Protocol of NIST-INMETRO bilateral comparison of Cryogenic Radiometers based on transfer standards.

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1. Introduction

1. NIST (USA) and Inmetro (Brazil) aim to perform a bilateral comparison of cryogenic radiometers. The subject is to give metrological equivalence to the measurement of optical power performed at Inmetro, using the reference value of this quantity derived from comparison CCPR-S3. NIST will be the linking laboratory.

2. This document describes the technical protocol for the bilateral comparison of cryogenic radiometers between NIST and Inmetro. It is based on the protocol for the comparison of cryogenic radiometers (CCPR-S3).

3. Both NMIs (Inmetro and NIST) have prepared the technical protocol and NIST will be the pilot of this comparison, responsible for data evaluation and final report.

2. Organization

2.1. Participants

1. The participants of this bilateral comparison are NIST – the United States National Institute of Metrology – and Inmetro – the Brazilian National Institute of Metrology. The information of both participants is included in the paragraph 2.2.

2. Once the protocol has been agreed, no change to it may be made without prior agreement of both participants.

2.2. Participants’ details

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Contact Persons</th>
<th>Contact Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIST</td>
<td>Allan Smith and Howard Yoon</td>
<td>100 Bureau Drive, MS 8441, Gaithersburg, MD, 20899, USA Telephone: 301-975-8536 (Smith) 301-975-2482 (Yoon) Allan’s email: <a href="mailto:allan.smith@nist.gov">allan.smith@nist.gov</a> Howard’s email: <a href="mailto:howard.yoon@nist.gov">howard.yoon@nist.gov</a></td>
</tr>
<tr>
<td>Inmetro</td>
<td>Thiago Menegotto and Giovanna Fonseca Borghi</td>
<td>Av. Nossa Senhora das Graças, 50, Prédio 4 Duque de Caxias, RJ, Brasil Telephone: +55 21 2679 9203</td>
</tr>
</tbody>
</table>
2.3. Form of comparison

1. Inmetro will provide two characterized reflection trap detectors for the comparison. These detectors are suitably mounted in a housing with standard BNC connector at the rear for electrical connection.

2. NIST will provide two characterized reflection trap detectors for the comparison. These detectors are suitably mounted in a housing with standard BNC connector at the rear for electrical connection.

3. Inmetro and NIST should calibrate all detectors. The order of calibration will be as follows:
   i. NIST(pilot) – in the period from April to June 2012;
   ii. Inmetro – in the period from July to September 2012;
   iii. NIST(pilot) - in the period from October to December 2012.

4. Both laboratories have three months for calibration and transportation of the detectors.

5. The NIST laboratory will prepare the report according to the CCPR guidelines.

6. After agreement regarding the final report, it will be sent to the chair of SIM WG-PR for approval. Then the pilot will forward the report to the CCPR WG-KC for final approval.

<table>
<thead>
<tr>
<th>Round of measurement</th>
<th>INM</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>NIST</td>
<td>April to June 2012</td>
</tr>
<tr>
<td>2nd</td>
<td>INMETRO</td>
<td>July to September 2012</td>
</tr>
<tr>
<td>3rd</td>
<td>NIST</td>
<td>October to December 2012</td>
</tr>
</tbody>
</table>

2.4. Handling of devices

1. The standard detectors should be examined immediately upon receipt at the final destination. However, care should be taken to ensure that the detectors have sufficient time to acclimatize to the room’s environment thus preventing any condensation. The condition of the detectors and associated packaging should be noted and communicated to the NIST laboratory. If possible, use the form in chapter section 6. The detectors should only be handled by authorized persons and stored in such a way as to prevent damage.
2. No cleaning of any detector should be attempted, except using dry air (see section 3). If a transfer standard appears damaged a replacement will be available from Inmetro or NIST.

3. During operation of the detectors, if there is any unusual occurrence, e.g. change of sensitivity etc., the both laboratories should be notified immediately before proceeding.

4. After the measurements, the detectors should be repackaged in their original transit cases. Ensure that the content of the package is complete before shipment. Always use the original packaging.

2.5. Transport of devices

1. It is of utmost importance that the devices be transported in a manner in which they will not be lost, damaged or handled by unauthorized persons.

2. Packaging for the devices should be suitably robust to protect them from being deformed or damaged during transportation.

3. The devices are sufficiently robust to be sent by courier. The packages should be marked as ‘Fragile’. If the possibility arises to hand-carry the packages this is preferred.

4. Inmetro will provide the transportation.

3. Description of the standards

3.1. Devices

3.1.1 Transfer Standards provided by Inmetro

1. Inmetro will provide 2 three-elements trap detectors containing Hamamatsu 1337-1010N (windowless) photodiodes. These detectors were mounted at Inmetro by selecting suitable photodiodes in housings purchased from Rantell Elekter.

2. The detectors are mechanically robust but sensitive to dust. When not in use, they must always be covered. Dust free clean air can be used to remove any apparent dust particle by gently blowing onto the detector.

