“DFX Conceptual Design Review” Report

20 February 2019 **EDMS 2086946 ver. 1.0**

Editor: Michele Modena

This document reports the outcome of the *“DFX Conceptual Design Review” (CDR)* held on **31 January 2019** and **12 February 2019** (https://indico.cern.ch/event/783116/ and https://indico.cern.ch/event/797964/).

The Report is structured in:

- *Introduction*
- *Executive Summary with main Recommendations*
- *Review of Contributions (providing for each presentation: “Findings”, “Comments” and “Recommendations”).*

Introduction

Review Scope, Mandate and Program were defined, by TE-MSC in agreement with HL-LHC Project, as follows:

Scope: Review the conceptual design of the DFX with the purpose of validating maturity and confirm readiness for starting the detailed design.

Mandate of the Review Committee:

1) Review the functional specification and confirm its completeness in terms of cryogenic, mechanical and electrical requirements;

2) Review the functionality of the design concept with respect to cryogenic design and operational aspects, mechanical design and interfaces, electrical design and interfaces;

3) Review the proposed integration and installation plan in the LHC machine and the compatibility of the DFX location with respect to the Tunnel environment (including preliminary plan for maintenance and repair interventions during operation);

4) Review cryogenic requirements for safety aspects and compatibility of safety equipment with Tunnel environment;

5) Review of plan for detailed design development;

6) Review schedule for prototype production, including strategy for intermediate validation and production of prototype lambda-plate.

Review Committee: S. Atieh, K. Brodzinski, M. Modena (chair), F. Rodriguez Mateos, D. Tommasini.

***Note**: The Review Committee retains that it was not in the scope of this review the comparison of the different DFX possible layouts (horizontal, inclined, vertical). The proposed vertical configuration is assumed to be the result of an evolution previously studied and accepted.*

Presentations:

- *Welcome (**L. Bottura**)*
- *1. WP6a master plan, key milestones, functional requirements, DFX within WP6a system (**A. Ballarino**)*
- *2. DFX Functional specification (**Y. Leclercq**)*
- *3. DFX Cryogenic cooling and flow scheme, interface with cryo-equipment (**S. Claudet**)*
- *4. DFX Conceptual design – including strategy for maintenance and repair **(Y. Yang)***
- *5. DFX Production strategy and plan – including production of CAD drawings **(W. Bailey)***
- *6. Nb-Ti Bus-bar design (**H. Prin**)*
- *7. Plug development: status, plan and key milestones for intermediate validation, production plan (**Y. Leclercq**)*
- *8. DFX instrumentation requirements (**J. Fleiter**)*
- *9. DFX safety aspects in the LHC Tunnel (**V. Parma**)*
- *10. Transport and integration of DFX in the LHC underground areas – LHC Tunnel aspects **(P. Fessia)***
- *11. Transport and integration of DFX in the LHC underground areas – DFX Integration and transport **(R. Betemps)***
- *12. Items supplied by CERN and procurement plan (**Y. Leclercq**)*
- *13 (extra). Electrical qualification of WP6a splices MgB_2-NbTi (**A. Ballarino)***

The Review Session of the 31 January 2019 was followed by a 2nd Session in the afternoon of 12 February (https://indico.cern.ch/event/797964/), where the outcome of the work done to solve the open aspects highlighted during the 31 January session, was presented and commented.

Acknowledgement

The Committee would like to thank all the Speakers for their presentations and involvement during the Review days. The content of presentations and information provided were clear and concise, and helped for the comprehension of the DFX system design, system that includes a wide variety of interfaces and functioning details to be integrated in a tight environment.

To be underlined are the intense revision activities done by WP6a in the days after the Review of the 31 January in order to analyse and solve the open questions about the cryogenic control aspects mentioned before.

A special thanks to M. Mendes who helped with a clear and careful annotation of all Comments & Questions.

Executive Summary:

Referring to the six **Review Mandate specifications**, the Review conclusions are here presented:

1) *"Review the functional specification and confirm its completeness in terms of cryogenic, mechanical and electrical requirements":*

The functional specification seems clear and in a well advanced status. The operating modes and boundary conditions (access during operation, access for maintenance etc.) are known but are not specified in the present version of the Functional/Interfaces Specification (EDMS 1905633).

