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Laser Safety Evaluation and Output Measurements for The VITAL[®]-2 Variable Intensity Tactical Aiming Light (Laser) Used With The Proforce M-4 System In Force-On-Force Exercises

Arnold L. Augustoni

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Arnold L. Augustoni
Lasers, Optics, and Remote Sensing Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-1423

Abstract

A laser safety hazard evaluation and pertinent output measurements were performed (June 2003 through August 2003) on several VITAL[®]-2 Variable Intensity Tactical Aiming Light – infrared laser, associated with the Proforce M-4 system used in force-on-force exercises. The VITAL-2 contains two diode lasers presenting “Extended Source” viewing out to a range on the order of 1.3 meters before reverting to a “Small Source” viewing hazard. Laser hazard evaluation was performed in concert with the *ANSI Std. Z136.1-2000* for the safe use of lasers and the *ANSI Std. Z136.6-2000* for the safe use of lasers outdoors. The results of the laser hazard analysis for the VITAL-2, indicates that this Tactical Aiming IR laser presents a Class 1 laser hazard to personnel in the area of use. Field measurements performed on 71 units confirmed that the radiant outputs were at all times below the Allowable Emission Limit and that the irradiance of the laser spot was at all locations below the Maximum Exposure Limit. This system is eye-safe and it may be used under current SNL policy in force-on-force exercises. The VITAL-2 Variable Intensity Tactical Aiming Light does not present a laser hazard greater than Class 1, to aided viewing with binoculars.

Summary

Seventy-one VITAL-2 units were laser safety tested and evaluated with the following results:

1. All units were verified as Laser Hazard **Class 1** for all modes of operations.
2. All of the VITAL-2 units tested are Laser Hazard **Class 1** under aided (binocular) viewing conditions.
3. Only 2 of the 71 units tested met published specification for the beam divergence. This situation caused wide variations in laser beam spot sizes at target distance.

Mission Impact

1. All VITAL-2 units tested are “eye-safe” and have no restrictions on their use.
2. The wide variations in the beam divergence, although presenting no adverse impact on laser safety may have an adverse impact on its utility, depending upon intended or specific mission use.

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I. Introduction

VITAL-2: Front View

Figure 1

Front View of the VITAL-2 Tactical Aiming Light

A. Overview of the VITAL[®]-2 Variable Intensity Tactical Aiming Light

The VITAL[®]-2 Variable Intensity Tactical Aiming Light is battery powered and incorporates two infrared (IR) diode lasers operated at a radiant wavelength of 830 nm that can be mounted on a small arms weapon, such as a M4 or a M16. The unit is a combined weapon aimer and area illuminator. The VITAL-2 has several modes of operation depending on ambient light conditions, target contrast and target range. The various modes of operation are user selectable.

B. Modes of Laser Operation

VITAL-2: Rear View

Figure 2

Rear View of the VITAL-2 Variable Intensity Tactical Aiming Light

The VITAL-2 may be operated in an “aimer” mode (clandestine) or in an aimer mode with a secondary area illuminator for close quarter battle (CQB) outputs. The aiming laser may be operated in continuous wave (CW) mode or in pulse mode. The area illuminator laser can be operated only in the CW mode. The pulse mode can be selected for either slow or fast pulse outputs. A mode selector is located on the rear of the unit.

Table 1

Modes Of Operations

Mode Selector	Aiming Laser	Area Illuminator
OFF	Off	Off
CW	On	Off
Slow Pulse	On	Off
Fast Pulse	On	Off
Dim	On*	On
Bright	On*	On

*Laser operated in CW mode.

II. Laser Parameters:

A. Data Sheet and Operator's Manual

The VITAL[®] Variable Intensity Tactical Aiming Light, specification sheet and operator's manual lists the following parameters for the VITAL-2:

Table 2

Listed Laser Parameters

VITAL-2	(Typical)
Radiant Wavelength*:	830 nm
Radiant Output:	0.7 mw
Exit Diameter:	0.5 mR [†]
Beam Shape:	Dot
Beam Divergence:	0.5 mR

*Operator's manual, page 11.

†Unit is in terms of divergence rather than diameter.

Data sheet available at: www.nvec-night-vision.com/products (select aimers, then select VITAL, click on "data sheet").

B. Measured Parameters

A number of the laser parameters reported in the VITAL-2 data sheet and the operator's manual were inconsistent or did not appear to be correct. For example, the reported beam diameter was listed in units of beam divergence as: "0.5 mR".

1. Spot Size

The exit aperture of the aiming laser is physically limited to 4.39 mm (measured: #17 drill, 0.173 inches).

The aiming laser beam shape at the exit window was somewhat circular at approximately 3 mm in diameter. The laser beam spot became more elliptical as it propagated from the unit.

The laser spot sizes were measured at several locations from the aimer laser. Examples of beam divergence calculations for two units follows; with the resultant beam divergences (θ) for all VITAL-2 units tested presented in Table 5 (page 17).

Spot sizes were measured using both of the following methods: (1) an IR phosphorous card (with concentric rings at one millimeter radial spacing) and (2) using an IR scope and block tracing the spot. The results obtained using these methods were consistent. The measurements made using the IR scope method confirmed the measurements obtained from the IR phosphorous card.

The spot sizes used for calculating the beam divergence for all the VITAL-2 units were measured at 1 and 3 meters using an IR scope and block tracing the laser spot on a Post-It[®] at each location. The dimensions of the major and minor axes were measured using a ruled scale with 1-mm graduations.

2. Beam Divergence

The beam divergence (θ) can be expressed as follows:

$$\theta = \tan^{-1}\left(\frac{\Delta D}{\Delta R}\right)$$

For angles less than 5 degrees the beam divergence can be approximate by the ratio of the spot sizes differences (ΔD) measured at two locations (ΔR).

$$\theta \approx \frac{\Delta D}{\Delta R}$$

$$\theta \approx \frac{(D_2 - D_1)}{(R_2 - R_1)} \quad \text{Radians}$$

Where;

- θ : Beam divergence
- D_1 Diameter measured at location, R_1 .
- D_2 Diameter measured at location, R_2 .
- R_1 Distance from the laser to location where the first measurement is made.
- R_2 Distance from the laser to location where the second measurement is made.

For elliptical shaped beams the diameter is measured in each axis and yields divergence angles for each axis.

The beam divergence for the **major axis** (θ_M) can be determined as follows:

$$\theta_M \approx \frac{(D_{M_2} - D_{M_1})}{(R_2 - R_1)} \quad \text{Radians}$$

Likewise for the **minor axis** (θ_m):

$$\theta_m \approx \frac{(D_{m_2} - D_{m_1})}{(R_2 - R_1)} \quad \text{Radians}$$

The measurement of spot sizes at various locations and sample calculated beam divergences for select units (SN3261 and SN 3262) follow.

Example for SN 3261:

Table 3

Spot Size at Various Distances for SN 3261

Axis	D @ Exit (mm)	D @ 1 m (mm)	D @ 2 m (mm)	D @ 3 m (mm)
Major	~ 4	12	18	24
Minor	~ 2	6	9	12

Beam Divergence (θ_M) - **Major axis** (1 meter to 3 meters):

$$\theta_M \approx \frac{24 \text{ mm} - 12 \text{ mm}}{3 \text{ m} - 1 \text{ m}} \text{ Radians}$$

$$\approx \frac{12 \text{ mm}}{2,000 \text{ mm}} \text{ Radians}$$

$$\approx 0.006 \text{ Radians}$$

$$\theta_M \approx 6 \text{ mR}$$

Beam Divergence (θ_m) - **Minor Axis** (1 meter to 3 meters):

$$\theta_m \approx \frac{12 \text{ mm} - 6 \text{ mm}}{3 \text{ m} - 1 \text{ m}} \text{ Radians}$$

$$\approx \frac{6 \text{ mm}}{2,000 \text{ mm}} \text{ Radians}$$

$$\approx 0.003 \text{ Radians}$$

$$\theta_m \approx 3 \text{ mR}$$

Example for SN 3262:

Table 4

Spot Size at Various Distances for SN 3262

Axis	Exit (mm)	D @ 1m (mm)	D @ 2 m (mm)	D @ 3 m (mm)	D @ 4 m (mm)	D @ 5 m (mm)	D @ 6 m (mm)
major	4	8	10	12	14	16	18
minor	2	4	5	6	7	8	9

Beam Divergence - **Major axis** (1 meter to 3 meters):

$$\theta_M \approx \frac{12 \text{ mm} - 8 \text{ mm}}{3 \text{ m} - 1 \text{ m}} \text{ Radians}$$

$$\approx \frac{4 \text{ mm}}{2,000 \text{ mm}} \text{ Radians}$$

$$\approx 0.002 \text{ Radians}$$

$$\theta_M \approx 2 \text{ mR}$$

To investigate consistency the beam divergence was also measured over a longer run.

Beam Divergence - **Major axis** (1 meter to 6 meters):

$$\theta_M \approx \frac{18 \text{ mm} - 8 \text{ mm}}{6 \text{ m} - 1 \text{ m}} \text{ Radians}$$

$$\approx \frac{10 \text{ mm}}{5,000 \text{ mm}}$$

$$\approx 0.002 \text{ Radians}$$

$$\theta_M \approx 2 \text{ mR}$$

Beam Divergence (θ_m) - **Minor Axis** (1 meter to 3 meters):

$$\theta_m \approx \frac{6 \text{ mm} - 4 \text{ mm}}{3 \text{ m} - 1 \text{ m}} \text{ Radians}$$

$$\approx \frac{2 \text{ mm}}{2,000 \text{ mm}} \text{ Radians}$$

$$\approx 0.001 \text{ Radians}$$

$$\theta_m \approx 1 \text{ mR}$$

Beam Divergence (θ_m) - **Minor Axis** (1 meter to 6 meters):

$$\theta_m \approx \frac{9 \text{ mm} - 4 \text{ mm}}{6 \text{ m} - 1 \text{ m}} \text{ Radians}$$

$$\approx \frac{5 \text{ mm}}{5,000 \text{ mm}} \text{ Radians}$$

$$\approx 0.001 \text{ Radians}$$

$$\theta_m \approx 1 \text{ mR}$$

The beam divergence measured for SN 3262 for both the range sets produced the same results.

The calculated beam divergences (major and minor axis) for all units tested are presented in Table 5.

Table 5**Spot Sizes at 1 & 3 meters –Calculated Beam Divergence**

Serial Number	D _{M1} (mm)	D _{m1} (mm)	D _{M3} (mm)	D _{m3} (mm)	θ_{major} (mR)	θ_{minor} (mR)
3223	7	6	11	8	2	1
3224	9	7	20	14	5.5	3.5
3225	6	4	10	8	2	2
3226	8	7	15	9	3.5	1
3227	6	5	8	7	1	1
3228	7	4	14	8	3.5	2
3229	8	6	20	11	6	2.5
3230	9	7	22	12	6.5	2.5
3231	8	6	13	9	2.5	1.5
3232	15	9	49	17	17	4
3233	10	5	18	11	4	3
3234	14	8	28	14	7	3
3235	11	9	30	20	9.5	5.5
3236	8	6	16	8	4	1
3237	10	8	16	10	3	1
3238	11	8	23	14	6	3
3239	10	7	24	13	7	3
3240	8	5	15	8	3.5	1.5
3241	8	6	14	10	3	2
3242	10	7	22	14	6	3.5
3243	14	10	34	16	10	3
3244	5	2	11	4	3	1
3245	8	4	10	6	1	1
3246	6	8	14	5	4	1.5
3247	20	8	50	16	15	4
3248	9	6	14	9	2.5	1.5
3249	8	5	14	9	3	2
3250	11	7	22	14	5.5	3.5
3251*	5	5	6	6	0.5	0.5
3252	10	6	17	9	3.5	1.5
3253	12	8	32	15	10	3.5
3254	6	4	11	7	2.5	1.5
3255	7	4	12	7	2.5	1.5
3256	8	5	12	8	2	1.5
3257	5	4	9	6	2	1

Table 5 (Continued)**Spot Sizes at 1 & 3 meters –Calculated Beam Divergence**

Serial Number	D _{M1} (mm)	D _{m1} (mm)	D _{M3} (mm)	D _{m3} (mm)	θ _{major} (mR)	θ _{minor} (mR)
3258	10	7	14	9	2	1
3259	8	7	15	10	3.5	1.5
3260*	8	5	9	6	0.5	0.5
3261	12	6	24	12	6	3
3262	8	4	12	6	2	1
3263	10	6.5	22	13	6	3.25
3264	10	6	14	10	2	2
3265	8	7	12	9	2	1
3266	8	4	10	6	1	1
3267	7	5	13	9	3	2
3268	9	7	21	12	6	2.5
3269	10	6	16	10	3	2
3270	15	11	33	18	9	3.5
3271	7	5	9	8	1	1.5
3272	8	4	14	7	3	1.5
3273	12	9	26	17	7	4
3274	7	6	15	8	4	1
3275	3.5	3	5	4	0.75	0.5
3279	11	8	29	16	9	4
3276	9	7	20	12	5.5	2.5
3277	13	7	27	15	7	4
3278	7	6	13	8	3	1
3279	11	8	29	16	9	4
3280	19	12	41	20	11	4
3281	6	3	8	6	1	1.5
3282	8	6	12	8	2	1
3283	7	6	10	7	1.5	0.5
3284	7	5	13	7	3	1
3285	9	6	15	12	3	3
3286	7	4	9	7	1	1.5
3287	8	4	12	10	2	3
3288	13	7	31	14	9	3.5
3289	6	3	12	6	3	1.5
3290	5	5	7	6	1	0.5
3291	6	4	9	6	1.5	1
3292	5	4	8	6	1.5	1

*Meets specification listed in the data sheet

3. Radiant Output

a. CW Output Measurements

Figure 3

Ophir power head with 7-mm limiting aperture
10 cm in front of VITAL-2 exit

The radiant outputs of the VITAL-2[®] units were measured to verify outputs less than the maximum value listed in the operator's manual and the data sheet. The CW radiant outputs were measured using an OPHIR[®] Model 2A-SH, visible and NIR power head (60 μ w to 2 watts), serial number 84208, with a centered 7-mm "limiting aperture" over the active area, as prescribed in *ANSI Std. Z136.1-2000 (9.2.1.1)*. The electrical output of the power head was monitored by an OPHIR[®] model NOVA display, serial number 30462, mode selected for: *Power-NIR*. The power head was placed 10 centimeters from the exit of the aiming laser as prescribed by *ANSI Std. Z136.1-2000 (9.2.1.1)*.

