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Review of night vision metrology

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A review of night vision metrology is presented in this paper. A set of reasons that create a rather chaotic metrologic situation on night vision market is presented. It is shown that there has been made a little progress in night vision metrology during last decades in spite of a big progress in night vision technology at the same period of time. It is concluded that such a big discrepancy between metrology development level and technology development can be an obstacle in the further development of night vision technology.

Keywords: metrology, night vision.

1. Night vision devices

Night vision devices (NVDs) are apparently simple systems built from three main blocks: optical objective, image intensifier tube (IIT), and optical ocular. The task of an optical objective is to create a low intensity, invisible image of the observed scenery at input plane of the IIT. The latter tube consisting of a photocathode, an anode in form of a phosphor screen, and other components intensifies an input low-luminance image into a brighter image created on the anode (screen). Finally, a human can view the output image created by the tube screen using the optical ocular.

In spite of apparent design simplicity the process of creating an output image by these imaging systems is quite sophisticated and evaluation of performance of night vision devices is a difficult task that requires knowledge of a set of parameters of NVD.

Big numbers of NVDs are used all over the world. Improvements of night vision technology during last several decades are impressive [1]. Importance of this technology for defence and security sector could suggest that metrological situation in area of night vision technology should be very good. However, real situation is bad in spite of earlier mentioned factors.

It is quite common to find on the world market two NVDs (or two IITs) of the same data sheet parameters, but of a totally different image quality. Inverse situation is possible, as well. Next, it is quite common that test systems from different manufacturers generate significantly different (over 20%) measurement results. What even more surprising, test systems from the same manufacturer can generate measurement different error depending on a type of tested NVD. There are literature sources presenting conflicting claims of different manufacturers about superiority of some types over other types of NVDs [2–8]. This situation is unexpected for many readers because nowadays in many areas of metrology (example: measurement of electrical quantities) measurement uncertainties are below 0.1%. In next sections complex reasons that have created this poor metrological situation are presented.

2. Recommendations of standards on test equipment

First NVDs were developed for military applications. Even now NVDs for defence/security applications form the most important segment of night vision market. Therefore, it is not surprising that both general concept and methods for testing NVDs were developed by military. These recommendations have been presented in a long series of US defence standards (often called military standard or MIL standards) that regulate testing of NVDs and IITs [9–20]. Nowadays, MIL standards are at least partially accepted by both manufacturers, test laboratories and final users of NVDs all over the world.

If we read several of these MIL standards we can find the presented below requirements on test equipment:

a) The radiation source used in the tests shall be a tungsten filament lamp operated at a colour temperature of 2856 kelvins (K), ±50 K.
b) The photometer used for screen brightness measurements shall be a Pritchard Model 1970 PR, or equal.
c) The photometer used for brightness measurements shall be calibrated against a standard source as specified below:
   - Tungsten filament lamp operated in conjunction with opal glass such that the colour temperature of the radiation emitted from the opal glass is 2856 kelvins (K), ±50 K.

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- Corning spectral filters Nos. 3–71 and 4–67, or equivalent.
- Opal glass to produce a uniform, Lambertian distribution.
- Output brightness to be 0.1 to 1.0 footlambert uniformly distributed.
- Tolerances on specified radiation levels shall be ±10%.
- Meters used for monitoring lamp current and voltage shall have accuracy of ±0.25%.
- Neutral density filters used in test equipment shall have transmission characteristics within 10 percent of the nominal filter transmission from 0.35 to 1.0 micrometer.
- The performance tests shall be performed at ambient temperature equal to 23°C with tolerances: +10°C and –2°C,
- Test chamber used for environmental temperature tests shall maintain the temperature within ±2°C.
- Resolution target shall be a positive, 100 percent contrast USAF 1951 resolving power test target.

From the analysis of these recommendations we can conclude that the MIL standards propose to use for testing NVDs a modular test station built by using seven modules (Fig. 1):

1. Calibrated tungsten filament lamp of a 2856 K colour temperature as a radiation source.
2. Opal glass as a diffuser plate to achieve a Lambertian light source.
3. Set of neutral filters to regulate light intensity.
4. USAF 1951 target to be used for resolution tests and other not defined targets for measurement of other parameters.
5. A luminance meter to measure illuminance at target plane and output luminance from ocular of the tested NVD; illuminance at target plane can be also optionally calculated if the lamp parameters, distance lamp-target, opal glass transmittance, target transmittance are known.
6. Not specified image projector (collimator).
7. Not specified human observer.

The task of the light source combined with opal glass is to illuminate uniformly entire area of the test target and to convert the target into a source of Lambertian light. The set of neutral filters is used to regulate illuminance at the target plane. A set of test targets is used to generate a series of images needed for measurement of different parameters (MIL standards propose directly only USAF 1951 resolution target). The collimator is needed to project image of the target located at collimator focal plane into direction of the tested devices simulating a target located at very long distance (so called "optical infinity"). A human observer is needed as a measuring tool in measurement of subjective parameters (like resolution) of NVDs. Luminance meter is needed for measurement of luminance of screen of IIT seen via ocular of the tested night vision device. Other not specified modules can be needed in case of systems for more expanded tests of NVDs.

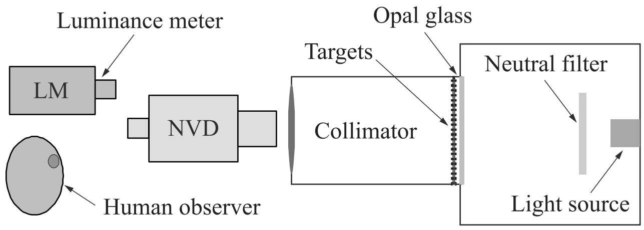


Fig. 1. Graphical concept of a system for testing NVDs according to MIL standards.

The presented above concept of tests of NVDs looks apparently simple. The station shown in Fig. 1 is a simple non-computerized image projector that projects images to be evaluated subjectively by human observers or using a hand held luminance meter. In detail, resolution, dark spots, FOV, and distortion are measured by a subjective analysis of the output image. Luminance gain and saturation level are to be measured with help of a luminance meter. Such a simple technical solution represents a sharp contrast to methods for testing electronic imaging systems (thermal imagers, TV cameras) based on computerized systems that enable accurate measurement of objective parameters of image quality (MTF) or objective criterion of noise/sensitivity (NETD, NEI, FPN, non-uniformity, SiTF).

In spite of its apparent simplicity it is practically difficult to design a quasi-universal, reliable, accurate test station following the MIL guidelines due to several reasons.

First, it is technically difficult to get a reliable, long life, a 2856 K colour temperature light source using a tungsten filament lamp combined with an opal glass. The latter optical module is characterized by a non-uniform, increasing with wavelength transmittance [21]. This feature creates a situation that the opal glass decreases colour temperature of the transmitted light. The result is that an about a 3000 K colour temperature (in the spectral range from about 500 nm to about 900 nm) tungsten/halogen lamp is needed in order to achieve a true 2856 K colour temperature output light coming out of the opal glass. However, the lamp of true a 3000 K colour temperature in the entire interesting spectral band from 500 nm to 900 nm (much wider than visible range) are characterized by short life time. Special filters that increase colour temperature are a possible solution to compensate earlier mentioned defect of the opal glass as a diffuser.

Another more professional solution is to use a photometric sphere as an optical integrator. This solution is mentioned in several MIL standards that regulate testing IITs [16]. However, the problem is that photometric spheres of big dimensions are required to achieve uniform light emitter of area sufficient for testing modern NVDs of wide field of view FOV (typically about 40°).

