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Laser Safety Evaluation of the Oscmar M203PI Grenade Launcher Simulator (GLS) and the Associated Umpire Control Gun

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Abstract

A laser safety evaluation and pertinent output measurements were performed (during March and April 2002) on the M203PI Grenade Launcher Simulator (GLS) and its associated Umpire Control Gun manufactured by Oscmar International Limited, Auckland, New Zealand. The results were the Oscmar Umpire Gun is laser hazard Class 1 and can be used without restrictions. The radiant energy output of the Oscmar M203PI GLS, under "Small Source" criteria at 10 centimeters, is laser hazard Class 3b and not usable, under SNL policy, in force-on-force exercises. However, due to a relatively large exit diameter and an intentionally large beam divergence, to simulate a large area blast, the output beam geometry met the criteria for "Extended Source" viewing [**ANSI Std. z136.1-2000 (8.1)**]. Under this "Extended Source" criteria the output of the M203PI GLS unit was, in fact, laser hazard Class 1 (eye safe), for 3 of the 4 possible modes of laser operation. The 4th mode, "Auto Fire", which simulates a continuous grenade firing every second and is not used at SNL, was laser hazard Class 3a (under the "Extended Source" viewing criteria). The M203PI GLS does present a laser hazard Class 3a to aided viewing with binoculars inside 3 meters from the unit. Farther than 3 meters it is "eye safe". The M203PI GLS can be considered a Class 1 laser hazard and can be used under SNL policy with the following restrictions:

1. The M203PI GLS unit shall only be programmed for: the “**Single Fire**” (which, includes “**Rapid Fire**) and the “**Auto Align**” (used in adjusting the alignment of the grenade launcher simulator system to the target) modes of operation.
2. The M203PI GLS shall never be directed against personnel, using binoculars, inside of 3 meters. **DOE Order 5480.16A**, Firearms Safety, (Chapter 1)(5)(a)(8)(d) and **DOE-STD-1091-96**, Firearms Safety (Chapter 4); already prevents ESS laser engagement of personnel (with or without binoculars), “closer than 10 feet (3.05 meters)”.

Both of these restrictions can be administratively imposed, through a formal Operating Procedure or Technical Work Document and by full compliance with DOE orders and standards.

I. Introduction

A. Overview of the Osmar M203PI Grenade Launcher Simulator ®.

The Osmar M203PI Grenade Launcher Simulator (GLS) is designed to simulate the M203PI, 40-mm Grenade Launcher mated to the M16 rifle or to a pistol grip used in engagement simulation system (ESS) force-on-force exercises. It uses an infrared (IR) laser diode with optics to simulate the wide area effect of an exploding 40-mm grenade. The unit consists of the M203PI Large Area Transmitter (LAT) and a M203PI Dummy Round (DR). The M203 is a breach-loaded weapon. The LAT is installed inside the M203 PI Grenade Launcher Tube (GLT) and is affixed to the “exit” end with a securing ring. The DR is loaded like a real round. The DR emits an IR signal, from a light emitting diode (LED) when the “firing” pin strikes the center of the DR base plate. The LAT initiates a “fire” sequence upon receiving a signal, through the IR link, from the DR. The LAT emits a series of laser pulses (coded output). The LAT may also emit laser pulses by the initiation of “Auto Align” or “Auto Fire” mode directive from the Umpire Gun and will continue to emit until directed to stop by the Umpire Gun (this occurs when the Umpire Gun directs a mode of operation that is not “Auto Align” or “Auto Fire”.

B. Modes of Laser Operations.

1. “Single Fire”.

The “Single Fire” mode of laser of operation simulates a 40-mm grenade being fired from a M203 grenade launcher. The LAT emits a series of coded laser pulses (in < 1 second) to indicate this event. The event is initiated by trigger pull, which causes the DR to emit an IR signal to the LAT, starting a “fire” sequence.

2. “Rapid Fire”.

Rapid fire is simply, a multiple “Single Fire” event. The DR is programmed to delay 5 seconds between “firings”, regardless of number of trigger pulls, to simulate a 40-mm grenade round being manually reloaded in the M203 grenade launcher. The standard exposure for IR lasers is 10 seconds [ANSI Std. z136.1-2000 (8.2.2)]. The maximum number of rounds that can be fired in any 10-second period is 2 rounds. This mode of operation would expose any personnel in the line-of-fire to two “Single Fire” laser events in a standard 10-second exposure.

