REPORT ON THE DESIGN REQUIREMENTS REVIEW OF THE PHYSICS ENVIRONMENT MONITORING (PEM)

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LIGO Detector Subsystem Review Report

DESIGN REQUIREMENTS REVIEW
Physics Environment Monitoring (PEM)

Title

Review Board: R. Bork, D. Coyne (Chair), F. Raab, G. Sanders, R. Weiss, M. Zucker

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This is an internal working note of the LIGO Project

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PARTICIPANTS

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R. Bork, D. Coyne (chair), F. Raab, G. Sanders, R. Weiss, M. Zucker

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B. Barish, K. Blackburn, P. Fritschel, G. Gonzalez, J. Klohoker, A. Lazzarini, D. Shoemaker, D. Sigg, S. Whitcomb, W. Young,

DOCUMENTS PRESENTED AND DISCUSSED

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Viewgraph Handouts

Physics (Environmental) Monitor Design Requirements Review Presentation, LIGO-G960201-00-D, 9/11/96.

ACRONYMS

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BS	BeamSplitter
BT	Beam Tube
CDS	Control and Data System
CT	Current Transducer
DAQ	Data Acquisition
DRD	Design Requirements Document
ETM	End Test Mass
FDR	Final Design Review
FMCS	Facility Monitoring and Control System
GW	Gravitational Wave
HAM	Horizontal Access Module
IFO	Interferometer

ITM	Input Test Mass
LA	Louisiana site
LSC	Length Sensing and Control system
LVEA	Laser and Vacuum Equipment Area
OSB	Operations Support Building
PEM	Physics Environment Monitoring system
PSL	Pre-Stabilized Laser system
RFI	Radio Frequency Interference
RGA	Residual Gas Analyzer
RM	Recycling Mirror
SEI	Seismic isolation system
SNR	Signal to Noise Ratio
SUS	Suspension system
TM	Test Mass
VE	Vacuum Equipment
VEA	Vacuum Equipment Area
WA	Washington site

REVIEW BOARD REPORT

The review was conducted on 12 Sep 1996, in the MIT LIGO Conference Room and (via conference phone) in the Caltech LIGO Engineering Conference Room. The presenters summarized the design requirements and conceptual design, illustrated by the viewgraph handouts, and the Board discussed the documents, the presentation, and the Requests for Action. The Review Board charge (as specified in document LIGO-L960662) and its response are as follows:

1) **Charge:** Determine whether the requirements identified in the Design Requirements Document (DRD) are complete; advise whether proposed requirement values are appropriate; if needed recommend additional requirements to be specified, and recommend other appropriate actions. Some specific points to consider are:
   a) definition of the scope and objectives
   b) delineation of interfaces
   c) performance requirements
   d) physical and environmental requirements
   e) documentation
   f) testing criteria
   g) Is the scope of the PEM appropriate, given our uncertainties about the degree to which the Interferometer is influenced by its environment?
   h) Are the performance requirements for the individual monitors appropriate?

   Response: The PEM requirements, as modified per the enclosed review board's recommendations and action items, are complete and appropriate except for questions to be resolved through some of the Action Items below. It is possible that the response to some of the Action Items will change or add to the Requirements, but the Review Board believes that they are substantially correct.
2) **Charge:** Evaluate the conceptual design of the PEM subsystem to determine if it is:
   a) consistent with the DRD

b) sufficiently developed to proceed with a Preliminary Design
Response: The conceptual design is appropriate and complete at the current stage of design, except for questions to be resolved through the Action Items below. We recommend that the PEM system proceed into Preliminary Design in parallel, insofar as possible, with the execution of the Action Items.

General Comments/Recommendations:

1. The committee recommends that the proposal to use a portable PEM subsystem (cart) be accepted as a cost effective means of providing (some elements of) interferometer diagnostics and for establishing the need for the number and sensitivity of instrumentation required in cases where there is too much uncertainty to warrant a large, speculative investment in instrumentation.

2. The committee recommends that the proposal to include environmental excitation sources within the PEM, in order to enable transfer function measurements (environmental parameter to Interferometer response), be accepted (with the caveat that the determination of whether the seismic excitation sensor for the suspended optics is in PEM or the SEI subsystem is yet to be determined).

