6. Committee Findings and Recommendations

The committee was very impressed with the progress made by a very small team in defining the cavern radiation and beam monitoring system. The content and quality of the presentations demonstrated that strenuous efforts are being made with very limited resources to bring an effective system to fruition in time for LHC start-up. The technology choices have been well justified and the concept presented is fundamentally sound. Specifications must now be rationalised and resources concentrated to ensure that a baseline system is indeed signed-off, constructed, installed and delivered on time. The schedule for this is very tight, but the system is indispensable.

6.1 Overall System Design and Functionality

The committee endorsed the overall concept for a 3-component monitoring of beam conditions at CMS, namely a fast system of diamond sensors and scintillators within the experiment near the beamline, an active cavern radiation monitoring system consistent with that used in the accelerator tunnel and a network of passive dosimeters.

Location

The proposed locations for the RADMONS, the BCM stations and the BCS scintillators appear to be carefully chosen. In particular, the committee agreed that the location of the inner BCM1 stations on the cylindrical beryllium section of pipe, outboard of the pixel tracker is constrained by signal timing (wrt the bunch structure) and the need to minimise background in the device from interaction in the beampipe. The impact of BCM1 material on the solid angle where CMS has effective particle detection has also been taken into account.

BCS

The committee pointed out that layout of the inner BCS scintillators, forming a closed ring close to the beampipe, though elegant, is not necessary for the monitoring function. The elements of the ring could be moved outwards, increasing the clearance to the beampipe (a concern of the LHC-VAC group), without affecting the basic functionality as a beam monitor. If, however, it is intended to use the BCS for triggering min bias events at low luminosity, continuity of (part of) the ring in azimuth may be required.

The committee felt that a BCS system will almost certainly prove to be required for the lifetime of the experiment. In consequence, it is recommended both to pursue vigorously the proposed initial system (BC408 tiles between HF and HF shielding doors) and to
make plans for a more radiation-tolerant successor in a more favourable location (eg in front of TOTEM T1 telescope).

**RADMON**

The choice for UXC Cavern monitoring of the RADMON system, being developed for LHC tunnel radiation monitoring was firmly endorsed by the committee. Such a choice capitalises on an existing development, will permit a uniform picture of backgrounds throughout the LSS, and automatically builds the credibility of the CMS monitoring system with the machine operations group.

**Passive Monitors**

The dosimetry cassettes, of which the major element is a TLD, seem well adapted to the passive monitoring role. The committee encouraged the procurement by CERN of an in-house system for readout of these dosimetry devices. The need to also install activation samples for INB purposes should be taken into account when selecting locations for these cassettes. Quantitative correlations between different devices should be exploited whenever possible.

**BCM**

The committee endorses the basic features of the BCM design but makes the following comments:

Having established a viable technology for the BCM and pointed out various alternatives, the operational requirements (speed, sensitivity, dynamic range, abort threshold, post-mortem buffer length and granularity etc) now need to be written down in more detail in order to converge rapidly on a simple and robust baseline system whose installation and operation could be guaranteed. This should be done in close cooperation with Technical Coordination and particularly with the Tracker project (pixel and silicon strip), as the Tracker is the principal detector being protected by the BCM. Given the tight schedule, the committee pointed out that the actual requirements for the first 2 years of LHC running might be less stringent, allowing for a simpler baseline system. Nevertheless, this should be designed with upgrade in mind, to accommodate the higher “background” (as seen by this system) from collisions as LHC machine performance improves.

The committee therefore recommends pursuing a baseline BCM detector based on a leakage current measurement from polycrystalline diamond sensors and giving a time resolution of order $1 \mu s$ (sufficient to resolve the abort gap). The committee is convinced of the eventual need for an independent additional detector with signal readout, operating at 40MHz (mounted on the same structure), but the exact specifications need to be better defined. Since this detector should also function with polycrystalline diamond sensors, this should be the baseline until more evidence is acquired of the suitability and superiority of single crystal sensors. If the specifications require the higher sensitivity of
single crystal CVD, this should be developed in parallel as an R&D project and implemented when the luminosity requires it. (The electronics should be compatible with this upgrade from day 1).

