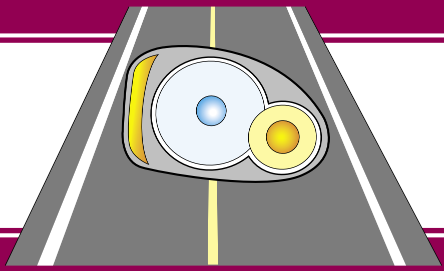


Volume XVII

Enhanced Night Visibility Series: Phases II and III–Characterization of Experimental Vision Enhancement Systems

PUBLICATION NO. FHWA-HRT-04-148
DECEMBER 2005

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

The overall goal of the Federal Highway Administration's (FHWA) Visibility Research Program is to enhance the safety of road users through near-term improvements of the visibility on and along the roadway. The program also promotes the advancement of new practices and technologies to improve visibility on a cost-effective basis.

The following document provides a characterization of vision enhancement systems used in the evaluation of the performance of drivers during nighttime driving in the Enhanced Night Visibility (ENV) project. These systems include halogen and high-intensity discharge headlamps, UV–A emitters used to augment the headlamps, and in-vehicle sensors for near-infrared emitters and far-infrared detectors. The ENV project provides a comprehensive evaluation of evolving and proposed headlamp technologies. The individual studies within the overall project are documented in an 18-volume series of FHWA reports, of which this is Volume XVII. It is anticipated that the reader will select those volumes that provide information of specific interest.

This report will be of interest to headlamp designers, automobile manufacturers and consumers, third-party headlamp manufacturers, human factors engineers, and people involved in headlamp and roadway specifications.

Michael F. Trentacoste
Director, Office of Safety
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-HRT-04-148		
4. Title and Subtitle Enhanced Night Visibility Series, Volume XVII: Phases II and III—Characterization of Experimental Vision Enhancement Systems		5. Report Date December 2005 6. Performing Organization Code:
7. Author(s) Ronald B. Gibbons, Clay Moulton		8. Performing Organization Report No.
9. Performing Organization Name and Address Virginia Tech Transportation Institute 3500 Transportation Research Plaza Blacksburg, VA 24061		10. Work Unit No. 11. Contract or Grant No. DTFH61-98-C-00049
12. Sponsoring Agency Name and Address Office of Safety Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code HRDS-05
15. Supplementary Notes Contracting Officer's Technical Representative (COTR): Carl Andersen, HRDS-05		

16. Abstract

This report is a summary of the photometric characterization of the headlamps that were included in the vision enhancement systems used for the Enhanced Night Visibility (ENV) project. Each of the visible light and ultraviolet sources used for the visibility studies have been photometrically characterized and documented in this report. The report also contains a discussion of the headlamp aiming method.

17. Key Words	18. Distribution Statement
Halogen, Headlamp, HID, Photometry, Ultraviolet	No restrictions. This document is available through the National Technical Information Service; Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	75	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

ENHANCED NIGHT VISIBILITY PROJECT REPORT SERIES

This volume is the 17th of 18 volumes in this research report series. Each volume is a different study or summary, and any reference to a report volume in this series will be referenced in the text as "ENV Volume I," "ENV Volume II," and so forth. A list of the report volumes follows:

Volume	Title	Report Number
I	Enhanced Night Visibility Series: Executive Summary	FHWA-HRT-04-132
II	Enhanced Night Visibility Series: Overview of Phase I and Development of Phase II Experimental Plan	FHWA-HRT-04-133
III	Enhanced Night Visibility Series: Phase II—Study 1: Visual Performance During Nighttime Driving in Clear Weather	FHWA-HRT-04-134
IV	Enhanced Night Visibility Series: Phase II—Study 2: Visual Performance During Nighttime Driving in Rain	FHWA-HRT-04-135
V	Enhanced Night Visibility Series: Phase II—Study 3: Visual Performance During Nighttime Driving in Snow	FHWA-HRT-04-136
VI	Enhanced Night Visibility Series: Phase II—Study 4: Visual Performance During Nighttime Driving in Fog	FHWA-HRT-04-137
VII	Enhanced Night Visibility Series: Phase II—Study 5: Evaluation of Discomfort Glare During Nighttime Driving in Clear Weather	FHWA-HRT-04-138
VIII	Enhanced Night Visibility Series: Phase II—Study 6: Detection of Pavement Markings During Nighttime Driving in Clear Weather	FHWA-HRT-04-139
IX	Enhanced Night Visibility Series: Phase II—Characterization of Experimental Objects	FHWA-HRT-04-140
X	Enhanced Night Visibility Series: Phase II—Visual Performance Simulation Software for Objects and Traffic Control Devices	FHWA-HRT-04-141
XI	Enhanced Night Visibility Series: Phase II—Cost-Benefit Analysis	FHWA-HRT-04-142
XII	Enhanced Night Visibility Series: Overview of Phase II and Development of Phase III Experimental Plan	FHWA-HRT-04-143
XIII	Enhanced Night Visibility Series: Phase III—Study 1: Comparison of Near Infrared, Far Infrared, High Intensity Discharge, and Halogen Headlamps on Object Detection in Nighttime Clear Weather	FHWA-HRT-04-144
XIV	Enhanced Night Visibility Series: Phase III—Study 2: Comparison of Near Infrared, Far Infrared, and Halogen Headlamps on Object Detection in Nighttime Rain	FHWA-HRT-04-145
XV	Enhanced Night Visibility Series: Phase III—Study 3: Influence of Beam Characteristics on Discomfort and Disability Glare	FHWA-HRT-04-146
XVI	Enhanced Night Visibility Series: Phase III—Characterization of Experimental Objects	FHWA-HRT-04-147
XVII	Enhanced Night Visibility Series: Phases II and III—Characterization of Experimental Vision Enhancement Systems	FHWA-HRT-04-148
XVIII	Enhanced Night Visibility Series: Overview of Phase III	FHWA-HRT-04-149

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

General Terms

ENV ....Enhanced Night Visibility
FMVSS ....Federal Motor Vehicle Safety Standards
OCH ....optical center height
OEM..................................original equipment manufacturer
SAE ....Society of Automotive Engineers
SD ....standard deviation
SPD ....spectral power distribution
UV–A ....ultraviolet A (wavelength 315 to 400 nanometers)
VES ....vision enhancement system
VOA ....visually optically aligned
VOR ....visually optically aligned right
VOL ....visually optically aligned left

Vision Enhancement Systems

HLB...................................halogen (i.e., tungsten-halogen) low beam
hybrid UV–A + HLB ....hybrid UV–A/visible output together with halogen low beam
three UV–A + HLB...........three UV–A headlamps together with halogen low beam
five UV–A + HLB ....five UV–A headlamps together with halogen low beam
HLB–LP............................halogen low beam at a lower profile
HHB ....halogen high beam
HOH..................................high output halogen
HID ....high intensity discharge
hybrid UV–A + HID ....hybrid UV–A/visible output together with high intensity discharge
three UV–A + HID ....three UV–A headlamps together with high intensity discharge
five UV–A + HID ....five UV–A headlamps together with high intensity discharge
NIR....................................near infrared vision system
FIR ....far infrared vision system

Measurements

cd.......................................candela
cm......................................centimeter
ft ....feet
h...hours
km/h ....kilometers per hour
lm ....lumens
lx ....lux
m ....meters
mi/h ....miles per hour
nm ....nanometers
sr..steradian
W.......................................Watts

Visible Light and Radiant Formulas

θ..angle of observation
λ..wavelength
Φ..flux
ω..solid angle
A ....area of the surface
E ....illuminance
I ....intensity
k..maximum spectral luminous efficacy in lumens per Watt
L ....luminance
$P(\lambda)$ ....spectral power distribution from source
$V(\lambda)$ ....human visual spectral response

CHAPTER 1—INTRODUCTION

The purpose of this document is to provide an archive of data about the vision enhancement systems (VESs) used during the Enhanced Night Visibility (ENV) project. All of the data collected about the photometric, radiometric, and spectral aspects of the headlamps are cataloged in this document; however, while information on the headlamps associated with the experimental infrared systems is presented, data on the infrared systems themselves are not included in this volume. A more indepth look at the technical specifications of the infrared systems is found in ENV Volume XIII, *Comparison of Near Infrared, Far Infrared, High Intensity Discharge, and Halogen Headlamps on Object Detection in Nighttime Clear Weather*.

BACKGROUND

The Enhanced Night Visibility project tested and compared 12 different VESs for their ability to provide object visibility to drivers. Twelve different headlamp types were used on eight experimental vehicles or rack systems to provide different visibility conditions during the Enhanced Night Visibility project. This volume characterizes all of these headlamps, with the exception of the infrared systems.

To fully characterize the output of the VESs used in the Enhanced Night Visibility project, two aspects of the individual headlamp systems were tested: spectral and radiant emissivity. The following paragraphs give more detail on the characterization procedure along with definitions to clarify the discussion.

Definitions and Nomenclature

Most of the definitions used in this project are adapted from the Illuminating Engineering Society of North America Handbook (2000).[(1)] Following is a list of definitions and formulas used in the analysis of headlamps in this project:

- *Light and radiant energy.* Radiant energy travels in electromagnetic waves. Light is electromagnetic radiation that is perceptible to the human eye. The human visual spectral response function, $V(\lambda)$, is used to weight the radiant energy from a source to its human perceptual response. Because the ENV project deals with sources that provide both visible and nonvisible radiation, the spectral distribution (energy per unit wavelength) of the lamp must be characterized with photometric (associated with visible light) and radiometric (associated with radiant energy) measurements.

- *Spectral power distribution.* The spectral power distribution (SPD), denoted as $P(\lambda)$, of a light source is the energy output per unit wavelength. It is measured using a spectroradiometer, which separates the broadband radiation emitted from a source into discrete wavelength intervals. The radiant energy from the source is measured in radiant Watts (W) for each interval. The width of the wavelength interval is usually fixed in nanometers (nm). This series of measurements is referred to as the spectral characterization. For visible light sources, the measurement is usually made through the visual range of the electromagnetic spectrum (380 to 800 nm). For ultraviolet sources, the measurement may include a range from the visible spectrum down to 100 nm. Ultraviolet A (UV–A), however, is defined as the region from 315 to 400 nm.

- *Headlamp or luminaire.* This term generally refers to the source of electromagnetic radiation (lamp), all means of optical control (reflectors and lenses), electrical control (wiring, terminals, and ballasts, as necessary) and the housing containing all of the components.

- *Lamp.* The lamp is the light- or radiation-generating source in the system. Typically, the lamp is small and removable to facilitate replacement of a failed lamp.

- *Lens.* The lens is the clear portion of the system that all of the light passes through. The lens typically provides primary control of the beam pattern of the emitted radiation from the luminaire. Headlamps use prismatic light control surface treatments, or lenticles, in the lens face to control the direction of the light or radiation emission.

- *Reflector.* The reflector is the surface behind the lens that redirects the radiation from the lamp through the lens, helping to control direction of the radiation. The reflector is usually highly polished.

- *Optics.* The optics system is defined as the combination of the lens and the reflector and possibly baffles. The term refers to all parts of the luminaire that control the radiation or light output.

- *Housing.* The housing is the shell around the lamp and the optics, providing protection for the system. This is typically a plastic assembly encompassing both the lens and the reflector and includes a mounting base.

- *Measurement units.* The definitions of the measurement units used in this report are found in figure 1 through figure 5. Photometric and radiometric terms are defined. In the formulas, Φ = radiant or luminous flux from a source, ω = solid angle, θ = angle of observation, A = area of a surface that reflects or emits electromagnetic radiation, $P(\lambda)$ = SPD of a source, $V(\lambda)$ = human visual spectral response function, λ = wavelength, I = radiant or luminous intensity, E = irradiance or illuminance, L = radiance or luminance, and k = maximum spectral luminous efficacy in lumens per Watt.

- *Radiant flux.* Figure 1 provides the equation to calculate the total radiant flux, in Watts , from a source:

$$\Phi = \int P(\lambda) d\lambda$$

Figure 1. Equation. Radiant flux.

- *Luminous flux.* The luminous flux, measured in lumens (lm), is the radiant flux of a source evaluated in terms of the human visual response. The coefficient k, the maximum spectral luminous efficacy, provides for conversion from Watts to lumens. For photopic vision, k is defined as having a value of 683 lm/W. Figure 2 provides the equation to calculate luminous flux:

$$\Phi = k \int P(\lambda) V(\lambda) d\lambda$$

Figure 2. Equation. Luminous flux.

- *Radiant and luminous intensity.* The intensity of a source is the flux per unit solid angle, propagated in a given direction. Figure 3 provides the equation to calculate the radiant or luminous intensity, as appropriate. For radiant intensity, the unit is Watts per steradian (W/sr), while luminous intensity is measured in candela (cd). One cd is equal to one lumen per steradian.

$$I = \frac{d\Phi}{d\omega}$$

Figure 3. Equation. Radiant or luminous intensity.

- *Irradiance and illuminance.* The density of the flux falling on a surface is defined as the irradiance or the illuminance. Figure 4 provides the equation to calculate the irradiance or illuminance, as appropriate. For irradiance, the unit is Watts per square meter (W/m^2). The unit of illuminance is the lux (lx), which is equal to one lumen per square meter.

$$E = \frac{d\Phi}{dA}$$

Figure 4. Equation. Irradiance or illuminance.

- *Radiance and luminance.* The flux reflected or emitted from a surface or through a projected area that is propagated in a given direction per unit solid angle is defined as the radiance or luminance of the area. Figure 5 provides the equation to calculate the radiance or luminance, as appropriate. The unit of radiance is Watts per steradian square meter ($W/sr\ m^2$), while the unit of luminance is candela per square meter (cd/m^2).

$$L = \frac{d^2\Phi}{d\omega dA \cos\theta}$$

Figure 5. Equation. Radiance and luminance.

- *Intensity profile.* The radiant or luminous intensity from a source is a measure of the directional aspects of the emitted radiation. The measurement of the intensity profile of a source is referred to as the spatial characterization of the source. The spatial characterization is performed using a goniometer and either a radiometer or photometer, as appropriate. The goniometer positions the source relative to the photometer or radiometer so that the flux emitted in a given direction or series of directions may be measured. The results are usually tabulated by horizontal and vertical angles relative to a defined orientation and then plotted.

Two plots that are often generated from luminous intensity data are the isocandela and isoilluminance plots. Isocandela plots show areas of common luminous intensity through an imaginary plane in front of the measured source. An isoilluminance plot is generated by placing the source (theoretically or in actual practice) at some position and orientation relative to a surface and illustrating the areas of equal illuminance provided by the source onto the surface.

Because the ENV project used VESs that emitted both visible light and UV–A radiation, combining a goniometer with a spectroradiometer provided measurement of the full range of spectral distribution at each measurement angle. This permitted generation of both radiant and luminous spatial characterizations from one data set.

Note that the combination of a goniometer with a photometer is often identified as a goniophotometer. The term goniophotometer is used in this document to identify a system dedicated to the measurement of a luminous intensity profile.

RESEARCH OBJECTIVES

The purpose of this volume of the ENV report is to define the performance of the various headlamps used to create the vision enhancement systems tested as part of the ENV studies. This volume provides a reference point for all the other volumes in the ENV series.

CHAPTER 2—METHODS

The characterization of the headlamps was performed in two efforts. The visible systems were measured with the assistance of a major automotive manufacturer at its photometry range. The ultraviolet systems were measured in cooperation with the University of Iowa at a corporate photometer range in St. Paul, MN. The testing was completed in multiple visits over several months.

APPARATUS

The VESs characterized included the following types of headlamps:

- Halogen (i.e., tungsten-halogen) low beam (HLB).
- Halogen high beam (HHB).
- High output halogen (HOH).
- High intensity discharge (HID).
- Ultraviolet A headlamps (UV–A).
- Hybrid UV–A with visible output (hybrid UV–A).

The apparatus for the visible light measurements is a turnkey goniophotometer that is owned by a major automotive manufacturer. The goniophotometer is designed to provide luminous intensity measurements using test methods that meet the requirements of recommendations J602, J575, and J1330 of the Society of Automotive Engineers (SAE).[2,3,4]

The primary apparatus used for the measurements made by the University of Iowa is a goniometer and a double monochromator. These instruments were used in concert to perform both a spectral (wavelength-by-wavelength) and spatial (differing-projection-angles) analysis of the various sources.

