Report of DFBX – Conceptual Design Review
Conducted on 2 December 1998

Introduction and Summary

This Conceptual Design Review is the first of a series of design reviews on the IR feed boxes (DFBX) to ensure the adequacy of the engineering design prior to the start of fabrication. For a system to pass the CDR, it must be demonstrated that the engineering design is feasible and that an adequate R&D program has been planned to develop and prove the design.

LBNL is responsible for providing the eight interaction region inner triplet cryogenic feedboxes. The feedboxes provide the interface from the inner triplet superconducting magnet system (including the single-aperture beam separation dipole at IR 2 and 8) to the LHC cryogenic, DC power and instrumentation systems.

The LBNL work scope includes:

- The design, development, fabrication, and shipping of the feedboxes.
- The specification, procurement, and testing of HTS current leads capable of carrying 6 kA to 13 kA.
- The design, development, and fabrication or procurement of shipping containers, internal and external systems of shipping restraints and instrumentation required to verify the condition of the feedboxes during shipping.
- The engineering work done in collaboration with Fermilab and CERN to define the requirements for the IR cooling system and for the valve boxes that interface to the feedboxes. (The fabrication of the valve boxes is CERN’s responsibility.)

The design review committee members were: P. Pfund, FNAL, Chairman, J. Strait, FNAL, R. Ostojic, CERN, R. van Weelderen, CERN, P. Sacre, CERN, L. Williams, CERN, S. Plate, BNL, T. Peterson, FNAL, and T. Nicol, FNAL.

The review covered the following topics in particular:

- General and specific requirements of the design
- Cryogenic design
- Finite element analysis of the vacuum vessel
- Helium vessel
- Equipment layouts in the tunnel locations
- Piping arrangements, sizes and pressure requirements
- Lambda plates
- Current leads, both HTS and conventional
- Preliminary identifications of hazard and safety assessments
- Plans for assembly, testing, and documentation

The Functional Specification documents and Interface Specification documents were listed in the CDR charge but were not explicitly covered in the review. They will need to be covered in other reviews.

Committee Recommendation

The committee recommended that the work go forward from conceptual to detailed design. The next review is an Engineering Design Review (EDR), scheduled for completion by July 2000.

The committee identified several issues that needed to be addressed after this review. The issues are listed in two categories: I. Issues Affecting the Concept and II. Issues Affecting Details of the Design. The committee requested that the designers address the issues in category I immediately while the issues in category II can be addressed as required to support the detailed design.

I. Issues Affecting the Concept

1) HTS Leads

a) Early release of the specification of HTS prototype leads may fix the design which in turn influences the design of the DFBX. The reviewers recommended waiting until the CERN test program for the 13 kA HTS leads is as complete as possible without delaying the Engineering Design Review for the DFBX.

   Action: Delay the purchase of the prototype leads to allow as much data to be collected from the CERN test program as possible, and to allow a more final specification of the interfaces of the leads to the rest of the DFBX, without delaying the overall engineering design schedule for the DFBX.

   Action: Continue with the development of the specification for the HTS lead but interface with CERN on the details of the HTS lead specifications regarding space, exchangeability, etc.

   Action: Subject the HTS lead specification to a thorough review before issuing it to vendors.

b) The 600 A leads are located on the back of the DFBX, facing the wall. Their relative inaccessibility leads to a design choice of using conventional rather than HTS leads. However CERN is developing 600 A HTS leads. If the CERN program results in leads that are more easily inserted and removed, they may be feasible to use in the 600 A lead location.

   Action: Remain cognizant of the CERN 600 A HTS lead development program. Use the results of the CERN program to re-evaluate the use of 600 A HTS leads before making a final commitment to conventional leads.

c) The DFBX is designed to have the HTS leads installed before shipping to CERN. Currently it is unknown whether the HTS leads are robust enough to be shipped installed in the DFBX.

Action: Evaluate whether the HTS leads can withstand the loads anticipated during the shipping of a DFBX. If not, then a design and procedure should be developed for insertion of the leads after arrival at CERN.

