



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

*LIGO Laboratory / LIGO Scientific Collaboration*

LIGO-E1000863-v2

*LIGO*

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## QA Test Procedure for aLIGO COC

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## 1 Introduction

This document describes the procedures for quality assurance (QA) measurements on aLIGO Core Optics per the requirements in LIGO-M1000211. These measurements will take place on the RTS bench at Caltech, the full measurements are defined in LIGO-E080494. They include bulk and coating absorptions, total integrated scattering (TIS), AR reflectance, HR transmittance and coating uniformity.

## 2 The RTS Bench

The RTS bench is a custom-made system in the OTF lab. It essentially consists of:

1. one X-Y stage with ranges of 600 and 200 mm in X and Y axes respectively
2. one 30 W Nd:YAG laser at 1064 nm
3. one 700 mW NPRO Nd:YAG laser at 1064 nm
4. one 5 mW He-Ne laser at 632.8 nm
5. three SRS lock-in amplifiers
6. two optical choppers
7. two power detector and meters
8. mirrors, photo-diode detectors and opto-mechanical mounts etc.

The X-Y stage and the DAQ are controlled through RS232 and GPIB buses in Labview program. The system is flexible, different measurements can be set up and the optic's surface can be mapped by using Labview. Fig.1 shows the control panel of the X-Y stage, the left button is for selecting 4 available step sizes and the right button allows the operator to define the moving direction. Fig. 2 shows a typical surface mapping measurement window. The scan shape, area, step size as well as DAQ channels can be programmed in Labview. All the Labview program libraries are on the local machine in C:\Documents and Settings\ligo\My Documents\labview\rts\.