The CW output radiance (Φ_o) was measured as received ("as is"). The maximum CW radiance (Φ_{max}) was measured with the unit's intensity adjusted for maximum output. The CW radiant outputs are summarized in Table 6. The CW radiant output (through the limiting aperture) as a function of range (Φ_r) for SN 3261 and SN 3262, were also measured at various distances (r) along the propagation axis. Additionally, the average output radiances (NOVA display set to average over 1-second) for the pulsed output modes of operation were measured and are presented in Tables 10 (Slow) and 11 (Fast).

The CW radiant output of the illuminator source was measured separately and is presented in Table 8.

Table 6
CW Aiming Output Radiance

Serial Number	Φ_o^* (μW)	Φ_{max} (μW)
3223	355	511
3224	111	558
3225	497	579
3226	243	541
3227	304	629
3228	492	615
3229	95	535
3230	252	582
3231	137	631
3232	324	525
3233	145	556
3234	132	603
3235	149	601
3236	361	596
3237	114	500
3238	285	525
3239	118	620
3240	123	580
3241	102	515
3242	196	618
3243	205	553
3244	142	490
3245	456	597
3246	128	600
3247	100	531
3248	90	537
3249	285	577
3250	100	510

Table 6 (Continued)

CW Aiming Output Radiance

Serial Number	Φ_o^* (μW)	Φ_{max} (μW)
3251	149	524
3252	445	584
3253	149	505
3254	145	460
3255	492	501
3256	273	646
3257	560	570
3258	162	490
3259	566	566
3260	286	568
3261	645	652
3262	550	†
3263	524	544
3264	408	557
3265	205	487
3266	173	565
3267	410	586
3268	292	403
3269	567	622
3270	203	553
3271	175	597
3272	580	608
3273	687	694
3274	435	548
3275	427	526
3276	130	592
3277	145	518
3278	158	550
3279	46	618
3280	57	449
3281	542	616
3282	24	560

Table 6 (Continued)

CW Aiming Output Radiance

Serial Number	Φ_o^* (μW)	Φ_{max} (μW)
3283	630	638
3284	242	591
3285	512	546
3286	147	579
3287	159	617
3288	478	564
3289	304	515
3290	118	572
3291	225	625
3292	148	468

*As received

†Not measured

The Vital-2 area illuminator (laser diode) emits light into a very wide cone angle (greatly divergent beam). The table below presents the radiant output, through a 7-mm aperture, of the area illuminator measured at 2.5 cm and at 10 cm from SN 3262.

Table 7

Radiant Output of the Vital-2 Illuminator at 2.5 & 10 cm, SN 3262

Illuminator Mode	$\Phi_{2.5 \text{ cm}}$ (mW)	$\Phi_{10 \text{ cm}}$ (μW)
Bright	3.7	385
Dim	0.1	$\sim 10^*$

*Minimum sensitivity level is 60 μW .

Table 8

Radiant Output of the Vital-2 Area Illuminators at 10 cm

Serial Number	Bright $\Phi_{10\text{ cm}}$ (μW)	Dim $\Phi_{10\text{ cm}}$ (μW)*
3223	481	12
3224	383	20
3225	680	15
3226	382	12
3227	514	14
3228	320	10
3229	513	10
3230	449	14
3231	482	10
3232	412	9
3233	255	10
3234	675	14
3235	485	13
3236	383	10
3237	435	11
3238	412	10
3239	293	11
3240	416	14
3241	419	13
3242	517	12
3243	520	12
3244	415	9
3245	327	14
3246	434	12
3247	552	18
3248	566	11
3249	625	19
3250	493	20
3251	429	12
3252	540	18
3253	644	16
3254	548	15
3255	499	13
3256	390	9
3257	512	18

Table 8 (Continued)

Radiant Output of the Vital-2 Area Illuminators at 10 cm

Serial Number	Bright $\Phi_{10\text{ cm}}$ (μW)	Dim $\Phi_{10\text{ cm}}$ (μW)*
3258	418	14
3259	290	20
3260	558	10
3262	385	10
3263	438	13
3264	371	13
3265	444	14
3266	590	17
3267	495	9
3268	363	9
3269	436	15
3270	200	9
3271	382	10
3272	450	13
3273	318	10
3274	585	19
3275	342	9
3276	537	18
3277	503	18
3278	382	12
3279	407	18
3280	339	9
3281	624	18
3282	469	17
3283	479	17
3284	457	18
3285	361	9
3286	587	18
3287	356	9
3288	476	16
3289	279	9
3290	429	14
3291	418	12
3292	412	9

*Approximate value (minimum sensitivity of power meter head is 60 μW).

b. Pulsed Parameters

Pulse Widths and Pulse Repetition Frequencies

For two of the VITAL-2[®]'s five modes of operation the output is pulsed. The pulse duration or pulse width of these pulses as well as the Pulse Repetition Frequencies (PRF) is critical in determining the Maximum Permissible Exposure (MPE). Neither the operator's manual nor the data sheet provides this information. As a consequence these values had to be measured.

The intensity-time histories (scope traces) of these pulses were obtained and measured using an EG&G[®] type C30810E photodiode monitored by a Tektronix[®] model 7104 oscilloscope with a 7A24 vertical amplifier (50 Ω input) and a 7B15 time base.

Figure 4

VITAL-2 output to EG&G photodiode.

The VITAL-2 aiming laser output was monitored for all five modes of operation.

The intensity-time histories for serial number 3261 are presented below.

The pulse width (t_{FWHM}) is measured between the half power points.

Figure 5

Intensity- Time History:
Pulse width for SN 3261, “slow pulse”.

Figure 6

Intensity-Time History:
The PRF for SN 3261, “slow pulse”.

Pulse width (t_{FWHM}) for the Slow Pulse mode for SN 3261:

$$t_{FWHM} = (8.5 \text{ div})(10 \text{ ms/div})$$

$$t_{FWHM} = \mathbf{85 \text{ ms}}$$

Pulse period (T) for the Slow Pulse mode for SN 3261:

$$2T = (9.5 \text{ div})(50 \text{ ms/div})$$

$$T = \mathbf{237.5 \text{ ms}}$$

PRF, for the Slow Pulse mode for SN 3261:

$$PRF = T^{-1}$$

$$PRF = (237.5 \times 10^{-3} \text{ sec})^{-1}$$

$$PRF = \mathbf{4.21 \text{ Hz}}$$

Fast-pulse mode for SN 3261:

Figure 7

Intensity-Time History:
Pulse width for SN 3261, "fast pulse".

Figure 8

Intensity-Time History:
The PRF for SN 3261, "fast pulse".

Pulse width (t_{FWHM}) Fast Pulse mode for SN 3261:

$$t_{FWHM} = (5 \text{ div})(10 \text{ ms/div})$$

$$t_{FWHM} = \mathbf{50 \text{ ms}}$$

Pulse period (T) Fast Pulse mode for SN 3261:

$$T = (8.8 \text{ div})(20 \text{ ms/div})$$

$$\mathbf{T = 176 \text{ ms}}$$

PRF, Fast Pulse mode for SN 3261:

$$PRF = T^{-1}$$

$$PRF = (176 \times 10^{-3} \text{ sec})^{-1}$$

$$\mathbf{PRF = 5.68 \text{ Hz}}$$

It was noted that the first pulse in the pulse train for each mode of pulse operation was somewhat longer than the pulse width of the subsequent pulses. As a consequence, the intensity-time histories were “shuttered” to sample the pulse train at a time after the occurrence of the first pulse.

Similarly for the SN 3262 unit:

Figure 9

Intensity-Time History:
Pulse width and PRF for SN 3262, “slow pulse”.

Pulse width (t_{FWHM}) Slow Pulse mode for SN 3262:

$$t_{FWHM} = (1.8 \text{ div})(50 \text{ ms/div})$$

$$\mathbf{t_{FWHM} = 90 \text{ ms}}$$

Pulse period (T) Slow Pulse mode for SN 3262:

$$T = (4.5 \text{ div})(50 \text{ ms/div})$$

$$\mathbf{T = 225 \text{ ms}}$$

$$\text{PRF} = T^{-1}$$

$$\text{PRF} = (225 \times 10^{-3} \text{ sec})^{-1}$$

$$\mathbf{PRF = 4.44 \text{ Hz}}$$

Figure 10

Intensity-Time History:
Pulse width and PRF, SN 3262, fast pulse.

Pulse width Fast Pulse mode for SN 3262:

$$t_{FWHM} = (1.2 \text{ div})(50 \text{ ms/div})$$

$$\mathbf{t_{FWHM} = 60 \text{ ms}}$$

Pulse period Fast Pulse mode for SN 3262:

$$T = (3.5 \text{ div})(50 \text{ ms/div})$$

$$\mathbf{T = 175 \text{ ms}}$$

PRF, Fast Pulse mode for SN 3262:

$$PRF = T^{-1}$$

$$PRF = (175 \times 10^{-3} \text{ sec})^{-1}$$

$$\mathbf{PRF = 5.71 \text{ Hz}}$$

Intensity-time histories were used to determine the pulse widths and the PRFs for each pulse mode of each unit tested. There were observed differences in pulse parameters from unit to unit. The results of these measurements are summarized in Table 9.

Table 9**Pulse Widths and Pulse Repetition Frequencies**

Serial Number	Pulse Width Slow-Pulse (ms)	Pulse Width Fast-Pulse (ms)	PRF Slow-Pulse (Hz)	PRF Fast-Pulse (Hz)
3223	73	46	4.35	5.75
3224	76	44	4.26	5.95
3225	78	46	4.17	5.71
3226	70	48	4.40	5.59
3227	70	47	4.55	5.68
3228	80	50	4.40	5.68
3229	89	64	5.00	5.68
3230	70	44	4.52	5.95
3231	72	46	4.55	5.85
3232	78	48	4.40	5.88
3233	80	49	4.15	5.62
3234	96	69	4.28	5.81
3235	85	49	4.57	6.10
3236	95	62	4.21	5.71
3237	80	50	4.32	5.65
3238	74	49	4.49	5.81
3239	74	44	4.32	5.85
3240	79	53	4.30	6.02
3241	90	46	4.55	5.65
3242	74	46	4.35	5.81
3243	62	54	5.71	6.90
3244	74	48	4.37	5.65
3245	90	63	4.40	5.85
3246	94	61.5	4.23	5.81
3247	89	62	4.94	5.78
3248	91	63	4.37	5.85
3249	79	48	4.88	5.75
3250	77	49	4.50	5.81
3251	94	62	4.62	5.65
3252	74	44	4.47	5.88
3253	74	48	4.47	5.88
3254	73	48	4.35	5.68
3255	94	68	4.17	5.44
3256	79	43	4.37	5.75
3257	73	44	4.42	6.02

Table 9**Pulse Widths and Pulse Repetition Frequencies**

Serial Number	Pulse Width Slow-Pulse (ms)	Pulse Width Fast-Pulse (ms)	PRF Slow-Pulse (Hz)	PRF Fast-Pulse (Hz)
3258	73	48	4.37	5.65
3259	88	52	4.35	5.88
3260	79	48	4.26	5.81
3261	85	50	4.21	5.68
3262	90	60	4.44	5.71
3263	88	54	4.04	5.44
3264	74	46	4.30	5.62
3265	74	49	4.52	6.02
3266	74	38	4.40	5.81
3267	77	49	4.39	5.75
3268	89	62	4.52	5.88
3269	79	51	4.40	5.75
3270	74	46	4.94	5.78
3271	72	44	4.60	6.06
3272	78	46	4.44	5.88
3273	72	48	4.49	5.81
3274	77	50	4.17	5.43
3275	76	46	4.17	5.56
3276	71	48	4.26	5.46
3277	73	47	4.40	5.88
3278	78	47	4.10	5.71
3279	72	45	4.40	5.75
3280	91	64	4.44	5.71
3281*	90	90	4.05	4.05
3282	73	45	4.32	5.75
3283	88	62	4.37	5.68
3284	71	46	4.40	5.68
3285	79	48	4.30	5.75
3286	71	45	4.44	5.88
3287	78	48	4.55	5.78
3288	86	46	4.21	5.75
3289	74	46	4.55	5.88
3290	78	48	4.19	5.56
3291	84	60	4.55	5.95
3292	69	45	4.52	5.88

*There was no difference in output between the two modes of pulse operations.

