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Cockpit Lighting Compatibility with Image Intensification Night Imaging Systems: Issues and Answers

(Reprint)

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ABSTRACT

Night imaging systems based on image intensification (I^2) tubes are a major factor in the night operation capability of U.S. Army rotary-wing aircraft. A major problem associated with the use of these systems is the detrimental effect caused by internal cockpit lighting. Instrument lamps, caution lamps, utility lights, and other light sources inside the cockpit activate the bright source protection control circuits of the intensification tubes, thereby reducing their sensitivity to external natural and artificial illumination. In 1986, a Tri-Service specification, MIL-L-85762, "Lighting, aircraft, interior, night vision imaging system compatible," was adopted to resolve the cockpit lighting problems. MIL-L-85762 defines the measurement instrumentation and techniques required to certify lighting components as "ANVIS compatible." The specification does not address compatibility problems associated with AN/PVS-5 usage. Ongoing efforts related to MIL-L-85762 include characterization of lighting incompatibilities in current U.S. Army aircraft, implementation of programs to modify the lighting in incompatible cockpits, and certification of proposed lighting components for future aircraft systems. Additional work has been done to provide "near compatible" solutions to lighting problems associated with the use of AN/PVS-5 systems.

1. BACKGROUND

U.S. Army aviation has a doctrine of being able to carry out missions in darkness and adverse weather conditions. To support this doctrine, night vision imaging systems have been introduced into the cockpit. As early as 1971, modified versions of a ground used system, the AN/PVS-5 Night Vision Goggles (NVG), were in use in U.S. Army aircraft. These first systems were a binocular mounting of second generation image intensification (I^2) tubes. Currently a new system, the Aviator's Night Vision Imaging System (ANVIS), is being fielded (Figure 1).

The ANVIS are passive, helmet-mounted, binocular devices that utilize third generation I^2 tubes. These tubes, which have a spectral response from 450 to 930 nanometers (nm), are extremely sensitive to radiation in the 600 to 900 nm portion of the electromagnetic spectrum (orange to near infrared). ANVIS operate by converting photons from an external scene into electrons using a Gallium-Arsenide photocathode, amplifying these electrons with a microchannel plate, and converting them back into visible light as they impinge upon a phosphor screen.

Because ANVIS amplify the intensity of light sources approximately 2000 times, bright lights emitting energy in that portion of the electromagnetic spectrum in which the ANVIS are sensitive produce severe veiling glare that can obscure the overall image.[1] To prevent this, and to protect the image intensifier assembly from permanent phosphor burns, ANVIS are equipped with a bright source protection (BSP) circuit, which operates as an automatic gain control. The BSP circuit decreases the sensitivity of the image intensifier tubes when they are exposed to bright lights emitting energy in the ANVIS-sensitive portion of the electromagnetic spectrum.

A more subtle problem develops when the ANVIS are exposed to light sources located inside the cockpit. Whenever these sources emit energy in the ANVIS-sensitive region, the ANVIS BSP is activated, reducing ANVIS response to energy originating from the external scene. The net result is a reduced capability to view outside the cockpit, a result often unnoticed by the aviator.

An analogous problem has and does exist for the AN/PVS-5s. When first introduced, the AN/PVS-5s required the interior cockpit lighting level to be greatly reduced. Numerous methods, i.e., low-reflectance black paint, light louvers, filters, low intensity lamps, etc., have been attempted to provide "compatible" cockpits.[2] Only limited success was achieved using any of these methods.

Therefore, when the ANVIS were designed, this problem was a major consideration. One solution was to coat the interior surface of the objective lenses in the ANVIS with a dielectric film (called a "minus-blue filter") that would reject wavelengths less than 625 nm. This design was planned to make the ANVIS compatible with cockpits having blue-green crewstation lighting. However, programs to convert current aircraft to blue-green lighting have not been fully implemented due to technical and budgetary constraints.

In 1983, after years of compatibility problems with the AN/PVS-5 and the potential ANVIS problems, a Joint Aeronautical Commanders Tri-Service Committee was established. Its goal was to develop a military specification for ensuring future ANVIS compatibility. The result was MIL-L-85762, "Lighting, aircraft, interior, night vision imaging system compatible." This specification defines acceptable parameters for compatible lighting components. It also details instrumentation and methodology requirements for validating these components.

