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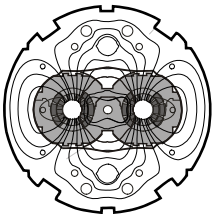

the
Large Hadron Collider
project

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Review Report

REPORT OF THE REVIEW OF HARDWARE COMMISSIONING

Abstract

This report is the outcome of the review of the Hardware Commissioning that took place at CERN during May 11-13th 2005. The aims were:

- Reviewing the programme, the logic, the coherence and the consistency
- Highlighting shortcomings in the organisation or in the coordination
- Highlighting interferences or/and incompatibilities with other ongoing activities
- Assessing the resource needs
- Obtaining the endorsement of the Department Heads and Group Leaders

The speakers were asked to justify the tests they were planning to carry-out on their equipment, evaluate their added value and the impact if they were not carried-out or were shortened.

The link to the program of the Review, the abstracts of the contributions and the slides is given below:

http://indico.cern.ch/conferenceTimeTable.py?confId=a053

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Secretaries : F.Rodríguez-Mateos, R.Saban

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History of Changes

Rev. No.	*Date*	*Pages*	*Description of Changes*
0.1	2005-07-15	21	First circulation to the authors
0.2	2005-07-27	All	Circulation to the session chairmen
0.3	2005-08-03	All	Minor modifications following circulation to session Chairmen
	2005-08-10	All	Submission for approval
1.0	2005-09-01	All	Released version

Table of Contents

1. EXECUTIVE SUMMARY

The Review found that the organisation and the proposed test programs were sound and that the resource requirements are generally adequate. This led to the approval of the report on the Resources for the Individual System Tests and the Hardware Commissioning of the LHC. (EDMS N° 503580)

The following **organisational matters** were judged worth further attention: the assessment of the usefulness of a field control room underground after the commissioning of the first two sectors, the setting-up of a crisis team, the creation of a Main Ring Group.

It was noted that Hardware Commissioning will be the first occasion where the **safety measures** (responsibility, training, access conditions, signalling, etc.) put in place for LHC will be evaluated for the first time. Furthermore, Hardware Commissioning will be a test of the new organisation of Safety at CERN; its impact must be monitored.

A number of **issues related to controls & informatics** were noted; they include: the need of a reference database reflecting the as installed state of the machine, a dedicated database piquet service during the hardware commissioning when the level of activities around the databases and the MTF is expected to be high, the implications of network security measures on the tests in the tunnel carried out using mobile equipment (Wi-Fi), further development of the automated test procedures and the creation of tools for the analysis of test results.

Important **technical issues** related to either the conditions under which the tests are carried-out (e.g. the ventilation of the tunnel during the tests) or the tests themselves were considered; some of them must be reconsidered in the light of the present installation and commissioning scenario. The list includes: the leak tests following the interconnections, the smoothing of the magnet alignment. Further studies to assess the impact of failures (e.g. how do leaks translate in repair times) were also requested.

The impact of the new schedule on the **uptime requirements of utilities** (e.g. electrical power, maintenance plans) and the associated contracts with the suppliers were also considered.

Many of the questions which were transmitted to the Session Chairmen had not been answered by the speakers; it was agreed that the latter required a first experience before a definitive answer can be given. It was therefore decided to hold a second shorter review (one day) after the commissioning of LSS8L is completed but before the Hardware Commissioning starts in 2006.

2. OVERVIEW

This section briefly summarizes the sessions, reports the open issues which were identified and formulates the recommendations of the review panel.

2.1 ORGANIZATION AND COORDINATION OF THE HC

The objective of this session was to describe the logic and the day to day organization including safety of personnel, explain the decision making process and recovery plans and fall-back solutions.

The importance of the **support from both the AB Controls and the TS Database & MTF Teams** was stressed. These tools must provide sequencer-like test procedures, assistance to the analysis of events, as well as easy interaction with the MTF and databases.

The usefulness for efficient operation of the Field Control Room was debated at length. The Review Panel recommends:

R1 The **Field Control Room** is installed in UA83; its usefulness will be assessed at a later stage and a decision taken on whether it will be re-installed underground in UA43, on the surface SR4 or the Hardware Commissioning continued from the CCC.

A number of documents (see Appendix I) considered critical for the efficient coordination of the HC were identified; the **list of missing documents** (see Appendix I) was sent to the Department Heads. The Review Panel therefore recommends:

R2 The preparation of the documents will be followed-up by the concerned Department Heads and regular reporting will be done at the TCC meetings.

Action: P.Ciriani, Ph.Lebrun, S.Myers, P.Proudlock

The **deployment of the HCC team in the field** was described; the team is deployed in the two sectors being cooled down, the two sectors being power-tested and the other sectors where either individual system tests or the commissioning of warm components is ongoing. In addition, office and analysis work must be carried-out. The composition of the team, the working hours were discussed.

The Field Staff for HCC should ideally already have the expertise required when Hardware Commissioning starts and that the experience acquired during the HC should not be lost; furthermore, their involvement in the preparation of the HC procedure was considered desirable. The Review Panel recommends:

R3 The **Field Staff for HCC** be found from the following three sources: redeployment, complements and National Institutes.