Second, regulation of light intensity using a set of neutral filters is a cumbersome regulation method. Only step regulation can be achieved. Transmittance of typical neutral filters is not uniform in the entire spectral band of sensitivity

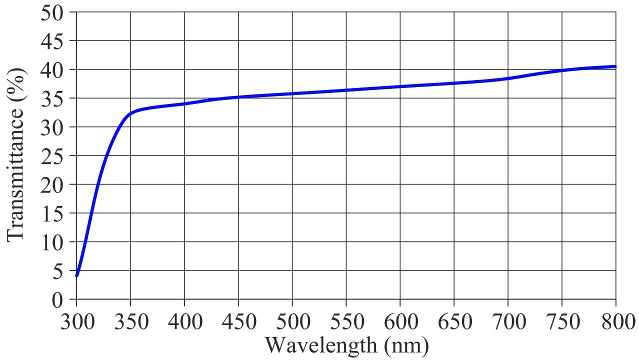


Fig. 2. Spectral transmittance of opal glass.

of NVDs from about 450 nm to about 900 nm (Fig. 2). Electrical methods cannot be used for control of required light level because change of voltage applied to the light source generates change of light spectrum.

Third, MIL recommendations do not propose any solution to compensate possible changes of intensity of the light source with time in a situation when it is commonly known that performance of tungsten lamps deteriorates with time.

Fourth, Pritchard Model 1970 PR luminance meter recommended to be used for measurements of output light intensity from the tested night vision device is a laboratory type rather big device. It is not possible to use this meter in any portable testers of NVDs. Next, field of view (FOV) of a Pritchard Model 1970 PR luminance meter is very narrow (about 2°). It is doubtful, if this meter is an optimal solution to test NVD generating an output image in a wide FOV up to 40°. Further on, a diameter of an input pupil of this luminance meter is many times bigger than a diameter of a pupil of the human eye. Therefore, it can be claimed that this luminance meter is a bad choice for a simulation of the human eye when testing NVDs.

All these technical drawbacks create big obstacles for the strict implementation of MIL recommendations in commercial test systems, or even in systems developed by scientific laboratories. However, in spite of these critical remarks, it must be accepted that MIL recommendations form the basis of systems for testing NVDs used in great majority of test laboratories.

There has been relatively recently published an ISO standard that presents a list of parameters of NVDs and methods to measure these parameters [22]. This standard includes also a quite detail recommendations on the test system used to measure recommended parameters of NVDs.

This ISO standard present list of parameters, test methods and recommendations to test equipment that differ significantly from data presented in MIL standards. Therefore, the *ISO/CD 14490–8:2011 Optics and photonics — Test methods for telescopic systems — Part 8: Test methods for NVDs*, as a standard issued by a senior international metrological organization, should radically change situation in night vision metrology. However, this new standard is practically ignored by the international community of specialists involved in testing NVDs due to a series of reasons:

- The ISO standard has been issued too late. After several decades of using terminology and methodology proposed by MIL standards, a sudden change to significantly different terminology and test methodology is very difficult, or even practically not possible.
- There are manufactures of test equipment that implemented at least partially MIL recommendations for testing NVDs. In other words there are manufacturers of test equipment that support MIL standards. However, so far there is no test equipment that enables testing NVDs according to ISO/CD 14490–8:2011 recommendations.
- This standard is issued by an international organization, but the leading role in a development of this standard played a Russian institute. This ISO standard is practically a shortened and modified version of recommendations from the previous Soviet Union time, a book on testing NVDs [23] and old Soviet standards on testing IITs [24]. The book and the standards present a comprehensive concept of testing NVDs/IITs: detail definitions of parameters, test methods, test equipment and accuracy analysis are presented. The error analysis is particularly useful as it is not present in MIL standards. However, both the book and the standards were published only in Russian and this factor limited dissemination of recommendations on testing NVDs and IITs presented in these valuable publications.
- There are basically two main markets of NVDs: military market and civilian/paramilitary market. Test of military NVDs is practically always done according to MILs' recommendations. It is theoretically possible that the ISO standard will be accepted for testing civilian grade NVDs. However, distributors of civilian grade NVDs often claim that they deliver military grade NVDs in order to promote their products. Therefore, it is unlikely that distributors of civilian grade NVDs will like to use a civilian standard.

Due to the reasons mentioned above, the ISO standard that regulates testing NVDs will not be further discussed as it can be expected that impact of this standard on night vision metrology will be negligible.

3. Test equipment- market situation

NVDs generate images that can be seen by humans and it is possible to evaluate these devices by using human sight. However, it is surprisingly difficult, even for an expert, to precisely evaluate NVDs only by looking on images of a typical scenery. Measurement of series of parameters is needed in order to accurately evaluate quality and possible performance of these devices.

Parameters are quantitative physical measures of NVDs. The measurement is typically done in laboratory conditions, but measured parameters enable an expert to predict how this NVD will perform under real observation conditions. Therefore, a professional test equipment is needed to evaluate NVDs.

The first test stations were developed almost immediately after appearance on the market of the first NVDs in 1950s. At that time night vision was a strictly military technology and these test stations were developed in military laboratories. Since 1950s there have been developed many specialized test stations for testing NVDs in many countries all over the world. Sometimes such test stations were developed by manufacturers of NVDs, sometimes by scientific institutes. However, these tests stations were targeted for testing specific types of NVDs and were not available commercially on world market. At the same time due to a narrow targeted market, these test stations were extremely expensive.

The first test station for testing a wide group of NVDs that became commercially available and gained wide popularity was TS 3895A UV test station developed by Hughes Optical in 1980s (later offered as TS-4348/UV test station from NiVisys Industries, LLC [25]). This was a relatively simple portable test station of limited test capabilities: measurement of resolution done using a non-standard target, only at two illumination levels, and image projection at too narrow field-of-view.

Much bigger changes came at the beginning of 1990s when Hoffman Engineering successfully developed a portable test system (the ANV-126 NVD Test Set) for testing NVDs of quite wide test capabilities: measurement of resolution, dark spots, brightness gain, and collimation error [26]. Significantly upgraded version of ANV-126 station coded as ANV-126A is now a flagship of test systems offered by Hoffman Engineering for testing NVDs.

The ANV-126A offers an increased field of view (full 40° FOV), enhanced resolution levels, and it uses a microprocessor for control of electronics, and a software to speed up test procedures. Menus guides the user through test sequences and provides pre-set test levels in addition to allowing manual settings. Input test levels for brightness gain measurement are pre-set with values (though user adjustable) and ratios arrived automatically. The ANV-126A test station can be shortly described as a small portable, universal station for testing modern NVDs. Test capabilities can be considered as fully acceptable for maintenance applications.

New Noga Light is another player on the equipment market for testing NVDs. Main Test Station (MTS) from this company is a self-contained portable test equipment, suitable for field and depot level maintenance of the NVDs (NVD). It is an electro-optic test system which contains high stability light detectors, precision optics, visible and infrared (IR) light sources. The MTS has the capability to check performance characteristics of the NVD, providing accurate checks of resolution, luminance gain, collimation, distortion, spot defects, current consumption, helmet adapters, as well as check the battery [27]. The MTS test station from New Noga Light can be treated basically as an equivalent of ANV-126A both from the point of test capabilities and internal/external design.

All the test stations discussed so far from three different commercial sources (TS 3895A UV test station, ANV 126A test station, and MTS test station) are compact, portable test stations designed to be used by military at any environmental conditions. These stations are qualified for the environmental requirements of MIL-STD- 810 military standard.

Test equipment for testing NVDs offered by the fourth manufacturer (Inframet) differs significantly from the three test stations mentioned earlier, both in terms of a design concept and test capabilities. The test stations offered by this company are designed as general application test equipment to be used mostly at laboratory/depot conditions. Therefore, Inframet test stations are bigger, heavier than their equivalents and do not full-fil environmental requirements of MIL-STD- 810 military standard [28]. This non-ability to work at military field conditions can be treated as an disadvantage of the Inframet test stations. However, when NVDs can be tested at laboratory/depot conditions, then Inframet test stations represent optimal solution due to bigger test capabilities, wider range of simulated light conditions, direct traceable calibration, and use of projection optics of not noticeable distortion.

Photos of the earlier discussed four commercial stations for testing NVDs are shown in Fig. 3.