3. Given the significant uncertainty in the value of monitoring a number of environment parameters and uncertainty regarding the required spatial sampling, the review board recommends that, rather than make significant up-front investment in instrumentation, a limited installation be pursued as early as possible with a planned program to evaluate the utility of the PEM measurements. However, the CDS infrastructure (data acquisition system, control and monitoring system) should be *extensible* enough to accommodate the number of channels and data rates that have been identified in the PEM DRD.
4. The review board recommends that only a single 2km long Beam Tube module be instrumented initially to determine the utility of these measurements as vetoes and in cross-correlation analysis (see also action item no. 1). However (as stated in no. 3 above), the CDS infrastructure (data acquisition system, control and monitoring system) should be *extensible* enough to accommodate the number of channels and data rates required for instrumenting all BT modules in the event that it is later determined to be of sufficient merit.
5. Although the stated philosophy for establishing PEM sensitivity requirements was to be capable of accurately monitoring minimum background levels, in fact this approach was not universally employed. The committee recommends that the philosophy for establishing sensitivity requirements be as follows:

   a) The PEM *requirement* should be to measure (with adequate SNR) the environmental level at which the *initial* interferometer is sensitive; the PEM *goal* should be to measure the background environmental level (i.e. if the cost impact is small improved sensitivity is justifiable).

   b) If the environmental level at which the initial interferometer is sensitive cannot be readily established with reasonable confidence, then the requirement should be to measure the

expected environmental level. However if measurement of the *expected* environmental level is beyond the capability of commercial equipment, then either:

- the capability of the best commercially available instrument shall be deemed acceptable, or (if warranted on a cost and schedule basis)
- the level at which the *initial* interferometer is sensitive must be established by test, analysis or simulation (and case(a) applies).

In either case the DRD should clearly state the basis upon which the requirement was derived.

6. The PEM should be included in the determination of the overall availability of the LIGO systems per the SRD, i.e. detector availability should include adequate means of determining the validity of the GW signal via an operational veto data collection system.

7. Although historically the system has had other names, the committee recommends that henceforth this subsystem be uniformly referred to as the "Physics Environment Monitoring (PEM)" subsystem.

RECOMMENDED ACTION ITEMS

General:

1. **Concern**: There is considerable uncertainty regarding the relevance to GW detection of BT instrumentation. Furthermore, exploratory measurements in support of instrument debugging and data collection in support of advanced instrument design do not warrant the (perceived) costs of an embedded system.
   Action: Limit the initial investment to instrumenting a single BT module at a single site. (Note: The alternative of using the PEM cart, for exploration of the relevance of these degrees of freedom, is deemed inadequate due to the long term (and concomitant high data volume) nature of the data collection.) Specifically, reduce the BT instrumentation from a set of sensors for monitoring all BT modules to a set for a single 2km module. In addition, determine an appropriate scope for PEM as applied to the BT consistent with the goal of exploring it's utility; the review board suggests that the level of BT instrumentation might be as follows:
   - 3 accelerometers every 500m (15 WA total)
   - RGA at the module midpoint (1 WA total)
   - temperature sensors every 500m (5 WA total)
   - humidity sensors every 500m (5 WA total)

   in order to establish the relevance of these degrees of freedom through long term monitoring. Assess the cost of providing signal and power wiring to support this instrumentation.

2. **Concern**: Sample rates are called out which are not required for the indicated bandwidths but which anticipate the details of the CDS Data Acquisition conceptual design.
   Action: List the sample rate requirements without regard for (perceived) CDS DAQ rates.

3. **Concern**: Requirements for veto, requirements for diagnostics use and requirements for transfer function (coupling) determination are not separated; this makes availability analysis difficult.
   Action: Provide a matrix of requirements for supporting the veto, diagnostics and coupling determination functionality for each instrument.