Action: P.Ciriani, Ph.Lebrun, S.Myers, R.Saban

The measures present for the safety of personnel were described together with the assumptions on the availability of the safety and access control systems. It was however noted that the difference between people involved in the tests and passers-by was not enough taken into account. For the different phases of the tests, the access conditions which apply both to the actors and people external to the activity

were found to require a better understanding. The Review Panel therefore recommends:

R4 The **access conditions** must be studied and defined in detail by the Coordination for HC (HCC) together with the Project Safety Officer, the Safety Coordinators, the SC Commission and the Groups concerned. The implication on the budget of HC must be evaluated.

The decision making process was examined in detail and the proposal for the creation of a Crisis Team was accepted. The Review Panel recommends:

R5 A **Crisis Team** be created; it will be activated when exceptional situations are encountered. The members of this team were proposed to the Department Leaders.
The Team is presently composed of Frédérick Bordry, Paul Cruikshank, Karl-Hubert Mess, Paul Proudlock, Félix Rodríguez-Mateos, Lucio Rossi, Roberto Saban, Rüdiger Schmidt and Luigi Serio.

The HCWG reviewed the failure scenarios for a number of systems in order to define strategies for at least a few case studies per major system. This will allow gaining in reactivity at the time of failures. The Review Panel recommends:

R6 The **failure scenarios** studies be documented. The titles and the author list is given in Appendix I

The new installation scenario (no QRL cold tests, no sequential installation of magnets, etc.) impose a change in some of the procedures. The Review Panel recommends:

R7 The **Leak Test Scenario** be revisited with AT-VAC, AT-CRI and AT-ACR in the light of the new magnet installation scenario

Action: P.Cruikshank

The event of a power cut due, for example to a thunderstorm, was discussed and the preparation for such an event was considered necessary in view of its impact. The Review Panel recommends:

R8 HCC must conduct a study of the **Effects, Consequences and the Recovery from power cuts, power glitches and electrical faults**. This study will be carried-out in conjunction with AB/OP-TI that has accumulated knowledge on the sensitivity of the different systems to different types of failures; they will be assisted by TS-EL.

Action: J.Pedersen, R.Saban, P.Sollander

2.2 QUALITY ASSURANCE AND DOCUMENTATION OF RESULTS

A number of issues were reported on the handling of non-conformities of subsystems by the MTF. The Review Panel recommends:

R9 HCC must take all necessary actions with the MTF Team to ensure that all the non-conformities are visible for hardware commissioning and during routine machine operation.

The reference database reflects the equipment, systems and machine as designed. Following non-conformities encountered during manufacturing and/or assembly, the installed machine will be different. The difference between the *as-designed* and the *as-built* reference database was discussed The Review Panel recommends:

R10 An **as-installed reference database** be created and maintained to represent the machine as installed and to reflect the differences with respect to the as-designed reference database. This task is assigned to the TS-CSE and TS-IC Groups.

Action: P.Ciriani, C.Hauviller, T.Pettersson

2.3 CONTROLS AND COMMUNICATIONS

The controls and communications needed for hardware commissioning was presented in two parts. The first part covered the infrastructure of the controls hardware while the second treated the software infrastructure.

2.3.1 HARDWARE INFRASTRUCTURE

Most parts of the complete controls infrastructure are already needed for hardware commissioning. This must clearly be installed and tested before hardware commissioning starts. The infrastructure here includes the Technical network itself, based on ethernet, the WorldFIP and the timing generation and distribution systems. The planning of the controls hardware is linked to the other Hardware commissioning activities. At present the plan is to get the control system tested and operational in 1-2 months before the start of the individual system tests.

For the WorldFIP there are already 160 units at CERN, waiting for testing. However there is a potentially serious problem with the bus arbiter card – a non systematic de-synchronization has been observed. This has been reported back to the manufacturer and their response is expected in July 2005. It is hoped that a solution can be found by re-programming the firmware on the cards.

R11 It is recommended that an urgent study be made of the impact of the de-synchronization error on all systems in case a solution cannot be implemented immediately. In addition, once a solution is agreed a plan must be drawn up for the corrective action to take on WorldFIP units that are already installed and potentially in use.

Action: AB/CO, M.vanden Eynden

The next WorldFIP installation (in IR7) has been delayed until a solution is implemented.

Other controls hardware needed for hardware commissioning includes remote reboot crates, terminal servers and technical consoles. These appear to be in good shape for LSS8 and installation around the ring is proceeding to plan. For the QRL test the Profibus system is in place and ready, however for the LSS8 tests some WorldFIP/Ethernet gateways are needed by the cryogenic system. These are not yet in place and will require software development by AB/CO.

For the timing infrastructure, the master system is in place and tested. This is presently installed in MCR. At some point it will have to be moved to the CCC. A careful planning of this move will be required to avoid perturbation of tests in the field. The distribution of GMT to Point 8 is in place and tested. The accelerator timing distribution equipment will be installed soon. It was noted that the definitions of the timing events needed for individual system tests and hardware commissioning needs to be finalized.

The WorldFIP is clearly a large and critical part of the infrastructure. Tests of the system must be undertaken as part of the installation procedure.