2. MILITARY SPECIFICATION MIL-L-85762

This military specification must be applied to all modes and types of interior aircraft lighting, from components to systems, which will contribute to any environment where third generation I^2 tubes are to be used.[3] It defines performance, testing, and acceptance requirements for the purpose of ensuring standardized aircraft ANVIS compatibility.

The instrumentation required to verify ANVIS *compatibility* consists of a spectroradiometer, a photometer, and a reflectance standard. The instrumentation must meet certain specifications for accuracy and sensitivity. For the spectroradiometer these specifications include radiance sensitivity and accuracy, wavelength accuracy and repeatability, current resolution, zero drift, linearity, and stray light.

The spectroradiometer is used to make spectral radiance and chromaticity measurements. As a complete system, the spectroradiometer must provide the capability to measure the radiance levels at a half-power band width of 10 nm and a signal to root-mean-square noise ratio of 10 to 1. These levels are: 1.0E-10 W/cm^2-sr-nm over 380-600 nm, 1.0E-11 W/cm^2-sr-nm over 600-900 nm, and 1.0E-10 W/cm^2-sr-nm over 900-930 nm. A sensitivity calibration must be performed within 6 months prior to taking a measurement. A wavelength accuracy of 1 nm is required.

The procedures for qualifying a lighting subsystem in accordance with MIL-L-85762 include, but are not limited to, unaided eye inspection, examination with ANVIS, human engineering inspection, luminance uniformity check, reflection examination, electromagnetic interference tests, and luminance, chromaticity, and spectral radiance measurements. An aircrew station mockup can be required for most of the tests. However, the spectral radiance, luminance, and chromaticity measurements are usually made in a laboratory setting (usually with a scaled down mockup instrument panel).

Spectral radiance data are measured in 5 nm steps over the spectral range of 380 to 930 nm. Measurements are taken with the lighting component luminance set by the rated drive condition or at 15.0 footlamberts, whichever is less. A luminance scaling factor (S) is calculated using the ratio of the specified test luminance (cited in MIL-L-85762) to the actual measured test luminance. For most lighting subsystems, the specified test luminance is 0.1 footlamberts.

Once the spectral radiance is measured, it is used to calculate a value called "ANVIS radiance." This value is defined as,

$$\text{ANVIS radiance} = SG(\lambda)_{max} \int_{450}^{930} G(\lambda)N(\lambda)d\lambda \qquad \text{(Equation 1)}$$

Where,

S	= scaling factor
$G(\lambda)_{max}$	= 1 mA/W
$N(\lambda)$	= spectral radiance of lighting component (W/cm^2-sr-nm)
$G(\lambda)$	= relative ANVIS response
$d\lambda$	= 5 nm

The maximum allowed ANVIS radiance value for most lighting subsystems, when calculated using Equation 1, is 1.7E-10. This value is derived from the application of Equation 1 to a selected target considered to be operationally significant and possessing low visibility, that of a defoliated tree illuminated by starlight.[4]

The luminance measurement may be made using the spectroradiometer or a photometer meeting the required specifications. When using the spectroradiometer, the luminance is calculated as follows:

$$L = 929\pi K(\lambda)_{max} \int_{380}^{780} K(\lambda)N(\lambda)d\lambda \qquad \text{(Equation 2)}$$

Where,

L	= luminance (footlamberts)
$K(\lambda)$	= normalized visual efficiency curve for 1931 CIE standard observer
$K(\lambda)_{max}$	= 683 lumens/watt
$N(\lambda)$	= spectral radiance of lighting component (W/cm^2-sr-nm)
$d\lambda$	= 5 nm

The calculated, or measured, luminance value is used to define the scaling factor required in Equation 1 for the calculation of ANVIS radiance.

Chromaticity coordinates also are calculated from the spectral radiance data using the 1931 Commission Internationale de l'Eclairage (CIE) and 1976 Uniform Color Scale (UCS) theories.[5] The measured UCS coordinates (u', v') for general crewstation lighting are required to lie within a color circle, referred to as "Green ANVIS A," and defined as,

$$(u' - u_1')^2 + (v' - v_1')^2 <= (r)^2, \qquad \text{(Equation 3)}$$

where $u_1' = 0.088$ and $v_1' = 0.543$ define the center, and $r = 0.037$ defines the radius of the circle (Figure 2).

