DFX Detailed Design Review: Outcome and Recommendations from the Review Panel

Review Panel:

S. Atieh, G. Ferlin, M. Modena (chair), F. Rodriguez Mateos, D. Tommasini, + M. Mendes (Scientific Secretary)

Introduction

- This “Detailed Design Review” follows the DFX Conceptual Design Review” (CDR) held on the 31 Jan 2019 . The Review Panel was mandated with the following:

Scope:

“Review the detailed design of the DFX with the purpose of validating maturity and confirm readiness for starting the prototype DFX”.

Mandate:

- 1) Review the functional specification and the technical specification and confirm their completeness in terms of cryogenic, mechanical and electrical requirements;
- 2) Review the detailed design wrt cryogenic design and operational aspects, mechanical design and interfaces, electrical design and interfaces;
- 3) Review the integration and installation sequence in the LHC machine and the compatibility of the DFX location wrt the tunnel environment (including 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 plan and schedule for prototype production, including production of prototype lambda plate;
- 6) Review strategy and plan for QA and QC, as well as plan for intermediate and final acceptance tests.

Introduction

Review Committee: *S. Atieh, G. Ferlin, M. Modena (chair), F. Rodriguez Mateos, D. Tommasini.*

(A special thanks to M. Mendes for his clear and careful annotation of all comments&questions and help in the reviewing).

Proposed Program of presentations *(Indico: https://indico.cern.ch/event/821876/):*

- Welcome: Luca Bottura (CERN)
- **DFX in WP6a, Master Plan**, Speaker: Dr Amalia Ballarino (CERN)
- **Follow up from Conceptual Design Review**, Speaker: Vittorio Parma (CERN)
- **DFX Functional specification**, Speaker: Yann Leclercq (CERN)
- **DFX Final cryogenic cooling and flow scheme**, Speakers: Antonio Perin (CERN), Serge Claudet (CERN)
- **DFX Detailed Design** – including production plan, assembly steps, cryogenic instrumentation, connectivity and routing for electrical instrumentation (IFS) and aspects for maintenance and repair in the LHC underground areas, Speaker: Yifeng Yang (University of Southampton (GB))
- **Manufacturing Plan**; Intermediate and Final Test Plan; Acceptance tests, Speaker: Yann Leclercq (CERN)
- **Integration of DFX in the LHC tunnel**, Speaker: Maria Amparo Gonzalez De La Aleja Cabana (CERN)
- **Transport and installation of DFX in the LHC underground areas**, Speakers: Robin Betemps (CERN), Vittorio Parma (CERN), Yann Leclercq (CERN)
- **Mechanical interfaces of the DFX** to the SC Link, Lambda-plate and DCM, cryogenic equipment, Speaker: Yann Leclercq (CERN)
- **Status of CAD drawings**, Speaker: Yifeng Yang (University of Southampton (GB))
- **Design and integration of safety equipment and safety aspects** in the LHC tunnel, Speakers: Thomas Otto (CERN), Vittorio Parma (CERN)
- **Electrical requirements of DFX components**: specification and tests, Speaker: Amalia Ballarino (CERN)
- **Instrumentation requirements and Busbars** in DFX, Speakers: Jerome Fleiter (CERN), Dr Simon Hopkins (CERN)
- **DFX Technical Specification status and QA/QC aspects**, Speaker: Yann Leclercq (CERN)

Outcome and recommendations

General remarks:

- *The Panel acknowledges the design advancement of these last 4 months towards a more detailed design of the full system.*
- *After the CDR it was decided to submit the "UK-2 Agreement" for the collaboration with Southampton University (SOTON) to the Finance Committee (FC) of September 2019 (instead of June 2019). This seems very positive, it should permit to arrive at the FC with a more complete and validated technical documentation (Functional Specification, Interface Specification and Technical Specification).*
- *The DFX 3D detailed model was developed by SOTON colleagues in close collaboration with CERN.*
- *The SOTON resources allocated to the project are limited, and a critical phase seems now the production of the complete folder of 2D drawings "for Tendering". It was reported that there is a plan with resources already allocated, to proceed on this task with CERN resources (Design Office).*
- *The Panel supports this plan; it should allows a faster and more efficient finalization of the technical design phase and so moving to the next critical phase: the prototype procurement.*

Outcome and recommendations

General remarks (cont.):