→RECOMMENDATION N.1: Complete the <u>Functional/Interfaces Specification</u> to make it a solid and sound document, to be used as the main part of the Technical Specification and as reference document for the future Collaboration Agreement with Southampton University. The following, less straightforward, design requirements should be added: access limitations due to the actual available volumes in the Tunnel, accessibility for maintenance/repair, re-working of components, electrical integrity aspects, etc.

2) *"Review the functionality of the design concept with respect to cryogenic design and operational aspects, mechanical design and interfaces, electrical design and interfaces":*

The functionality of the design concept seems fine but with some concerns: during the Review, some important questions appeared about the mechanical design compatibility with respect to the cryogenic functionality. They were subsequently investigated by WP6a/WP9/SOTON Teams and a first evaluation was reported to the Review Committee in the 2nd meeting held on 12 February.

The reporting on 12 February clarified the major improvement and development of the mechanical layout of the central inner vertical vessel of the DFX. The new design, based on a "cryo-fountain" concept, seems to significantly improve and solve the open questions of helium phases separation and LHe level control. The proposal for the safety equipment implementation (safety valve and burst disk) needs further improvements.

→RECOMMENDATION N.2: Complete the design of the new developed concept of "cryo-fountain". A final optimization of the two chambers volume ratio should be done considering nominal operation conditions (5 g/s of He flow generation for the DSHX) and pre-defined limits for Cryo OK signals for powering. The committee recommends to investigate the setting of minimum operation autonomy of the system, in case of He supply cut, to 10 min. Design of the extension pipe for the safety devices shall avoid horizontal position and have enough height (potentially with thermalization) to guarantee a correct stratification of helium in order to prevent ice formation on the safety devices (this last point will need a tight collaboration with WP15 to integrate the proposed solution at the Tunnel/vertical core interface).

The conceptual mechanical design seems complete, but the technical details that still need to be finalized could become critical for the correct and successful assembly of the DFX "in situ" and in case of future required intervention for maintenance/repair.

The final diameter of the horizontal DFX vessel could probably be reduced and this will have a positive impact on the reduction of the total LHe volume of the system.

The final position of the plug must be fixed (it will also depend on the integration of the Cold Diode Box to be developed together with WP03).

→ RECOMMENDATION N.3**: **Finalize the mechanical design of the system/components. <u>Optimize</u> aspects like:

- <u>Mountability</u>: Number of components, welds feasibility and their QA/QC aspects, integration of ancillaries, required tooling.

- <u>Reliability</u>: Minimize risk of leaks, optimize instrumentation integrity aspects.

- <u>Maintainability</u>: Minimize the planned interventions on cryogenic and protection instrumentation sensors; for each expected intervention, check the availability of space (at completion of LS3 installations, this will be one of the most crowded regions of the LHC Tunnel).

- <u>Reparability</u>: Check the existence of tooling (e.g. welds-cutting and welding machines) and allocated space for its utilization in case of inspections and minor repairs to be done in the Tunnel (ex. repair of instrumentations, repair of leaks, etc.).

It is recommended to further investigate the possible integration of the vacuum barrier on the top flange interface with the DSHX. This solution should bring advantages as minimization of acting forces eventually developed and a better vacuum sectorization between different elements of the system.

Interfaces of the DFS system seem to be correctly accounted for.
The electrical design, based on equipment already reviewed in another occasion (MgB_2 conductor, bus bars, etc.) seems under control. The plugs and lambda-plates are developed starting from the LHC experience but a full re-qualification of design-components-processes is needed and is ongoing.
→ ***RECOMMENDATION N.4**: **Procurement plan for feedthroughs for voltage taps should be activated as soon as possible in synergy with other WPs that could have the same needs.***
N.B. It was requested during the Review to discuss this issue in the Magnet Circuit Forum.

3) *"Review the proposed integration and installation plan in the LHC machine and the compatibility of the DFX location with respect to the Tunnel environment (including preliminary plan for maintenance and repair interventions during operation)":*

A conceptual "Installation Sequence" was presented but not a real Installation Plan. This should be presented in detail at the future DDR (Detailed Design Review).
In a similar way, conceptual considerations for (some) repair cases were presented.
The DFX Integration in the HL-LHC layout seems under control with WP15 (Integration) participating in the DFX Technical Meetings and providing Integration models and Equipment Integration Notes (EDMS 1991506). This work will need a continuous and tight monitoring to follow the DFX design evolution.
→ ***RECOMMENDATION N.5**: **A detailed analysis of the Installation and Repair/De-installation sequencing is essential to be developed in parallel to the DFX system design. This is due to the impact that the sequence of operations could have on the details and finalization of the mechanical design.***

The MgB_2/NbTi splices repair was reported as an: "exceptional major intervention in the Tunnel for the unlikely case that a splice would need to be repaired". It is not obvious to the Review Committee that a detailed study on the feasibility of the repair of these splices in the Tunnel has been done.

