

Date:	14 Feb 2008
Refer to:	L080018-00
Subject:	Comments and Questions on the COC PDR documents
To:	COC Team (GariLynn Billingsley, Bill Kells)
From:	COC PDR review committee (Doug Cook, Dennis Coyne (chair), Peter Fritschel, Eric Gustafson, David Reitze, Norna Robertson, Ken Strain, Bill Tyler, Hiro Yamamoto)

The review committee for the COC PDR met Feb 14th to discuss the COC Design Requirements Document (DRD). Our comments and questions on this document are given below. We will meet again Feb 15th to discuss the design document. We will meet with the COC team on Feb 21st as planned to discuss their responses to our questions.

COC Design Requirements Document (DRD)

While there are many comments and questions, the DRD is clearly well developed and nearly complete for the PDR stage. We commend the COC team on getting defined specifications on most of the COC, especially given the recent change to the stable recycling cavities.

The comments/questions below are presented in sequential order by document section. Significant/important, potentially controversial or uncertain items in the list below which may require discussion between the review committee and the design team are highlighted.

- 1) Use T000127-03 (new revision), not a new document number (i.e. T080026). Otherwise we have two documents with the same title and unfortunate searchers who happen upon the old document don't realize that there is a newer one (which obsoletes the one they happened upon). Also note that the document & version number on body page headers are not consistent with that on front page.
- 2) Section 2: "The original development plan for manufacture and test ... was the COC development plan, LIGO-T000128." Is this an obsolete plan?
- 3) Section 2.1:
 - a. Change "High reflectance coating applied to surface 1 of each optic." to "High reflectance coating applied to surface 1 of each optic, with the exception of the BS (50/50 coating) and the SRM and PRM (partially transmissive)."
 - b. Add a "TBD" to the gold plating on the CP.
- 4) Section 2.1.1.1 (and other sections through out the document): In conjunction with the very recent decision to employ stable recycling cavities, we propose that:
 - a. COC should define the requirements for the mode matching telescopes now set within the recycling cavities. (The requirements for the power recycling mode

matching telescope (MMT) in the IO DRD only addresses coupling efficiency, alignment and beam steering.)

- b. IO should have the lead design responsibility for the input and output mode-matching telescope (MMT) design,
- c. AOS will have no scope in design or procurement of the output MMTs¹,
- d. COC will have procurement scope for the large MMT elements, i.e. PRM3 and SRM3, and
- e. IO will have the procurement scope for the small MMT elements (i.e. PRM1, PRM2, SRM1, SRM2).²

This division of responsibility will be documented in a (pending) RODA.

- 5) Section 2.2: some acronyms are missing, eg. ESD, FT, HR, CP, OPD, MTTR, CD. In most cases, it's obvious what the abbreviation stands for, but worth including. Some are inconsistent with the text, eg. IO vs IOO.
- 6) Section 2.3.1:
 - a. The title for M040405-00 is "Advanced LIGO Substrate Selection Recommendation"
 - b. E030647-01 has no title and is not in the DCC
 - c. Add P080004-00, Design of the Advanced LIGO Recycling Cavities
 - d. Add T020103-04, Test Mass Material Down-Select Plan
 - e. Add T040199-00, Dimensions for Advanced LIGO Fused Silica Test Masses
 - f. Add T040232-00, Beamsplitter First Elastic Mode Frequency versus Dimensions
 - g. Add E070070, Specification: LASTI Test Mass Handling and Shipping Procedures
 - h. Add T070233-00, LASTI Test Mass Coating Characterization
 - i. Add T070247-00, AdvLIGO Interferometer Sensing and Control Conceptual Design
- 7) Section 3.2.4: Remove the last paragraph stating that there is a possible use of BK7 for some of the recycling cavity elements³.
- 8) Section 3.3:

¹ Historically these were to be compact, off-axis parabolic, telescopes, but they are now identical in concept to the input MMT

² This will necessitate a transfer of project funds nominally from AOS to IO to cover the cost of the output MMT optical elements. This accounting transfer should be done in the context of the larger issue of setting budgets properly for the new stable recycling cavity choice.