The goniometer consists of a large, flat plate that can be rotated in four axes of freedom. The headlamp was mounted on the front surface of the plate using the same mounting hardware as that used on the vehicles. Alignment of the headlamp was performed using both the angular freedom in the goniometer and the alignment capabilities of the headlamp itself. The automated control of the goniometer was then used to adjust the angle of view from the detector to the headlamp system. The detector for the system was either an illuminance meter or the double monochromator. These two detectors were located 15 m (approximately 49 ft) from the headlamps, and they could be swapped for different portions of the testing.

The double monochromator was used to establish the spectral characteristics of the light sources. The output of the source, whether UV–A or visible light, was determined based on a spectral analysis of the flux. The spectral characteristics of the headlamp sources were measured from a wavelength interval of 200 to 800 nm with a 2-nm bandpass.

VISIBLE LIGHT SYSTEM MEASUREMENT

The visible light headlamps were measured following SAE Recommended Practice J575 chapter 4, section 5.[3] Each headlamp was mounted on the goniophotometer and aimed according to either the mechanical aiming pads or the visual methods, depending on the nature of the headlamp being tested. The luminous intensity of each headlamp was measured from 10° up to 15° down and from 45° to the left to 45° to the right. Measurements were taken in 0.1° increments in both the horizontal and vertical planes. All headlamps were measured while the bulbs were steadily burning and powered according to their respective power requirements.

UV–A SYSTEM MEASUREMENT

The UV–A sources were spectrally and spatially characterized using the goniometer and the double monochromator. During the measurement process, a complete spectral power distribution, from 200 to 800 nm in 2-nm intervals, was measured at the center point of the beam (0,0). To obtain a full matrix of distribution angles, a less detailed spectral measurement was performed at all of the subsequently tested orientations. The measurements were performed for all the combinations of vertical angles, −20°, −10°, 0°, 10° and 20°, and horizontal angles, −20°, −10°, 0°, 10° and 20°. In all, 25 measurements were made. All units were powered according to their respective power requirements.

CHAPTER 3—HEADLAMP AIMING PROCEDURES

The aiming of the headlamps in this project was a critical component of the ENV vehicle setup. The repeatability of the aim for a headlamp was vital to the reduction of uncertainty caused by the lighting conditions. The general methods for the aiming of all of the headlamps in the project are provided in appendix A. Specific methods are shown in each of the ENV experimental reports.

The headlamps used for the HLB, HID, HOH, HHB, and UV–A VES configurations were located on external light bars. For the HLB and the HID light sources, the VESs were moved onto, off of, and between vehicles to change from one configuration to the next. Each light assembly movement required a re-aiming process, which took place before starting the experimental session each night. Headlamps are designed so that the system may be either visually optically aligned (VOA) or mechanically aimed. At the beginning of the ENV project, a headlamp aimer was not available, so an aiming protocol that could be used with either type of system was developed with the help of experts in the field. (See references 5, 6, 7, 8, and 9.) The method used for this project is a modified version of the typical SAE aiming method.

The aiming method required the selection of a reference point and then the aiming of the headlamp beam relative to that reference point. No standard is available for the aiming of UV–A headlamps, so a similar method was selected for these headlamp types. For this procedure, an alignment board was placed 10.7 m (35 ft) from the experimental vehicle. This distance, which is a departure from the 7.6-m (25-ft) vehicle distance used by the SAE methodology, was selected during the original ENV process and maintained throughout the investigation for all of the aimed headlamps. The 10.7-m (35-ft) distance was the maximum possible in the aiming area at the contractor's facility. A comparison of alignment at the two distances was performed to ensure validity of the methodology.

The alignment board was marked with each headlamp system's reference points, which were chosen following SAE J599, 1997.[10] The horizontal position (side to side) of the reference point was directly in front of the vehicle coincident with the vertical optical centerline of the headlamp (usually denoted on the headlamp as a circle or a cross etched into the lens). The vertical position (up and down) of the reference point depended on the height of the experimental vehicle. The

SAE specifies that if the optical center of the headlamp, or optical center height (OCH), is less than 90 cm (36 inches) above the roadway surface, then the reference point should be at the same height as the optical center. If the optical center is more than 90 cm (36 inches) above the roadway surface, the reference point should be 5 cm (2 inches) below the headlamp optical center. These reference points were adjusted for the greater alignment distance.[10] Figure 6 shows a comparison between the 7.6-m (25-ft) and 10.7-m (35-ft) alignment distances. The units, a mix of English and the International System of Units, are prescribed by the SAE guidelines.

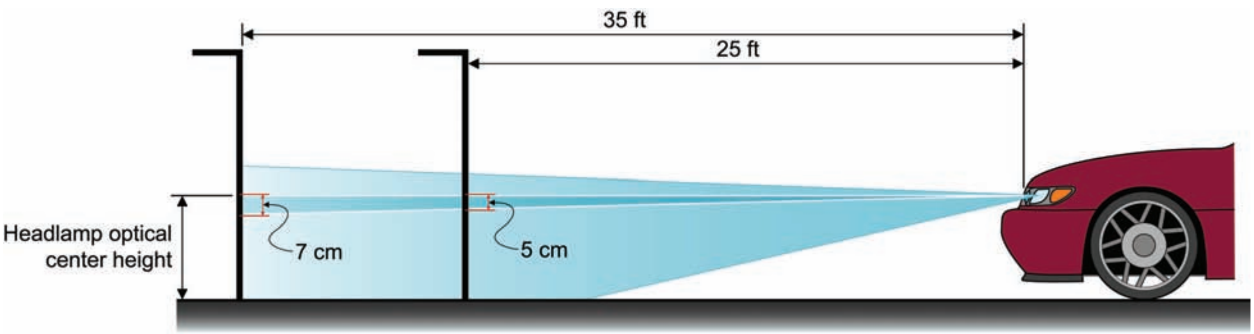


Figure 6. Diagram. Comparison of vertical reference point for 25-ft and 35-ft headlamp alignment distances.

VISUALLY OPTICALLY ALIGNED AIMING

There are two subtypes of the visually optically aligned (VOA) systems, visually optically aligned left (VOL) and visually optically aligned right (VOR). VOL headlamps are aimed so that the sharp cutoff of the light pattern on the left of the lamp is aimed to a vertical aiming plane. VOR headlamps are aimed using the right portion of the beam as the reference. VOL systems have a vertical aiming plane 0.6° below the vertical reference point on the alignment board. VOR systems have a vertical aiming plane at the same height as the reference point. Figure 7 and figure 8 show the aiming planes used.

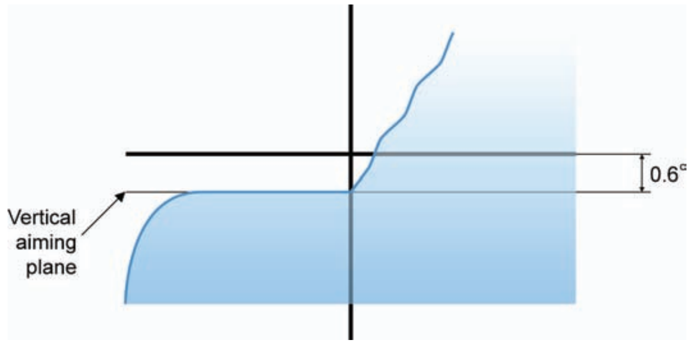


Figure 7. Diagram. VOL aiming.

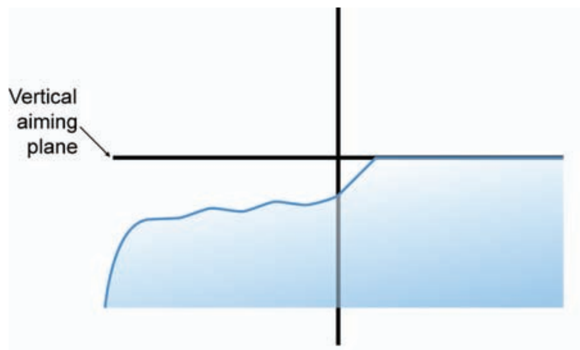


Figure 8. Diagram. VOR aiming.

MECHANICALLY AIMED HEADLAMP AIMING

The HLB, HOH, and HHB headlamps used in this study were mechanically aimed systems. With this type of headlamp, the reference for the position of the headlamp is based on three aiming pads located on the lens of the luminaire. These pads and measurements shown on the headlamp are used with a mechanical aiming device. Optical aimers that analyze the beam pattern and set the maximum luminous intensity of the headlamp beam to a specified location also can be used to aim this type of headlamp.

For this investigation, neither an optical aimer nor a mechanical aimer was available. It was decided that an illuminance meter with a remote sensor would be used to find the maximum luminous intensity of the beam, and then the headlamps would be aimed so that this maximum point was located at a selected point relative to the reference point. As with the VOA headlamps, the reference point was chosen as specified by SAE J599, 1997.[10] The point selected for the maximum luminous intensity of the beam was at 2.5 cm (1 inch) to the right and 2.5 cm (1 inch) below this reference point at the 10.7-m (35-ft) alignment distance. The sensor element of an illuminance meter was positioned at this point while the headlamp was slowly adjusted to determine the orientation at which the maximum luminous intensity of the beam (hotspot) was directed toward the selected point (figure 9).

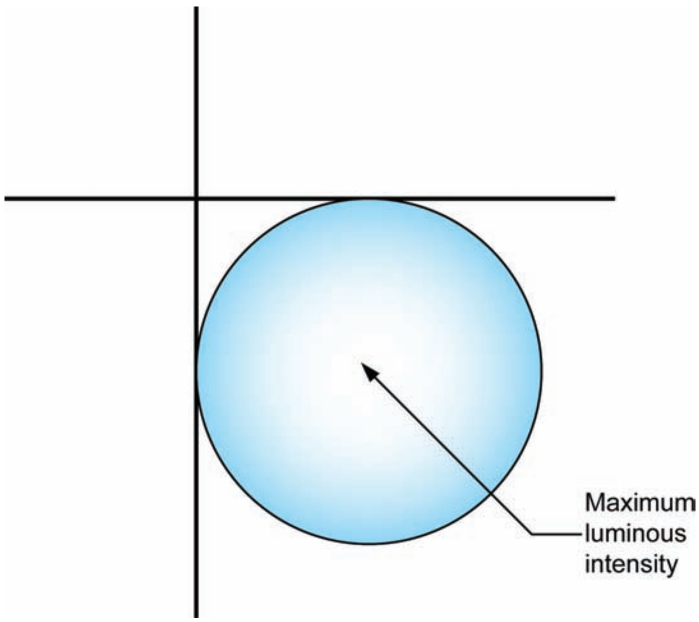


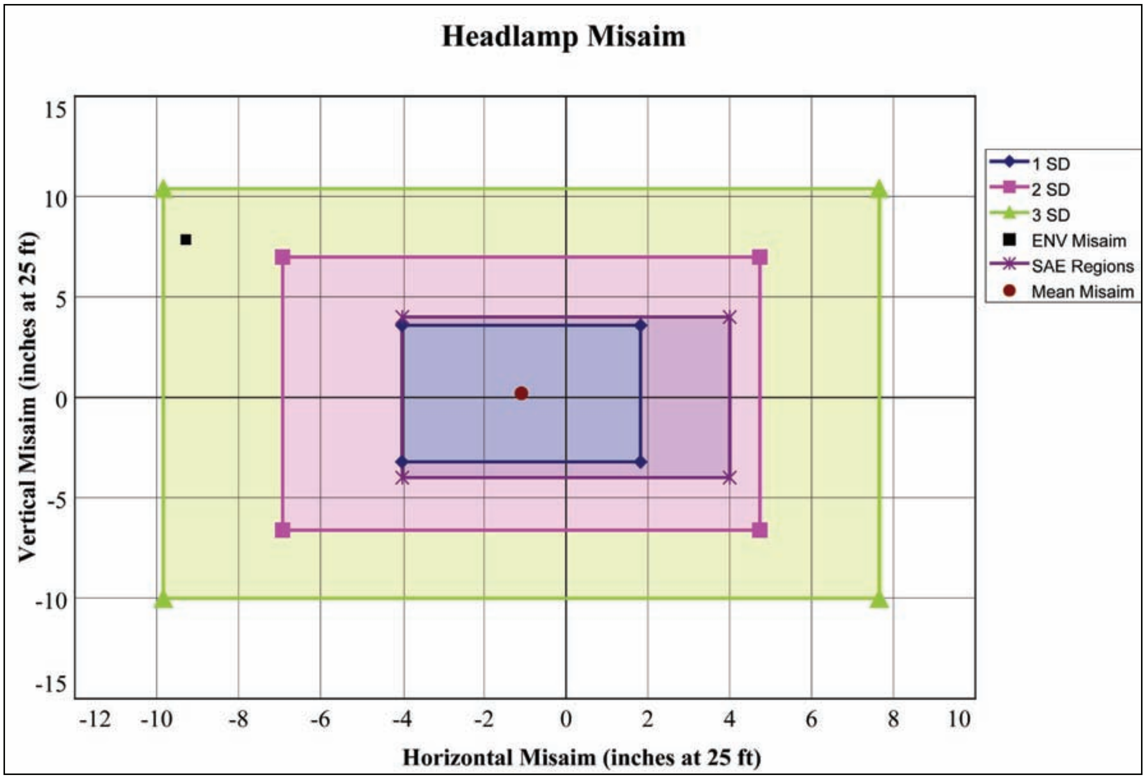
Figure 9. Diagram. Hotspot aiming for mechanically aimed lamps.

During the measurements made as part of this characterization, it was discovered that this is not the typical location for the maximum luminous intensity of the beam. Although not an exact specification, SAE 1383, 1996, shows that the maximum allowable luminous intensity of the beam should be located approximately 1.5 down and 2 to the right of the reference point (table 3A of SAE 1383 1996).[11] At 10.7 m (35 ft), these dimensions translate to 27.9 cm (11 inches) down and 37.2 cm (14.7 inches) to the right, the location used by optical aimers.[9] This means that the aiming of the HLB, HOH, and HHB all have a deviation of approximately 1.36° above and 1.77° to the left of the typical point of maximum luminous intensity. This deviation was consistent across all of the studies performed with these headlamps.

To investigate the magnitude of this deviation, a review of the literature was undertaken, and two sources were found: the SAE standard and a fleet misaim investigation performed by Copenhaver and Jones.[12] In the SAE J599 1997 standard, an allowance of 10 cm (4 inches) of variance was defined around the reference point at an alignment distance of 25 ft (7.62 m). This means the HLB, HOH, and HHB aiming points used in this study were 0.6 degrees above and

1.0 degrees to the left of the extreme upper left position defined by the SAE aiming variance guidelines.[10]

Copenhaver and Jones investigated the typical amount of misaim found in the vehicle population to establish the variability that exists in the real world.[12] In this study, the headlight aim of 768 vehicles was measured. The mean result for misaim was 0.36 cm (0.143 inches) up and 2.01 cm (0.82 inches) left for the left headlamp and 0.59 cm (0.23 inches) up and 3.46 cm (1.36 inches) left for the right headlamp. The standard deviation (SD) of these measurements was 8.71 cm (3.43 inches) vertically and 7.14 cm (2.81 inches) horizontally for the left headlamp and 8.56 cm (3.37 inches) vertically and 7.67 cm (3.02 inches) horizontally for the right headlamp. Note that these dimensions refer to a misaim at the typical aiming distance of 7.6 m (25 ft). The misaim in the ENV project was within three standard deviations of the mean of this data. Figure 10 shows the ENV misaim in relation to the Copenhaver and Jones data and the SAE allowable misaim. In this figure, the (0,0) reference point is the proper aiming location. The blue, pink, and green areas refer to one, two, and three standard deviations, respectively, according to the Copenhaver and Jones data, and the purple box is the SAE variance region. It can be seen that the aiming point used in the ENV investigation is within the third standard deviation area of the Copenhaver and Jones data.



1 inch = 2.54 cm
1 ft = 0.305 m

Figure 10. Graph. Misaim from the Copenhaver and Jones data.(12)

The effect of this aiming variance on the results of the visibility experiments varied for each study. For the HLB and the HOH lamp types, the selected aim point likely resulted in greater illumination at points farther down the road, which in turn may have increased the detection distances and glare ratings. The HHB aiming may have actually reduced the amount of light reaching the objects on the roadway and reflected back to the observers, possibly decreasing the detection distances and glare ratings; however, it is not known what effect the aiming had on the results for the various weather conditions tested (ENV Volumes IV, V, VI, and XIV).