It is recommended to perform this study (considering the activation level expected, "in situ" vertical splicing assembly, etc.) and compare it with other more destructive repairing scenarios. In case an "in situ" repair is unfeasible, or a more destructive scenario is preferred, this specific repairing case should not be considered as a mandatory requirement for the DFX design (as it is at present).

Design effort and resources should be focused on maximising the QA/QC in the manufacturing of the key components/assemblies and on the study and development of procedures only for the more realistic and probable repair scenarios.

It was understood that up to the present design phase, HL WP16 (String & Commissioning) was not involved in the technical discussions and meetings.
→ ***RECOMMENDATION N.6: Since the DFX prototype will be firstly tested in SM18 and needed for the HL-LHC String program, WP16 Team should be involved in the DFX Technical Meetings in order to check the compatibility of the design with the SM18 requirements and the studies for the String.***

→ ***RECOMMENDATION N.7: During the 1st assembly and test in SM18, a plan should be prepared to recreate conditions as similar as possible to the ones in the LHC Tunnel. In other words: use the DFX assembly activities in SM18 as a real test of what will be done later in the Tunnel. This could provide valuable indications for optimization of the assembly procedures.***

4) *"Review cryogenic requirements for safety aspects and compatibility of safety equipment with Tunnel environment":*

The conceptual Cryogenic safety requirements seem correctly addressed. Nevertheless the open points mentioned at 2) could have an impact on the final design or final positioning of safety equipment (ex. GHe release valves) ***(→ refer to RECOMMENDATION N.2)***

5) *"Review of plan for detailed design development":*

The committee understands that SOTON is responsible for the detailed design of the DFX including the Manufacturing Drawings. The design must fulfil PED requirements. The exact role of CERN in this process was not clear to the committee.

→ ***RECOMMENDATION N.8: The review committee recommends to organize the next DFX review (DDR) only once the technical design report is completed. The interface between CERN and SOTON regarding development and approval of Manufacturing Drawings should be clarified.***

6) *"Review schedule for prototype production, including strategy for intermediate validation and production of prototype lambda-plate":*

The WP6a General Schedule including the DFX prototype and series procurement was addressed in the 1st presentation. For the DFX prototype procurement the schedule seems very tight. In discussions after the review, details on the future main milestones were provided. Our remarks are:

- For the DDR, scope and charge should be correctly settled since it will be very difficult to have all the final design details defined for the proposed date of March 2019.
- For the FC of June 2019 it seems that the necessity is to have released a technical document to support the approval of the Collaboration Agreement with Southampton University and the commitment of resources: this delivery seems feasible.
- For the DFX prototype, the date of delivery at CERN (fully assembled and partially tested) is April 2020: this milestone seems very tight.

→ ***RECOMMENDATION N.9: In order to keep a realistic prototype procurement schedule, revise and analyse the procurement phases trying to identify eventual back-up solutions or mitigation actions.***

→ ***RECOMMENDATION N.10: Even though this point is not strictly part of a conceptual design phase, the strategy and policy for the DFX spares procurement and spare assembly in the Tunnel should be defined (e.g. availability of spares as individual components).***
The extreme boundary conditions in the LHC Tunnel imply that some "controlled dismounting" activities will be probably not feasible.
Possible variants (due to R/L symmetry and IP1/5 slopes) must be properly incorporated within the spare policy.

Review of Contributions:

1. *WP6a master plan, key milestones, functional requirements, DFX within WP6a system (**A. Ballarino**)*

Findings:

Concerning DFX (feeding boxes for: Triplets (IT), D1 and Corrector Package (CP)), the 4 needed DFX units are identical at IR1 and IR5 apart for the compensation of the Tunnel slope and symmetry respect to the IPs.

