NIST traceable measurements of radiance and luminance levels of night-vision-goggle test-instruments

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ABSTRACT

In order to perform radiance and luminance level measurements of night-vision-goggle (NVG) test instruments, NIST developed new-generation transfer-standard radiometers (TR). The new TRs can perform low-level radiance and luminance measurements with SI traceability and low uncertainty. The TRs were calibrated against NIST detector/radiometer standards holding the NIST photometric and radiometric scales. An 815 nm diode laser was used at NIST for the radiance responsivity calibrations. A spectrally flat (constant) filter correction was made for the TRs to correct the spectral responsivity change of the built-in Si photodiode for LEDs peaking at different wavelengths in the different test sets. The radiance responsivity transfer to the test instruments (test-sets) is discussed. The radiance values of the test instruments were measured with the TRs. The TRs propagate the traceability to the NIST detector-based reference scales. The radiance uncertainty obtained from three TR measurements was 4.6 % (k=2) at a luminance of 3.43 x 10^{-4} cd/m^2. The output radiance of the previously used IR sphere source and the radiance responsivity of a previously used secondary standard detector unit, which was originally calibrated against an IR sphere source, were also measured with the TRs. The manufacturer produced radiance and luminance levels were calibrated with SI/NIST traceability.

Keywords: night vision goggle, goggle gain measurement, goggle test-set, night vision transfer standard radiometers, radiance scale transfer

1. INTRODUCTION

The radiometric and photometric levels are not known in the presently used night vision goggle (NVG) test instruments. It is necessary for uniform and low uncertainty NVG gain calibrations to know the radiance levels and luminance levels in the available large-number of test instruments used in the field. The purpose of the work described here is to produce transfer standard radiometers/photometers to propagate the NIST detector-based scales to the test-instruments to obtain SI traceable radiance and luminance levels in the test instruments.

The manufacturer, Hoffman Engineering [1] determined 2.482 · 10^{-6} W/(cm^2 sr) radiance is used for 3.43 cd/m^2 luminance in the present test-set calibrations. At present no corrections are used to the types of the applied NVGs and IR-LEDs. Neglecting these corrections can lead to an error in the radiance level at which the NVG parameters are measured. The goal was to measure the output radiance and luminance of the commercial test instruments to minimize calibration uncertainties.

2. NEW TRANSFER STANDARD RADIOMETERS

As shown in Fig. 1, the widely used multiple-lens input imaging optics (PVS7) of radiance meters was replaced with a biconvex lens. The simple input optics design improved the out-of-target rejection (blocking) by an order of magnitude at the +/- 15^o radiance measurement angles [2]. This angular range is somewhat smaller than the +/- 20^o angular range of night vision goggles. A few angular response measurements are shown in Fig. 2. The Si photodiode is cooled with a built in TE cooler. The temperature is stabilized with an external temperature controller. As a result of cooling, the photodiode has a high shunt resistance that keeps the drift and noise amplification for the output of the current-to-voltage converter low. The converter was built with a 24-bit A/D converter. The highest signal gain was 10^{10} V/A.

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The current-to-voltage converter had an auto-range mode and also a high resolution measurement mode. It could perform 1 measurement per second and averaging was made from 13 data points. By averaging of the measured data, a drift and noise equivalent dark-current of 1 fA was obtained, which is three times lower than in previously used NV radiometers and two times smaller than the test-set (LED-source produced) noise of 2.16 fA at $3.43 \cdot 10^{-6}$ cd/m^2 (the low end). The radiometric and photopic filters could be alternately attached to the input optics.

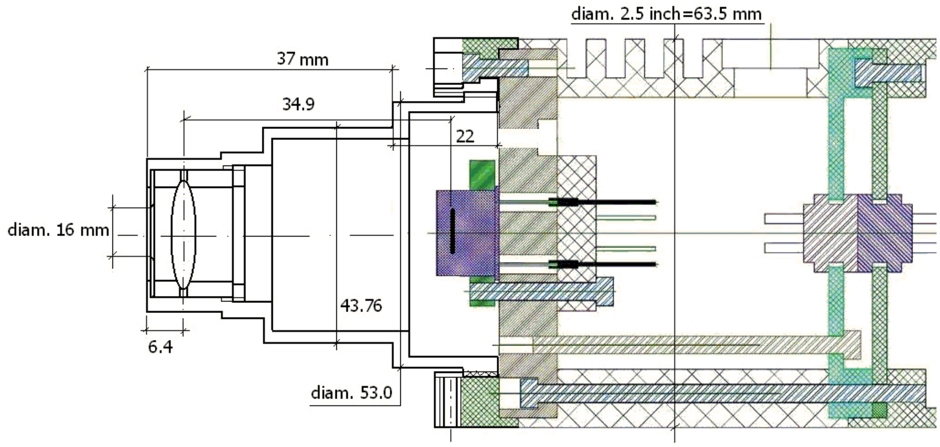

Fig. 1. Scheme of the front arrangement of a night vision transfer standard radiometer.