4. **Concern**: The requirement to "operate independently" of the interferometer and the operational modes of the PEM are not defined.
   Action: Define what it means to "operate independently" of the interferometer and define the operational modes of the PEM. The committee suggests the following definition: The PEM system shall be able to perform its *sensing* functions (as opposed to excitation e.g.) without requiring any other IFO subsystem to be operational.

5. **Concern**: As originally envisioned the PEM would be among the last of the detector systems to be installed. However, much benefit can be derived from establishing as early as possible the nature of the environment in which the interferometer will operate.
   Action: Plan for the implementation of the two carts as early as possible so that a site survey can be performed as soon as the buildings are available for occupancy.

6. **Concern**: The PEM data rate is high (> 1 MB/s). It is not obvious that all monitors need to run continuously (e.g. RGA gas burst monitoring, muon detection, etc.). Although the possibility of using trigger or threshold levels was indicated in the DRD, it's use was not defined.
   Action: Identify continuous signals and triggered/thresholded burst-mode signals.

7. **Concern**: The PEM carts will be used for long periods of data logging and have many parameters to be set and potentially varied.
   Action: Define a requirement on a remote control function via the CDS Control and Monitoring system.

8. **Concern**: Reliability of PEM and its impact on LIGO availability needs to be addressed for the PDR (see "general comments/recommendations" no. 5). However, this is difficult to assess since the significance of environment parameter effects on the interferometer are in many cases quite uncertain (as stated in "general comments/recommendations" no. 3).
   Action: As a baseline, develop reliability requirements on the assumption that all environment parameters which have been speculated to have a coupling to the interferometer are significant. Even so, many sensors are either redundant or are not directly needed for GW signal vetoes. This should be factored into a reliability table for each PEM subsystem/sensor and for PEM as a whole, including a determination of which sensors are needed for what types of searches (coalescence, periodic, stochastic, etc.).

Interfaces:

9. **Concern**: Interfaces are not well defined.
   Action: Identify the need to interface, and define the nature of the interface, with:
   - Facility Monitor and Control System (FMCS)
   - Vacuum Control and Monitoring System (VCMS)
   - CDS
   - Detector subsystems (ASC, LSC, SEI, SUS, PSL, etc.)

   In particular mention:
   - The determination of whether the seismic excitation sensor for the suspended optics is in PEM or the SEI subsystem is yet to be determined and in either event entails an interface(s) to the PEM.
   - Sensor mounting (e.g. RGA heads on flanges in the VE) should be explicitly called out as an interface (even if the specific locations can not be identified as yet).

10. **Concern**: Current Transducers (CTs) have been specified to be placed on main power busses within the facilities, and monitored by the FMCS, anticipating PEM use; the DRD/DRR is silent on the utilization of these CTs to detect and localize transient events due to power load variation of the facility equipment.
    Action: Review the RMP DCCD and Facility FDR information and incorporate the use of the CTs into the PEM design.

RGA:

11. **Concern**: The allocation of one RGA per building does not adequately cover the vacuum system due to the isolatable volumes.
Action: Determine the appropriate number of RGAs required to monitor the isolatable vacuum volumes. One possible allocation offered for consideration is as follows: The number of RGAs could be limited to one head per isolatable vacuum volume, excluding the BT modules and cryopumps, (not per chamber) plus one controller per building plus one per each portable system (cart):

    - 4 isolatable volumes per LVEA x 2 LVEAs + 1 isolatable volume per VEA x 6 VEAs + 1 per cart x 2 carts = 16 total RGA heads

    - 1 controller/bldg. x 8 bldgs + 1 controller/cart x 2 carts = 10 RGA controllers

RFI:

12. **Concern**: The RFI monitoring does not address the need for narrow band monitoring near interferometer modulation frequencies.
Action: Expand the requirements from the general, broadband background monitoring to include a requirement for narrowband monitoring and propose a conceptual approach for this requirement.

13. **Concern**: Broadband RFI should not vary significantly across the site; This can also be confirmed by an initial survey at the site and periodic checks if deemed necessary.
Action: Limit the broadband RFI monitoring to one per site (instead of one per building).