The full system: (DFHX – DSHX – DFX) will inter-connect areas where access of personnel during LHC powering and run will be permitted (e.g. UR galleries) with areas where access is not permitted (e.g. UL galleries and LHC Tunnel).

The DFX as the DSHX will contain 19 sets of cables with current rates from 2 to 18 kA.

The DFX has various interface functions: electrical, cryogenic, vacuum and it fills the role of generating the GHe flow needed for the functioning of the DSHX.

The current DFX design allows a certain number of standard and exceptional maintenance interventions to be performed without opening of the DFX vessel. The review committee is not convinced that the repair of the MgB_2/NbTi splice (also mentioned as exceptional major intervention) will be feasible due the exceptional boundary conditions in the Tunnel (radiation doses, limited space, etc.). The Committee considers that this aspect shouldn't be included as a mandatory requirement for the DFX design.

The proposed DFX design is the result of a "quick" evolution from: a "horizontal" version, an "inclined" version and finally the current "vertical" version.

The present design is considered the most promising since it provides major advantages for the MgB_2/NbTi splicing operation which is considered the most delicate to be done on the SC cables.

A global Schedule with all major milestones exists and seems feasible.

The design activities are done inside a Collaboration between CERN and University of Southampton (SOTON).

Comments:

- A discussion on the minimum number of NbTi/NbTi splices inside the DFX vessel took place. The present design foresees one splice, but in case there will be two, this should not be a major issue also from the SC cable protection point of view.
- It was underlined the delicate aspect of the forces that will act in the DFX on the fix points of the leads coming from the DSHX (vertical), as well as the stresses due to thermal contractions and thermal cycling. These aspects will be more deeply investigated.
- Clarification on what is tested in the Demo1 as concerning lambda-plate and plugs was provided.
- Some concerns about integration of the DFX test in SM18 and planning were raised by WP16 (M. Baiko).
- The strategy to pass the June FC for the in-kind contribution approval was reminded.

- The pressure drop between the DFX (operating at 1.3 bar) and the inlet to QXL (considering local losses, height differences, current leads and control valve) must be carefully verified for all operating modes and presented at the DDR. Lessons learnt from LHC operation show that for reliable operation of a DFB with its current leads, a minimum of 100 mbar of ΔP and typically about 150 mbar are needed to provide efficient circulation of helium via the system. Since the DFX can also operate at higher pressure (1.6-1.8 bar), such pressures will not harm the system but the proper assessment must be done versus the design itself and sizing of the safety devices with their opening pressure.

Recommendations:

- Further design steps should check and validate mechanical design vs. leads fix points (detailed evaluation of stresses and forces).
- Be attentive in the finalization of the Cryogenic design and working parameters, including operation aspects as well as safety and integration with other interfaced systems.
- Enlarge the technical discussion and integration meeting to the WP16 (HL-LHC String) and SM18 Team.

2. *DFX Functional specification (**Y. Leclercq**)*

Finding:

The DFX cold powering system was presented with reference to the existing Technical Specifications (functional and interfaces).

The requirements of compliance to CERN and European Design and Safety Rules were reminded.

The interface requirements and main details (electrical, cryogenic, vacuum insulation, mechanical and integration) were presented and discussed.

Expected radiation dose in the DFX region and impact (ALARA) on preventive maintenance and repair actions was highlighted.

Comments:

- The positioning of the DFX vessel in Cat.3 of the Pressure Equipment Directive (PED) was raised *(see later more detailed comments in V. Parma talk).*
- Questions about reference documents for the collaboration with SOTON and on who will write the TS for the procurement were raised. It was assured that the work on the design is a collaboration “fully under control” (with SOTON collaborators very often working at CERN for long periods) and that the TS will be written by CERN. The TS “for procurement” and their follow-up will be done by SOTON.
- It was clarified that the expected presence of the Cold Diode Module (CDM - very soon in the HL baseline) will be transparent for the DFX design, at least in this conceptual design phase and probably also at the detailed design one. This because CDM will be positioned after the interface with the plugs/λ-plate at the DFX extremity towards D1, (it was also later clarified that the CDM is responsibility of WP3 and not of WP6a).
- It was noted that the Functional/Interfaces Specification doesn’t contain reference to electrical integrity and HV tests. The point should be corrected.

- In a similar way it was noted that references to CERN documents on special material specifications and other special requirements are missing. The point should be corrected.
- It was confirmed that the DFX procurement will be done with CE Certification.