Average Pulse Energies

The average radiant pulse energy can be calculated from the measured average radiant power (Φ_{avg}) emitted by the VITAL-2 operated in the “Pulsed” modes divided by the measured PRF.

$$\overline{Q}(\text{joules}) = \frac{\Phi(\text{watts})}{PRF(\text{sec}^{-1})}$$

Example for SN 3261:

$$\begin{aligned}\overline{Q}_{slow} &= \frac{232\mu\text{w}}{4.21\text{sec}^{-1}} \\ &= \frac{232\left(\frac{\mu\text{J}}{\text{sec}}\right)\text{sec}}{4.21}\end{aligned}$$

$$\overline{Q}_{slow} = 55.1\mu\text{J}$$

The following tables (Table 10 and Table 11) summarizes the average radiant pulse energies of the VITAL-2 units operated in the “slow” and “fast” pulsed modes.

Table 10**Average Radiant Pulse Energies****“Slow” Pulse Mode**

Serial Number	Φ_{slow} (μW)	PRF_{slow} (sec^{-1})	Q_{slow} (μJ)
3223	166	4.35	38.2
3224	181	4.26	42.5
3225	198	4.17	47.5
3226	174	4.40	39.5
3227	206	4.55	45.3
3228	205	4.40	46.6
3229	212	5.00	42.4
3230	190	4.52	42.0
3231	208	4.55	45.7
3232	185	4.40	42.0
3233	203	4.14	49.0
3234	256	4.28	59.8
3235	242	4.57	53.0
3236	204	4.21	48.5
3237	176	4.32	40.7
3238	177	4.49	39.4
3239	223	4.32	51.6
3240	201	4.30	46.7
3241	173	4.55	38.0
3242	202	4.35	46.4
3243	214	5.71	37.5
3244	164	4.37	37.5
3245	248	4.40	56.4
3246	204	4.23	48.2
3247	210	4.94	42.5
3248	183	4.37	41.9
3249	205	4.88	42.0
3250	175	4.50	38.9
3251	179	4.62	38.7
3252	194	4.47	43.4
3253	175	4.47	39.1
3254	152	4.35	34.9
3255	196	4.17	47.0
3256	193	4.37	44.2
3257	188	4.42	42.5

Table 10 (Continued)

Average Radiant Pulse Energies

“Slow” Pulse Mode

Serial Number	Φ_{slow} (μW)	PRF_{slow} (sec^{-1})	Q_{slow} (μJ)
3258	159	4.37	36.4
3259	215	4.35	49.4
3260	197	4.26	46.2
3261	232	4.21	54.1
3263	198	4.04	49.0
3264	175	4.30	40.7
3265	169	4.52	37.4
3266	190	4.40	43.2
3267	203	4.39	46.2
3268	125	4.52	27.7
3269	200	4.40	45.5
3270	180	4.94	36.4
3271	201	4.60	43.7
3272	195	4.35	44.8
3273	218	4.49	48.6
3274	176	4.17	42.2
3275	170	4.17	40.8
3276	183	4.26	43.0
3277	172	4.40	39.1
3278	183	4.10	44.6
3279	202	4.40	45.9
3280	161	4.44	36.3
3281	195	4.05	48.1
3282	184	4.32	42.6
3283	248	4.37	56.8
3284	193	4.40	43.9
3285	184	4.30	42.8
3286	191	4.44	43.0
3287	222	4.55	48.8
3288	189	4.21	44.9
3289	180	4.55	39.6
3290	192	4.19	45.8
3291	242	4.55	53.2
3292	161	4.52	35.6

Table 11**Average Radiant Pulse Energies****“Fast” Pulse Mode**

Serial Number	Φ_{fast} (μW)	PRF_{fast} (sec^{-1})	Q_{fast} (μJ)
3223	140	5.75	24.3
3224	150	5.95	25.2
3225	163	5.71	28.5
3226	155	5.59	27.7
3227	176	5.68	31.0
3228	166	5.68	29.2
3229	205	5.68	36.1
3230	163	5.95	27.4
3231	174	5.85	29.7
3232	159	5.88	27.0
3233	168	5.62	29.9
3234	247	5.81	42.5
3235	225	6.10	36.9
3236	169	5.71	29.6
3237	148	5.65	26.2
3238	152	5.81	26.2
3239	169	5.85	28.9
3240	194	6.02	32.2
3241	145	5.65	25.7
3242	171	5.81	29.4
3243	210	6.90	30.4
3244	139	5.65	24.6
3245	232	5.85	39.7
3246	167	5.81	28.7
3247	195	5.78	33.7
3248	164	5.85	28.0
3249	172	5.75	29.9
3250	146	5.81	25.1
3251	152	5.65	26.9
3252	157	5.88	26.7
3253	151	5.88	25.7
3254	132	5.68	23.2
3255	182	5.44	33.5
3256	161	5.75	28.0
3257	162	6.02	26.9

Table 11 (Continued)

Average Radiant Pulse Energies

“Fast” Pulse Mode

Serial Number	Φ_{fast} (μW)	PRF_{fast} (sec^{-1})	Q_{fast} (μJ)
3258	137	5.65	24.2
3259	174	5.88	29.6
3260	168	5.81	28.9
3261	183	5.68	32.2
3263	167	5.44	30.7
3264	146	5.62	26.0
3265	155	6.02	25.7
3266	161	5.81	27.7
3267	173	5.75	30.1
3268	116	5.88	19.7
3269	171	5.75	29.7
3270	151	5.78	26.1
3271	166	6.06	27.4
3272	164	5.88	27.9
3273	193	5.81	33.2
3274	166	5.43	30.6
3275	131	5.56	23.6
3276	162	5.46	29.7
3277	149	5.88	25.3
3278	155	5.71	26.8
3279	171	5.75	29.7
3280	137	5.71	24.0
3281	195	4.05	48.1
3282	153	5.75	26.6
3283	236	5.68	41.5
3284	163	5.68	28.7
3285	154	5.75	26.8
3286	161	5.88	27.4
3287	175	5.78	30.3
3288	159	5.75	27.7
3289	151	5.88	25.7
3290	166	5.56	29.9
3291	225	5.95	37.8
3292	139	5.88	23.6

Pulse Rise Time and “turn-on” Transient

Figure 11

Intensity Time History: SN 3262

The intensity-time history traces show a “turn-on” or transient spike. The rise and decay times associated with this transient were investigated.

The rise time of a pulse is defined as the time it takes the intensity to increase from the 10 % level to the 90 % level. The pulse rise time is measured between these two points.

Determination of the Pulse Rise Time for SN 3261 in Slow Pulse mode

Figure 12

Intensity-Time History:
Rise Time, SN 3261, “slow pulse”.

Rise Time (t_r) is measure between the 10% and the 90% of peak value.

$$V_{\text{peak}} = (4.4 \text{ div})$$

$$(0.1) V_{\text{peak}} \sim 0.45 \text{ div}$$

$$(0.9) V_{\text{peak}} \sim 4 \text{ div}$$

Rise Time is:

$$t_r = (4.1 \text{ div})(100 \mu\text{s}/\text{div})$$

$$t_r = 410 \mu\text{s}$$

Determination of the Pulse Rise Time for SN 3262 in Slow Pulse mode

Figure 13

Intensity-Time History:
Rise time, SN 3262, "slow pulse"

Rise Time, t_r , is measure between the 10% and the 90% of peak value.

$$V_{\text{peak}} = (3.2 \text{ div})$$

$$(0.1) V_{\text{peak}} \sim 0.3 \text{ div}$$

$$(0.9) V_{\text{peak}} \sim 2.9 \text{ div}$$

Rise Time:

$$t_{\text{rise}} = (6.8 \text{ div})(50 \text{ } \mu\text{s/div})$$

$$t_{\text{rise}} = 340 \text{ } \mu\text{s}$$

Decay Time to Steady State Level

It was observed that the intensity “turn-on” transient peak decayed to a “steady state level where it remained throughout the remainder of the pulse.

SN 3261:

Figure 14

Intensity-Time History:
Decay Time for SN 3261, “slow pulse”.

$$t_{\text{decay}} = (7.3 \text{ div})(1 \text{ ms/ div})$$

$$t_{\text{decay}} = 7.3 \text{ ms}$$

SN 3262:

Figure 15

Intensity-Time History:
Decay Time for SN 3262, “slow pulse”.

$$t_{\text{decay}} = (3.9 \text{ div})(2 \text{ ms/ div})$$

$$t_{\text{decay}} = 7.8 \text{ ms}$$

Table12

Pulse Rise and Decay Times – Slow Pulse Mode

Serial Number	Rise Time	Decay Time
3261	410 μs	7.3 ms
3262	340 μs	7.8 ms

Comparison of Transient Regions of “Slow” and “Fast” Pulse Mode

Figure 16

Intensity-Time Histories: SN 3261, Slow-pulse and fast pulse comparison.

A comparison of the intensity-time histories of SN 3261 for both the slow and fast pulse modes clearly show that the only difference in the output parameters between these two modes of operation is the duration of the composite pulse.

$$\Phi_{peak-slow} = \Phi_{peak-fast}$$

$$\Phi_{CW-slow} = \Phi_{CW-fast}$$

$$t_{decay-slow} = t_{decay-fast}$$

CW and Pulse Steady State Intensity Levels

The pulsed modes of operation are actually the CW mode switched “on and off”. As can be seen from the following composite pulsed and CW intensity-time history traces that the steady state level of the pulses in both the slow and fast-pulse modes is at the same intensity level as the CW intensity level.

Figure 17

Intensity-Time History:
Composite CW-slow pulse overlay.

Figure 18

Intensity-Time History:
Composite CW-fast pulse overlay.

Radiant Energy in the Transient Region

Each emitted laser pulse contains a “turn on” transient region, which has peak intensity on the order of twice the pulse steady state intensity level. This may have an impact on the laser safety aspect of the VITAL-2 operated in the pulse modes. The MPE(s) and AEL(s) of the *transient region* were investigated.

The radiant energy can be expressed as the integral of radiant intensity.

$$Q = \int \Phi dt$$

The radiant energy of this transient region can be calculated from the measurement of the area under the intensity-time history trace for this region.

The intensity-time history of the VITAL-2 pulsed output can be divided into three basic regions, which approximate geometrical shapes. The “turn on” transient region can be approximated as a ramped pulse triangular in shape. The second region, the “decay to steady state”, can be approximated by rombus shaped pulse with a declining ramp triangle area sitting on a rectangular area. The third region is the dominant steady state, which can be approximated by pulse with a rectangular area. The radiant energy in each area can be approximated from the intensity-time histories. The time duration of each region can be treated as separate pulses. The “turn on” and “decay to steady state” and be treated as short duration pulse and can be compared to the MPE(s) and AEL(s) appropriate to the short pulse duration.

Figure 19

Intensity-Time History:
Areas composing the transient region

Approximation For The Radiant Energy In The “Turn On” Region

The shape of the transient (turn on) region can be approximated by: an area that is essentially triangular. The area of this triangle can approximate the area under the intensity-time history trace and would yield reasonable values for the radiant energy in this region.

The radiant pulse energy contained in the transient (“turn on”) region (of the intensity-time history) can be approximated by; equating this energy to the area of a triangle. The approximate radiant energy is one-half the product of the peak intensity (height of the triangle) and the time duration to the peak intensity (base of the triangle). The time duration to peak (t_{peak}) is not the same as the pulse rise time, which was defined earlier.

$$Q_{turn-on} \approx \frac{1}{2} (\Phi_{peak} \cdot t_{peak})$$

The following examples are specific to SN 3261 and SN 3262 but the technique presented is applicable to the other VITAL-2 units as well. The resultant radiant pulse energies for the transient region for all the VITAL-2 tested are presented in Table 15.

Example for SN 3261

The following sample measurements, calculations and approximations are specific to SN 3261.

Figure 20

Intensity-Time History:
Area approximation for the "turn-on" region, SN 3261.

The radiant pulse energy contained in the "turn-on" region can be approximated by area A_0 of the intensity-time history for SN 3261. This triangular area is greater than the actual area under this intensity-time region and will yield larger pulse energy than the actual radiance of this region. This will tend to yield laser safety results with a conservative bias.

