

UMTRI-2001-19

**HIGH-BEAM AND LOW-BEAM
HEADLIGHTING PATTERNS IN
THE U.S. AND EUROPE AT
THE TURN OF THE MILLENNIUM**

**Brandon Schoettle
Michael Sivak
Michael J. Flannagan**

May 2001

HIGH-BEAM AND LOW-BEAM HEADLIGHTING PATTERNS IN
THE U.S. AND EUROPE AT THE TURN OF THE MILLENNIUM

Brandon Schoettle
Michael Sivak
Michael J. Flannagan

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

Report No. UMTRI-2001-19
May 2001

1. Report No. UMTRI-2001-19	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle High-Beam and Low-Beam Headlighting Patterns in the U.S. and Europe at the Turn of the Millennium		5. Report Date May 2001	
		6. Performing Organization Code 302753	
7. Author(s) Schoettle, B., Sivak, M., and Flannagan, M.J.		8. Performing Organization Report No. UMTRI-2001-19	
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.		10. Work Unit no. (TRAIS)	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety		13. Type of Report and Period Covered	
		14. Sponsoring Agency Code	
15. Supplementary Notes The Affiliation Program currently includes Adac Plastics, AGC America, Automotive Lighting, Avery Dennison, BMW, Corning, DaimlerChrysler, Denso, Donnelly, Federal-Mogul Lighting Products, Fiat, Ford, GE, Gentex, GM NAO Safety Center, Guardian Industries, Guide Corporation, Hella, Ichikoh Industries, Koito Manufacturing, LumiLeds, Magna International, Meridian Automotive Systems, North American Lighting, OSRAM Sylvania, Pennzoil-Quaker State, Philips Lighting, PPG Industries, Reflexite, Renault, Schefenacker International, Stanley Electric, TEXTRON Automotive, Valeo, Vidrio Plano, Visteon, Yoroka, 3M Personal Safety Products, and 3M Traffic Control Materials. Information about the Affiliation Program is available at: http://www.umich.edu/~industry/			
16. Abstract This study was designed to provide photometric information about current U.S. and European high- and low-beam headlamps. The sample included 20 headlamps manufactured for use on the 20 best-selling passenger vehicles for model year 2000 in the U.S., and 20 headlamps manufactured for use on the 20 best-selling passenger vehicles for model year 2000 in Europe. The vehicles sampled represent 49% and 47%, respectively, of all vehicles sold in the U.S. and in Europe. The lamps were purchased directly from vehicle dealerships. The photometric information for each lamp was weighted by the sales figures for the corresponding vehicle. The results are presented both in tabular form for the 25th-percentile, the median (50th-percentile), and the 75th-percentile luminous intensities, as well as in graphical form (for the median luminous intensities), both for high- and low-beam headlamps (from 45° left to 45° right, and from 5° down to 7° up).			
17. Key Words headlighting, headlamps, photometry, United States, Europe, low beams, high beams, passing beams, driving beams, sales, market weighted		18. Distribution Statement Unlimited	
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 29	22. Price

ACKNOWLEDGMENTS

Appreciation is extended to the members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research. The current members of the Program are:

Adac Plastics
AGC America
Automotive Lighting
Avery Dennison
BMW
Corning
DaimlerChrysler
Denso
Donnelly
Federal-Mogul Lighting Products
Fiat
Ford
GE
Gentex
GM NAO Safety Center
Guardian Industries
Guide Corporation
Hella
Ichikoh Industries
Koito Manufacturing
LumiLeds
Magna International
Meridian Automotive Systems
North American Lighting
OSRAM Sylvania
Pennzoil-Quaker State
Philips Lighting
PPG Industries
Reflexite
Renault
Schefenacker International
Stanley Electric
TEXTRON Automotive
Valeo
Vidrio Plano
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

We thank the Technical Research Centre of Finland for obtaining and shipping the European lamps, Walter Kosmatka for performing the photometry, and Lawrence Mead and Bernadette Ritley of GE Lighting for allowing us to use their facilities to perform the photometry.

CONTENTS

ACKNOWLEDGMENTS	ii
INTRODUCTION	1
METHOD.....	2
RESULTS.....	7
DISCUSSION.....	24
REFERENCES.....	25

INTRODUCTION

In 1997 we published a report that included a market-weighted description of low-beam headlighting patterns in the U.S. (Sivak, Flannagan, Kojima, & Traube, 1997). That information was based on the photometry of headlamps on the 23 best-selling passenger vehicles for model year 1997. A subsequent report contained a market-weighted description of low-beam headlighting patterns in Europe (Sivak, Flannagan, & Schoettle, 2000), based on the photometry of headlamps on the 20 best-selling passenger vehicles for model year 2000.

The present study was designed to (1) develop an analogous database of current U.S. and European high-beam headlamps, and (2) update the U.S. low-beam database. The main features of this study were as follows: First, the lamps to be photometered were purchased directly from vehicle dealerships, thus avoiding the potential selection problems with donated lamps. Second, the selected lamps were designed for use on 49% of all passenger vehicles currently being sold in the U.S., and 47% of all passenger vehicles currently being sold in 17 European countries. Third, the obtained photometric information was weighted by the current sales figures for the respective vehicle models.

METHOD

Approach

The approach consisted of the following steps:

- (1) Obtain a luminous-intensity matrix for lamps designed to be used on the best-selling passenger vehicles in the U.S. and Europe.
- (2) Use the current sales data for the respective vehicles (within each sample group) to derive a sales-weighted distribution of luminous intensities at each test point.
- (3) For each test point, calculate selected percentiles—25th, 50th (median), and 75th—of the sales-weighted distribution of luminous intensities.

Photometry

The measurements were made in a photometry laboratory using a goniophotometer. The aiming of all lamps was performed by the same person—a lighting engineer with 35 years of headlighting experience. (For the European low beams, the horizontal aim placed the right end of the horizontal part of the vertical cutoff at the vertical axis; the vertical aim was set by first aligning the vertical cutoff on the left side with the horizontal, and then displacing the beam 0.6° (1%) down.) The high beams were not re-aimed vertically or horizontally. A small lateral adjustment was made to position the high beam in the center of the goniophotometer rotation.

The lamps were allowed to heat up for three minutes before the measurements were taken. All measurements were made at 12.8 V (the same as in Sivak et al., 1997 and Sivak et al., 2000), with the appropriate bulb. (Because we were interested in real-world light output, we did not use a rated bulb.) The angular parameters for the photometry are shown in Table 1 by lamp sample.

Table 1
Angular parameters for the photometric data collection.

Sample	Beam type	Horizontal Range	Vertical Range	Step size	Number of test points
U.S.	High	45° L to 45° R	10° D to 10° U	0.5°	7,421
Europe	High	45° L to 45° R	10° D to 10° U	0.5°	7,421
U.S.	Low	45° L to 45° R	10° D to 10° U	0.25°	29,241
Europe	Low*	45° L to 45° R	5° D to 7° U	0.25°	17,689

* The European low beam is not a new sample. The data here are repeated from Sivak et al. (2000) for completeness.

Lamp selection

A total of 20 lamps, all for model year 2000, constituted each sample (40 lamps total). The U.S. lamps were purchased in March 2001 at vehicle dealerships in Ann Arbor, Michigan. All were left-side lamps for model year 2000 vehicles. The lamps were manufactured for use on the 20 best-selling passenger vehicles in the U.S. according to the sales data for the calendar year 2000.

The 20 U.S. vehicles sampled were as follows (in descending order of total U.S. sales): Ford F-series, Chevrolet Silverado, Ford Explorer, Toyota Camry, Honda Accord, Ford Taurus, Dodge Ram, Ford Ranger, Honda Civic, Ford Focus, Dodge Caravan/Grand Caravan, Jeep Grand Cherokee, Chevrolet Cavalier, Toyota Corolla, Chevrolet Blazer, Ford Windstar, Pontiac Grand Am, Ford Expedition, Chevrolet S-10 Pickup, and Chevrolet Malibu (Automotive News, 2001). These 20 vehicles constituted 49% of all passenger vehicles sold in the U.S. during 2000 (Automotive News, 2001).

The European lamps were purchased in June 2000 at vehicle dealerships in the Helsinki metropolitan area, Finland. All were left-side lamps for model year 2000 vehicles. The lamps were manufactured for use on the 20 best-selling passenger vehicles in Europe according to the sales data for the calendar year 1999. The European vehicle sales data included the following 17 countries (in descending order of total European sales): Germany, Italy, United Kingdom, France, Spain, The Netherlands, Belgium, Austria, Switzerland, Portugal, Sweden, Ireland, Denmark, Greece, Finland, Norway, and Luxembourg (Automotive News Europe, 2000). These 17 countries include all 15 members of the European Union, plus Norway and Switzerland.

The 20 European vehicles sampled were as follows (also in descending order of total sales): Volkswagen Golf, Opel Astra, Ford Focus, Renault Clio, Opel Corsa, Fiat Punto, Peugeot 206, Volkswagen Polo, Renault Megane, Volkswagen Passat, Ford Fiesta, Opel Vectra, BMW Series 3, Peugeot 306, Citroen Xsara, Renault Scenic/New Scenic (we tested a lamp for New Scenic), Ford Mondeo, Citroen Saxo, Peugeot 406, and Audi A4 (Automotive News Europe, 2000). These 20 vehicles constituted 47% of all passenger vehicles sold during 1999 (Automotive News Europe, 2000).

Lamp description

Several vehicles offered optional high-intensity discharge (HID) lamps, along with standard tungsten-halogen lamps. Our sample included only lamps with tungsten-halogen bulbs. A breakdown of lamps by light source for the 40 vehicle models surveyed is shown in Table 2.

Table 2
Breakdown of the light sources used in the tested lamps.

Sample	Beam type	Light Source	Number of vehicles	Sales-weighted Percentage
U.S.	High	HB1 (9004)	1	5.6
		HB2 (9003)*	3	12.3
		HB3 (9005)	7	35.0
		HB5 (9007)	9	47.0
		Subtotal	20	100.0
Europe	High	H1	6	30.7
		H4*	5	25.7
		H7	8	34.0
		HB3 (9005)	1	9.6
		Subtotal	20	100.0
U.S.	Low	HB1 (9004)	1	5.6
		HB2 (9003)*	3	12.3
		HB4 (9006)	7	35.0
		HB5 (9007)	9	47.0
		Subtotal	20	100.0
Europe	Low	H4*	5	25.7
		H7	14	67.9
		HB3 (9005)	1	6.4
		Subtotal	20	100.0

* H4 and HB2 (9003) bulbs are conceptually the same, differing only in acceptable manufacturing tolerances.

Summaries of several design features of the tested lamps are shown in Tables 3 through 5. The features covered are lamp optics (Table 3), lens material (Table 4), and aiming methods of the U.S. lamps (Table 5).

Table 3
Optics of the tested lamps.

Sample	Beam type	Optics	Number of vehicles	Sales-weighted percentage
U.S.	High	Complex reflector	13	60.6
		Lens optics	7	39.4
		Subtotal	20	100.0
Europe	High	Complex reflector	16	78.6
		Lens optics*	4	21.4
		Subtotal	20	100.0
U.S.	Low	Complex reflector	12	51.2
		Lens optics	8	48.8
		Subtotal	20	100.0
Europe	Low	Complex reflector	13	65.3
		Lens optics*	4	19.6
		Projector	3	15.1
		Subtotal	20	100.0

* In the European sample, one lamp used lens optics for the low beam and complex reflector for the high beam. Another lamp used projector for the low beam and lens optics for the high beam. These two designs account for the fact that although four vehicles are listed as having “lens optics” for each European beam type, the corresponding sales-weighted percentages are different.

Table 4
 Lens materials of the tested lamps.