3. “Auto Align”.

The user’s manual indicates that the auto align mode produces a “low energy” output (one event every second) to aid in aligning the LAT to the target area. In actuality it was found that the radiant pulse energy was constant but the number of laser pulses emitted was reduced (form 22 per event to 6). This mode of laser operation must be initiated and terminated by the Umpire Gun.

4. “Auto Fire”

The auto fire mode is a continuous “Single Fire” event (one event every second) simulating a 40-mm grenade firing every second. This mode of operation also must be initiated and terminated by the Umpire Gun.

C. Overview of the Osmar Umpire Control Gun ®.

1. Osmar Umpire Gun.

The Umpire Control Gun interacts with M203PI GLS and receiving gear. The Umpire Gun is used to program the M203PI GLS LAT and can be used to select, any of a number of other features (the modes of operation).

2. Mode of laser operation.

A single trigger pull will generate a sequence of output coded laser pulses, which can interact with M203PI GLS. Two seconds must pass before another trigger pull will generate an output. The modes of laser operations for the Umpire Control Gun are as follows:

- a. Single Trigger Pull (single event).
- b. Multiple Trigger Pulls (maximum of 5 single events in any 10 second period).

II. Laser Parameters.

To perform a laser safety evaluation of the M203PI GLS the following information is critical: the wavelength of the diode laser, the radiant pulse energy output of the laser, the laser pulse duration, the number of laser pulses in the exposure, the exit beam diameter, and the beam divergence. The M203PI GLS LAT was investigated first followed by an investigation of the Umpire Gun.

A. Laser Parameters (owners manual).

The manual listed the M203PI GLS LAT laser as a **Class 3b** IR laser. The manual does not specify the laser’s emission wavelength, radiant pulse energy, the pulse width, the number of pulses in a “fire” sequence, the exit diameter, or the beam divergence.

The manual does specify the following:

1. Nominal Ocular Hazard Distance (NOHD) as 2 meters.
2. Extended Ocular Hazard Distance (EOHD) as 15 meters, for 50 mm optics.

The manufacture indicated, by email, the emission wavelength of the laser diode as 905 nm.

B. Laser Parameters (measured).

Most of the laser parameters required to perform a laser safety evaluation had to be measured since these were not provided in the user's manual.

1. Test Equipment & Instruments.

- a. Ophir Optronics Incorporated, model **PD10 Head**, serial number: 100556, calibration due: 5 October 2002, calibration accuracy: +/- 5%. Used for measuring average laser pulse energy and average laser power. Active photodiode area is 1 cm (10 mm) diameter with a 7 mm diameter (limiting) aperture placed over, attached and centered on this active area [ANSI Std. z136.1 (9.2.2.1)].
- b. Ophir Optronics Incorporated, model **NOVA digital meter**, serial number: 47407, calibration due: 28 June 2002, electrical accuracy: +/- 0.3 %

System accuracy for pulse energy and laser power measurements is the square root of the sum of the squares: +/- 5.01%.

$$\text{System Accuracy} = [(5)^2 + (0.3)^2]^{0.5} = +/- 5.01$$

PD10 Head with 7 mm limiting aperture was place 10 cm (minimum viewing distance) from the exit window of the SALT [ANSI Std. z136.1-2000 (9.2.1.1)].

- c. Schwartz Electro-Optics, **Model LTE 1003 Calibrator Detector** (fast photodiode), serial number 3090. Monitored by oscilloscopes to measure the intensity-time histories of the individual laser pulses and pulse-train. Calibration (past) due: 29 September 2000.
- d. Hamamatsu, model R1193U fast photodiode, biased at 900 volts dc. Used to determine "intensity-time" histories.
- e. Tektronix, **Model 7104 Oscilloscope**, serial number: B074120 with Tektronix model **7A24** Dual 50 Ω Vertical Amplifier, serial number: B133863, calibration due: 11 March 2002 and Tektronix model **7B15** Delaying Time Base, serial number: B035526, calibration due: 7 March 2002. Used to determine pulse width, Full Width at Half Maximum (FWHM). Also used to determine the number of laser pulses in a "fire" event and any variations in the radiant energy between pulses.

