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HL-LHC PROJECT

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(see document ref. EDMS 1271880 for the detailed procedure)

Date: 2018-03-28

ENGINEERING CHANGE REQUEST

Amorphous carbon coating in standalone magnets of the LHC in IR2 and IR8 during LS2 2019-2020

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

This ECR proposes and describes the "in-situ" coating of the beam screens in the LHC standalone magnets Q5R2, Q6R2, Q5L8 and Q6L8 with a thin film of amorphous carbon (a-C) during LS2.

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SUMMARY OF THE ACTIONS TO BE UNDERTAKEN:

<u>During LS2 2019-2020</u>: amorphous Carbon (a-C) coating of both beam screens of LHC standalone magnets Q5R2, Q6R2, Q5L8 and Q6L8. In synergy with the replacement of the anti-multipacting solenoids in high radiation areas of the LHC, the RF inserts of the vacuum modules at the extremities of these magnets will be replaced by a-C coated ones.

Note: When approved, an Engineering Change Request becomes an Engineering Change Order.

1. EXISTING SITUATION AND INTRODUCTION

The Electron Cloud (EC) phenomenon, has been recognised as a limiting factor for the achievement of HL-LHC performance. For the cryogenic parts of LHC the EC provides a high level of heat load, which will further increase with the 25ns bunch spaced beams at HL-LHC intensity.

In the region of the inner triplet magnets, the heat load represents an identified issue since Run 2 ("The heat load on beam screens (e-cloud) and inner triplets (secondaries) pose the main limitations to the cryogenic system during Run 2." [1]) and will exceed the cooling capability of the foreseen cryogenic plant [2] in the HL-LHC era. The baseline measure to overcome this limitation is the coating of the beam screens of the inner triplet magnets with a low Secondary Electron Yield (SEY) a-C thin film.

CERN developed carbon coatings with low SEY to mitigate the EC phenomenon in the SPS. At present about 20 dipoles and 15 quadrupoles were coated during LS1, EYETS and YETS "in-situ" in the tunnel and a stepwise deployment is foreseen to continue in LS2. In the development and installation phase it was concluded that a-C coating effectively suppresses the e-cloud, does not deteriorate in performance over time and is mechanically stable (no peel off, no dust formation).

The specific development for the LHC BS configuration has been shown ([3], [4]). At present, the coating of 10m long BS with performance within specification has been demonstrated.

For the inner triplets in IR2 and IR8, the coating will be deployed "in-situ", without removing the magnets from their positions in the tunnel. For those in IR1 and IR5, the coating will be applied during the fabrication of the new inner triplet magnets. These actions are planned for LS3.

In the LSS of IR2 Right and IR8 Left, the standalone magnets of the matching sections share the cooling circuit with the magnets in the adjacent arcs and the expected heat load will approach the installed cooling capacity (LEP-type refrigerators). In order to validate the in-situ coating process in the LHC and increase the margin for arc cooling in sectors 23 and 78 for the HL-LHC era, a proposal to coat some standalone magnets was presented in the LHC Performance Workshop 2018, coming from the development team [5] and from the Task Force on Beam Induced Heat Load [6]. The proposal has been endorsed by the recommendations of the CMAC ("The plan presented to mitigate the e-cloud impact on the inner triplet and standalone magnet beam screens is convincing. The committee supports the coating of the free standing magnets during LS2." [7]. The very same strategy has been endorsed by the 46th HL-LHC TCC following the presentation of WP12 [8].

This ECR proposes and describes the in-situ coating of standalone magnets in the regions Q5R2-Q6R2 and Q5L8-Q6L8 during the LS2 period, as a first step of a possible staged deployment of a-C coating in the triplet region.

2. REASON FOR THE CHANGE

As stated in the introduction, the EC will become a problem for the heat load of part of the arcs and triplet regions of LHC at HL-LHC intensity.

Coating a selected number of Q5 and Q6's BS during LS2, in combination with additional instrumentation, will enable to estimate the heat load reduction with LIU beams. It will also allow early validation of the in-situ coating procedure, tooling and activity duration in anticipation of the LS3 in-situ campaign.