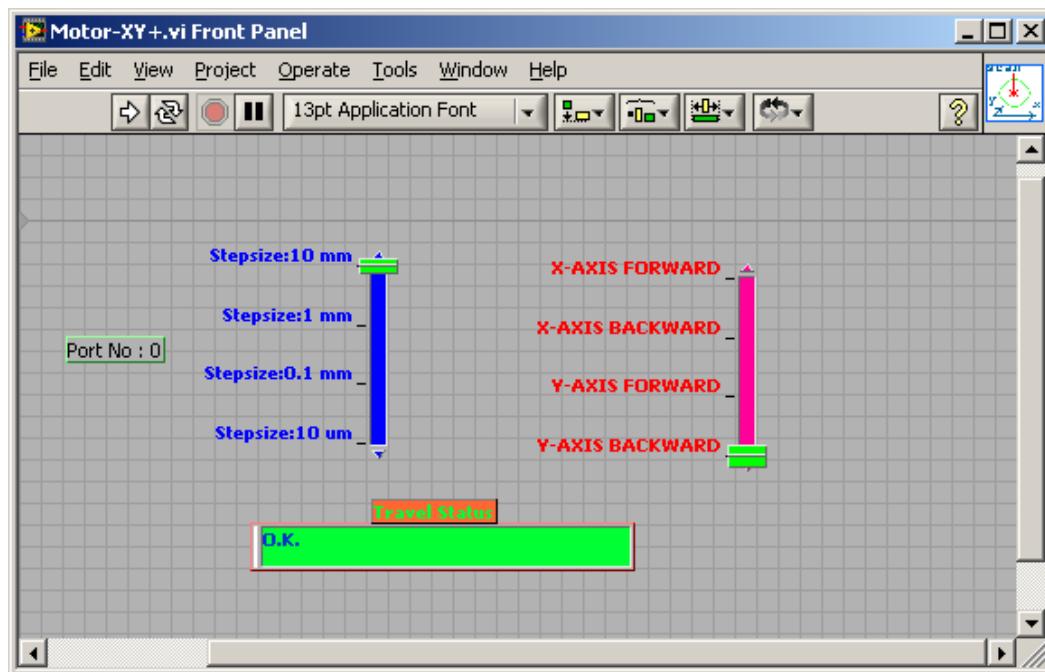


Figure 1: Labview control panel for x-y stage

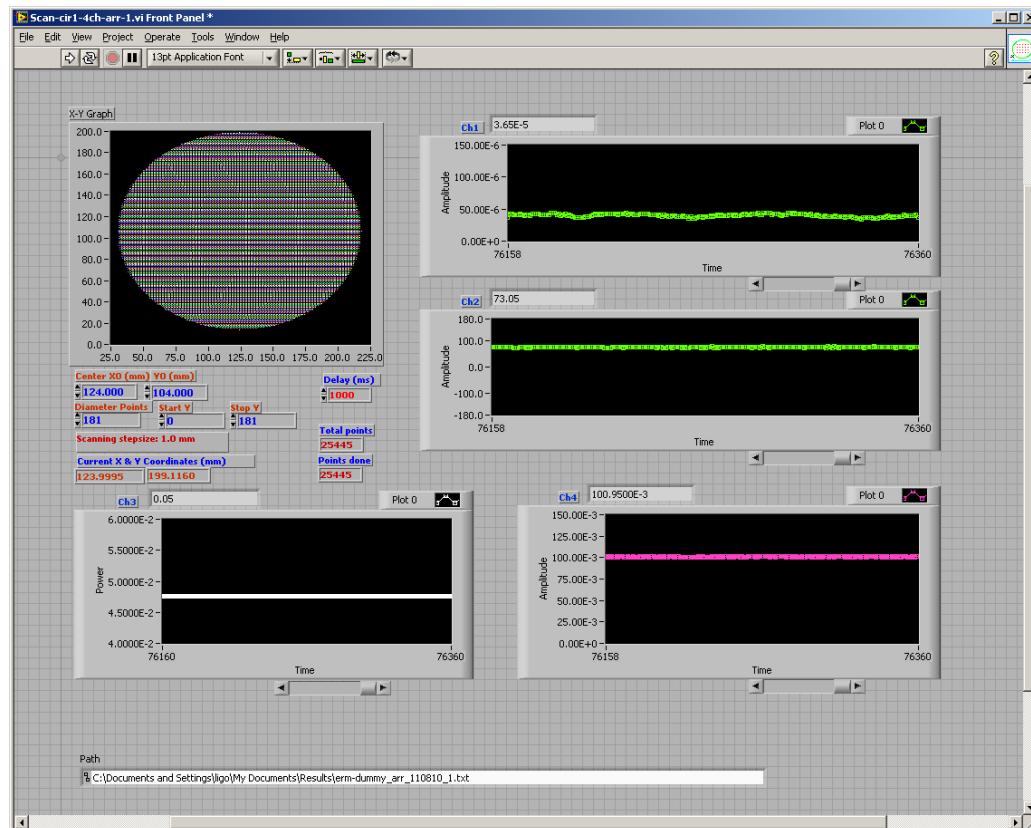
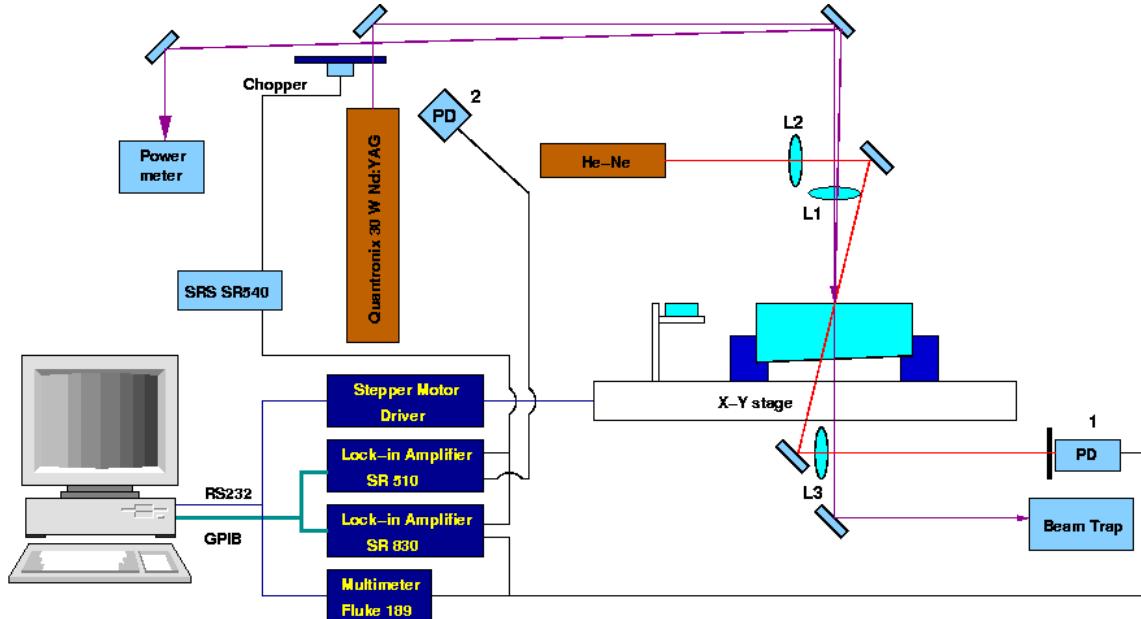