2. Pulse Width Determination for the M203PI GLS LAT.

The laser pulse width is critical in the determination of the appropriate MPE, because table 5a (ANSI Std. z136.1) presents a series of MPE formulas, which are dependent on the pulse width or exposure duration. The pulse duration, as defined by the ANSI standard is the width between the half power points [ANSI Std. z136.1-2000 (8.2.2)]. This is referred to as the Time at Full Width at Half Maximum (T_{FWHM}). This value is arrived at by measuring the peak value of the laser pulse as represented by the photodiode signal, divide this value by 2 and measure the time between the half value points. It was found that the pulse shape (intensity-time history) of the M203PI GLS, as monitored by fast photodiodes (Hamamatsu, model R1193U and the SEO calibrator) was very consistent, pulse-to-pulse, for all modes of LAT laser operations. A 7-mm diameter (limiting) aperture was placed on the center of the photodiode. See photo below.

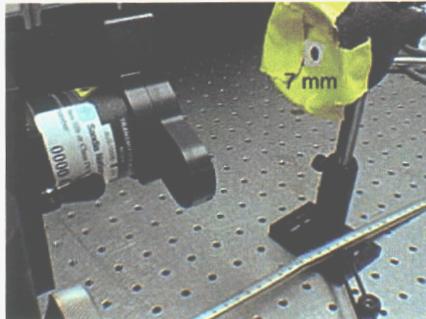


Figure 1.

Hamamatsu, model R1193U photodiode with a 7-mm diameter aperture is placed 10 centimeters from the M203PI GLS LAT.

The pulse width was found to be approximately **130 ns**.

Below are the intensity-time history traces for various modes of operations.

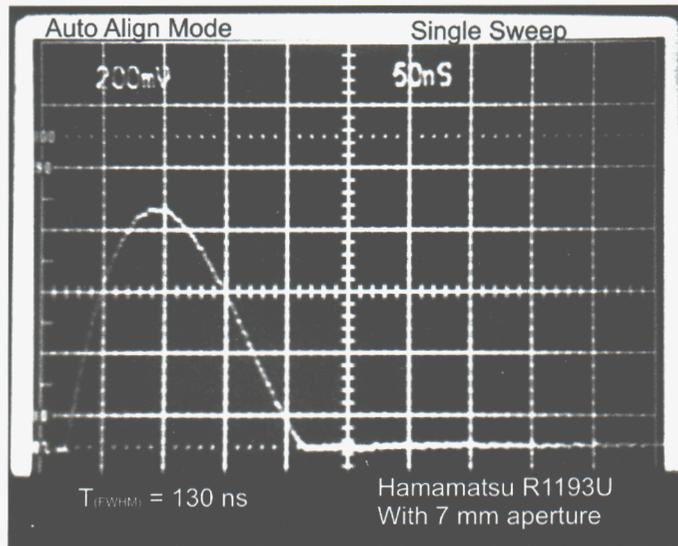


Figure 2.

Auto Align Mode: Single Pulse

The intensity-time output was very consistent pulse-to-pulse as indicated below for an overlay exposure of 60 consecutive pulses.

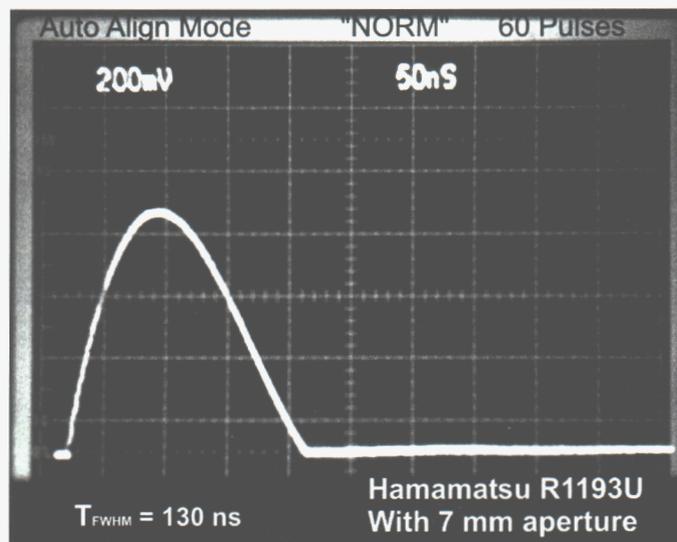


Figure 3.