Sample	Lens material	Number of vehicles	Sales-weighted percentage
U.S.	Plastic	20	100.0
	Glass	0	0.0
	Subtotal	20	100.0
Europe	Plastic	16	76.7
	Glass	4	23.3
	Subtotal	20	100.0

Table 5
 Aiming methods of the U.S. lamps.

Sample	Aiming method	Number of vehicles	Sales-weighted percentage
U.S.	Mechanical	12	61.8
	VOR	6	29.0
	VHAD	2	9.2
	Total	20	100.0

RESULTS

High beams

Table 6 lists the 25th percentile, the median, and the 75th percentile luminous intensities for the U.S. high beams. Analogous information for the European high beams is provided in Table 7. Please note that, because of space limitations, Tables 6 and 7 provide only subsets of the available data. Specifically, the horizontal steps in Tables 3 and 4 are 0.5° between 0° and 5° , 1° between 5° and 10° , and 5° between 10° and 45° (all for left or right); the vertical steps are 0.5° throughout. Furthermore, for consistency with the low-beam data to follow, the information for high beams is displayed only from 5° down to 7° up.

Figures 1 and 2 present isocandela diagrams corresponding to the median luminous intensities for the U.S. high beams and the European high beams, respectively.

Figures 3 and 4 present isoilluminance diagrams (in vertical lux) corresponding to the median illuminance incident on the roadway for the U.S. high beams and the European high beams, respectively. These calculations (and the calculations below for the low beams) assume that the lamp mounting height is 0.62 m and the lamp separation is 1.12 m (Sivak et al., 1996).

Low beams

Table 8 lists the 25th percentile, the median, and the 75th percentile luminous intensities for the U.S. low beams. Analogous information for the European low beams is provided in Table 9. As mentioned above for Tables 6 and 7, Tables 8 and 9 provide only subsets of the available data. The horizontal steps in Tables 8 and 9 are 0.5° between 0° and 5° , 1° between 5° and 10° , and 5° between 10° and 45° (all for left or right); the vertical steps are 0.5° throughout.

Figures 5 and 6 present isocandela diagrams corresponding to the median luminous intensities for the U.S. low beams and the European low beams, respectively.

Figures 7 and 8 present isoilluminance diagrams (in vertical lux) corresponding to the median illuminance incident on the roadway for the U.S. low beams and the European low beams, respectively.

Table 7

Luminous intensities (cd) for the sales-weighted sample representing the high-beam headlamps on current passenger vehicles in Europe. The entries in each cell are (from top to bottom) the 25th percentile, median (50th percentile), and 75th percentile. (Test voltage: 12.8 V.)

	45L	40L	35L	30L	25L	20L	15L	10L	9L	8L	7L	6L	5L	4.5L	4L	3.5L	3L	2.5L	2L	1.5L	1L	0.5L	0	
7U	123	118	129	88	83	83	102	170	180	193	205	221	218	219	214	216	216	224	234	239	246	253	253	
	179	176	160	137	133	111	148	201	228	253	309	311	343	353	352	362	392	441	472	461	469	474	465	
	253	234	190	193	164	196	202	265	308	329	356	373	438	448	465	493	512	515	587	678	701	725	745	
6.5U	113	112	119	94	85	80	128	175	187	200	212	237	251	245	241	235	255	277	282	296	312	314	297	
	170	176	159	129	130	122	162	246	265	300	316	352	384	408	410	411	414	446	477	501	524	524	534	
	230	215	219	182	173	194	211	341	413	450	447	481	525	553	556	577	618	687	711	806	848	901	956	
6U	112	112	109	95	87	80	141	179	181	201	223	260	270	265	261	265	306	338	371	373	365	342	318	
	178	178	155	135	121	127	184	273	302	358	417	450	465	471	493	553	533	540	548	567	581	590	588	
	238	224	182	176	171	202	206	508	552	607	616	622	636	680	721	735	758	785	835	940	1023	1041	1045	
5.5U	131	133	107	90	85	77	155	187	195	210	247	279	297	294	302	309	346	399	428	436	433	408	377	
	178	169	153	121	111	125	187	289	367	424	508	557	592	610	626	627	622	639	738	767	785	775	730	
	221	223	184	168	190	195	285	608	752	813	820	844	843	860	853	868	895	950	998	1064	1227	1307	1263	
5U	123	141	110	84	89	81	154	204	214	231	273	311	344	363	391	409	481	530	549	543	529	492	437	
	174	180	150	124	113	123	193	331	394	464	619	715	756	775	809	844	877	895	1015	1095	1147	1199	1256	
	221	219	174	166	207	189	422	796	963	1166	1261	1187	1185	1193	1421	1429	1382	1369	1389	1444	2002	2054	1904	
4.5U	127	134	109	82	85	88	153	216	246	269	320	396	459	501	529	544	568	663	716	712	698	663	620	
	172	180	150	119	111	124	195	406	489	562	796	937	1017	1042	1084	1141	1150	1282	1347	1533	1595	1641	1616	
	212	221	183	166	223	185	480	935	1150	1494	1724	1767	1810	1835	1879	1881	1793	1806	1777	1928	2650	2774	2738	
4U	120	131	105	79	82	95	153	248	310	350	417	579	651	711	768	881	981	1060	1100	1109	1102	1090	1076	
	169	166	154	124	124	124	203	552	613	763	1029	1195	1446	1438	1484	1443	1535	1657	2038	2113	2127	2130	2078	
	209	218	177	171	219	195	541	1146	1333	1704	2100	2163	2385	2511	2533	2556	2597	2715	2655	3018	3784	3905	3907	
3.5U	116	105	102	74	81	81	191	303	463	555	655	830	1106	1222	1402	1471	1747	2007	1868	1875	1931	1983	1968	
	162	158	150	121	122	130	205	727	896	1136	1595	1779	1927	1990	1983	2068	2108	2475	2612	2623	2591	2554	2507	
	200	225	179	164	216	216	684	1509	1706	2058	2607	3160	3246	3272	3300	3367	3495	3629	3749	4699	5220	5566	6109	
3U	110	105	97	81	80	91	193	374	633	866	946	1234	1717	1857	2040	2381	2951	2981	2978	3055	3024	2879	2852	
	164	152	139	125	131	129	225	1077	1387	1734	2366	2723	3037	3362	3370	3632	3570	3817	3974	4125	4314	4323	4204	3999
	202	207	172	167	184	250	811	1813	1949	2477	3147	4117	4201	4307	4495	4756	5161	5776	6168	7262	7547	8064	7640	
2.5U	102	97	94	81	89	83	176	402	749	1080	1350	1927	2706	2826	3046	3584	4010	4269	4662	4808	4739	4576	4340	
	158	147	147	126	120	129	230	1251	1779	2521	3154	3542	4178	4638	4928	5175	5642	6467	6642	6926	7050	6952	6733	
	190	203	177	177	197	261	1103	2176	2439	3040	3857	5145	5744	6141	6586	7093	7828	8440	8935	9808	11241	10497	10215	
2U	101	87	84	69	89	83	181	438	818	1479	2010	2734	3871	4111	5076	5961	6294	6584	6958	7260	7462	7062	6980	
	153	139	130	128	124	127	235	1445	2090	3095	4003	4372	6063	6688	7385	8010	8618	9882	10087	10112	10658	11099	10838	
	191	200	185	189	216	317	1353	2987	3256	3955	4807	7063	8354	8876	9560	10322	11064	11735	12564	14632	15129	16319	15835	
1.5U	90	83	83	60	80	82	191	469	869	1753	2650	3863	5255	5588	6644	7960	8643	9550	10483	11859	11762	10785	10458	
	150	146	130	136	117	127	265	1435	2250	3220	4936	5788	8016	9457	10610	12288	12723	14372	14780	14195	15544	15862	15822	
	191	193	181	196	228	288	1207	3609	4124	5118	5966	7960	10924	11505	12528	14046	15511	16792	18982	20860	22236	23661	24379	
1U	92	75	80	61	87	69	202	491	919	1801	3265	5252	7532	7907	9311	11461	12647	13912	15785	18761	19970	18856	16697	
	149	140	140	127	124	134	296	1608	3010	3755	5544	7178	9458	11525	14214	16097	17633	21335	23832	24417	24641	24479	24868	
	199	181	193	200	181	264	1210	3661	4756	6113	7617	9887	13235	15111	17355	19918	22129	24218	26060	28127	30028	34442	35553	
0.5U	94	80	67	59	50	60	202	540	1096	1858	3360	5784	8960	9739	10266	12072	16283	17922	20291	23233	28522	30227	31121	
	148	128	129	108	119	144	298	1595	2922	3796	5234	7677	11874	15046	17606	19975	22676	25261	29709	32470	35247	36485	36167	
	204	181	203	210	200	283	1164	3125	4117	5955	7768	10381	13985	16462	20763	24243	28678	33353	37708	41152	44382	44338	45319	
0	90	72	70	60	54	77	194	577	1060	2009	3736	6613	9154	10135	11576	13637	16841	18839	21034	23226	24794	25424	29664	
	146	135	121	110	125	141	280	1801	2839	3744	5238	7808	12160	15918	19315	22605	26115	30070	33935	38784	41863	46450	47862	
	200	190	209	203	210	321	1107	2844	4384	6406	7930	11359	16241	18820	21767	27392	33356	39393	44582	50078	53931	57979	53797	
0.5D	90	72	80	60	56	78	215	626	1084	2219	3512	5950	8424	10152	11730	13405	15612	16922	19111	21722	23558	23326	22629	
	152	137	121	121	135	140	275	1737	2349	3199	4533	7962	11543	13838	16045	19501	21737	24544	27371	30736	35688	44178	48867	
	200	173	193	191	259	346	1037	2514	3975	6677	8373	9965	14950	19283	24041	27401	32816	39450	44660	47916	51364	54526	55837	
1D	90	81	80	60	55	79	196	637	1005	1895	3780	5130	7579	8634	9812	11312	14863	15766	15930	17915	17713	16387	16501	
	171	130	133	121	128	140	333	1774	2475	3168	4236	6926	9594	11416	13078	14432	17195	19139	20171	22056	26183	30591	34144	
	186	190	222	190	229	359	974	2468	4325	6255	8053	9731	14306	17821	21903	25401	29649	35023	37488	43186	50072	49530	48172	
1.5D	81	78	80	63	60	81	210	617	994	1854	3106	3953	5488	6346	7165	8122	9676	9890	10088	9775	9914	10521	11834	
	148	144	128	111	132	130	335	1376	2016	2706	3807	6182	8223	9538	10763	11775	12522	13299	14466	15765	16323	17452	18706	
	181	186	219	186	235	286	764	2360	3273	5398	7227	8521	13866	15722	16972	19964	20938	24776	25427	25558	26349	28759	31372	
2D	86	71	78	63	60	76	212	582	948	1589	2153	2762	3967	4380	4727	5148	5329	5621	5664	6393	7159	7187	7595	
	143	140	140	109	140	140	350	1376	1891	2501	3295	5524	6820	7238	7600	8345	8727	9264	9849	10440	10215	9915	10393	
	181	185	214	197	231	284	678	2305	3242	4370	5799	7038	10387	11639	12759	14437	14136	14078	14199	15046	15811	16487	16998	
2.5D	86	81	73	71	60	79	205	566	863	1331	1790	2109	2700	2870	3106	3408	3632	3798	4069	4557	5171	5449	5	

