Characterization of a FEL lamp type source towards a blue light irradiance intercomparison in medical field

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Abstract. This work presents the characterization of modified FEL 1000W lamp housing to be used as a transference standard in the blue light irradiance intercomparison. It aims to support the metrological issues of medical equipment manufactures concerning the phototherapy treatment stated on the standard NBR/IEC 60601-2-50. The light source characterization consists of lamp seasoning, lamp short-term drift and lamp irradiance relative spatial distribution at the plane of measurement. The lamp seasoning is performed by a software developed in LabView® which measures the lamp voltage, current and irradiance at each 5 minutes during 25 hours of seasoning. The lamp short-term drift is evaluated by measuring the lamp irradiance during a sequence of 2 hours of lamp using. The lamp irradiance relative spatial distribution is verified using a radiometer head with a reduced aperture attached to an YZ positing system at each 2 mm in an interval of 24 mm. The lamp presented variation of about 0.1%/h during seasoning. Short-term drift for the lamp after a warm-up of 20 minutes was less than 0.9% for series of 4 lamp switching cycles. Lamp irradiance relative spatial distribution showed a variation of ±1.25% for a circular diameter of 20 mm. The overall uncertainty for lamp irradiance was 3.65%.

1. Introduction
The FEL-type quartz-halogen lamps are used by some of the most important National Metrology Institutes (NMIs) worldwide as spectral irradiance and photometrical transfer standards [1,2]. These FEL lamps have the advantages of being inexpensive, able to operate at high distribution temperature and suitable as a photometrical or spectral irradiance source from 250 nm upwards. The studies over these lamps have been considered them as stable devices if pre-aged (seasoned) carefully in periods of seasoning which varies from 30 to 60 hours. Over this period the behavior of the lamps regarding the voltage, radiation output and current are observed. Many papers describe the operating characteristics and ageing of these lamps [3-7].

The characterized lamp is an important instrument to perform intercomparison or to maintain the traceability of optical quantities. Considering the needs of Brazilian medical equipment manufacturing industries and the lack of a NMI which could supply an irradiance standard at Brazil or even at South America [8], IPT has started a project in order to create an intercomparison program for blue light irradiance measurements according NBR/IEC 60601-2-50. To do so, a facility to spectral irradiance
measurements with traceability at Germany NMI and a transfer standard which its characteristic is presented in this work were developed.

2. Experimental method
The experimental method describes the system and instrumentation used to perform the lamp evaluation and the software which was developed.

2.1. System and instrumentation for lamp evaluation
For the measurements set-up a system assembly was arranged using two 6 ½ digital voltmeter (DVM) model 34401A from HP, a 0.1 Ω standard resistor model 1682 from Tinsley 1682, a current power source model 69935 from Newport, a lamp housing with a FEL 1000W lamp model 66885 from Newport and a digital radiometer model IL 1700 from International Light.

The lamp housing was modified to make possible the measurement of the lamp voltage in the lamp terminals with separated wires and to connect the standard resistor as a shunt for lamp current measurement. The radiometer head was placed at approximately 700 mm in the opposite side of the lamp housing exit and a shutter was placed at the entrance of radiometer head to avoid the effect of overexposure radiation. The temperature of the radiometer head was kept at 27 ºC by a cooling system during all measurements. One 6 ½ digital voltmeter was connected to the lamp terminal by separated wires for the voltage measurements and the other was connected to the standard resistor for current measurements.

The lamp housing was aligned with the detector head by position a pinhole aperture in the lamp housing exit so that a lamp filament projection could be seen in the detector head plane. The detector head was positioned in the center of lamp filament projection and aligned so that the lamp filament projection was reflected back in the pinhole aperture. To improve the reflection of lamp filament projection a detector neutral density filter was attached to the detector head. The detector head had pick responsivity at 470 nm with a half band width of 50 nm. During the measurements the room’s lamp was switched off to avoid its interference on lamp measurement. The whole data measurement process was controlled by a software developed in Labview® and it was used to evaluated the lamp seasoning and lamp short-term drift. The software can control the instruments mentioned above acquiring their data simultaneously and storing them on a data sheet, for further analysis. Figure 1 shows an arrangement picture.

Figure 1. Experimental arrangement used for lamp seasoning and short-term drift measurements.

Figure 2. Experimental arrangement used for lamp irradiance spatial distribution.

The lamp irradiance relative spatial distribution was verified using the radiometer head attached to an YZ positing system, figure 2. The radiometer aperture was reduced to approximately 2 mm which decreases irradiance average area without compromise the spatial distribution, once this was
normalized by the central irradiance value. The lamp irradiance relative spatial distribution was measured at 24 mm interval in YZ directions in steps of 2 mm.

2.2. Software description
The first software input was the measurement interval between the data acquirement which was 5 minutes for each session of measurement. At each of these sessions a block of 5 measurements for the lamp voltage, current and irradiance was taken in order to calculate measurements average and minimize errors. After that, the interval between these 5 measurements was the next input of the software which was 5 seconds. The software opens the shutter 20 seconds before the measurement session for irradiance measurement and closes it after.

The software presents on the screen the instruments measurements in graphics and numerically simultaneously. The time that each measurement is taken it is also presented on the box “TIME READ”. The software runs continuously until the button “stop” is pressed and so the data is stored in a data sheet for further analysis. Figure 3 shows the software screen.

Figure 3. Software screen.

