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MEMORANDUM

DATE: 6 June 2014

TO: aLIGO Contamination Control Working Group
CC: aligo_sys@ligo.caltech.edu
FROM: Dennis Coyne
SUBJECT: **Particulate Contamination Requirements**
Refer to: LIGO-T1300511-v2

Contents

1   Introduction

Currently the best reference defining the required particulate cleanliness levels for the vacuum chambers and sensitive cavity optics for Advanced LIGO is T080067-v1, "Protecting installed core optics from particulates"[1]. In T080067-v1, reasonable and conservative limits and approximations were employed as prudent, with the caveat that they be feasible. We have since found that these particulate contamination levels may not be feasible to achieve in the LIGO vacuum chambers with our current cleanliness protocols and infrastructure.

The purpose of this memo is to look for relief, by revisiting these requirements and taking out conservatism. This memo complements (does not invalidate) T080067. This is also not (yet) to be taken as a restatement of requirements, but rather a discussion of what might be acceptable, and what measurements are needed to improve our understanding of what is (or is not) acceptable.

I seek ultimately to answer the following questions:
How clean do the cavity optics need to be in order to operate at full power?
What power level can we operate at as a function of particulate cleanliness level?
What measurements or experiments should we perform to fill in missing information?

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[1] M. Zucker, "Protecting installed core optics from particulates", T080067-v1, which in addition to defining particulate requirements, for both scatter and absorption consideration, also discussed the state of knowledge with regard to particulate size distributions and mitigation measures.

2 Absorption Requirements

In T080067, Mike Zucker established that absorption requirements are more restrictive than scattering requirements on allowable particulate contamination. In T080067, Mike concluded that particulate absorption should contribute ≤ 0.1 ppm.

The Core Optics Components (COC) Design Requirements Document (DRD), T000127-v2, Table 5, gives the total cumulative HR surface absorption as follows:
- <1 ppm for ITM, ETM
- <4 ppm for BS, RM

where the pristine (uncontaminated) High Reflectance (HR) coating absorption was assumed to be < 0.5 ppm.

The Thermal Compensation System (TCS) CO_2 Projector (CO_2P) Final Design Document (FDD), T1100570-v3, section 3.2, states that TCS is designed for 0.5 ppm HR surface absorption of the ITM & ETM, with a safety factor of 2. Consequently the TCS is designed for a worst case absorption of ≤ 1 ppm HR surface absorption of TMs (consistent with the COC DRD)[2].

Measurements of as-built coating absorption (found at https://nebula.ligo.caltech.edu/optics/) are as follows:
- 0.3 ppm generally, max 0.4 ppm for ITM, ETM
- ≤ 0.7 ppm generally, max 1.0 ppm for PRM, PR2, PR3
- ≤ 0.6 ppm for BS

Consequently the allowable absorption due to contamination is:
- ≤ 0.7 ppm generally for ITM, ETM
- ≤ 3.3 ppm generally for BS, PRM, PR2, PR3

This allowable absorption must be allocated (budgeted) to both hydrocarbon deposition and particulates.

Measurements to date (E1000193-x0, LIGO UHV Qualification Test Results) show no measureable absorption due to hydrocarbon film deposition, so assume[3]:
- ≤ 0.1 ppm due to hydrocarbon film deposition

Consequently the allowable absorption levels due to particulates are as follows:
- ≤ 0.6 ppm for particulates on ITMs, ETMs
- ≤ 3.2 ppm for particulates on BS, PRM, PR2, PR3

N.B.: These allowable absorption levels are considerably higher than the value (≤0.1 ppm) assumed in section 2 of T080067-v1, "Protecting installed core optics from particulates".

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[2] ⚠ N.B.: Here I'm suggesting that "we", Systems, 'take' the design margin that TCS designed into their subsystem. This is only possible if TCS exceeds their requirements and achieves their design goal. This suggested action is tantamount to a retro-active increase in requirements and should be taken cautiously, if at all.

[3] ⚠ N.B.: Here I am suggesting, perhaps in contradiction to some iLIGO observations, that hydrocarbon, or film, deposition on our optics is essentially not a problem. The relationship between hydrocarbon partial pressure and optical loss is still actively being examined at this time.

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3   Particle Size Distribution

In T080067 Mike Zucker includes a very good discussion regarding the particle size distribution functions used in the literature, in specifications and found in practice. In particular he notes that the industry standard for characterizing surface particulate cleanliness, IEST-STD-CC1246D[4] employs a distribution which (a) does not apply to particle sizes < 1 micron and (b) does not accurately reflect surveys of actual contaminated surfaces, where there is an excess of larger particles. It has been suggested that the IEST-STD-1246D is only applicable to surfaces which have been recently precision cleaned.

We intend to evolve to the following state and practices:
1) improve the particulate cleanliness of the chamber environments by successive cleanings,
2) perform First Contact™ cleaning of all critical optical surfaces as the last step before closing up for a science run, and
3) pump down slowly enough that particulates are not entrained and lofted into the airflow

In this case, the IEST-STD-1246D particle size distribution may apply to our vertically oriented and freshly cleaned optical surfaces.