It is not the aim of this paper to discuss in detail technical advantages/disadvantages of the earlier mentioned commercial test systems. From scientific, metrologic point of view more interesting is a fact that none of the earlier mentioned manufacturers of commercially available equipment for testing NVDs follows strictly guidelines of the MIL standards. If we analyse technical solutions used by four manufacturers of such test equipment, we will find several big differences with recommendations of the MIL standards.

First, all commercially available, professional tests stations use LEDs as light sources. Only one manufacturer use a halogen bulb, but only as a non-regulated reference light source [28].

Second, control of light intensity is achieved not by use of neutral filters (step regulations), but by using electronic control of LED sources (continuous regulation).

Third, none of these manufacturers use bulky Pritchard Model 1970 PR meter for luminance measurement.

From the other side, three manufacturers use USAF 1951 resolution target to measure resolution of NVDs recommended by MIL standards. Next, all these commercial test systems are calibrated in a reference of a 2856 K colour temperature light source as recommended by the MIL standards.

On the basis of arguments presented above we can conclude that manufacturers of professional test equipment ignore some parts of guidelines presented by the MIL standards, but are still trying to preserve basic principles of test methods shown in these standards. Situation that manufacturers of a professional equipment for testing NVDs do not follow strictly recommendations of MIL standards on test equipment should not be treated as much alarming because

Fig. 3. Photos of four commercial test stations: (a) TS 4348/UV from Nivisys (after Ref. 25), (b) ANV-126A from Hoffman Engineering (after Ref. 26), (c)MTS from New Noga Light (after Ref. 27), and (d)NVT from Inframet (after Ref. 28).

there is a similar situation in case of equipment of testing thermal imagers. Here, the manufacturers of the test equipment implemented several significant improvements in comparison to regulations of STANAG No. 4349 which present requirements for equipment for testing thermal imagers [29]. Next, almost nobody cares about old MIL standards that presents rather archaic proposal for systems for testing thermal imagers [30–31]. However metrological situation in thermal imaging technology is much better than metrological situation in night vision technology due to two basic reasons:

- Manufacturers of equipment for testing thermal imagers offer test systems of very similar design and based on the same measurement methods in situation when there are differences between systems for testing NVDs are much bigger.
- Accuracy of measurement of noise/sensitivity parameters (NETD, FPN, non-uniformity, SiTF) of thermal imagers is generally better than accuracy of measurement of similar parameters (brightness gain, saturation level, signal/noise ratio) of NVDs. Differences between measurement results of thermal imagers over level 20% generated by systems from different manufacturers occur rarely in a situation when such differences are quite common when testing NVDs.

In the next sections, reasons why accuracy of testing of NVDs/IITs is significantly lower than accuracy of testing thermal imagers is discussed.

4. LED light sources

As it was mentioned in Sect. 3, manufacturers of commercial equipment for testing NVDs use typically monochromatic LED light sources instead of tungsten filament lamps emitting polychromatic light of a 2856 K colour temperature in spectral range from about 400 nm to about 900 nm recommended by the MIL standards. This technical solution enables a design of compact, electronically controlled test stations. However, the use of LED light sources has also a negative impact on measurement accuracy of NVDs' photometric parameters due to the reasons mentioned below.

There is no so far polychromatic LEDs emitting light of a 2856 K colour temperature in the entire spectral range from about 400 nm to about 900 nm. The so called warm white LEDs emit polychromatic light of a colour temperature of 3300–3500K but only in a visible band. Additionally, even in a visible band, the spectrum differs significantly from proper spectrum of a greybody. Therefore, monochromatic LEDs are used in a real test station to simulate polychromatic tungsten filament lamps of a 2856 K colour temperature. It is possible to calibrate a monochromatic LED to simulate accurately the earlier mentioned polychromatic tungsten lamp. The problem is that such a calibration is dependent on a spectral sensitivity curve of tested night vision device [32]. Therefore, the commercial test stations based only on a single monochromatic LED light source can be truly accurately calibrated only for one type of NVD of a specific spectral sensitivity curve (so called typical/reference NVD). Therefore, test stations built using only a single monochromatic LED light source are inherently vulnerable to any variation of spectral sensitivity curve of tested NVD/IIT from typical situation.

The most popular test station on market (ANV-126A test station) is typically calibrated for a case of NVD built using typical Gen 3 tube and Class A filter (Fig. 4). It means that measurement results of photometric parameters of NVDs (like brightness gain) can be accurately measured only when tested NVD has the same spectral sensitivity curve as the reference NVD used as a standard during calibration of this test station. However, probability of such a situation is low due to several reasons.

- Many NVDs on the market are built using Gen 2/ Gen 2+ tubes of spectral sensitivity curves differing significantly from spectral sensitivity of so called typical Gen 3 tubes. The differences shown in Fig. 5 [34] are exaggerated but still spectral sensitivity of NVDs containing Gen 2/Gen 2+ tubes differ significantly from spectral sensitivity of NVDs built using Gen 3 tubes.
- Gen 3 tubes differ significantly in their spectral sensitivity curves (Fig. 6). The errors due to the difference of

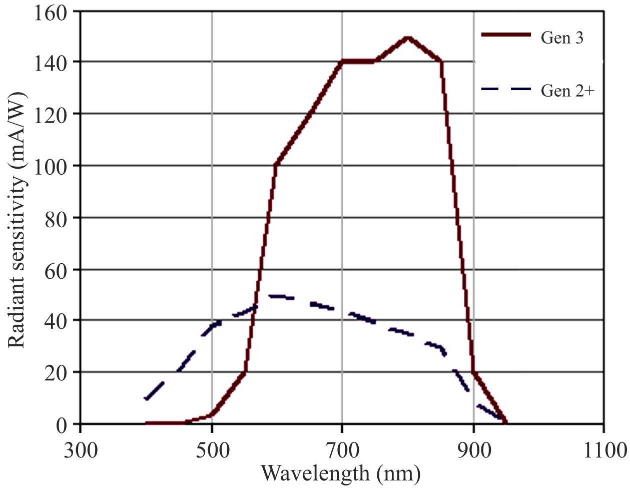


Fig. 5. Radiant sensitivity curves of exemplary Gen 2 tube photocathodes (extended red multialcali) and Gen 3 tube (GaAs) photocathodes (after Ref. 34).

Table 1-4. Optical Specifications

Optical Light Source (gain)	IR LED
Optical Light Source (probe check)	Green LED
Reference Detectors (internal)	Slilicon photo diode
Luminance Detector (external)	Silicon photo diode
Test Set Optics	Multi-element lens
Focal Adjustment Range	Set of Infinity
Resolution Target Range	0.107–3.056 Cy/mR (Spatial Resolution)
Field of View	40 degrees, circular field
Spot Defect Test Capability	Quality zones 1 and 2
	Gauge spots for .003, .006, .009,.012 & .015 inch defects
Internal Source:	0.000 (OFF) to 3.000 mfL, plus an equivalent 10 fL bright light
Equivalent Luminance Range	±3% at 1.000 mfL[1,2]
Test Source Accuracy	±5% at 0.100 mfL[1,2]
Output Luminance Test Range	0.000 – 8.000 footlamberts
Luminance Probe Field of View	15 degrees, circular field
Probe Eye Relief	15 mm
NVD Gain Mode:	NVD output luminance/input luminance
Gain Display Range	0 to 100,000 (luminance gain, fL/fL)
Left/Right Collimation Test:	Left target: Vertical/Horizontal limit boxes
Requires collimation bridge with beam combiner prism to view.	Right target: bright cross on dark background

[1]Relative to NIST standards maintained by Hoffman Engineering Calibration Laboratory.
[2]IR source provides radiance equivalent to the footlambert level specified for 2856 Kelvin white light. Equivalence for Gen-III AN/AVS-6 NVD's having NVIS Class A spectral response per MIL-L-85762.