	0.5R	1R	1.5R	2R	2.5R	3R	3.5R	4R	4.5R	5R	6R	7R	8R	9R	10R	15R	20R	25R	30R	35R	40R	45R
7U	256	260	253	256	252	254	253	249	247	242	231	216	192	180	163	92	52	46	32	21	12	8
	459	438	448	436	434	431	405	404	418	407	368	293	247	219	210	118	99	93	58	35	22	12
	729	737	784	793	747	727	710	659	609	574	501	452	423	399	339	181	145	116	72	71	44	23
6.5U	283	278	274	283	272	275	278	274	271	267	254	232	219	198	177	109	55	43	30	22	12	5
	520	485	491	490	474	452	474	501	529	504	448	368	311	255	222	132	99	83	62	35	23	12
	976	1000	1016	997	921	843	772	715	696	747	666	554	471	444	388	188	133	115	85	66	42	27
6U	313	309	319	313	316	350	352	337	327	327	300	259	231	220	197	103	65	44	36	19	10	4
	561	558	562	544	504	533	547	539	514	494	463	442	406	267	230	132	93	83	57	34	18	11
	1043	1049	1056	1044	963	927	914	895	855	831	824	650	510	464	422	196	122	115	95	74	42	27
5.5U	356	359	359	372	385	393	386	366	330	312	283	259	261	247	222	111	68	44	30	19	10	4
	691	688	691	679	641	653	610	607	588	561	515	495	439	370	272	134	97	88	64	34	19	11
	1277	1266	1227	1225	1200	1189	1142	1125	1085	1057	1038	842	662	491	459	222	134	117	95	68	36	29
5U	421	424	446	461	434	435	435	420	407	396	361	324	315	278	245	130	65	45	33	22	10	4
	1240	1158	1053	990	965	899	883	852	819	784	689	591	518	424	365	157	101	97	59	35	20	11
	1615	1655	1654	1600	1591	1633	1589	1539	1485	1450	1250	1043	850	835	661	222	141	118	96	61	37	32
4.5U	631	655	647	646	645	644	631	620	605	585	567	496	433	418	344	124	69	43	30	24	10	4
	1532	1422	1331	1262	1202	1162	1240	1176	1168	1143	936	776	643	539	487	164	100	88	70	40	20	11
	2623	2203	2185	2267	2267	2296	2213	2081	1973	1868	1481	1247	1076	1042	800	254	142	119	95	54	35	29
4U	1054	1075	1146	1222	1179	1141	1106	1067	1026	992	920	710	610	513	466	133	69	45	34	24	10	2
	1984	1860	1747	1674	1611	1549	1597	1633	1662	1586	1348	985	818	703	546	187	93	100	79	39	19	10
	3893	3689	3578	3393	3232	3152	3069	2929	2790	2496	1930	1668	1395	1305	1158	333	145	113	107	58	37	29
3.5U	1935	1889	1824	1775	1767	1701	1588	1486	1398	1339	1321	1187	775	617	548	144	65	43	33	18	10	5
	2401	2256	2136	2170	2176	2172	2143	2149	2269	2176	1880	1252	1035	876	704	218	101	103	64	37	18	10
	5993	5601	5241	5013	4698	4386	4134	3939	3755	3453	2676	2146	1807	1463	1266	383	135	114	93	66	36	27
3U	2879	2836	2631	2424	2367	2268	2164	2052	1946	1845	1685	1442	1053	642	521	146	70	43	34	18	9	4
	3860	3740	3660	3600	3634	3796	3841	3468	3309	3233	2763	1719	1340	1121	942	227	119	83	67	36	19	7
	7633	7584	7519	7181	7308	7055	6589	5866	5081	4313	3328	3011	2291	1704	1335	422	150	127	97	82	39	29
2.5U	4188	4079	3994	4144	3700	3555	3432	3422	3075	2686	2144	1897	1417	750	601	156	62	44	25	10	8	5
	6571	6576	6479	6417	6552	6587	6091	5528	5195	4815	3635	2444	1673	1403	1157	254	98	83	49	32	13	10
	10549	10268	10175	10387	10637	10906	9199	8200	6782	6338	5443	4132	3114	2259	1582	545	173	133	99	83	39	17
2U	6771	6549	6280	6332	5690	5420	5785	5448	4749	4239	3129	2428	1740	941	595	158	70	53	30	17	5	5
	10407	10461	10446	10712	10729	9791	8653	8095	7099	6116	4378	2889	2067	1736	1447	306	102	89	45	31	16	9
	15341	15251	15371	15639	15615	13857	13171	11531	9904	8460	7143	4758	3680	2639	1721	595	196	134	100	79	37	15
1.5U	10216	9880	9653	10272	9290	9287	8928	7867	6996	6149	4423	2926	2040	1023	663	160	70	50	30	10	5	5
	16086	15533	15720	15541	14492	12989	11288	10203	8816	7144	5215	3849	2655	2133	1727	342	99	87	45	29	10	5
	24148	22432	21841	21831	21343	19634	18156	16095	14233	12193	9545	5986	4665	3371	2169	660	231	144	100	79	32	14
1U	15962	16618	17564	15547	14368	13131	11525	10133	9104	7942	4856	3519	2361	1349	736	178	80	33	31	13	5	3
	25186	25306	25077	23660	19520	17457	14285	12758	10724	8951	6705	5032	3058	2302	1910	323	99	89	40	30	11	5
	36433	33750	32242	31924	28679	25082	22110	19233	16762	14924	10863	7502	5326	3675	2728	792	253	144	113	62	40	19
0.5U	29462	31250	29136	25923	20651	18123	14813	12332	11252	8776	5844	3610	2559	1437	785	192	89	36	28	12	5	5
	36325	37487	33327	29445	23887	20290	17472	15294	12611	11715	9393	6725	4315	2576	2162	306	106	83	43	30	11	10
	47251	46742	47467	42118	33994	30215	25939	23049	19055	16681	11736	9007	7104	4695	3526	1016	250	121	111	50	48	23
0	32931	33370	30448	27534	24264	19942	17431	13971	11971	9953	6446	3768	2885	1569	971	192	87	50	30	10	5	5
	45699	43345	39950	34221	29613	24200	20445	18634	16201	13916	10130	6707	4336	2536	2216	288	120	87	40	28	10	6
	54280	51399	45063	40138	34684	29987	25249	22034	18835	16534	12056	9750	6880	5204	4213	1146	230	104	96	49	40	20
0.5D	24932	26502	27164	28215	22392	17102	15912	14341	11083	9729	6401	4025	2851	1573	939	183	83	48	21	11	6	5
	48241	44287	38971	33789	30506	25142	21911	19040	16003	12770	9041	7253	5060	2588	2209	307	120	90	40	23	11	10
	53359	54222	48645	44541	37092	32151	27160	23458	21485	18425	13530	10761	7598	4994	3721	1115	243	100	107	51	50	19
1D	17418	18577	18364	20329	16856	14474	12497	10304	9180	7940	5754	3823	2867	1379	1087	168	76	49	23	10	5	4
	34350	33831	33488	31217	25358	22494	18853	16342	14088	11600	9292	6499	4204	2457	2064	283	119	99	40	30	10	6
	46820	42582	38046	34001	29894	24679	21392	18819	16556	14584	12344	10125	6918	4903	3596	1089	260	110	100	50	30	19
1.5D	12375	12720	12304	10933	10677	11900	11294	9595	8694	7209	5218	3342	2484	1231	1019	186	76	52	26	10	5	5
	20249	17369	16841	17176	16079	16023	15513	12906	11129	10139	7170	5784	2925	2132	1790	266	110	91	50	25	11	9
	33679	32627	29693	26110	22980	19469	16747	15162	13393	11777	9781	7648	5820	4454	3408	989	222	125	87	55	26	19
2D	7971	8199	8048	7947	7840	7783	7471	6734	6088	5716	4291	2731	1197	1026	899	156	75	54	20	11	6	4
	10763	10383	10265	11206	11075	10132	10553	9763	8378	7401	5484	4107	2821	1892	1418	225	109	90	46	30	17	5
	16955	16908	17736	16528	16587	14470	12008	10308	9316	8376	6780	5566	4521	3663	3097	865	187	107	95	67	30	12
2.5D	5683	6164	6125	5903	5282	4920	5486	5135	4672	4068	3067	1839	985	807	714	133	75	53	32	14	6	5
	6990	6938	6875	6861	6772	6671	6474	6594	5989	5210	4005	3162	2287	1548	1154	220	104	97	56	28	21	10
	11306	10971	10293	9662	10745	9747	8497	7169	6471	5897	5018	4370	3552	3017	2663	682	169	130	95	52	33	12
3D	4189	4168	3956	3994	3727	3609	3528	3650	3477	3056	2131	1390	919	669	583	137	71	47	35	14	6	5
	4768	4811	4851	4805	4572	4635	4539	4384	4039	3629	2887	2310	1727	1276	939	198	98	95	58	31	20	10
	7296	7105	6970	7040	6559	6168	5846	5126	4396	4071	3648	3125	267									

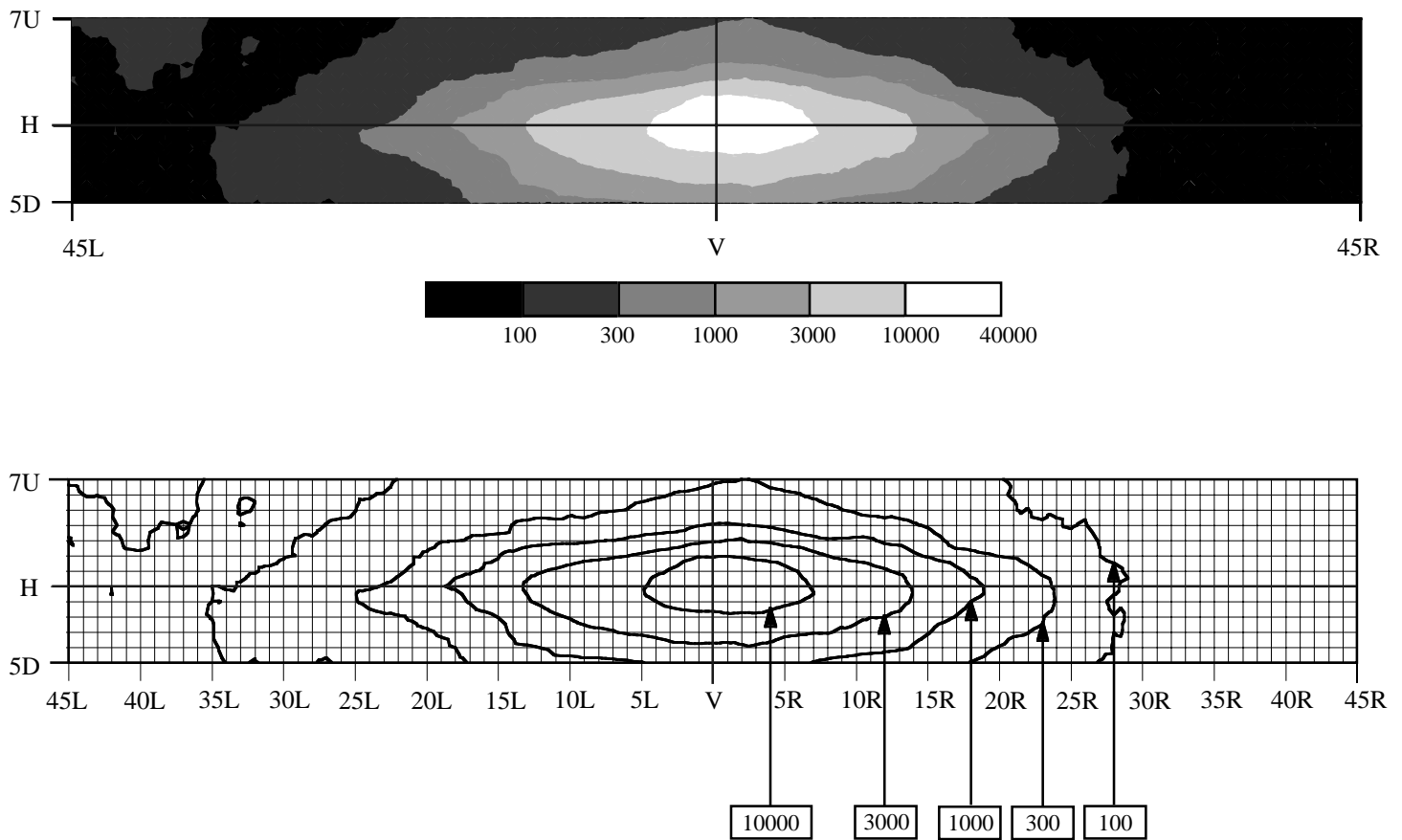


Figure 1. Isocandela diagrams of the median (50th percentile) luminous intensities for the sales-weighted sample representing the high-beam headlamps on current passenger vehicles in the U.S. The two panels represent the same information in different formats. (Test voltage: 12.8 V.)