3. SEARCHING FOR COMPATIBLE COMPONENTS

Three different projects relating to testing and evaluation for ANVIS lighting compatibility currently are in progress. Two of the projects, involving panel lamps and supplemental pilot lighting aids, require strict compliance with MIL-L-85762. The third project, involving ANVIS compatible flashlight filters, falls into an area which currently is not addressed in the specification. Representative components are shown in Figure 3.

Panel lamps

With an ANVIS compatible cockpit as a goal, the U.S. Army is attempting to redesign cockpit instruments which incorporate light sources or, where possible, replace current lamps with ones which meet MIL-L-85762. The replacement lamps tend to be tungsten filaments surrounded by a filter material. To obtain a compatible lamp, the filter material must severely reduce the spectral radiance of the filament for wavelengths beyond 600 nm. The filter also must produce a final lamp assembly whose chromaticity coordinates meet MIL-L-85762 requirements.

Several panel lamp assembly designs have been evaluated and found to meet the MIL-L-85762 requirements. A typical spectral radiance curve representing the lamp assemblies tested is provided in Figure 4. These data multiplied by the ANVIS response curve are shown in Figure 5. The average ANVIS radiance value of these lamp assemblies is 1.1E-10, meeting the requirement of a maximum allowable value of 1.7E-10. The chromaticity coordinates are also within specification.

Only one problem seems to exist for the various lamp assemblies tested and found to meet MIL-L-85762 requirements. The differences in design and choice of filtering material have produced lamp assemblies which provide a wide range of luminance values for a given operating voltage. Since numerous instruments often operate from a single power bus, mixing lamps from different manufacturers may result in the inability to balance the lumminance across the overall instrument panel.

Supplemental lighting

One result of the various lighting modifications implemented to achieve ANVIS cockpit compatibility is a reduction in the overall level of illumination in the cockpit. This has created the need for supplemental lighting devices, referred to as pilot lighting aids (PLAs). These devices will give crewmembers the capability to selectively illuminate certain instruments or recessed areas of the aircraft.

Two classes of lighting aids are being considered: lip lights and finger lights. Lip lights are lip-activated, microphone-mounted devices using light emitting diodes (LEDs) as the light source. Finger lights use a similar concept, but are worn about the aviator's gloved finger.

In addition to meeting the radiance and chromaticity specifications of MIL-L-85762, these lighting aids must satisfy certain other requirements. While most of these additional requirements involve health hazard and human factors issues, there is one which further constrains the characteristics of the actual lighting source. This constraint is that 95 percent of the source's energy output must be confined within the spectral range of 400-600 nm.

None of the PLA designs submitted for evaluation met all of the stated requirements. Representative spectral radiance and "ANVIS weighted" curves are provided in Figures 6 and 7, respectively. All of the samples tested failed to meet the MIL-L-85762 requirements for ANVIS radiance (typical measured value of 2.5E-09) and chromaticity. In addition, all of the designs suffered from inadequate human factors engineering, mostly associated with the location and operation of the switches.

Flashlight filters

An important task for the aviator, both prior to and during flight, is navigation. This function requires the reading of color-coded maps. It has been determined a need exists to develop flashlight filters, compatible with current U.S. Army flashlights, which will provide this capability, but not severely degrade ANVIS operation.

MIl-L-85762 does not cover the compatibility requirements for such filters. In addition, the nature of the function of the flashlight and filter, i.e., map reading, necessitates special requirements which conflict with those of the lighting components addressed in the military specification. The Naval Air Development Center, Warminster, Pennsylvania, in coordination with various U.S. Army agencies, has developed a set of proposed requirements for these filters. The requirements specify allowable values for ANVIS radiance, chromaticity, and photopic transmittance.