Fig. 4. A part of manual of ANV-126A (after Ref. 33).

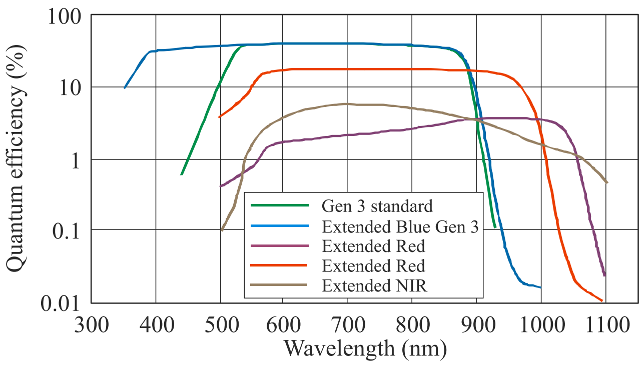


Fig. 6. Spectral quantum efficiency of Gen 3 tubes (after Ref. 35).

spectral sensitivity of the tested NVD and spectral sensitivity of reference device can appear even when Gen 3 NVDs are tested.

- Class A filters are only one of types of spectral filters used by aviator night vision goggles. There are big differences between spectral sensitivity of NVG equipped with different filters (Fig. 7). In addition, it should be remembered that majority of NVDs on market is not equipped with aviation filters at all.

Due to the reasons mentioned earlier there are cases when measurement errors of photometric parameters (like brightness gain) of NVDs measured using commercial test stations based on LED source can be over 50%. There are also cases when these test stations generate negligible measurement errors. Theoretically, estimation and possible correction of measurement errors is possible but only when spectral sensitivity curve of tested NVDs is known. Practically, such a correction of measurement results is rarely possible.

The data in Fig. 4 presents also another source for accuracy problems when testing NVDs. Accuracy of the light source claimed to be at level of ±3% looks very well. However, the statement below the data table clarifies that this relative error presents only information about differences in performance of the light source used in this station and the manufacturer standard light source. This means that so called "accuracy" parameter shown in Fig. 4 is not a true accuracy understood as a difference between readings of the light source and the true value of illumination at plane of the light source.

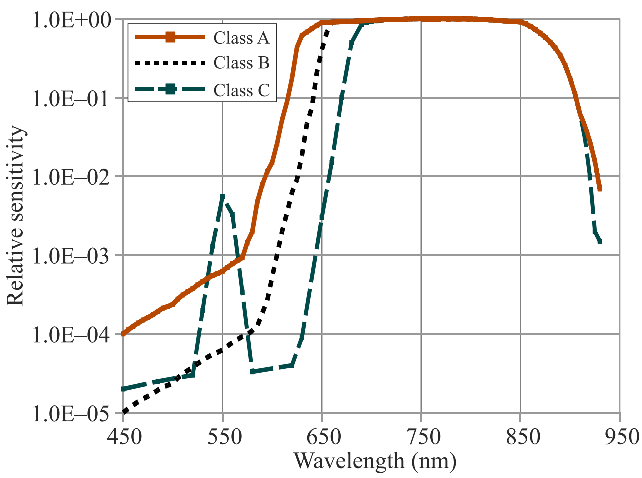


Fig. 7. Relative spectral sensitivity of night vision goggles compatible to lighting in aircraft/helicopter cockpits (after Ref. 36).

As mentioned earlier, the data in Fig. 4 is a part of manual of the most popular test station used for testing NVDs. For many people the results generated by ANV 126A station are treated as reference results. Few specialists in NVD technology are aware about earlier mentioned accuracy limitations of the ANV 126A test station. Great majority of night vision community think that this test station produces very accurate measurement results for any type of NVDs.

It looks that a manufacturer of the earlier discussed test stations is aware about possible accuracy problems when photometric parameters of NVDs are measured because a separate ANV-120 station is offered for measurement of brightness gain of NVDs [26]. However, the latter station is rarely used for testing NVDs because market prefers more universal ANV 126A capable to measure all important parameters of NVDs over ANV-120 station capable to measure only a single parameter.

There is a solution to eliminate the earlier mentioned drawback of the stations based on monochromatic LED light sources. Test stations equipped with two light sources (regulated LED source and non-regulated halogen source) were proposed by one of manufacturers of test equipment [37]. Then photometric parameters like brightness gain can be measured using a halogen light source. Imaging parameters (resolution, FOV, dark spots, distortion, collimation etc.) are measured using LED light source. The LED source can be recalibrated by the user of the test station to simulate a 2856 K colour temperature source for any type of NVDs.

To summarize all manufacturers of NVD test stations use monochromatic LED light sources instead of tungsten filament lamps due to significant advantages of the LED sources from designer point of view. However, there is also negative effect of use of LED based light sources on accuracy of NVD test stations and users of such test stations should be aware of this effect.

5. Photometric tools

Three main photometric tools are needed in order to build a test station for testing NVDs (or IITs):

- regulated polychromatic light source of a 2856 K colour temperature,
- illuminance meter (to measure illuminance at photometric sphere of the light source),
- luminance meter (to measure output luminance from screen of IIT via ocular of tested NVD).

Design of any of these tools capable to offer relative error below 10% is a technical challenge. This statement may be surprising to readers accustomed to a situation that relative error of meters of electrical quantities is typically below a fraction of percent.

First, there are many low cost tungsten/halogen lamps of a 2856 K colour temperature on the market (at least according to data sheets). The problem is that most of these lamps emit light of spectrum that resemble reasonably well light from a greybody of a 2856 K temperature only in visible range; not in the entire interesting spectral range from 400 nm up to about 900 nm. There are distributors of lamps for photometric applications that claim they deliver lamps of colour temperature with tolerances not more than 5–10 K. However, practically this tolerance level refers only to accuracy of a mathematical algorithm used for approximation of real spectrum emitted by the lamp not for differences between real spectrum of the lamp and spectrum of a 2856 K greybody.

Second, tungsten/halogen lamps used in testing NVDs are often traceable to national photometric standards of a 2856 K colour temperature. However, few national photometric laboratories have broadband a 2856 K colour temperature light sources calibrated in both visible and near infrared range. Staff from majority of national metrology institutes is not aware what is spectrum of their standards outside visible band.

Third, spectrum of radiation (colour temperature) emitted by tungsten/halogen lamps varies with time. This phenomenon is noticeable even in specially seasoned photometric lamps.

Fourth, there are also cases when a light source for testing NVDs is built by using a halogen bulb of a true 2856 K colour temperature and the bulb is integrated with a diffusing opal glass plate. The problem is that spectral transmittance of typical opal glass plates is not uniform in a spectral band of 400–900 nm (see Fig. 2) and the use of a diffusing plate can change colour temperature of transmitted light even more than 300 K.

The earlier mentioned situation means that two light sources generating the same illuminance, measured in a visible range, can generate a different output signal from tested NVD due to differences in light spectrum in near infrared range.

The problem with a proper spectrum of light source could be solved by the use of ultra-high temperature blackbodies (temperature equal to 2856 K) as both national standards, and also as light sources in night vision test stations instead of tungsten/halogen bulbs. Such ultra-high temperature blackbodies are already technically available and slowly gain popularity in national metrological institutes [38]. However, it is doubtful if in the near future these blackbodies will find application in night vision metrology due to high price, big dimensions and short life time.

There are many low cost but still reasonably accurate illuminance meters on market. The crux is that these meters are typically capable to measure illuminance with reasonable accuracy but at levels over about 1 lx. Another group of professional illuminance meters enables measurement of illuminance at levels over about 0.01 lx but this level is still not sufficient for use of such meters in night vision metrology. Only very few and also very expensive illuminance meters (like exemplary meter in Ref. 39) enable direct measurement of illuminance at light sources at mentioned earlier levels met in night vision metrology.