Magnetic Field:

14. **Concern**: Commercially available magnetic field sensors cannot measure the background magnetic field.
Action: By application of the recommended approach for requirements definition (Recommendation #3), the sensitivity requirement should be based upon the environmental level at which the initial interferometer is sensitive.

15. **Concern**: The Bartington magnetometers proposed in the conceptual design cannot measure the background fluctuation without somehow "bucking out" the earth's DC field.
Action: Further definition is required.

16. **Concern**: Internal magnetometers will pick up LIGO generated fields which makes detection, and correlation between the sites, of a ambient environmental transient (from a lightening strike) more difficult.
Action: Specify a single externally placed magnetometer for use in site-to-site correlation.

17. **Concern**: Many of the transient magnetic field sources are likely to be common between the all of the chambers, so that separate sensors for each chamber may not be required. At any rate, a survey and data logging exercise during commissioning of the first interferometer can be used to determine if further investment in magnetometers is justified.
Action: Determine the appropriate quantity and locations of magnetometers for initial installation and a plan (including criteria) for surveying the site and making subsequent recommendations on any additionally required magnetometers. One approach for initial installation, offered for consideration, is the following distribution of 3-axis magnetometers:
    6 = one for each chamber with a core optic (RM, BS, 2 x ITM, 2 x ETM)
    2 = one for each cart x 2 carts
    8 = total

Acoustic:

18. **Concern**: The criteria used to establish the acoustic sensor sensitivity requirement is unclear (may be what can be readily achieved with commercial microphones).
Action: Apply the recommended approach for requirements definition (Recommendation #3) to the definition of the acoustic sensor sensitivity requirement.

Muon:

19. **Concern**: Cosmic ray monitoring appears to be unnecessary; a single horizontal shower event cannot expose both sites due to the earth's curvature and the rate of simultaneous, independent showers of sufficient energy is low.
Action: Determine the rate of simultaneous, independent showers of sufficient energy to excite test mass motion above the *initial* interferometer sensitivity. On the basis of this rate determine if muon detection is required. If required, determine if each site requires a detector oneach building.

Seismic high frequency:

20. **Concern**: The number of accelerometers specified (6 per chamber) is more than required for veto and is (apparently) based on a desire to permit cross-correlation analysis with the GW signal for noise reduction; the merit of the measurement of these degrees of freedom for such a signal analysis is uncertain and does not merit up-front investment.
Action: Determine the appropriate quantity and locations of accelerometers. One approach, offered for consideration, is to plan for an initial installation of 6 accelerometers per test mass chamber (for correlation analysis) for the WA 4km IFO only and 3 accelerometers for each of the other chambers and for each PSL bench:
    - WA 4k IFO: 4 TM chambers x 6
      + (1 BS + 3 Input HAMs + 2 Output HAMs + 1 PSL) x 3 = 45
    - WA 2k IFO: (10 chambers + 1 PSL) x 3 = 33
    - LA 4k IFO: (10 chambers + 1 PSL) x 3 = 33

total = 111

Particle Detectors:

21. **Concern**: There are no particle counters within the LIGO facilities.
Action: Add a requirement for PEM to provide particle counters for LIGO cleanrooms (fixed and portable) and for the LVEA and VEA spaces. Determine the appropriate quantity and locations of these particle counters and their specifications. A suggestion is the following quantities and locations:
    1 per OSB optics lab (fixed cleanroom)
    1 per OSB Vacuum Equip. Preparation room (fixed cleanroom)
    2 per LVEA
    1 per VEA
    1 per Mid & End-Station optics lab
    1 per portable cleanroom

Power Line Monitoring:

22. **Concern**: Apriori determination of the requirements for power line monitoring is problematical; one cannot apply the recommended approach for requirements definition (Recommendation #3) since (a) the sensitivity of the interferometer to power line fluctuations (amplitude, phase, frequency, spikes, etc.) can only be determined credibly via test on the system and (b) the expected power line fluctuations are likewise only credibly determined via test on the system. Consequently, a considerable investment to instrument every technical power bus should be deferred until firm requirements are established through the commissioning phase.
Action: Specify a requirement for one or two, commercially available instruments to monitor a technical power buss. Stipulate a plan to use this monitor in a roving fashion to measure the power quality and perform cross-correlation analysis with the interferometer during commissioning in order to determine the factors and levels to which the interferometer is sensitive and establish the requirements for a complete power monitoring system for later installation.