R12 The final qualification of each segment can only really be done once the cabling is finalized and the real equipment is attached to the bus. These qualification and acceptance tests must therefore be programmed and added to the HC planning.

Action: AB/CO, HCC

2.3.2 APPLICATIONS INFRASTRUCTURE

The high level software for hardware commissioning and later for LHC operation will be built on experience gained during the commissioning of the transfer lines and LEIR. However, for hardware commissioning the first extensive use of industrial control systems will have to be included. These systems cover cryogenics, quench protection, vacuum and powering interlocks. All controls will make use of common basic services – such as alarms logging, fixed displays and post-mortem. Deployment of the control software will be progressive and the functionality mapped to the identified needs.

R13 It is recommended to check that all needs have been clearly identified and both the equipment specialists and the software teams agree on the planning for deployment.

Action: HCC

For major extensions to the control software functionality the importance of dry runs cannot be overstressed. During these periods the controls chain can be checked and stressed from application, via the communications to the real equipment to be accessed.

R14 It is vital that such dry runs be slotted in at appropriate points within the framework of the other activities via the HCC.

The scope of control applications for the hardware commissioning activities in LSS8 was outlined and the requirements are known. It is clear that the Controls Middleware (CMW) is the glue for the controls applications and is presently being debugged and deployed on other installations - such as LEIR. Other common services will get their first real test during the hardware commissioning of LSS8. In particular post-mortem and logging will be vital to the success of the hardware commissioning. For the post mortem system, there is some experience from the commissioning of TT40 and TI8. The data collection chain has been tested and works for power converters. A prototype visualization tool is in place. It was noted that there are still issues between the post-mortem system and the CMW. These are under investigation and must be resolved soon. Tools to allow correlation and analysis of post-mortem data are much less developed. They are presently essentially still at the software analysis stage. Correlation of QPS, interlock and power converter signals is vital for hardware

commissioning. Since the post-mortem system is a pre-requisite for the powering test, the Review Panel recommends:

R15 Sufficient effort is put to make the **post-mortem system** available for the first powering tests in December 2005.

Action: AB/CO, HCC

For the cryogenic system: the controls are well underway. Development is over 50% complete. Parts have been validated and some installations are operational. In the case of the cryogenic distribution (QRL, DFB, Magnets), the same framework will be used as for the rest of the system. However, the configuration is different. The implementation should be ready in time for the first tests.

The other large deployments of industrial controls cover the PIC (Power Interlock Controller), the QPS (Quench Protection System) and the Vacuum system. In the case of the PIC the development is delayed but not yet late – The first operational prototype should be ready in August '05. The complete version for power test is needed in December. For the QPS a system for surface tests is already in place. A new version is under development which complies with LHC naming conventions. This will be available soon for use in the tunnel. Finally the vacuum system will use the same software that is presently deployed for the SPS and the transfer lines.

The high level application software for control of powering circuits has already been deployed for TT40, TI8 and LEIR. One additional facility is the sequencer. A version 1 application is in place and tested. This will be a very useful tool for series tests and effort should be made to develop additional testing procedures that can use it.

Some outstanding issues remain for the software infrastructure. The data exchange between systems is principally based on CMW for most communications but also on DIP. Bridges between PVSS and the CMW are in progress but not yet complete (needed for QPS and PIC). The bridge between PVSS and DIP is available but not yet operational (needed for vacuum & QRL). In addition, some new applications for hardware commissioning are still at the stage of user requirements collection. In other cases the requirements are already known and implementation is following.

R16 A careful check is needed to ensure that the planned deployment of the software infrastructure for the exchange of data between systems matches the need.

Action: AB/CO, HCC

The implementation of the same software system on TI8, LEIR and LHC is a good thing – but tends to make competing demands on software developers.

A policy document on network security policy is presently under discussion. This has been prepared by the working group for Computing and Network Infrastructure for Controls (CNIC). The policy aims to improve security and would limit access to the technical network. There will be no problem where applications run on approved computers on the technical network. However, access from outside the Technical Network will be severely limited and require the use of application servers. The use of Wi-Fi and portable computers is strongly discouraged.

R17 Computers on the Wi-Fi in the tunnel must be able to connect to the Technical Network. It is urgent that the implications of the recommended security policy on the hardware commissioning be studied before implementation begins.

Action: T.Pettersson, The Controls Board, IT/CS

2.4 INFRASTRUCTURE

The Hardware Commissioning programme will be followed by the Energy Panel in order to match the forecast with the type of contract. In fact, the new installation schedule, which foresees commissioning activities (cool downs, cryogenic operation and power tests) during the winter, indicates a power requirement profile different than what was the case in the past. It is clear that the present electricity contract is not optimal for the planned electricity needs for HC. The Review Panel therefore recommends:

R18 P.Ciriani will study and renegotiate to adapt the **electricity contract** to the requirements of the present installation, commissioning and machine start-up schedule.

The cooling and ventilation system will be on time for HC. It was noted that **the control of the ventilation system will be in manual mode**.

Different activities, which sometimes take place in parallel in the same sector require different ventilation conditions. The Review Panel recommends:

R19 The **Tunnel Ventilation Modes** must be adapted to the ongoing activity (leak test, survey, interconnection, etc.) and negotiated with all the concurrent actors by HCC.