Measurement of illuminance at exit of the light source at levels as low as 1 mlx is needed during tests of NVDs. Measurement of illuminance at photocathode plane at levels as low as 0.02 mlx is needed during tests of IITs. Design of ultra-sensitive illuminance meters is a real technical challenge due to very low electrical signals generated by typical Si photodiodes. Therefore, some of commercial ultra-sensitive illuminance meters are designed using photomultipliers. However, noticeable temporal degradation of photomultipier is a drawback of this technical solution.

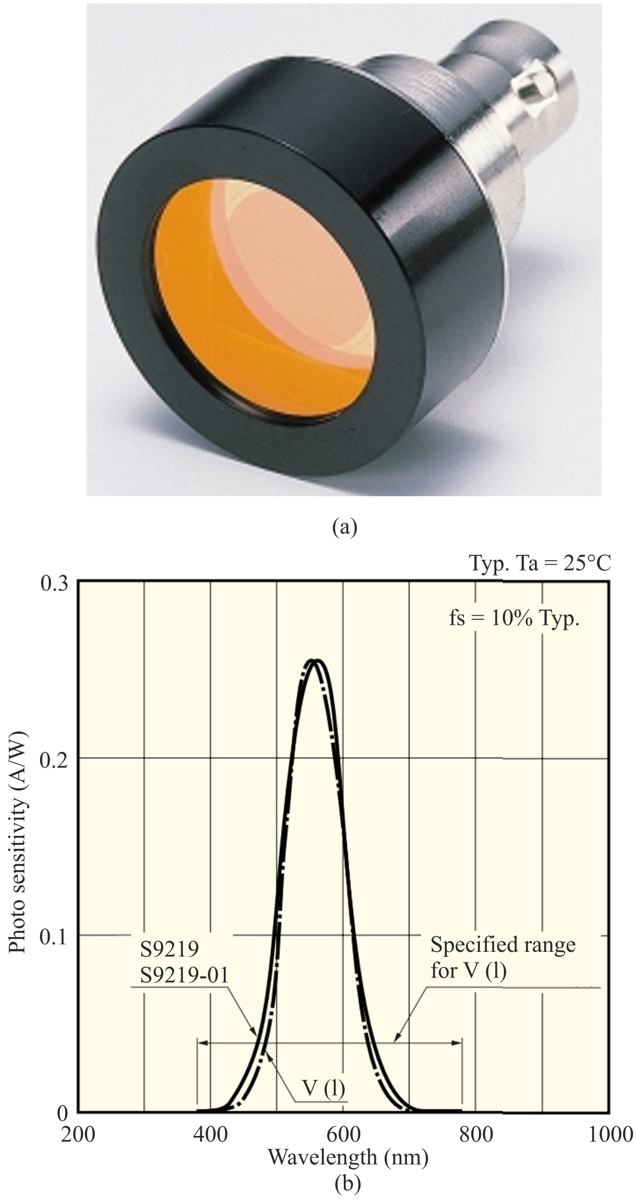
Light emitted by screen of IIT seen via ocular of NVD is quite strong (typically over 1 cd/m^2). Therefore, it should be expected that there are no technical problems with measurement accuracy of luminance of screens of IIT seen via ocular of NVDs. However, there are two technical problems that must be overcome to achieve accurate measurement of output luminance of NVDs.

- Special luminance probes are needed for testing NVDs. The reason is that NVDs are optimized to enable observation of screen of IIT using an ocular by a human eye located as a distance of a dozen of millimeters. A human eye works as a receiver of light emitted by screen of IIT. Therefore, luminance meter should simulate human eye if an indication of this device is to be proportional to human perception of brightness. Such a situation is possible only if the luminance meter is built using optical objective of an input pupil not bigger than pupil of a human eye (6–10 mm). Acceptance angle of such an optimized luminance meter should cover at least central part of the screen. These requirements practically eliminate typical commercial luminance meters that are built using big optical objectives (diameter of input pupil of at least 25 mm) and that offer narrow acceptance angle typically not bigger than 2° [see Fig. 8(a)]. Special luminance meters with a small attachable luminance probe are needed in systems for testing NVDs [see Fig. 8(b)].
- Luminance meters are basically meters of brightness perceived by human observer. Therefore, spectral sensitivity of luminance meters is expected to match well sensitivity of a so called CIE luminosity function, V(λ). However, differences between spectral sensitivity function of even best silicon photodiodes optimized for photometric applications and ideal CIE luminosity function, V(λ), are not lower than 10% (Fig. 9) [40]. This level of accuracy of approximation of V(λ) by photometric sensor is perfectly acceptable in typical applications when luminance of broadband light sources having slow dependence of light intensity with wavelength like halogen bulbs or warm white LEDs, is measured. However, phosphor screens of IITs are narrow-band light sources of fast dependence of light intensity with wavelength and indications of luminance meters are extremely sensitive to accuracy of the approximation of V(λ). Therefore, luminance meters used in night vision metrology need special light sensors having spec-

(a)

(b)

Fig. 8. Photos of two luminance meters: (a) typical commercial luminance meter LS-100 with big optical objective and ultra-narrow FOV (after Ref. 41), and (b) luminance meter LM-1 optimized for night vision metrology with a small attachable luminance probe (after Ref.42).



(a)

(b)

Fig. 9. S9219 photodiode from Hamamatsu Corp: (a)photo, and (b) photodiode spectral sensitivity *vs*. CIE luminosity function, V(λ).

tral sensitivity function of negligible differences with the CIE luminosity function, V(λ). The latter condition is extremely difficult to full-fil.

So far technological problems to design high sensitivity and high accuracy illuminance/luminance meters were presented. However, in addition to design problems there are also calibration problems to be solved by manufacturers of light meters for applications in night vision metrology.

Calibration of ultra-sensitive luminance meters is another big issue. It can be surprising for many readers but great majority of national metrological institutes offer calibration of illuminance meters only at range over 1 lx (Fig. 10). This is valid even in case of well-known national metrological laboratories [43]. Therefore, both manufacturers of commercial ultra-sensitive illuminance meters or manufacturers of equipment for testing NVD/IITs use indirect calibration of their light meters. In this way, they can still claim that the calibration is traceable to national metrology institutes, but it is not a direct calibration by national metrology institutes.

Moreover, luminance meters are typically calibrated in national metrological centres against so called luminance A type (source of a 2856 K temperature) light source in situation when luminance meters in systems for testing NVDs are used to measure light emitted by a phosphor screen of a drastically different spectrum. The result is that two identically calibrated luminance meters can generate two significantly different luminance measurement results during tests of NVDs or IITs due to minor differences in spectral sensitivity curves of these luminance meters. At the same time national metrology institutes are unwilling to offer calibration of luminance meters directly against precisely defined phosphor screens.

To summarize there are real technological challenges in both design and calibration of photometric tools needed in systems for testing NVDs/IITs in spite of progress of modern electro-optical technology.

Facility Details	
Directional photometric facility and correlated colour temperature facility	• 8 m optical bench • NPL high accuracy photometer • High specification colorimeter colour temperature measurements • Telephotometer and calibrated white tile for illuminance measurements
Ranges	• Luminous Intensity: 1 to 10,000 cd • Illuminance: 1 to 50,000 lux • Luminance: 1 to 10,000 cdm^{-2} • Correlated Colour Temperature: 2000 to 3200 K
Transfer standards	• Tungsten based lamps; also available calibrated with accredited certification
Other Photometers and Luxmeters	• Photometer spectral responsivity calibration facility • Luxmeter calibration facility

Fig. 10. Offer of calibration services from exemplary national laboratory (after Ref.43).