UV–A HEADLAMP AIMING

As mentioned, there is no standard method for aiming UV–A headlamps. The method developed for this project was to aim each headlamp straight ahead of the vehicle. The reference points were selected in a similar method to the visible light headlamps. During the aiming process, a UV–A radiance meter was used to find the maximum radiant intensity output from the headlamp. Because of the headlamp mounting mechanism, a wider margin of error was selected for the

UV–A headlamps; the hotspot was then aimed within 5 cm (2 inches) of the reference point. The aiming region is shown in figure 11.

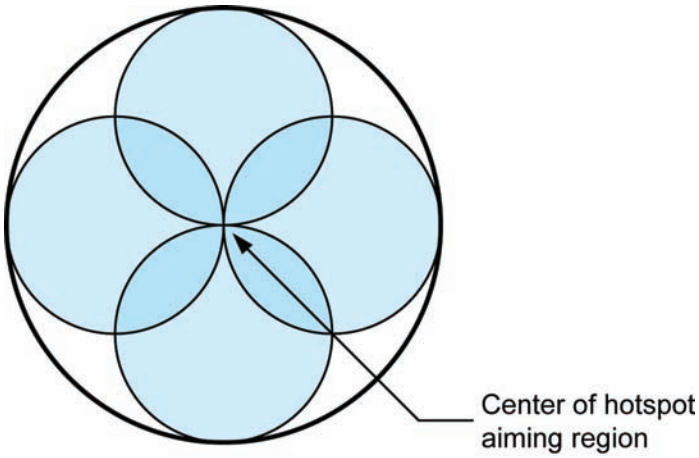


Figure 11. Diagram. Hotspot aiming for UV–A lamps.

CHAPTER 4—CHARACTERIZATION RESULTS

The results have been subdivided into visible and ultraviolet systems. The individual VESs are shown within each of these groups. Images of the VES housings are also provided where available.

VISIBLE SYSTEMS

Halogen

Halogen headlamp bulbs generate visible light by passing electric current through a high-resistance tungsten filament. The filament is surrounded by halogen gas, allowing for higher operating temperature and longer filament life. Much of the energy output of a halogen bulb is in the infrared band of the electromagnetic spectrum. The visible light output is yellow in color. Because the ultraviolet output of a halogen lamp is minimal, only the spectral distribution within the visible spectrum appears in figure 12. In this study, both the halogen low beam and high output halogen used this technology.

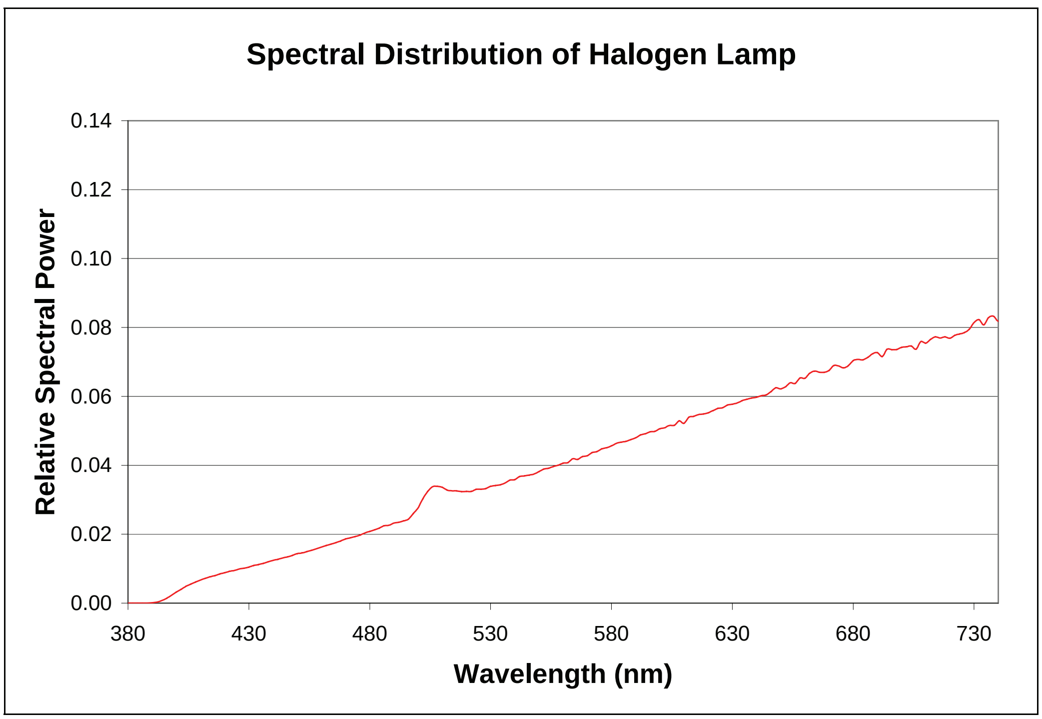


Figure 12. Line graph. Visible light spectral power distribution of halogen lamp ranging from 380 nm to 730 nm.

HID

High intensity discharge (HID) lamps produce light by means of an electrical arc discharge maintained by passing an electrical current through an ionized gas. While there are several technologies defined as HID lamps, those used in vehicle headlamps are part of the metal halide group. The lamp contains an arc tube terminated with tungsten electrodes. The arc tube typically contains xenon gas as a starting gas. The xenon gas is relatively easy to ionize at normal ambient temperatures when a high-voltage arc is passed between the electrodes. The arc tube also contains various metal halides that vaporize as the lamp reaches operating temperature. When the vaporized metal halide approaches the high-temperature arc, it disassociates into halogen and metal atoms. The heated metal vapor radiates line spectra associated with the metal. Convection currents move the halogen and metal atoms near the cooler arc tube wall where they recombine and the cycle repeats. The correlated color temperature of the emitted light is determined by selection of the metal halides contained within the lamp. For vehicle headlamps, the majority of the radiated energy is in the visible spectrum, and the resulting light appears blue-white in color. Like the halogen headlamp, the ultraviolet output is minimal; figure 13 shows the spectral distribution of the HID headlamp only within the visible spectrum.

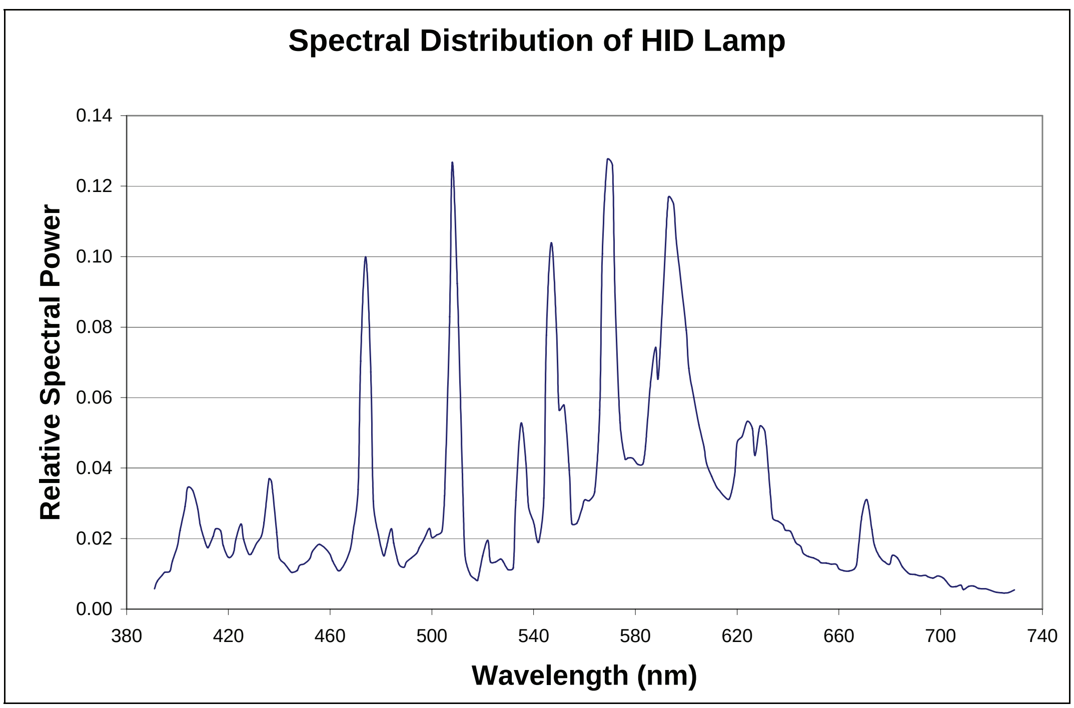


Figure 13. Line graph. Spectral power distribution of HID lamp ranging from 380 nm to 740 nm.

LUMINAIRE CHARACTERISTICS

This section contains descriptions of each headlamp system with up to 11 parameters. The descriptions include the lamp technology (halogen, HID, UV–A, or hybrid UV–A) and beam type (low beam or high beam) of the headlamp system. The ENV abbreviation convention for each VES and a list of the ENV volumes in which it appears are included. The lamp type is the Federal Motor Vehicle Safety Standards (FMVSS) headlamp designation if a replaceable lamp is specified. The alignment type is listed according to the FMVSS 108 designation marking on the headlamp lens. The optical position for each VES is provided in table 2 through table 24. The optical center height is measured vertically from the ground plane. The distance between the optical centers of headlamp pairs is measured horizontally across the front of the vehicle or the rack. The mounting type includes three headlamp mounting methods. The original equipment manufacturer (OEM) mount, pictured in figure 14, specifies a stock mounting location and stock hardware. The rack mount, pictured in figure 15, specifies mounting on an auxiliary headlamp rack attached to the front of a vehicle. The glare rack mount, pictured in figure 16, specifies mounting on a glare rack used in studies where the experiment required oncoming headlamp glare. Relevant pictures, which include front, side, plan, and rear views of the headlamp system, are provided where available. A graph of the luminous intensity for each headlamp system is also provided. The maximum luminous intensity of the headlamp beam in candela (cd) is listed, as well as its location in degrees horizontal and degrees vertical.

Figure 14. Photo. Example of an OEM mount.

Figure 15. Photo. Rack mount.

Figure 16. Photo. Glare rack mount.

Phase II Headlamp Systems

The Phase II headlamp systems appear in ENV Volumes III through VIII.

Halogen Low Beam

Table 1. Halogen low beam description.

Model description	Halogen low beam
Lamp type	HB5 halogen
ENV abbreviation	HLB
In ENV volumes	III, IV, V, VI, VII, VIII, XIII, XIV, XV
Alignment type	Non-VOA mechanical aiming pads
Max beam candlepower	23,421 cd
Maximum beam location	1, −2

Table 2. Halogen low beam optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
OEM mount	32.25	42.50
Rack mount	31.38	48.00
Glare rack mount	31.75	46.00

1 inch = 2.54 cm

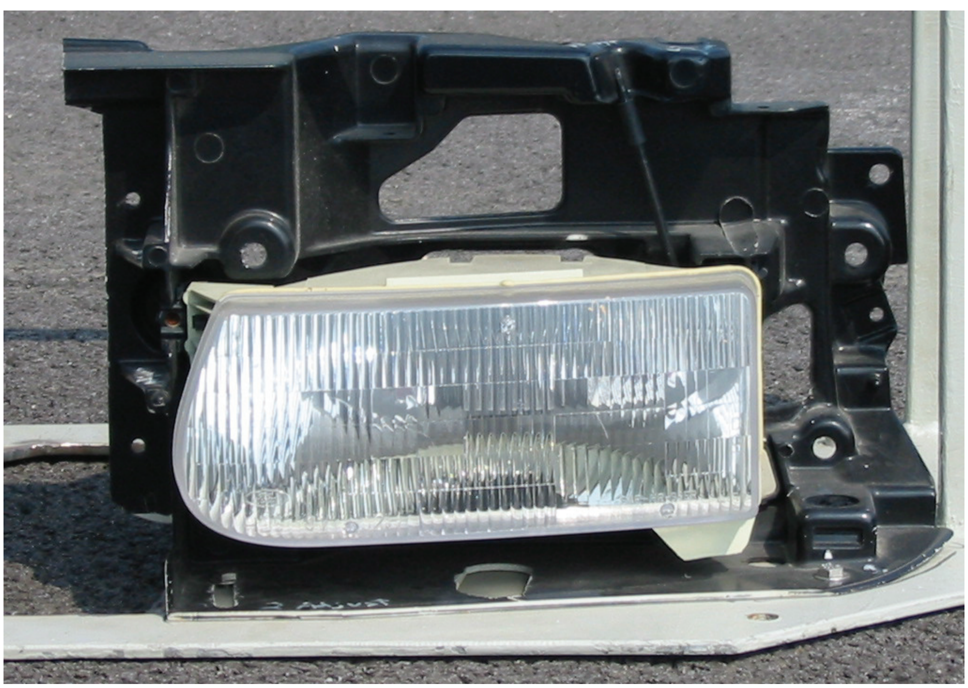


Figure 17. Photo. Halogen low beam front view.

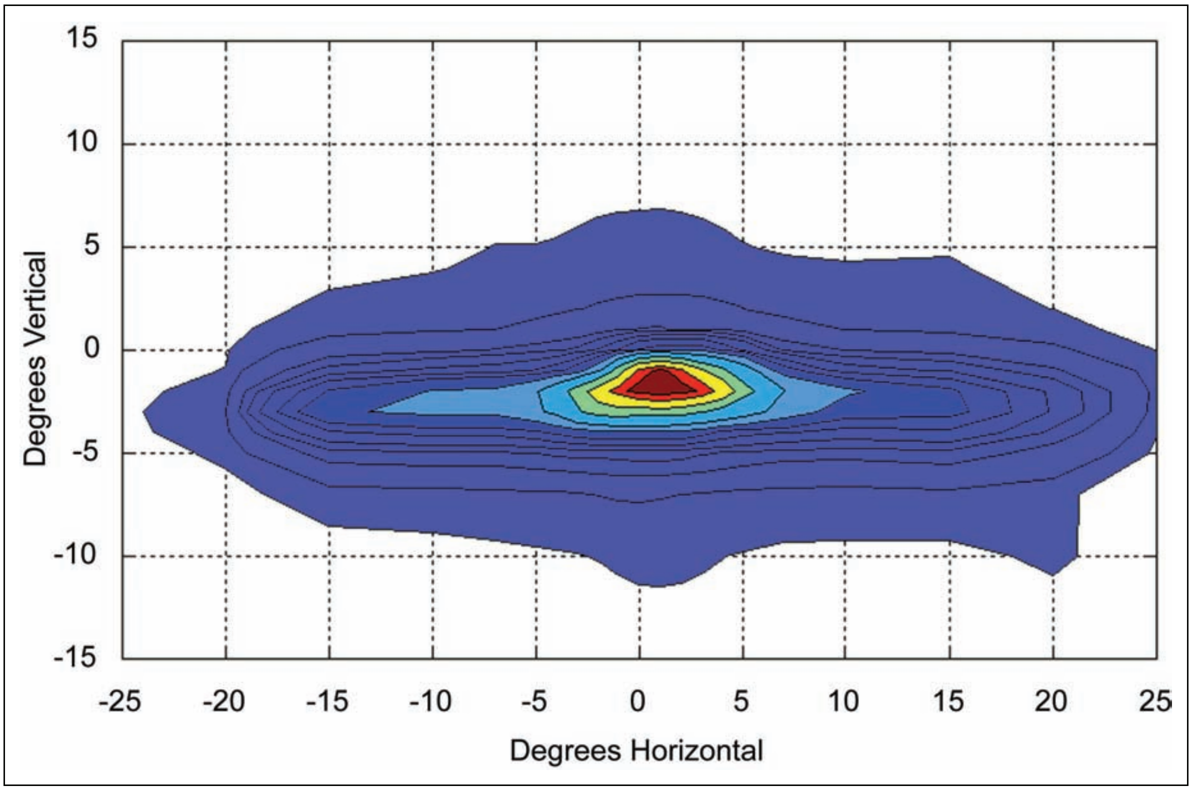


Figure 18. Graph. Halogen low beam isocandela plot (right headlamp).

Halogen Low Beam Low Profile

Table 3. Halogen low beam low profile description.

Model description	Halogen low beam
Lamp type	Halogen
ENV abbreviation	HLB–LP
In ENV volumes	III, IV, VI, VII, VIII
Alignment type	VOL (mechanical aiming methods used for this headlamp type)
Max beam candlepower	26,794 cd
Maximum beam location	2 , −1

Table 4. Halogen low beam low profile optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
OEM mount	22.63	50.50

1 inch = 2.54 cm

Figure 19. Photo. Halogen low beam low profile front view.