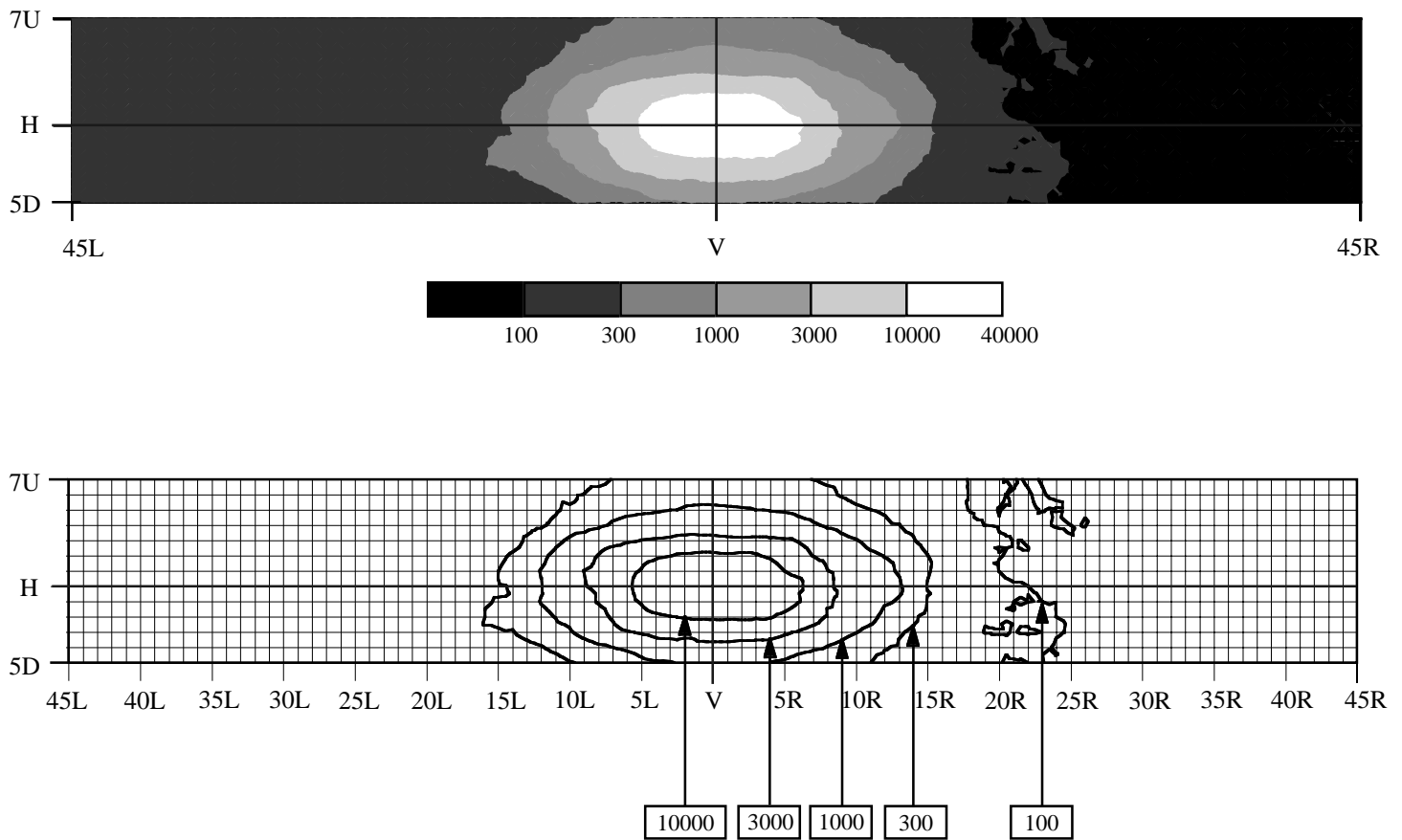


Figure 2. Isocandela diagrams of the median (50th percentile) luminous intensities for the sales-weighted sample representing the high-beam headlamps on current passenger vehicles in Europe. The two panels represent the same information in different formats. (Test voltage: 12.8 V.)

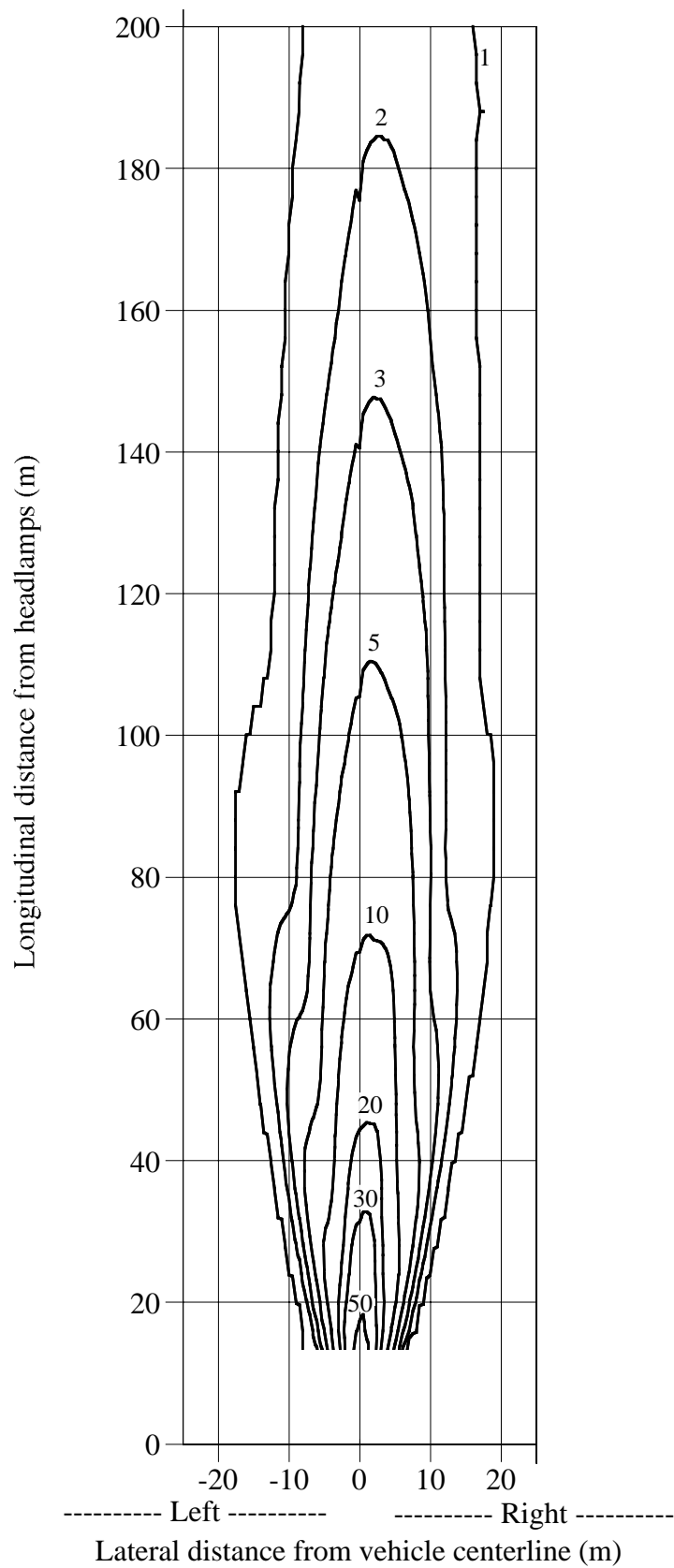


Figure 3. Isoilluminance diagram (in vertical lux) at the road surface from a pair of lamps having the median (50th percentile) luminous intensities for the sales-weighted sample representing the high-beam headlamps on current passenger vehicles in the U.S. (Test voltage: 12.8 V. Lamp mounting height: 0.62 m. Lamp separation: 1.12 m.)

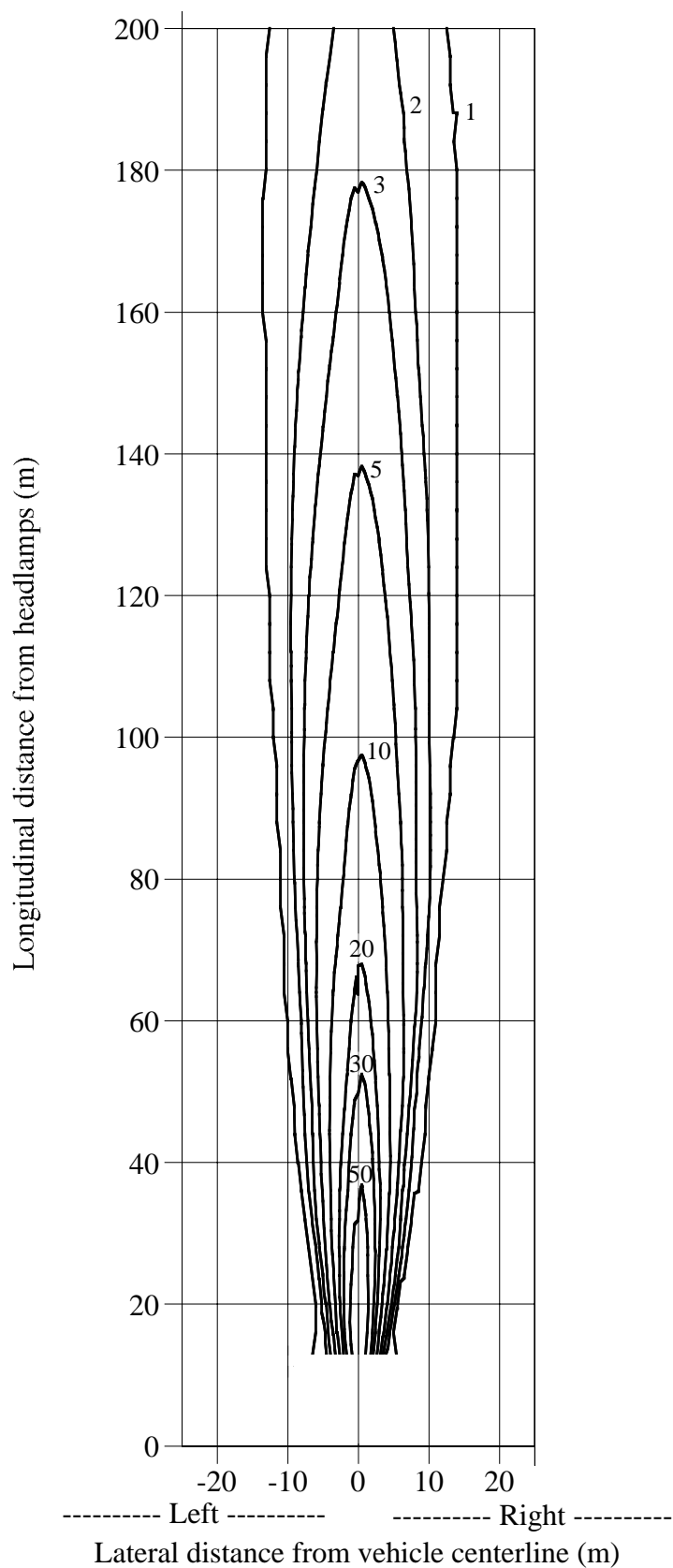


Figure4. Isoilluminance diagram (in vertical lux) at the road surface from a pair of lamps having the median (50th percentile) luminous intensities for the sales-weighted sample representing the high-beam headlamps on current passenger vehicles in Europe. (Test voltage: 12.8 V. Lamp mounting height: 0.62 m. Lamp separation: 1.12 m.)