The spectral transmittance of a proposed ANVIS compatible flashlight filter is measured using the equipment and techniques defined in the MIL-L-85762. This transmittance function then is mathematically multiplied by a 2100 degrees Kelvin black body curve. The resulting data are analyzed for chromaticity, ANVIS radiance (when scaled to

0.1 footlambert), and photopic transmittance. The chromaticity of the filter, expressed in the UCS system of coordinates, must be within the area bounded by a circle with a center point of u' = 0.180, v' = 0.500 and radius of r = 0.055. The photopic transmittance must be at least 10 percent at 2100 degrees Kelvin and the ANVIS radiance, when scaled to 0.1 footlambert, must not exceed 1E-09. The differences between the requirements for the filter/flashlight combination and the lighting sources covered by MIL-L-85762 are a result of the necessity of providing light with a broader spectral content to provide the capability of color discrimination with the maps.

Fifteen different filter types have been tested. These filters were all off-the-shelf items originally designed for other applications. While no single filter type met all of the requirements, most of the filters did meet those of photopic transmittance and ANVIS radiance. Only four of the filter types met the chromaticity requirement. A curve representing the spectral transmittance of one filter type meeting the ANVIS radiance requirement is provided in Figure 8. For this particular filter, the measured ANVIS radiance value was 5.8E-10.

Adjusting the chromaticity of one or more of the filters which met the ANVIS radiance and photopic transmittance specifications should result in filters which will provide the capability of map reading while maintaining an acceptable level of ANVIS compatibility.

4. SUMMARY

The operational performance of the U.S. Army's Aviator's Night Vision Imaging System (ANVIS) is degraded by certain instrument lamps and other light sources used within the cockpit. Using a military specification developed to ensure ANVIS lighting compatibility (MIL-L-85762), proposed replacement instrument lamps and an array of supplemental pilot lighting aids have been evaluated for their compatibility with ANVIS.

5. ACKNOWLEDGMENTS

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Special note: This paper addresses lighting compatibility issues associated with U.S. Army use of the Aviator's Night Vision Imaging System (ANVIS), which uses a 625 nm cutoff filter. Lighting components and subsystems intended for use with ANVIS are designated as "Class A" components and subsystems. An alternate classification is used for components and subsystems intended for Night Vision Imaging Systems using a 665 nm cutoff filter. This classification is addressed in a revised version of the military specification (MIL-L-85762A).

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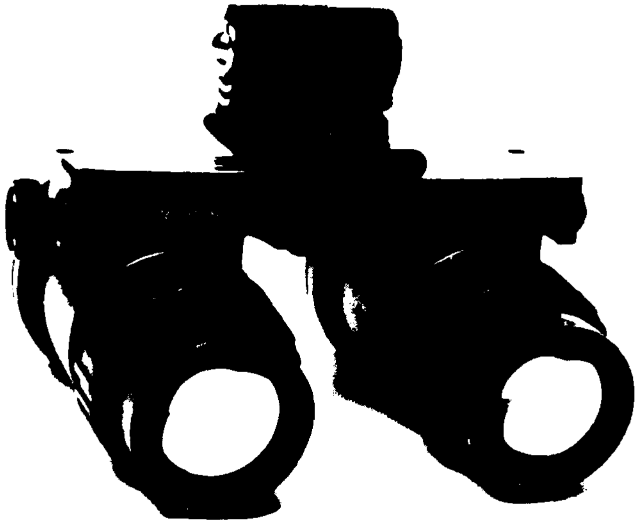

Figure 1. The Aviator's Night Vision Imaging System (ANVIS).