Measured Values for SN 3261

$$\Phi_{CW} = 1.65 \text{ div} = 0.652 \text{ mw}$$

$$\Phi_{peak} = (4 \text{ div}) \left(\frac{0.652 \text{ mw}}{1.65 \text{ div}} \right) = 1.58 \text{ mw}$$

$$t_{peak} = (3 \text{ div}) \left(100 \frac{\mu s}{\text{div}} \right) = 300 \mu s$$

$$Q_{turn-on} \approx A_0 = \frac{1}{2} \Phi_{peak} \cdot t_{peak}$$

$$Q_{turn-on} \approx \frac{1}{2} (1.58 \text{ mw}) (300 \mu s)$$

$$\approx \frac{(1.58 \times 10^{-3} \text{ J/s}) (300 \times 10^{-6} \text{ s})}{2}$$

$$Q_{turn-on} = 237 \times 10^{-9} \text{ joules}$$

Example for SN 3262

Figure 21

Intensity-Time History:
Area approximation for the “turn-on” region of SN 3262.

The radiant pulse energy contained in the “turn-on” region can be approximated by area A_0 of the intensity-time history. This triangular area is greater than the actual area under this intensity-time region and will yield larger pulse energy than the actual radiance of this region. This will tend yield laser safety results with a conservative bias.

Measured Values for SN 3262

$$\Phi_{CW} = 1.15 \text{ div} = 0.55 \text{ mw}$$

$$\Phi_{peak} = (3.5 \text{ div}) \left(\frac{0.55 \text{ mw}}{1.15 \text{ div}} \right) = 1.67 \text{ mw}$$

$$t_{peak} = (6 \text{ div}) \left(50 \frac{\mu s}{\text{div}} \right) = 300 \mu s$$

Calculated Values for SN 3262

$$Q_{turn-on} \approx A_0 = \frac{1}{2} \Phi_{peak} \cdot t_{peak}$$

$$Q_{turn-on} \approx \frac{1}{2} (1.67mw) (300\mu s)$$

$$\approx \frac{(1.67 \times 10^{-3} J/s) (300 \times 10^{-6} s)}{2}$$

$$Q_{turn-on} = 251 \times 10^{-9} \text{ joules}$$

Table 13

Transient (“Turn-On”) Region Parameters for SN 3261 & SN 3262

Serial Number	Φ_{peak} (mw)	t_{peak} (μs)	$Q_{turn-on}$ (nJ)
3261	1.58	300	237
3262	1.67	300	251

Approximation For The Radiant Energy In The “Decay” Region

The radiant energy in the “decay to steady state” region can be approximated by the sum of two areas (A_1 and A_2) under the intensity-time history traces. The area A_1 is a triangle and area A_2 is a rectangle. In all cases this estimated area is greater than the actual area, giving rise to a conservative laser safety bias.

Example for SN 3261

Figure 22

Intensity-Time History: Area approximation for the “decay to steady state” region, SN 3261

Measured Values (SN 3261)

$$\Phi_{CW} = 1.65 \text{ div} = 0.652 \text{ mw}$$

$$\Phi_{d-max} = (3.5 \text{ div}) \left(\frac{0.652 \text{ mw}}{1.65 \text{ div}} \right) = 1.38 \text{ mw}$$

$$t_{decay} = (7.3 \text{ div}) \left(1 \text{ ms/div} \right) = 7.3 \text{ ms}$$

Calculated Values (SN 3261)

$$Q_{decay} \approx A_1 + A_2$$

$$Q_{decay} \approx \left[\frac{1}{2} (\Phi_{d-\max} - \Phi_{CW}) \cdot t_{decay} \right] + [\Phi_{CW} \cdot t_{decay}]$$

$$Q_{decay} \approx \left[\frac{1}{2} (1.38mw - 0.652mw)(7.3ms) \right] + [0.652mw \cdot 7.3ms]$$

$$Q_{decay} \approx 2.67 \mu J + 4.76 \mu J$$

$$Q_{decay} \approx 7.43 \mu J$$

Example for SN 3262

Figure 23

Intensity-Time History: Area approximation for the “decay to steady state” region, SN 3262.

Measured Values (SN 3262)

$$\Phi_{CW} = 1.15 \text{ div} = 0.55 \text{ mw}$$

$$\Phi_{d-\max} = (3 \text{ div}) \left(\frac{0.55 \text{ mw}}{1.15 \text{ div}} \right) = 1.43 \text{ mw}$$

$$t_{\text{decay}} = (3.9 \text{ div}) \left(2 \text{ ms/div} \right) = 7.8 \text{ ms}$$

Calculated Values (SN 3262)

$$Q_{decay} \approx A_1 + A_2$$

$$Q_{decay} \approx \left[\frac{1}{2} (\Phi_{d-max} - \Phi_{CW}) \cdot t_{decay} \right] + [\Phi_{CW} \cdot t_{decay}]$$

$$Q_{decay} \approx \left[\frac{1}{2} (1.43mw - 0.55mw) (7.8ms) \right] + [0.55mw \cdot 7.8ms]$$

$$Q_{decay} \approx 3.43 \mu J + 4.29 \mu J$$

$$Q_{decay} \approx 7.72 \mu J$$

Table 14

Transient (“Decay”) Region Parameters for SN 3261 & SN 3262

Serial Number	Φ_{d-max} (mw)	Φ_{CW} (μ w)	t_{decay} (ms)	Q_{decay} (μ J)
3261	1.38	652	7.3	7.43
3262	1.43	550	7.8	7.72

Table 15**Radiance of Transient Region**

Serial Number	Q_{turn-on} (nJ)	Q_{decay} (μJ)
3223	153	7.08
3224	186	6.11
3225	194	6.78
3226	188	6.40
3227	210	6.90
3228	127	4.51
3229	204	6.43
3230	215	6.92
3231	227	7.17
3232	212	6.36
3233	206	6.42
3234	234	7.32
3235	218	7.02
3236	195	6.44
3237	156	5.09
3238	146	4.92
3239	209	6.73
3240	174	6.04
3241	183	6.01
3243	228	6.57
3244	179	5.70
3245	224	7.06
3246	248	6.88
3247	133	4.80
3249	260	6.85
3251	207	6.59
3252	191	6.00
3253	197	5.87
3254	159	5.78
3255	135	5.26
3256	200	6.74
3257	203	6.59

Table 15 (Continued)

Radiance of Transient Region

Serial Number	$Q_{\text{turn-on}}$ (nJ)	Q_{decay} (μJ)
3258	153	5.06
3259	207	6.51
3260	278	7.16
3261	237	7.43
3262	251	7.72
3263	200	6.24
3264	210	6.30
3265	201	6.35
3266	192	6.06
3277	282	6.99
3268	152	4.71
3269	252	6.52
3270	195	5.39
3271	197	6.36
3272	209	6.86
3274	167	5.51
3275	174	5.65
3276	213	5.99
3277	176	5.65
3278	209	6.40
3279	225	6.72
3280	173	5.69
3281	200	6.57
3282	185	6.19
3283	236	7.49
3284	207	3.99
3285	189	6.14
3286	200	6.43
3287	167	5.79
3288	216	6.93
3289	249	6.88
3290	221	6.89
3291	185	6.24
3292	171	5.73

III. Laser Hazard Analysis

Laser hazard analysis is concerned with the determination of the laser hazard Class, determination of possible hazard zones, the potential for injurious personnel exposures, the laser's intended use, and where the laser is to be used (indoors / outdoors).

A. Documentation

There are a number of industry and government documents that define hazard classes of laser operations. The following is a list of documents that deal with defining the various classes of laser operation:

1. General Laser Operations:
 - a. FDA-CDRH, Compliance Guide for Laser Products.
 - b. 21 CFR 1040, Laser Product Performance Standard.
 - c. ANSI Standard Z136.1-2000, for Safe Use of Lasers.
 - d. ACGIH, 2003 Threshold Limit Values for Chemical Substances & Physical Agents & Biological Exposure Indices.
2. Outdoor Laser Operations:
 - a. ANSI Standard Z136.6-2000, for Safe Use of Laser Outdoors.
 - b. FAA 7400.2D Chapter 34, Outdoor Laser / High Intensity Light Demonstrations.
3. DOE Laser Engagement Simulation System Operations:
 - a. DOE Order 5480.16A, Firearms Safety
 - b. DOE-STD-1091-96, Firearms Safety Standard
4. SNL Laser Operations:

ES&H Manual, Chapter 6G.

B. Laser Use In Force-On-Force Exercises

Lasers used in Force-On-Force (FOF) exercises, whether as aiming devices or weapon simulators must comply with the following guidelines. Specific laser safety requirements and restrictions that apply to the weapon simulator (laser) also apply to the weapon's aiming device (laser).

Laser Engagement Simulation Systems used in Force-On-Force Exercises.

1. ANSI Std. Z136.6-2000: "Force-On-Force"

- a. Section (4.2.5): Direct Fire Simulator, "Small arms simulators (pistols, rifles and machine guns, etc.), used in force-on-force exercises... should be Class 1 based on a 10 second exposure". Under certain, conditions and restrictions the *ANSI Z136.6* standard for outdoor lasers allows, "weapon simulators ...limited to Class 3a. The upper limit allowed is less than, "twice the Class 3a AEL", which is in the Class 3b laser hazard regime.
- b. Laser operations above Class 1 involved in force-on-force exercises require, "all the participants (to) have received specialized training...**shall** be approved for the application and be confined to a designated training area. Approval shall be by the Technical Laser System Safety Authority."

2. DOE Force-On-Force

DOE Order 5480.16A and DOE-STD-1091-96 require laser transmitters used in Engagement Simulation Systems (ESS) to comply with the *ANSI Std. Z136.1-1986*. Specifically in regard to labeling, warnings, certification, and safe distances calculated, "using the methodologies in *ANSI Z136.1-1986*".

3. SNL Force-On-Force Policy

SNL policy restricts lasers used in "force-on-force" exercises to laser hazard **Class 1 only**.

C. Accessible Emission (Exposure) Limits (ANSI Std. Z136.1-2000)

The Accessible Emission Limit (AEL) for a laser hazard class is the largest radiant output that a laser can have and still be considered to be in that hazard class. The AEL is a function (product) of the Maximum Permissible Exposure (MPE) and the area of the limiting aperture. Relative to personnel exposed to small source laser emission, this “accessible emission” limit can be considered an “allowable exposure” limit and will hereafter be referred to as the “Allowable Exposure Limit” (AEL). These two terms are interchangeable for small source lasers.

Class 1 Allowable Exposure Limit (Small Source Viewing).

In the case of the VITAL-2 Variable Intensity Tactical Aiming Light the determination of the appropriate MPE must be made for each mode of laser operation (CW, slow pulse and fast pulse).

1. Determination of the MPE (CW mode)

The determination of the appropriate MPE applicable to the VITAL-2 operated in the CW mode is found by applying the formula given in *ANSI Std. Z136.1-2000 (Table 5a)*.

$$MPE_{cw} = C_A \times 10^{-3} \text{ W/cm}^2 \quad \begin{array}{l} 700 \text{ nm} \leq \lambda < 1.05 \text{ } \mu\text{m} \\ 10 \text{ sec} \leq T \leq 30 \times 10^3 \end{array}$$

The *wavelength correction factor* (C_A) is given in *ANSI Std. Z136.1-2000 (Table 6)*.

$$\begin{aligned} C_A &= 10^{2(\lambda-0.7)} \\ &= 10^{2(0.83-0.7)} \\ &= 10^{2(0.13)} \\ C_A &= 1.82 \end{aligned}$$

Hence the MPE_{CW} is as follows.

$$MPE_{CW} = C_A \times 10^{-3} \text{ w/cm}^2$$

$$MPE_{CW} = 1.82 \times 10^{-3} \text{ w/cm}^2$$

2. Allowable Exposure Limit (CW Mode)

The Allowable Exposure Limit is the product of the MPE and the area of the limiting aperture presented in *ANSI Std. Z136.1-2000 (Table 8)*.

$$AEL_{830nm} = MPE \frac{\pi(d_{lim})^2}{4}$$

$$= (1.82 \times 10^{-3} \text{ w/cm}^2) \frac{\pi(0.7cm)^2}{4}$$

$$AEL_{830nm} = 701 \times 10^{-6} \text{ watts}$$

3. Extended Source Correction

The ANSI standard allows for the use of an *extended source correction factor* (C_E) for lasers with emission wavelengths in the visible and near infrared portion of the spectrum if the angle of the emission source subtended by the eye (α) is greater than some minimum angle ($\alpha_{\min}$). The extended source correction factor, in general, applies to laser diode.

The “notes” section of *ANSI Std. Z136.1-2000 (Table 6)* gives the value of the “minimum angle” for extended source condition.

$$\alpha_{\min} = 1.5 \text{ milliradians} \qquad 400 \text{ nm} \leq \lambda < 1.4 \text{ }\mu\text{m}$$

The viewing angle (α) of the emitting source subtended at the eye is dependent on the diameter of the emitting source (d_e) and the distance from the emitting source (R).

$$\alpha = \frac{d_e}{R}$$

The minimum viewing distance is defined by the ANSI standard as 10 cm from the emission source. The largest viewing angle ($\alpha_{10 \text{ cm}}$) occurs at this distance.

$$\alpha_{10 \text{ cm}} = \frac{d_e}{0.1 \text{ meter}}$$

There is some distance (R_x) from the emitting source where the viewing angle (α) is equal to the minimum-viewing angle ($\alpha_{\min}$). This is the extend source to small source crossover distance. When the observer is inside this distance the extended source correction factor (C_E) applies to the MPE determination. Outside this distance the small source MPE applies.