Contamination Monitor:

23. **Concern**: A determination of what the true requirements for contamination monitoring may be too late for PEM design efforts.
Action: Plan on procuring crystal deposition monitors and dropping any further research or debate on what sensor or technique will ultimately prove adequate. Plan to establish whether or not the crystal deposition monitor is adequate and whether additional units are required after experience is gained during commissioning of the interferometer. The recommended initial installation of crystal deposition monitors is:
    - one head per isolatable vacuum volume (excluding the beam tube), or 8 in WA and 5 in LA, and
    - one control unit per building, or 5 in WA and 3 in LA

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3. **Concern**: Requirements for veto, requirements for diagnostics use and requirements for transfer function (coupling) determination are not separated; this makes availability analysis difficult.
   Action: Provide a matrix of requirements for supporting the veto, diagnostics and coupling determination functionality for each instrument.

4. **Concern**: The requirement to "operate independently" of the interferometer and the operational modes of the PEM are not defined.
   Action: Define what it means to "operate independently" of the interferometer and define the operational modes of the PEM. The committee suggests the following definition: The PEM system shall be able to perform its *sensing* functions (as opposed to excitation e.g.) without requiring any other IFO subsystem to be operational.

5. **Concern**: As originally envisioned the PEM would be among the last of the detector systems to be installed. However, much benefit can be derived from establishing as early as possible the nature of the environment in which the interferometer will operate.
   Action: Plan for the implementation of the two carts as early as possible so that a site survey can be performed as soon as the buildings are available for occupancy.

6. **Concern**: The PEM data rate is high (> 1 MB/s). It is not obvious that all monitors need to run continuously (e.g. RGA gas burst monitoring, muon detection, etc.). Although the possibility of using trigger or threshold levels was indicated in the DRD, it's use was not defined.
   Action: Identify continuous signals and triggered/thresholded burst-mode signals.

7. **Concern**: The PEM carts will be used for long periods of data logging and have many parameters to be set and potentially varied.
   Action: Define a requirement on a remote control function via the CDS Control and Monitoring system.

8. **Concern**: Reliability of PEM and its impact on LIGO availability needs to be addressed for the PDR (see "general comments/recommendations" no. 5). However, this is difficult to assess since the significance of environment parameter effects on the interferometer are in many cases quite uncertain (as stated in "general comments/recommendations" no. 3).
   Action: As a baseline, develop reliability requirements on the assumption that all environment parameters which have been speculated to have a coupling to the interferometer are significant. Even so, many sensors are either redundant or are not directly needed for GW signal vetoes. This should be factored into a reliability table for each PEM subsystem/sensor and for PEM as a whole, including a determination of which sensors are needed for what types of searches (coalescence, periodic, stochastic, etc.).

Interfaces:

9. **Concern**: Interfaces are not well defined.
   Action: Identify the need to interface, and define the nature of the interface, with:
   - Facility Monitor and Control System (FMCS)
   - Vacuum Control and Monitoring System (VCMS)
   - CDS
   - Detector subsystems (ASC, LSC, SEI, SUS, PSL, etc.)

   In particular mention:
   - The determination of whether the seismic excitation sensor for the suspended optics is in PEM or the SEI subsystem is yet to be determined and in either event entails an interface(s) to the PEM.
   - Sensor mounting (e.g. RGA heads on flanges in the VE) should be explicitly called out as an interface (even if the specific locations can not be identified as yet).

10. **Concern**: Current Transducers (CTs) have been specified to be placed on main power busses within the facilities, and monitored by the FMCS, anticipating PEM use; the DRD/DRR is silent on the utilization of these CTs to detect and localize transient events due to power load variation of the facility equipment.
    Action: Review the RMP DCCD and Facility FDR information and incorporate the use of the CTs into the PEM design.