Table 8
Luminous intensities (cd) for the sales-weighted sample representing the low-beam headlamps on current passenger vehicles in the U.S. The entries in each cell are (from top to bottom) the 25th percentile, median (50th percentile), and 75th percentile. (Test voltage: 12.8 V.)

	45L	40L	35L	30L	25L	20L	15L	10L	9L	8L	7L	6L	5L	4.5L	4L	3.5L	3L	2.5L	2L	1.5L	1L	0.5L	0
7U	8	13	14	20	22	26	35	46	43	44	45	47	48	49	50	51	52	54	55	56	57	58	59
	32	22	19	35	30	34	44	59	65	66	67	69	70	66	66	67	68	69	69	69	70	71	74
	64	60	58	48	47	53	63	69	74	81	87	86	82	81	82	84	91	88	87	85	87	86	87
6.5U	9	14	14	20	24	27	38	48	45	46	49	50	51	52	53	54	55	57	57	60	61	62	63
	34	22	19	23	30	35	45	66	69	72	72	74	72	72	72	71	71	73	73	73	75	78	80
	64	60	59	47	45	56	64	78	81	83	86	86	86	87	91	99	96	98	97	98	94	96	98
6U	10	14	14	21	25	28	40	51	50	48	50	54	56	56	57	58	58	60	61	63	66	67	67
	30	23	20	23	31	37	49	69	71	75	78	79	80	79	79	79	79	79	81	84	85	87	90
	62	58	60	47	46	60	68	86	89	96	101	104	103	100	103	111	109	108	111	104	104	106	109
5.5U	11	14	15	22	29	31	41	51	59	56	56	57	61	62	63	64	64	65	65	67	70	71	72
	32	25	21	24	33	40	52	73	77	82	83	84	83	83	84	86	86	88	90	93	96	97	99
	60	63	57	46	48	62	72	93	99	97	112	119	116	117	122	121	123	122	122	118	120	122	123
5U	12	15	16	22	30	32	44	51	63	65	61	63	66	68	71	74	71	72	73	74	76	77	78
	38	27	21	27	40	43	56	78	80	84	88	87	89	89	90	90	93	96	101	103	106	106	107
	57	64	55	48	51	66	75	99	108	108	109	116	119	124	137	132	134	137	138	132	138	142	142
4.5U	13	16	17	23	30	36	50	55	59	70	67	70	74	74	78	80	81	82	81	84	85	88	88
	36	28	22	31	45	47	62	87	89	89	94	94	95	95	96	99	102	105	111	114	117	120	121
	59	64	54	48	52	65	81	109	118	117	120	126	130	145	142	139	141	143	147	150	153	152	154
4U	14	18	17	23	31	38	53	63	66	70	77	82	85	85	91	94	94	91	93	96	99	99	104
	32	29	22	39	47	51	67	95	98	99	102	98	102	105	108	111	115	119	123	129	131	136	137
	60	64	55	49	54	68	88	117	124	123	129	134	145	153	152	152	155	157	161	167	170	177	183
3.5U	16	17	17	22	32	39	55	71	73	78	83	95	101	102	108	106	109	109	112	116	118	122	122
	30	29	23	43	54	56	73	102	107	110	104	109	115	118	122	125	130	133	141	147	150	159	163
	60	61	54	54	57	73	98	125	133	132	140	148	166	169	166	166	172	179	180	186	191	196	202
3U	17	18	16	23	32	41	61	82	88	91	97	104	113	117	121	127	132	139	147	153	165	174	184
	28	27	25	43	56	64	81	114	119	123	119	125	131	141	149	148	151	156	167	174	176	182	195
	59	57	54	56	64	83	110	136	145	150	165	168	189	191	188	192	198	202	211	214	221	227	237
2.5U	18	19	17	25	37	46	69	99	105	116	113	120	131	136	138	145	155	164	172	182	197	207	222
	28	28	30	44	61	76	88	115	126	136	139	146	155	162	174	190	200	206	222	235	241	253	259
	59	53	53	58	76	96	121	154	163	170	187	189	214	212	212	220	225	233	252	269	263	261	286
2U	18	18	19	26	35	55	75	116	125	136	134	146	164	166	165	172	182	194	206	221	244	263	270
	33	29	36	45	65	83	101	132	150	165	185	186	200	208	227	235	237	241	253	264	276	295	311
	57	55	54	70	92	111	135	177	189	194	205	216	238	239	245	261	274	286	329	327	329	348	364
1.5U	18	18	19	24	34	64	98	138	135	150	155	171	191	200	206	211	231	250	275	289	305	321	335
	39	29	41	50	69	97	121	193	212	225	234	253	263	269	276	285	293	296	307	322	343	361	393
	55	51	54	85	126	134	170	216	240	247	262	283	293	310	307	306	315	327	352	375	398	407	456
1U	18	18	14	23	35	70	118	171	183	189	211	230	254	270	281	291	296	300	314	329	351	389	409
	34	30	43	55	72	107	161	246	262	280	290	304	325	338	350	364	375	390	402	448	475	504	517
	55	54	61	88	163	216	210	279	323	324	347	368	364	370	381	396	416	438	477	497	533	632	697
0.5U	16	17	14	25	41	95	157	278	307	334	356	396	416	431	457	475	487	496	527	573	595	665	759
	26	31	40	60	85	146	250	345	390	409	442	451	471	477	484	505	543	586	666	707	777	887	1149
	54	53	63	90	219	376	303	402	437	454	499	524	555	576	604	607	689	691	786	962	1078	1156	1274
0	9	10	16	33	52	132	237	395	451	529	591	636	690	734	779	822	888	919	1014	1168	1344	1584	2135
	18	33	34	68	101	188	457	563	642	633	711	736	779	787	846	905	941	1023	1156	1267	1500	1900	2386
	53	53	68	98	281	559	759	819	831	850	879	964	1003	1040	1071	1084	1157	1185	1342	1557	1854	2177	2651
0.5D	5	5	10	45	90	188	368	736	808	905	992	1076	1205	1284	1230	1349	1499	1661	1866	2177	2592	3540	4748
	10	20	30	60	119	266	717	988	1110	1268	1646	1674	1633	1753	1876	1899	1896	1935	2305	2674	2960	4482	6110
	40	40	57	112	414	745	1250	1608	1678	1772	1837	1916	2122	2230	2431	2651	2992	3727	4022	4344	4722	5371	7526
1D	5	5	16	60	122	298	647	1465	1650	1802	1962	2108	2333	2621	2991	3251	3127	3287	3532	4011	4847	6552	9476
	9	20	30	100	190	454	1324	2201	2546	2821	3124	3289	3420	3540	3690	3930	4298	5126	5691	6012	6405	8154	10861
	40	40	65	129	565	1123	1849	2606	2789	3166	3380	3641	3954	4706	4739	5080	5760	6500	7670	8229	9262	10388	13732
1.5D	5	5	20	90	200	322	873	2226	2474	2956	3068	3300	3827	4123	4295	4590	4883	5216	5526	6019	7447	8794	10128
	10	20	30	118	271	631	1614	3018	3532	3908	4120	4315	4640	4850	5094	5610	6049	6796	7023	7690	8668	10730	14562
	40	40	71	156	719	1159	2620	3555	3863	4145	4687	5080	5440	5592	5985	6392	6991	8280	9450	10781	11920	13689	17027
2D	5	5	10	120	278	396	1208	2791	3102	3396	3757	4067	4398	4842	5157	5553	5840	5982	5917	6517	7358	8046	8977
	10	20	30	132	325	730	1833	3306	3759	4272	4520	4689	4978	5290	5619	6239	6663	7230	7780	8690	10000	11590	13424
	40	40	81	180	771	1254	2699	4292	4607	4781	5100	5380	5697	6089	6212	7071	8190	8795	9565	11398	12672	14500	17154
2.5D	5	5	10	120	296	468	1603	2843	3173	3630	3822	4132	4591	4910	5203	5500	5566	5617	5660	5760	6548	7155	7726
	10	20	30	174	424	809	2083	3519	3939	4243	4290	4504	4798	5053	5222	5900	6460	7186	7698	8358	9221	10191	10691
	40	40	90	230	784	1559	2659	4324	4574	4924	5362	5525	5732	5861	6316	6819	7722	8437	9679	11461	12358	13090	15098
3D	5	8	21	136	295	550	1664	2849	2827	2974	3273	3580	3944	4194	4326	4660	5019	5223	5471	5597	5741	6082	6246
	10	30	38	194	489	729	2152	3112	3356	3663	3999	4128	4535	4789	5045	5351	5967	5950	6028	6235	6928	7297	7828
	40	40	100	269	1030	1989	2506	3668	4332	4549	4778	4977	4969	5178	5728	6389	6659	7993	8431	9338	9687	9942	10763
3.5D	3	8	23	120	277	456	1632	2286	2401	2561	2699	2826	307										