The spot size, at the exit window (aperture), for the VITAL-2 units are similar for both SN3261 and SN3262 and are approximately 3 millimeters in diameter (both axis). The largest viewing angle ($\alpha_{10\text{ cm}}$) is calculated at the minimum viewing distance of 10 cm to be as follows.

$$\alpha_{10\text{ cm}} = \frac{3\text{ mm}}{10\text{ cm}} = \frac{3\text{ mm}}{0.1\text{ m}} = 30 \text{ milliradians}$$

The ANSI standard lists $\alpha_{\text{max}} = 100 \text{ mrad}$ (ANSI *Table 6* – notes)

The viewing angle is greater than 1.5 mR; therefore the extended source correction factor would apply in the determination of the MPE within the extended source viewing range. The extended source viewing range extends from 10 cm to the extended source – small source crossover distance.

a. Extended Source – Small Source Crossover Distance

The extended source – small source crossover distance occurs at the distance from the emitting source where the viewing angle subtended by the eye is equal to 1.5 mR and can be calculated as follows.

$$\alpha_{\text{min}} = \frac{d_e}{R_x}$$

Where,

α_{min} Viewing angle at the extended source crossover.

d_e Diameter of emitting source.

R_x Distance to extended source to small source crossover.

The distance to the crossover point (R_X) can be expressed as follows.

$$R_X = \frac{d_e}{\alpha_{\min}}$$

Specifically for the VITAL-2 units this crossover distance is as follows.

$$R_X = \frac{\sim 3 \text{ mm}}{1.5 \text{ mrad}}$$

$$R_X \approx 2 \text{ meters}$$

For viewing distances greater than 10 cm but less than 2 meters the extended source correction factor (C_E) applies in the determination of the MPE.

b. Extended Source Correction Factor

The extended source correction factor is presented in the *ANSI Std. Z136.1-2000* (Table 6) and given as a function of the viewing angle as follows.

$$C_E = \frac{\alpha}{\alpha_{\min}} \quad \text{for } 0.4\mu m \leq \lambda \leq 1.4\mu m$$

The viewing is a function of the diameter of the emitting source and the viewing distance.

$$\alpha = \frac{d_e}{R}$$

Therefore the extended source correction factor can be expressed as a function of the diameter of the emitting source and the viewing distance.

$$C_E = \frac{d_e / R}{\alpha_{\min}}$$

$$C_E = f(R) = \frac{d_e}{R \alpha_{\min}}$$

For the VITAL-2 units this can be evaluated as a function of the range, R, as follows.

$$C_E = f(R) = \frac{3 \text{ mm}}{R \left(1.5 \text{ mR} \right)}$$

$$C_E = f(R) = \frac{2}{R}$$

c. Extended Source MPE

The extended source MPE is the product of the small source MPE and the extended source correction factor [ANSI Std. Z136.1-2000 (8.1)].

$$MPE_{ES} = C_E \cdot MPE_{SS} \quad \text{for: } 10 \text{ cm} \leq R \leq R_x$$

Applied to the VITAL-2 units the extended source CW MPE is as follows.

$$MPE_{ES-CW} = \left(\frac{2}{R} \right) (1.82 \text{ mw/cm}^2) \quad \text{for: } 10 \text{ cm} \leq R \leq 2 \text{ meters}$$

Extended Source MPE versus Distance From Emitting Source

d. MPE (Extended Source-Small Source Continuum)

The appropriate MPE consists of the extended source MPE for distances from 10 centimeters to 2 meters and the small source MPE for all distances greater than 2 meters, as depicted in the following plot.

MPE versus Distance From Emitting Source

e. AEL (Extended Source-Small Source Continuum)

Again the AEL is the product of the appropriate MPE and the area of the limiting aperture.

$$AEL = MPE \cdot A_{\text{lim}}$$

The area of the limiting aperture, in this case, is 0.385 square centimeters. This scale factor applied to the previous curve yields a plot of the AEL as a function of distance from the emitting source for both the extended source and small source viewing regions, as depicted below.

AEL versus Distance From Emitting Source

As indicated in the “AEL versus Distance From Emitting Source” curve above, radiant outputs below the AEL curve indicate a Class 1 Laser Hazard (eye-safe) and radiant output above the Class 1 AEL curve (but less than 5 times the AEL value) are a Class 3a Laser Hazard (not eye-safe).

Power Measurements At Various Distances

Power measurements, made through a 7-mm aperture, were taken at various distances from the VITAL-2 emitting sources for SN 3261 and SN 3262. The power measurements were plotted on the “AEL versus Distance From Emitting Source” curve, given previously, and in all cases these data points were below the

value of the small source AEL (701 μW) as well as the extended source correction region of the AEL curve. All data points below the AEL curve depict a Class 1 Laser Hazard (eye-safe).

As a result of the above power measurement plot which clearly shows that the radiant outputs of the VITAL-2 (SN 3261 and SN 3262) measured at 10 centimeters, were below the small source AEL and remained below the small source AEL at varying distances from the emitting sources. The radiant output CW power measurements for the remaining VITAL-2 units were made at the 10-centimeter location and these radiant power measurements were compared to the small source AEL for the determination of the laser hazard class. The results of these measurements are presented in Table 20 on page 84.

4. Determination of the MPE (Pulsed mode)

The determination of the appropriate MPE for repetitive-pulse lasers is given in *ANSI Std. Z136.1-2000 (8.2.3)*. The **appropriate MPE** is the **smallest** of the MPE(s) determined by **Rules 1, 2 & 3**. Small source viewing MPE formulae are presented in table 5a (*ANSI Std. Z136.1-2000*).

Rule 1 (Single Pulse)

The ANSI standard requires that the exposure from any single pulse in a multiple pulse exposure shall not exceed the MPE for the single pulse exposure given in *Table 5a* of the ANSI standard [*ANSI Std. Z136.1-2000 (8.2.3-Rule 1)*].

$$MPE_{s.p.} = 1.8C_A t^{0.75} \times 10^{-3} J/cm^2$$

$0.7 \mu m \leq \lambda < 1.05 \mu m$
 $18 \times 10^{-6} \text{ sec} \leq t < 10 \text{ sec}$

MPE Pulse Width Dependency

The single pulse MPE formula presented in *ANSI Table 5a* appropriate to the output parameters of the VITAL-2 indicates a pulse width (t) dependency.

The MPE for this wavelength can be expressed as:

$$MPE_{s.p.} = (1.8)(1.82) t^{0.75} \times 10^{-3} J/cm^2$$

The single pulse MPE as a function of the pulse width can be expressed as

for : $18 \times 10^{-6} \text{ sec} \leq t < 10 \text{ sec}$

$$MPE_{s.p.}(t) = 3.28 t^{0.75} \times 10^{-3} J/cm^2$$

Maximum Permissible Exposure As A Function Of The Pulse Width

Rule 2 (Average Power MPE for Thermal and Photochemical Hazard)

The ANSI standard requires that the exposure from any group of pulses delivered in an exposure (T) shall not exceed the MPE of the exposure (T) distributed over each pulse in the exposure [*ANSI Std. Z136.1-2000 (8.2.3-Rule 2)*].

$$MPE_{pulse} = \frac{MPE_{s.p.} \cdot T}{n}$$

The number of pulses in the exposure is the product of the Pulse Repetition Frequency (PRF) and the exposure duration.

$$n = PRF \cdot T$$

$$MPE_{pulse} = \frac{MPE_{s.p.} \cdot T}{PRF \cdot T}$$

$$MPE_{pulse} = \frac{MPE_{s.p.}}{PRF}$$

Rule 3 (Multiple-pulse MPE for Thermal Hazards)

The ANSI standard requires that the exposure for any single pulse within a group of pulses shall not exceed the thermal MPE of single pulse times the multiple pulse correction factor (C_p).

$$MPE_{m.p.} = C_p MPE_{thermal}$$

Where C_p is given in *ANSI Table 6* as:

$$C_p = n^{-0.25}$$

The multiple pulse MPE can be expressed in terms of the number of pulses in the exposure.

$$MPE_{m.p.} = \left(n^{-0.25} \right) MPE_{thermal}$$

Rule 2-Rule 3 Crossover

For pulse trains of uniform laser pulses the appropriate MPE will be derived from either the *ANSI Rule 2* or the *ANSI Rule 3*. There exist a specific number of laser pulses, here referred to as the crossover number (n_x), after which, the per-pulse MPE shifts from *ANSI Rule 3* dominant to *ANSI Rule 2* dominant. This crossover number can be determined by equating the formulae for *ANSI Rule 2 and 3*. The MPE for exposures where the number of laser pulses are less than the crossover point number are *ANSI Rule 3* dominant. The MPE for exposures where this number is greater than the crossover number are *ANSI Rule 2* dominant.

$$MPE_{Rule2} = MPE_{Rule3}$$

$$\frac{MPE_{cw} \cdot T}{n_x} = \left(n_x^{-0.25} \right) MPE_{s.p.}$$

$$n_x = \left[\frac{MPE_{cw} \cdot T}{MPE_{s.p.}} \right]^{4/3}$$

$$n_x = \left[\frac{C_A \cdot T \times 10^{-3} \text{ w/cm}^2}{1.8 C_A t^{3/4} \times 10^{-3} \text{ J/cm}^2} \right]^{4/3}$$

$$n_x = \left[\frac{T \text{ (watts)}}{1.8 t^{3/4} \text{ (Joules)}} \right]^{4/3}$$

The standard exposure (for lasers with emissions in the NIR) is given in ANSI *Table 4a* as 10 seconds.

$$n_x = \left[\frac{(10 \text{ sec}) \text{ (watts)}}{1.8 t^{3/4} \text{ (Joules)}} \right]^{4/3}$$

The number of laser pulses to the crossover point as a function of the pulse duration is given as follows.

$$n_x(t) = \frac{9.84}{t}$$

Evaluation of the Crossover Point

The pulse duration for the VITAL-2 varied dependent upon mode of operation (slow pulse or fast pulse) and from unit to unit. The pulse durations given in Table 9 ranged for 38 ms to 96 ms.

The number of pulses in the standard exposure (ANSI standard *Table 4a*) to the crossover point is as follows.

$$n_{x(38ms)} = \frac{9.84}{0.038} = 259 \text{ pulses}$$

$$n_{x(96ms)} = \frac{9.84}{0.096} = 103 \text{ pulses}$$

The number of laser pulses emitted in the standard exposure duration is the product of the PRF and the exposure. The PRF for the VITAL-2 units varied from 4.17 hertz and 6.1 hertz.

For 4.17 Hz:

$$n_{4.17Hz} = (4.17 \text{ sec}^{-1}) (10 \text{ sec}) = 41.7 \text{ pulses}$$
$$n_{4.17Hz} = 42^* \text{ pulses}$$

*Note: Fractional numbers of laser pulses are rounded up to the next whole number.

For 6.10 Hz:

$$n_{6.10Hz} = (6.10 \text{ sec}^{-1}) (10 \text{ sec})$$
$$n_{6.10Hz} = 61 \text{ pulses}$$

The number of laser pulses in the standard exposure for the VITAL-2 units are less than the crossover-number therefore the MPE is *ANSI Rule 3* dominant.

Appropriate MPE

The appropriate MPE for the multiple pulse output of the VITAL-2 is derived by the application of *ANSI Rule 3* and is the product of this single MPE and the pulse correction factor (C_p) for a 10-second standard IR exposure.

$$MPE_{m.p.} = C_p MPE_{s.p.}$$

Where C_p is given in *ANSI Table 6* as:

$$C_p = n^{-0.25}$$

The number of pulses (n) in the exposure (T) is the product of the Pulse Repetition Rate and the exposure duration.

$$n = PRF \cdot T$$

The number (n) of pulses used in calculating the pulse correction factor is always an integer. In cases, such as here, where the product of the PRF and the standard exposure is not an integer the product is rounded up to the next integer for this calculation.

Appropriate AEL

The Allowable Exposure Limit (*AEL*) in this case is also a function of the pulse width and is expressed as the product of the multiple-pulse MPE and the area of the limiting aperture given in *ANSI Table 8*.

$$AEL(t) = [MPE_{m.p.}(t)] \frac{\pi(d_{\text{lim}})^2}{4}$$

The calculated MPE(s) and AEL(s) for the measured output pulse widths of the slow and fast pulse modes of the various VITAL-2 units are presented in Table 16 and Table 17.