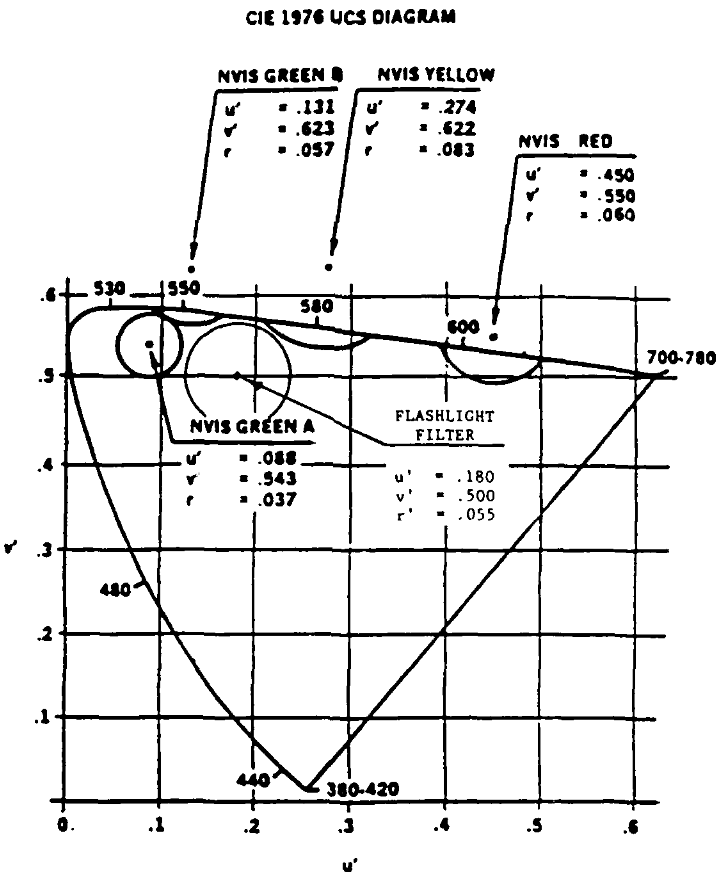

Figure 2. 1976 Uniform Color Scale diagram showing allowable color circle for ANVIS Green A lighting components.

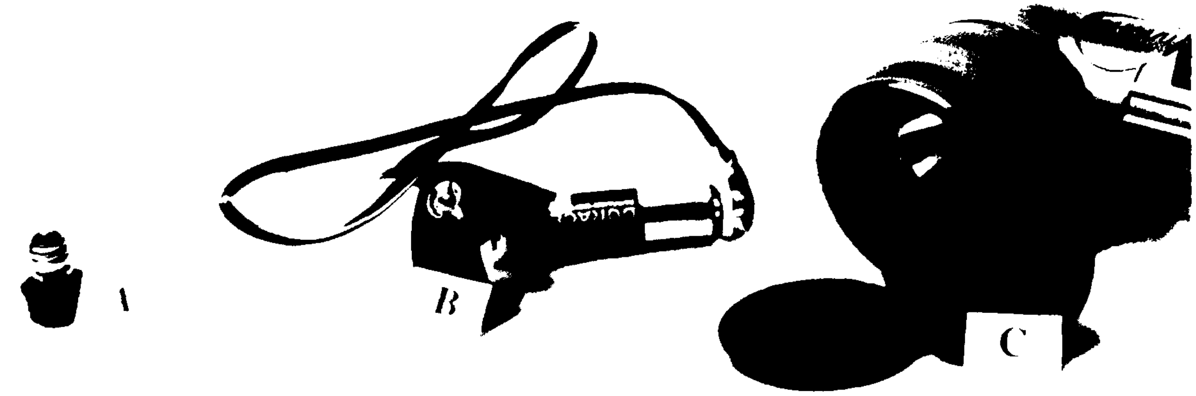

Figure 3. Samples of (a) panel lamps, (b) pilot lighting aids, and (c) flashlight filters under test for MIL-L-85762 compatibility.