2) Elastomer Seals

The design is attempting to avoid all use of elastomer seals. This was felt to possibly be too restrictive.

Action: The default design position should be to use elastomers except where they specifically are prohibited or are functionally inadequate.

Action: Obtain the necessary information on the nature and levels of radiation to determine specifically whether elastomers can or cannot be used.

3) Phase Separator

The location of a phase separator was unclear for locations where the DFBX is downhill from the MQX. There may not be room in the cryostat and the default assumption appears to be that it should be placed in the DFBX. The FNAL system designer has estimated the required volume.

Action: Work with the FNAL system designer and the FNAL cryostat engineer to determine the size and location of phase separator.

4) Fixed Points

The fixed points for the DFBX and the expansion elements on either side of the DFBX have not been determined. These will be needed for establishing contraction and vacuum loads. There may be a need to provide for flexibility of leads on both sides of the interface between the DFBX and a magnet. The fixed point of the superconducting D1, a RHIC-type dipole, is already determined.

Action: Work with the FNAL system designer and the BNL magnet engineer to determine the fixed points and expansion elements in the DFBX, inner triplet, and D1. Obtain information about the superconducting D1 fixed point from BNL.

5) Gas Recovery Valves

The current design for the DFBX assumes that the valves in the warm recovery line for lead cooling flow will be on the CERN side of the interface. They would be provided by CERN but their requirements need to be provided to CERN.

Action: Verify with CERN that the valves will be on the CERN side of the interface and will be provided by CERN.

Action: Provide CERN with the flow requirements of the valves that they will be providing.

6) Beam Tube Design

The required characteristics of the beam pipe in the DFBX still need to be identified. These depend on the beam pipe features of the adjacent magnets and on requirements set by the CERN vacuum group. The committee conjectured that the DFBX should probably be fitted with a D1 sized beam tube because it is larger. There would have to be a gradual transition to the Q3 connection. Features such as size, transition, cooling, liners, etc. need to be determined.

Action: Obtain beam tube design requirements from CERN and beam tube interface details from the designers of the MQX and D1 magnets.

7) Alignment System

The DFBX concept as presented does not yet include a system for alignment. The beam tube in the DFBX would have to be aligned with the D1 beam tube on one side and the Q3 beam tube on the other side.

Action: Add a system of alignment fiducials adapted to the inner triplet alignment scheme. Estimate the alignment uncertainty of the beam tube with respect to the outside fiducials and the stability of the alignment during operation.

Action: Work with CERN to determine requirements for alignment and for the alignment hardware.

8) Design Pressure of the LHe Chamber

The conceptual design pressure of 20 bar for the LHe chamber was questioned. The CERN specification for the HTS leads limits the pressure to a maximum of 3.5 bar. This would require the LHe chamber to be relieved at a pressure low enough to protect the leads. The committee felt that a design pressure of 20 bar for the LHe chamber may not be required if the chamber is to be relieved at 3.5 bar due to the design pressure of the leads. On the other hand, the committee felt that the design pressure of 20 bar for the lambda plate was appropriate.

Action: Conduct an analysis to determine the maximum pressure build-up in the LHe chamber under normal and off-normal conditions, including the failure of the safety shut-off valve to isolate the vessel from line D.

Action: Remain cognizant of analyses at CERN of the safety consequences of the apparent conflict between the rated pressure of the HTS leads and the maximum possible pressure in line D. This conflict occurs in all DFB's in the LHC.

Action: Include a design feature to limit the pressure in the LHe chamber to the maximum pressure specified for the leads.

9) TOTEM

The conceptual design of the DFBX has not incorporated the possible addition of the TOTEM experiment to the LHC. R. Ostojic informed the committee that the probability is very high that the TOTEM experiment will be included. This will affect the design of the DFBX at locations IP1 and IP5. In the powering scheme presently discussed, each DFBX will need to provide:

- 3 pairs of Quadrupole of 8 KA or 13 KA HTS leads, an increase of 2 pairs over the current design
- 5 pairs of 600 A leads, a decrease of 1 pair from the current design
- Up to 9 pairs of leads, rated at up to 100 A, depending on the number and design of corrector layers in the final design.