3. Results
The results for the lamp seasoning, lamp short-term drift and irradiance spatial distribution were presented in this section. All the instruments were warmed up for 30 minutes before measurements had been taken.

3.1. Lamp seasoning
Lamp seasoning is an important tool to guarantee the choice of a reliable and stable transfer standard to be used in an intercomparison. The seasoning process consisted in monitor the lamp voltage, current and irradiance output for a period of 25 hours. The room temperature and relative humidity during seasoning varied from 21.8°C to 24.9°C and 35.8% to 56.7% respectively. The result of seasoning is presented in the figure 4. This result presented 1.5% of irradiance variation during the 25 hours of seasoning which was increased by some current variation in the power supply presented in a detailed view of current in the figure 5. The current power supply variation obtained is according to the manufacture specification of a line regulation better than 0.05%.

3.2. Lamp short-term drift
The evaluation of the short-term drift can furnish information of lamp stability for short period of use which occurs very often in intercomparison. The short-term drift was evaluated by measuring the lamp
output in four cycles of 4 hours (2 hours with lamp on and 2 hours with lamp off) which were performed in two days, that means 2 cycles per day. The short-term drift result is presented in the figure 6. It is observed in the short-term results a drift of 0.9% among the 4 cycles after a lamp warm-up of 20 minutes.

Figure 4. Relative variation obtained in the lamp seasoning for the current, voltage and irradiance.

Figure 5. Detailed view of current relative variation obtained in the lamp seasoning.
3.3. Lamp irradiance spatial distribution

The lamp irradiance spatial distribution provides information about the irradiance uniformity in the plane of irradiance measurement. Using this information it is possible to ensure a maximum diameter of detector heads that could be used in an intercomparison and define the contribution of this parameter in the global uncertainty. The lamp illuminance spatial distribution measured at distance of 700 mm is presented in the figure 7. The distribution was normalized by central irradiance value. It can be seen that for 10 mm radius circular area the irradiance variation is approximately ±1.25%.

**Figure 6.** Relative variation obtained during the 4 cycles of short-term drift.

**Figure 7.** Result of lamp irradiance spatial distribution.
3.4. Uncertainty calculation
The overall uncertainty of lamp irradiance is calculated using the components which are evaluated and other components related to the measurement process [9]. The uncertainty budget is present in table 1.

| Quantity                     | Estimate | Probability distribution | Standard uncertainty | Sensitivity coefficient | Uncertainty contribution | Degrees of freedom |
|------------------------------|----------|--------------------------|----------------------|-------------------------|-------------------------|--------------------|
| Lamp spatial distribution    | R        | 1.04%                    | 1.00                 | 1.443%                  | ∞                       |
| Lamp spatial distribution variance | 0.475W/m³ | N                         | 0.00211W/m³          | 2.10 m²/W             | 0.445%                 | 4                  |
| Shunt DVM voltage drift      | 0.706V   | R                        | 0.016mV              | 14.16 V⁻¹             | 0.023%                 | ∞                  |
| Shunt DVM resolution         | 4°C      | R                        | 0.6µV                | 14.16 V⁻¹             | 0.001%                 | ∞                  |
| Power supply current regulation | R       | 0.0289%                 | 0.009%               | 4                       |
| Lamp seasoning drift         | 10h      | R                        | 0.0577%/h            | 0.023%                 | 10 h                   | 0.577%             |
| Radiometer short-term drift  | 1.091W/m³ | R                        | 0.577%               | 0.053%                 | 0.023%                 | ∞                  |
| Lamp short-term drift        | 0.52%    | R                        | 0.023%               | 0.520%                 | ∞                       |

The uncertainty budget does not include de absolute calibration from the voltmeter, shunt resistance and radiometer because the measurements are normalized. These uncertainty components will be included in the intercomparison results. The uncertainty calculation considers 10 hours of lamp use which will allow at least 10 measurements in the intercomparison. If the diameter used to evaluate the lamp spatial distribution is reduced to 10 mm, it will result a variation of ±0.75% and the total uncertainty in this assumption will be ±2.8%. However, this diameter reduction can limit the type of sensor that the participants of intercomparison might use.

4. Conclusions
A lamp seasoning arrangement controlled by software was presented. The modified lamp housing presented small variation during seasoning of about 0.1%/h, however it had irradiance level shifts which were related to a current drift in the power source. The short-term drift for the lamp after a lamp warm-up of 20 minutes was less than 0.9% which indicated a good stability for series of 4 lamp switching cycles. The lamp illuminance relative spatial distribution showed a drift of ±1.25% for a circular diameter of 20 mm.

Considering the evaluated parameters, the lamp characterized in this work could be used as a transfer standard within an overall uncertainty of ±3.65% which is 5 times smaller than the requirements of standard NBR/IEC 60601-2-50.

5. References
[1] DeCusatis C 1997 “Photometric Standards” in Handbook of Applied Photometry (NY: Springer-Verlag) p 56-98.
[2] DeCusatis C 1997 “Spectroradiometry Methods” in Handbook of Applied Photometry (NY: Springer-Verlag) p 246-250.
[3] Stock K D, et al 2000 Metrologia 37 441-444.
[4] Ohno Y, Jackson J K. 1995/96 Metrologia 32 693-696.
[5] Harrison N J, Woolliams E R, Fox N P 2000 Metrologia, 37, 453-456.
Note: Specific firms and trade names are identified in this paper to describe the experimental procedure adequately. Such identification does not imply recommendation or endorsement by the authors, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.