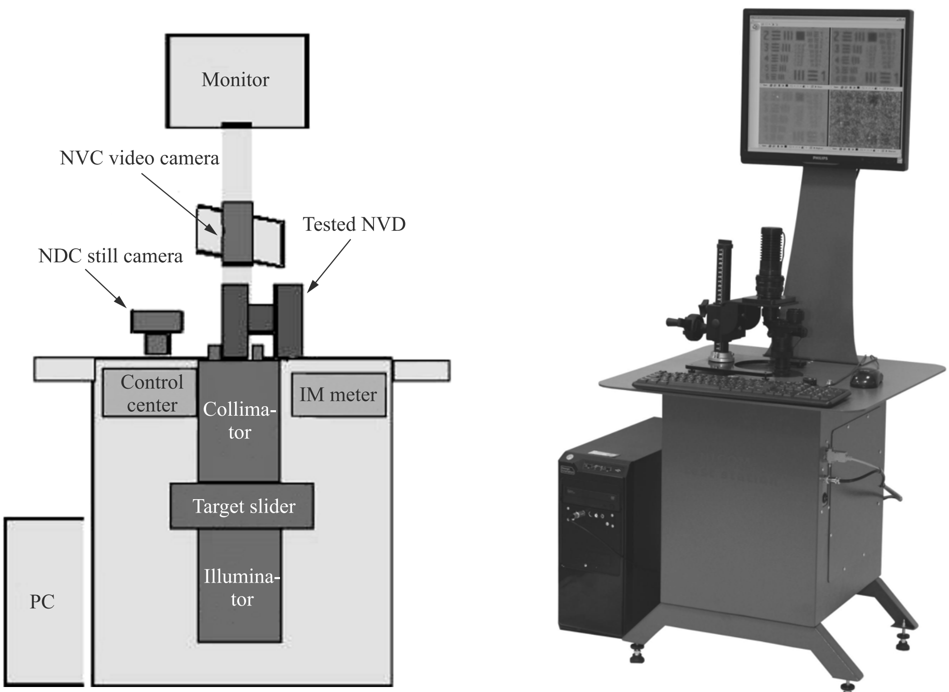
6. Computerisation

MIL standards present recommendations for a simple, non--computerized test stations for testing NVDs [9–13]. Such recommendations are logical because these standards were created several decades ago when computers were not available for metrology applications. Next, there have always been pressure from military users for creations of compact, simple test stations.

Simple, compact, non-computerized test stations can be an optimal choice for final military users. However, it should be logically expected that manufacturers, scientific institutes, test laboratories should carry out much more advanced testing of NVDs using computerized test stations that enable semi-automatic testing and digital recording of measurement results.

The latter scenario has not materialized, so far. The real situation is that practically there are almost no computerized test station on the market. Only previous year one of the manufacturers has launched a computerized station for testing NVDs [44]. Therefore, computerized stations are still a novelty on market and is not sure if these new stations will get market acceptance. Situation with computerized stations for testing IITs looks better and such test stations are available for almost a decade and are popular [45].

Lack of computerized stations for testing NVDs can be considered as one of reasons of difficulties in effective, accurate evaluation of these devices. We must remember that humans can compare very well quality of several images seen at the same time, but have big problems to evaluate quality of images seen at different moments of time. The result is quite a big variability of indications during measurement of resolution of NVDs or IITs. Modern computer ized test system like this shown in Fig. 11 could help to improve accuracy of resolution measurements. These stations can, at the same time, generate dynamic images of the resolution target generated by the tested NVD and a reference dynamic image. Computerized test systems offer also



(a) (b)

Fig. 11. NICOM computerized station for testing NVDs: (a) block diagram, and (b) photo (after Ref. 44).

a measurement of important objective parameters like modulation transfer function MTF and signal to noise ratio SNR. Further on, blemishes in images generated by tested NVDs are analysed and determined automatically by software.

These changes are important and can significantly improve accuracy of tests of NVDs in situation when typical non computerized test systems offer measurement of imaging parameters (resolution, blemishes, distortion, operational defects, cosmetic defects) using only subjective methods of limited accuracy.

Finally, it should be noted that computerized test stations can potentially reduce differences between methodology of testing NVDs and methodology of testing electronic imagers like thermal imagers, and visible/NIR cameras. So far, due to mostly historical reasons there are big differences between set of parameters used to characterize NVDs and electronic imaging systems. However, nowadays, there is basically no major technical obstacles to use well matured methodology of testing visible/NIR cameras also for testing NVDs. This scenario would potentially enable easy comparison of performance of NVDs and low light level visible/NIR cameras.

7. Testing image intensifier tubes

The concept of testing NVDs presented in MIL standards [9–13] is based on an assumption that a series of parameters of IITs (most important module of NVD) is known. The parameters of IITs are supposed to be measured according to recommendations of another set of MIL standards [14–17]. Therefore, parameters of IITs (like resolution, SNR, MTF, dark spots, image alignment, luminance gain, etc.) are often included in data sheets of NVDs.

This test concept looks sound and should work perfectly but there are problems with methodology of testing IITs. Basically, the MIL standards that regulate testing IITs [14–20] present some outdated recommendations and are not strictly followed by manufacturers of test equipment. Here we will site several examples of rather historical, clearly outdated recommendations that significantly reduce accuracy of test results.

- MIL standards propose to use 10x power magnifier to measure resolution of IITs. Such magnifiers were acceptable for measuring resolution of IITs in 1980s when average resolution was at the level close to 30 lp/mm, but not nowadays, when resolution of best tubes is about 80 lp/mm. Therefore, 50x power microscopes or high magnification video microscopes are needed for accurate tests of modern IITs. Measurement of resolution of IITs using 10x power magnifier would be very unfair for manufacturers of high quality image intensifier tubes because measurement results would be very pessimistic.
- It is recommended to measure MTF using sine targets. It is an archaic method used before the advent of digital techniques that have enabled to use much faster slit/edge method based on Fourier transform.
- These standards propose subjective evaluation of blemishes by humans using a microscope. This measurement method is time consuming, subjective and of low repeatability. Therefore, this recommendation is clearly archaic in situation when digital imaging systems capable to capture, record, and analyse images are available.
- A photoamplifier tube with a pinhole is proposed for a SNR measurement. It is a difficult and time consuming process to align this photoamplifier tube relative to the spot on the tested IIT. At present imaging radiometers (linearized video cameras) are available and this task can be done using such imagers.
- General concept of test system presented by MIL standards is basically a collection of laboratory tools from different manufactures placed on a big optical table located in a dark room. Measurements using such equipment are slow due to lack of support of modern software and depressing for humans forced to work many hours in darkness.
- MIL standards propose to use phosphor dependent correction coefficient in measurement of signal to noise ratio (SNR). However, this correction coefficient is defined only for P20 and P43 phosphors. In case of tubes with P20 phosphor the measured SNR is supposed to be divided by 1.19, and in case of tubes with P43 phosphor the measured SNR is supposed to be divided by 1.15.
- There are not published correction coefficients for other phosphors used in IIT technology like: P22, P45 and P30. This lack of precision data for the latter phosphors enables easy manipulation of measurement results of SNR measurements built using these non-standard phosphors because the test team can use any coefficient they want. Further on, because the origin of the K correction coefficient is forgotten in history and not understood, the test teams sometimes use this correction and sometimes not. This means that SNR value can easily and legally manipulated.
- Luminance gain of IITs is determined as a ratio of illuminance at photocathode plane of IIT to luminance of screen of the IIT. MIL standards recommend measurement of screen luminance using rather typical luminance meter of narrow FOV (acceptance angle not bigger than 2°). Distance meter- tube should be regulated until the meter acceptance angle subtends almost complete screen area (17 mm diameter in case of 18 mm tubes, or 24 mm diameter in case of 25 mm tubes).
- The recommendation that the meter should measure output luminance as an average brightness of almost total tube screen looks sound. However, practical implementation of this recommendation can generate significant error of measurement of luminance gain of modern IITs. Thirty years ago (times when most MILs were created) all IITs had flat screens (flat output fibre optics). At present, a majority of IITs is manufactured having curved fibre optics. They are two basic reasons to use such curved fibre tapers. First, it is easier to design aberration-free oculars for curved screen surface than for flat

screen surface. Second, image of phosphor screen generated via curved fibre taper and seen by an ocular is more uniform for curved fibre tapers than in case of flat fibre tapers. Tubes having curved fibre optics, when viewed by ocular of short focal length, look more uniform than tubes with flat fibre output optics. However, this rule is inverted when such a tube is viewed from a longer distance directly by a human eye or by a luminance meter (Fig. 12). In the latter case an image of the outer area looks significantly darker than an image of the centre part, even if brightness of a tube screen is truly uniform. This phenomenon means the luminance meter recommended by MILs (meter of narrow FOV looking on almost whole screen from a distance about 0.5 m) will indicate a lower luminance than a true luminance perceived by observer looking on the screen via ocular of NVD. This error depends on curvature of output fibre optics, acceptance angle of luminance meter, tube non uniformity, and analysed area of screen of tested tube. In case of IITs with a strong curvature (short radius equal to 18 mm) this error can be higher than 20%.