Furthermore, an additional margin in the refrigeration power for the sectors 23 and 78 would be achieved by coating the standalone magnets in R2 and L8 with a low SEY a-C thin film. This is particularly relevant for the HL-LHC era, since these sectors are cooled by ex-LEP's refrigerators.

3. DETAILED DESCRIPTION

3.1 MAGNETS TO BE COATED

The magnets to be coated are the Q5 and Q6 in the matching sections in the LSS of IR2 Right and IR8 Left. These are twin-bore magnets equipped with 50L type beam screens, (drawing number LHCVSSB_126), assembled with the smallest aperture in the horizontal direction (H) for one beam and in the vertical direction (V) for the other beam [9]. The orientation of the beam screens in each magnet is shown in Table 1 together with the number of the drawings relevant to the coating process: layout of the LSS's, assembly operation, and the cold/warm transitions. Both beam screens in each magnet will be coated and the expected (simulated) heat load due to electron cloud for the cases of maximal SEY of 1.3 (conditioned) and 1.1 (a-C coated) in the presence of HL-LHC beam [10] is also displayed in Table 1. Figures 1 and 2 shows photos of the interconnections at the extremity of each magnet.

Table 1 — Beam screen orientation, drawings relevant to the coating campaign and the heat loads expected with HL-LHC beam for the cases of maximal SEY of 1.3 and 1.1 [10].

		Q5R2	Q6R2	Q5L8	Q6L8
Beam screen orientation beam 1 beam 2		H V	V H	V H	H V
Layout drawing		LHCLSX__0004	LHCLSX__0004	LHCLSX__0015	LHCLSX__0015
Assembly operation drawing		LHCLQS_S0130	LHCLQS_S0166	LHCLQS_S0130	LHCLQS_S0131
Cold/Warm transition upstream		LHCLVTB_0002	LHCLVTB_0001	LHCLVTB_0002	LHCLVTB_0001
Cold/Warm transition downstream		LHCLVTB_0003	LHCLVTB_0004	LHCLVTB_0003	LHCLVTB_0004
Heat load due to e-cloud (simulated)	SEY_{max} = 1.3	162 W	192 W	162 W	192 W
	SEY_{max} = 1.1	1 W	1 W	1 W	1 W