³ BK7, while better for possible future thermal actuation in the MMT (not baselined), has too much thermally induced absorption for realistic coating absorption levels (~10 ppm) in the PRC. While one could use BK7 for SRM1 & SRM2, this would require unique suspension variants. Since the TCS CP appears to have sufficient authority/range to compensate for residual mismatch, we will use FS everywhere.

- a. Please include a simple diagram showing the COC and IO elements with labels (BS, CP, PRM1, PRM2, etc.)
- b. Remove the parenthetic comment "(LIGO I Type)". The Advanced LIGO wire suspensions are considerably different than the Initial LIGO design.

9) Table 1.

- a. Add a row with "surface reflectivity at wavelength(s) other than the carrier", "AOS", "For use in initial alignment", and "Specific mirror reflectivity at specific wavelengths".
Since this is subordinate to other coating requirements, there is no need to state required reflectance at specific wavelengths as this can be handled in the preliminary design document (PDD).
- b. In the row for "Element mass and aspect ratio", add under the column "Requirement Category", "Thermal Noise". See T040199-00 for the trade-off between thermal noise and diffraction loss.
- c. In the row "Element surface contamination control", by "Lowering of Qs" do you mean "Lowering of optical Qs" (i.e. Finesse)? If lowering of mechanical Qs is meant, what is the evidence that contamination (at realistic levels) can degrade mechanical Q?
- d. Add a row for consideration of factors effecting loss in the Michelson cavity and mode matching to the arms
- e. Add a row to address the effect of BS wedge and ROC on astigmatism and resulting CD

10) Section 4.2.2.1, 4th item: The PRM and SRM can be either concave or convex. In the stable power recycling cavity design presented in the IO preliminary design document (T060269-02) the PRM1 is convex.

11) Section 4.2.2.1.1.1:

- a. not exceed 20ppm : where does this come from?
- b. Are you sure that the total loss in RC is dominated by the AR reflectivity and internal telescope diffractive loss and not the BS size?
- c. BS wedge angle introduces large astigmatic error; 4% when going through (Y-arm to SRM) and 8% when bent (X-arm to SRM). This can introduce increased contrast defect. What are the tolerable limits?
- d. BS surface curvature can also introduce astigmatism. What is an acceptable ROC lower limit?

12) Section 4.2.2.1.1.4: states "AOS design requires that IFO control signals are derived from leakage through several of these FT HR mirrors." Please revise the statement to read "IFO control and alignment signals are required through PRM2 (for input MMT alignment, PSL intensity stabilization and the BS pickoff beam) and SRM2 (for output MMT alignment)."

13) Section 4.2.2.1.1.5, Fold Mirrors: FM surface curvature can also introduce astigmatism. What is an acceptable ROC lower limit?

14) Section 4.2.2.1.1.5 Compensation Plates should actually be 4.2.2.1.1.6.

15) Table 2:

- a. Since phase map metrology only needs to be done to verify the transmission map, we do not need a wedge angle. This would in turn simplify AOS's job of dumping the associated ghost beams.
- b. Recycling cavity mirror dimensions are not correct (75mmx25mm). They should be 150 mm dia. x 75 mm thick (per IO PDD, T060269-02)
- c. The mass of the RM (i.e. PRM1 and SRM1) is ~3 kg, not 15.6 kg.
- d. Note that the thickness is measured at the thick end for wedged optics.
- e. The ITM wedge (0.32 deg) is incorrect. More generally, it may not be necessary and/or appropriate to list parameters which are defined by other considerations outside of COC, such as wedge angles and ROC. For wedge angles one could state the requirement is to be consistent with optical layout requirements defined by SYS. If one does choose to cite specific values, they will need to be updated to stay consistent with the COC DRD and other source documents.
- f. The "flat" surface 1 ROC for the BS and FM should be a minimum absolute (unsigned) value.

16) Section 4.2.2.2.2.1. Please provide motivation for the $1e-7$ loss limit -- where does this put the substrate brownian noise in comparison to the coating noise and the science requirements?

17) Section 4.2.2.2.2.2:

- a. Based on current coating values and the Bench code, we think that the per mirror thermo-optic noise is expected to be $7e-21$ m/rtHz @100 Hz and not $3e-21$ as stated; Please check.
- b. It should be emphasized in this section that the requirement is for the coatings to be designed for low thermal noise, in addition to low absorption and low scatter; A specific numerical target gives context and motivation, but isn't the requirement per se.