Figure 2: Control Panel screen showing an AR reflection measurement

Fig.2 shows the control panel of an AR reflection measurement. Ch1 and Ch2 shows the amplitude and phase of the reflected beam. Ch3 monitors the DC laser power before the optical chopper. Ch4 monitors the AC laser power after the chopper.

### 3 Absorption Measurement

Absorptions at the ppm level in bulk substrate and coatings of will be measured using the Common-Path Interferometer (CPI), as described in LIGO-G010352 and LIGO-G080315. Qualitatively, a chopped high power Nd:YAG beam is focused on the sample and the optical path difference (OPD) is probed by a low power CW He-Ne beam with a beam size of a few times larger than that of the chopped Nd:YAG beam. The OPD changes due to the absorption caused by thermal refractive index change ( $dn/dt$ ) and thermal expansion. At a distance of (~10 mm) from the interaction point, the perturbed center of the He-Ne beam interferes with the non-perturbed part of the beam and converts the absorption induced OPD into an intensity signal. This signal is read by using a pinhole, a photodiode and a lock-in amplifier at the modulation frequency.



**Figure 3: Schematic of the absorption measurement setup**

#### Absorption Measurement Procedure:

- 1) Turn on the 5 mW He-Ne laser, check and optimize the coarse alignment.
- 2) Turn on the 30 W Nd:YAG laser, check and optimize the coarse alignment with the power as low as possible.
- 3) Set up a beam profiler at the interaction plane, adjust the lens L1 ( $f \sim 100$  mm) to make sure the IR beam waist is on the interaction plane. The IR beam size ( $1/e$ ) should be about 100  $\mu\text{m}$ .
- 4) Adjust the lens L2 and make sure the He-Ne beam size is about 400~500  $\mu\text{m}$ .

- 5) Using the beam profiler, align the two beams so that they are collinear at the interaction plane.
- 6) Using a 1" mirror, set up a power meter on the reflection side and a beam dump on the transmission side of the IR beam.
- 7) Set up and adjust the imaging lens L3 to let the detector capture an image of a point slightly behind (~5mm) the interaction plane. The accuracy at this point could be very rough, e.g.  $\pm$  5mm.
- 8) Set up the photo detector (PD -1 in Fig. 3) with a pinhole of  $\sim$ 200  $\mu\text{m}$  installed.
- 9) Using a ND filter, find the photo thermal signal with low power (1~2 W) IR beam and improve the alignment.
- 10) Using a high absorption mirror ( $\sim$ 10 ppm) optimize the alignment with high power ( $\sim$ 15 W) IR beam.
- 11) Using a contamination cavity mirror (0.6 ppm measured in the contamination cavity, as shown in P990032) calibrate the system. The system noise floor (rms) should be at about 0.1 ppm.
- 12) Using a simple scan of 2x2, check all the DAQ channels. Usually, the 1<sup>st</sup> channel is for the amplitude of the CPI signal (R in SR830), the 2<sup>nd</sup> one for the phase angle of the CPI signal.
- 13) Set up the mapping scan and manually check several points at the mapping boundary to make sure that the alignment is good within the entire scan area and there is no mechanical interference.
- 14) Check the data saving path and input the new file name.
- 15) Do a final cleaning of the optic and check with the stinger flash light to make sure the area to be scanned is clean. Dust or contaminants on the optic can be burned by the laser, which will damage or downgrade the coating and substrates.

16) Start the scan.