The **connection of the flexible tubes for water cooling** (power converters, cables, magnets) has always been a delicate operation. A document describing all the steps of this operation is being prepared by the CV Group in conjunction with the equipment owners.

Action: F.Rodríguez-Mateos

The Access System – which comprises both the Access Safety and the Access Control Systems - will be ready on-time for the operation with beam of the LHC. Transitory measures will be put in place during the HC. No access control system is planned for Point 5 during the construction and the HC. There exists **some concern about the acceptance of the Access Safety System by the INB**.

Following the experience with other machines, the SU Group recommends the final alignment (smoothing) of the magnets. This operation is not yet included in the General Coordination Schedule. The Review Panel recommends:

R20 R.Saban and S.Weisz, in conjunction with the SU Group, were asked to find or create (!) a time slot for the **final alignment (smoothing)** activity which is compatible with installation, transport and the hardware commissioning.

10 weeks are needed per sector for a team of three surveyors working alone in the sector.

2.5 VACUUM

The installation and commissioning of the room-temperature (LSS) vacuum system follows well-established procedures developed and validated on other colliders, with additional precautions required by the use of NEG-coated vacuum chambers. This requires in particular careful commissioning and interlocking of vacuum sector valves once the corresponding sectors are baked and the NEG activated. The interference through the ventilation, of the presence of helium with leak detection in the tunnel was discussed, however without clear conclusion: on one hand, reduced air speed helps with leak detection, while on the other hand, strong ventilation will flush the tunnel from residual helium. For operator safety reasons, there should be no powering of room-temperature magnets during leak detection in the LSS.

The Review Panel recommends:

R21 Define optimal ventilation conditions for helium leak detection in tunnel

Action AT-VAC

As concerns the cryogenic vacuum system, leak test and commissioning procedures exist but details are missing and the documentation is not complete. In particular, the global pressure test during which the final leak detection is performed has no identified “owner”.

The Review Panel recommends:

R22 Groups responsible for supplying and installing pressure equipment take ownership for the global pressure test

Action AT-ACR and AT-CRI

The time impact of vacuum failures has been estimated for a number of cases; the leaks which require replacement and/or warm-up of magnets have the biggest time impact. Moreover, unforeseen interventions on the cryogenic vacuum system may be required due to other systems failure.

Although teams for baseline activities and for special interventions are planned in the present organization, no “piquet” service is foreseen for HC.

The Review Panel recommends:

R23 Assess cost and benefit of implementing vacuum “piquet” service for HC

Action AT-VAC

2.6 CRYOGENICS

The detailed requirements and program for cool-down and cryogenic commissioning of sectors was presented. Cryogenics is a high-level process which requires availability of utilities (electrical power, cooling water, cryogen supply) and of supporting technologies (vacuum, controls, communications); conversely, its reliability is strongly impacted by interruption of these utilities and supporting technologies, in most cases with a down time amplification factor accounting for the long time constants encountered in thermal processes. Another consequence of these long time constants is that the on-duty time for cryogenic experts largely exceeds the on-duty time for

users of the equipment; in particular, 2x8 hour shift work for conducting the HC program would imply more than 2x8 hour shift work for cryogenics, which is not presently foreseen.

The Review Panel recommends:

R24 Include cryogenic preparation & recovery times in 2X8 hour shift program of HC

The system architecture is complex, with many control loops to be tuned – though in families – after reaching operating conditions (30 control loops per sector for magnet temperature, and 150 per sector for current leads).

The Review Panel recommends:

R25 Define and implement generic procedures for swift tuning of cryogenic control loop families, including "sufficient performance" criteria

Action AT-ACR

Although the risks resulting from cryogenic failures in the tunnel are low by design and documented, the first cool-down and fill of a sector will constitute the first full-scale test of the quality of construction; by decision of the SC, personnel access will be forbidden during this phase. However, cryogenic experts will have to get access to the equipment in the tunnel during several phases of HC.

The Review Panel recommends:

R26 Negotiate and establish with the SC the detailed cryogenic conditions of forbidden, restricted and free access to the tunnel

Action AT-ACR, SC-GS, Ph. Lebrun

The strong dependence of HC cryogenics on the industrial support contract for operation and maintenance of CERN cryogenic plants, due to terminate in 2007, calls for an extension providing a time perspective well beyond the scheduled completion of HC, in order to avoid early loss of competence and staffing perturbations.

The Review Panel recommends:

R27 Plan for an exceptional extension of the cryogenics operation and maintenance support contract beyond 2007

Action AT-ACR, Ph. Lebrun

Cryogenic instrumentation is a large system, with 1900 channels in 125 crates per sector, which needs to be installed, connected and commissioned before HC. This is time consuming and additional personnel resources must be allocated to meet the project schedule. The presentation pointed out one problem which may also affect other systems, i.e. the non-uniqueness of naming due to inconsistencies between the MTF and LHC reference data base on one side, and that used by controls and operations groups on the other side.

The electrical feed boxes DFB and superconducting links DSL, although designed and built in a modular way, feature a large number of variants. Moreover, they are novel, complex cryogenic and electrical objects housing critical components such as HTS leads operating at high current density. Due to compression of the general schedule, they will not undergo functional testing before being installed in their final locations in the tunnel, and connected to the superconducting magnet strings which they feed.