RGA:

11. **Concern**: The allocation of one RGA per building does not adequately cover the vacuum system due to the isolatable volumes.
Action: Determine the appropriate number of RGAs required to monitor the isolatable vacuum volumes. One possible allocation offered for consideration is as follows: The number of RGAs could be limited to one head per isolatable vacuum volume, excluding the BT modules and cryopumps, (not per chamber) plus one controller per building plus one per each portable system (cart):

    - 4 isolatable volumes per LVEA x 2 LVEAs + 1 isolatable volume per VEA x 6 VEAs + 1 per cart x 2 carts = 16 total RGA heads

    - 1 controller/bldg. x 8 bldgs + 1 controller/cart x 2 carts = 10 RGA controllers

RFI:

12. **Concern**: The RFI monitoring does not address the need for narrow band monitoring near interferometer modulation frequencies.
Action: Expand the requirements from the general, broadband background monitoring to include a requirement for narrowband monitoring and propose a conceptual approach for this requirement.

13. **Concern**: Broadband RFI should not vary significantly across the site; This can also be confirmed by an initial survey at the site and periodic checks if deemed necessary.
Action: Limit the broadband RFI monitoring to one per site (instead of one per building).

Magnetic Field:

14. **Concern**: Commercially available magnetic field sensors cannot measure the background magnetic field.
Action: By application of the recommended approach for requirements definition (Recommendation #3), the sensitivity requirement should be based upon the environmental level at which the initial interferometer is sensitive.

15. **Concern**: The Bartington magnetometers proposed in the conceptual design cannot measure the background fluctuation without somehow "bucking out" the earth's DC field.
Action: Further definition is required.

16. **Concern**: Internal magnetometers will pick up LIGO generated fields which makes detection, and correlation between the sites, of a ambient environmental transient (from a lightening strike) more difficult.
Action: Specify a single externally placed magnetometer for use in site-to-site correlation.

17. **Concern**: Many of the transient magnetic field sources are likely to be common between the all of the chambers, so that separate sensors for each chamber may not be required. At any rate, a survey and data logging exercise during commissioning of the first interferometer can be used to determine if further investment in magnetometers is justified.
Action: Determine the appropriate quantity and locations of magnetometers for initial installation and a plan (including criteria) for surveying the site and making subsequent recommendations on any additionally required magnetometers. One approach for initial installation, offered for consideration, is the following distribution of 3-axis magnetometers:
    6 = one for each chamber with a core optic (RM, BS, 2 x ITM, 2 x ETM)
    2 = one for each cart x 2 carts
    8 = total

Acoustic:

18. **Concern**: The criteria used to establish the acoustic sensor sensitivity requirement is unclear (may be what can be readily achieved with commercial microphones).
Action: Apply the recommended approach for requirements definition (Recommendation #3) to the definition of the acoustic sensor sensitivity requirement.

Muon:

19. **Concern**: Cosmic ray monitoring appears to be unnecessary; a single horizontal shower event cannot expose both sites due to the earth's curvature and the rate of simultaneous, independent showers of sufficient energy is low.
Action: Determine the rate of simultaneous, independent showers of sufficient energy to excite test mass motion above the *initial* interferometer sensitivity. On the basis of this rate determine if muon detection is required. If required, determine if each site requires a detector oneach building.

Seismic high frequency:

20. **Concern**: The number of accelerometers specified (6 per chamber) is more than required for veto and is (apparently) based on a desire to permit cross-correlation analysis with the GW signal for noise reduction; the merit of the measurement of these degrees of freedom for such a signal analysis is uncertain and does not merit up-front investment.
Action: Determine the appropriate quantity and locations of accelerometers. One approach, offered for consideration, is to plan for an initial installation of 6 accelerometers per test mass chamber (for correlation analysis) for the WA 4km IFO only and 3 accelerometers for each of the other chambers and for each PSL bench:
    - WA 4k IFO: 4 TM chambers x 6
      + (1 BS + 3 Input HAMs + 2 Output HAMs + 1 PSL) x 3 = 45
    - WA 2k IFO: (10 chambers + 1 PSL) x 3 = 33
    - LA 4k IFO: (10 chambers + 1 PSL) x 3 = 33