Auto Align Mode: 60 Pulses Overlay

The laser pulse shape was consistent pulse to pulse regardless of the mode of fire. Below is an intensity-time history trace with a single sweep “auto-align” overlay on a single sweep “auto fire” trace. They are clearly the same shape.

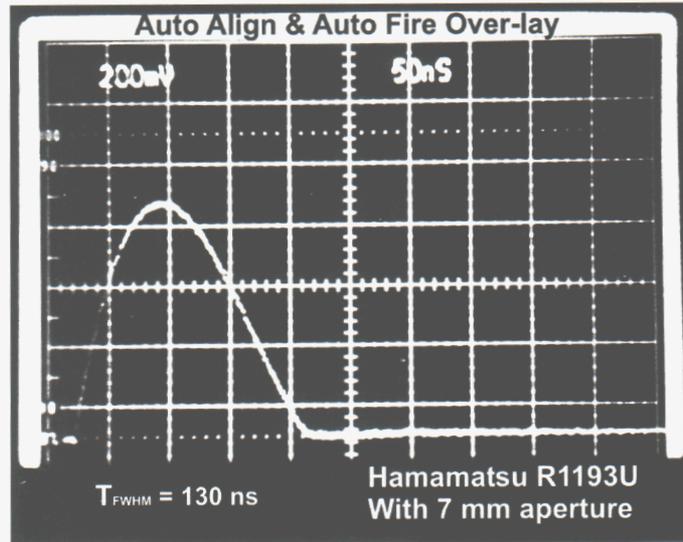


Figure 4.

Single Pulse Overlay of “Auto Align” and “Auto Fire”.

3. T_{min} Comparison for the M203PI GLS LAT

The term T_{min} is the maximum time duration, where the specific MPE is equaled to the MPE for pulse duration of 1 nanosecond. All laser pulses delivered within t_{min} are summed together as if the combined energies were delivered in a single pulse [ANSI Std. z136.1-2000 (8.3.2)]. It is important when performing the laser safety evaluation and hazard analysis to determine if any laser pulses are delivered in less than t_{min} . The t_{min} for 905 nm laser light is given by table 5a, ANSI Std. z136.1-2000, as 18 μ sec (18×10^{-6} seconds).

The setup for this determination was the same as that for the above traces. The sweep rate for the oscilloscope was set for 2 μ sec/div. This displayed a time window of 20 μ sec. The oscilloscope was set for internal triggering at the normal (NORM) mode, such that as the electrical signal from the Hamamatsu model R1193U photodiode (indicating the presence of a laser pulse) would trigger the oscilloscope to trace for a 20 μ sec sweep and capture the intensity-time history of the photodiode recording all pulses within the 20 μ sec sweep.

No additional laser pulses were observed (to have been emitted) within t_{min} .

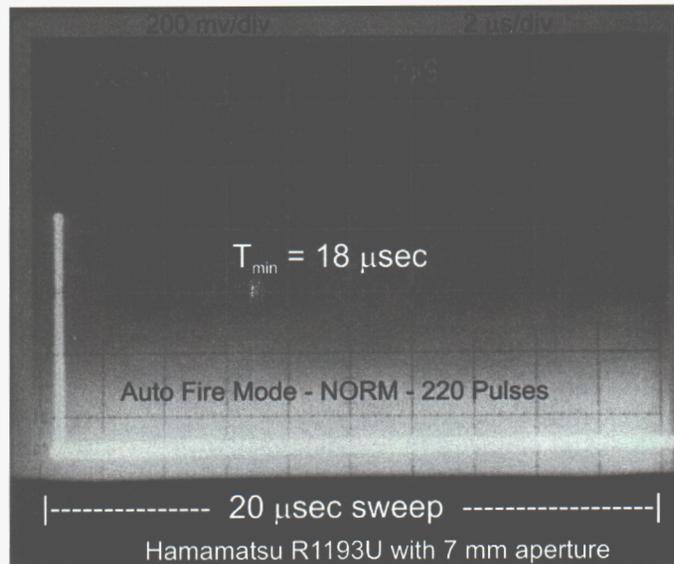


Figure 5.

Pulse separation greater than T_{\min} for 220 pulses (10 second exposure).