The Review Panel recommends:

R28 Reserve suitable time in HC schedule for thorough functional testing *in situ* of the first DFB and DSL

Testing the DFB and DSL connected to large inductive loads in non-nominal conditions may entail high technical risk for the equipment concerned.

The Review Panel recommends:

R29 Assess risk and benefit of non-nominal tests, establish and enforce conservative test program for DFB and DSL in tunnel

Action AT-ACR, AT-MEL

2.7 ELECTRICAL CIRCUITS AND MAGNETS (WARM AND COLD)

The protective covers over the connections of the warm magnets do not have micro-switches interlocking the power converters. The covers are designed to avoid accidental contact with the live connections but can not be considered foolproof. This was considered acceptable and it will improve operation reliability. Training for access will stress the dangers involved. There are no live bus-bars powering the warm magnets as found in the SPS. The cold magnets of LHC have large stored energy giving rise to particular electrical dangers during disconnection on the warm side. Specific procedures will be put in place to cover this and the subject will be covered in the training for access. This will apply also for the operation of the machine.The Review Panel recommends:

R30 Special procedures must be put in place to cover the disconnection and reconnection of superconducting circuits; including the closed-orbit corrector power converters which have a long time constant (170 s) and high inductance (6H).

Action: F.Rodríguez-Mateos

Access training must cover the specific electrical dangers associated with LHC.

Action: HCC, PSO, SC

Before continuing to higher currents, careful analysis of the quench curves and of the signals from non-quenching magnets is necessary. The expertise for this can be found only in MEL and MTM groups. All this takes time. To help in this task and to make it a realistic proposition automatic and rapid analysis is needed to aid the HC teams. A comprehensive post mortem analysis is also needed. The software specialists needed to carry out these developments in a reasonable time are not yet identified.

Considering that beam loss may cause several magnets to quench, it is essential that everything is tested. The Review Panel recommends:

R31 **Automatic analysis software tools** of the electrical behaviour of the magnets are developed along with a post mortem system.

Action: AB/CO, HCC

Once operational the QPS will be tested once a month which will take 3 hours in a sector. Again the issue of making this automated, faster and more frequent was raised. However this may not improve reliability in all cases. The Review Panel recommends:

R32 Consideration be given to developing **a more rapid automatic QPS testing**

Action: AT/MEL

A missed quench on a corrector chain would at least need the opening of the interconnects for bypassing and may require a magnet change.

It was not clear to what extent the synchronisation problem on the WorldFIP would have on the QPS system. This should be clarified particularly considering the forthcoming sub-sector test in LSS 8L. In all respects, the sub-sector test will be an important milestone for HC allowing procedures to be fine tuned.

During initial powering it may be necessary to measure voltage drops which are lower than the sensitivity of the quench detectors in order to detect bad splices. The Review Panel recommends:

R33 Studies to determine the required sensitivity of the quench detection during initial powering be made. Proper instrumentation exists for the **detailed measurement of the circuit characteristics** at first powering.

Action: F.Rodríguez-Mateos

Damage to the power converters may result if they absorb more energy than the freewheeling circuits were designed for. This could occur if there are failures in the energy extraction system (switch and heater failure). In general the failure within the Power Converter is failsafe in that the thyristors making up the freewheeling circuit will short-circuit. However, considerable damage will result. This is also the case when the decay time constant in doubled due to single switch opening.

The short circuit tests of the power converters will also give a complete test to the cooling and ventilation systems as well as the electrical distribution. It was noted that the HCC has a mandate to take the circuits to nominal current and not above. (The power converters and cables will be taken individually to ultimate current during the short-circuit tests.) While synchronisation between circuits of the same sector is possible (e.g. MB with Quads), the synchronisation of all eight sectors can only be done with beam in the machine.

All main magnets (MB, MQ) have been validated to run to 12 kA during the SM18 cold test in order to give a margin of about 150 A with respect to the 7 Tev conditions. To run the magnets once at 12 kA appreciably decreases the risk of spontaneous quenches. The Review Panel recommends:

R34 The main magnet chains (MB, MQ) are powered to **12 kA**.

The resistive current leads of the 60/120A circuits are protected against overheating by the Power Converters and the voltage signals are not available in the control room. The voltage across the current leads is available on the Digital Interface Module. It can be read by expert diagnostic interface. It was not foreseen to be systematically published at high rate but it can be surveyed by a dedicate application polling at around 60s. The Review Panel recommends:

R35 The voltage signals across the current leads of the 60 and 120 A circuits are made available to the control system and subsequently available in the Control Room for the commissioning of the circuits.

Action: AB/PO

The water cooled cables in Point 3 which connect the warm magnets of the insertion to the TZ 32 tunnel have sufficient section to operate without water and are therefore not interlocked. The water cooling is only needed in order to reduce heat dissipation to the machine tunnel air.

The supervision system of the Power Interlock Controllers (PIC) is underway and work will soon start on the Warm Interlock Controller (WIC). The WIC supervision system can store up to 2000 events in the PLC and will be able to identify which magnet in a chain has caused a trip. This will be available on local display panels and will be made available in the Control Room. It will be possible to correlate the timing of a WIC trip with that of a PC trip.