The committee approved of the plans for prototype testing and validation of the BCM design, in particular the intention to use CDF as a test-bed for CMS BCM stations is strongly endorsed.

6.2 Options and variations

Whilst agreeing that there are other interesting options for on-detector radiation monitoring (eg progressive deterioration of light transmission in fibres, or of opto-hybrids), the committee firmly believes that these should be set aside at present to allow concentration on delivering a baseline system.

6.3 Detailed comment on the BCM specifications

Given the inaccessibility except during long shutdowns, the system should be designed to be 100% reliable (with built in redundancy).

The BCM system should generate an abort request once a certain threshold is reached, or on the basis of a certain sustained (high) rate of increase of signal. It should also generate a warning alarm on a sustained lower radiation rate (with a duration of a few seconds). As a guideline, the Tracker group should provide an estimate in Gy/s of the thresholds for warning and dump, allowing a possibility to connect this to the BCM1 current through simulations. The logic for current threshold and rate of increase requires some work, but is necessary to guarantee that this basic functionality exists in the baseline system.

The decision to abort-request due to high rate should be taken on a timescale comparable to the abort firing time (200-300 μs).

Following the model established at LEP, the normalised output of the device should be available on the top status page of CMS (“CMS page1”), say on a scale of 1-10, with 10 being the abort request level. This, plus its recent history, should also be made available to the LHC operators.

The abort request signal must be able to be masked at the experiment end for commissioning and diagnostic purposes.

The capture of the continuously overwritten post-mortem buffer should be triggered by an abort signal from the accelerator (in normal operation) or optionally (for diagnostic and commissioning purposes) from an abort request from the system itself. Precision time stamping of abort request and abort notification signals with respect to this buffer is essential. The buffer information should allow raw BCM, LHC and other CMS data to be studied for the periods immediately before and after the abort.
The system should be able to detect losses during the abort gap and trigger a warning, with the option to pass this to the accelerator. (This will simply be a complement to the machine instrumentation for detecting beam in the abort gap). The committee endorses the view that basic beam-condition monitoring and diagnostics must be independent from the central DAQ or DCS. Again, the committee recommends writing down formal specifications for the independent system before specifying the architecture and resources needed.

As proposed, the baseline leakage current system should be field-proven as far as possible at CDF. Over a period of a few months, the aim should be to show that, with appropriately adjusted thresholds for luminosity $10^{32}$ and comparing with existing CDF beam monitoring devices, the BCM makes all valid abort requests, with no spurious requests.

Corresponding thresholds for start-up of the basic “leakage current” BCM at CMS should be set based on CDF experience and measurements, plus the conversion between Gy/s in the Tracker and leakage currents (eventually also signal-counting) established via simulation.

Over the first few months, the signal readout should be operated in passive, diagnostic mode, until it is conclusively demonstrated that it would always make only valid abort requests (comparing to the baseline leakage current measurement and to any pathological conditions which the baseline system failed to identify). After this, as luminosity demands, abort request generation could be switched to the signal readout system.

A protocol describing the initial commissioning of the BCM as part of the machine abort system should be agreed with the LHC operations group.

The signal counting and current calibration of the BCM2 station should be compared to nearby TLD dosimetry.

6.4 Mechanical Support

BCM1

The committee recognises that the design of a common support structure for the BCM and PLT was pursued following a recommendation of the CMS Steering Committee, underwritten by CMS technical coordination. Nevertheless, much other work needs to be done before a PLT design can be approved (see section 7.0 below) and thus the committee strongly recommends retaining a BCM-only cradle as the baseline support for BCM1, with an option to review this in Spring 2006 if sufficient progress is made with validating the PLT design for insertion in 07-08.
The committee strongly recommends validating the baseline cradle insertion, cable connection and removal procedures on the full scale beam pipe region model, in close collaboration with the LHC-VAC group.