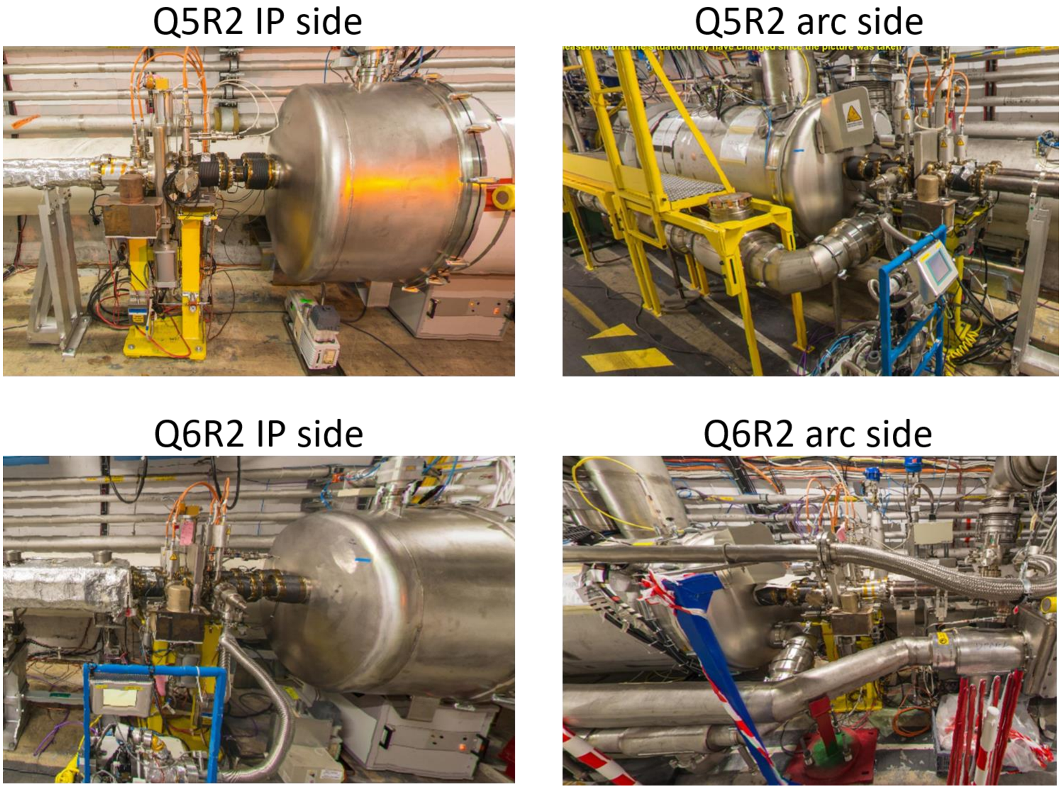


Figure 1 — The Q5 and Q6 standalone magnets in the LSS of IR2 Right (source: CERN layout database).

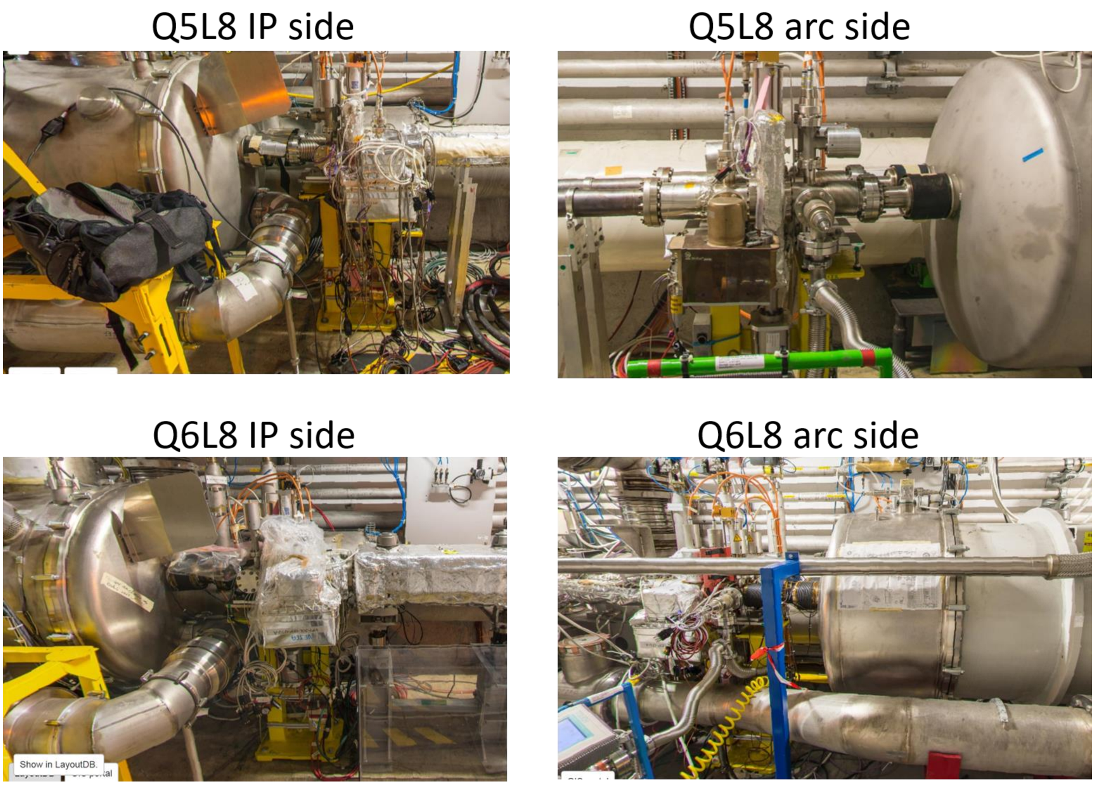


Figure 2 — The Q5 and Q6 standalone magnets in the LSS of IR8 Left (source: CERN layout database).