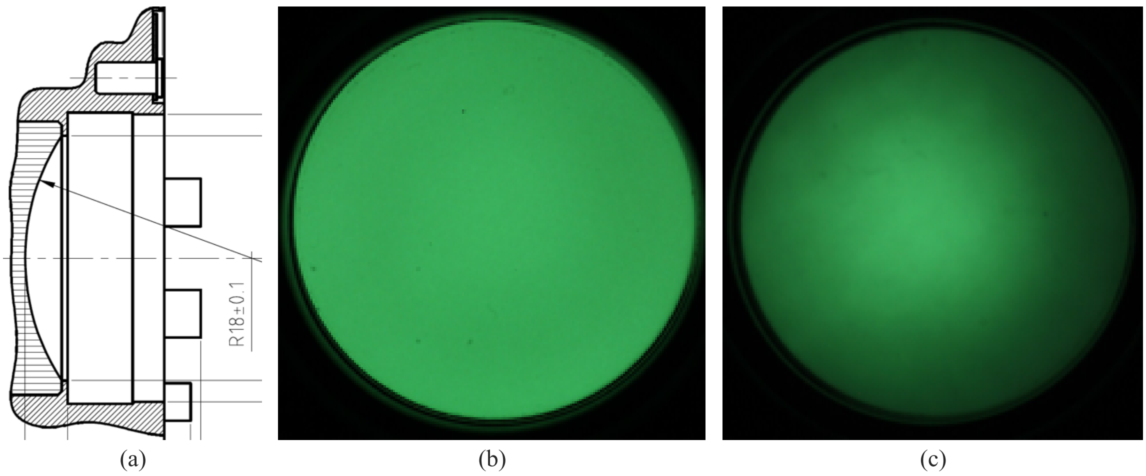
The earlier presented drawbacks of MIL standards that regulate testing of II tubes show clearly that these standards need to be significantly updated. The second conclusion is that manufacturers of test equipment need to make careful analysis of these documents to make important decisions how much to follow MILs and at which points to make technical changes.

8. Calibration of test stations

Test stations for the measurement of parameters of night vision devices/image intensifier tubes are measuring instruments like meters of voltage, pressure, temperature etc. Therefore, it looks apparently logical that these test stations should be calibrated in the same manner as typical meters by different national metrological organizations like NIST in USA, PTB in Germany, NIM in China, KRISS in Korea, etc. However, it should be noted that these national metrological organizations work generally in field of metrology of basic physical quantities like weight, voltage, temperature, etc. They offer a well developed metrology system during last several centuries and these organizations are capable to offer calibration of meters of typical physical quantities with uncertainty below 1%. National metrological organizations, even if working in a field of photometry/radiometry, are typically not capable to carry out calibration/certification of complete tests stations (for example calibration of measurement for luminance gain, resolution of NVDs) due to a lack of reference test stations and know-how in field of night vision metrology. Next, they are usually unwilling to engage more in a field of modern electro-optical metrology arguing that their main task is to maintain system to calibrate SI physical quantities.

Calibration of complete test stations for testing NVDs (and other imaging systems used in defence/security) should be a task of military metrology system that is separate from a typical civilian system. However, this metrology system is still at preliminary stage of development. The most advanced example of this system is Night Vision and Electronic Sensors Directorate (NVESD) capable to carry out reference tests of most of optronic imaging/laser systems and to carry out calibration of test stations. Similar military metrology centres are also in several other countries, but at lower level of development. So far, NVESD is probably the only one organization capable to do calibration of testers of NVDs, but an increase of capabilities of other military metrology centres can be expected. However, it is a slow process as a significant investment in test equipment and in people is needed. Next, cooperation between different military metrology centres is needed to create international military metrology system. Different interest of big national manufacturers can be obstacle for such cooperation.

For reasons mentioned earlier civilian metrological organizations cannot calibrate complete test stations for night vision metrology. At least theoretically, these organizations



(a) (b) (c)

Fig. 12. Screen of near perfect IIT having curved output fibre optics: (a) mechanical drawing (after Ref. 3), (b) photo of curved screen of IIT taken by author using a digital camera located just behind an ocular of NVD, and (c) photo taken using a digital camera looking directly to IIT from distance of 0.5 m.

should be capable to calibrate the photometric tools used in these test stations: luminance meters, light sources of a 2856 K colour temperature, illuminance meters. However, as it is discussed in Sect. 5, there are severe limitations on capabilities of metrological institutes to calibrate photometric tools needed in stations for testing NVDs. This certification situation is less gloomy in case of most technologically advanced countries having well established metrological system like USA, Germany, France, but is not perfect anywhere.

In a situation with lack of direct calibration of photometric tools used in stations for testing NVDs/IITs, the manufacturers use indirect calibration methods developed by themselves using two stage calibration. In the first stage the luminance/illuminance meters (or light sources) are calibrated at high light level by a metrological institute. In the second stage these photometric tools are recalibrated for low light levels using methods developed by the manufacturers. This is a workable solution and generate reasonable results, but direct calibration by metrological institutes would bring better compatibility between test stations from different manufacturers.

It should be noted here that the situation with calibration/certification of a station for testing NVDs/IITs is much worse than in case of such stations for testing thermal imagers. The concept of testing of thermal imagers is based on an idea of using a blackbody of regulated temperature. Calibration of differential blackbodies used in testing thermal imagers is not an easy task due to high requirements on temperature meters (temperature resolution at level of 1 mK) but this task can be done by every national metrological institute in technologically advanced countries.

It may be surprising to readers that so called quality systems (ISO 9000, etc.) widely implemented by many organizations can sometimes increase chaos in night vision metrology. These quality systems are usually implemented by big companies having metrological systems established over a period of many years. When such companies purchase new test equipment they typically expect that new apparatus should generate the same results as the old "certified" apparatus. In a situation when there is no internationally accepted metrological body capable to certify complete equipment for testing NVDs/IITs, the supplier of new test station must typically accept "non-accuracy" claims presented by big purchasers and recalibrate delivered test stations to generate so called "proper" measurement results.

9. Evaluation of measurement errors

MIL standards that regulate testing NVD/IITs do not present any error (uncertainty) analysis that could provide information what accuracy can be expected if we use metrological tools that full-fil requirements on accuracy presented in these standards (Table 1). It is beyond the scope of this paper to carry out accuracy analysis of measurement of parameters of NVDs/IITs. However, rough analysis of accuracy of measurement of brightness gain (calculated as output luminance divided by input illuminance) would suggest that in the worst case scenario the measurement error will be about 30% even if all MIL requirements on accuracy of measuring tools (meters of ±10% accuracy, filter with ±10% non-uniformity, light source with an acceptable ±50 K colour temperature variation) are ful-filled.

Table 1. Requirements of MIL standards on accuracy of modules of test system.