4. Determination of the Number of Pulses in Exposures for the Various Modes of Operation of the M203PI GLS LAT.

The number of laser pulses in an exposure for each mode of operation was determined by the use of a Hamamatsu R1193U fast photodiode monitored by an oscilloscope. For the “Auto Align” mode, the “Auto Fire” mode, and the Rapid Fire Mode the standard 10-second exposure was used to determine the total number of laser pulses in the exposure. For the “Single Fire” mode the actual number of in the event (1 second) was determined. The results are presented in the table following the intensity-time history traces.

Note: The Rapid Fire consists of multiple Single Fire events (5 second delay between events).

a. Auto Align Mode.

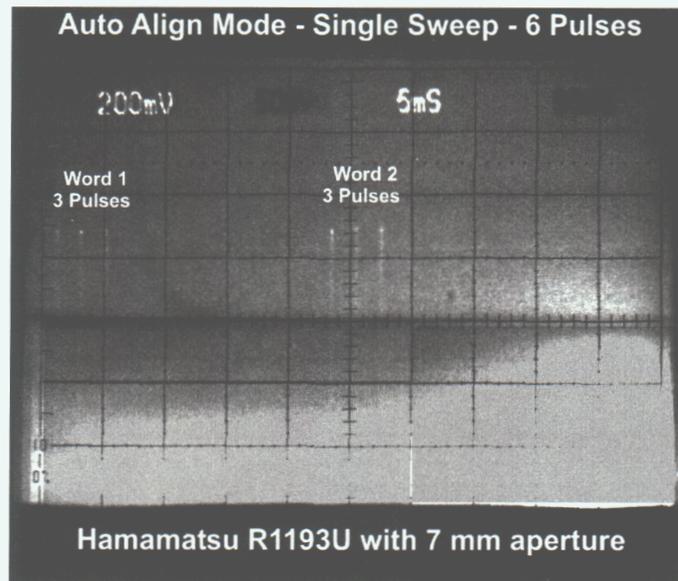


Figure 6.

Auto Align Mode:
Consists of 6-pulses (in 2 word groups) per second.

b. Auto Fire Mode.

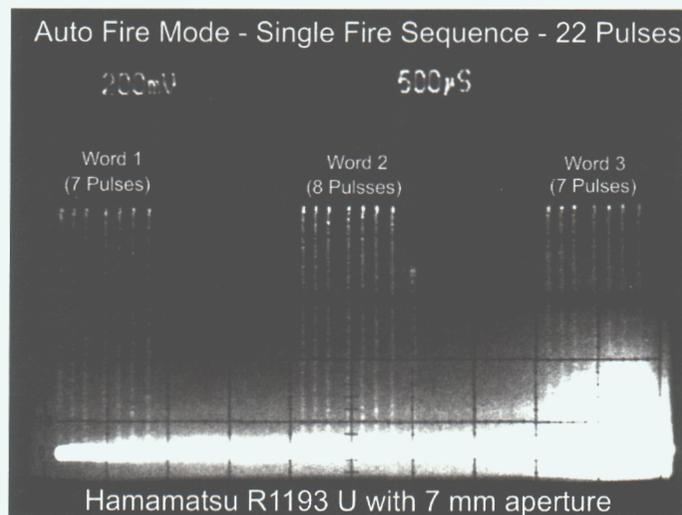


Figure 7.

Auto Fire Mode:
Consists of 22-pulses (in 3 word groups) per second.

Table 1

Number of Laser Pulses per Exposure for Various Modes of LAT Operation

Mode	Exposure Time	Number of Pulses
Single Fire	1 second	22
Rapid Fire	10 seconds	44
Auto Align	10 seconds	60
Auto Fire	10 seconds	220

5. Determination of the Number of Pulses in Exposures for the Various Modes of Operation of the Umpire Gun laser diode emission.

a. Single Trigger Pull.

The PD-10 head and the Nova meter were used to measure the PRF. The Umpire Gun emitted 3 pulse clusters. The number of laser pulses emitted by the Umpire Gun for a single trigger pull was determined to be 165.

b. Rapid Trigger Pull

The maximum number of trigger pulls, that result in an output emission is 5 in any 10-second period. Therefore the maximum number of pulses that can be emitted in any 10-second period is 5 times the number for a single trigger pull or 825 pulses.