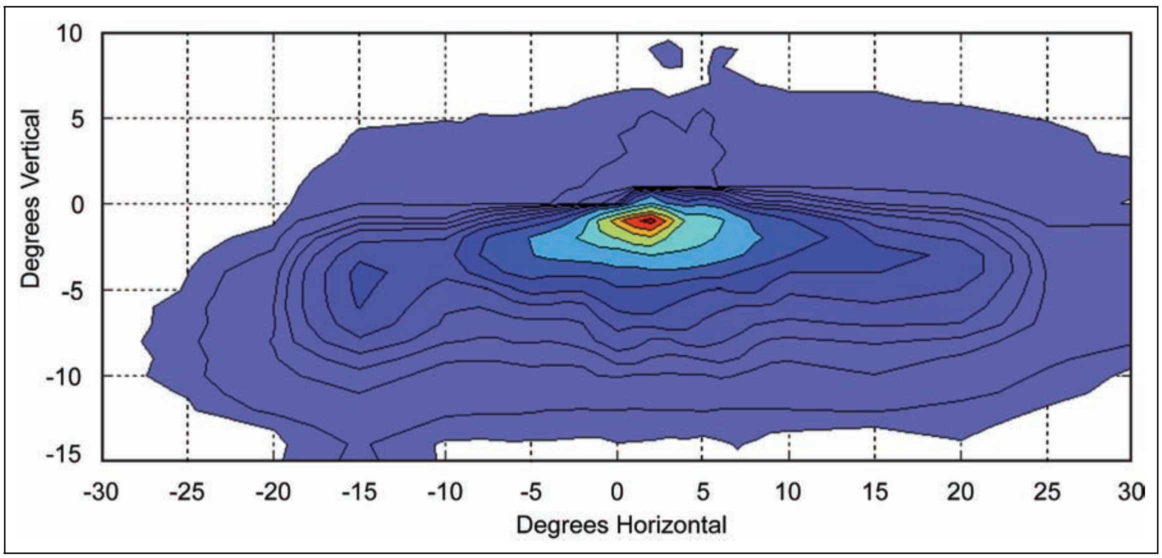


Figure 20. Graph. Halogen low beam low profile isocandela plot (right headlamp).

Halogen High Beam

Table 5. Halogen high beam description.

Model description	High beam
Lamp type	Halogen
ENV abbreviation	HHB
In ENV volumes	III, IV, VII, VIII
Alignment type	VOL (mechanical aiming methods used for this lamp type; aligned in same housing as the HOH below)
Max beam candlepower	36,581 cd
Maximum beam location	0, 0

Table 6. Halogen high beam optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	35.50	56.00

1 inch = 2.54 cm

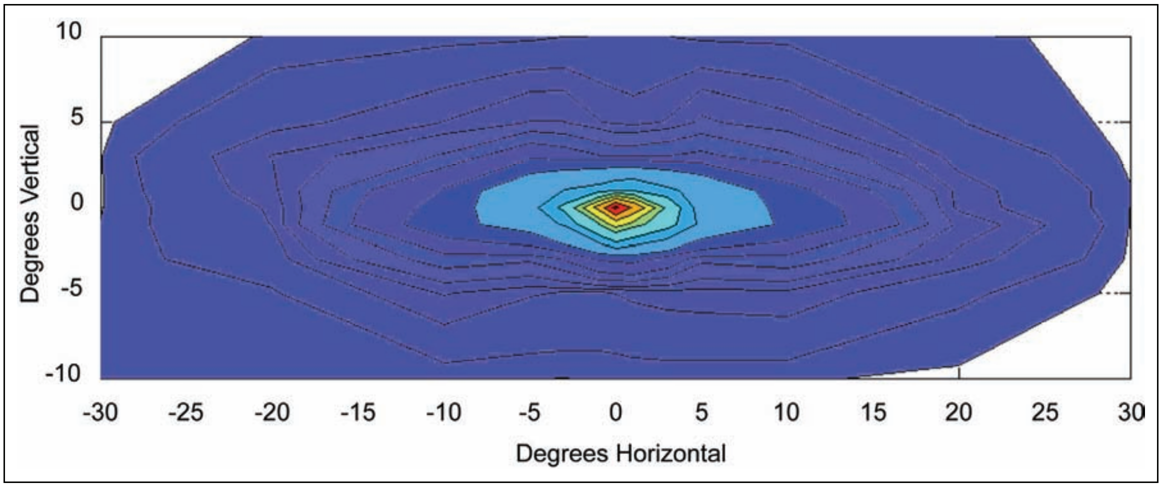


Figure 21. Graph. Halogen high beam isocandela plot (right headlamp).

High Output Halogen Low Beam

Table 7. High output halogen low beam description.

Model description	High output halogen low beam (Note: This was a prototype replacement bulb of higher output used in the OEM housing; see figure 19.)
Lamp type	Halogen
ENV abbreviation	HOH
In ENV volumes	III, IV, VII, VIII
Alignment type	VOL (mechanical aiming methods used for this lamp type)
Max beam candlepower	22,752 cd
Maximum beam location	−1, −2

Table 8. High output halogen low beam optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	35.50	56.00

1 inch = 2.54 cm

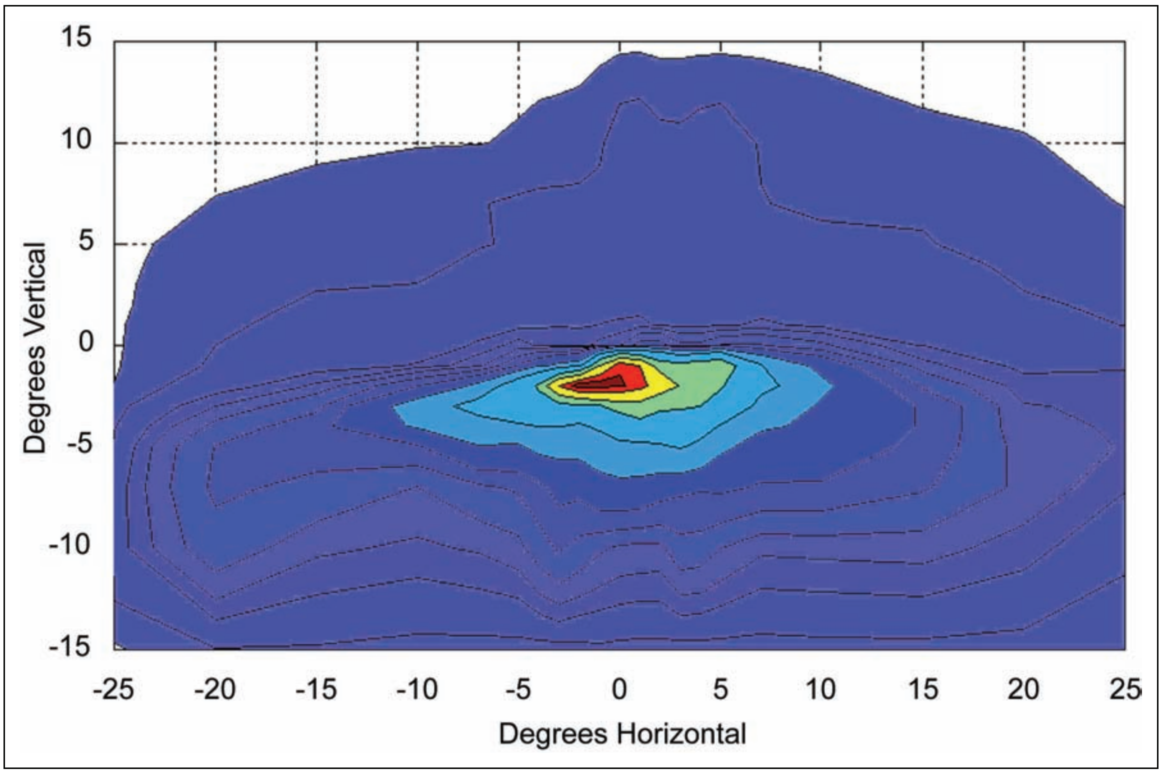


Figure 22. Graph. High output halogen low beam isocandela plot (right headlamp).

High Intensity Discharge Low Beam

Table 9. High intensity discharge low beam description.

Model description	High intensity discharge low beam
Lamp type	High intensity discharge
ENV abbreviation	HID (HID 4 in Phase III)
In ENV volumes	III, IV, V, VI, VII, VIII, XV
Alignment type	VOL
Max beam candlepower	42,525 cd
Maximum beam location	1, 0

Table 10. High intensity discharge low beam optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	34.75	42.00
Glare rack mount	36.00	44.25

1 inch = 2.54 cm

Figure 23. Photo. High intensity discharge front view.

Figure 24. Photo. High intensity discharge side view.

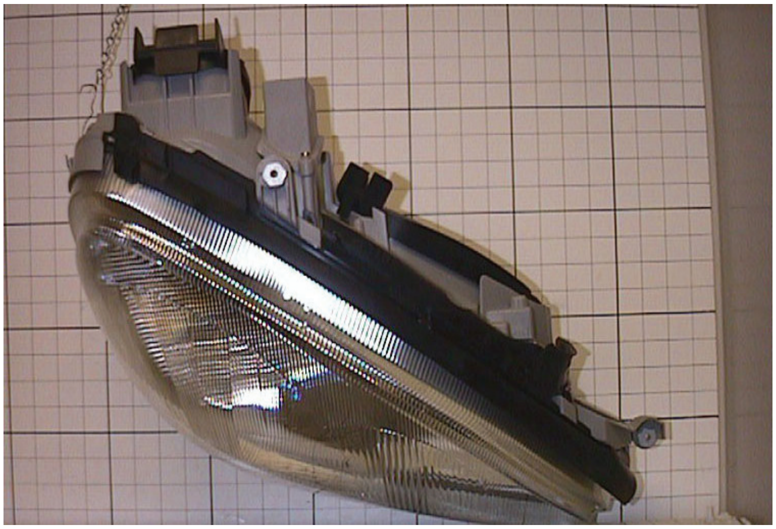


Figure 25. Photo. High intensity discharge plan view.

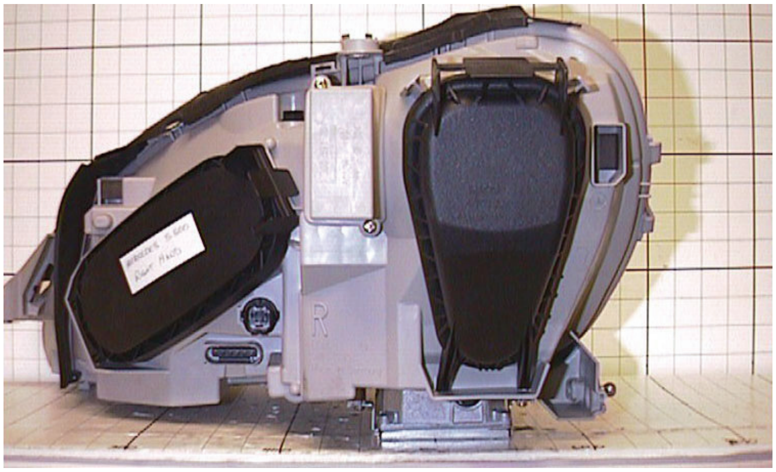


Figure 26. Photo. High intensity discharge rear view.

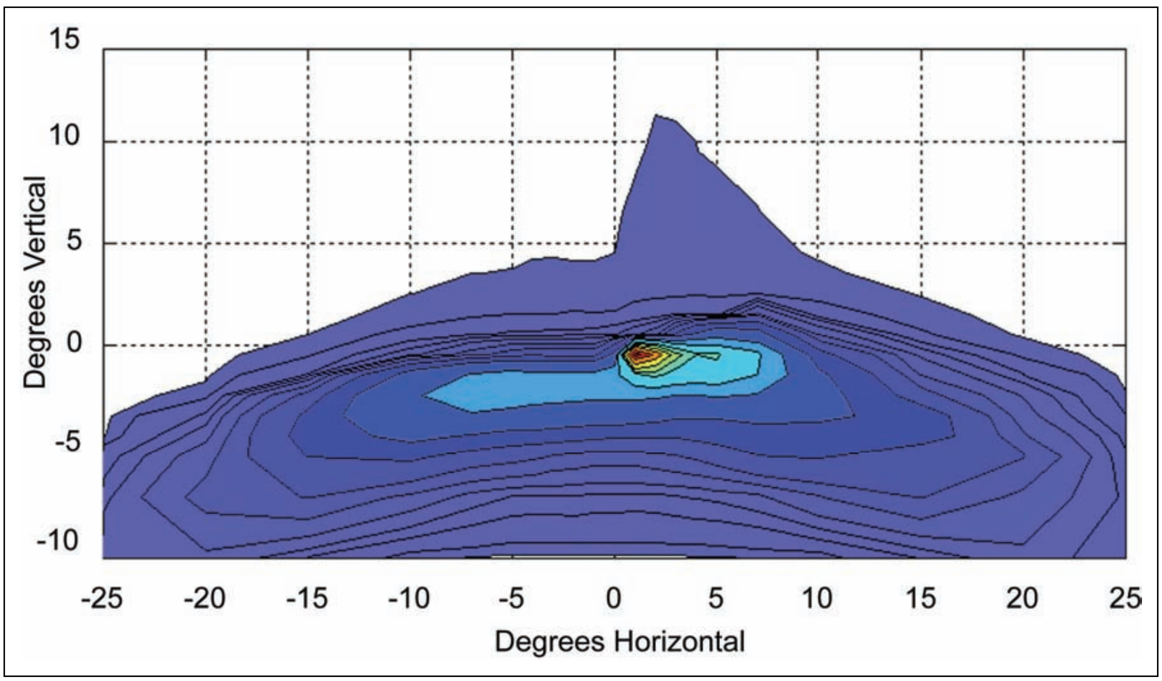


Figure 27. Graph. High intensity discharge low beam isocandela plot (right headlamp).

Phase III Headlamp Systems

Phase III headlamp systems appear in ENV Volumes XIII through XVI. The headlamps used exclusively for the Phase III studies (ENV Volumes XIII, XIV, and XV) are highlighted below. In addition to these headlamps, the HLB and the HID from Phase II were used. The HID from Phase II was designated HID 4 in Phase III.

Companion Headlamp to Near Infrared 2 (NIR 2) and Far Infrared (FIR)

Table 11. Companion headlamp to NIR 2 and FIR description.

Model description	Companion headlamp to NIR 2 and FIR
Lamp type	Halogen
ENV abbreviation	Used in conjunction with NIR 2 and FIR
In ENV volumes	XIII, XIV
Alignment type	VOL
Max beam candlepower	29,944 cd
Maximum beam location	2 , −2

Table 12. Companion headlamp to NIR 2 and FIR optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	33.00	44.25
OEM mount	37.00	58.50

1 inch = 2.54 cm

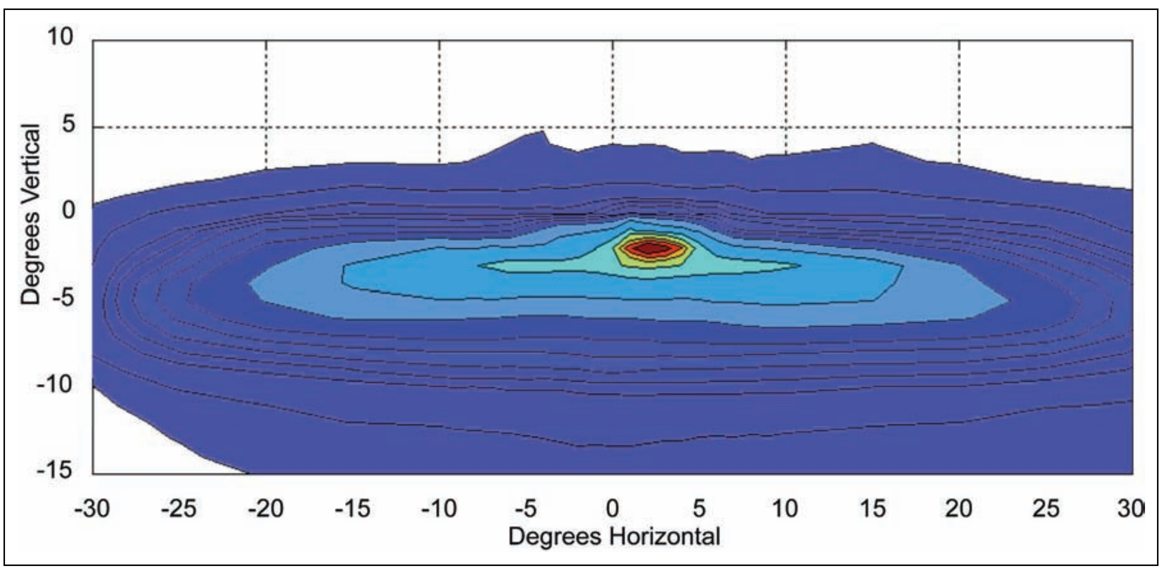


Figure 28. Graph. Companion headlamp to NIR 2 and FIR isocandela plot (right headlamp).