A very impressive demonstration was given of the sequencer for the interlock ISTs. This will not only be important for HC but of great value in the future when coming out of a shutdown.

Damage would result on the cold protection diodes even at low current if the relevant power converters are connected with the wrong polarity. No simple electrical test can verify this polarity once the magnets are cold.

The use of automated tests particularly for large series of circuits such as the orbit correctors is necessary. This is important in order to make sure that nothing is forgotten and that procedures are followed. Such systems once developed can be used for future cold check outs.

Following the very convincing presentation of automated procedures for the interlock system tests, the Review Panel recommends:

R36 HCC must conduct a study to identify other possible candidates for **Parallel, automated test and analysis procedures** for the systems where this is not foreseen yet.

To this effect two additional software engineers were allocated to AB/CO in the report for the resources for the ISTs and HC.

R37 A prioritized list of the needed procedures across systems must be prepared.

Action: R.Saban

It was noted that support will be needed for the MTFs. The support for MTF is provided by a joint TS/IT team with the understanding that there is always one competent person available at all times from both groups without having a formal piquet service.

2.8 BEAM SYSTEMS

There was a set of talks on beam related systems. No specific recommendations were issued by the Review Panel. A summary of these talks can be found in Appendix II.

2.9 COMPATIBILITY OF HARDWARE COMMISSIONING WITH INSTALLATION

The main incompatibility between the installation and the HC will be encountered during **the first cool down of the sectors 78 and 81.** In fact, access to the sectors will be forbidden but the transport of machine components is ongoing for sector 67. Another delicate area is the installation of the elements in the TI2 tunnel which will take place during the HC of sectors 21 and 23.

The **installation and commissioning of the experiments does not seem to present incompatibilities**; however, very tight coordination between HC and the experiments will have to be maintained by the TS-LEA Group.

The logistics for the installation are very dense therefore **any perturbation will have a strong impact** on the installation and assembly activities. The general feeling is that there will be inevitable interferences between some of the co-activities (e.g. QRL installation and Hardware Commissioning, magnet interconnections and transport).

2.10 FROM HARDWARE COMMISSIONING TO COLD CHECKOUT

According to the General Coordination Schedule LHC-PM-MS-0005 rev 2.0, Hardware Commissioning of the 8 sectors of LHC is scheduled to take place successively around Points 8, 4, 6 and 2, with each quadrant finished in November 2006, March 2007, May 2007 and June 2007 respectively. This work will be carried out under the responsibility of the Hardware Commissioning Team. In July 2007 the AB Operations group will coordinate a full Machine Checkout before embarking on commissioning with beam. This planning leads to a number of uncertainties encapsulated in two questions;

- What happens to a sector after Hardware Commissioning?
- Who is responsible for sectors between Hardware Commissioning and the Machine Checkout?

At the end of Hardware Commissioning of a sector, all equipment in that sector should ideally have been tested to allow nominal performance for operation at 7TeV. It is possible, however, that this will not be the case for two reasons. Firstly, some equipment may not reach nominal performance levels in the allotted time, and will need further work. Secondly, the Hardware Commissioning Team will not wait for late but non-essential equipment, which will have to be commissioned later. These late activities will be performed by the relevant equipment specialists, coordinated by the Hardware Commissioning Team. The Review Panel recommends:

R38 Careful planning and configuration management to keep track of modifications to already commissioned sectors.

Action: HCC

Any modification, additional tests, etc. must be authorized by HCC, that retains the responsibility for the sector.

The present planning does not foresee that the first 4 sectors (7-8, 8-1, 3-4 and 4-5) will be kept cold after hardware commissioning. Rather they will be left to float, will slowly warm up, and will need to be re-cooled before the Machine Checkout. This strategy poses a number of problems. In general, sector cool down requires resources

from vacuum and cryogenic groups, and is estimated to take a total of 5 weeks per octant. Furthermore, if the sector has warmed to a temperature above 80K, a full electrical quality assurance will need to be remade once the sector is cold again. In Point 4, RF commissioning/conditioning is planned through 2007, and so will need to be at cryogenic temperatures (4.5 K). The Review Panel recommends:

R39 To keep all the other commissioned sectors below 80 K to avoid the repetition of the full electrical quality assurance tests.

The cost of doing this was not precisely known at the time of the review; however, information provided after the review for comprehensive costs per sector kept cold and per month are:

1.9 K winter	195 kCHF
1.9 K summer	175 kCHF
75 K winter	55 kCHF
75 K summer	50 kCHF

Due to the variation of electrical costs throughout the year, detailed figures are needed month by month, both for keeping the systems at operational temperatures and for holding them below 80K.

Keeping all the other commissioned sectors below 80 K is the pre-requisite to maintain the compressed schedule.

Supposing that the above issues have been taken care of, we can assume that all equipment has been exercised to nominal performance level and is (again) cold before the Machine Checkout. It will then be necessary to restart and retest all systems in preparation for operation. These activities should be kept to the minimum required by Operations but will need solid coordination, and this type of work is very similar to that performed every year towards the end of the annual shutdown of the accelerators. Indeed this will be the case for the LHC after every long shutdown, where responsibility is expected to be entrusted to an LHC shutdown coordinator.