No	Module	Accuracy requirement (or influence)
1	Tungsten light source	2856 ±50 K
2	Neutral filters	Uniform transmittance from 300 nm to 1000 nm within ±10%
3	Opal glass	Not specified (but opal glass can decrease colour temperature of transmitting light by 100 K–200 K)
4	Illuminance meter	±10%
5	Luminance meter	±10%

The high value of potential measurement errors well agree with error analysis presented in literature on testing NVDs/IITs published in former Soviet Union [23,24]. These high measurement errors should be treated as a warning that high accuracy in night vision metrology should not be expected when measuring tools of accuracy described by MILs are used. Better accuracy of measurement of photometric parameters of NVD (or IITs) is possible only if photometric tools of better accuracy are available. However, the latter scenario rarely occurs because it is very difficult to develop photometric tools of accuracy that exceed requirements shown in Table 1.

It should be noted that important photometric parameters of NVDs like brightness gain or parameters of image intensifiers like signal to noise ratio, luminance gain, luminous sensitivity are measured in indirect way. This means that several input parameters are measured first and then the final output parameter is calculated. It is a well-known fact in metrology that accuracy of measurement of indirect parameters is significantly worse that accuracy of parameters measured in a direct way. Therefore, even if accuracy of photometric tools is slightly improved then big gains in accuracy of measurement of photometric parameters of NVDs/IITs should not be expected.

10. Literature on testing NVDs

Testing of NVDs has received much less attention from international scientific community than testing thermal imagers. There are some publications on subject of testing NVDs [46–50] but publications related to thermal imagers metrology are much more numerous. What is even more important, there are no widely disseminated books presenting parameters, test methods, test equipment, evaluation methods needed for testing and evaluation modern NVDs. Such books on subject of thermal imaging metrology [51–53] widely used brought very positive effect by promoting uniform test methodology to be accepted by manufacturers of test equipment and by increasing education level of users of test equipment.

There is a set of several reasons that caused this low interest of scientific community to night vision metrology.

Technology of IITs (crucial module of night vision device) have been developed mostly by big manufacturers of such tubes, not by scientific institutes. The manufacturers have a natural unwillingness to free access publications in contrast of scientific institutes.

Test equipment needed for testing IITs was also developed by tubes manufacturers for their internal use, typically without any scientific publications. Next, test stations for testing IITs offered by independent companies specializing in metrology is a relatively new trend.

Both manufacturers and scientific institutes working in field of night vision metrology are typically connected with military authorities. Special permissions are needed sometimes even to publish more detail data sheets with information how parameters are measured. Such a situation immediately limit numbers of open access publications.

It was predicted many times that night vision technology will demise in near future due to competitions from more modern surveillance imagers like thermal imagers, LLLTV cameras, SWIR imagers. Therefore night vision technology (including night vision metrology) has always been treated by most scientists as rather old, unfashionable technology and few scientists have been interested in night vision technology, and very few – in night vision metrology.

11. Evaluation of night vision devices

NVDs are typically used for surveillance applications; a significant portion of these devices is used in military applications. It is possible to evaluate properly NVDs on the basis of known parameters like resolution, brightness gain, dark spots, etc. However, such evaluation method is suitable for experts; practically not possible for typical military users of NVDs. The latter ones prefer evaluation of NVDs characterized by detection, recognition, identification ranges of some standard targets.

The concept of evaluation of surveillance devices by calculation of effective surveillance ranges is commonly used for evaluation of thermal imagers. There are two NATO standards that regulate evaluation of surveillance thermal imagers [29,55]. The first standard presents a method to calculate detection, recognition, identification ranges of a so called "NATO target" using thermal imagers of known minimal resolvable temperature difference (MRTD) characteristic. The second one presents a method to measure MRTD as the most important parameter of an imager to be evaluated. There are also internationally accepted computer programs that can be used for more accurate calculation of surveillance ranges with thermal imagers [56,57]. Finally, there are computer programs that generate realistically thermal images of some targets and enable easy evaluation of simulated thermal imagers by non-specialists [58].

The situation in evaluation of NVDs is unfortunately much worse. Two NATO standards that presented a detail concept of evaluation of NVDs were published in 1990s [59,60]. The first standard presented a method to measure minimal resolvable contrast (MRC) as the most important parameter. The second standard presented a method to calculate detection, recognition, identification ranges of a so called "NATO target" using the evaluated NVD. The problem is that both two standards were later cancelled for unclear reasons. Therefore, nowadays there is no valid standards that regulate evaluation of tested NVDs. Next, for several decades there have been no internationally accepted computer programs that could enable modelling and later calculation of surveillance ranges with NVDs. Only previous year, Night Vision and Electronic Sensors Directorate (USA) launched a new computer program (Night Vision Integrated Performance Model capable to model performance of a series of different imaging devices including NVDs [56]. This program enables calculation of surveillance ranges using the modelled NVD of a series of targets in different observation conditions. However, NV-IPM model is of limited use for majority of users of NVDs who do not known required detail input data (design parameters of IIT, optical objective, ocular). There is also available a freeware computer simulator [54] that generates images that resemble realistically images generated by simulated IITs. However, significant development is needed to expand capabilities of this program to enable realistic simulation of complete NVDs.

12. Conclusions

There have been presented a rather gloomy picture of present status of night vision metrology: test standards presenting outdated recommendations, data sheets that cannot be trusted, manufacturers of test equipment who do not follow recommendations of the test standards, metrological institutes unable to carry out not only calibration of complete systems for testing NVDs but quite often also calibration of crucial modules of such test systems, little specialist literature on night vision metrology, lack of internationally accepted standards, and lack of computer programs to support evaluation NVDs. It is surprising that this gloomy picture of night vision metrology contrast strongly with a bright picture of night vision technology that have made impressive progress during last several decades and is still quickly improving.

It looks that awareness about this bad situation in night vision metrology is rather low. General public believes in sometimes ridiculous claims of dealers of NVDs/IITs. Military personnel in most countries is often not aware of well documented importance of NVDs for safety of night missions and necessity of regular metrological checks [61]. Situation in USA and several other most technologically advanced co untries is better than average situation described earlier but even there the system of night vision metrology is not perfect and needs significant improvements.

The general progress in night vision metrology is slow. There is some work done by NIST on a development of calibrated receivers that would replace calibrated light sources as standards to be used in night vision metrology [62,63]. There are rumours about plans to start work development of new NATO standard that would regulate evaluation of NVDs. Recently launched Night Vision-Integrated Performance Model enables computer modelling of NVDs and prediction of performance parameters [56]. European Aviation Safety Agency/Federal Aviation Administration published recommendations that emphasized that maintenance of airborne night vision imaging systems is a generic' safety subject [64]. Probably there are also some other projects the author is not aware that could improve situation in night vision metrology. However, reported facts are not major improvements in night vision metrology and such major changes cannot be expected quickly.

Most of leading manufacturers of IITs and NVDs are located in USA and EU. Therefore, it would be natural to expect some efforts from these two blocks to improve situation in night vision metrology. Uniform approach from both USA and EU would be preferable. NATO panels provide an ideal opportunity. However, considering a long history of competition of US manufacturers with EU manufacturers in field of image intensifier tubes such cooperation is unlikely in near future unless both sides are forced to cooperate by competitions from third countries.

New international standards regulating testing NVDs/IITs produced by cooperating US and EU night vision centres would be an ideal solution. However, it is highly probable that well prepared standards would be accepted by international community even if such standards are produced alone in USA, or in EU or in third countries. It is also possible that well prepared recommendations from non-standard documents (books, scientific papers, computer programs) can also be accepted by international community and could start functioning as some kind of semi-standards. The latter situation is clearly possible if we look on situation in thermal imaging metrology where some books or computer programs achieved status of semi-standards. This situation presents an opportunity for scientific world-wide centres to carry out research in the field of night vision metrology and make impact in this field for next several decades.

At the end of this review of the present status of night vision metrology should be noted that this paper presents a vision of present situation from a rather narrow perspective of one of manufacturers of equipment for testing night vision devices. Opinions from other manufacturers and scientific institutes can be different. Therefore, wide discussion and cooperation between different centres engaged in night vision metrology is needed to improve the current situation in night vision metrology.

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