3.2 THE COATING PROCESS

The coating will be applied "in-situ", (with the magnet in its position in the ring), by physical vapour deposition using a modular magnetron sputtering source with two targets: one of titanium and another of graphite (Figure 3). The sputtering source is pulled by cables in order to deploy the coating along the beam screens. In a first step a 150 nm thick titanium layer is applied in order to enhance the adhesion and to decrease the outgassing of the beam screen and the cold bore, and in a second phase a top layer of carbon (50 nm thick) is deposited. During the deposition of the carbon layer, titanium is also deposited (and subsequently covered by the carbon) in order to pump the hydrogen and the water molecules present in the plasma and ensure that the maximal secondary electron yield remains below 1.1. The overall thickness of the titanium layer will not exceed 500 nm, the operation is done at ambient temperature and no bakeout is applied. During the deposition, the maximal power applied to the sputtering source is 30 W, distributed along 30 cm of target. This results on a maximal temperature at the cold bore below 65°C. Details of the coating process and setup can be found in [4].

The beam screens will be fully coated but, due to the geometry of the coating source, the first 30 cm of the cold/warm transitions will not be completely covered with the carbon layer. In these zones, the e-cloud will be mitigated by the anti-multipacting solenoids already installed in the SSS flange+bellow assembly as indicated in Figure 4.

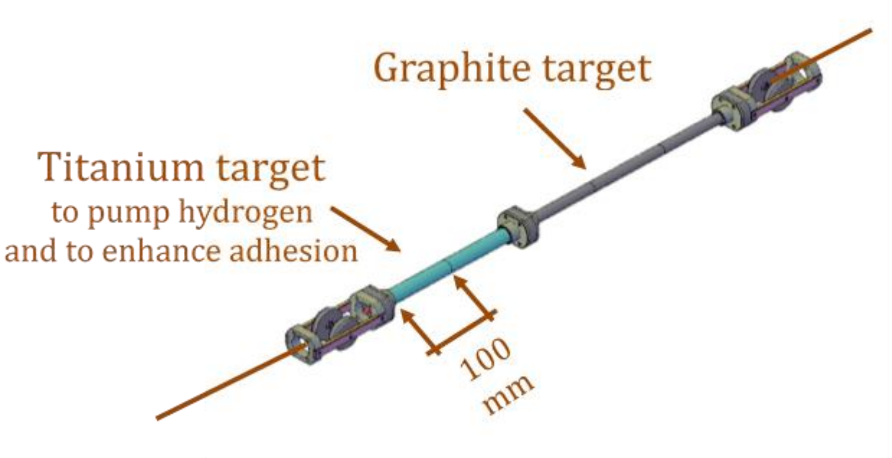
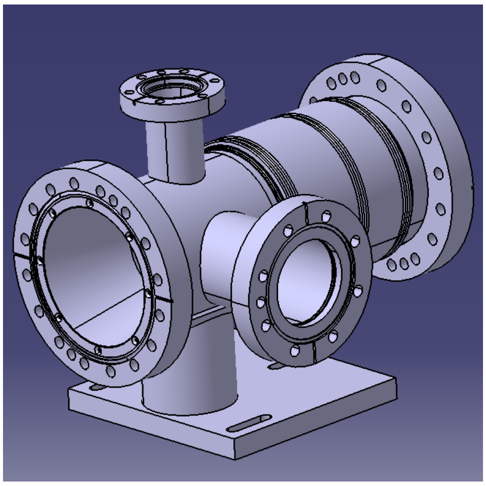


Figure 3 — Schematic view of the modular sputtering source with the titanium and the graphite targets.

In order to insert the coating source, the vacuum modules between the magnets and the sector valves (Figure 4) have to be dismounted; the RF inserts in these modules will be replaced by a-C coated ones. This is in line with the campaign to remove the number of anti-multipacting solenoids by replacing the existing RF modules by a-C coated ones. This intervention is described in another ECR (EDMS document 1911881 [11]). The sector valves will remain closed to keep the NEG coated drift chambers upstream and downstream of the magnets under vacuum.