Companion Headlamp to Near Infrared 1 (NIR 1)

Table 13. Companion headlamp to NIR 1 description.

Model description	Companion headlamp to NIR 1
Lamp type	Halogen
ENV abbreviation	Used in conjunction with NIR 1
In ENV volumes	XIII, XIV
Alignment type	VOR
Max beam candlepower	21,847 cd
Maximum beam location	2, −1

Table 14. Companion headlamp to NIR 1 optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	33.00	48.25
OEM mount	36.50	57.25

1 inch = 2.54 cm

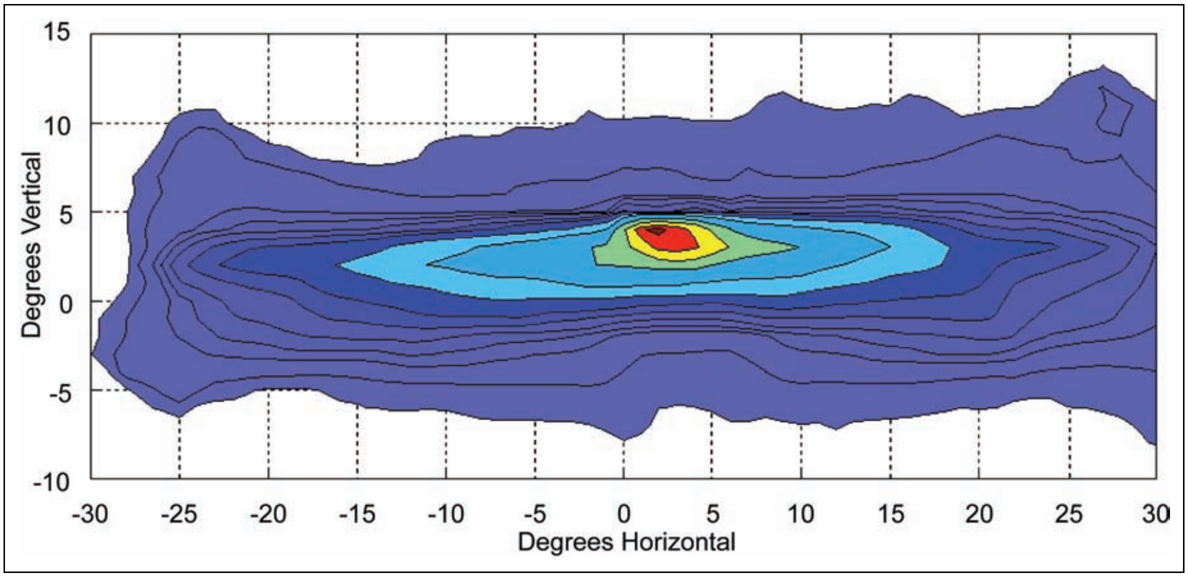


Figure 29. Graph. Companion headlamp to NIR 1 isocandela plot (right headlamp).

High Intensity Discharge Low Beam 1 (HID 1)

Table 15. High intensity discharge low beam 1 description.

Model description	High intensity discharge low beam
Lamp type	High intensity discharge
ENV abbreviation	HID 1
In ENV volumes	XIII, XIV, XV
Alignment type	VOL
Max beam candlepower	17,453 cd
Maximum beam location	5, −1

Table 16. High intensity discharge low beam 1 optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	32.75	45.00
Glare rack mount	34.50	46.00

1 inch = 2.54 cm

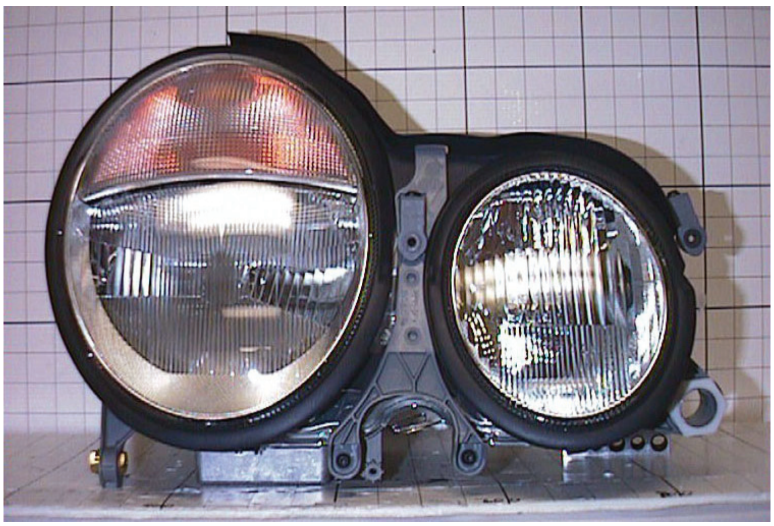


Figure 30. Photo. High intensity discharge 1 front view.

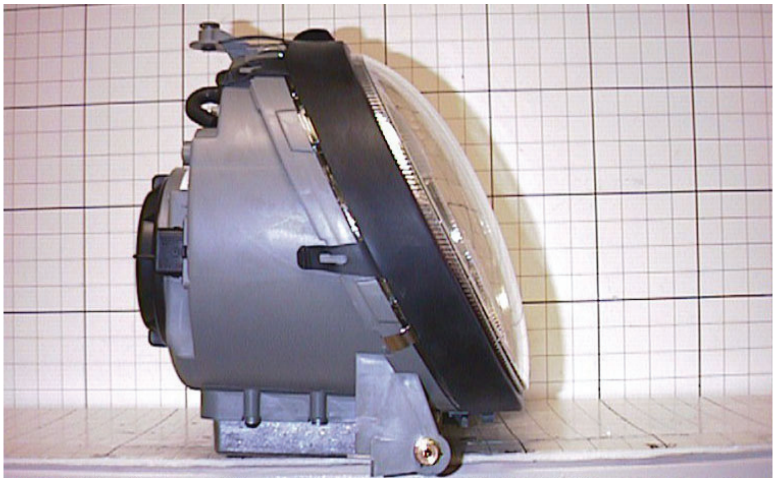


Figure 31. Photo. High intensity discharge 1 side view.

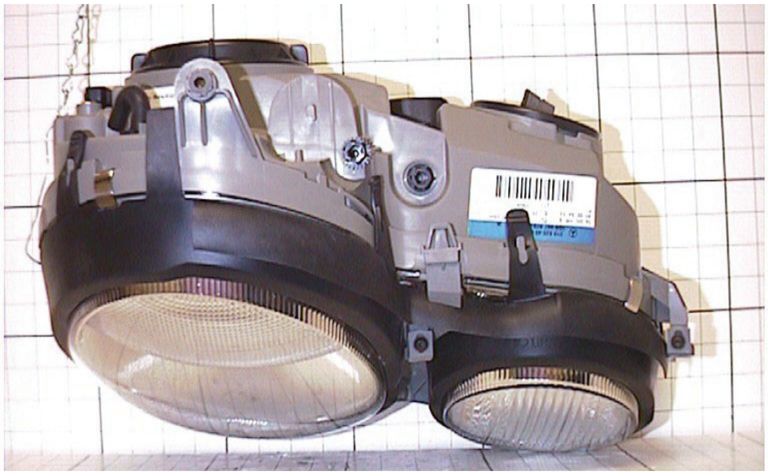


Figure 32. Photo. High intensity discharge 1 plan view.

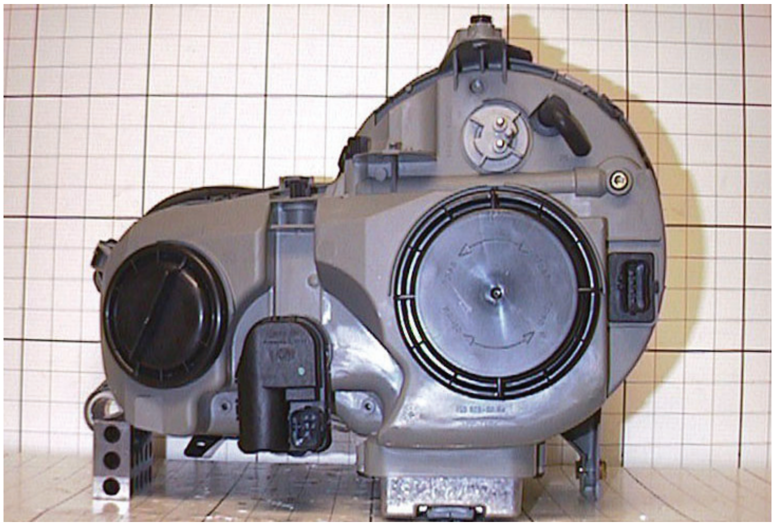


Figure 33. Photo. High intensity discharge 1 rear view.

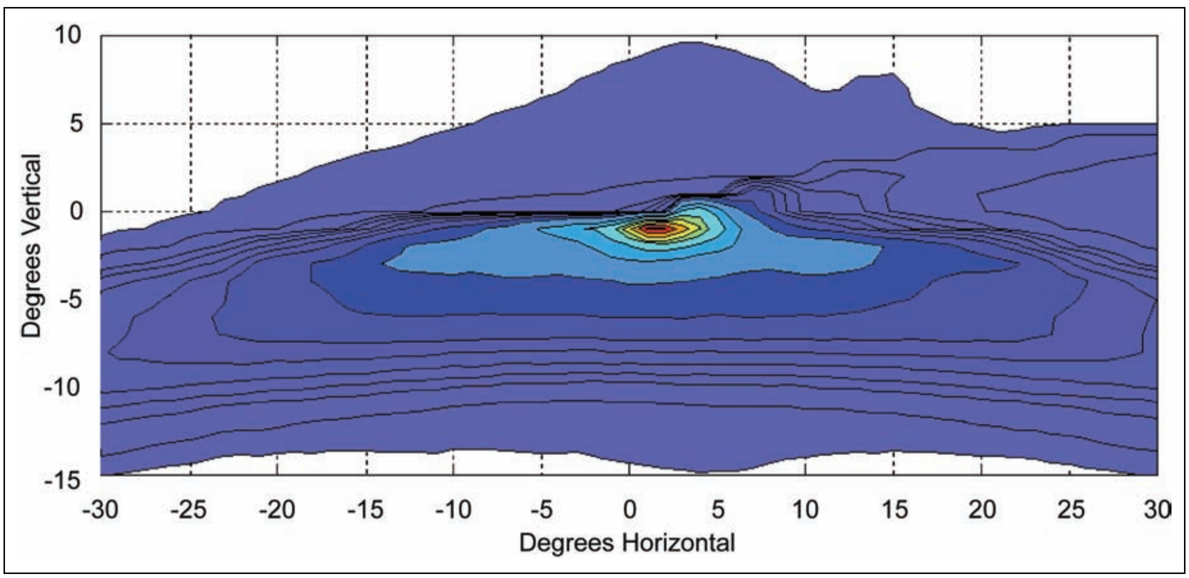


Figure 34. Graph. High intensity discharge low beam 1 isocandela plot (right headlamp).

High Intensity Discharge Low Beam 2 (HID 2)

Table 17. High intensity discharge low beam 2 description.

Model description	High intensity discharge low beam
Lamp type	High intensity discharge
ENV abbreviation	HID 2
In ENV volumes	XIII, XIV, XV
Alignment type	VOR
Max beam candlepower	32,472 cd
Maximum beam location	0, −3

Table 18. High intensity discharge low beam 2 optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	33.00	48.25
OEM mount	36.50	57.25

1 inch = 2.54 cm

Figure 35. Photo. High intensity discharge 2 front view.

Figure 36. Photo. High intensity discharge 2 side view.

Figure 37. Photo. High intensity discharge 2 plan view.

Figure 38. Photo. High intensity discharge 2 rear view.

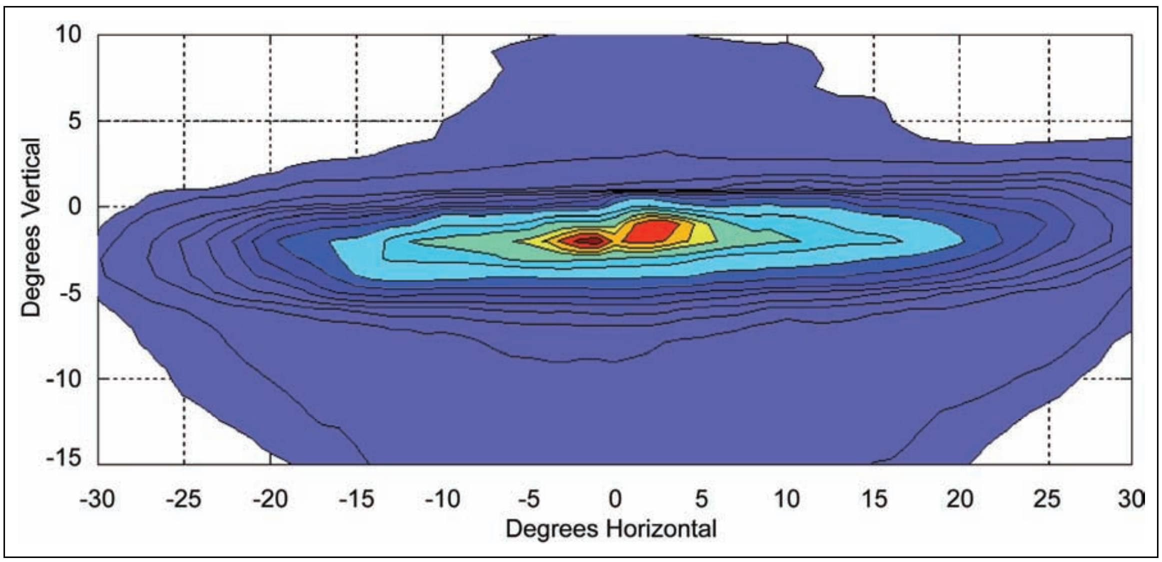


Figure 39. Graph. High intensity discharge low beam 2 isocandela plot (right headlamp).

High Intensity Discharge Low Beam 3 (HID 3)

Table 19. High intensity discharge low beam 3 description.

Model description	High intensity discharge low beam
Lamp type	High intensity discharge
ENV abbreviation	HID 3
In ENV volumes	XV
Alignment type	VOL
Max beam candlepower	22,895
Maximum beam location	0, −2

Table 20. High intensity discharge low beam 3 optical center position

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Glare rack mount	34.25	44.50

1 inch = 2.54 cm

Figure 40. Photo. High intensity discharge 3 front view.

Figure 41. Photo. High intensity discharge 3 side view.

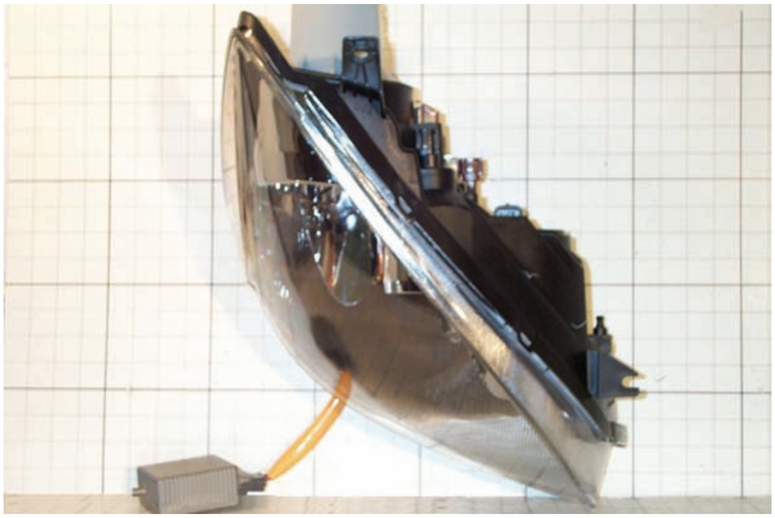


Figure 42. Photo. High intensity discharge 3 plan view.