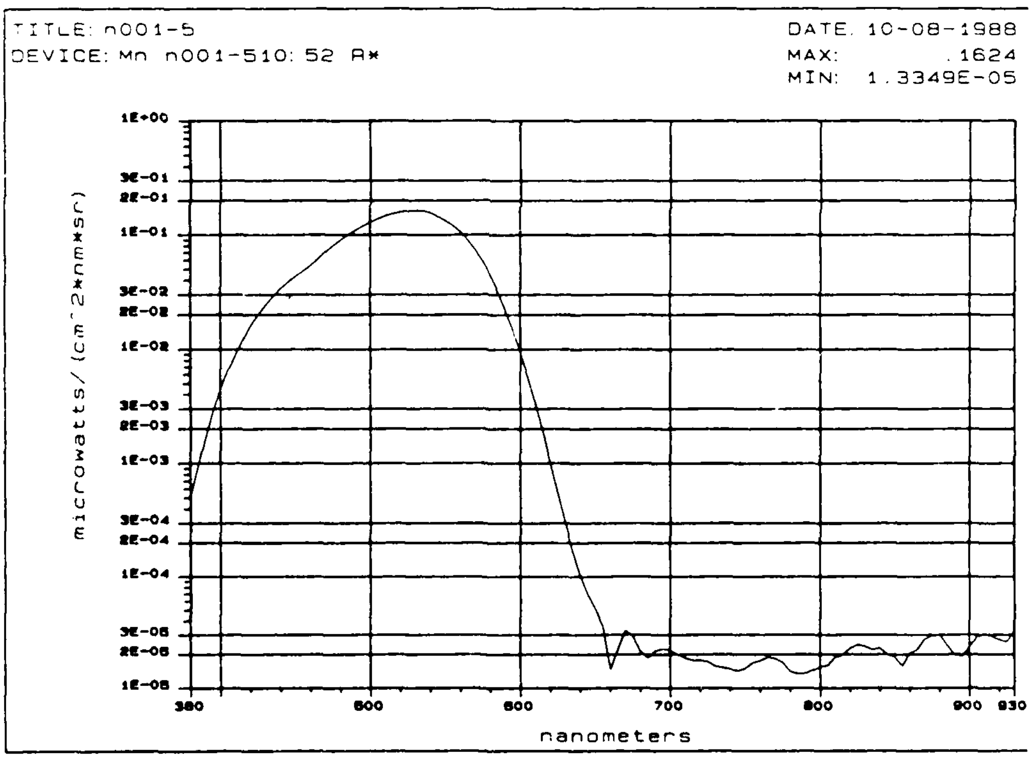

Figure 4. Spectral radiance curve for representative MIL-L-85762 compatible lamp.

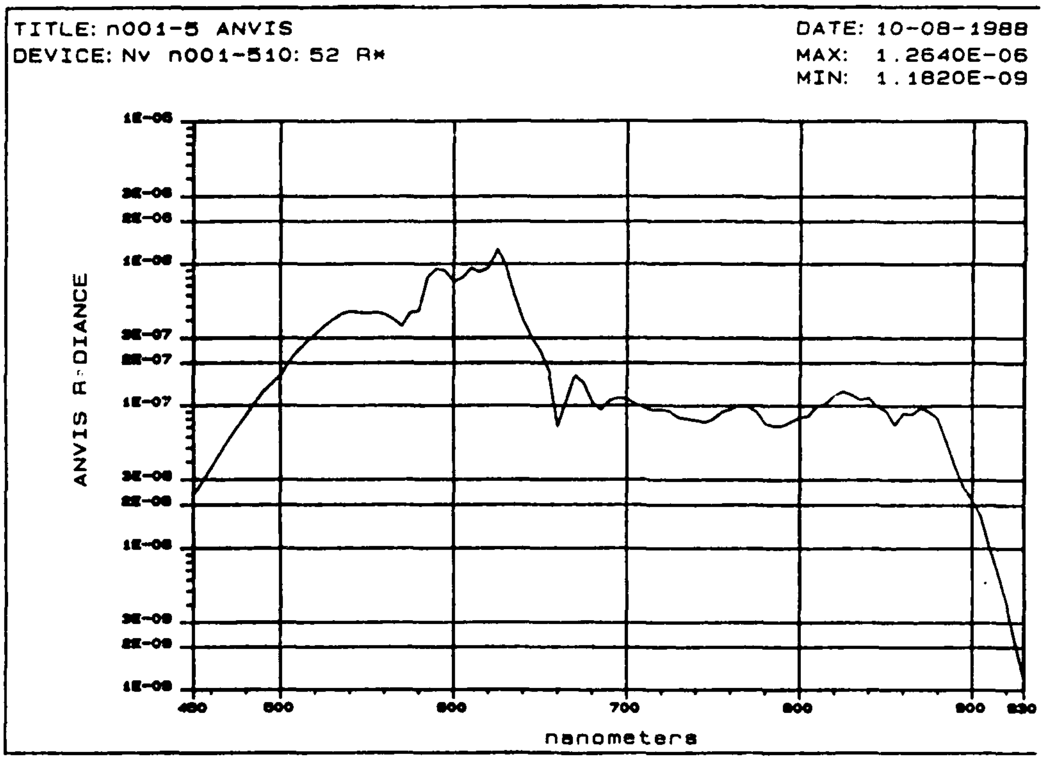

Figure 5. Spectral radiance data multiplied by ANVIS response for representative MIL-L-85762 compatible lamp.