	0.5R	1R	1.5R	2R	2.5R	3R	3.5R	4R	4.5R	5R	6R	7R	8R	9R	10R	15R	20R	25R	30R	35R	40R	45R
7U	61	62	62	62	63	63	62	62	62	61	54	51	49	48	46	40	32	17	11	4	2	1
	76	78	80	82	83	84	84	83	80	76	71	67	65	62	59	45	38	27	21	9	5	4
	88	90	90	93	94	95	92	91	89	89	87	87	85	80	74	62	51	43	38	26	19	13
6.5U	63	65	65	67	66	66	66	66	66	61	58	55	52	52	50	42	33	18	11	4	2	1
	82	84	86	88	89	88	88	88	89	84	77	71	70	68	66	50	44	29	21	10	5	4
	100	104	104	106	106	107	106	103	102	101	100	99	96	90	84	66	56	42	40	27	19	13
6U	66	69	71	71	70	70	69	69	69	67	63	59	58	58	55	43	33	21	13	4	2	1
	88	90	95	96	96	94	93	91	89	88	82	77	76	74	71	53	46	29	20	10	7	4
	113	116	117	119	120	123	123	120	118	114	119	112	107	101	92	70	55	42	40	26	17	13
5.5U	73	75	78	79	78	77	77	76	74	72	69	66	66	60	58	45	36	22	14	4	2	1
	101	103	104	105	105	104	99	98	97	97	93	87	83	81	75	58	45	31	22	10	7	4
	126	132	136	137	135	142	150	149	144	140	133	123	111	109	101	76	59	51	40	25	18	13
5U	80	82	86	88	89	88	87	86	84	81	75	75	72	66	60	54	43	24	13	5	2	1
	111	114	116	117	118	116	116	115	115	114	108	99	96	91	85	63	49	36	24	10	6	4
	148	150	155	157	156	167	168	165	156	149	134	120	119	122	110	85	63	54	41	26	19	13
4.5U	90	92	94	98	104	102	100	99	97	91	85	80	78	77	78	59	45	26	13	5	2	1
	123	127	130	131	133	131	130	129	128	126	122	120	116	102	100	71	54	38	28	11	7	4
	162	173	180	184	191	194	190	189	185	179	169	160	148	131	121	92	65	53	42	28	21	13
4U	104	108	110	112	113	111	110	115	117	107	94	91	89	87	87	65	53	27	15	6	2	1
	142	148	152	152	153	152	153	151	149	145	140	135	128	121	116	80	60	41	30	13	7	5
	189	192	200	200	202	194	186	184	187	187	179	160	153	143	132	99	72	56	43	28	23	13
3.5U	120	120	122	125	127	133	135	135	137	133	112	104	101	97	102	72	52	33	16	6	2	1
	166	173	179	178	177	176	176	175	175	176	164	154	142	133	132	90	68	43	30	14	9	3
	211	219	222	223	220	215	207	205	205	208	193	177	172	155	144	109	85	57	48	27	25	14
3U	191	196	161	159	160	163	164	172	172	160	147	133	126	128	127	83	54	33	16	6	2	1
	211	210	210	216	213	212	216	214	211	202	191	181	164	151	147	102	71	46	33	15	9	3
	243	252	259	257	255	252	253	250	241	230	229	200	201	187	164	121	99	64	51	29	24	14
2.5U	241	242	242	248	238	236	234	229	225	207	190	177	180	162	147	103	61	34	18	7	2	1
	272	291	276	266	264	262	260	252	246	248	214	209	194	189	172	118	76	49	31	17	10	4
	290	303	298	301	302	296	293	288	276	276	260	246	234	215	196	138	118	72	53	30	23	14
2U	279	285	304	298	298	301	292	280	275	268	244	228	213	192	171	124	75	37	23	8	3	1
	334	349	348	348	345	330	322	306	299	292	271	267	254	229	194	143	83	49	31	17	10	4
	376	406	413	394	404	396	360	349	333	333	320	298	285	265	247	187	136	81	53	29	22	14
1.5U	334	339	345	355	360	363	352	343	340	328	300	266	253	225	196	144	88	49	26	11	4	1
	415	431	437	446	460	462	440	435	397	385	360	333	304	265	231	162	101	66	40	18	11	6
	498	516	544	565	515	518	497	479	467	445	397	370	364	335	300	213	151	94	57	28	21	13
1U	432	450	471	451	459	466	441	438	454	414	375	327	330	284	257	174	106	60	31	11	3	1
	544	557	576	613	622	614	598	587	567	540	493	439	373	323	309	212	153	106	50	24	10	4
	821	802	839	838	815	796	786	758	710	674	570	511	503	477	404	253	193	110	69	30	20	13
0.5U	901	969	994	1032	1006	954	891	872	795	715	584	501	467	407	365	244	128	75	39	10	1	1
	1159	1252	1341	1318	1293	1235	1144	1117	1153	1123	811	662	581	488	460	297	259	135	57	25	9	3
	1435	1635	1709	1796	1786	1821	1775	1653	1632	1557	1285	956	850	810	767	429	311	192	110	46	21	13
0	2628	3270	4047	4634	4661	4088	3480	2985	2458	1945	1271	998	866	632	580	316	178	93	42	9	2	1
	3216	3779	4467	4822	5031	4461	4250	3730	3342	3101	2237	1387	1066	885	810	540	334	170	73	23	5	4
	3584	4880	5100	5477	5626	6002	5135	4961	4974	4717	3616	2810	2069	1687	1498	742	545	320	146	48	20	13
0.5D	6907	8960	11652	13117	13873	13625	12447	9788	7309	6057	3285	2423	1930	1424	1153	554	277	123	41	5	5	3
	8551	11684	13537	14732	14581	14402	13526	12236	10484	7555	4530	2820	2274	1750	1650	893	506	250	78	13	5	5
	10323	13220	15158	16699	17454	16720	15105	13613	11794	9863	7168	5058	3695	3020	2552	1457	782	414	155	20	10	5
1D	12414	15766	18502	20640	21201	19919	17826	15565	12862	10353	6875	4145	3300	2636	2057	1057	512	191	67	5	5	5
	13838	17669	20182	21175	22212	21940	20972	17946	14595	12377	7401	5329	4209	3270	2861	1424	671	313	101	10	5	5
	17321	20533	22465	25310	26760	25274	23441	21413	18755	14855	8475	6496	4915	4261	3521	2599	1451	555	224	30	10	5
1.5D	11856	13204	14887	16151	16416	16269	14304	13101	11796	10195	7828	6013	4663	3910	3288	1398	610	253	80	5	5	3
	19466	21013	21891	22104	24440	25548	24337	20711	15902	13545	10362	6070	5030	4189	3864	2307	1083	336	135	10	5	5
	20428	23171	25183	27289	27938	27340	27986	25096	22627	20124	11853	9397	7410	6000	4780	3362	2360	578	236	30	10	5
2D	9554	10501	12375	13689	14355	12856	12274	10617	9696	9140	7795	6372	5374	4773	4307	1816	778	311	98	5	5	5
	15997	16438	16623	18140	20509	21122	20840	19582	16688	14459	10660	7813	6259	5297	4803	3024	1256	409	179	17	5	5
	19816	21797	23066	23716	24420	23897	23296	22017	20451	19377	12800	9994	8015	6538	5701	4276	2801	854	275	30	10	7
2.5D	8595	9331	10076	10134	10441	10793	9678	9338	8679	7966	7333	6351	5704	4956	4549	2146	983	363	122	5	5	5
	11514	12203	12616	13535	15018	14444	13597	13152	12506	11796	9778	7218	6019	5642	5337	3423	1388	529	219	20	5	5
	16883	17718	17659	17900	18839	18678	18313	17763	16104	14656	11622	9408	8438	7726	6676	4513	2998	1093	325	30	10	10
3D	7063	7604	7862	8001	8113	7689	7278	7323	7051	6947	6565	5629	5047	4515	3986	2394	1150	392	120	5	5	2
	8524	8823	9151	9170	8883	8698	8500	8359	8347	8341	7040	6355	6000	5619	4970	3098	1419	741	243	26	5	5
	12098	12610	12136	12586	12611	12724	12270	12266	13243	13233	9346	7698	6903	6517	6293	4539	2710	1494	528	33	11	11
3.5D	5641	6184	5524	5322	5335	5932	5694	5755	5415	5375	5335	4886	4396	3935	3490	2462	1103	364	189	6	2	1
	6318	6419	6557	6674	6603	6621	6570	6581	6566	6325	6155	5631	5289	5039	4789	2804	1395	767	295	28	5	3
	8429	8836	9031	8597	8180	8107	8295	8252	8207	7734												

Table 9
Luminous intensities (cd) for the sales-weighted sample representing the low-beam headlamps on current passenger vehicles in Europe. The entries in each cell are (from top to bottom) the 25th percentile, median (50th percentile), and 75th percentile. (Test voltage: 12.8 V.)

	45L	40L	35L	30L	25L	20L	15L	10L	9L	8L	7L	6L	5L	4.5L	4L	3.5L	3L	2.5L	2L	1.5L	1L	0.5L	0
7U	15	15	15	17	23	32	35	44	44	44	43	42	42	44	45	44	43	43	44	44	44	44	44
	30	22	22	28	35	41	44	52	52	52	54	56	59	60	59	60	61	60	62	64	65	69	71
	72	59	45	54	59	78	93	103	105	107	117	113	128	126	123	126	123	123	118	117	125	125	124
6.5U	15	15	15	17	23	32	37	47	47	46	45	44	44	45	47	45	46	46	47	47	47	47	49
	31	22	23	32	35	41	49	55	56	57	58	59	62	65	66	66	66	67	66	68	69	71	72
	69	55	43	53	66	79	96	110	116	119	123	120	131	130	129	127	130	129	125	124	126	125	125
6U	18	13	15	17	24	33	41	49	51	52	48	49	47	48	49	48	59	59	63	55	55	55	54
	28	22	23	33	36	41	56	59	62	60	63	63	63	64	67	69	68	69	71	72	73	75	77
	65	55	41	51	74	82	102	120	121	127	123	127	136	138	140	139	134	131	129	134	129	127	126
5.5U	19	13	15	19	24	34	39	51	52	51	49	52	52	55	55	53	54	54	56	75	61	60	60
	28	22	25	34	38	43	52	64	67	68	69	71	72	70	69	70	72	74	75	77	81	80	79
	60	55	40	54	76	81	110	136	127	129	133	146	147	150	148	148	141	135	133	137	139	135	134
5U	18	12	15	19	25	35	42	51	53	56	53	53	55	57	58	58	57	58	57	60	58	60	60
	28	22	26	32	39	44	48	66	68	72	72	74	79	84	82	85	85	84	82	84	87	91	93
	55	62	38	52	73	81	116	142	146	144	145	154	154	153	158	154	151	149	148	147	147	145	139
4.5U	18	13	15	19	25	37	41	54	56	58	56	58	60	61	59	60	59	60	62	64	62	63	63
	28	23	26	32	40	47	53	76	76	78	79	81	81	81	81	83	88	92	96	106	108	111	116
	55	53	36	52	66	84	124	145	153	166	158	163	164	165	164	164	163	161	159	162	165	167	168
4U	19	14	15	20	26	37	40	57	57	59	61	65	68	68	66	67	66	67	72	69	69	66	67
	27	27	28	35	41	52	57	79	84	83	88	88	89	90	91	92	94	96	98	102	110	118	128
	52	58	39	55	68	91	133	147	159	177	179	176	179	172	171	174	174	173	176	182	185	188	189
3.5U	20	16	14	19	27	38	44	57	60	64	65	65	68	69	70	71	72	72	73	77	72	71	72
	25	36	29	37	42	54	63	86	87	91	96	94	98	99	102	103	105	106	108	113	118	118	121
	73	61	39	53	71	100	140	155	163	184	189	186	187	181	181	186	186	184	190	196	200	203	204
3U	19	18	14	17	30	37	47	58	62	67	69	69	72	72	72	73	75	77	80	84	82	81	82
	24	36	29	38	44	57	71	96	96	101	107	112	116	113	112	116	119	122	124	128	129	132	135
	66	57	41	51	76	103	148	165	175	188	203	206	196	193	195	198	200	198	200	206	210	213	213
2.5U	20	18	14	17	28	38	51	64	66	71	74	79	81	82	82	83	85	91	96	96	95	96	96
	24	37	29	39	50	63	81	102	105	112	119	125	125	127	128	132	137	141	144	147	152	155	158
	71	57	42	55	82	108	155	180	194	205	216	228	215	214	218	220	221	222	222	226	232	237	238
2U	19	19	16	17	29	41	52	71	74	77	78	83	88	88	90	92	94	99	108	111	110	112	113
	23	36	30	39	52	75	92	113	118	126	135	140	142	145	149	154	160	164	170	176	181	185	188
	66	58	43	56	86	117	164	203	214	228	240	252	246	247	248	253	254	257	258	261	269	274	277
1.5U	16	20	18	22	34	45	56	85	92	93	92	94	98	100	105	107	110	113	118	120	121	122	125
	23	37	32	42	56	85	109	130	135	146	156	164	170	174	184	191	197	204	211	209	219	225	231
	65	56	50	61	89	123	176	219	232	250	265	282	282	280	284	290	290	292	296	302	305	311	313
1U	15	20	18	29	38	53	65	109	116	126	117	116	119	117	119	123	127	132	135	139	141	142	144
	23	46	36	43	59	110	129	159	164	178	193	203	213	219	227	232	252	256	258	269	278	276	278
	62	57	53	66	95	132	195	244	258	270	296	328	328	321	319	327	329	332	339	337	343	351	365
0.5U	13	18	18	39	41	62	87	136	149	151	157	172	164	163	161	161	163	167	174	191	212	216	217
	21	51	38	64	75	123	167	201	205	221	241	248	258	264	273	284	294	301	316	329	333	334	339
	64	58	60	80	106	149	207	255	273	296	336	374	382	384	382	382	378	378	384	394	408	420	451
0	11	18	13	36	53	82	111	146	194	224	251	266	234	235	226	227	237	257	294	325	332	341	331
	20	30	39	74	112	163	200	257	290	311	339	340	359	361	371	373	374	396	419	424	462	492	535
	64	55	59	87	140	219	337	320	330	357	414	464	463	470	474	481	494	511	529	543	563	606	665
0.5D	5	11	6	40	81	130	214	351	384	419	468	517	552	591	595	614	614	612	650	663	683	701	921
	14	25	31	62	140	190	330	491	530	651	790	806	831	885	995	1042	1055	1043	1000	1016	1233	1300	1400
	59	42	55	102	252	469	879	731	795	904	998	1065	1197	1250	1232	1275	1332	1265	1474	1605	1539	1710	2230
1D	5	5	6	59	112	232	465	1565	1887	1882	2164	2262	2380	2551	3048	3838	3897	4165	4426	4827	5297	5982	7132
	5	25	25	78	279	588	910	2364	2302	2603	3058	3422	3836	4012	4391	4391	5282	6335	6268	6260	7638	9481	10230
	44	40	44	169	446	828	1776	2650	3021	3768	4770	5582	6762	7106	6756	6877	7688	8144	9893	10967	10996	14012	15308
1.5D	5	5	6	50	151	373	973	2175	2539	2956	3574	4331	4916	5076	5342	5751	6171	6533	7576	7847	8179	8912	9168
	5	20	34	140	381	872	1551	3356	3764	4306	4989	6105	6689	7232	7884	7966	8589	9821	11037	11995	12856	15275	16940
	36	39	43	255	510	1057	2467	5431	5863	6019	6833	7454	8192	8995	9600	10306	11677	12943	14973	16361	17479	18800	19629
2D	5	5	5	37	177	523	1275	2363	2856	3496	4095	4568	4894	5065	5415	5974	6656	7440	7773	8153	8338	8523	8781
	5	10	27	194	420	897	1997	3843	4157	4252	4836	6360	7799	8158	8948	9851	10831	11964	12638	13192	13782	15423	17721
	26	32	66	260	636	1498	3303	6474	7935	8375	9394	10254	10916	11134	11486	12562	13913	16221	17072	19332	20239	20607	21608
2.5D	5	5	10	45	230	622	1350	2531	2931	3600	4159	4861	5444	5822	6079	6422	6683	7348	7039	6572	6984	7999	8819
	5	21	32	220	507	1057	2258	4169	4355	5082	5300	5782	7050	7912	8251	8513	9154	9887	10619	11202	12592	14124	14760
	43	30	136	295	743	1750	3806	7249	8700	9799	10215	10829	11371	12024	12368	12680	13481	14810	16491	17482	17378	17116	17296
3D	5	5	10	59	246	639	1452	2538	3008	3564	3782	4388	5085	5140	5293	5658	6478	6643	6481	6256	6290	6871	7517
	5	16	34	224	582	1328	2498	4151	4230	4693	5209	5944	6965	7626	8037	8077	8260	8949	9581	10248	10439	10839	11482
	35	32	158	318	878	2006	3645	6938	6721	7372	8571	9302	9970	10291	10505	10756	11587	12039	12156	12477	12846	13067	14101
3.5D	5	10	21	61	249	786	1495	2576	3113	3156	3449	3857	4709	4754	5088	5604	5704	5897	5856	5817	5867	5957	6