During the intervention, the transport passage in the tunnel will not be blocked. In Table 2 are shown the different operations and intervening teams.

Additional instrumentation to measure the heat load in the coated magnets will be proposed by the Beam Induced Heat Load task force and implemented during LS2.



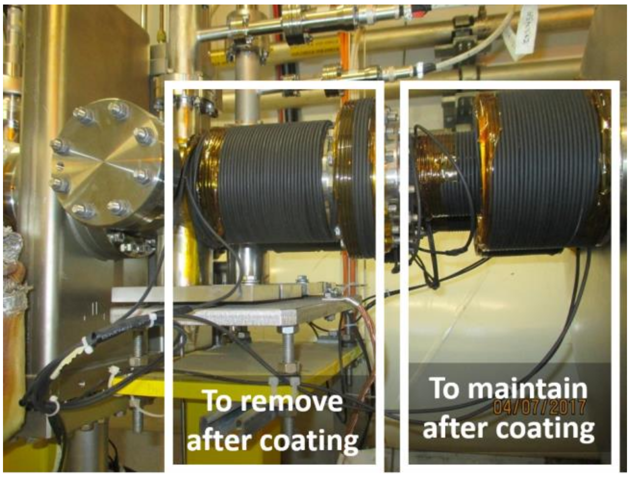


Figure 4 — (Left) Vacuum module VMAOC for the internal beam, upstream, of Q5R2. (Right) Anti-multipacting solenoids wrapped around the cold-to-warm transition in Q5R2. After the coating,

Table 2 — Schematic of the operations and intervening teams to deploy the coating in the Q5 and Q6 magnets.

Operation	intervenient
Removal of solenoids and vacuum modules	TE-VSC-BVO
Remove the line connecting the collector of the current leads of the DFB and the warm He recovery line. (Q6 only)	TE-CRG
Install new instrumentation to measure heat load (valves, thermocouples).	TE-CRG
Optical inspection (endoscopy with camera)	TE-VSC-SCC
Coating	TE-VSC-SCC
Reinstallation of vacuum modules	TE-VSC-BVO
Pump down and leak detection	TE-VSC-BVO
Reinstallation of the line connecting the collector of the current leads of the DFB and the warm He recovery line (Q6 only)	TE-CRG

4. IMPACT ON OTHER ITEMS

4.1 IMPACT ON ITEMS/SYSTEMS

Item/System xxxxx	[Use this table to detail the impact on any equipment, items or systems that will be affected by the change.]
Item/System xxxxx	For Q6R2 and Q6L8, temporary removal of part of the line connecting the collector of the current leads of the DFB and the warm He recovery line. (Figures 1 and 2). For Q6R2 the tube is dismountable through flanges while for Q6L8 cutting/welding is required. TE-CRG (Antonio Perin)
Item/System xxxxx	

4.2 IMPACT ON UTILITIES AND SERVICES

Raw water:	--
Demineralized water:	--
Compressed air:	--
Electricity, cable pulling (power, signal, optical fibres…):	The systems will be connected to the electrical sockets dedicated to the bakeout racks.
DEC/DIC:	--
Racks (name and location):	--
Vacuum (bake outs, sectorisation…):	Venting (before intervention) and pump down after the completion of the operation are assured by TE-VSC. The section valves at the extremity of each magnet will remain closed to keep the drift zones under vacuum (NEG coated chambers). No bakeout is required.
Special transport/ handling:	--
Temporary storage of conventional/radioactive components:	The vacuum modules dismounted to allow access the beam screens of the magnets will be stored in the tunnel under the adjacent drift tubes.
Alignment and positioning:	--
Scaffolding:	--
Controls:	--
GSM/WIFI networks:	--
Cryogenics:	--
Contractor(s):	--

Surface building(s):	--
Others: layout database	The layout database will be updated to reflect that the beam screens are coated. The same principle of the RF insert NEG coated will be used. This implementation is managed by VSC-BVO and EN-ACE.