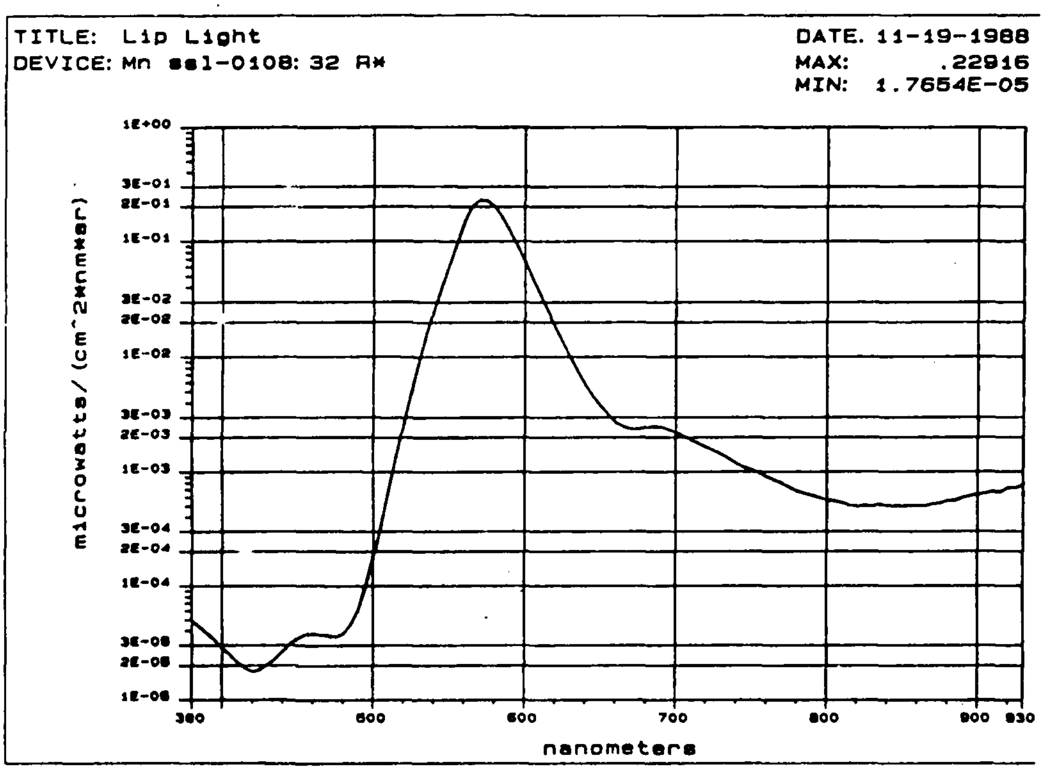

Figure 6. Spectral radiance curve for representative pilot lighting aid (PLA).