- *A part-time presence of SOTON colleagues at CERN seems nevertheless necessary to finalize in a more efficient way the last open points (e.g. final technical design details, assembly and maintenance plan and sequences compatible with integration in HL-LHC Tunnel, etc.).*
- *During the Conceptual Design activities phase, it appeared that the presence of SOTON colleagues at CERN worked very positively. The collaboration already provided a solution for hosting a representative from SOTON at CERN, and a similar solution seems to be available also for this second phase.*
- *Concerning the Procurement phase, the Review would like to stress the importance to have adequate resources allocated by SOTON for the industrial follow-up.*

Outcome and recommendations

Referring to the six Review Mandate specifications, the preliminary Review conclusions are here reported:

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

- The functional specification (as well as the Technical specification and interface specification) DRAFT presented, seem clear and close to completion. With respect to the 1st Review (CDR) report, several points are now clearly specified; e.g. the number of required dismounts (main welds) was clarified (5 times); the minimum operation time without LHe supply was clearly specified and sized in the cryogenic scheme (10 minutes); the interface with the WP3 (Lambda-plate) is now officialised, etc.).
- → ***RECOMMENDATION N.1:*** *Pursue on the finalization of the reference documents (Functional Interface and Technical specifications), interacting with ALL interfaces (WP9, WP15, WP3, WP17.1, HSE, etc.) in order to have these documents fully checked and approved BEFORE the FC of September 2019.*

Outcome and recommendations

2. "Review the detailed design wrt cryogenic design and operational aspects, mechanical design and interfaces, electrical design and interfaces":

- A). The cryogenic design developed and presented during the CDR was consolidated. All functionalities seem correctly addressed and sound. There are still some details to be clarified in order to proceed with the detailed design "for manufacturing".
- Interfaces with other WPs and services seem correctly addressed.
- → ***RECOMMENDATION N.2:*** *Finalize the last open questions of the conceptual and cryogenic functional design e.g. (not exhaustive list, please refer also to the "Contribution Review" section):*

- *The decision on the redundancy of the LHe heaters (to provide the GHe for DSHX cooling).*
- *The routing of some cryogenic lines is not fully coherent throughout the cryogenic and mechanical conceptual DFX schematics presented; clarify this point.*
- *Converge on the definition on an appropriate (but higher if possible) He operation pressure (the question seems still to subsist):*

  The choice of the design pressure of the cryogenic system, now set to 2.5 Bara, seems low, but it is driven by the design pressure of the DSHX. → Finalize this point among WP6a, WP9 (and HSE) in order to possibly set a higher final design pressure for the whole system (DFX-DSHX-DFHX) considering the specificity and priority for each subsystem: safety of personnel in UR, safety of equipment in UL and LHC Tunnel, reliable operation of the cryogenic system, and considering ALARA approach to minimize the number of interventions (e.g. changing burst disks, etc.).
- *Evaluate the risk of thermo-acoustic oscillations cooling effect and ice formation on the safety devices on the final cryogenic layout.*

Outcome and recommendations

B). The mechanical design development was presented. Since the CDR review, a lot of aspects have passed through further analysis ameliorations and detailed design.

- → ***RECOMMENDATION N.3:*** *Finalize the mechanical design of the system/components. Finalize points like (not exhaustive list, please refer also to the "Contribution Review" section):*

  - LHe inlet pipe into the "fountain": optimize the piping routing and shape in order to minimize the presence of double-phase He.

  - He inlet connection: flexible pipes and cryostats are proposed, it seems that there is space to improve reliability and safe operation with a more "hybrid" design (rigid + flexible parts and connections).

  - O-rings reliability is a critical issue due to the difficulties linked to any special maintenance (or in worst case, reparation). → Discuss with VSC Group the procurement of "the best possible" O-rings (not the "just appropriate" ones) considering reliability and withstanding to radiation.

  - Some welds of the DFX inner part (e.g. weld #3) will be technically very challenging, so becoming indeed a critical issue of the system. → Plan to validate all the critical welds with full size mock-ups and during the system tests recreating the real environment and space constraints of the HL-LHC Tunnel.

→ ***RECOMMENDATION N.3 (cont.)***:

- Check the computation and design wrt the finally chosen design pressure value (see previous Recommendation) and versus the Pressure Equipment Directive (PED) requirement. PED remains the reference standard for the design.

- A reduction of the LHe volumes in the DFX horizontal part would be effective from several points of view. This reduction could be implemented easily with filling pieces (eventually integrated in the busbars supports still to be finalized). Consider this point in the further detailed design development.