R. Ostojic indicated that at Points 1 and 5 the resistive D1 could be moved away from the Interaction Point if additional space is needed.

Action: Continue the DFBX design assuming that TOTEM will be implemented at IR1 and IR5.

Action: Determine impact of the TOTEM experiment and inner triplet correction scheme on the DFBX design.

Action: Determine the cost increase associated with TOTEM implementation.

II. Issues Affecting Details of the Design

1) Radial Slope of the Tunnel

The design has taken position and slot length dimensions from LHC drawing no. LHCLSXG_00010G for D1-Q3 separation, DFB center-IP separation, and axial slope. The design indicates radial slope values as uncertain. CERN indicated that the radial slope of the tunnel is 0% everywhere. However, the machine is in a tilted plane, which implies that all elements, in particular quadrupoles, are tilted using their supports and alignment systems.

Action: Design sufficient travel into the alignment system, compatible to that of the inner triplet cryostat, to accommodate the radial slope of the tilted plane.

2) Cooling of TAS2 and TAS3

The conceptual design schematic provides for active cooling of TAS2 and TAS3. The committee believed that both of the absorbers will be cooled actively but the MQX cryostat designers have not determined how they will be cooled. CERN indicated they prefer the control valve for TAS2 and TAS3 cooling be located in the return rather than supply line.

Action: Work with the cryostat designer to confirm the cooling strategies for TAS2 and TAS3.

3) Review Need for All Valves

The review committee identified two valves at IP1 & IP5 and one valve at IP2 & IP8 that may not be required. The committee felt that it would be appropriate to review with the IR system designers the need for each of the valves.

Action: Work with the IR system designers at FNAL and at CERN to review the purpose and need of all valves.

4) Vapor recovery of 4.5K bath

The flow lines for vapor recovery from the 4.5K bath may need to be changed. CERN recommends a connection, not shown in the DFBX conceptual design, for redirecting the 4.5 K vapor into the 20 K HTS lead cooling supply. In doing so, the vapor enthalpy provides about 10% of the necessary HTS cooling at 20 K. In addition, following a quench it provides a means of recirculating some of the remaining coolant from the 4.5 K bath to the 20 K supply, when normally the supply would be shut off. The pressure control valve in the connecting line would be in the valve box rather than in the DFBX.

Action: Work with CERN and the IR system designers to modify the cryogenic circuitry to utilize the recirculation line recommended, and partially provided, by CERN.

5) Current Rating of HTS Leads

The nominal rating of "6 kA" HTS leads was not known exactly. The precise rating needs to be specified before the final design.

Action: Verify the proper rating of all HTS leads in addition to those nominally referred to as 6 KA.

6) HTS Lead Repair and Replacement

The conceptual design includes the requirement that the HTS leads be removable. The process would involve cutting access holes in the wall of the DFBX and the

LHe chamber, disconnecting the leads, and removing them. Re-installation would reverse the process and require that the access holes be welded shut. The committee questioned whether radiation levels in the vicinity of the DFBX made it feasible to go through this process. CERN has developed a technique for replacing the LHC main dipoles, which involves breaking the dipole interconnects. A similar procedure could be considered for the DFBX either for exchange of leads in an underground or surface areas, or for a complete module exchange when it become too radioactive.

Action: Evaluate the CERN technique for replacing main arc dipoles to determine whether it is feasible for the DFBX.

Action: Determine the radiation levels in the vicinity of the DFBX and evaluate the impact on the process of removal and replacement of HTS leads, and of a complete DFBX.

7) Axial Forces Due to Vacuum Loading

The conceptual design assumes that the DFBX will be restrained in the center to minimize the displacements of the HTS leads. The DFBX must therefore restrain axial and lateral loads from either side. The net forces due to vacuum loads on the bellows due to differences in cross sectional areas need to be checked.