Recommendations:

- ➢ Improve the Functional and Interface specification (EDMS 1905633) with
  - Reference to electrical integrity and HV tests;
  - Reference to CERN Documents on material special requirements for accelerator and cryogenic applications (e.g. stainless steel forged blanks for ultra-high vacuum applications EDMS 790775, etc.);
  - Clarification on applicable (and required) EC Standards and Certifications.

3. *DFX Cryogenic cooling and flow scheme, interface with cryo-equipment* ***(S. Claudet)***

Findings:

The Cryogenic architecture for IR1 and IR5 was presented. It is still open as an option the recovery of some cold GHe via the D line in the DFHX modules. This would be advantageous during the transients and in case of quenches in the DSH (which anyway is not expected with the current design and foreseen cryo-conditions). This choice will not impact the design of the DFX.

It was underlined an aspect about the harmonization of the Line C design pressure (4 bar) and DFX design pressure (3.5 bar). Changing the DFX design pressure to 4 bar will have some functional advantages for CRYO, but in case it is not possible or too costly, CRYO can accept to change the Line C design pressure to 3.5 Bar, reminding that anyway the lowest admissible value for this line is 3 bar.

Other aspects (e.g. jumper interface) were presented as “not yet studied” but judged as “should not be critical”.

It was also clarified that the evaluation of the needed cryogenic instrumentation for the global control of the entire cold powering system, is not yet completed and this could increase the number of signal/control cables (with implications on the final sizing of the DFX feedthrough elements).

The two-heaters type solution (thermo-hydraulic and electrical) was presented and the advantages (mainly redundancy and reliability) discussed.

The presence in the design of flexible hoses does not seem to create problems if they are sized and procured following standard rules and best practice.

Comments:

- The proposed cryogenic architecture for the full cryogenic current lead systems seems functional and under control. Some development and completion of study/design must be done (e.g. instrumentation, recovery during transients, etc.). It is important to “freeze” ASAP the design aspects that could have an impact on the DFX design given the tight schedule for the prototype procurement.
- Regarding the cryogenic system operation stability, an autonomy of about 5 min in case of He supply stopping, seems a bit short; to be investigated the possibility to improve it to about 10

min of autonomy. (Note: this is based also from operation experience of all DFBs in LHC machine).

- Even if probability of failure is low, the PT redundancy shall be considered regarding radiation level in the zone and potential dose to be taken during repairs (installation of a second PT should be technically not complicated nor too expensive - ALARA).

Recommendations:

- ➢ It is recommended to investigate the possibility to improve the autonomy of the system in case of He supply stopping, to about 10 min of autonomy.
- ➢ Consider adding redundancy on Pressure Sensors.
- ➢ Complete as soon as possible the design of the cryogenic interfaces that could have impact on the DFX detailed design.

4. DFX Conceptual design – including strategy for maintenance and repair ***(Y. Yang)***

Findings:

- The DFX conceptual layout and schematic, developed from the existing constraints, as well as the proposed approach maximising the mechanical protection of the MgB_2/NbTi splices, was presented.
- The DFX prototype (first and most urgent deliverable) will also serve as future spare. This means that the prototype design must be fully compatible with the Tunnel requirements.
- It was presented the rationale in the fix point choices (i.e. fixing the NbTi/NbTi splices and not the MgB_2/NbTi leaving to the latter the possibility to slide inside its protection sleeve).
- The chosen approach for the vacuum sectorization (with the consequent mechanical forces developed) was presented and discussed.
- The instrumentation feedthrough preferred routing is not yet decided: at least 2 solutions exist. This point will be finalized for the DDR.
- The presentation moved then to the assembly phase “in situ” and the implications of this aspect on the main components design.
- The aspect of the DFX support (not yet studied in details) was then briefly discussed.
- The available vertical space for DFX is limited and, as consequence, challenging for the correct design of helium phases separation and correct safety devices installation.
- The main design open question (i.e. not enough GHe volume and regulation height to guarantee a correct Helium phase separation and liquid level regulation of the DFX) was raised.
- Risk of thermo-acoustic oscillations’ cooling effect and ice formation on the safety devices was also addressed.