- Regarding the 3D Model, it is understood that SOTON shall provide the mechanical analysis and assessments following to PED requirements (and its related harmonised standards) in order to fulfil the technical and HSE requirements.

- Review the vacuum barrier rod support system that seems complex for the assembly sequence and with potential issues (leak tightness).

- Make, as soon as possible, the transition from conceptual design to a design to cost (i.e. include manufacture reliability, manufacturing techniques, cost implications).

Outcome and recommendations

3) "Review the integration and installation sequence in the LHC machine and the compatibility of the DFX location wrt the tunnel environment (including plan for maintenance and repair interventions during operation)":

- HL-WP15 "Integration" is providing a constant follow-up and support to WP6a in order to develop a DFX design compatible with the HL-LHC constraints and boundary conditions. This aspect is critical since (DFX installation region completely NEW region from civil engineering and extremely crowded by future equipment installation points of view). WP15 has started "ad hoc" meetings to follow these questions (for DFX and DFM). It is essential that all concerned Teams participate actively to these meetings/discussion.
- Furthermore, the required final assembly of the DFX "in situ" implies a delicate integration aspect that concerns: available space, assembly tooling manipulation and sequence of integration of neighbour equipment (D1, QXL, DSHM, etc.). During the review the specificities of the 4 different installation sites were highlighted. It was also clarified the share of responsibility between SOTON and CERN as concerning DFX design and assembly sequencing and procurement of assembly tooling for the installation in the HL-LHC Tunnel (it was confirmed that the installation of the DFX in the tunnel is responsibility of CERN).

Outcome and recommendations

- → ***RECOMMENDATION N.4:***
- *For the DFX design finalization phase it will be critical a tight collaboration between WP6a and WP15–Integration with all other concerned Teams in order to finalize the design in a compatible manner with the HL-LHC Tunnel configuration and neighbouring equipment and services.*
- *The general assembly sequence (for system test and in the HL-LHC) was presented, there is a major open point concerning the assembly of the DFX with the DSHX (the vertical "lowering and raising" manipulation with consequent loads and charges on the system's main components):*
  - *As discussed after the review, the present design makes the complex installation sequence not the safest from the handling point of view and does not minimize the risk of future intervention (ALARA approach). The need to "lower and rise" the assemblies is driven by the need to get adequate space for weld #3. The actual space seems too tight to correctly perform the weld. → Analyse and evaluate if in the locations where the integration deems it necessary, space could be safely gained. This could be done with an eventual adaptation of the core/LHC tunnel vault interface design, proposing an enlargement of the end part of the core. Discuss this possibility with WP15 and WP17.1.*
- *The sequence for standard and exceptional maintenance intervention, the development of dedicated tooling, the sequence of neighbouring equipment installation (or de-installation in case of maintenance/reparation) was not yet analysed/developed. These aspects become now critical issues in order to validate the DFX design in terms of assembly and maintenance feasibility. We remind and aware that radioprotection aspects make any intervention (apart from the first installation) critical for ALARA considerations. The Panel recommends to complete the analysis and the consequent design and sequencing.*

Outcome and recommendations

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

- The presentations covered the cryogenic safety aspects (only). With respect to the CDR review, there was a revision of He volumes. The design operating pressure is now proposed to be 2.5 Bara. With those values, the equipment is now positioned well inside Cat. 3 of PED standard (before it was more at the limit Cat 3-4). HSE was present at the Review, clarifying that, if asked and if necessary, they could act as the "de facto" Notified body, and to assume the associated equivalent responsibility and authority (as stated and described in the HSE Memo*randum EDMS 1698982).*

- → ***RECOMMENDATION N.5****: the DFX design and its technical documentation has to coherently address the point of the design standard applied (PED) and consequent requirements all along the procurement, assembly and testing phases.*

  The role of HSE must be discussed and fully clarified as soon as possible.

- *The integration of gas deflectors in the design is a critical integration aspect and should be address and discuss with HSE and WP15 (for their integration in the crowded Tunnel regions).*

Outcome and recommendations

5). "Review plan and schedule for prototype production, including production of prototype lambda plate":

- The "plan&schedule" should consider finalization and procurement of different type of deliverables and equipment:
  - General Documentation (e.g. Functional and Technical Specifications, needed for FC and then for industrial procurement and assembly at SOTON and at CERN)
  - Technical Documentation (e.g. components drawings folder "for procurement").
  - Special components (e.g. IFS systems, lambda-plate, busbars). During the review, the status of the IFS (instrumentation) design and procurement as well as the lambda-plate were discussed (a full scale lambda-plate mock-up was shown).
  - Some of the electrical components or aspects linked to them (e.g. the IFS procurement and the redundancy of the instrumentation cablings) are planned to be discussed at the MCF forum.
  - The global DFX procurement and testing plans were presented. Some contingency is present in the estimation of the start of LS3 installation phase for WP6a (assumed in Jan 2024 but in reality not before the Fall 2024).
- At the moment the DFX procurement doesn't show critical aspects.