	0.5R	1R	1.5R	2R	2.5R	3R	3.5R	4R	4.5R	5R	6R	7R	8R	9R	10R	15R	20R	25R	30R	35R	40R	45R
7U	44	44	45	45	46	47	46	47	46	45	43	45	45	43	40	31	27	20	11	8	6	3
	75	76	77	72	70	68	67	66	64	62	64	59	56	55	55	55	47	39	25	15	12	9
	125	124	124	122	121	109	108	107	108	115	121	106	105	101	101	100	68	58	40	30	24	31
6.5U	49	48	48	49	51	50	49	49	48	47	45	45	46	44	42	33	26	20	13	8	5	3
	75	82	80	79	79	76	72	71	69	69	67	64	62	61	60	58	47	37	24	18	13	9
	125	126	127	128	128	112	110	111	113	120	138	119	114	109	108	107	71	60	43	31	39	30
6U	55	53	53	54	56	56	54	54	52	51	52	49	48	45	43	35	27	21	18	9	5	4
	80	82	83	82	82	80	77	76	76	75	72	72	70	69	67	61	51	37	25	20	13	9
	125	126	126	123	116	116	116	118	118	120	141	128	129	126	124	112	72	63	45	49	46	25
5.5U	62	74	76	63	63	65	61	56	53	52	58	56	54	50	43	36	28	23	19	9	5	4
	79	81	81	84	83	82	83	83	82	79	78	76	75	75	75	65	53	37	31	18	13	9
	128	126	124	123	122	121	123	125	128	131	135	143	138	132	129	120	78	65	48	45	41	21
5U	59	58	62	62	62	60	57	56	54	53	60	58	60	60	56	38	30	28	20	9	5	4
	94	99	106	106	106	107	106	107	92	85	84	82	81	79	76	67	55	41	30	20	14	10
	137	136	135	133	131	131	133	136	140	142	144	152	142	140	130	126	84	68	57	53	37	19
4.5U	62	63	63	63	61	60	57	56	55	54	64	62	64	64	61	39	36	28	20	10	6	4
	119	117	117	118	118	118	118	120	122	122	93	89	92	97	85	73	57	45	31	20	14	10
	168	168	161	157	153	150	153	150	151	154	155	158	152	150	140	130	94	94	57	70	31	24
4U	68	67	69	67	65	61	59	58	57	60	70	66	69	68	60	42	42	29	20	11	7	4
	127	127	126	127	129	129	130	134	136	134	132	133	121	120	111	78	60	44	32	19	14	9
	187	185	181	178	174	171	172	176	181	187	172	164	161	164	161	135	104	105	61	60	27	32
3.5U	74	74	74	70	69	67	64	63	64	67	72	72	74	69	63	46	43	31	21	11	8	4
	141	140	131	133	144	145	147	150	147	148	148	149	148	149	137	90	70	42	34	18	14	9
	202	200	197	195	190	191	189	187	189	221	194	187	177	182	181	141	121	99	67	47	24	26
3U	82	82	80	79	75	73	73	71	76	86	84	87	73	80	54	46	31	24	12	8	4	4
	135	136	140	140	146	141	152	166	153	151	161	143	159	158	151	114	83	45	34	18	14	10
	212	212	209	211	209	210	209	208	203	198	198	193	197	206	197	158	136	96	81	54	30	17
2.5U	97	94	94	90	87	86	85	83	83	86	98	100	95	99	98	68	52	32	24	13	9	4
	158	156	158	157	158	161	161	163	165	171	164	153	160	175	174	141	92	52	37	18	15	12
	236	240	242	244	244	241	241	231	225	216	211	215	233	225	226	205	156	98	77	56	35	16
2U	109	107	105	104	103	103	101	100	100	104	119	121	120	107	102	87	59	34	24	14	9	4
	188	189	186	179	182	185	184	187	191	197	184	174	169	178	196	186	101	81	47	26	17	12
	276	285	290	291	289	284	281	273	263	256	250	263	281	264	256	267	171	101	79	59	37	19
1.5U	126	122	122	125	127	126	128	129	129	132	160	153	145	128	178	94	61	37	25	14	9	4
	231	233	227	219	223	214	211	213	213	214	227	217	255	287	287	225	151	95	46	25	19	11
	321	334	343	339	336	326	325	315	314	310	313	394	367	536	443	517	195	128	103	80	54	23
1U	145	148	151	159	165	166	167	172	194	198	243	296	364	331	314	99	67	40	26	15	9	4
	287	287	293	297	296	285	286	283	279	294	366	460	605	700	524	286	190	109	46	29	18	10
	384	403	414	417	420	423	430	460	453	564	584	1320	1396	1271	1431	564	221	128	102	62	74	32
0.5U	216	217	217	227	249	256	305	370	425	553	976	1426	598	769	643	123	70	49	30	15	10	3
	352	361	371	386	398	425	429	524	839	992	1858	1853	1771	1267	871	367	193	115	49	29	18	9
	473	485	520	587	699	739	846	904	1132	2119	3131	2946	2727	2319	2233	678	254	140	111	57	77	29
0	404	404	403	529	599	900	1892	2326	2925	3189	2790	1956	1303	1206	801	259	120	44	25	11	5	5
	569	700	698	856	1324	2127	3501	4008	3925	4345	4112	3274	2511	1722	1416	465	226	136	42	25	17	7
	778	968	1091	1446	2844	4854	5776	7092	7316	6455	4833	4151	3775	3187	2879	1070	314	186	129	63	82	24
0.5D	1113	1913	3418	4648	5568	5723	5638	5444	5063	4370	3375	2788	2007	1400	1013	348	152	45	22	10	5	3
	2299	3233	4718	6966	10118	11059	10659	9334	7103	6527	5310	4172	3083	2426	1690	579	326	138	66	24	10	5
	3218	6794	11218	13766	14165	14668	13011	11122	9535	8154	6359	5573	4324	3921	3284	1359	575	233	145	74	77	30
1D	8948	10139	10090	9582	9114	8719	8427	7870	6342	5560	4817	4249	2874	1853	1540	402	158	45	13	5	5	5
	12840	15806	16252	15554	15413	14431	12935	10875	9129	8183	6260	4886	3576	3221	2532	875	363	156	72	20	5	5
	16033	17246	18269	20066	19586	17771	15334	13579	11356	9946	7416	5471	4927	4055	3425	1520	707	390	204	84	67	31
1.5D	10424	11503	11666	12081	12290	11695	10705	9198	8025	7001	5705	5009	3268	2354	1897	557	231	89	18	10	5	5
	17526	17458	17327	16527	15764	15084	13951	11844	10391	9535	7775	5516	4702	3799	3168	1306	410	194	90	20	9	5
	24876	27934	26936	24681	20173	17754	15073	13788	12602	11492	9626	7305	5811	4585	3858	1670	830	417	200	128	69	26
2D	8840	9147	9440	9651	9978	10128	9270	8433	7784	7276	6018	5170	4164	3212	2648	900	391	132	20	9	5	5
	20389	19176	19473	18082	16720	14947	13768	11930	10195	9384	8085	6504	4839	4084	3398	1490	743	250	134	24	5	5
	22206	23280	22503	20369	19276	17018	15999	15018	14441	12678	9317	7820	6476	5898	4988	2319	916	446	227	148	77	20
2.5D	9147	8924	8524	9148	9351	9227	8741	8194	7738	7295	6020	4848	4082	3280	2770	1291	492	153	18	10	5	5
	15240	15504	15460	15317	13812	12409	11513	10487	9290	8142	6837	5509	4669	4158	4014	2137	901	317	148	36	5	5
	18676	19769	18269	17777	16642	15269	14110	13934	12985	12175	10153	8305	7457	6547	5945	2679	1345	518	359	160	81	43
3D	7908	8102	8100	8397	8513	8232	7798	7323	6830	6131	5158	4355	3981	3516	2649	1377	619	184	20	10	5	5
	11548	11360	11321	11268	10776	9776	9417	9056	8371	7464	6828	5617	4534	3795	3674	2503	885	334	160	52	5	5
	14232	14591	14201	13728	13488	12942	11755	11057	11087	11114	9761	8468	7410	6875	6238	3580	1752	761	337	170	83	44
3.5D	6605	6937	7128	7329	7008	7002	6939	6154	5682	5323	4813	4154	3694	3256	2860	1410	802	219	38	20	5	4
	8952	8731	8528	8565	8311	7800	7385	6821	6656	6525	6156	5548	4716	3986	3728	2543	997	360	166	78	10	5
	11146	11411	11093	10822	10760	10398	9981	9129	8550	8229	7458	7111	6999	6760	6088	4004	1686	852	386	157	84	41
4D	6012	6003	6046	6116	6149	5834	5572															