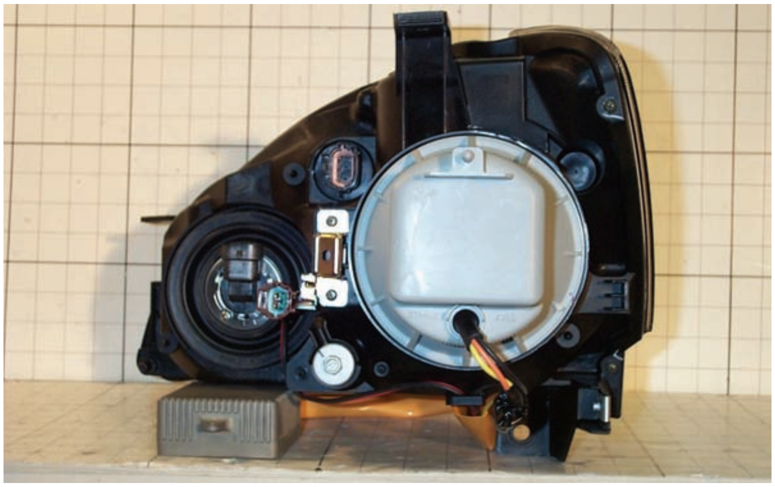


Figure 43. Photo. High intensity discharge 3 rear view.

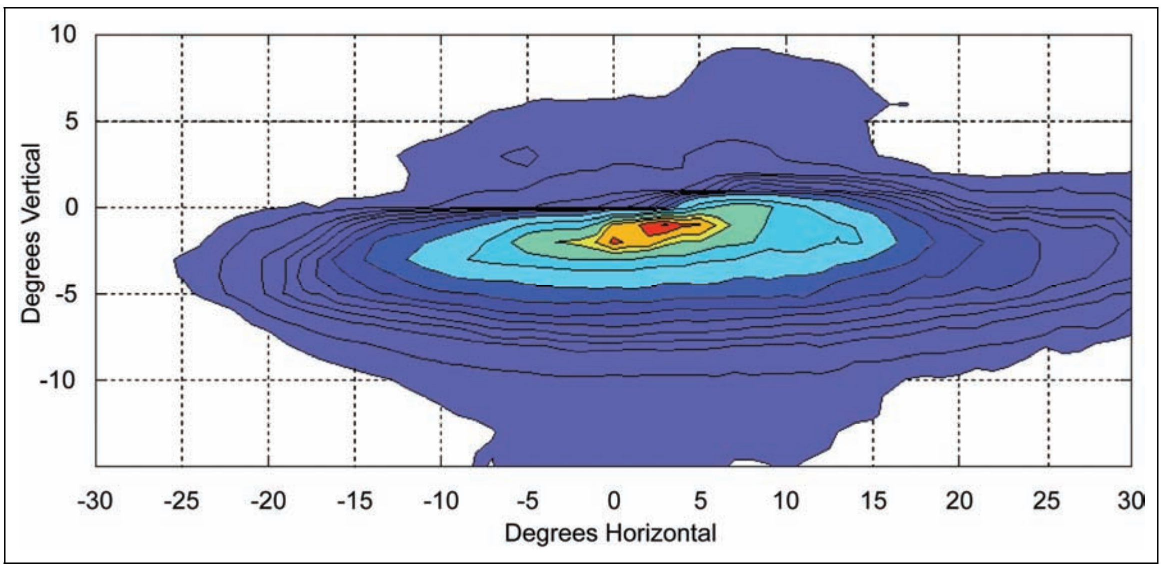


Figure 44. Graph. High intensity discharge low beam 3 isocandela plot (right headlamp).

UV–A SYSTEMS FROM PHASE II STUDIES

UV–A systems appear in ENV Volumes III through X.

Sources

Two sources were used to generate the ultraviolet radiation used in the Phase II investigations. These included a prototype hybrid visible light/UV–A light source and a UV–A-only source that had been used previously on Norwegian snowplows. The lamp characteristics are shown in figure 45 and figure 46.

UV–A

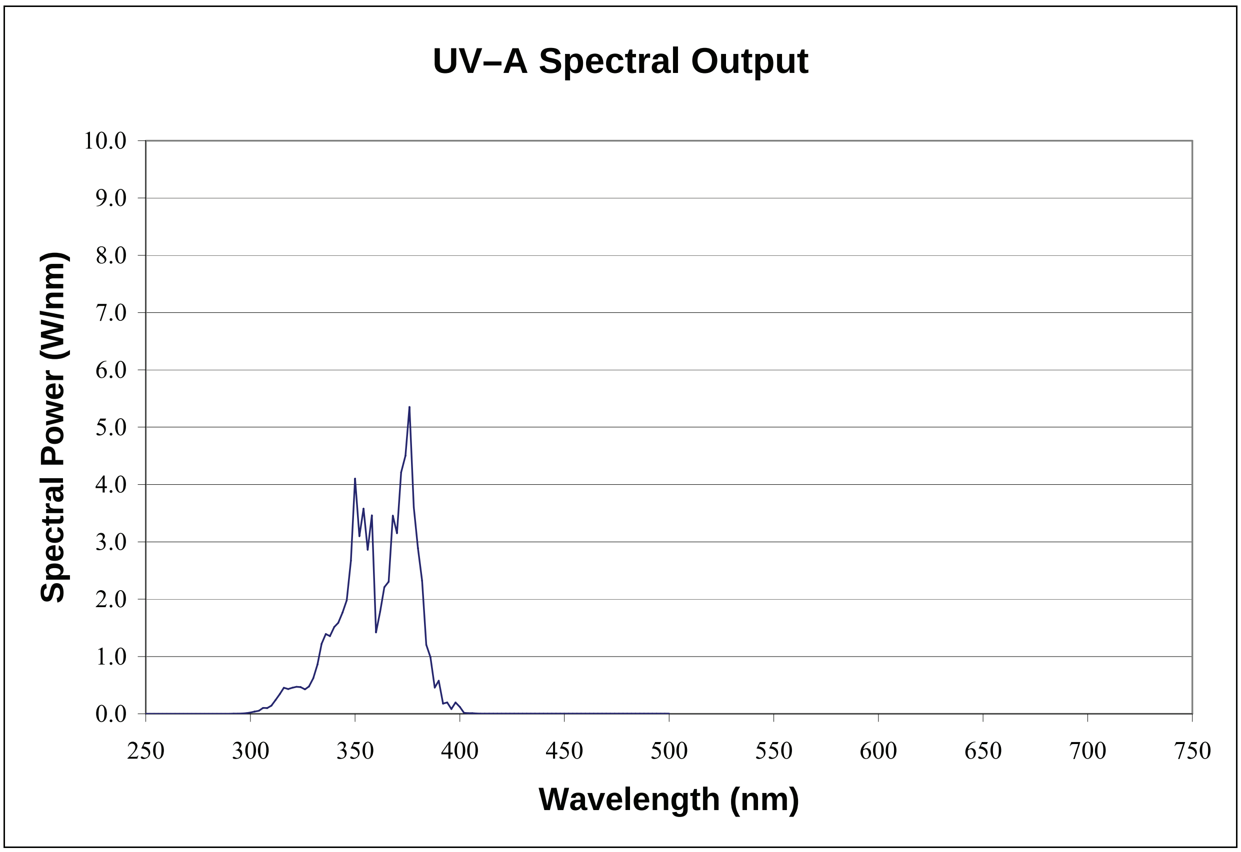


Figure 45. Line graph. Spectral power distribution of the UV–A source.

Hybrid UV–A

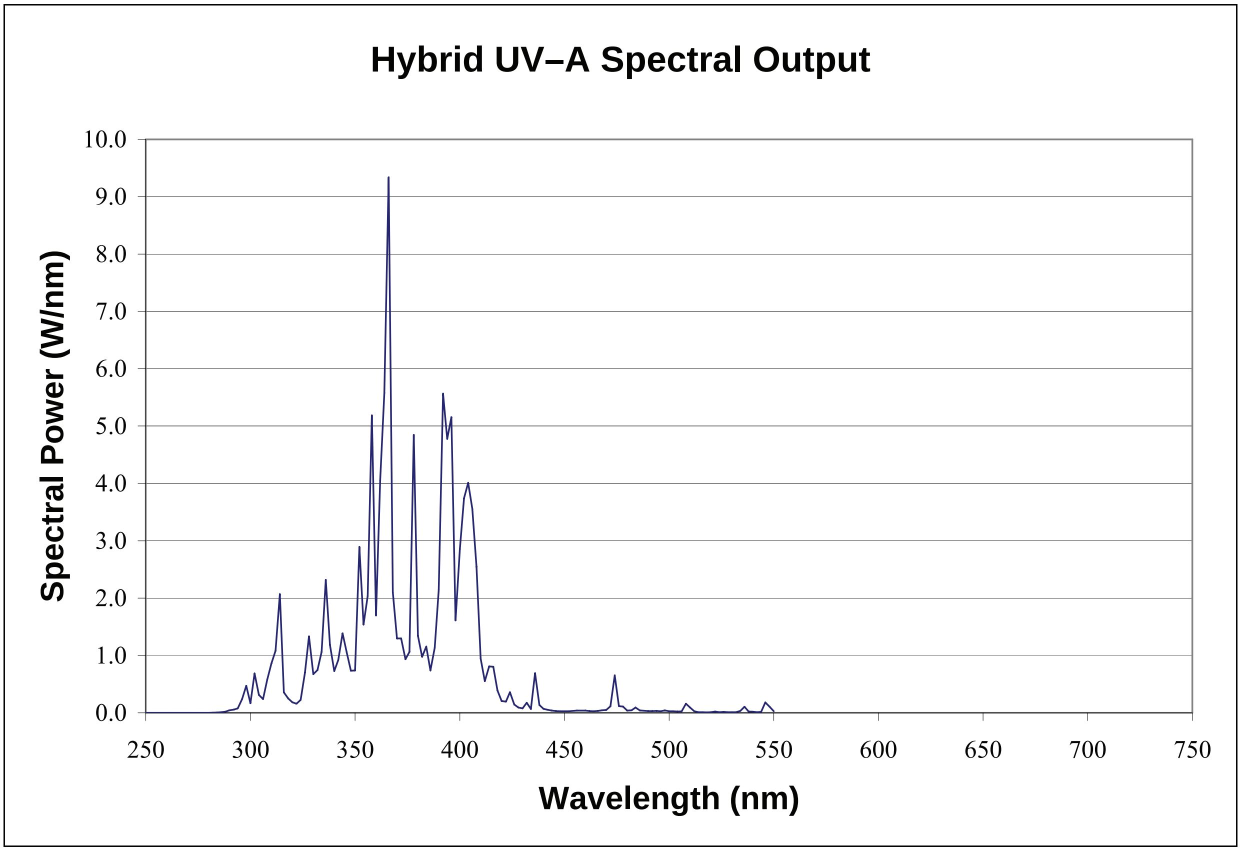


Figure 46. Line graph. Spectral power distribution of the hybrid UV–A source.

Luminaire Characteristics

Hybrid UV–A

Table 21. Hybrid UV–A description.

Lamp type	Hybrid UV–A
ENV abbreviation	Hybrid UV–A
In ENV volumes	III, IV, V, VI, VII, VIII
Max beam radiance	115 W
Maximum angular location	0, 0

Table 22. Hybrid UV–A optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (inches)
Rack mount	29.50	25.25

1 inch = 2.54 cm

Figure 47. Photo. Hybrid UV–A front view.

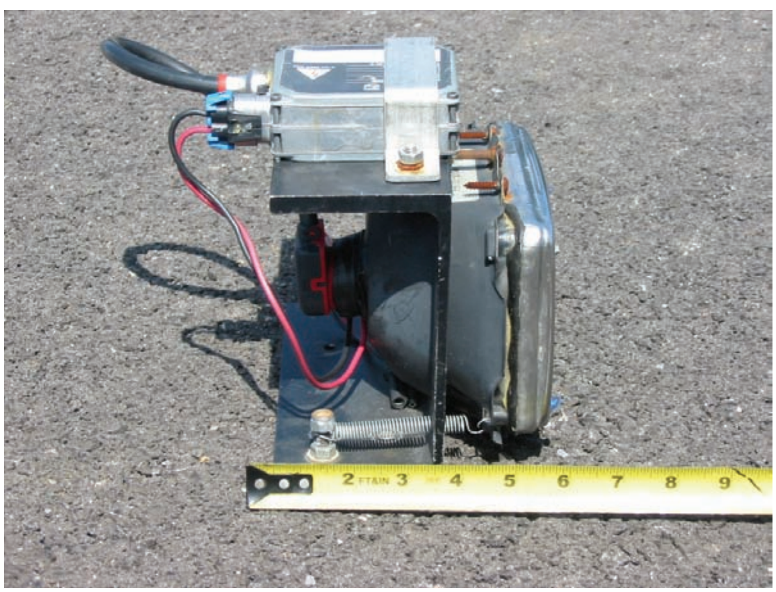


Figure 48. Photo. Hybrid UV–A side view.

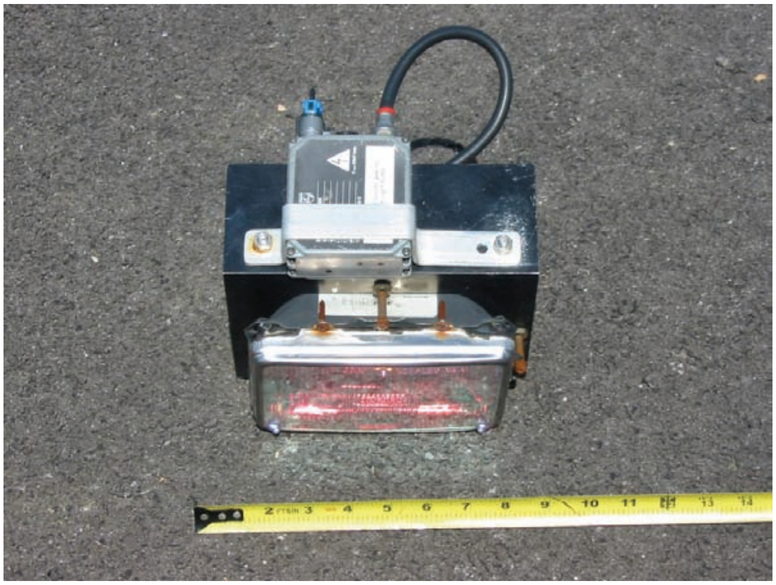


Figure 49. Photo. Hybrid UV–A plan view.

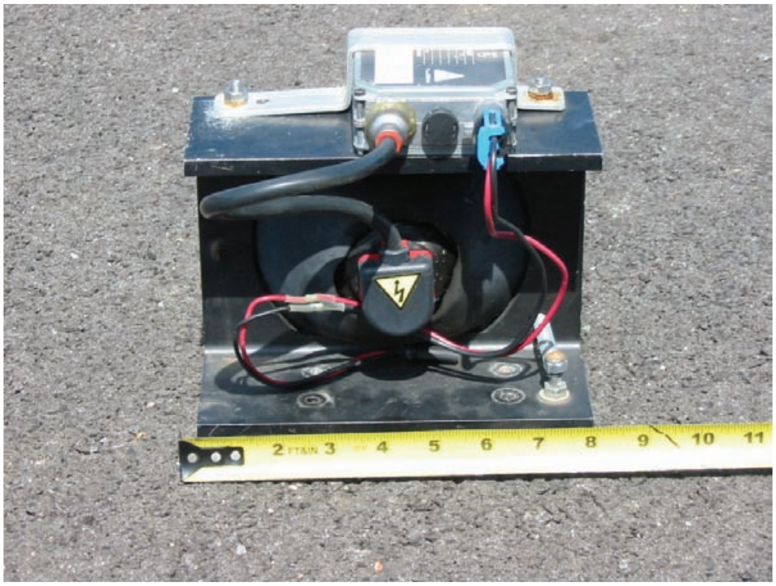


Figure 50. Photo. Hybrid UV–A rear view.