Table 16**MPE and AEL Values (Slow Pulse Mode)**

Serial Number	t (ms)	MPE(t) ($\mu\text{J}/\text{cm}^2$)	n(T)	C_p	MPE_{mp} ($\mu\text{J}/\text{cm}^2$)	AEL (μJ)
3223	73	460	44	0.388	179	68.8
3224	76	474	43	0.391	185	71.3
3225	78	484	42	0.393	190	73.1
3226	70	446	44	0.388	173	66.6
3227	70	446	46	0.384	171	65.9
3228	80	493	44	0.388	191	73.7
3229	89	534	50	0.376	201	77.3
3230	70	446	46	0.384	171	65.9
3231	72	455	46	0.384	175	67.3
3232	78	484	44	0.388	188	72.3
3233	80	493	42	0.393	194	74.5
3234	96	565	43	0.391	221	84.9
3235	85	516	46	0.384	198	76.2
3236	95	561	42	0.393	220	84.8
3237	80	493	44	0.388	191	73.7
3238	74	465	45	0.386	179	69.1
3239	74	465	44	0.388	180	69.5
3240	79	488	43	0.391	191	73.4
3241	90	538	46	0.384	207	79.6
3242	74	465	44	0.388	180	69.5
3243	62	407	57	0.364	148	57.0
3244	74	465	44	0.388	180	69.5
3245	90	538	44	0.388	209	80.5
3246	94	556	43	0.391	217	83.6
3247	89	534	50	0.376	201	77.3
3248	91	543	44	0.388	211	81.1
3249	79	488	49	0.378	185	71.0
3250	77	479	45	0.386	185	71.2
3251	94	556	47	0.382	212	81.8
3252	74	465	45	0.386	179	69.1
3253	74	465	45	0.386	179	69.1
3254	73	460	44	0.388	179	68.8
3255	94	556	42	0.393	218	84.1
3256	79	488	44	0.388	190	73.0
3257	73	460	45	0.386	178	68.4

Table 16 (Continued)**MPE and AEL Values (Slow Pulse Mode)**

Serial Number	t (ms)	MPE(t) ($\mu\text{J}/\text{cm}^2$)	n(T)	C_p	MPE_{mp} ($\mu\text{J}/\text{cm}^2$)	AEL (μJ)
3258	73	460	44	0.388	179	68.8
3259	88	529	44	0.388	205	79.1
3260	79	488	43	0.391	191	73.4
3261	85	516	42	0.393	203	78.0
3262	90	538	45	0.386	208	80.0
3263	88	529	41	0.395	209	80.5
3264	74	465	43	0.391	182	69.9
3265	74	465	46	0.384	178	68.7
3266	74	465	44	0.388	180	69.5
3267	77	479	44	0.388	186	71.6
3268	89	534	46	0.384	205	78.9
3269	79	488	44	0.388	190	73.0
3270	74	465	50	0.376	175	67.3
3271	72	455	46	0.384	175	67.3
3272	78	484	44	0.388	188	72.3
3273	72	455	45	0.386	176	67.7
3274	77	479	42	0.393	188	72.4
3275	76	474	42	0.393	186	71.7
3276	71	451	43	0.391	176	67.7
3277	73	460	44	0.388	179	68.8
3278	78	484	41	0.395	191	73.6
3279	72	455	44	0.388	177	68.1
3280	91	543	45	0.386	210	80.7
3281	90	538	41	0.395	213	81.9
3282	73	460	44	0.388	179	68.8
3283	88	529	44	0.388	206	79.1
3284	71	451	44	0.388	175	67.4
3285	79	488	43	0.391	191	73.4
3286	71	451	45	0.386	174	67.0
3287	78	484	46	0.384	186	71.5
3288	86	520	42	0.393	204	78.7
3289	74	465	46	0.384	178	68.7
3290	78	484	42	0.393	190	73.1
3291	84	511	46	0.384	196	75.6
3292	69	441	46	0.384	169	65.2

Table 17**MPE and AEL Values (Fast Pulse Mode)**

Serial Number	t (ms)	MPE(t) ($\mu\text{J}/\text{cm}^2$)	n(T)	C_p	MPE_{mp} ($\mu\text{J}/\text{cm}^2$)	AEL (μJ)
3223	46	325	58	0.362	118	45.4
3224	44	315	60	0.359	113	43.5
3225	46	325	57	0.364	118	45.6
3226	48	336	56	0.366	123	47.3
3227	47	331	57	0.364	120	46.3
3228	50	346	57	0.364	126	48.5
3229	64	417	57	0.364	152	58.4
3230	44	315	60	0.359	113	43.5
3231	46	325	59	0.361	117	45.2
3232	48	336	59	0.361	121	46.7
3233	49	341	57	0.364	124	47.8
3234	69	441	58	0.362	160	61.5
3235	49	341	61	0.358	122	47.0
3236	62	407	57	0.364	148	57.0
3237	50	346	57	0.364	126	48.5
3238	49	341	58	0.362	124	47.6
3239	44	315	59	0.361	114	43.7
3240	53	362	61	0.358	129	49.9
3241	46	325	57	0.364	118	45.6
3242	46	325	58	0.362	118	45.4
3243	54	367	69	0.347	127	49.0
3244	48	336	57	0.364	122	47.1
3245	63	412	59	0.361	149	57.2
3246	61.5	405	58	0.362	147	56.4
3247	62	407	58	0.362	147	56.8
3248	63	412	59	0.361	149	57.2
3249	48	336	58	0.362	122	46.9
3250	49	341	58	0.362	124	47.6
3251	62	407	57	0.364	148	57.0
3252	44	315	59	0.361	114	43.7
3253	48	336	59	0.361	121	46.7
3254	48	336	57	0.364	122	47.1
3255	68	436	55	0.367	160	61.7
3256	43	309	58	0.362	112	43.2
3257	44	315	61	0.358	113	43.4

Table 17 (Continued)**MPE and AEL Values (Fast Pulse Mode)**

Serial Number	t (ms)	MPE(t) ($\mu\text{J}/\text{cm}^2$)	n(T)	C_p	MPE_{mp} ($\mu\text{J}/\text{cm}^2$)	AEL (μJ)
3258	48	336	57	0.364	122	47.1
3259	52	357	59	0.361	129	49.6
3260	48	336	58	0.363	122	46.9
3261	50	346	57	0.364	126	48.5
3262	60	397	57	0.364	145	55.6
3263	54	367	45	0.386	142	54.6
3264	46	325	56	0.366	119	45.8
3265	49	341	61	0.358	122	47.0
3266	38	282	58	0.362	102	39.3
3267	49	341	58	0.362	123	47.6
3268	62	407	59	0.361	147	56.5
3269	51	352	58	0.362	127	49.0
3270	46	325	58	0.362	118	45.4
3271	44	315	61	0.358	113	43.4
3272	46	325	59	0.361	117	45.2
3273	48	336	58	0.362	122	46.9
3274	50	346	55	0.367	127	49.0
3275	46	325	56	0.366	119	45.8
3276	48	336	55	0.367	123	47.5
3277	47	331	59	0.361	119	45.9
3278	47	331	57	0.364	120	46.3
3279	45	320	58	0.362	116	44.7
3280	64	417	57	0.364	152	58.4
3281*	90	538	41	0.395	213	81.9
3282	45	320	58	0.362	116	44.7
3283	62	407	57	0.364	148	57.0
3284	46	325	57	0.364	118	45.6
3285	48	336	58	0.362	122	46.9
3286	45	320	59	0.361	115	44.5
3287	48	336	58	0.362	122	46.9
3288	46	325	58	0.362	118	45.4
3289	46	325	59	0.361	117	45.2
3290	48	336	56	0.366	123	47.3
3291	60	397	60	0.359	143	54.9
3292	45	320	59	0.361	115	44.5

* Output the same for both modes of pulsed operations

MPE For The “Turn On” Region

Sample Calculations for SN3262 (Slow Pulse):

From the *Law Of Sines* the pulse width (t_{FWHM}) of the area approximation triangle used to determine the MPE is set as:

$$\frac{\Phi_{\max}}{300\mu s} = \frac{\frac{1}{2}\Phi_{\max}}{t_{FWHM}}$$

$$t_{FWHM} = \left(\frac{1}{2}\right) (300\mu s) = 150 \mu s$$

$$MPE_{s.p.-turn-on(150\mu s)} = (3.28 \times 10^{-3}) [150 \times 10^{-6}]^{0.75} J/cm^2$$

$$MPE_{s.p.-turn-on(150\mu s)} = 4.44 \times 10^{-6} J/cm^2$$

$$n = PRF \cdot T = (4.44 \text{ sec}^{-1}) (10 \text{ sec}) = 44.4 \text{ pulses}$$

$$n \approx 45$$

$$C_p = n^{-0.25}$$

$$C_p = (45)^{-0.25} = 0.386$$

$$MPE_{m.p.} = C_p MPE_{s.p.}$$

$$MPE_{turn-on(SN3262)} = (0.386) (4.44 \times 10^{-6} J/cm^2)$$

$$MPE_{turn-on(SN3262)} = 1.71 \times 10^{-6} J/cm^2$$

Determination Of The AEL In The “Turn-On” Region

$$AEL_{turn-on(SN3262)} = (0.385 \text{ cm}^2) (1.71 \times 10^{-6} J/cm^2)$$

$$AEL_{turn-on(SN3262)} = 660 \times 10^{-9} J$$

Table 18**MPE and AEL For The “Turn On” Region**

Serial Number	T_{FWHM} (μs)	MPE(t) (μJ/cm²)	n(T)	C_p	MPE_{turn on} (μJ/cm²)	AEL (nJ)
3223	150	4.44	44	0.388	1.72	664
3224	150	4.44	44	0.388	1.72	664
3225	150	4.44	42	0.393	1.74	672
3226	150	4.44	44	0.388	1.72	664
3227	150	4.44	46	0.384	1.70	656
3228	150	4.44	44	0.388	1.72	664
3229	150	4.44	50	0.376	1.67	643
3230	150	4.44	46	0.384	1.70	656
3231	150	4.44	46	0.384	1.70	656
3232	150	4.44	44	0.388	1.72	664
3233	150	4.44	42	0.393	1.74	672
3234	150	4.44	43	0.391	1.73	668
3235	150	4.44	46	0.384	1.70	656
3236	150	4.44	42	0.393	1.74	672
3237	150	4.44	44	0.388	1.72	664
3238	150	4.44	45	0.386	1.71	660
3239	150	4.44	44	0.388	1.72	664
3240	150	4.44	43	0.391	1.73	668
3241	150	4.44	46	0.384	1.70	656
3243	150	4.44	57	0.364	1.62	622
3244	150	4.44	44	0.388	1.72	664
3245	150	4.44	44	0.388	1.72	664
3246	150	4.44	43	0.391	1.73	668
3247	150	4.44	50	0.376	1.67	643
3249	150	4.44	49	0.378	1.68	646
3251	150	4.44	47	0.382	1.70	653
3252	150	4.44	45	0.386	1.71	660
3253	150	4.44	45	0.386	1.71	660
3254	150	4.44	44	0.388	1.72	664
3255	150	4.44	42	0.393	1.74	672
3256	150	4.44	44	0.388	1.72	664
3257	150	4.44	45	0.386	1.71	660

Table 18 (Continued)

MPE and AEL For The “Turn On” Region

Serial Number	T_{FWHM} (μs)	MPE(t) (μJ/cm²)	n(T)	C_p	MPE_{turn on} (μJ/cm²)	AEL (nJ)
3258	150	4.44	44	0.388	1.72	664
3259	150	4.44	44	0.388	1.72	664
3260	150	4.44	43	0.391	1.73	668
3261	150	4.44	42	0.393	1.74	672
3262	150	4.44	45	0.386	1.71	660
3263	150	4.44	41	0.395	1.75	676
3264	150	4.44	44	0.388	1.72	664
3265	150	4.44	46	0.384	1.70	656
3266	150	4.44	44	0.388	1.72	664
3267	150	4.44	44	0.388	1.72	664
3268	150	4.44	46	0.384	1.70	656
3269	150	4.44	44	0.388	1.72	664
3270	150	4.44	50	0.376	1.67	643
3271	150	4.44	46	0.384	1.70	656
3272	150	4.44	44	0.388	1.72	664
3274	150	4.44	42	0.393	1.74	672
3275	150	4.44	42	0.393	1.74	672
3276	150	4.44	43	0.391	1.73	668
3277	150	4.44	44	0.388	1.72	664
3278	150	4.44	41	0.395	1.75	676
3279	150	4.44	44	0.388	1.72	664
3280	150	4.44	45	0.386	1.71	660
3281	150	4.44	41	0.395	1.75	676
3282	150	4.44	44	0.388	1.72	664
3283	150	4.44	44	0.388	1.72	664
3284	150	4.44	44	0.388	1.72	664
3285	150	4.44	43	0.391	1.73	668
3286	150	4.44	45	0.386	1.71	660
3287	150	4.44	46	0.384	1.70	656
3286	150	4.44	45	0.386	1.71	660
3288	150	4.44	42	0.393	1.74	672
3289	150	4.44	46	0.384	1.70	656
3290	150	4.44	42	0.393	1.74	672
3291	150	4.44	46	0.384	1.70	656
3292	150	4.44	46	0.384	1.70	656

MPE For The “Decay-” Region

Sample Calculations for SN 3262 (Slow Pulse):

The pulse width, t_{decay} , of the approximation rombus is as follows.