Comments:

- It was asked the impact of the (presented) expected dose in the region of DFX on the equipment. The dose in HL-LHC is of course higher with respect to the current situation, but it doesn’t seem critical comparing to what other equipment (e.g. magnets) will have to tolerate. ALARA approach is of course taken in consideration as mandatory.

- The presented assembly layout opened the question of the needed tooling to be developed. These particular assembly activities have to be done at about 2.5 m from the Tunnel floor, handling elements of around 70-80 kg.
- In the same way, the DFX assembly procedure opened the question of the intermediate tests that will be required during assembly in the Tunnel. A detailed list of tests (intermediate and final) for the assembly is not yet available but is planned to be developed soon. It was also remarked that such tests will have also a legal obligation (e.g. welds checks).
- Placing the vacuum barrier in the middle of the cryostat does not seem to bring really full functionality for the vacuum sectorization since all connections of piping and instrumentation tapping are done in the link vacuum volume. In addition, the size of the proposed barrier and by consequence the acting force on the barrier is large (~5 t – presented during review).
- Following on Reviewers questions, it was confirmed that the responsibility for the engineering detailed drawings is with SOTON inside a tight collaboration with CERN. The procurement drawings will be responsibility of SOTON with some verification done by CERN.
- It was reminded that the full assembly procedure will be tested in SM18. The assembly (the "prototype") will be needed for the HL String program and later become available as a spare (but "assembled", that means it will need to be fully dismounted in order to eventually become a spare for the DFX in LHC).
- Availability on the market of welds cutting machine for such diameters and compatible with the Tunnel layout is not assured and must be checked.
- As a general remark, the DFX assembly process looks very complex, with a lot of assembling and testing steps to be performed in a tight and limited environment (the LHC Tunnel). The further detailed design phase needs to consider this aspect carefully. Any design development that could bring simplification in the final assembly should be pursued.

Recommendations:

- Plan to reproduce during the prototype assembly and testing in SM18 all the main logistic and assembly boundary conditions that will be present later in the LHC Tunnel.
- For a reason of full functionality of the vacuum barrier (sectorization and leak tightness testing) it is suggested to further investigate the design and positioning of the vacuum barrier integrated on the top flange interface to the DSHX (the screen line could be used for thermalization if needed). If this solution is not feasible, vacuum sectorization of DSHX and DFX should be defined together with VSC experts.
- It is recommended to finalize the DFX design looking at optimization of components pre-fabrication, assembly steps (e.g. welds and their geometry), tooling and tests to simplify as much as possible the activities in the Tunnel.
- The connection pipe to the safety devices shall be designed in such a way to avoid thermo-acoustic oscillation cooling effect. The design of the system must avoid ice formation on the safety devices and potential mechanical blockage of the release *(see also at 4.)*
- The supra level gauge should be protected within a tube if projection of the droplets could not be avoided.
- The level gauge shall cover all depth of the cryostat.
- The total volume of helium in the DFX is significantly larger than in any other part of the machine (counting per meter of length). Reduction of the volume shall be studied (this concerns mainly the horizontal part of the DFX vessel).

- General suggestion to keep design and implementation as simple & standardized as possible, putting emphasis on the development of adequate tooling, pre-qualification and string tests.

5. *DFX Production strategy and plan – including production of CAD drawings* ***(W. Bailey)***

Findings:

The DFX Design and Prototype procurement phases were presented the main milestones highlighted.

Comments:

- General agreement that the CERN resources provided by EN-MME are correctly sized and right for the DFX design task.
- It was confirmed that the Series production of the DFX will start only after validation of the prototype.
- The completion of the design phase and the procurement plan seems challenging.

(Note: after the review, in private communication with A. Ballarino, it was clarified the exact schedule of procurement steps where the DDR of March 2019 must validate the engineering design to the point of correct estimation of cost of the procurement. This estimation is needed for the FC of June 2019 where the collaboration CERN/SOTON will be formalized and the resources committed. The procurement design folder will be needed for August 2019).

Recommendations:

- Due to the assembly complexity, the helium leak test sequence during fabrication/assembly shall be clearly defined including the adequate tooling.

(No other specific Recommendation for this section since several remarks and comments on design and prototype procurement were given in other sections).