→ ***RECOMMENDATION N.6****: A detailed list of supplies (with delivery dates) from CERN and responsibility for minor tooling procurement shared between SOTON and CERN should be established in the Technical Specification.*

Outcome and recommendations

→ RECOMMENDATION N.6 (cont.):

- *The procurement of the series components is planned to start before the System Test (i.e. test of the prototype at SM18).*
- *The Review recommends to analyse the possibility to start the series procurement AFTER the System Test (following the presented plan this seems feasible), allowing in such a way the possibility to bring minor modifications to the DFX series design if the System Test performance deems it necessary.*
- *Important aspects concerning prototype production to be fully addressed in the future follow-up plan are:*
  - *Qualification of all critical welds in a "HL-LHC Tunnel configuration" (including necessary mock-up and tooling test)*
  - *On the presented "qualification sequence table", it seems that electrical tests are absent. Even if they will be partial (due to the absence of MgB2 and NbTi leads), plan anyway to include all the possible electrical checks (instrumentations, insulators, etc.) in the qualification list.*
  - *An appropriate planning for the tooling procurement should be done in order to use the System Test and String Test as a validation for the Tunnel installation, which means all tooling must be available for the System Test. The cutting machines (since the prototype will become a spare) should also be available by that time.*
- *WP6a envisages to organize in due time a Production Readiness Review (PRR) for the DFX procurement. The panel strongly support this proposal.*

Outcome and recommendations

6). "Review strategy and plan for QA and QC, as well as plan for intermediate and final acceptance tests":

- The QA and QC plans are under definition. A (not exhaustive) list of QA requirements with reference to applicable standards was presented, as well as reference to other general applicable standards, like PED, EN12300 (cleaning requirements), MTF (for documents traceability and follow-up). All these aspects will be part of the finalization of the TS that is undergoing.
- The Intermediate and Final test plans are under definition too. The responsibility between SOTON and CERN seems clear considering also the different assembly phases and consequent test plans: in industry (under SOTON supervision), at SM18 (for System Test and on the String), and finally in the HL-LHC Tunnel.
- There is an open point regarding the DFX acceptance test:
  - the baseline (CERN) is to weld the full DFX assembly in order to perform full leak and pressure tests. This configuration would be fully representative of the final object, providing an accurate check on the forces and stresses of the real object. This should be done in industry, and the test reports would be part of CERN's acceptance criteria.

Outcome and recommendations

- SOTON proposes an alternative plan, where the final assembly test in industry is done without welding the main subcomponents, but with the use of bolted joints tested by clamshells. This would allow saving the cut of one weld, but CERN does not consider this option fully representative of the real assembly.

→ ***RECOMMENDATION N.7****: It will be essential to list and clarify the exact responsibility, technical requirement (sequence and tests) for the different assembly scenarios:*

- *in industry (under SOTON supervision);*
- *at WP6A System Test;*
- *at the following installation on the String;*
- *and finally in the HL-LHC Tunnel.*

- *The final agreement on how final acceptance test in industry will be conducted (assembly with dismountable flanges vs welds) should be found.*
- *A complete QA/QC plan must be agreed between CERN, SOTON and HSE for the pressure vessel requirements and implemented in the TS.*

→ *(Last)* ***RECOMMENDATION N.8:*** *As already remarked at the CDR review, the strategy and policy for the DFX spares procurement and spare assembly in the Tunnel must be properly defined and included in the procurement strategy.*

- *In the current plan the prototype DFX should become a "universal DFX spare", but it must still be proven that it is not necessary to have specific spare components to then assemble a "Right" or a "Left", "IP1 or IP5", spare, since the layouts in the tunnel (connection to QXL, and other cryogenic connections.) are different or specular.*
- *Also the different tunnel slopes at IP1 and 5 and between R and L sides, could create variants that must be analysed if compatible with only one spare type.*
- *Since the DFX spare is the prototype that will be used in WP6A System Test and String Test (thus welded and cut 3 times), a reconditioning of the flanges subject to welds will be necessary to prepare it as an appropriate spare.*