Green and infrared LEDs are used in the test instruments for NVG calibration purposes. The measured spectral functions of the sources and detectors used in the test instruments are illustrated in Fig. 3. The photopic filter measures a green LED and the radiometric filter measures different IR LEDs. The IR LEDs emit radiation with peaks at 690 nm, 810 nm, and 820 nm. The peak wavelengths and the spectral bandwidths can change among the applied components. The wavelength of the 814.5 nm diode-laser in the NIST Transfer-Radiometer Calibration Facility is roughly in the center of the wavelength interval where the test-instrument LEDs emit radiation. The Model 070 is a Hoffman Unit with a photometer channel (filtered Si detector) and an infrared (Si detector) channel. As shown in Fig. 4, the spectral

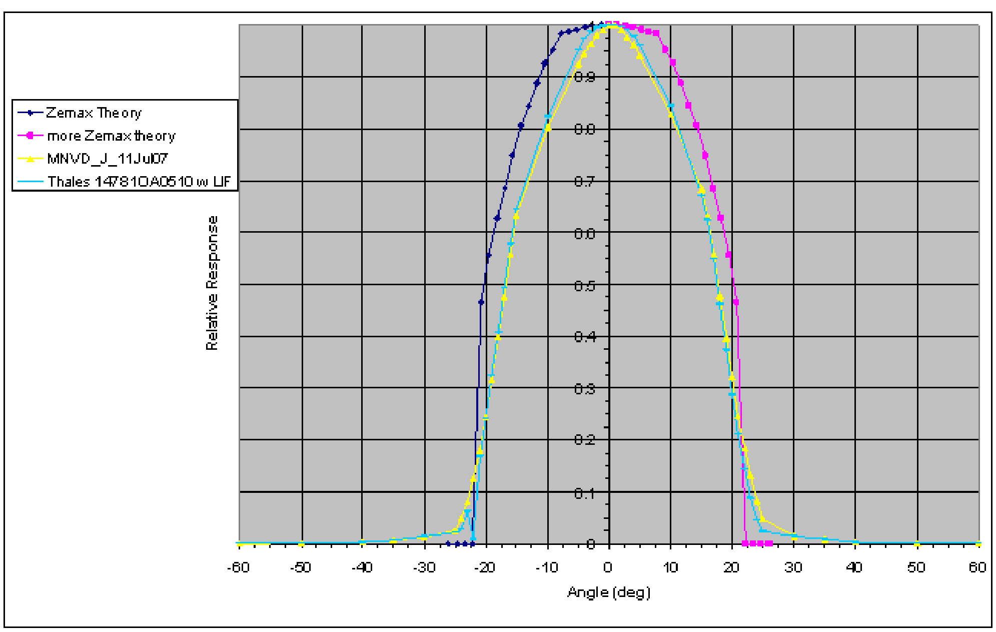

Fig. 2. Navy measured angular responses of NVGs.