In tabular form:

Table 2

Number of Pulses in an Umpire Control Gun Exposure

Mode	Exposure Time	Number of Pulses In The Exposure
Single Trigger Pull	1 seconds	165
Rapid Trigger Pull	10 seconds	825

6. Radiant Pulse Energy Measurement

a. M203PI GLS LAT

The average radiant pulse energy was measured using an Ophir model PD-10 energy/power head with Nova meter, as described in measurement section (II)(B)(1)(a) & (b) above. The PD-10 was placed 10 centimeters from the exit of the M203PI GLS LAT [ANSI Std. z136.1-2000 (9.2.1.1)]. The PD-10 had a 7-mm diameter (limiting) aperture attached and centered on the active area of the head as prescribed in section 9 of the ANSI standard. (See photo below.)

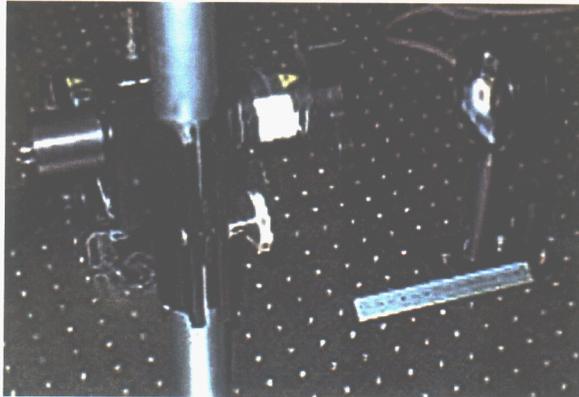


Figure 8.

The lab setup: for measuring the M203PI GLS LAT radiant energy.

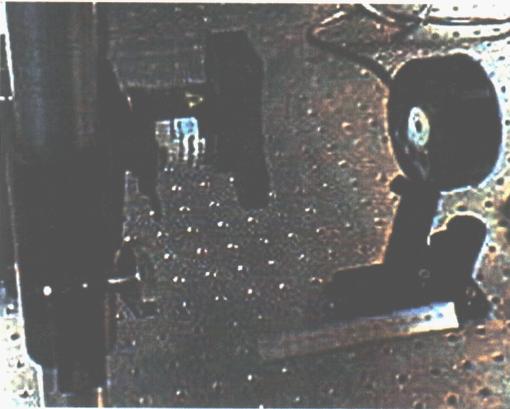


Figure 9.

The PD-10 with a 7-mm diameter aperture is placed 10 centimeters from the M203PI GLS LAT.

The average **radiant energy** (initially) was measured and found to be approximately **4.5μJ** +/- 0.3 μJ (4.5×10^{-6} Joules, +/- 6.67 %). The radiant energy was found to vary with the condition of the unit's battery. This 4.5μJ pulse energy represented the largest measured value for the radiant energy output of the unit for several batteries used. The **4.5μJ** value was used for determining "worst case" situation.

b. The UMPIRE CONTROL GUN.

The average radiant energy for the Umpire Control Gun was measured in a similar manner as described for the M203PI GLS LAT. The average radiant energy was measured and found to be approximately 23.5 nJ +/- 1.6 nJ (23.1×10^{-9} Joules, +/- 6.8 %).

III. Laser Safety Governing Documents.

There are a number of industry and government documents that define 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, 2001 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.

2. 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.

IV. Laser Engagement Simulation System used in Force-On-Force Exercises.

A. 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”.

B. SNL Force-On-Force Policy.

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

C. ANSI Std. z136.6: “Force-On-Force”.

1. 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 z136.3 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.
2. 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.”

V. Allowable Emission (Exposure) Limits (ANSI Std. z136.1-2000).

The Allowable Emission Limit 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 the laser emission, this “emission” limit can be considered an “exposure” limit and will hereafter be referred to as the “Allowable Exposure Limit” (AEL).