The Review Panel recommends:

R40 The same strategy is applied to the period in question, as an early role for the aforementioned shutdown coordinator. This position has in the past been performed from within a **Main Rings Group**, and it would be a good idea to put in place something similar for the LHC already in 2007. This group or team would hand over to AB Operations for the Machine Checkout.

Action: S.Myers

The LHC tunnel is considered as a single worksite, and so responsibility for safety for all sectors should stay in the TS department until the end of all Hardware Commissioning and enforced by the Project Safety Officer assisted by the Safety Coordinators. Safety procedures have been established for both Installation and Hardware Commissioning, and these should be applied until the various safety systems are certified for machine operation. The only exception to this would be the Injection Test into sector 8-7, scheduled for late 2006. The Review Panel recommends:

R41 During **the injection test the responsibility for safety** is transferred to the AB department and returned to the TS department when the test is finished. A procedure for this temporary hand over of responsibility needs to be defined.

Action: M.Lamont

Appendix I List of missing documents

Individual System Tests

Beam Dumping System	J.Uythoven
Cold vacuum sub-sectors	P.Cruikshank
Cryogenic Instrumentation	P.Gomes
Electrical Quality Assurance	D.Bozzini
Energy Extraction	K.Dahlerup-Petersen
Hardware Infrastructure for Controls (fieldbuses, timing, networks, gateways)	R.Lauckner
Quench Protection	R.Denz
Software Infrastructure for Controls (e-logbook, post-mortem system, logging system, alarm system)	R.Lauckner
Warm vacuum sub-sectors	JM.Jimenez

Failure Scenarios

Cryogenics	L.Serio
Superconducting Electrical Circuits	F.Rodriguez-Mateos
Vacuum	P.Cruikshank

Appendix II Summary of talks on Beam Systems

AB-ATB EQUIPMENT

The ATB group is responsible for beam intercepting devices around the LHC ring (beside Point 4) and the transfer lines. A total of 125 objects have to be installed and commissioned, a large quantity out of it are collimators.

Concerning the non-collimators the objects have been already produced and partially installed or are actually under construction. The scheduled dates are listed in the table below:

Equipment	Objects	Production Status
Safety stoppers (TBSE)	3	completed
Dumps for the transfer lines (TED) in TI2, TI8 and CNGS	3	3 completed, 1 to be installed in Q1 2007
LHC Beam dumps (TDE)	2	1 in 12/2005, 1 in 12/2006
Injection protection dumps (TDI)	2	1 in 4/2006, 1 in 2007
Injection shielding (TCDD)	2	Design in 6/2005, Needed?

The prerequisites for Hardware Commissioning are:

- Installation completed
- Water and Electricity
- Control Network available
- Vacuum and bake out done
- Access to the tunnel

For the collimator production the contract has been signed and a schedule will be implemented by the company in June. The goal is to fulfill the installation schedule of LHC and in the same time guaranteeing the minimum performance criteria's for the first years of operation. The main steps for the collimator conditioning are the following:

Preparation on Surface 2006 - 2007

Equipment assembled on surface

UHV Test of the system

Functionality test of the full system on surface (Motorization, monitoring, cooling, vacuum)

Relative alignment by metrology of the moving components, calibration of motors and encoders

Align with reference to the planned position in the tunnel

Underground work summer 2006 - 2007

Installation of the support units and alignment with mock-up

Check the cabling (motors, controls, interlocks) (done by cabling service)

Connect to the cooling circuit

Vacuum chamber connection

Verification of the alignment

Commissioning of the local control system (motors, switches, temperature and position sensors, …)

AB-BT EQUIPMENT

The responsibility of the BT group covers the specific BT equipment, in the various kickers and the dump protection devices, and also the overall injection and dump machine systems. For the injection kickers in Points 8 and 2 the hardware commissioning procedures have been defined and published, and the HWC is planned for summer 2006 and spring 2007, respectively. The injection system HWC will take place shortly before the LHC sector test for Point 8, and before the first full LHC operation for Point 2. For the HWC date is not yet defined; it will probably be after the rest of the Point 4 HWC activities. For the beam dump kickers, the procedural documentation is still in preparation - the HWC will be at the end of 2006, to be followed by a 3 month 'reliability run' of the beam dumping system, which is the system level commissioning, to take place in spring 2007. This will be in parallel with the injection system commissioning in Point 2. The main concerns are: the need for a detailed planning of equipment HWC activities, especially to check for interferences, which should be included in the overall LHC planning; the need for detailed planning of system level tests, with scheduling and responsibility to be defined; the critical path for the downstream end of TI 2 end and the Point 2 injection; the inclusion of the dump system reliability run in the overall LHC planning.

AB-RF EQUIPMENT

The set of tests which will be carried-out to condition and validate for operation all the components of the RF systems (ACS, ADT) has been presented. Details can be found in EDMS document 476511.