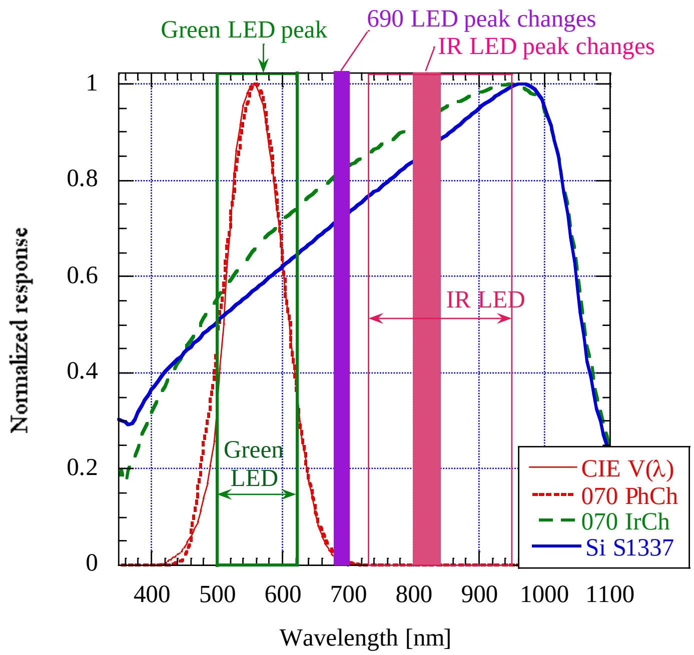

Fig. 3. Spectral characteristics of components used in the scale transfer

responsivity of a TR is corrected to a constant value (similarly to the spectral response of NV goggles) using a radiometric filter combination optimized for the 600 nm to 900 nm spectral range. The filters modified the spectral response of the Hamamatsu made Si S1337 photodiode. They are Schott made KG1 (0.249 mm thick), BG23 (0.083 mm thick), and BK7 (2 mm thick) filters glued together with an optical cement. The result is decreased uncertainty in the radiance transfer. The photopic filters were also Schott filters: BG18, OG530, FG13, OG515, and OG435. The thickness of the filters depends on the batches of the glass manufacturer they are taken from.

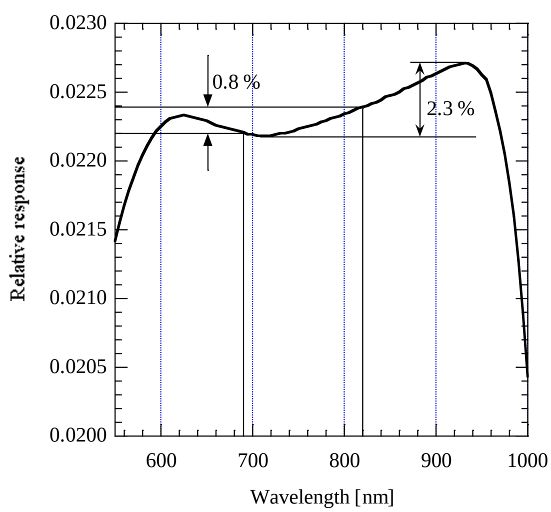

Fig. 4. Filter corrected spectrally “flat” response of the TR in radiance measurement mode.

The photopic filter of the TR was optimized for the spectral range of the green LED shown in Fig. 3. The CIE f1' value was equal to 0.9 % between 480 nm and 680 nm. This value increased to 1.2 % for the 380 nm to 780 nm overall photopic range. The source spectral distribution and the spectral responsivities of the TR (reference) and 070 test detectors were measured to apply spectral mismatch corrections in the transfer of the luminance responsivity first from the NIST standard to the TR and then from the TR to the test device. The picture of the TR is shown in Fig. 5. The radiometric filter combination is on the left lower corner. The photopic filter combination is mounted in the right adapter.

Fig. 5. The picture of the TR with the two front adapters,
the left one with the radiometric and the right one with the photometric filter combinations.

The cross section of the front-adapter is shown in Fig. 6. The radiometric and photometric filter combinations are glued into the front of separate adapters. It was important to make the input hole diameter large enough to avoid beam clipping in the radiance and luminance measurements.

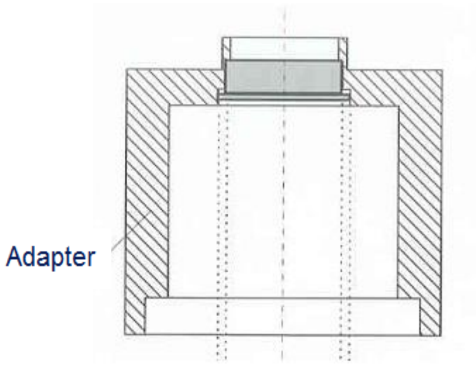

Fig. 6. The cross section of the front-adapter with the inserted filter combination at the front.

3. TRANSFER OF SI TRACEABLE NIST SCALES TO TEST-SETS

The radiance-transfer from NIST to the test-sets is performed with the TSRs in three steps:

1) The spectral radiance responsivity of the TSR, $s(\lambda) = s$, is determined at the Night-Vision Calibration Facility of NIST using a diode-laser source for flux-transfer with an emission-wavelength similar to the LED-peak in the test-set(s). The wavelength is λ.