The IEST-STD-1246D standard gives the particle size distribution in the form of a complementary cumulative distribution function (CCDF, aka tail distribution), for the number density N[x,L] for particles of size x or larger for cleanliness level L. A cleanliness level of L means a particulate surface density at which there is only 1 particle of L microns or larger on a 0.1 m^2 surface. A normalized cumulative distribution function CDF and its associated probability density function (PDF) are shown in Figure 1.
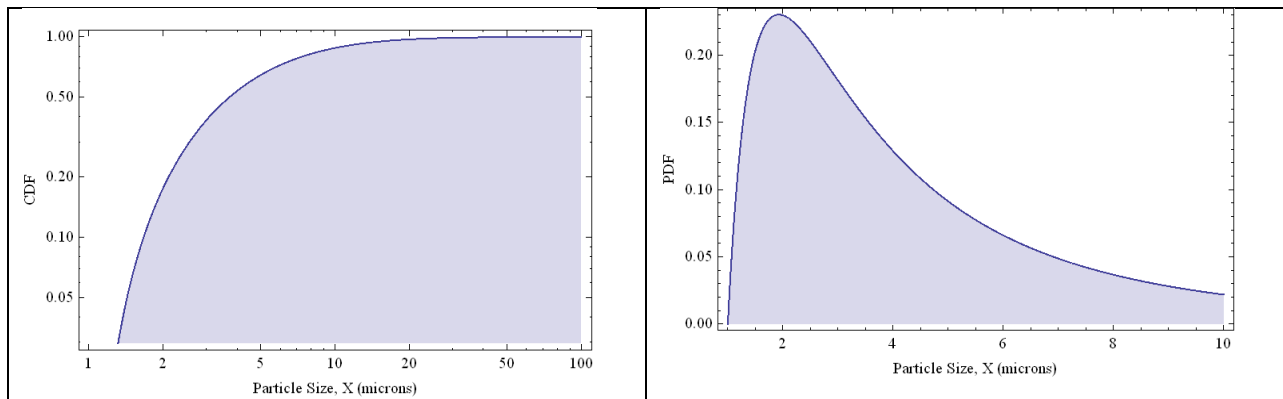

Figure 1 The normalized complementary CDF and PDF functions for IEST-STYD-1246D

Note that there is an assumed, sharp cutoff in particulates below 1 micron and that the PDF peaks at ~2 microns.

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[4] Product Cleanliness Levels and Contamination Control Program, Institute of Environmental Sciences and Technology (IEST), Contamination Control Division, Standard 1246D, (IETS-STD-CC1246D)

If we integrate the PDF times the particle projected (cross-sectional) area, assuming all particles are spherical or round, and vary the cleanliness level, L, until the obscuration ratio is 0.6 ppm (our maximum acceptable amount assuming an albedo of 1), we find that L = 65.

As Mike Zucker noted in T080067, there must be a particle size upper limit, particularly for our vertically inclined optical surfaces (where the gravity force overcomes electrostatic or van der Waals forces). He postulated ~200 microns. While this is important if the roll-off in the distribution function, with particle size, is not fast (as is the case for surfaces with long integrated exposure) it is not important for the IEST-STD-1246D distribution, as shown in Figure 2.
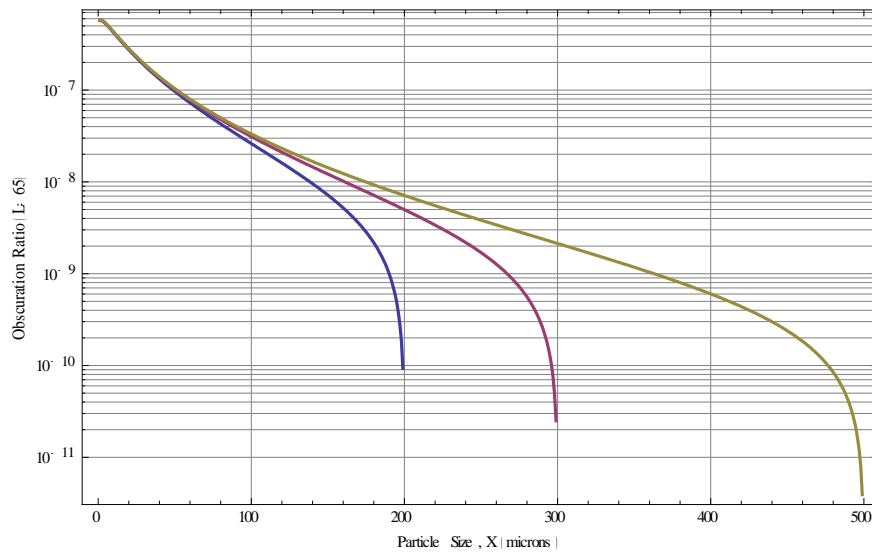

Figure 2 Obscuration Ratio Integral (for particle size > x) with particle size cutoffs of 200, 300 and 500 microns

The ratio of particulate density for various cleanliness levels, L, higher than our minimum "requirement" of 65 is given in Table 1.

Table 1 Ratio of particulate density over our minimum "requirement" for various cleanliness levels, L

L	Density Factor above "Requirement"
65	1
100	5
150	22
200	72
300	435
500	5034
750	40818