**BCM2 and BCS**

The support structures for BCS and BCM2 appeared to be conceptually sound, and the committee commented only on the need to ensure that maintenance, around the regions of HF which become activated, must be planned with the ALARA principle governing the dose to workers.

**6.5 Integration and Installation**

**BCS:**

Since the BCS relies on the HF cable chain for services from, and readout to, USC, the immediate BCS integration challenge is to decide on the number of independently supplied channels and to find space for services in the already well-packed HF cable chain.

Several other integration issues need to be pursued with almost as much urgency, for instance the location and magnetic shielding of BCS phototubes on the HF structures.

**RADMON**

The integration of the RADMON units onto the UXC and experiment infrastructure should be confirmed in approved drawings. All units need to be assigned a unique identification and bar-coded according to the agreed INB compliant labelling scheme.

**BCM:**

The committee endorses the concept that independent BCM1 installation and maintenance should be possible in the presence of any combination of fully or partially installed pixel detectors. The provision of services for the BCM1 within the allocation agreed with the pixel community was noted. The third rail solution presented appears to be a logical solution, but integration issues, particularly the installation tooling which interfaces to the rail, need further study. The committee recommended confirming the stated negligible impact on the material budget affecting performance and pointed out that very little of the rail is needed once the cradle is in the final position.

Since BCM1 inserts inside the forward pixel service cylinder and no confirmation could be given of the inner radius of services on the inside of this cylinder, the committee recommends that possible interference between the BCM and forward pixel volumes be studied with high priority.
The committee noted that the cradle design takes note of the recently modified beam-pipe support mechanism as detailed in ECR https://edms.cern.ch/document/637653/1 and due to be confirmed early in 2006. I was also noted that the insertion clearances to the beampipe are being designed to exceed those of the pixel system and that the installed clearance to the beampipe is being designed to be larger than that of the barrel pixels (It was also remarked that a shorter, BCM-only cradle would have larger clearances). However, since the device, though very low mass, is very close to the beampipe, further consultation with the LHC-VAC group should take place as soon as possible, resulting, if necessary, in a further ECR to formalise the mechanical integration understanding.

Whilst recognising that mechanical studies for a common integration with a possible PLT, as endorsed by the CMS Steering Committee, have made excellent progress, the committee recommended that the BCM design team should develop a simpler insertion cradle for BCM only, which it understands can be done in a short timescale from existing drawings. This simpler cradle should then become the de facto baseline. The viability or otherwise of the PLT proposal (for which the common cradle design is a vital pre-ingredient) should be established within the next 3 months, so that a final design review can be completed by March 2006, allowing enough time for manufacture and testing of the baseline BCM cradle or a fully developed common cradle, by October 2006.

A full-scale envelope model of (at least) the baseline cradle should be manufactured in time for the tests, planned for early 06, of beampipe installation, bakeout jacket installation and removal, and pixel installation and removal.

The BCM2 integration challenges appear much less severe, with space identified for both the detectors and the services.

### 6.6 Sensors and Electronics

The committee recognises and commends the excellent quality of the detailed studies over 3 years which have clearly demonstrated the suitability and viability of CVD diamond as the sensor for the BCM. The committee strongly supports the proposed future programme of work at test-beams and at CDF to demonstrate the functioning of as much of the radiation monitoring system (BCM and RADMONS) as possible before operation in CMS.

The committee endorses the proposal to use standard LHC BLM “mothercards: for the system back-end to facilitate interfacing to the accelerator abort system, to capitalize on LHC engineering support and further build acceptance and credibility of the system with the LHC operations group. Nevertheless, a fair amount of development is still required, as none of the already developed mezzanine cards match the needs of the BCM system. The group should also come up with firm plans for transferring data to CMS.