Action: Check axial forces due to vacuum loading on either side of the DFBX.

8) LHC Alignment Tube

An alignment tube runs along the tunnel and passes very close to the DFBX. The conceptual design did not include the alignment tube in its layout of interferences. The alignment tube appears to pass just beside the wall of the DFBX and just under the jumpers, but the precise clearances need to be determined.

Action: Determine the precise location of the LHC alignment tube and establish the necessary clearances in the DFBX layout.

9) Hi-pot Specification

The conceptual design specifies 5 kV as a test voltage for electrical cables. The committee felt this may be unnecessarily high. The specification for the LHC arc DFBs is currently being developed and is due out by the end of January 1999. It is believed that some of the test voltages for the arc DFBs will be lower than 5 kA. It is also possible that the test voltage for the triplet may be lower than that of the arc because of the lower stored energy and inductance relative to the arc regions.

Action: Obtain hi-pot voltage specifications for the magnets to be powered through the DFBX and base the DFBX hi-pot specifications on these.

Action: Obtain the LHC test voltage specification LHC-PM-ES-0001.00 when it is released and conform to the specification if reasonable to do so.

10) Lambda Plate Test Program

The test program in general, and specifically that for the lambda plates, needs to be defined. The committee raised concerns over their reliability related to thermal cycling, pressure loading, and leakage.

Action: Develop a test program for the lambda plate and maintain an awareness of the work at CERN in this area.

11) Vacuum Pumping Equipment

Space needs to be reserved for the feedbox insulation vacuum pumping equipment.

Action: Determine the best location for vacuum pumping equipment and reserve space for it.

12) Installation in the Tunnel

The committee recognized the need to carefully evaluate interfaces, tight fits, and clearances in and around the DFBX. The IR systems designers will be utilizing 3D solid modeling to evaluate the components and their integration. The DFBX should also be modeled in 3D.

Action: Model the DFBX, its internal components and interfaces in 3D.

Action: Supply relevant DFBX information to FNAL and CERN system integrators for modeling integration with the triplet and D1 and for confirmation of installation in the tunnel.

13) FEA Modeling

The finite element modeling demonstrated the basic feasibility of the box concept. The current model does not include the large number of penetrations in the top plate through which the leads are passed and side plates through which other connections may be passed. The committee felt that as the design is developed in detail, the structural behavior of the box must be modeled to evaluate the loads and deflections of the structure.

Action: Model all the features of the feedbox in detail to determine the loads and deflections of the flanges, alignment fiducials, and HTS leads.

14) Standard Design and Fabrication Codes

The conceptual design did not address the standard regulatory, institute, or industry codes that would apply to a device such as the DFBX. The designers assured the committee that the appropriate codes would be followed. The US LHC Accelerator Project expects to establish a memorandum of understanding with CERN which will enable the US labs to follow their standard procedures and practices for the design and fabrication of equipment that meets specified requirements and is safe to operate.

Action: Address the appropriate design and fabrication codes at the Engineering Design Review (EDR) which is the next design review to be scheduled.

Appendix A

Conceptual Design Review – Charge
Distribution Feedbox

Background:

LBNL is responsible for providing the eight interaction region inner triplet cryogenic feedboxes. The feedboxes provide the interface from the inner triplet superconducting magnet system (including the single-aperture beam separation dipole at IR 2 and 8) to the LHC cryogenic, DC power and instrumentation systems.

The LBNL work scope includes:

- The design, development, fabrication, and shipping of the feedboxes.
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- The design, development, and fabrication or procurement of shipping containers, internal and external systems of shipping restraints and instrumentation required to verify the condition of the feedboxes during shipping.
- The engineering work done in collaboration with Fermilab and CERN to define the requirements for the IR cooling system and for the valve boxes that interface to the feedboxes. (The fabrication of the valve boxes is CERN's responsibility.)