The CPI method is a relative measurement. The measured photo thermal signal of a sample should be calibrated by comparing it with that of a contamination cavity mirror. The HR coating absorption of the calibration mirror should be measured by fitting the beat frequency change vs the output power, as in T030023. The photo thermal signal is proportional to the IR and He-Ne intensities. These intensities are monitored by a photo diode (PD-2 in Fig. 3) and a multimeter. Both of these signals should be taken into account in the calibration. There are 4 DAQ channels, recording into the columns 1-4 of data file the Nd:YAG power, CPI signal amplitude and phase as well as He-Ne probe beam power respectively. Please note the instrument settings are not automatically recorded in the data file.

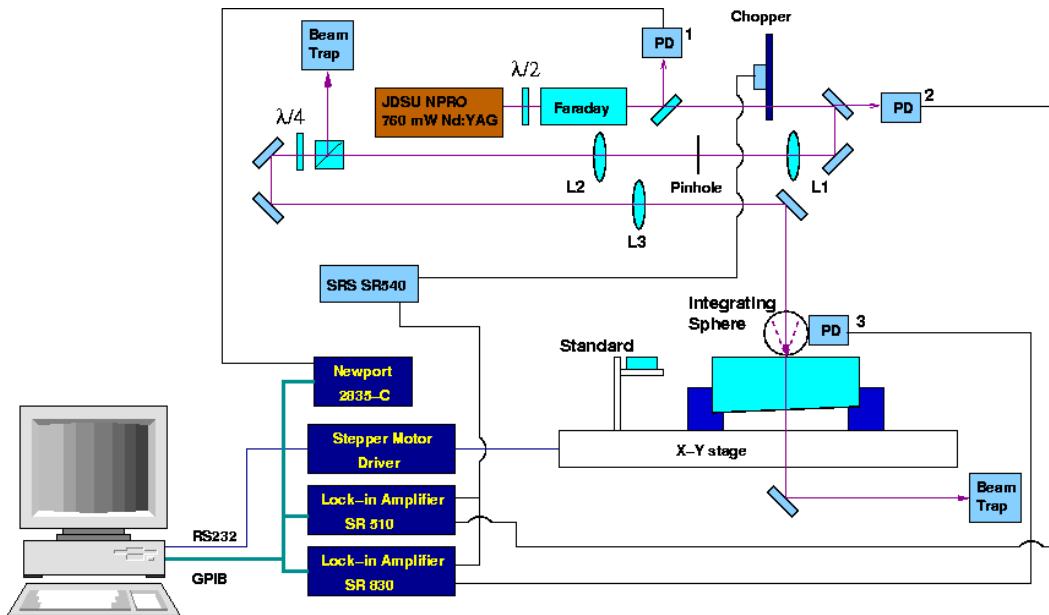
## 4 Total Integrated Scattering Measurement

The total integrated scattering (TIS) from a HR coating is measured using an integrating sphere. The schematic of the experimental set-up is shown below in Fig. 4. The 1064 nm output of a JDSU NPRO laser is regulated by a half-wave plate and a Faraday isolator. Photo diodes are placed

before and after the optical chopper to monitor the power of laser beam going into the integrating sphere. They are labeled PD-1 and PD-2 in Fig. 4. The collimated beam is aligned to go through the center of the top port. The beam that reflects off of the HR coating of the sample also goes through the center of the top port. The polar angle collection range of the integrating sphere is defined by the sizes of the top and bottom ports. The current set-up has a collection range from  $1.5^\circ$  to  $78^\circ$ , corresponding to a bandwidth of spatial frequency  $250 - 9100 \text{ cm}^{-1}$ .

The collected scatter is measured by photo diode PD-3, which couples to the right port of the integrating sphere. To calibrate, first normalize the measured signal to the incident power by installing a diffuse reflectance standard (Labsphere Spectralon) at the bottom port and attenuating the incident power to avoid saturating the photodiode. The attenuation ratio can be read by the two power monitors, these should be consistent within a few percent of each other.

The TIS measurement results of LIGO-1 mirrors are summarized in G080162.