5. IMPACT ON COST, SCHEDULE AND PERFORMANCE

5.1 IMPACT ON COST

Detailed breakdown of the change cost:	Total hardware cost: 245 kCHF from which 185 kCHF is for construction of the main systems (2 for production + 1 spare parts) that will be used in LS3 to coat the inner triplets. The remaining 60 kCHF are for specific tooling to coat the standalone magnets and will be used again during LS3 to coat Q4 and D2. Manpower (coating team): 1 FELL + 1 TTE for 2 years. This represents an additional cost, (relative to the coating of inner triplets), specific to the coatings of standalone magnets in LSS2 and LSS8. Within the 2 year presence, 6 months will be required for training and trials, plus 6 months for the in-situ intervention. The remaining time will be devoted to the baseline developments for triplet in-situ and ex-situ coating. The 6 month intervention period may be segmented depending on LS2 planning constraints.
Budget code:	Hardware: 91706 Manpower: 91711 (1 FELL + 1 TTE)

5.2 IMPACT ON SCHEDULE

Proposed installation schedule:	Preferentially the coating campaign would start in April 2019 to be completed by September 2019.
Proposed test schedule (if applicable):	--
Estimated duration:	6 months
Urgency:	--
Flexibility of scheduling:	Can start up to July 2020 (to be completed by December 2020). It can also be split in two or more periods.

5.3 IMPACT ON PERFORMANCE

Mechanical aperture:	--
Impedance:	A study conducted by BE-ABP concluded that in spite of an increase of the impedance in the high frequency range, (above 100 MHz), the overall impact is negligible compared to the other sources of impedance. [12]
Optics/MADX	--
Electron cloud (NEG coating, solenoid…)	Electron cloud will be eliminated.
Insulation (enamelled flange, grounding…)	--
Vacuum performance:	The thermal outgassing at room temperature after 20 hours of pumping will be two times higher.

	Elimination of electron stimulated desorption in dynamic conditions (with beam).
Others:	

6. IMPACT ON OPERATIONAL SAFETY

[This chapter aims at assessing the impact of the modification on people safety, on the environment, and on the safety of operations, including maintenance, access, egress, circulation and evacuation.]

6.1 ÉLÉMENT(S) IMPORTANT(S) DE SECURITÉ

[Indicate if the change will have an impact on an *Elément Important de Sécurité* (EIS). The list of EIS components is available in EDMS document: 1182293 – "Définition et Inventaire des EIS-Faisceau et EIS-Machine en Opération".]

Requirement	Yes	No	Comments
EIS-Access		X	[Provide further details on the impacted EIS.]
EIS-Beam		X	
EIS-Machine		X	

6.2 OTHER OPERATIONAL SAFETY ASPECTS

Have new hazards been created or changed?	[e.g. obstruction of evacuation paths, new voltage supply, new chemical introduced, etc.] --
Could the change affect existing risk control measures?	[e.g. safety systems may need relocation, or additional safety systems or monitoring systems have to be installed, etc.] --
What risk controls have to be put in place?	--
Safety documentation to update after the modification	--
Define the need for training or information after the change	--

7. WORKSITE SAFETY

[Refer to EDMS document: 1155899 – "Working on the CERN Site".]

[Following the implementation of the change, the Safety File of the facility shall be updated. In the temporary absence of the Safety File, the hazards inventory and risk analysis of the concerned installation shall be established.]

7.1 ORGANISATION

Requirement	Yes	No	Comments
IMPACT – VIC:	X		The IMPACT will be managed by TE-VSC. In the case of Q6L8, a VIC may be required for the dismounting/mounting of the tube between the collector of the current leads of the DFB and the warm He line.
Operational radiation protection (surveys, DIMR…):		X	
Radioactive storage of material:		X	The RF inserts removed from all the modules, (being replaced by a-C coated ones), will be stored in the VSC bunker and considered as spares for future use in the machine.
Radioactive waste:	X		Small components like gaskets and bolts will be radioactive waste.
Non-radioactive waste:	X		Copper gaskets, bolts, aluminium foil, Nitril gloves.
Fire risk/permit (IS41) (welding, grinding…):	X		Grinding will be necessary before the intervention in Q6L8 (to remove temporarily the tube between the collector of the current leads of the DFB and the warm He recovery line). After the coating operation, welding will be required to restore the initial configuration.
Alarms deactivation/activation (IS37):			--
Others:			--

