in SciFi tracker, November 2014, EDMS 1421023 and https://twiki.cern.ch/twiki/pub/LHCb/C6K/Memo_on_irradiation_damage_for_C6K.pdf

12. ATLAS Thermosyphon project, EDMS ….

13. From the 3M Product Bulletin “What you need to know about Novec….”
   - “Novec 1230 reacts with moisture to form HFC-227ea and pentafluoropropionic acid (PFPA).
   - “Novec 1230 fluid **reacts with water only when dissolved in water and it is only minimally soluble in water**. Accordingly, only a very small amount of acid is formed when Novec 1230 fluid contacts liquid water and **no acid is formed when Novec 1230 fluid contacts water vapor.** This has been verified through numerous laboratory and full-scale tests in which Novec 1230 fluid was discharged into a humid atmosphere and monitored via methods such as FTIR. No formation of PFPA has been detected.”