3. A schematic sketch of the detectors housings are shown in the figure below.
3.1.2 Transfer Standards provided by NIST

1. NIST will provide 2 Graseby detectors, model QED150.

4. Measurement instructions

4.1. Traceability

1. Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

2. Electrical measurements should be independently traceable to the latest realization of the Ampere and Volt.

4.2. General Information about Measurement

1. As well as in the main supplementary comparison (CCPR-S3), the method of indirect comparison by means of transfer detectors was chosen. This means that although the measurand of cryogenic radiometers are optical power, the comparison will be held by the determination of responsivity of some reflection trap detectors.

2. The responsivity is function of the wavelength of the radiation. It should be measured with the beam centered in the detector active area.

3. The measurements should be performed in suitable laboratory environment with the ambient temperature in the vicinity of the detectors maintained as close as possible to
23 °C. The exact temperature of the laboratory during the time of the measurements must be reported.

4. Each independent measurement should consist of the detector being realigned in the measurement facility. It should be noted that each independent measurement may consist of more than one set of measurements, the exact number should be that normally used by the participating laboratory to obtain the appropriate accuracy as limited by the noise characteristics of their specific measurement facility. The exact number of measurements used should be stated in the measurement report but only the mean or final declared value of the set is required to be included.

5. The alignment for all detectors used at Inmetro and NIST laboratories is described in section 7 of this document.

6. Before starting measurements, sufficient time should be allowed to let the detectors reach thermal equilibrium.

7. We propose the measurement of responsivity at 3 wavelengths of both Ar ion and HeNe lasers: 457.9 nm and 514.5 nm of Ar⁺; 632.8 nm of HeNe.

8. The spectral responsivity of the trap detectors should be measured for each selected wavelength by comparison to its cryogenic radiometer.

9. No other measurements are to be attempted by participants or any modification to the operating conditions during the course of this comparison. In particular, the detectors must never be intentionally exposed to radiation below 300 nm nor above 1100 nm. They must never be placed under vacuum. The optical power should be lower than 300 µW for a 2 mm diameter beam (1/e² diameter). The transfer standards used in this comparison should not be used for any purpose other than described in this document.

5. Report of results

1. On completion of measurements by Inmetro, the provisional results of the measurements should be sent to the NIST laboratory with the transfer detectors. As stated previously, the final results should be sent to NIST within six weeks.

2. The report on the calibrations must contain a comprehensive uncertainty budget, comprising all the contributions to the total uncertainty – Table 1 gives a summary of the main sources of uncertainty – which shall be estimated according to the ISO Guide to the Expression of Uncertainty in Measurements.

3. The report on the calibrations must include a description of the participant’s measurement facility. It would be useful to include a schematic diagram of the experimental setup.
Table 1: Main sources of uncertainty contributing to the calibration of transfer detectors.

<table>
<thead>
<tr>
<th>Sources of uncertainty</th>
</tr>
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<tbody>
<tr>
<td><strong>CryoRad II - CRI</strong></td>
</tr>
<tr>
<td>Window transmittance</td>
</tr>
<tr>
<td>Cavity absorbance</td>
</tr>
<tr>
<td>Non-equivalence electrical / optical power</td>
</tr>
<tr>
<td>Electrical power measurement</td>
</tr>
<tr>
<td>Repeatability power measurement</td>
</tr>
<tr>
<td><strong>Trap detector calibration</strong></td>
</tr>
<tr>
<td>Spatial non-uniformity</td>
</tr>
<tr>
<td>Electrical calibration - DVM and Picoammeter</td>
</tr>
<tr>
<td>Repeatability current measurement</td>
</tr>
</tbody>
</table>
6. Receipt confirmation

To: ......................................

From: ..............................

We confirm having received the transfer standards of the Inmetro- NIST bilateral comparison of cryogenic radiometers.

on .........................................(date).

1) Has the detector transportation package been opened during transit? e.g. Customs...Y / N
   If Yes please give details........................................................................................................

2) Is there any damage to the transportation package?.....Y / N.
   If Yes please give details........................................................................................................

3) Are there any visible signs of damage to the detector or housing?....Y / N
   If Yes please give details (e.g. scratches, dust, etc) .........................................................

Laboratory: ........................................................................................................................

Date: ...................................... Signature: .................................................................
7. Alignment procedure for the reflection trap

1. At Inmetro and at NIST, the alignment is made using the laser beam to be measured, so that the weak beam reflected from the trap can be observed.

2. Rotate the trap detector so that the identification mark is at the top and lying in a vertical plane parallel to the polarization axis of the laser radiation. For the Inmetro detectors, the polarization should be aligned to the 4 mm screw hole. For the NIST detectors, the polarization should be aligned perpendicular to the bottom surface with the four rubber feet.

3. Translate the trap along the x and y axis to align the central hole in the beam. Then adjust the translation until the peak signal is obtained. There will usually be a plateau area (an area which is constant) and the centre of this should be selected, which is not necessarily the geometric centre of the trap entrance hole.

4. Adjust tilt of the trap so that the weak residual reflected beam is approximately collinear with the input beam.

5. Repeat steps 3 to 4 to check both the position and the orientation.