7.2 REGULATORY TESTS

Requirement	Yes	No	Responsible Group	Comments
Pressure/leak tests:	X		TE-VSC	After remounting, all the vacuum modules will be leak tested.
Electrical tests:		X		
Others:		X		

7.3 PARTICULAR RISKS

Requirement	Yes	No	Comments
Hazardous substances (chemicals, gas, asbestos…):		X	
Work at height:		X	
Confined space working:		X	
Noise:		X	

Cryogenic risks:		X	
Industrial X-ray (*tirs radio*):	X		After remounting, the RF bridges of each vacuum module will be inspected by x-rays.
Ionizing radiation risks (radioactive components):		X	
Others:		X	

8. FOLLOW-UP OF ACTIONS

BY THE TECHNICAL COORDINATION

Action	Done	Date	Comments
Carry out site activities:			
Carry out tests:			
Update layout drawings:			
Update equipment drawings:			
Update layout database:			
Update naming database:			
Update optics (MADX)			
Update procedures for maintenance and operations			
Update Safety File according to EDMS document 1177755:			
Others:			

9. REFERENCES

[1] F.Bordry, Summary of the LHC performance meeting of Chamonix 2017, 1.3.2017 *http://indico.cern.ch/event/614870/attachments/1422196/2179961/Fk_Bordry_Chamonix_2017_Summary.pptx*

[2] G.Skrypka and G.Iadarola, Beam-induced heat load on the beam screens of the inner triplets for the HL-LHC http://cds.cern.ch/record/2305245/files/CERN-ACC-NOTE-2018-0009.pdf?version=1

[3] P.Costa Pinto, Coating options for IR2 and IR8, LHC performance meeting Chamonix 2016, http://indico.cern.ch/event/448109/contributions/1942068/attachments/1218949/1780986/Chamonix_2016_Coating_Options_for_IR2_and_IR8_pedro.pptx

[4] P.Costa Pinto, In situ aC coating performances and status of LESS and tunnel implementation for LS2, 7th HL-LHC collaboration meeting, Madrid 2017, https://indico.cern.ch/event/647714/contributions/2633173/

[5] P.Chiggiato, Beamscreen treatment for LHC's Point 2 and 8, https://indico.cern.ch/event/676124/contributions/2775544/attachments/1590646/2521523/Chamonix_TE-VSC_presentation_Paolo_Chiggiato.pdf

[6] L.Tavian, Report from the task force on beam induced heat load https://indico.cern.ch/event/676124/contributions/2767828/attachments/1591069/2518196/Chamonix18_Tavian_Final.pdf

[7] CMAC recommendation, Chamonix 2018.

[8] V.Baglin, Preparation of the ECR regarding the modification of the HL-LHC base line for a-C coating, 46th HL-LHC TCC, 2018 https://indico.cern.ch/event/705929/contributions/2896933/attachments/1605341/2547064/46_HL-LHC_TCC-AOB-aC_coating-_V_Baglin.pdf]

[9] V. Baglin, N. Kos, Beam screens for the LHC Long Straight Sections, EDMS 334961

[10] G. Iadarola, E. Metral, G. Rumolo, Beam induced heat loads on the beam-screens of the twin-bore magnets in the IRs of the HL-LHC, CERN-ACC-2016-0112

[11] E. Page, ECR regarding the Removal of Electron Multipacting Suppressor Solenoids in High Radiation Area of the LHC (EDMS 1911881), 2018.

https://edms.cern.ch/file/1911881/0.1/LHC-V-EC-0012-0-1.docx

[12] S. Antipov, D. Amorim, N. Biancacci, B. Salvant, Impedance effects of the HL-LHC coated inner triplets, presented at the 136th BE-ABP-HSC section meeting 19-03-2018. https://indico.cern.ch/event/712792/contributions/2928183/attachments/1619137/2574964/Impedance_effects_of_the_HL-LHC_coated_inner_triplets.pdf