**Figure 4: Schematic of TIS set-up**

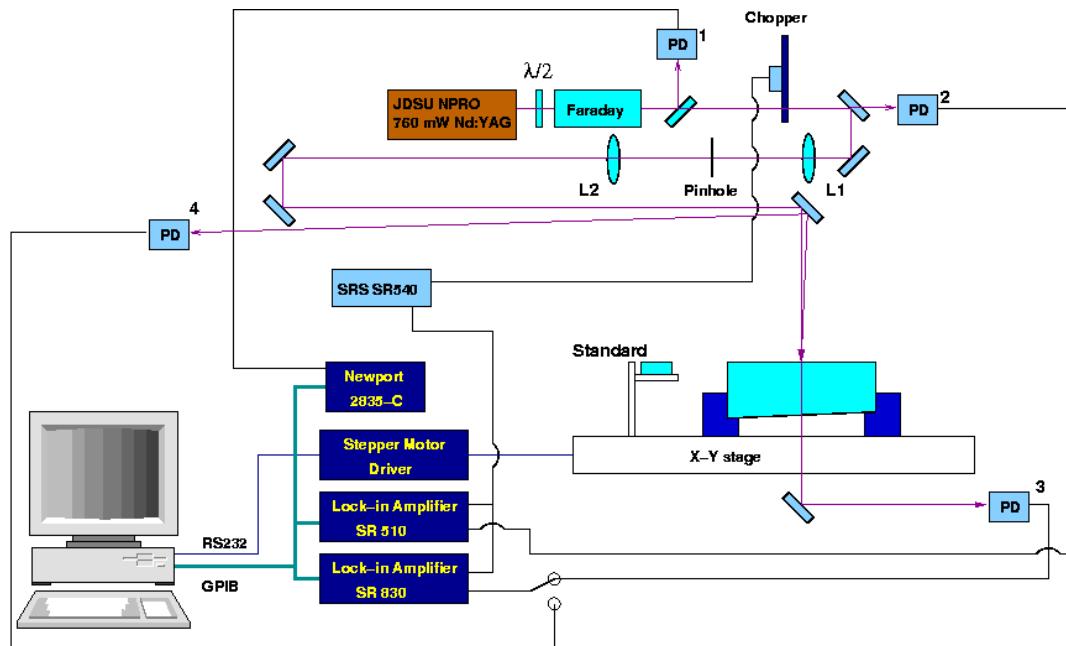
#### Total Integrated Scatter measurement Procedure:

- 1) Check all components to make sure they are in position.
- 2) Turn on the NPRO laser and set the half-wave plate at the output port of NPRO to get the minimum reading of the power monitors.
- 3) Install the mirror and make sure its top surface is horizontal.
- 4) Remove the top cap of the integrating sphere and align the reflected beam to the beam trap on the reflection side.
- 5) Increase the power and align the transmitted beam into the beam trap on the transmission side.

- 6) Install the top cap and fine tune the position of integrating sphere to minimize the reading of PD-3.
- 7) Clean the mirror and set up maximum incident power, find sweet spots by moving the X-Y stage and take readings with the three photodiodes. This is the micro roughness component of the measurement.
- 8) Set up minimum incident power, install the diffuse reflectance standard at the bottom port of sphere and take readings of the three photodiodes. These are for the total incident power.
- 9) Remove the diffuse standard and install a cap with a hole of the same size as that on the top cap, set up maximum power and take the readings. This is the noise level dominated by forward scattering caused by the upstream optics.
- 10) Calibrate the noise level, if it's too high (>5 ppm), try cleaning and fine tuning the alignment of the upstream mirrors.
- 11) Set up a simple scan to make sure all the DAQs are working properly.
- 12) Check the data saving path and input a new file name.
- 13) Set up a full scan and start. There are 4 DAQ channels, recording into columns 1-4 of the data the DC monitoring of the NPRO output power, TIS signal amplitude and phase as well as AC monitoring of the NPRO power respectively. Please note the instrument settings are not automatically recorded in the data file.

## 5 Transmittance and Reflectance Measurements

The measurements of HR coating transmittance and AR reflectance are fairly straight forward. The measured signals should be normalized to that of the incident beam as they pass through the same optical path. Fig. 5 shows a schematic of the set-up.