A. Class 1 Allowable Exposure Limit (Small Source Viewing).

1. Determination of the appropriate MPE for a laser emission of 905 nm laser light.

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:

$$\text{MPE}_{\text{s.p.}} = 5.0 C_A \times 10^{-7} \text{ J/cm}^2$$

[Table 5a of ANSI Std. z136.1]:
700 nm < λ < 1050 nm
 10^{-9} sec < T_p < 18×10^{-6} sec

$$C_A = 10^{2(\lambda-0.7)}$$

[Table 6 of ANSI Std. z136.1]:
700 nm < λ < 1050 nm

$$\text{MPE}_{\text{s.p.}} = 5 [10^{2(\lambda-0.7)}] \times 10^{-7} \text{ J/cm}^2$$

$$\begin{aligned} \text{MPE}_{\text{s.p.}} &= 5 [10^{2(0.905-0.7)}] \times 10^{-7} \text{ J/cm}^2 \\ &= 5 [2.56 \times 10^{-7}] \text{ J/cm}^2 \end{aligned}$$

$$\text{MPE}_{\text{s.p.}} = 1.29 \times 10^{-6} \text{ J/cm}^2$$

Rule 2: Average Power MPE for Thermal & Photochemical Hazards

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

[Table 5a of ANSI Std. z136.1]:

$$C_A = 10^{2(\lambda-0.7)}$$

[Table 6 of ANSI Std. z136.1]:
700 nm < λ < 1050 nm

$$\text{MPE}_{\text{CW}} = 10^{2(\lambda-0.7)} \times 10^{-3} \text{ w/cm}^2$$

$$\text{MPE}_{\text{CW}} = 10^{2(0.905-0.7)} \times 10^{-3} \text{ w/cm}^2$$

$$\text{MPE}_{\text{CW}} = 2.57 \times 10^{-3} \text{ w/cm}^2$$

Per Pulse MPE:

$$\text{MPE}_{\text{CW(PP)}} = 2.57 \times 10^{-3} / (\text{PRF}) \text{ J/cm}^2$$

Where:

PRF is the Pulse Repetition Frequency

Rule 3: *Multiple-pulse MPE for Thermal Hazards*
(Protects against sub-threshold pulse-cumulative thermal injury)

The appropriate per pulse MPE_{rp} is determined by the total number of laser pulses emitted in the exposure time. This number can be arrived at either by counting the pulses in the exposure or by:

$$n = (\text{PRF}) \times T_{\text{exposure}}$$

Where:

T_{exposure} is the duration of the exposure, in seconds
 PRF is the Pulse Repetition Frequency

The maximum exposure time considered for “normal”, not forced, viewing for IR lasers (905 nm) is given as 10 seconds [ANSI Std. z136.1-2000 (8.2.2)]. In most cases for PRF(s) below the critical frequency (f_c) Rule 3 derives the appropriate MPE because it yields the smallest value. The critical frequency for a 905 nm laser is given as 55 KHz ($55 \times 10^3 \text{ sec}^{-1}$) [ANSI Std. z136.1-2000 (8.2.3.2) (note)]. The Appropriate MPE for a repetitively pulsed laser is the product of the single pulse MPE and a repetitive pulse correction factor (C_p) ANSI Std. z136.1-2000 (8.2.3) (rule 3).

$$MPE_{r,p} = C_p \times MPE_{s,p}$$

Where the pulse correction factor (C_p) is:

$$C_p = n^{-0.25} \quad \text{[Table 6 of ANSI Std. z136.1]}$$

Where “n” is the number of laser pulses in the exposure.

$$MPE_{r,p} = (n^{-0.25}) \times MPE_{s,p}^*$$

$$MPE_{r,p} = (n^{-0.25}) \times (1.29 \times 10^{-6} \text{ J/cm}^2)^* \text{ (per pulse)}$$

*Note: This is the same as the Threshold Limit Value (form and value) published in 2001: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices by American Conference of Government Industrial Hygienists, pages 134-137.

Table 3

ANSI Std. z136.1-2000: MPE(s) for 905 nm Lasers (Small Source Viewing)

Rule	MPE	Comments
Rule 1	$1.29 \times 10^{-6} \text{ J/cm}^2$	
Rule 2	$2.57 \times 10^{-3} \text{ w/cm}^2$	
Rule 3	$(n^{-0.25}) (1.29 \times 10^{-6}) \text{ J/cm}^2$	Smallest value

Appropriate MPE is the **smallest** value determined by rule 1,2, & 3.

The number of laser pulses, in each of the appropriate exposures for the four modes of M203PI GLS LAT laser operation and the Single Trigger Pull as well as the maximum exposure for Rapid Trigger Pulls for the Umpire Gun, were applied to Rule 3 and are presented in the table below.