The RF commissioning can be divided in three periods of time, as a function of the services required to perform the tests:

The first period can be called the “Infrastructure & Hardware Checks”. It corresponds to the individual equipment tests, the RF cable calibration, optical fibres checks, PLC tests. In addition to the basic services (e.g. 230/400V) the availability of the control system is required (network, RF control software)

The second period is the “POWER SYSTEMS COMMISSIONING”. During this period most of the high voltage and high power RF equipment are tested. To perform these tests, additional services must be available: water cooling, klystron power converters, ventilation (incl. Faraday cages), and chilled water.

The “RF COMMISSIONING” is the most demanding period, in terms of services since it requires the access system to be commissioned for RUX45, the SC cavities to be cooled down, filled with liquid helium, the pressure in the QRL headers stabilized and the process control for cavity operation verified and running. Cryogenics fine tuning with RF power will be done during this period.

Although these periods of time can overlap, it is expected that the “RF commissioning” will last about six months: during all this time the SC cavities must remain cold and the cryogenic system must be stable. The ADT system, which is quite an important RF system, will be commissioned in the shadow of the ACS system.

AB-BDI EQUIPMENT

The BDI equipment is not part of the hardware commissioning proper, but may interfere with the HWC due to late monitor deliveries. The only exceptions are the systems interfaced to the Machine Protection system, i.e. the BLMs and BCTs, where a proper test procedure without beam has to be defined.

BDI equipment is mainly concerned by the commissioning with beam.

BDI equipment is comprised of:

two large distributed systems: BPMs and BLMs

two Luminosity monitoring stations in IR1 and IR5 provided by a US collaboration, where progress is being made

many special systems installed around IP4:

BCTs: Fast and DC monitors

Special BPMs for tune and chromaticity measurements

Transverse Profile Monitors: Screens, Wire Scanners, Synchrotron Light monitors, Gas Profile monitors

Longitudinal profile monitor

Screens and BCTs in the Injection and Dump lines

The reference for the BDI work is S. Weisz's planning (dated 1/04/05) and BDI's ultimate aim is to be ready for the LHC start-up scheduled for the moment for July 2007.

For the two large distributed systems the situation is as follows.

For the BPMs, the cold ones in the arcs follow the SSS planning, the others may be Just In Time, for instance BPM_A Q7R8. For the warm ones, manufactured at Novosibirsk, the ones for LSS8 may be Just In Time. There is a small problem with the order and subsequent delivery of delay lines, which may mean that 4 cards per quadrupole may have to be installed after the main installation campaign and hence may need some special access.

For the BLMs, the production of 4000 ICs will start in Protvino and the delivery should be Just In Time for installation. If not enough ICs will be available, 2 ICs per quadrupole will be installed during the planned installation campaign until the production catches up with the installation, and the last four ones will be installed later. Anyhow, the last IC has to be installed after the interconnect closure and the one on the passage will be installed after the last magnet transport through the considered zone. There again, special access will be needed.

The production of 340 SEMs for the SSS, IR3 and IR7, will start after the IC production.

The special systems in IP4, the injection areas and Dump lines, should be available just in time wrt the installation planning.

This is the case for the BCTs, the special BPMs, including the Schottky monitors designed at Fermilab and produced by CERN, the Transverse profile Monitors, i.e. the screens, wire scanners, synchrotron light monitors with SC undulator, and the ionisation gas monitors. The longitudinal monitor will be an RF Wall Current Monitor for the start-up in 2007 and will be available for the installation date.

Part of the installations will take place during the period foreseen for RF hardware checks, which will not be a problem if the cavities are not powered. There should be a small interference during the RF power tests starting in November 2006 when access will be needed to certain instruments. This will have to be coordinated carefully between the two groups. The interference will be minimal if access to UA43 and 47 is possible during the RF power tests, as foreseen.

Concerning the Instrumentation for the Dump lines, the design has just started in the TS design Office as the final details concerning location and vacuum chamber dimensions have been sorted out between AB/BDI, AB/BT and AT/VAC. For providing a foreseeable status of these Instruments wrt the installation planning, a more detailed planning for the Dump Lines has to be available.

AB-BEAM INTERLOCK SYSTEM

The LHC Beam Interlock System (BIS) is designed to be a highly dependable communications link between many distributed User Systems and the LHC Beam Dumping System (LBDS) its main function is to transmit a User request for a beam dump to the LBDS with minimum delay. The Hardware Commissioning for this system will take place in two main steps. Firstly, Individual System Tests (ISTs) are foreseen that ensure the system is internally correct and capable of operating within specification. Secondly, the system is tested in conjunction with the many User Systems (listed within presentation) to ensure the interfaces to the BIS are functioning. Once these have been performed, LHC can be considered ready for beam operation.

The IST is performed to ensure that the BIS conforms to the Safety Integrity Level - 3 specification (SIL-3), providing a highly dependable link from User through to LBDS. The LHC will be unable to start beam operation until the BIS testing is completed. The BIS commissioning is foreseen to take place concurrent to that of other systems, HC coordination may be required to schedule and organise the final commissioning step of the BIS with these User Systems. As the schedule for BIS Installation is currently foreseen, BIS commissioning will be completed on time, and if problems should arise, methods exist to accurately diagnose the nature of the problem, determining the faulty hardware and allowing the BIS to return to an available state in a short time. ISTs are foreseen to take place before each injection, and a full commissioning of the system is expected to take place after every machine shutdown