**Figure 5: Schematic of the HR transmittance and AR reflectance measurement setup**

### HR Transmittance and AR Reflectance Procedure:

- 1) Check the components and make sure the set-up is roughly aligned.
- 2) Turn on the 700 mW NPRO laser and set up the power monitoring readings (PD-1&2) to minimum (for safety reason).
- 3) Check and align the transmission and reflection beams into the two photodiodes PD-3 and PD-4 respectively. Move or adjust the fold mirror if it's necessary.
- 4) Move X-Y stage to the standard position.
- 5) Without installing a standard, take the total signal (PD-3) for the transmittance calibration and write down the two power monitoring readings.
- 6) Installing a HR mirror ( $T < 100$  ppm), take the total signal (PD-4) for the reflectance calibration and write down the two power monitor readings.
- 7) Move the X-Y stage back to the position of mirror; test the DAQ channels starting a scan of a few points, for example 2x2.
- 8) Check the data saving path and input the new file name.
- 9) Set up a full scan and start. Like in TIS measurement, there are 4 DAQ channels, recording into columns 1-4 of the data the DC monitoring of the NPRO output power, transmission or reflection signal amplitude and phase as well as AC monitoring of the NPRO power respectively. Please note the instrument settings are not automatically recorded in the data file.

## 6 HR Coating Uniformity Measurement

The HR coating uniformity measurement is not required for characterization. It is a diagnostic tool used to evaluate coating configurations. The HR coating uniformity can be examined by combining a spectrometer and the X-Y stage, as shown in T0900465. The idea is to take the reflectance spectrum of 550 – 1000 nm at different positions on the mirror and analyze the characteristic peaks in that range. Fig. 6 shows a schematic of the measurement set-up. The measured spectra should be calibrated according to the Al standard. The broad reflectance has already been calibrated at Ocean Optics.

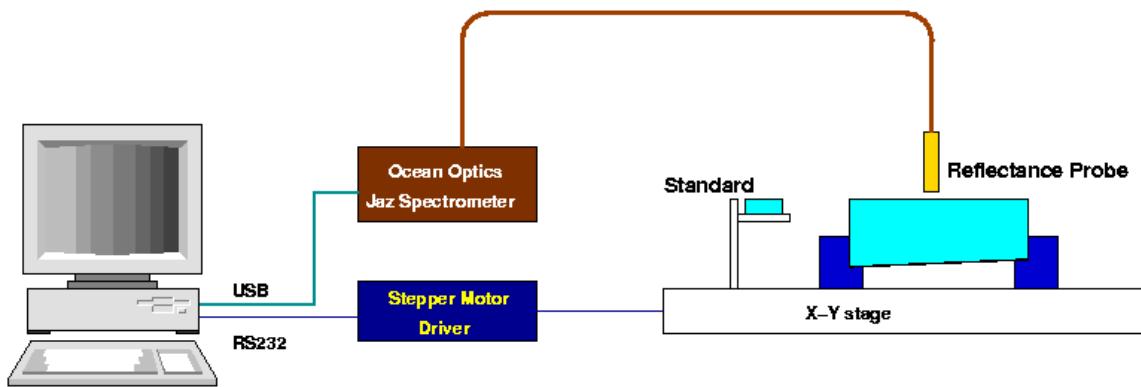


Figure 6: Schematic of the HR coating uniformity measurement

#### HR coating uniformity measurement procedure:

- 1) Install the reflectance probe over the Al standard; adjust the distance between the probe and the standard surface as well as the integration time and average times to get a smooth spectrum from 550 to 1000 nm.
- 2) Move to the mirror; check the DAQ using a simple scan.
- 3) Check the data saving path and input a new file name.
- 4) Set up a full scan and start.

## 7 Data Analysis and Test Report

The scan's raw data is saved in ASCII format and can be read with a text editor. Each row consists of a list of data points and each column lists the data's channels. Usually, columns 1 and 2 are for X and Y coordinates, columns 3 and 4 for amplitude and phase of the signal channel, and columns 5 and 6 are AC and DC power monitoring channels. The data analysis can be done using software like Excel, Matlab and PAW (Physics Analysis Workstation.).

Each measurement should be reported in an E-document with the template shown in E1000864. The statistic results and conclusion should be summarized in a table on the 1<sup>st</sup> page. Discussions and comments can be added following the table. Color maps, histograms and figures etc should be reported in following pages.

Per the requirement of M1000211, each COC has a test report page in the DCC, as summarized in <https://nebula.ligo.caltech.edu/optics/>. For example, all the measurement reports of BS01 should be reference DCC number [E100787](#). Each measurement report should be linked to the COC's test report document.