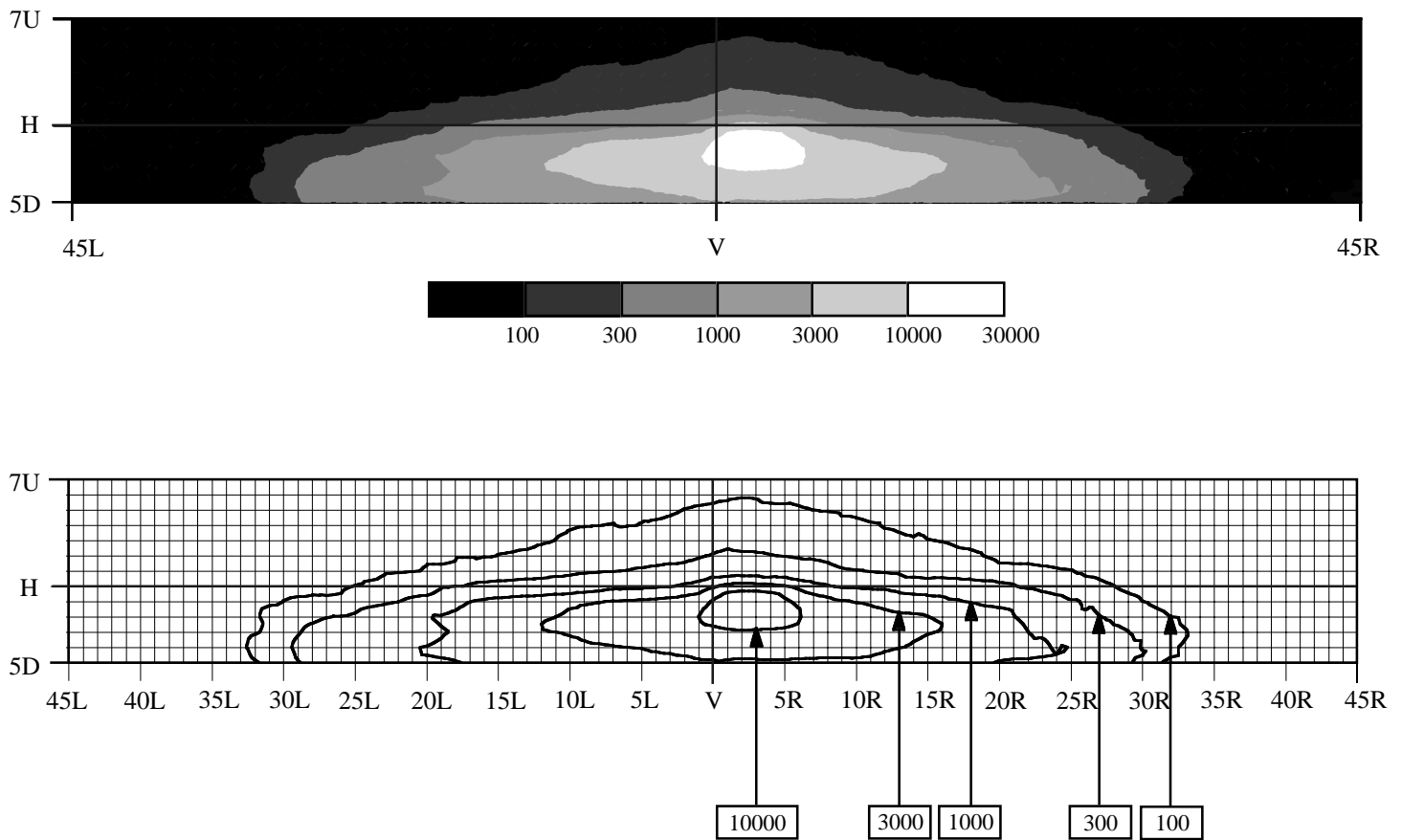


Figure 5. Isocandela diagrams of the median (50th percentile) luminous intensities for the sales-weighted sample representing the low-beam headlamps on current passenger vehicles in the U.S. The two panels represent the same information in different formats. (Test voltage: 12.8 V.)

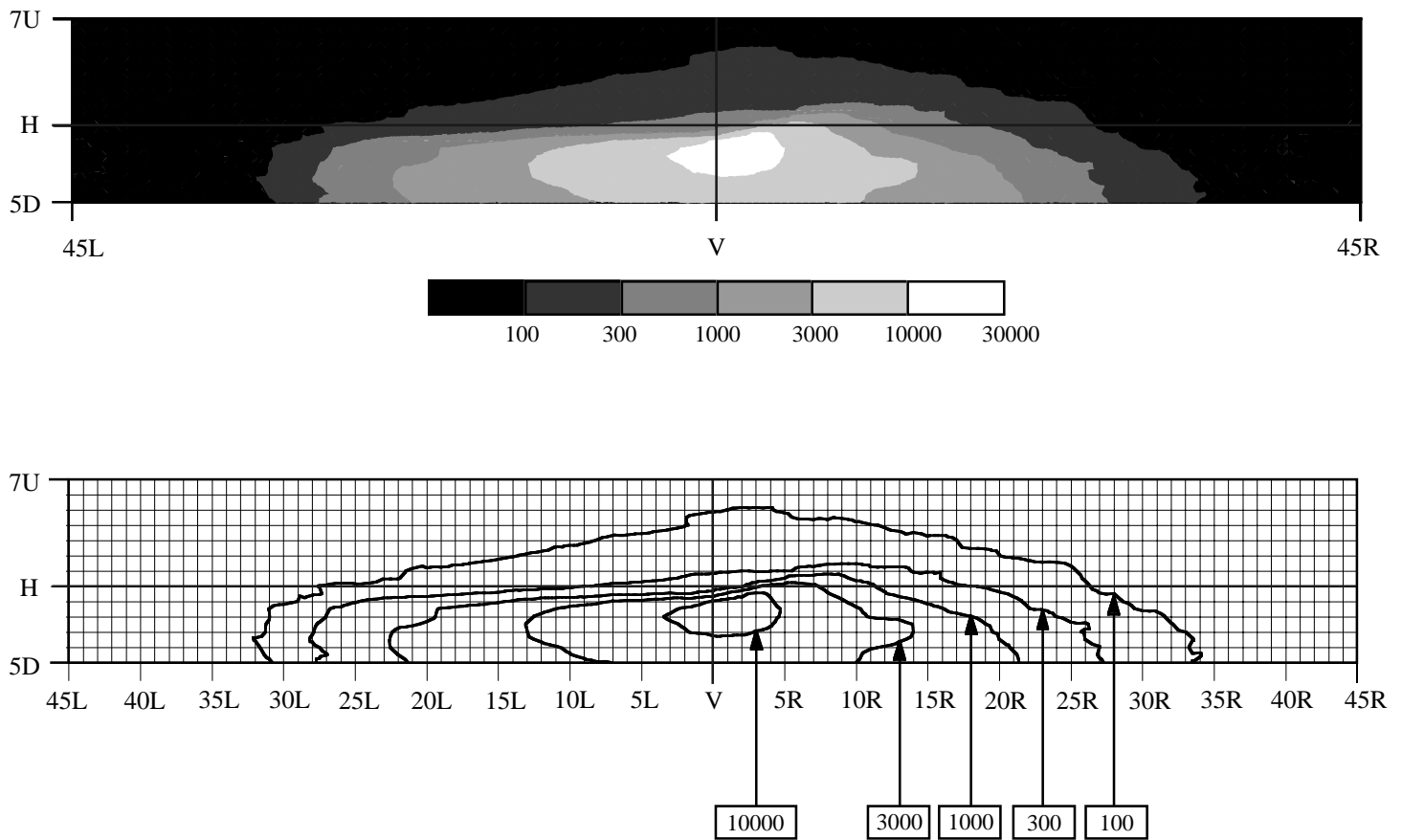


Figure 6. Isocandela diagrams of the median (50th percentile) luminous intensities for the sales-weighted sample representing the low-beam headlamps on current passenger vehicles in Europe. The two panels represent the same information in different formats. (Test voltage: 12.8 V.)



Figure 7. Isoillumination diagram (in vertical lux) at the road surface from a pair of lamps having the median (50th percentile) luminous intensities for the sales-weighted sample representing the low-beam headlamps on current passenger vehicles in the U.S. (Test voltage: 12.8 V. Lamp mounting height: 0.62 m. Lamp separation: 1.12 m.)



Figure 8. Isoillumination diagram (in vertical lux) at the road surface from a pair of lamps having the median (50th percentile) luminous intensities for the sales-weighted sample representing the low-beam headlamps on current passenger vehicles in Europe. (Test voltage: 12.8 V. Lamp mounting height: 0.62 m. Lamp separation: 1.12 m.)

DISCUSSION

The present analysis is not based on a complete census of current headlamps in the U.S. and Europe, but on samples constituting 49% and 47% (respectively) of all lamps for passenger vehicles sold in the U.S. and 17 European countries (all 15 members of the European Union, plus Norway and Switzerland). However, we do not have reasons to believe that there are any systematic differences between the lamps that were sampled and those that were not (with the possible exception of HID headlamps). We believe that the data presented in this report provide valid estimates of the luminous intensities that can be expected at various angles with respect to the headlamp axes of tungsten-halogen headlamps currently used in the U.S. and Europe. Thus, the data could be used to calculate the expected illuminances reaching targets with known geometric relationships to the headlamps, such as traffic signs, road delineation, the eyes of oncoming drivers, or rearview mirrors on preceding vehicles.

As we pointed out in our previous descriptions of U.S. and European low beams (Sivak et al., 1997 and Sivak et al., 2000), data such as these should not be used to calculate gradients of luminous intensities for adjacent points in space (e.g., for estimating the sharpness of the cutoff that is important for visual aiming of the beam pattern). This is because the transitions from the more intense to the less intense parts of the beam pattern are not precisely in the same locations for all lamps. Consequently, although the present analysis provides valid estimates of luminous intensities for individual points, a computation of gradients between points based on the present analysis would underestimate the actual gradients. This caveat applies not only to the present data, but also to any aggregate data for non-identical beam patterns.

REFERENCES

- Automotive News* (2001, January 8). Detroit: Crain Communications Inc.
- Automotive News Europe* (2000, January 31). London: Crain Communications Inc.
- Sivak, M., Flannagan, M.J., Budnik, E.A., Flannagan, C.C., & Kojima, S. (1996). *The locations of headlamps and driver eye positions in vehicles sold in the U.S.* (Technical Report No. UMTRI-96-36). Ann Arbor: The University of Michigan Transportation Research Institute.
- Sivak, M., Flannagan, M.J., Kojima, S., & Traube, E.C. (1997). *A market-weighted description of low-beam headlighting patterns in the U.S.* (Technical Report No. UMTRI-97-37). Ann Arbor: The University of Michigan Transportation Research Institute.
- Sivak, M., Flannagan, M.J., & Schoettle, B. (2000). *A market-weighted description of low-beam headlighting patterns in Europe* (Technical Report No. UMTRI-2000-36). Ann Arbor: The University of Michigan Transportation Research Institute.