6. *Nb-Ti Bus-bar design (**H. Prin**)*

Findings:

- The protection strategy for the magnet circuits concerned by the DSHX were presented with the main parameters for those circuits.
- The conceptual design of the routing of the circuits through DSHX-DFX-CDM was presented and discussed, bringing attention to the number and types of splices.
- The procurement scenario for the Bus-Bar (BB) of the Inner Triplets magnets and DFX was presented and commented.
- Different solutions are present for the choice of the cross-sections of the BB in the DFX. This aspect will be clarified and finalized in the next weeks.

Comments:

- It was discussed and compared the proposed layouts of 18 kA BB (flat and round) with details on the Cu content, stabilization requirement, design constraints and safety factor provided by the different Cu sections.

Recommendations:

- ➢ It is recommend to prepare a complete and clear schematic document with the types of BB and splices in the full system: DSH-DFX-CDM-Magnets.
- ➢ Decision on final cross-section for the BB to be routed inside the DFX (lower part) should be quickly taken as could impact the design of the DFX horizontal part.

*7. Plug development: status, plan and key milestones for intermediate validation, production plan (**Y. Leclercq**)*

Findings:

- The scenario of the needed plugs for the DFX project was presented; the main parameters, construction characteristics and qualification tests reminded.
- The status of the "Plugs Laboratory" infrastructure and know-how was briefly presented.
- Design and technologies are based on the LHC experience, but all must be re-qualified.

Comments:

- It was clarified that all the BB passing through the plugs will be "flat" apart the 2 kA cases
- It was clarified the layout of the BB into the plugs and their connection with the derivation for the cold diodes.
- Details about impregnation layout and procedure (e.g. removing part of the cable insulation) were discussed.

Recommendations:

None.

*8. DFX instrumentation requirements (**J. Fleiter**)*

Findings:

- The present design and plan for instrumentations, feedthroughs and spares was presented and discussed.
- The instrumentation is needed for: cryogenic control, electrical circuit protection, vacuum monitoring.
- A special case is the thermo-hydraulic heater (by GHe, so not electrical), that was also briefly presented but not technically discussed (since covered in the Cryogenic presentation).
- The total number of instrumentation wires/channel was reminded. The total number of Vtaps for circuit protections nominally required is 190 (10 Vtaps per each circuit)

Comments:

- The electrical instrumentation layout has still to be finalized.
- The Vtap across the plug (Ch. 0) needs further assessment (i.e. wires routing) to avoid electrical noise problems.

Recommendations:

- ➢ The Vtaps layout and numbers (i.e. spares) has to be checked with WP07 and discussed at MCF. The total number of wires is relevant (190 wires), to be checked if some optimization (reduction) can be done.
- ➢ The routing of instrumentation, position and design of feedthroughs should be finalised early enough as to allow for timely procurement of related components.

*9. DFX safety aspects in the LHC Tunnel (**V. Parma**)*

Findings:

- The positioning of the DFX versus the PED requirements was presented and widely discussed (e.g. consequences of a Notified Body presence, nominal and design pressure values, etc.).
- Consequences for the UR access versus He venting events in the DFX/DSH equipment were discussed.
- A risk assessment table was presented and commented.

Comments:

- The current PED Classification is Cat 3. The design has been developed to try to remain in this category.
  (Note: after the Review, in discussion with HL-QA Office it was clarified that the question of CERN obligation vs. the PED EC Directive is a subject under clarification and there will be soon a document from CERN HSE and HL-LHC Project clarifying this aspect).
- The Design Pressure of 3.5 Bar is acceptable for TE/CRG, although their current baseline for the recovery line is 4 Bar (see also presentation 3.).
- The design of the ODH system shall be defined and optimized to preserve the access of personnel in UR during LHC operation (a major important feature of the entire HL-LHC Project).
- Sizing and positioning of the release valves is not yet completed and could become critical for the DFX integration.
- A 1st version of Risk Analysis table exist but must be completed adding for example the "impact on LHC operation", and further developing the "mitigations actions". The analysis has to add the impact on the DSH system too.
- How the ODH system shall be designed (layout) to correctly detect local decrease of the oxygen concentration? – to be investigated and studied (the assumption of a perfect mixing of released He with air inside the cavern/Tunnel section seems to not be correct, especially in the case of fast release of large amount of He).

Recommendations:

- Electrical safety (bus-bars isolation, splices, electrical instrumentation, etc.) was not specifically presented. To be analysed and added for the DDR.
- The identification of the MCI and its impact on the design finalization must be done.
- Some open questions on the design could have impact on the Safety aspects and Risk analysis. Design development to be tightly followed from this point of view too.