Radiant Intensity

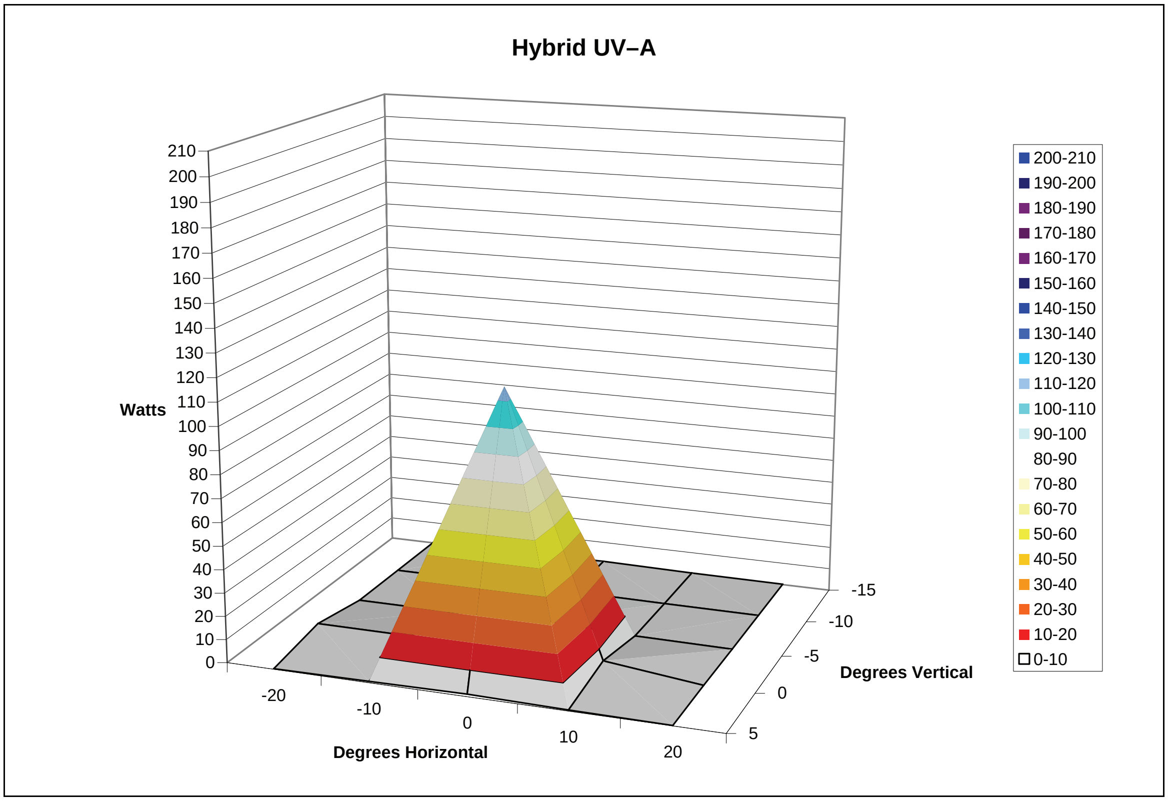


Figure 51. Graph. Hybrid UV–A radiant intensity.

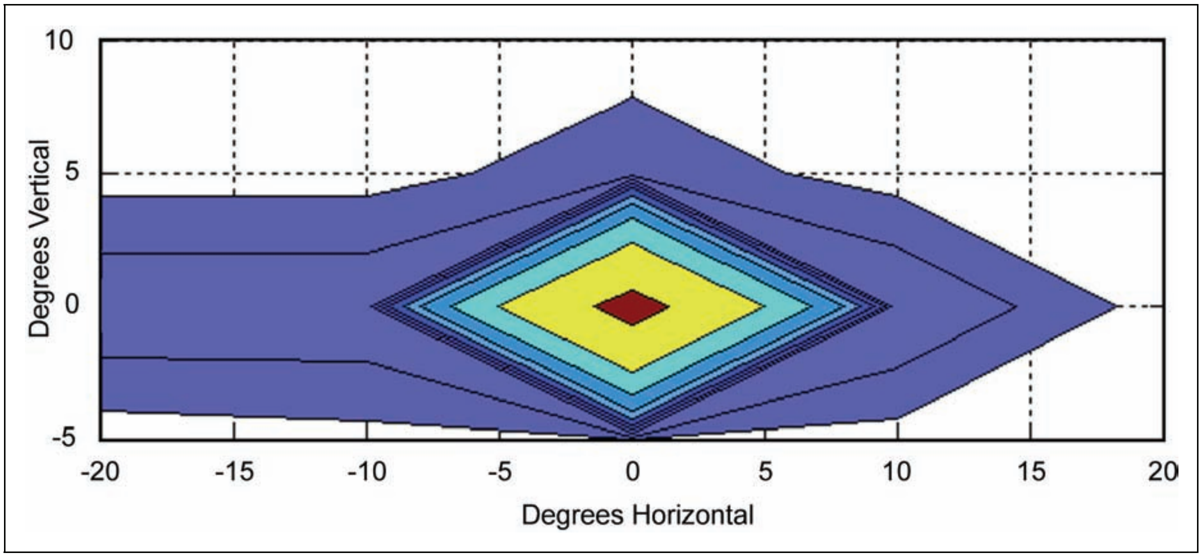


Figure 52. Graph. Hybrid UV–A isoWatt plot of radiant intensity.

UV–A

Table 23. UV–A description.

Lamp type	UV–A
ENV abbreviation	three UV–A and five UV–A (see figure 53)
In ENV volumes	III, IV, V, VI, VII, VIII
Max beam candlepower	201 W
Maximum beam location	0, 0

Upper row of headlamps used for three UV–A configurations.
Upper and lower rows of headlamps used for five UV–A configurations.

Figure 53. Photo. UV–A lamps on the rack mount.

Table 24. UV–A optical center position.

Mounting Type	VES Optical Center Height (inches)	VES Optical Center to Optical Center Distance (outermost lamps) (inches)
Rack mount (upper row)	33.75	19.00
Rack mount (lower row)	23.00	42.00

1 inch = 2.54 cm

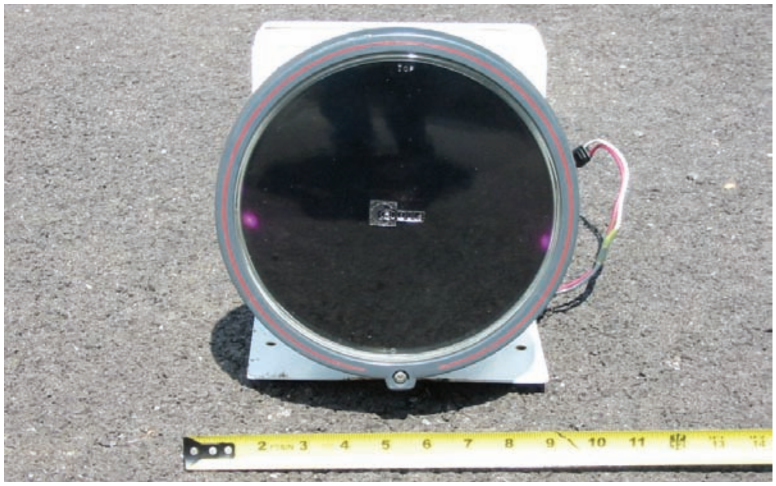


Figure 54. Photo. UV–A front view.

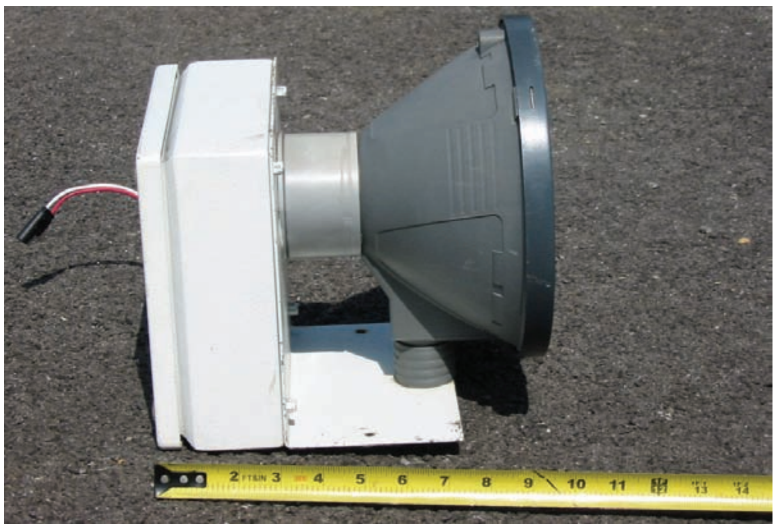


Figure 55. Photo. UV–A side view.

Figure 56. Photo. UV–A top view.

Radiant Intensity

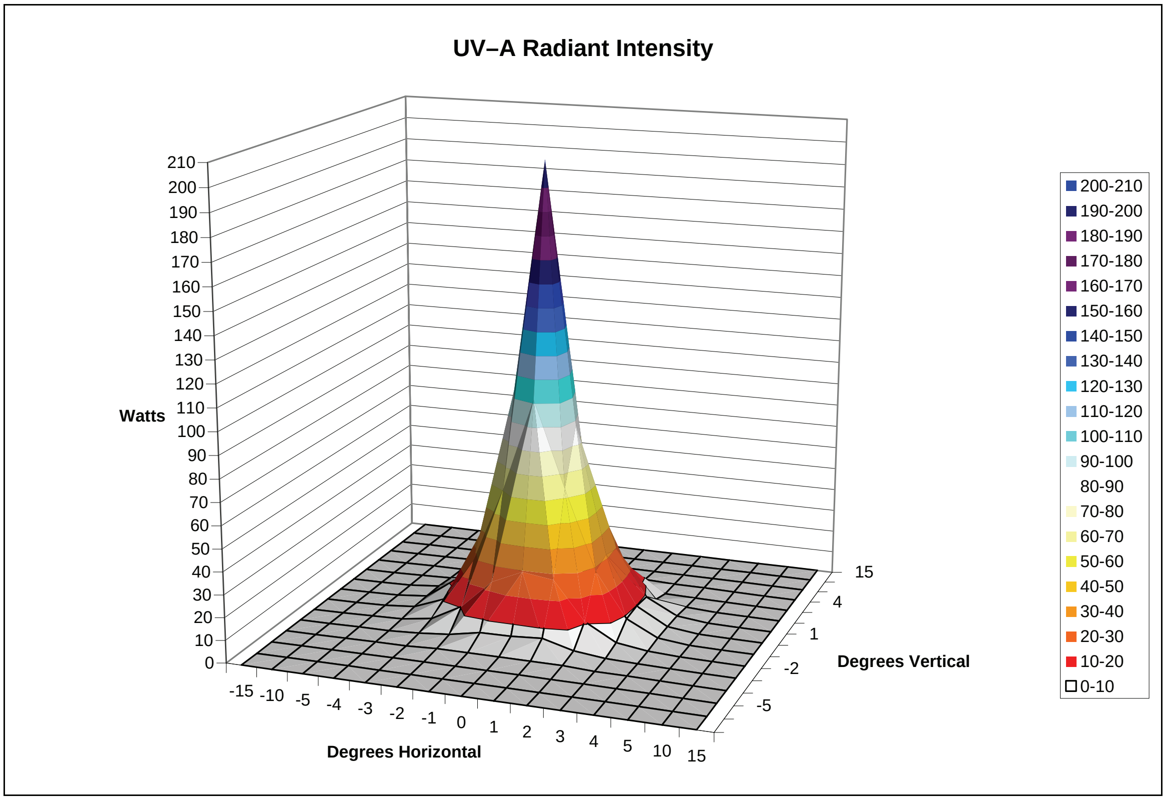


Figure 57. Graph. UV–A radiant intensity.

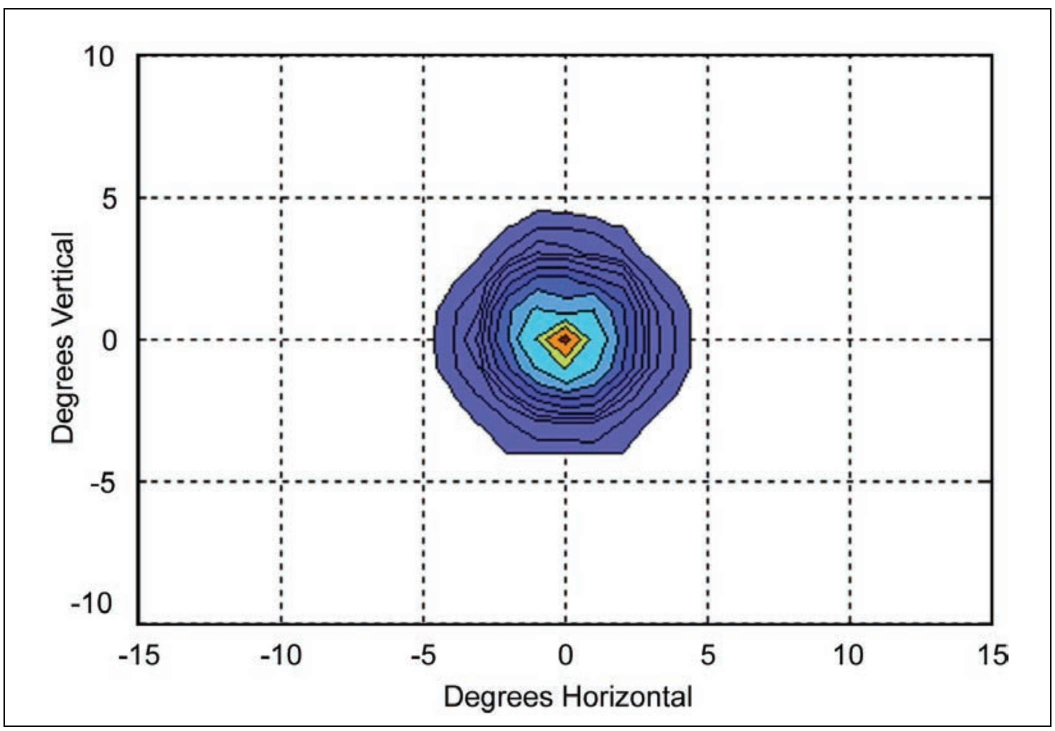


Figure 58. Graph. UV–A isoWatt plot of radiant intensity.

CHAPTER 5—HEADLAMP CHARACTERIZATION

In ENV Volume XV, *Influence of Beam Characteristics on Discomfort and Disability Glare*, the beam patterns of various headlamps were objectively classified for use as an independent variable. Accordingly, a method for comparatively determining the beam patterns was created. Headlamps were classified as low, medium, or high in relative intensity of the beam and as wide, medium, or narrow in the relative width of the beam. A comparison across all data from available designs was made by determining the width at the intensity level of 12,000 cd. This level was used because it was the closest region approximate to half of the maximum intensity (i.e., 50 percent beam angle) for the lowest available value obtained (25,978 cd) from all of the headlamp designs. Table 25 shows the beam characterizations of various headlamp designs and their extremes and norms. Table 26 shows the headlamps and their corresponding beam characteristics selected for use in ENV Volume XV.

Table 25. Headlamp characterization data.

Headlamp	Beam Width	Dist F @ 1.5 Lux	20 m / −3 Left	Hotspot Max	Left 2,000	Right 2,000	Width 2,000	Up 2,000	Down 2,000	Height 2,000
HID	Narrow	19.5	0.65Lux	34449 0.8D/2.6R	−23.5	23.5	47.0	0.5	−9.0	9.5
HLB*	Narrow	no data	no data	30139.84 2.0D/0R	−17.5	17.5	35.0	0.0	−7.5	7.5
HID/HID 4*	Narrow	20.5	0.45Lux	40778 1.0D/1.6R	−29.5	30.0	59.5	0.5	−8.0	8.5
HID	Narrow	19.0	0.55Lux	26984 0.8D/1.8R	−33.0	40.0	73.0	0.5	−7.0	7.5
HID	Narrow	23.5	0.65Lux	30666 1.4D/1.8R	−31.5	23.5	55.0	−0.5	−8.0	7.5
HID	Narrow	23.0	0.85Lux	32882 1.6D/1.8R	−22.0	26.5	48.5	0.0	−10.0	10.0
HID	Narrow	19.5	0.90Lux	27145 0.6D/2.0R	−23.5	27.0	50.5	0.0	−7.0	7.0
HID	Narrow	22.0	0.55Lux	38795 1.8D/2.0R	−27.0	27.0	54.0	0.0	−7.0	7.0
HID	Medium	21.5	0.75Lux	30753 1.2D/1.8R	−23.0	23.0	46.0	0.5	−8.0	8.5
HID	Medium	24.0	0.85Lux	39953 0.8D/2.0R	−22.5	31.0	53.5	0.0	−9.0	9.0
HID	Medium	26.0	0.75Lux	41431 1.4D/2.8R	−26.0	21.5	47.5	1.0	−7.0	8.0
HID	Medium	25.0	0.95Lux	41830 1.0D/2.2R	−29.5	33.5	63.0	0.0	−9.0	9.0
HID	Medium	21.5	0.75Lux	28120 0.8D/3.6R	−26.5	27.0	53.5	0.5	−8.5	9.0
HID 3*	Medium	21.5	0.65Lux	35771 0.8D/2.2R	−17.0	25.0	42.0	1.0	−6.5	7.5
HID	Medium	22.0	0.85Lux	28864 1.0D/1.8R	−31.0	33.5	64.5	1.5	−7.5	9.0
HID	Medium	24.0	0.75Lux	35916 1.8D/2.2R	−25.0	26.5	51.5	−0.5	−13.0	12.5
HID	Medium	22.0	0.95Lux	43430 0.8D/2.4R	−26.0	31.0	57.0	0.5	−8.0	8.5
HID	Wide	26.0	0.95Lux	45034 1.0D/2.4R	−27.0	35.0	62.0	1.0	−10.0	11.0
HID	Wide	22.5	0.95Lux	27127 1.4D/2.0R	−29.0	27.0	56.0	0.0	−7.5	7.5
HID	Wide	24.0	1.00Lux	36847 1.2/3.0R	−23.0	23.0	46.0	0.0	−7.5	7.5
HID	Wide	25.0	0.75Lux	41562 1.2D/2.0R	−22.5	25.5	48.0	0.0	−7.5	7.5
HID	Wide	24.0	0.85Lux	36061 1.6D/2.2R	−22.5	23.0	45.5	-0.5	−8.0	7.5
HID	Wide	24.5	1.00Lux	40472 0.8D/0.2R	−28.5	27.0	55.5	0.0	−15.0	15.0
HID 1*	Wide	20.0	0.95Lux	28772 0.2D/2.0R	−23.0	25.0	48.0	2.0	−5.5	7.5
HID	Wide	21.5	0.95Lux	25978 0.8D/3.2R	−35.5	42.0	77.5	1.5	−10.0	11.5
HID 2*	Wide	23.5	0.75Lux	43181 2.2D/.4R	−23.0	26.5	49.5	0.5	−7.0	7.5

* Headlamp selected for use in study.