Planned Design Reviews:

This Conceptual Design Review is the first of a series of design reviews to ensure the adequacy of the engineering design prior to the start of fabrication. These reviews will also address the proper functioning and integration of the components into the LHC, the budget impact of the procurement or fabrication method proposed, the schedule and the program plan. The CDR is generally conducted once the basic engineering design has been established. For a system to pass the CDR, it must be demonstrated that the engineering design is feasible and that an adequate R&D program has been planned to develop and prove the design.

This CDR will be followed by at least two other major design reviews, the Engineering Design Review (EDR) and the Production Readiness Review (PDR). The EDR will be conducted when most of the R&D is complete and the engineering design has been finalized. For a system to pass the EDR, it must be demonstrated that all of the technical and engineering challenges have been adequately addressed allowing the design and purchase of parts and tooling for full-scale prototypes and production deliverables to proceed. The PRR will occur after final proof-of-design is complete, i.e., after prototypes are delivered and tested successfully, etc. It will occur before the final production of the deliverables for the LHC. The PRR must include a strategy for fabrication or procurement, quality assurance, and a component test plan.

Design Team:

The design is represented by:

- W. Turner, LBNL Project Manager

Appendix A

Conceptual Design Review – Charge
Distribution Feedbox

- J. Zbasnik, LBNL DFB Lead

Design Review Committee:

The design review committee members are as follows:

- P. Pfund, FNAL, Chairman
- J. Strait, FNAL
- R. Ostojic, CERN
- R. van Weelderen, CERN
- P. Sacre, CERN
- L. Williams, CERN
- S. Plate, BNL
- T. Peterson, FNAL
- T. Nicol, FNAL

Scope of the Review:

The review will cover the following items in particular:

- Proposed design and plans for development of the eight distribution feedboxes including potential testing to support design decisions.
- Arrangement of interfaces and piping that passes through the DFB.
- Arrangement of high and low current magnet buses.
- Plans for the specification, procurement, and testing of HTS leads.
- Requirements for the IR cooling system and the valve boxes that interface to the feedboxes.
- R&D plans, specifically HTS leads.
- Functional Specification and Interface Specification documents that are being prepared which together define the requirements to be met by the design.

The design review committee has the usual freedom to investigate other areas of the DFB design that present a risk to the successful completion of the project, installation, and operation in the LHC.

Timing of the Review:

The review is scheduled for Wednesday, December 2, 1998 at Fermilab. It is anticipated to take one day.

Results of the Review:

This review is a Level-3 project milestone, scheduled for completion by December 15, 1998. The review will be complete with the issuing of a report summarizing the technical designs reviewed, committee recommendations, and action items.

CDR Agenda – Distribution Feedbox (DFBX)

8:30 am	Design Review Committee Planning Session (committee only)
9:00 am	Introduction to the CDR: P. A. Pfund
9:05 am	Introduction to the Design: W. Turner
9:15 am	Presentation and Discussion of Design: J. Zbasnik
12:00 pm	Lunch
1:00 pm	Design Review Committee Planning Session (committee only)
1:30 pm	Design Review Committee Working Session (with designers)
3:30 pm	Design Review Wrap-up, Reviewers and Presenters
4:00 pm	Adjourn

Designers	Reviewers	Observers
W. Turner	P. A. Pfund, Chairman	B. Strauss, DOE
J. Zbasnik	J. B. Strait	M. Lamm, FNAL
G. Millos	R. Ostojic, CERN	
	R. van Weelderen, CERN	
	L. Williams, CERN	
	P. Sacre, CERN	
	S. Plate, BNL	
	T. Peterson, FNAL	
	T. Nicol, FNAL	

CDR Schedule – Distribution Feedbox

11/3/98	Contents of Preview Package Selected
11/13/98	Preview Package Sent to Design Reviewers
11/24/98	Reviewer Preliminary Comments Returned to Chairman
12/2/98	Design Review Meeting Conducted
12/8/98	CDR Report Draft Circulated
12/11/98	Reviewer Comments Returned to Chairman
12/15/98	Final Review Report Issued