Exact requirements for the performance of the electronics were not really clear. The
justification for MIP level response needs to be understood and justified. The shaping time/synchronization accuracy also should be clearly defined. The requirement to measure each bunch independently at 40Mhz with 1-MIP level response requires further justification.

Given the limited effort available, R&D into single crystal sensors for the BCM has to be justified in terms of a strong requirement for single MIP detection and excellent time resolution.

The group is encouraged to contact other groups in CMS, as well as the MIC group, to discuss possible amplifier choices, which are also strongly influenced by the requirements. If an MPW run is needed for the NA60 chip, this should be understood as early as possible.

The choice of the DOH (instead of the AOH) seems reasonable for sending analog signals off-detector. The minimum and maximum distance between the sensor unit and the optohybrid should be understood precisely. The match between the analog bandwidth and the actual requirements should also be confirmed (see above). Tests with candidate amplifiers and sensors should proceed as soon as possible.

6.7 Controls and software

This aspect of the project was mentioned very little and the committee points out that software engineering is also needed very urgently to ensure that features such as independent DAQ and post-mortem facilities and the interface to CMS monitoring, control and logging are available when needed.

6.8 Organisation, cost & schedule

Project specification

A technical requirements and baseline specifications document should be circulated and approved. Using this as a justification, the baseline solutions in-hand, any open questions and the priorities can then be specified.

Project organisation

The committee noted that the very commendable progress evident from the presentations is being achieved with an integrated work-force of only 2-3 FTE (as can be seen from the narrow range of presenters), depending heavily on goodwill and ingenuity. This is clearly insufficient to deliver even a simplified baseline project. There is a particularly obvious lack of electronic engineering, controls and software support. This will rapidly prove fatal if not properly addressed. Whilst recognising the difficulty of undertaking a new, though small, project outside the long ago frozen project structure of CMS, the committee urges that a more formal project organization for the Cavern Radiation and Beam Monitoring Project should now be put in place and the human resources necessary to carry out the
The project should be specified and identified. The project management responsibility and reporting line, currently a (deliberately) understated one to Technical Coordination, should be confirmed and formalised.

Good working relationships have been established with the LHC machine operation groups and with TS-LEA, and the committee emphasises that these are essential foundations for a successful project. Some written formalities may be required to cement these links. The equally important interactions with LHC-VAC, the CMS General Integration Office and the CMS Tracker project, although in some cases already effective at a practical level, need to assume a more formal and regular structure. The committee noted that concerns were expressed about the general integration of the entire volume inside the Tracker (in which two of the BCM stations reside) and about communications between the various individuals involved. Whilst technically outside the scope of this review, the committee urges those concerned to resolve any such uncertainties as soon as possible.

Although the PLT and BCM happen to work using similar technology and in the same physical volume, it must be properly recognised that the BCM is an approved, high-priority project, vital for CMS start-up, which must be completed on a very tight timescale. In contrast the PLT is on the CMS “wish-list” and supported for further R &D plus preliminary design. Whilst the synergies can be exploited to the benefit of both projects, their interdependence and priority for CMS resources need to be understood in the context of this difference.

Costs

The committee found the total material-only cost estimate for the project to be reasonable for the baseline system of 4 polycrystalline CVD BCM stations, 2 sets of BCS scintillators, and the 18 RADMON units. All non-baseline and add-on options should be staged in order to generate reasonable contingency (25%).

The committee recommends that the engineering and technical manpower required to complete the mechanical design, integration, construction and installation should be separately costed and the source of this manpower identified. This will allow “in-kind” or non-accountable contributions to be better recognised, and help identify any component of the manpower which has to be included in real budgeting for the project.

Schedule

As mentioned above, all non-baseline add-ons or options should be postponed until the baseline system is secured.