2) The output signal (photocurrent) of the TSR when plugged into a test-set is:

$$i = \int_{\lambda} L(\lambda) s(\lambda) \mathrm{d}\lambda \tag{1}$$

where $L(\lambda)$ is the spectral radiance of the test-set to be determined.

3) Since the spectral radiance responsivity of the TSR is corrected with the radiometric filter combination to a constant value (shown in Fig. 4), the broad-band (integrated) test-set radiance will be

$$\overline{L} = \frac{i}{s} \tag{2}$$

with a unit of [W / cm^2 sr], where the unit of s is A cm^2 sr / W and the unit of i is A.

As an example, the radiance responsivity of the TR-110603 at 815 nm was 0.00818 A cm^2 sr / W with a responsivity uncertainty of 3.0 % (k=2).

The luminance responsivity was determined against a NIST reference luminance meter. The luminance responsivity of the same TR using the photometric adapter was 0.621 nA m^2 sr / lm with a responsivity uncertainty of 2.0 % (k=2).

4. CALIBRATION OF TEST-SET RADIANCE AND LUMINANCE LEVELS

The output radiance levels of two Hoffman Engineering test-sets have been measured versus the manually set luminance values on the test-sets. The radiance levels that belong to the selected different set values were measured against NIST detector-based reference scales, using the TRs to establish SI traceability for NVG gain calibrations. There are two basic levels in a test-set. The fixed high level is provided by a green LED for instrument (test-set) checkup. In the other mode, the level is adjustable from $10 \cdot 10^{-3}$ cd/m^2 to zero. The adjustable luminance can be utilized for selecting low radiance levels using an IR-LED with 815 nm (or similar) peak. The low output radiance of the test-set can be used for NVG gain measurements. Both the high luminance of the test-set (set by Hoffman Engineering) and the test-set output radiance values were measured with the new NIST NV-TRs. The TRs were calibrated against NIST detector/radiometer standards holding the NIST photometric and radiometric scales. An 815 nm diode laser was used at NIST for the TR radiance responsivity calibrations. The radiometric filter combination was attached to the TR to correct the spectral responsivity of the Si detector to a spectrally constant function for LEDs peaking at different wavelengths in the different test sets. The uncertainty of the radiance responsivity transfer when using this monochromatic source at NIST and an LED in a test-set is discussed in ref. [2]. The radiance responsivity transfer can also be performed with LED sources (at the NIST calibration) that are similar (or possibly equal) to the LED source(s) used in the different test-set(s).

The measured output radiance versus set luminance curve(s) gives the SI traceability for the test-set(s). The selected radiance values together with the also SI traceable luminance value (also transferred to the test-set) can be used for SI traceable calibration of NVGs.

The 3.43 cd/m^2 fixed luminance for the two test-sets were measured. The measured luminance was 3.02 cd/m^2 for test-set #3805 and 2.98 cd/m^2 for test-set #3679. The calibration uncertainty of the luminance transfer from the NIST standard to the test-sets was 2.0 % (k=2).

The luminance in the range from 10 mcd/m^2 to 0 cd/m^2 was measured in the radiance calibration mode of the TRs. In this measurement mode, the IR-LED was operated in the Hoffman Engineering made ANV-126A-001 test-sets. The measured radiance values versus set-values of luminance are shown in Fig. 7. The measured output radiance curve shows high nonlinearity and poor radiance stability at lower than about 10^{-4} cd/m^2 levels. Figure 8 shows the Hoffman Engineering determined and the NIST NV-TR measured calibration factors (ratio of test-set radiance to the luminance selected on the test-set in cd/m^2). The Hoffman Engineering determined calibration factor (radiance/luminance) is a constant line versus the selected (set) luminance. The other three functions were measured with three different NIST NV-TRs. In an ideal situation these functions are equal to the expected constant calibration factor. For the test-set #3805, the TR determined calibration factors in the range above $3 \cdot 10^{-4}$ cd/m^2 were measured about 9 % different than the Hoffman preset constant calibration factor. All future calibrations are suggested to be performed at radiance levels equal to or higher than $3 \cdot 10^{-4}$ cd/m^2 where the highest standard deviation of the mean was 0.6 % for a NV-TR measured signal in this interval. The radiance uncertainty obtained from the three NV-TR measurements was 4.6 % (k=2) at $3 \cdot 10^{-4}$ cd/m^2. The uncertainty of the radiance responsivity of each TR was 3 % (k=2). The errors at 1 µcd/m^2 are close to 300 %. This high error is caused by the non-linear operation of the IR-LED source at very low drive currents. The Hoffman Engineering used calibration factor of $2.48 \cdot 10^{-6}$ W/cm^2 sr was determined for the luminance reading (using English units) of the test-set. The calibration factor for the SI 1 cd/m^2 is 3.43 times smaller, $0.723 \cdot 10^{-7}$ W/cm^2 sr. For the set value of 0 cd/m^2 (not shown in the graph), the output radiation of this test-set was still significant.