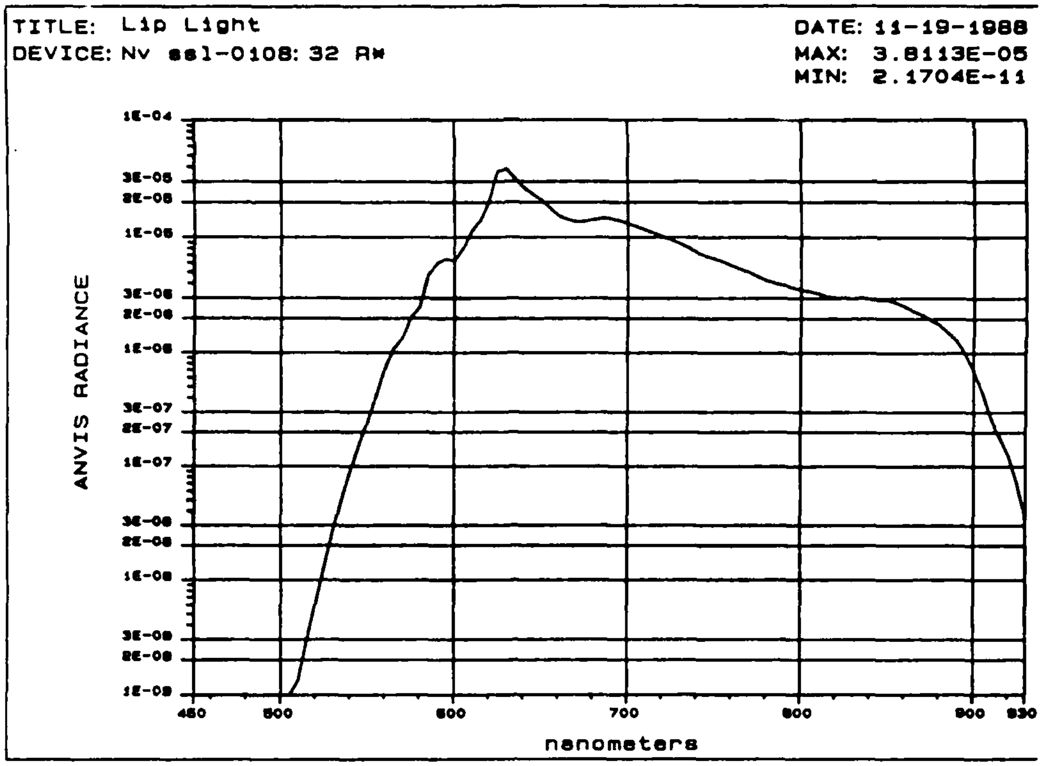

Figure 7. Spectral radiance data multiplied by ANVIS response for representative pilot lighting aid.

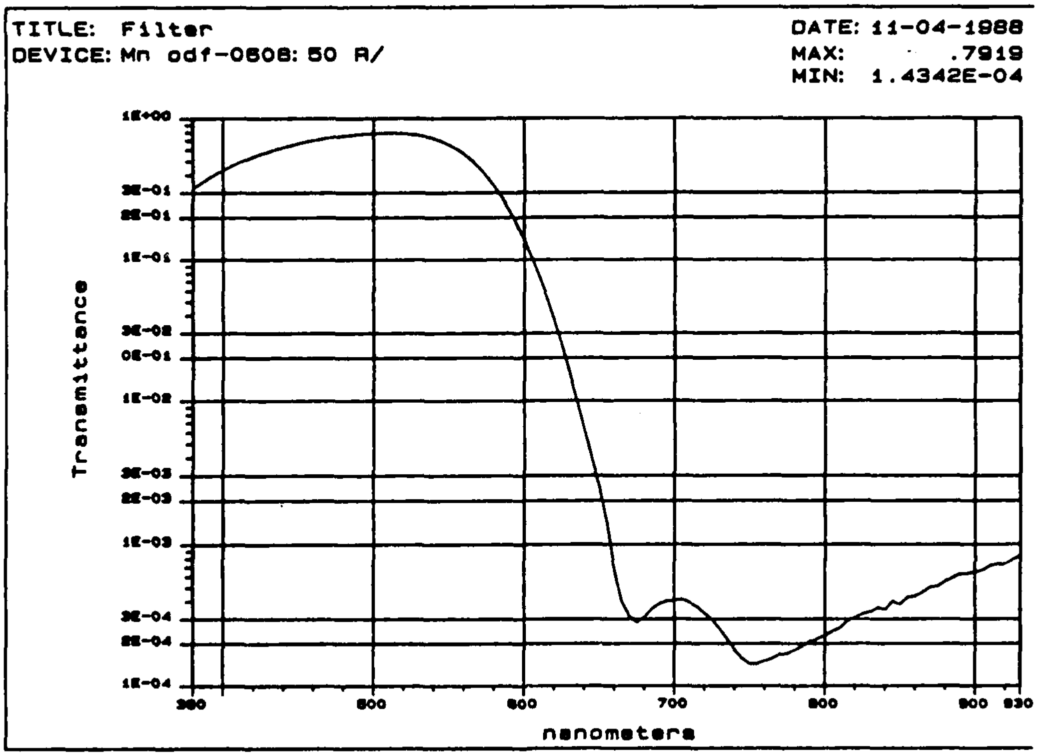

Figure 8. Spectral transmittance curve for a flashlight filter meeting the ANVIS radiance requirement.

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