10. *Transport and integration of DFX in the LHC underground areas – LHC Tunnel aspects* ***(P. Fessia)***

Findings:

- A global view of the DFX system integration in the HL-LHC and LHC cavern and Tunnel was presented highlighting the particularities of the different (four) installation sites.
- Status of current integration studies was presented. HL WP15 is tightly following the design evolution participating to the technical meetings, providing (and updating) the integration models and Equipment Integration Notes needed.
- At the moment, the integration seems globally feasible but experience shows that problems often appear with the integration of the "ancillaries", with accessibility considerations and supporting systems integration (none of these are yet known or fully defined).

Comments:

- Concerning expected interventions in the Tunnel, to be reminded that today's baseline is: interventions during Technical Stops (TS) should be considered exceptional. Standard and preventive maintenance should be performed during YETS, not during TS. This aspect has to be implemented in the ancillaries design.
- TE-CRG Team is studying a possible platform on the T-module of QXL that could be useful also for DFX installation and maintenance.

Recommendations:

- Study and provide as soon as possible to WP15 the "ancillaries" systems, their space requirements and the DFX supporting systems design. The integration of the new proposed solution for the safety release valve and burst disk seems critical and to be study with high priority.
- The needed space for routine maintenance and for extraordinary maintenance should be defined together with the design evolution and presented to the technical meeting with WP15

11. *Transport and integration of DFX in the LHC underground areas – DFX Integration and transport* ***(R. Betemps)***

Findings:

- A global picture of DFX installation (with transport limitation in the Tunnel, and specificities of the 4 installation sites as concerning the Tunnel slope) was presented.

- The assembly sequence, starting with the installation of the DFX top flange at the LHC Tunnel/core interface (used also as reference), was then presented and discussed.
- The main and most critical assembly operations "in situ" (e.g. the bending of the NbTi BB, welding of main components of the vessel, instrumentation routing) were presented and discussed.
- The question of the required tooling development for the assembly (and disassembly) was also discussed.
- Some general considerations about disassembly scenarios (for repair) were finally briefly presented.

Comments:

- The intermediate welding inspections and tests are open points which are considered critical for the design finalization.
- The weld cutting procedure and tooling (if it exists) must be investigated.
- The disassembly study in case of repair is at the initial phase and will need further development for its potential impact on the design finalization.

Recommendations:

- ➢ The current baseline foresees several possible "re-works" of the main vessel components in case of unexpected repairs. The DFX detailed design must check the feasibility, the coherency through the full chain of components and implement this requirement in the final design.
- ➢ It will be critical and essential to put enough Quality Assurance/Control in the Technical Specification and in the work in order to produce high quality splices and assembly to minimize the risk of need for further repairs. Interventions to access the main cables splices for repairs will be extremely complicated, with heavy impact on vicinity equipment (e.g dismounting of LHC beam pipes), requiring use of special tooling, multiple weld cuts, re-welding, etc. It is advised to try to further simplify (if/where possible) the design and assembly process and eventually to redefine the mandatory repairs requirement considered as input for the DFX design.
- ➢ A complete strategy and policy for the DFX spares must be defined (availability of individual/dismantled components, number of variants, and for this symmetrization of the design, number of units. etc.)

*12. Items supplied by CERN and procurement plan (**Y. Leclercq**)*

Findings:

- The list of CERN delivered items was presented.
- The Procurement Plan for the DFX prototype was reminded.

Comments:

Recommendations:

- ➢ Feedthroughs for voltage taps: an external procurement line should be activated as soon as possible since their design might be complicated. Other HL WPs need the same type of product. Coordinate the design through MCF forum.

13. Electrical qualification of WP6a splices MgB_2-NbTi ***(A. Ballarino)***

Finding:

- This additional presentation was required during the Review since the subject was not covered by any of the planned contributions.
- In addition to recalling the main circuit layout and parameters, the insulation electrical tests policy (n. of test and test values) was presented.
- Demo1 results and performances were presented.
- The presented values and conditions for insulation tests are in agreement with the recommendations established by the HL-LHC Project.

Comments:

- A discussion took place in order to check if the vertical length of the MgB_2 splices could be reduced (in order to lower the LHe level in the vertical vessel), but this seems not possible.

Recommendations:

None.