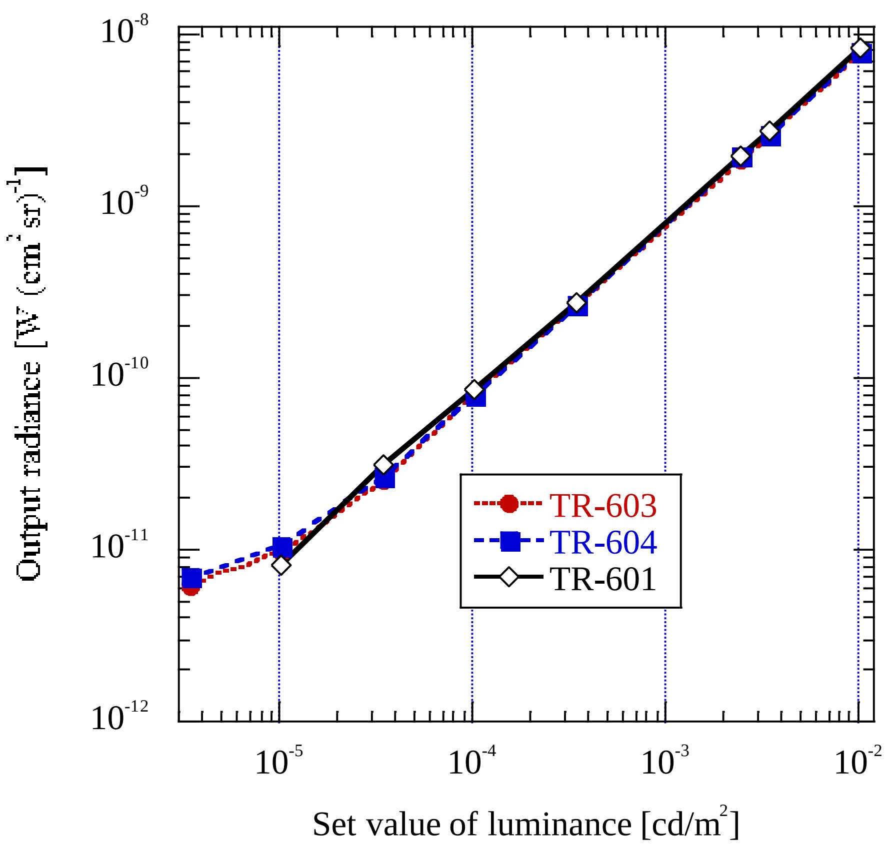

Fig. 7. TR measured radiance levels of a ANV-126A-001 NVG test-set.