A target schedule would be:

- Confirm basic specification : end 05
- Order RADMONS, poly CVD : end 05
- Integration tests on full scale model and HF : early 06
Basic design and integration done : Mar 06  
Engineering Design Review : April 06  
Design interface electronics BCM and BCS : Jan-Jun 06  
Electronics Review in ESSC : Jun 06  
Cradle and BCS support delivery : Nov 06  
Ready for installation : Feb 06

### 6.9 Comments on the PLT

The committee was not charged with reviewing the PLT proposal, but made the following comments which it hopes will prove useful:

Once a PLT is seriously pursued, mounting the PLT on a common installation cradle with the BCM appears as an attractive option. Defining a viable independent mechanical support structure was essential to making any further progress in defining the proposed PLT and assessing its viability.

The specifications should be critically reviewed. The need for a 1% accuracy online luminosity measurement per bunch every second requires justification. A priori the committee felt that a 5% global measurement every 5s-10s (within the attention span of an operator seeking the effect of a machine adjustment) should be quite adequate, with more accurate luminosity per bunch information being available, say, every minute or few minutes. Relaxation of the specification could result in significant simplification in the design.

Other issues to be addressed before a further review of the PLT include:

The technology of single crystal diamond, bump-bonded to the CMS pixel chip. The committee considered this as innovative and likely to succeed, but as yet unproven.

The service and readout cable+ fibre composition and routing. It was not clear that sufficient provision for the PLT has been made within the existing Pixel cable+ fibre budget.

Confirmation that the PLT detector, support and services material has no significant negative influence on the performance of the CMS and TOTEM detectors.

Required accuracy of the absolute and relative position and alignment of the telescopes, plus the means for achieving this.

Estimation of the heat load inflicted on nearby systems by the detector and on-board electronics and agreement that this is acceptable.

Demonstration (CAD + preferably 1:1 beampipe model tests) that the PLT can be inserted with adequate clearances to neighbouring systems and objects.
Demonstration that the system (BCM in particular) can be removed for maintenance and re-inserted without disturbing the pixel tracker or beampipe.

7. **Summary of principal conclusions and recommendations**

1) The choice of diamond sensors for the BCM is endorsed
2) The RADMON and passive dosimetry solutions are endorsed and will fulfil CMS requirements.
3) The purchase of polycrystalline diamond for a baseline BCM is endorsed.
4) The baseline detector should exploit a “slow” (resolution ~ 1μs) DC-coupled leakage current measurement as a primary functionality, suitable for CMS commissioning at low luminosity during 2007.
5) The conceptual readout architecture, though incomplete, is endorsed (especially use of BLM back-end)
6) The committee believes that a fast readout (40 MHz, ~25 ns resolution) using an on-board radiation hard amplifier will also be needed and is convinced that this also could be achieved with polycrystalline diamond sensors, with an option to upgrade to single crystal once the technology is further proven.
6) At the time of the review, though the potential advantages of single crystal diamond for the fast readout were clearly explained, more practical experience is necessary before a significant purchase (beyond that necessary for prototyping) could be approved for the baseline project. The purchase of detectors needed for this prototyping is approved.
7) The plan to use CDF as a test bed for a CMS system is strongly endorsed.
8) Joint efforts on the BCM and PLT projects should recognise that the BCM is the priority project, indispensable for LHC start-up. The PLT still needs much work in many areas to establish its viability, and should be considered as an upgrade to the start-up CMS.
8) The baseline support cradle for BCM1 should revert to the BCM-only version, with integration studies continuing until Spring 06, when a final decision on the start-up configuration will have to be taken, depending on progress with validating the PLT concept.
9) Appropriate resources must be committed to complete the project on the required timescale. In particular, electronic engineering support is urgently required for the interface between the sensors and the LHC-BLM based back-end. Software engineering is also needed very urgently to ensure that independent DAQ and post-mortem facilities and the interface to CMS monitoring, control and logging is achieved when needed.

8. **Follow-up review**

The committee recommends that an Engineering Design Review be conducted in April 2006, with the minimum aim of endorsing manufacture of the support cradle for delivery by October 2006, and endorsing any further significant purchases needed.