18) Section 4.2.2.2.2.4: Change "The loss angle and Young's modulus of any contacting material must not cause an increase in thermal noise." to "The contribution to thermal noise, due to the loss angle and Young's modulus of any contacting material, must not exceed $1/10^{\text{th}}$ of the thermal noise of a pristine optic."

19) Section 4.2.2.3.1: Arm finesse is 450. Where did the T matching of $\pm 2\%$ come from? Our target is to balance the arm power to 1% to limit technical radiation pressure (per section 5.5 of the System Design Document, T010075-00).

20) Section 4.2.2.3.2: PRM transmission will be close to 3% (per Table 5 of the ISC draft CDD, T070247-00). How did you determine the tolerance?

21) Section 4.2.2.3.3. SRM transmission will be close to 20%. (per Table 5 of the ISC draft CDD, T070247-00)

- 22) Section 4.2.2.3.4. ETM transmission should be specified as 5 ± 1 ppm (an ISC design choice).
- 23) Section 4.2.2.3.5 – The AR coating reflectivity requirement should explicitly state that the AR coatings will provide adequate light levels when the interferometer is operated in low power mode.
- 24) Section 4.2.2.3.7:
- Replace the reference for the limit of TM diameter to 34 cm from “fabrication exigencies” to “Dimensions for Advanced LIGO Fused Silica Test Masses”, T040199-00
 - We get different ROCs to give spot radii on the mirrors of 5.55 cm and 6.2 cm; namely, ITM ROC 1970 m, ETM ROC 2192 m ($L = 3995$ m). Please check.
 - The TM ROC tolerance of ± 10 m is relative, not absolute. The absolute tolerances are much higher ($\sim \pm 36$ m).
 - The TCS barrel ring heater decreases the ROC of the TM. The proposed polished ROC bias is in the wrong direction.
 - However, we are unsure about the proposal to rely on TCS to achieve the desired ROCs at all power levels. If it's feasible to get the TMs delivered to sufficient accuracy, which it looks like it is, then we shouldn't take this approach. Please interpret Figure 1 for us: what are the ROC tolerances that we should specify to the vendors if we don't rely on TCS for tuning at all powers?
 - Similarly, we're not convinced it's a good idea to polish the ROCs at 10 m under the desired values (which could be 20 m under with the proposed tolerance).
 - My reading of the TCS documentation is that the TM ring heater gives $\Delta R = 70$ m at 20 W input (which I think is max power), not 116 m ... how do you get your number?
- 25) Section 4.2.2.3.8.
- We assume that the length adjustment of the telescope is an initial static adjustment for the cold (low power) case and that there is no proposed requirement to dynamically adjust the telescope length. Please make this explicit in the text.
 - Don't understand the bottom line of this section; We would expect to read the proposed ROC tolerances for all (6) recycling cavity optics.
 - The beam heating ROC change of 0.16% relative for the RM doesn't look right (I get a much smaller number, even for 10 ppm absorption).
- 26) Section 4.2.2.4.1. The $\sigma < 0.7$ nm spec was based (we think) in large part on FFT simulations of arm cavities. Please show in this document the simulation results that led to this requirement (or cite a document where the derivation is given). From Hiro Yamamoto:
- Regarding the diffractive loss vs roughness requirement, my FFT study differs from Bill's modal analysis to some extent. By generating surface with spatial spectrum f^{-2} , the rate that the diffractive loss per arm > 40 ppm is 5% for $\sigma = 0.5$ nm, while it is 50% for $\sigma = 0.7$ nm. This is the result keeping Zernike term ≥ 5 . If Zernike terms ≥ 6 are kept, i.e., roughness is more from shorter wavelength, the rate to have*

diffractive loss ≥ 40 ppm becomes 10% for $\sigma = 0.5$ nm and 75% for $\sigma = 0.7$ nm. So, the requirement of 0.7nm is not stringent, but rather a compromise.

27) Section 4.2.2.4.2. How bad could the transmission distortion be for the ETM trans beam?