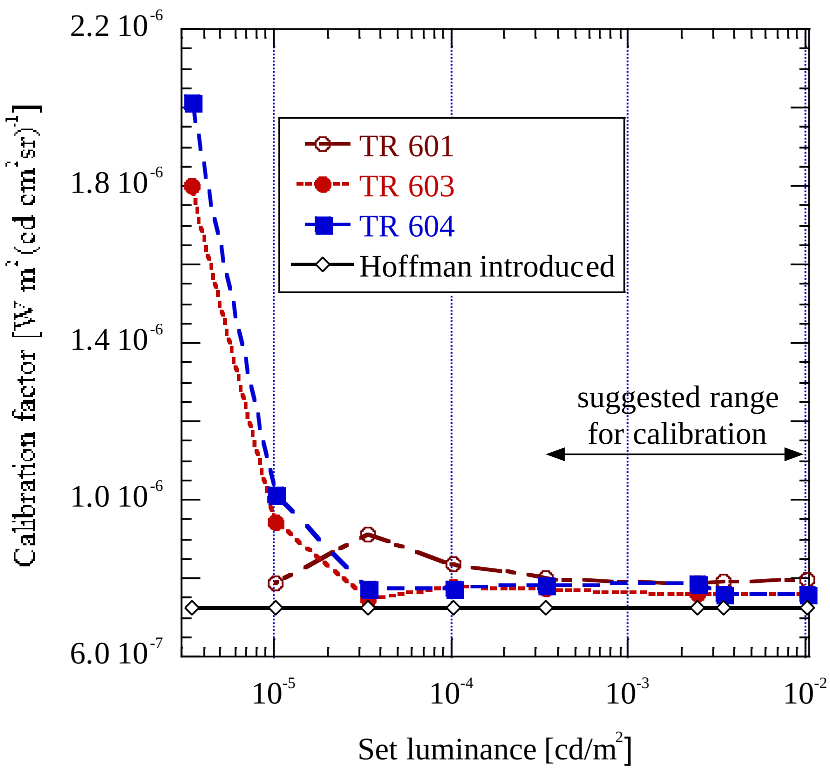

Fig. 8. Measured test-set radiance to set luminance (cd/m^2) ratios compared to the Hoffman Engineering introduced calibration factor (converted here to SI).

5. RADIANCE AND LUMINANCE LEVELS OF PREVIOUS SOURCE STANDARD

The Hoffman Engineering Model 885 sphere-source was used as a transfer (but not a standard) source to propagate both the luminance and radiance responsivities from the new NIST TRs to the Hoffman Model 070 Detector Unit. Originally, the 885 sphere-source was the standard and it was yearly calibrated by Hoffman Engineering. The 070 Detector Unit that includes a photometer and a Si radiometer, was originally calibrated against the 885 sphere-source and used as a secondary standard to perform calibration of the Hoffman test-sets. The 885 sphere-source has two LEDs: a green LED to produce a luminance output and an IR-LED to produce an output radiance that peaks at about 820 nm. Both the photometric and the radiometric outputs were measured with the new NIST TRs.

According to the specification of Hoffman Engineering, the luminance output of the sphere-source was expected to be 3.43+/-0.01 cd/m^2. Using the #110603 NIST TR with the photometric input adapter, a luminance level of 0.2 % lower was measured. The measurement uncertainty was 2.0 % (k=2).

For the output radiance of the 885 sphere-source, 3.43 $\cdot$ 10^{-3} cd/m^2 is specified. According to the calibration factor (which is also a conversion coefficient) used by Hoffman Engineering, this luminance should correspond to a radiance of 2.482 $\cdot$ 10^{-9} W/(cm^2 sr). The measurement result obtained with the #110603 TR was 2.99 $\cdot$ 10^{-9} W/(cm^2 sr). This is about 12 % higher than the radiance calculated from the specified equivalent luminance. Additional discussion of this inconsistency is described below.

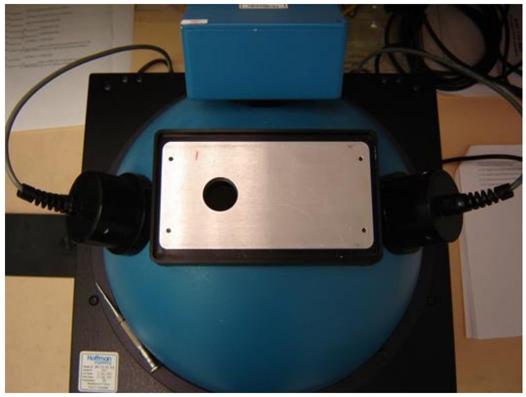

Fig. 9. Sphere source with adapter plate for the TRs.

6. RADIANCE AND LUMINANCE RESPONSIVITIES OF MODEL 070

Originally, the secondary (working) standard Hoffman Engineering Model 070 unit was calibrated against the Model 885 sphere-source tested above. The scale for the 070 Unit was designed to obtain a 1 V (measured) voltage for 3.43 cd/m^2 luminance from the green LED. The reading of the performed measurement was 0.992 V using a Fluke 79 multimeter. This reading is in good agreement with the expected value. The luminance responsivity of the 070 Unit was found to be 0.994 V / 3.43 cd/m^2 (where the 3.43 cd/m^2 is equal to 1 fL, the English unit for luminance) with a responsivity uncertainty of 2.0 % (k=2).