$$t_{decay} = (3.4 \text{ div}) (2 \text{ ms/div}) = 7.8 \text{ ms}$$

$$MPE_{s.p.-decay(7.8ms)} = (3.28 \times 10^{-3}) [7.8 \times 10^{-3}]^{0.75} J/cm^2$$

$$MPE_{s.p.-decay(7.8ms)} = 86.0 \times 10^{-6} J/cm^2$$

$$n = PRF \cdot T = (4.44 \text{ sec}^{-1}) (10 \text{ sec}) = 44.4 \text{ pulses}$$

$$n \approx 45$$

$$C_p = n^{-0.25}$$

$$C_p = (45)^{-0.25} = 0.386$$

$$MPE_{m.p.} = C_p MPE_{s.p.}$$

$$MPE_{decay(SN3262)} = (0.386) (86.0 \times 10^{-6} J/cm^2)$$

$$MPE_{decay(SN3262)} = 33.2 \times 10^{-6} J/cm^2$$

Determination Of The AEL In The “Turn-On” Region

$$AEL_{decay(SN3262)} = (0.385 \text{ cm}^2) (33.2 \times 10^{-6} J/cm^2)$$

$$AEL_{decay(SN3262)} = 12.8 \times 10^{-6} J$$

Table 19**MPE and AEL For The “Decay” Region Of The Laser Pulses**

Serial Number	T_{decay} (ms)	MPE(t) (μJ/cm²)	n(T)	C_p	MPE_{turn on} (μJ/cm²)	AEL (μJ)
3223	7.5	83.5	44	0.388	32.4	12.5
3224	7.5	83.5	44	0.388	32.4	12.5
3225	7.8	86.0	42	0.393	33.8	13.0
3226	7.8	86.0	44	0.388	33.4	12.9
3227	7.5	83.5	46	0.384	32.1	12.3
3228	7.5	83.5	44	0.388	32.4	12.5
3229	7.5	83.5	50	0.376	31.4	12.1
3230	7.6	84.3	46	0.384	32.4	12.5
3231	7.5	83.5	46	0.384	32.1	12.3
3232	7.5	83.5	44	0.388	32.4	12.5
3233	7.4	82.7	42	0.393	32.5	12.5
3234	7.5	83.5	43	0.391	32.6	12.6
3235	7.5	83.5	46	0.384	32.1	12.3
3236	7.5	83.5	42	0.393	32.8	12.6
3237	7.5	83.5	44	0.388	32.4	12.5
3238	7.6	84.3	45	0.386	32.6	12.5
3239	7.4	82.7	44	0.388	32.1	12.4
3240	7.5	83.5	43	0.391	32.6	12.6
3241	7.4	82.7	46	0.384	31.7	12.2
3243	7.4	82.7	57	0.364	30.1	11.6
3244	7.5	83.5	44	0.388	32.4	12.5
3245	7.4	82.7	44	0.388	32.1	12.4
3246	7.5	83.5	43	0.391	32.6	12.6
3247	7.4	82.7	50	0.376	31.1	12.0
3249	7.0	79.3	49	0.378	30.0	11.5
3251	7.6	84.3	47	0.382	32.2	12.4
3252	7.3	81.8	45	0.386	31.6	12.2
3253	7.5	83.5	45	0.386	32.2	12.4
3254	7.6	84.3	44	0.388	32.7	12.6
3255	7.5	83.5	42	0.393	32.8	12.6
3256	7.5	83.5	44	0.388	32.4	12.5
3257	7.4	82.7	45	0.386	31.9	12.3

Table 19 (Continued)**MPE and AEL For The “Decay” Region Of The Laser Pulses**

Serial Number	T_{decay} (ms)	MPE(t) (μJ/cm²)	n(T)	C_p	MPE_{turn on} (μJ/cm²)	AEL (μJ)
3258	7.6	84.3	44	0.388	32.7	12.6
3259	7.5	83.5	44	0.388	32.4	12.5
3260	7.2	81.0	43	0.391	31.6	12.2
3261	7.3	81.8	42	0.393	32.1	12.4
3262	7.8	86.0	45	0.386	33.2	12.8
3263	7.5	83.5	41	0.395	33.0	12.7
3264	7.5	83.5	44	0.388	32.4	12.5
3265	7.8	86.0	46	0.384	33.0	12.7
3266	7.5	83.5	44	0.388	32.4	12.5
3267	7.0	79.3	44	0.388	30.8	11.9
3268	7.4	82.7	46	0.384	31.7	12.2
3269	7.0	79.3	44	0.388	30.8	11.9
3270	7.8	86.0	50	0.376	32.3	12.4
3271	7.5	83.5	46	0.384	32.1	12.3
3272	7.5	83.5	44	0.388	32.4	12.5
3274	7.6	84.3	42	0.393	33.1	12.8
3275	7.5	83.5	42	0.393	32.8	12.6
3276	7.0	79.3	43	0.391	31.0	11.9
3277	7.4	82.7	44	0.388	32.1	12.4
3278	7.4	82.7	41	0.395	32.7	12.6
3279	7.0	79.3	44	0.388	30.8	11.9
3280	7.8	86.0	45	0.386	33.2	12.8
3281	7.4	82.7	41	0.395	32.7	12.6
3282	7.6	84.3	44	0.388	32.7	12.6
3283	7.5	83.6	44	0.388	32.4	12.5
3284	7.0	79.3	44	0.388	30.8	11.9
3285	7.5	83.5	43	0.391	32.6	12.6
3286	7.4	82.7	45	0.386	31.9	12.3
3287	7.5	83.5	46	0.384	32.1	12.3
3288	7.6	84.3	42	0.393	33.1	12.8
3289	7.5	83.5	46	0.384	32.1	12.3
3290	7.6	84.3	42	0.393	33.1	12.8
3291	7.5	83.5	46	0.384	32.1	12.3
3292	7.8	86.0	46	0.384	33.0	12.7

IV. Results

A. CW Mode

In all cases presented the radiant CW output power measurements were made through a 7-mm “limiting” aperture at a distance of 10-centimeters from the emitting source. The results are presented in Table 20 and Table 21. All VITAL-2 units tested were Class 1 (eye-safe) laser operations.

Table 20

Laser Hazard – Aiming Laser

Serial Number	Φ_o^* (μW)	Φ_{max} (μW)	AEL (μW)	Hazard Class
3223	355	511	701	1
3224	111	558	701	1
3225	497	579	701	1
3226	243	541	701	1
3227	304	629	701	1
3228	492	615	701	1
3229	95	535	701	1
3230	252	582	701	1
3231	137	631	701	1
3232	324	525	701	1
3233	145	556	701	1
3234	132	603	701	1
3235	149	601	701	1
3236	361	596	701	1
3237	114	500	701	1
3238	285	525	701	1
3239	118	620	701	1
3240	123	580	701	1
3241	102	515	701	1
3242	196	618	701	1
3243	205	553	701	1

Table 20 (Continued)**Laser Hazard – Aiming Laser**

Serial Number	Φ_o^* (μW)	Φ_{max} (μW)	AEL (μW)	Hazard Class
3244	142	490	701	1
3245	456	597	701	1
3246	128	600	701	1
3247	100	531	701	1
3248	90	557	701	1
3249	285	577	701	1
3250	100	510	701	1
3251	149	524	701	1
3252	445	584	701	1
3253	149	505	701	1
3254	145	460	701	1
3255	492	501	701	1
3256	273	646	701	1
3257	560	570	701	1
3258	162	490	701	1
3259	566	566	701	1
3260	286	568	701	1
3261	645	652	701	1
3262	550	†	701	1
3263	524	544	701	1
3264	408	557	701	1
3265	205	487	701	1
3266	173	565	701	1
3267	410	586	701	1
3268	292	403	701	1
3269	567	622	701	1
3270	203	553	701	1
3271	175	597	701	1
3272	580	608	701	1
3273	687	694	701	1

Table 20 (Continued)

Laser Hazard – Aiming Laser

Serial Number	Φ_o^* (μW)	Φ_{max} (μW)	AEL (μW)	Hazard Class
3274	435	548	701	1
3275	427	526	701	1
3276	130	592	701	1
3277	145	518	701	1
3278	158	550	701	1
3279	46	618	701	1
3280	57	449	701	1
3281	542	616	701	1
3282	24	560	701	1
3283	630	638	701	1
3284	242	591	701	1
3285	512	546	701	1
3286	147	579	701	1
3287	159	617	701	1
3288	478	564	701	1
3289	304	515	701	1
3290	118	572	701	1
3291	225	625	701	1
3292	148	468	701	1

Table 21**Laser Hazard – Area Illuminator**

Serial Number	Bright $\Phi_{10\text{ cm}}$ (μw)	Dim $\Phi_{10\text{ cm}}$ (μw)	AEL (μw)	Hazard Class
3223	481	12	701	1
3224	383	20	701	1
3225	680	15	701	1
3226	382	12	701	1
3227	514	14	701	1
3228	320	10	701	1
3229	513	10	701	1
3230	449	14	701	1
3231	482	10	701	1
3232	412	9	701	1
3233	255	10	701	1
3234	675	14	701	1
3235	485	13	701	1
3236	383	10	701	1
3237	435	11	701	1
3239	293	11	701	1
3240	416	14	701	1
3241	419	13	701	1
3242	517	12	701	1
3243	520	12	701	1
3244	415	9	701	1
3245	327	14	701	1
3246	434	12	701	1
3247	552	18	701	1
3248	566	11	701	1
3249	625	19	701	1
3250	493	20	701	1
3251	429	12	701	1
3252	540	18	701	1
3253	644	16	701	1
3254	548	15	701	1
3255	499	13	701	1
3256	390	9	701	1
3257	512	18	701	1

Table 21 (Continued)

Laser Hazard – Area Illuminator

Serial Number	Bright $\Phi_{10\text{ cm}}$ (μW)	Dim $\Phi_{10\text{ cm}}$ (μW)	AEL (μW)	Hazard Class
3258	418	14	701	1
3259	290	20	701	1
3260	558	10	701	1
3262	385	10	701	1
3263	438	13	701	1
3264	371	13	701	1
3265	444	14	701	1
3266	590	17	701	1
3267	495	9	701	1
3268	363	9	701	1
3269	436	15	701	1
3270	200	9	701	1
3271	382	10	701	1
3272	450	13	701	1
3273	318	10	701	1
3274	585	19	701	1
3275	342	9	701	1
3276	537	18	701	1
3277	503	18	701	1
3278	382	12	701	1
3279	407	18	701	1
3280	339	9	701	1
3281	624	18	701	1
3282	469	17	701	1
3283	479	17	701	1
3284	457	18	701	1
3285	361	9	701	1
3286	587	18	701	1
3287	356	9	701	1
3288	476	16	701	1
3289	279	9	701	1
3290	429	14	701	1
3291	418	12	701	1
3292	412	9	701	1

B. Pulse Mode

In all cases presented, the radiant output energy was calculated from the average power measurements of the pulsed mode, made through a 7-mm “limiting” aperture at a distance of 10-centimeters from the emitting source. The results are presented in the following two tables for the “slow pulse mode and the “fast” pulse mode of operation. All VITAL-2 units tested were below AEL and are Class 1 (eye-safe) laser operations.

Table 22

Laser Hazard – Slow Pulse Mode

Serial Number	Q_o (μJ)	AEL (μJ)	Hazard Class
3223	38.2	68.8	1
3224	42.5	71.3	1
3225	47.5	73.1	1
3226	39.5	66.6	1
3227	45.3	65.9	1
3228	46.6	73.7	1
3229	42.4	77.3	1
3230	42.0	65.9	1
3231	45.7	67.3	1
3232	42.0	72.3	1
3233	49.0	74.5	1
3234	59.8	84.9	1
3235	53.0	76.2	1
3236	48.5	84.8	1
3237	40.7	73.7	1
3238	39.4	69.1	1
3239	51.6	69.5	1
3240	46.7	73.4	1
3241	38.0	79.6	1
3242	46.4	69.5	1
3243	37.5	57.0	1
3244	37.5	69.5	1
3245	56.4	80.5	1
3246	48.2	83.6	1
3247	42.5	77.3	1
3248	41.9	81.1	1
3249	42.0	71.0	1
5250	38.9	71.2	1
3251	38.7	81.8	1
3252	43.4	69.1	1

Table 22 (Continued)**Laser Hazard – Slow Pulse Mode**

Serial Number	Q_o (μJ)	AEL (μJ)	Hazard Class
3253	39.1	69.1	1
3254	34.9	68.8	1
3255	47.0	84.1	1
3256	44.2	73.0	1
3257	42.5	68.4	1
3258	36.4	68.8	1
3259	49.4	79.1	1
3260	46.2	73.4	1
3261	55.1	78.0	1
3262	50.0	80.0	1
3263	49.0	80.5	1
3264	40.7	69.9	1
3265	37.4	68.7	1
3266	43.2	69.5	1
3267	46.2	71.6	1
3268	27.7	78.9	1
3269	45.5	73.0	1
3270	36.4	67.3	1
3271	43.7	67.3	1
3272	44.8	72.4	1
3273	48.6	67.7	1
3274	42.2	72.4	1
3275	40.8	71.7	1
3276	43.0	67.7	1
3277	39.1	68.8	1
3278	44.6	73.6	1
3279	45.9	68.1	1
3280	36.3	80.7	1
3282	42.6	68.8	1
3283	56.8	79.1	1
3284	43.9	67.4	1
3285	42.8	73.4	1
3286	43.0	67.0	1
3287	48.8	71.5	1
3288	44.9	78.7	1
3289	39.6	68.7	1
3290	45.8	73.1	1
3291	53.2	75.6	1
3292	35.6	65.2	1