28) Table 3:

- a. If we interpret the first line correctly, the arm-arm match of ITM/ETM ROC is 3 m (+/- or total?) --- if so, this seems inconsistent with the ± 10 m given in 4.2.2.3.7.
- b. What does .00x wrt flat mean?
- c. What's the definition of micro-roughness? (spatial wavelength range)
- d. Please compare these specs (for the TMs) to the pathfinder polisher specs -- some of these are different, I think; why?
- e. In general the basis for these requirements is not documented. Cite other documents, include results (e.g. FFT analyses) or supporting rationale.

29) Section 4.2.2.4.3: It is stated that thermally induced birefringence effects have been studied, found to dominate over intrinsic material birefringence but to be small relative to beam heating OPD phase distortions. Has thermal stress birefringence in both the substrate and the coating been considered? Include the results of these studies, or cite appropriate references.

30) Section 4.2.2.4.4: The astigmatism due to the BS wedge can introduce ROC change by 4% (X-arm to SRM 8%, Y-arm to SRM 4%) and a beam size change of 2% (each direction). Rough mode coupling gives 10^{-2} to 10^{-4} mode mismatch. So the CD may need to be revisited.

31) Section 4.2.2.4.6

- a. Include FFT results or cite reference.
- b. Last sentence: "...(<2.1 nm rms requirement, Table 3)". There is no 2.1 nm rms values called out in Table 3. Should this be <3.0 nm rms?

32) Section 4.2.2.5: We suggest just providing overall loss limit requirements in the DRD and then the breakout into instrument ranges in the PDD.

33) Section 4.2.2.5.1. The claim is made that 5 ppm of scattering on an AdL coating has been demonstrated (last sentence). The LASTI optic coated at LMA shows ~15 ppm of scattering. CSIRO data indicated ~25 ppm loss for the middle range roughness (~1 mm wavelength. Please cite the data supporting 5 ppm scatter loss.

34) Section 4.2.2.5.2. Mean scatter of < 5 ppm ... again, please show the data. OTF measurements, including T070233 show most of the large scale optics have large angle losses > 10 ppm.

35) Section 4.2.2.5.3:

- a. What is 'mid-large scale' ?
- b. What 30 ppm entry on Table 3 -- I think you mean Table 4, but I don't see the 30 ppm entry. Please clarify. Note that FFT simulations, under various

assumptions, indicate that roughness with $\sigma = 0.7$ does contribute substantial (several 10s of ppm) loss.

- 36) Section 4.2.2.6: It is stated that the absorption goal values given will result in ~ 11 K increase above [radiative] ambient. Does this include the heat deposited by the TCS? How much excess absorption caused by contamination on the coating can we compensate with the TCS? If the excess absorption were at the maximum the TCS could compensate at what temperature would the mirror then be? Do we run out of authority on the TCS before the properties of the substrate and the coating begin to change outside of our design limits? Is the "accumulated absorption surface 1" in table 4 the excess absorption due to contamination? Over what time frame?
- 37) Section 4.2.2.6.1. All bulk material in the RCs are to have ultra low absorption, <0.2 ppm/cm, not just the BS.
- 38) Section 4.2.2.6.4 The AR reflectivity for the BS, which is used to deliver the ITMx pick-off beam, should be marked as TBD.
- 39) Section 4.2.5
- Change
"Given the COC operational environment (UHV) it is anticipated that the only mechanism for dealing with contaminated elements will be to change them out. However every effort will be made to investigate and develop possible in situ cleaning procedures."
to
"Given the COC operational environment (UHV) it is anticipated necessitating removal for the purpose of cleaning is impractical on a routine operational basis. Therefore every effort will be made to investigate and develop in situ cleaning procedures."
 - The down time goal of 1 month/year for cleaning COC optics = 8% does not seem to be good enough. Unless we have proof or convincing evidence that we can't do better within reasonable cost limitations, I'd set this level to at least 2 times better as a goal.
- 40) Section 4.2.6.1.1 surely operating conditions are tighter than stated in Table 5. It would be useful to put expected in-vacuum temperature range based on TCS and main beam heating. Also state expected conditions for metrology based on available facilities.
- 41) Section 4.2.7: The reference E070293-00 is incorrect – please revise with the correct reference.
- 42) Blank sub-sections under 4.2 and 4.3, such as "Atmospheric Pressure", "Interchangeability", "Human Engineering", etc. should be marked as "Not applicable".
- 43) Section 4.3.4, the LIGO System safety plan title and revision are not correct, "LIGO System Safety Plan" M950046-D.