The specified output of the 070 Unit was expected to be 1.000 V +/- 0.004 V for the IR sphere-source output radiance of $2.482 \cdot 10^{-9}$ W/(cm^2 sr). The obtained reading was 1.072 V, 7.2 % higher than the expected value. While this reading is an indication of the higher radiance at the 885 sphere-source output, there is still a remaining ~ 5 % (12 % - 7.2 %) discrepancy for the reading of the 070 Unit. This discrepancy may be corrected by the special gain adjustment procedure recommended for the calibration of the 070 Unit. The radiance responsivity of the 070 Unit was found to be $3.6 \cdot 10^8$ (V cm^2 sr)/W with a 3 % (k=2) uncertainty.

7. CALIBRATION FACTOR ISSUES

The variations in the calibration-factors produce large uncertainties when different NVGs and test-set IR-LEDs are used. However, these calibration factors can be used until an SI traceable NVG gain-definition and calibration procedure are developed.

The NIST developed TRs measured the unknown radiometric and photometric levels in the Hoffman Engineering developed and fabricated instruments such as test-sets and sphere-sources. These TRs were calibrated against NIST detector-based scales to establish traceability when Hoffman Engineering test instruments are used for NVG calibrations and measurements. The radiometric and photometric levels measured in the different test instruments disagreed at about the 10 % level compared to the Hoffman Engineering value. The NIST measured calibration factors were 5 % to 11 % higher than the Hoffman Engineering calibration factor between $3.43 \cdot 10^{-4}$ cd/m^2 and 10^{-2} cd/m^2. These comparisons were made using Class "B" NVGs and in the radiance range where the NVG calibrations are to be performed.

Based on the described measurements and considerations, the above discussed 2.48×10^{-10} W/(cm^2 sr) radiance for $3.43 \cdot 10^{-4}$ cd/m^2 can also be used for NVG calibrations. In the future, the radiance and luminance levels in the test instruments can be measured with the NIST developed TRs.

8. CONCLUSIONS

At present, there is no SI traceability for radiance and luminance level measurements in the NVG test instruments (test-set) needed for uniform NVG characterizations and calibrations. Thus, the set input-radiance for NVG calibrations is significantly different than the radiance calculated from the selected (dialed) luminance on the test-sets. The linearity of the output radiance versus the set luminance was unknown. Because of the differences between the real and the set levels, the output of a test-set using both green and IR-LEDs needed a significant scale correction. New night-vision transfer-standard (TR) radiance/luminance meters have been developed at NIST that can measure the radiance levels in a wide radiance range down to $3.4 \cdot 10^{-6}$ cd/m^2. The NV-TRs in radiance mode have been filter corrected to obtain a spectrally constant responsivity for the different LEDs used in the different test-sets. The NV-TRs have been calibrated at NIST for both radiance and luminance responsivities. These calibrations give the SI traceability for the Hoffman Engineering instruments and also for the NVGs. Both the radiance and luminance levels of the test-sets and sphere-sources have been measured. The Hoffman Engineering working standard detectors (inside of the 070 Unit) have been calibrated against the TR using the Hoffman Engineering sphere-source (Model 885). This sphere source was previously the standard. Now, it is used as a transfer (but not a standard) source. The standards are the new TRs. The TRs have also been used in luminance mode to transfer the NIST luminance scale to the Hoffman Engineering test instruments.

In order to make uniform measurements with low uncertainty, a new NVG gain definition is needed which has traceability to SI/NIST. There is also a need to convert the NVG gain obtained with the existing (old) definition to the gain obtained with a new definition. In order to obtain a dimensionless gain, the new NVG gain definition should be based on radiance units (for both the output and the input of the NVG). In this case, the measured output luminance could be converted into output radiance and the measurement geometry for both the input and the output of the NVGs would be the same for both calibrations and field applications. The NIST developed TRs can be used to transfer the detector-based radiance and the luminance scales to NVG test instruments.

9. ACKNOWLEDGEMENTS

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REFERENCES

[1] Disclaimer, C*ertain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by NIST, nor does imply that the equipment are necessarily the best available for the purpose.*

[2] G. P. Eppeldauer, Uniform calibration of night vision goggles and test sets, SPIE Europe Security and Defense Symposium, Electro-Optical and Infrared Systems: Technology and Applications IV, Vol. 6737, p. 67370M-1 to 67370M-16, 2007.