Table 23**Laser Hazard –Fast Pulse Mode**

Serial Number	Q_o (μJ)	AEL (μJ)	Hazard Class
3223	24.3	45.4	1
3224	25.2	43.5	1
3225	28.5	45.6	1
3226	27.7	47.3	1
3227	31.0	46.3	1
3228	29.2	48.5	1
3229	36.1	58.4	1
3230	27.4	43.5	1
3231	29.7	45.2	1
3232	27.0	46.7	1
3233	29.9	47.8	1
3234	42.5	61.5	1
3235	36.9	47.0	1
3236	29.6	57.0	1
3237	26.2	48.5	1
3238	26.2	47.6	1
3239	28.9	43.7	1
3240	32.2	49.9	1
3241	25.7	45.6	1
3242	29.4	45.4	1
3243	30.4	49.0	1
3244	24.6	47.1	1
3245	39.7	57.2	1
3246	28.7	56.4	1
3247	33.7	56.8	1
3248	28.0	57.2	1
3249	29.9	46.9	1
5250	25.1	47.6	1
3251	26.9	57.0	1
3252	26.7	43.7	1
3253	25.7	46.7	1
3254	23.2	47.1	1
3255	33.5	61.7	1
3256	28.0	43.2	1
3257	26.9	43.4	1

Table 23 (Continued)

Laser Hazard –Fast Pulse Mode

Serial Number	Q_o (μJ)	AEL (μJ)	Hazard Class
3258	24.2	47.1	1
3259	29.6	49.6	1
3260	28.9	46.9	1
3261	32.2	48.5	1
3262	33.0	55.6	1
3263	30.7	54.6	1
3264	26.0	45.8	1
3265	25.7	47.0	1
3266	27.7	39.3	1
3267	30.1	47.6	1
3268	19.7	56.5	1
3269	29.7	49.0	1
3270	26.1	45.4	1
3271	27.4	43.4	1
3272	27.9	45.2	1
3273	33.2	46.9	1
3274	30.6	49.0	1
3275	23.6	45.8	1
3276	29.7	47.5	1
3277	25.3	45.9	1
3278	26.8	46.3	1
3279	29.7	44.7	1
3280	24.0	58.4	1
3282	26.6	44.7	1
3283	41.5	57.0	1
3284	28.7	45.6	1
3285	26.8	46.9	1
3286	27.4	44.5	1
3287	30.3	46.8	1
3288	27.7	45.4	1
3289	25.7	45.2	1
3290	29.9	47.3	1
3291	37.8	54.9	1
3292	23.6	44.5	1

Table 24**Laser Hazard – “Turn-On” Region**

Serial Number	$Q_{\text{turn-on}}$ (nJ)	$AEL_{\text{turn-on}}$ (nJ)	Hazard Class
3223	153	664	1
3224	186	664	1
3225	194	672	1
3226	188	664	1
3227	210	656	1
3228	127	664	1
3229	204	643	1
3230	215	656	1
3231	227	656	1
3232	212	664	1
3233	206	672	1
3234	234	668	1
3235	218	656	1
3236	195	672	1
3237	156	664	1
3238	146	660	1
3239	209	664	1
3240	174	668	1
3241	183	656	1
3243	228	622	1
3244	179	664	1
3245	224	664	1
3246	248	668	1
3247	133	643	1
3249	260	646	1
3251	207	653	1
3252	191	660	1
3253	197	660	1
3254	159	664	1
3255	135	672	1
3256	200	664	1
3257	203	660	1

Table 24 (Continued)**Laser Hazard – “Turn-On” Region**

Serial Number	$Q_{\text{turn-on}}$ (nJ)	$AEL_{\text{turn-on}}$ (nJ)	Hazard Class
3258	153	664	1
3259	207	664	1
3260	278	668	1
3261	237	672	1
3262	251	660	1
3263	200	676	1
3264	210	664	1
3265	201	656	1
3266	192	664	1
3267	282	664	1
3268	152	656	1
3269	252	664	1
3270	195	643	1
3271	197	656	1
3272	209	664	1
3274	167	672	1
3275	174	672	1
3276	213	668	1
3277	176	664	1
3278	209	676	1
3279	225	664	1
3280	173	660	1
3281	200	676	1
3282	185	664	1
3283	236	664	1
3284	207	664	1
3285	189	668	1
3286	200	660	1
3287	167	656	1
3288	216	672	1
3289	249	656	1
3290	221	672	1
3291	185	656	1
3292	171	656	1

Table 25**Laser Hazard – “Decay to Steady State” Region**

Serial Number	Q_{decay} (μJ)	AEL_{decay} (μJ)	Laser Hazard Class
3223	7.08	12.5	1
3224	6.11	12.5	1
3225	6.78	13.0	1
3226	6.40	12.9	1
3227	6.90	12.3	1
3228	4.51	12.5	1
3229	6.43	12.1	1
3230	6.92	12.5	1
3231	7.17	12.3	1
3232	6.36	12.5	1
3233	6.42	12.5	1
3234	7.32	12.6	1
3235	7.02	12.3	1
3236	6.44	12.6	1
3237	5.09	12.5	1
3238	4.92	12.5	1
3239	6.73	12.4	1
3240	6.04	12.6	1
3241	6.01	12.2	1
3243	6.57	11.6	1
3244	5.70	12.5	1
3245	7.06	12.4	1
3246	6.88	12.6	1
3247	4.80	12.0	1
3249	6.85	11.5	1
3251	6.59	12.4	1
3252	6.00	11.2	1
3253	5.87	12.4	1
3254	5.78	12.6	1
3255	5.26	12.6	1
3256	6.74	12.5	1
3257	6.59	12.3	1

Table 25 (Continued)

Laser Hazard – “Decay to Steady State” Region

Serial Number	Q_{decay} (μJ)	AEL_{decay} (μJ)	Laser Hazard Class
3258	5.06	12.6	1
3259	6.51	12.5	1
3260	7.16	12.2	1
3261	7.42	12.4	1
3262	7.72	12.8	1
3263	6.24	12.7	1
3264	6.30	12.5	1
3265	6.35	12.7	1
3266	6.06	12.5	1
3267	6.99	11.9	1
3268	4.71	12.2	1
3269	6.52	11.9	1
3270	5.39	12.4	1
3271	6.36	12.3	1
3272	6.86	12.5	1
3274	5.51	12.8	1
3275	5.65	12.6	1
3276	5.99	11.9	1
3277	5.65	12.4	1
3278	6.40	12.6	1
3279	6.72	11.9	1
3280	5.69	12.8	1
3281	6.57	12.6	1
3282	6.19	12.6	1
3283	7.49	12.5	1
3284	3.99	11.9	1
3285	6.14	12.6	1
3286	6.43	12.3	1
3287	5.79	12.3	1
3288	6.93	12.8	1
3289	6.88	12.3	1
3290	6.89	12.8	1
3291	6.24	12.3	1
3292	5.73	12.7	1

V. Conclusions

1. In all cases the VITAL-2 units tested were Class 1 (eye-safe) Laser Hazard for all modes of operation (CW, Pulsed and Area Illumination).
2. Assuming all the available laser radiance enters an optical viewing aid this would still present only a Class 1 Laser Hazard to aided (binocular) viewing.
3. The temporal regions of the VITAL-2 laser pulses which, presented intensities above the steady state (CW levels), such as the “turn on” transient (spike) and the decay to steady state region all contained radiant energies below the appropriate AEL(s) for those temporal regions and present a Class 1 (eye-safe) Laser Hazard.
4. The measured beam divergence for the various VITAL-2 units differed widely from unit to unit. Except for two of the 71 units tested (which met the listed beam divergence specifications) all were in excess of the beam divergence value cited in the data sheet. The beam divergence of these units exceeded the listed value, some by factors of as much as **34** times the value cited. This was manifested by, the various VITAL-2 units, presenting widely varying spot sizes on targets located at the same distance from the emitting source. Whereas, this may present an adverse impact to specific missions or mission requirements, this excess beam divergence does not have an adverse effect on the overall Laser Safety aspect of the VITAL-2s.
5. The widely varying beam divergence may have arisen from the lack of precision in placing the collimating lens in relation to the emitting surface of the laser diode.

VI. Symbols and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
AEL	Allowable Exposure Limit
AEL _{es}	Extended source Allowable Exposure Limit
AEL _{ss}	Small source Allowable Exposure Limit
ANSI	American National Standard Institute
Auto	Automatic
C _A	Wavelength correction factor
CDRH	Center for Device and Radiological Health
C _E	Extended Source correction factor
CFR	Code of Federal Regulations
cm	Centimeter (10^{-2} meters)
C _p	Pulse correction factor
CQB	Close Quarter Battle
CW	Continuous Wave
D, d	Diameter
d _{aid}	Diameter of the entrance optic of viewing aid
d _e	Diameter of the emitting surface
d _{lim}	Diameter of limiting aperture
D _{M1}	Diameter, major axis at 1 meter
D _{M3}	Diameter, major axis at 3 meters
D _{m1}	Diameter, minor axis at 1 meter
D _{m3}	Diameter, minor axis at 3 meters
DOE-STD	Department Of Energy Standard
E	Irradiance (J/cm^2)
ES&H	Environmental, Safety & Health
ESS	Engagement Simulation System
FAA	Federal Aviation Administration
FDA	Food and Drug Administration
FOF	Force On Force
FWHM	Full Width at Half Maximum
Hz	Hertz (sec^{-1})
IR	Infrared
J	Joules
LAT	Large Area Transmitter
LE	Laser Emitter

min	Minute
MPE	Maximum Permissible Exposure
MPE _{es}	Extended source Maximum Permissible Exposure
MPE _{ss}	Small source Maximum Permissible Exposure
mm	Millimeter (10^{-3} meters)
mR	Milliradian (10^{-3} radians)
ms	Millisecond (10^{-3} seconds)
mw	Milliwatt (10^{-3} watts)
NEPA	National Environment and Protection Act
nJ	Nanojoule (10^{-9} Joules)
NHZ	Nominal Hazard Zone
nm	Nanometer (10^{-9} meters)
OD	Optical Density
OP	Operating Procedure
PRF	Pulse Repetition Frequency
Q	Radiant Energy in joules
Q _{decay}	Radiant energy in the “decay to steady state” region of the pulse
Q _o	Output energy
Q _p	Pulse Energy
Q _{turn-on}	Radiant energy in the “turn-on” region of the pulse
R _{EOHD}	Range to the Extended Ocular Hazard Distance (eye safe distance)
R _{NOHD}	Range to the Nominal Ocular Hazard Distance (eye safe distance)
R _s	Range for extended source to small source cross-over point
sec	Second
Semi	Semiautomatic
SN	Serial Number
SNLA	Sandia National Laboratories – Albuquerque
Sr	Steradian
Std	Standard
T, t	Time period
t _d	Decay time.
t _{FWHM}	Pulse width (full width at half maximum)
t _{peak}	Time to peak value of the pulse
t _r	Rise time.
VITAL	Variable Intensity Tactical Aim Light
V _{peak}	Peak voltage

w	Watt
α	Alpha- view angle
$\alpha_{\min}$	Minimum viewing angle (1.5×10^{-3} radians)
$\alpha_{\max}$	Maximum viewing angle (100×10^{-3} radians)
β	Cone angle
$\beta/2$	Half angle
Δ	Delta- difference.
λ	Lambda- wavelength.
μw	Microwatt (10^{-6} watts).
μJ	Microjoule (10^{-6} joules).
Φ	Radiant power (watts).
Φ_{avg}	Average radiant power (watts).
Φ_{CW}	Continuous wave radiance (watts).
$\Phi_{\text{d-max}}$	Maximum radiant power in the “decay” region of pulse
Φ_{peak}	Peak radiant power or intensity (watts).
Φ_{max}	Maximum radiant power (watts).
Φ_{o}	Output radiant power (watts).
Φ_{r}	Radiant power at distance, r from the source (watts).
τ	Transmission factor.
θ	Beam divergence angle (radians).
θ_{major}	Beam divergence angle, major axis (radians).
θ_{minor}	Beam divergence angle, minor axis (radians).
$\sim$	Approximate or “proportional to”.
$\approx$	Approximately “equal to”.

VII. References

	21 CFR 1040, <u>Laser Product Performance Standard</u>
	ACGIH, <u>2003 Threshold Limit Values for Chemical Substances & Physical Agents & Biological Exposure Indices</u>
	ANSI Std. Z136.1-2000: <u>for Safe Use of Lasers</u> , Published by the Laser Institute of America.
	ANSI Std. Z136.6-2000: <u>for Safe Use of Lasers Outdoors</u> , Published by the Laser Institute of America.
	DOE Order 5480.16A, <u>Firearms Safety</u> .
	DOE-STD-1091-96, <u>Firearms Safety</u> .
	FAA 7400.2D Chapter 34, <u>Outdoor Laser/High Intensity Light Demonstrations</u> .
	FDA CDRH: <u>Compliance Guide for Laser Products</u> .
	<u>Variable Intensity Tactical Aiming Light with CQB Illuminator – Operator’s Manual</u> , © Night Vision Equipment Company, Inc.
	<u>VITAL® Variable Intensity Tactical Aiming Light – Data Sheet</u> , nvec-night-vision.com

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