Table 25. Headlamp characterization data. (continued)

Headlamp	Left 12,000	Right 12,000	Width 12,000	Up 12,000	Down 12,000	Height 12,000
	−3.0	6.0	9.0	0.5	−2.5	3.00
HLB*	−4.0	5.5	9.5	0.0	−3.25	3.25
HID/HID 4*	−3.5	6.0	9.5	0.0	−2.5	2.50
	−5.5	6.5	12.0	0.0	−2.0	2.00
	−7.0	7.0	14.0	0.0	−3.0	3.00
	−5.5	9.5	15.0	−0.5	−3.5	3.00
	−7.0	9.0	16.0	0.0	−4.0	4.00
	−9.0	8.0	17.0	−1.0	−4.0	3.00
	−7.5	10.5	18.0	0.0	−2.5	2.50
	−8.0	11.5	19.5	0.5	−2.5	3.00
	−8.5	11.0	19.5	0.0	−2.5	2.50
	−5.0	14.5	19.5	0.5	−2.0	2.50
	−8.0	12.0	20.0	1.0	−2.0	3.00
HID 3*	−9.0	11.0	20.0	0.5	−3.0	3.50
	−9.0	11.5	20.5	−0.5	−4.0	3.50
	−9.5	11.0	20.5	−1.0	−6.0	5.00
	−11.0	12.5	23.5	−0.5	−2.5	2.00
	−9.5	14.0	23.5	0.0	−3.5	3.50
	−13.0	11.0	24.0	0.0	−4.5	4.50
	−11.0	13.0	24.0	0.0	−3.0	3.00
	−11.0	13.0	24.0	−0.5	−3.0	2.50
	−11.0	13.5	24.5	0.0	−2.5	2.50
	−12.0	12.5	24.5	0.0	−4.0	4.00
HID 1*	−10.5	14.5	25.0	1.5	−2.5	4.00
	−12.5	13.5	26.0	0.0	−3.0	3.00
HID 2*	−13.0	13.5	26.5	0.0	−2.5	2.50

* Headlamp selected for use in study.

Table 26. Headlamp characterization matrix.

	Narrow Beam Width	Medium Beam Width	Wide Beam Width
High Beam Intensity	HID 1		HID 2
Medium Beam Intensity		HID 3	
Low Beam Intensity	HLB		HID/HID 4

APPENDIX A—PHASES II AND III HEADLAMP ALIGNMENT PROTOCOL

Protocol Summary

The protocol presented below represents the consensus of experts in the field on the appropriate procedure that should be followed for headlamp alignment:

- An alignment plate should be mounted onto the ground 35 ft from and parallel to the alignment wall.
- The alignment wall should be as flat as possible.
- The wheels should be straight against the plate and perpendicular to the alignment wall.
- The perpendicular position can be reached by creating a 90-degree angle configuration on the floor that will guide the vehicle to the right position. A simple "L" shape mark on the floor should suffice.
- A laser that marks the center of the vehicle should be used to make sure the screen is centered to the vehicle. Each vehicle should have its own line on the screen. The lines are labeled directly on the screen to avoid confusion.
- Markings of the photometric center of the headlamp beam should be performed for each headlamp with respect to the floor.
- The appropriate headlamps should be turned on, while making sure no auxiliary lights (parking lights, fog lights, daytime running lights) are on.
- One headlamp should be covered up or unplugged so that readings are taken for only one light at a time.
- For the HID, HLB, and HOH configurations, align the headlamps so that the "hotspot" is located in the lower right quadrant. This can be performed by positioning the photometer sensor tangent to both the horizontal and vertical lines. When measuring the hotspot in that quadrant, the outside top and left borders of the sensor's circumference (the sensor is 1 inch in diameter) need to touch both axes of the crosshairs. This will position the hotspot half an inch down and to the right from the center of the crosshair.
- The photometer should be "ZEROed" prior to checking each measurement. To do this, make sure that all headlamps are turned off. Remove the cap from the sensor. Place the sensor at the alignment location for the headlamp to be aligned. Press the "ZERO" button; this will allow the photometer to measure the background and remove its effects from the actual source value. After zeroing, turn the headlamp on and begin alignment.
- Adjustment of the headlight aim should be performed as needed.

The only difference between the alignment of the UV–A or HHB headlamps and this previous headlamp alignment procedure (HID, HLB, and HOH) is that the "hotspot" must be at the center of the crosshairs.

Detailed Protocol

Vehicle/Headlamp Combinations Acronym List:

BLK HID1	BLK HID 2	Black [SUV] High Intensity Discharge 1 & 2
BLK HLB 1	BLK HLB 2	Black [SUV] Halogen Low Beam 1 & 2
BLK LO UV–A 1	BLK LO UV–A 2	Black [SUV] Low output UV–A 1 & 2
WH HID 1	WH HID 2	White [SUV] High Intensity Discharge 1 & 2
WH HLB 1	WH HLB 2	White [SUV] Halogen Low Beam 1 & 2
WH MID/HI UV–A 1 thru WH MID/HI UV–A 5		White [SUV] Mid/High output UV–A 1 thru 5
P/U HOH(HHB) 1	P/U HOH(HHB) 2	Pickup Truck, High Output Halogen (Halogen High Beam)

Special Notes for Sim Bay Room Prep:

It is very important to make sure that you have enough time to align all of the headlights prior to the team meeting, especially prior to the road preparations. Minimum alignment time is 1 hour when no headlamps need to be switched between vehicles, but you should plan on 1 ¼ - 1 ½ hours as a general rule. Alignment times will be greater on days when headlamps must be moved.

Since we are leaving half of the lights on, it is important to remember to use the ZERO function on the photometer prior to aligning each light. This is particularly important when recording the photometer values on the Headlamp Alignment form.

1. Setting up the Non-UV–A headlamps

Applies to the following Vehicle/Headlamp combinations:

WH HID (1&2), BLK HID (1&2)

WH HLB (1&2), BLK HLB (1&2)

P/U HOH(HHB) (1&2)

Pull the vehicle up to the alignment plate mounted onto the ground. This should be located 35 feet from the alignment wall. Make sure the wheels are straight against the plate.

Use the laser to make sure the screen is centered to the vehicle. Each vehicle has a different line on the screen. The lines are labeled directly on the screen.

Locate the appropriate markings on the wall for each VES.

Turn on the appropriate headlamps, making sure no auxiliary lights (parking lights, fog lights, daytime running lights) are on.

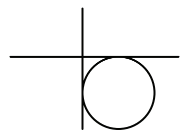
Cover up or unplug one headlamp so that you are only taking readings for one light at a time.

Align the VES so that the "hotspot" is located in the first (or lower right) quadrant, tangent to both the horizontal and vertical lines. The sensor, when measuring the hotspot in that quadrant, will touch both axes of the crosshairs. The headlamps have both gross and fine adjustments. Typically, only fine adjustments will be required if the headlights are not switched; gross will be required if the headlights are switched.

Note: Why do we align these lights off-center point?

When these types of lights are aligned straight ahead, the lights are placed in a "High Beam" configuration. *We do not want to use the "High Beam" for these configurations*. Our alignment procedure allows each light to be directed slightly to the right and below the exact center line for that light.

Hotspot Location: The circle represents the target hotspot location with respect to the target crosshairs. The center of the circle is the center of the hotspot.



To determine if the hotspot is in the correct location, you will need to use the International Light®, Inc., IL1400A Radiometer/Photometer to measure the area of greatest intensity. There are two sensors for the photometer; the sensor for the visible light is marked with a "REG" label, and the sensor for the UV light is marked with a "UV–A" label. Use the sensor marked "REG."

Remember to "ZERO" the photometer prior to checking each measurement. To do this, make sure that all headlamps are turned off. Remove the cap from the photometric sensor. Place the sensor at the alignment location for the headlamp to be aligned. Press the "ZERO" button; this will allow the photometer to measure any undesired background light and remove its effects from the actual light source value. The photometer is ready when the "ZEROING" message has changed back to the "SIGNAL" message. Turn the headlamp on and begin alignment.

Once you find the area you believe has the highest intensity, readings need to be taken in all directions around that location to ensure that is the hotspot. If the hotspot is in the correct location, the light is aligned and you can align the other light(s).

Remember that the HIDs require alignment with the photometer for rightmost (no. 2) headlamp and visual alignment based of the left (no. 1) headlamp based on the aligned right headlamp. This is noted on the alignment form.

2. Setting up the UV–A headlamps

Applies to the following Vehicle/Headlamp combinations:

- **WH MID/HI UV–A (1-5)**
- **BLK LO UV–A (1&2)**

Pull the vehicle up to the alignment plate on the ground. This should be located 35 feet from the alignment wall. Make sure the wheels are straight against the plate. In addition, the vehicle needs to be centered along the white line painted from the wall.

Turn on the appropriate headlamps, making sure no auxiliary lights (parking lights, fog lights, daytime running lights) are on.

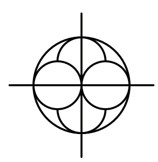
Locate the appropriate markings on the wall for that headlamp.

Cover up one headlamp so that you are only taking readings for one light at a time.

Align the headlamps so that the "hotspot" is located on the crosshairs. The UV–A low headlamps have fine adjustments. The UV–A high headlamps require shimming for the vertical location and wrench adjustments for the horizontal adjustment.

Note that it is sufficient to line up the sensor on the crosshairs such that at least the edge of the sensor touches the center of the crosshairs. This means that there is a circular space around the center of the crosshairs, with a radius the size of the sensor in all directions (about 2 inches in diameter), in which the hotspot may be found. This is a larger margin of alignment error than allowed for the non-UV lights and is due to the nature of the mounting of the lights.

Hotspot Location: The large outer circle represents the overall target area. The center of the large circle is the target hotspot location.



To determine if the hotspot is in the correct location, you will need to use the International Light, Inc., IL1400A Radiometer/Photometer to measure the area of greatest intensity. There are two sensors for the photometer; the sensor for the visible light is marked with a "REG" label, and the sensor for the UV light is marked with a "UV–A" label. For UV–A light, use the photometer sensor marked "UV–A."

Remember to "ZERO" the photometer prior to checking each measurement. To do this, make sure that all headlamps are turned off. Remove the cap from the photometric sensor. Place the sensor at the alignment location for the headlamp to be aligned. Press the "ZERO" button; this will allow the photometer to measure any undesired background light and remove its effects from the actual light source value. The photometer is ready when the “ZEROING” message has changed back to the “SIGNAL” message. Turn the headlamp on and begin alignment.

Once you find the area you believe has the highest intensity, readings need to be taken in all directions around that location to ensure that is the hotspot. If the hotspot is in the correct location, the headlamp is aligned and you can align the other light(s).

Reference values for the Various Headlamps:

Note: You look at this table as you look at the *wall* for calibration; it's backwards when looking directly at the vehicles.

P/U HOH(HHB) [Pickup truck]	
1 (Left)	*2 (Right)*
42.2 w/cm^2	45.2 w/cm^2

WH HID; BLK HID [either SUV]	
1 (Left)	*2 (Right)*
visual alignment based on other light	41.6 w/cm^2

WH HLB; BLK HLB [either SUV]	
1 (Left)	*2 (Right)*
44.7 w/cm^2	50.1 w/cm^2

BLK LO UV–A [Black SUV]	
1 (Left)	*2 (Right)*
100 μw/cm^2	92.0 μw/cm^2

WH MID/HI UV–A [White SUV]				
Top Row lights				
1 (Top Left)	*2 (Top Center)*		*3 (Top Right)*	
590 µw/cm^2	472 µw/cm^2		484 µw/cm^2	
Bottom Row lights				
4 (Bottom Left)		*5 (Bottom Right)*		
486 µw/cm^2		565 µw/cm^2		

Headlamp Alignment Date: _______________

Initials: _______________

Reference values for the various headlamps are included on the top line. Actual/current values are written inside each box as appropriate. Alignment data should be recorded once a week to provide a continuous record of the health of the headlamps. Note: You look at this table as you look at the *wall* for calibration; it's backwards when looking directly at the vehicles.

P/U HOH(HHB) [Pickup truck]	
1 (Left)	*2 (Right)*
42.2 w/cm^2 Actual:	45.2 w/cm^2 Actual:

WH HID; BLK HID [either SUV]	
1 (Left)	*2 (Right)*
visual alignment based on other light Actual:	41.6 w/cm^2 Actual:

WH HLB; BLK HLB [either SUV]	
1 (Left)	*2 (Right)*
44.7 w/cm^2 Actual:	50.1 w/cm^2 Actual:

BLK LO UV–A [Black SUV]	
1 (Left)	*2 (Right)*
100 µw/cm^2 Actual:	92.0 µw/cm^2 Actual:

WH MID/HI UV–A [White SUV]		
Top Row lights		
1 (Top Left)	*2 (Top Center)*	*3 (Top Right)*
590 µw/cm^2 Actual:	472 µw/cm^2 Actual:	484 µw/cm^2 Actual:

Bottom Row lights	
4 (Bottom Left)	*5 (Bottom Right)*
486 μw/cm^2 Actual:	565 μw/cm^2 Actual:

REFERENCES

1. Illuminating Engineering Society of North America. 2000. *IESNA Handbook*, Ninth Edition, New York.
2. Society of Automotive Engineers. 1989. *SAE Surface Vehicle Standard J602: Headlamp Aiming Device for Mechanically Aimable Headlamp Units*. Warrendale, PA: Society of Automotive Engineers.
3. Society of Automotive Engineers. 2004. *SAE Surface Vehicle Recommended Practice J575: Test Methods and Equipment for Lighting Devices and Components for Use on Vehicles Less than 2032 mm in Overall Width*. Warrendale, PA: Society of Automotive Engineers.
4. Society of Automotive Engineers. 2000. *SAE Surface Vehicle Information Report J1330: Photometry Laboratory Accuracy Guidelines*. Warrendale, PA: Society of Automotive Engineers.
5. Calderas, J., personal communication, August 22, 2000.
6. Erion, J., personal communication, June 5, 2000.
7. Dutke, F.F., personal communication, June 20, 2000.
8. Schnell, T., personal communication, August 24, 2000.
9. Wall, D., personal communication, November 1, 2004.
10. Society of Automotive Engineers. 1997. *SAE Surface Vehicle Standard J599: Lighting Inspection Code*. Warrendale, PA: Society of Automotive Engineers.
11. Society of Automotive Engineers. 1996. *SAE Surface Vehicle Recommended Practice J1383: Performance Requirements for Motor Vehicle Headlamps*. Warrendale, PA: Society of Automotive Engineers.
12. Copenhaver, M.M., & Jones, Jr., R.E. (1992). *Measurement of Headlamp Aim and the Electrical and Photometric Performance Characteristics of Rear Lighting Systems* (Tech. Report DOT HS 807 930). Washington, DC: National Highway Traffic Safety Administration.