Table 4

Specific MPE (small source) for the Various Modes of Laser Operations

Laser Unit	Mode of Operation	Number of Pulses	Per Pulse MPE
M203 LAT	Single Fire	22	$593 \times 10^{-9} \text{ J/cm}^2$
M203 LAT	Rapid Fire	44	$499 \times 10^{-9} \text{ J/cm}^2$
M203 LAT	Auto Align	60	$462 \times 10^{-9} \text{ J/cm}^2$
M203 LAT	Auto Fire	220	$334 \times 10^{-9} \text{ J/cm}^2$
Umpire Gun	Single Trigger Pull	165	$359 \times 10^{-9} \text{ J/cm}^2$
Umpire Gun	Rapid Trigger Pull	825	$240 \times 10^{-9} \text{ J/cm}^2$

2. Determination of Class 1 AEL (Small Source):

The appropriate AEL is derived from the appropriate MPE (smallest of rules 1 through 3).

$$\text{Class 1 AEL} = \text{MPE} \times (\text{Area of limiting aperture})$$

$$D_{\text{lim}} = 0.7 \text{ cm}$$

[Table 8 of ANSI Std. z136.1]
400 nm < λ < 1400 nm

$$\text{AEL} = \text{MPE} \times \pi (0.7 \text{ cm})^2 / 4$$

$$\text{AEL} = \text{MPE} (\text{J/cm}^2) \times 0.385 \text{ cm}^2$$

$\text{AEL} = (0.385 \text{ cm}^2) \text{ MPE } \text{J/cm}^2$
--

Rule 1 (Single Pulse):

$$AEL = (0.385 \text{ cm}^2) (\text{MPE J/cm}^2)$$

$$AEL = (0.385 \text{ cm}^2) (1.29 \times 10^{-6} \text{ J/cm}^2)$$

$$AEL_{\text{rule 1}} = 495 \times 10^{-9} \text{ Joules}$$

Rule 2 (CW):

$$AEL = (0.385 \text{ cm}^2) \text{ MPE (J/cm}^2)$$

$$AEL = (0.385 \text{ cm}^2) (2.57 \times 10^{-3} / \text{PRF J/cm}^2)$$

$$AEL_{\text{rule 2}} = 989 \times 10^{-6} / \text{PRF Joules (per pulse)}$$

Rule 3 (Multiple Pulse):

$$AEL \text{ per pulse} = (C_p) \times (\text{MPE}_{s,p}) \times \pi (0.7 \text{ cm})^2 / 4$$

$$AEL = (n^{-0.25}) \times (1.29 \times 10^{-6} \text{ J/cm}^2) \times (0.385 \text{ cm}^2)$$

$$AEL_{\text{rule 3}} = (495 \times 10^{-9}) n^{-0.25} \text{ Joules (per pulse)}$$

Note: For laser pulses delivered in less than t_{\min} , the sum of the pulse energies are considered as if they were delivered in a single pulse [ANSI Std. Z136.1-2000 (8.2.3)(Rule 3)]. Similarly the appropriate per pulse MPE is distributed among the pulses delivered in t_{\min} . That is, the MPE for the pulses delivered within t_{\min} can be determined by dividing the MPE, calculated for t_{\min} , by the number of pulses delivered inside the t_{\min} .

Rule 3 yields the smallest value and is therefore the appropriate AEL.

Table 5

ANSI Std. z136.1-2000 MPE(s) and AEL(s) for 905 nm Lasers (Small Source Viewing)

Rule		MPE	AEL	Comments
Rule 1	Single Pulse	$1.29 \times 10^{-6} \text{ J/cm}^2$	$495 \times 10^{-9} \text{ Joules}$	
Rule 2	CW	$2.57 \times 10^{-3} \text{ w/cm}^2$	$989 \times 10^{-6} \text{ W}$	
Rule 2	CW per pulse	$2.57 \times 10^{-3} / \text{PRF} \text{ J/cm}^2$	$986 \times 10^{-6} / (\text{PRF}) \text{ J}$	
Rule 3	Multi Pulse per pulse	$(1.29 \times 10^{-6}) (n^{-0.25}) \text{ J/cm}^2$	$(495 \times 10^{-9}) (n^{-0.25}) \text{ J}$ (see chart below)	Smallest value

Appropriate AEL is the **smallest** value determined by rule 1,2, & 3.

Per Pulse Allowable Exposure Limit for 905 nm Lasers

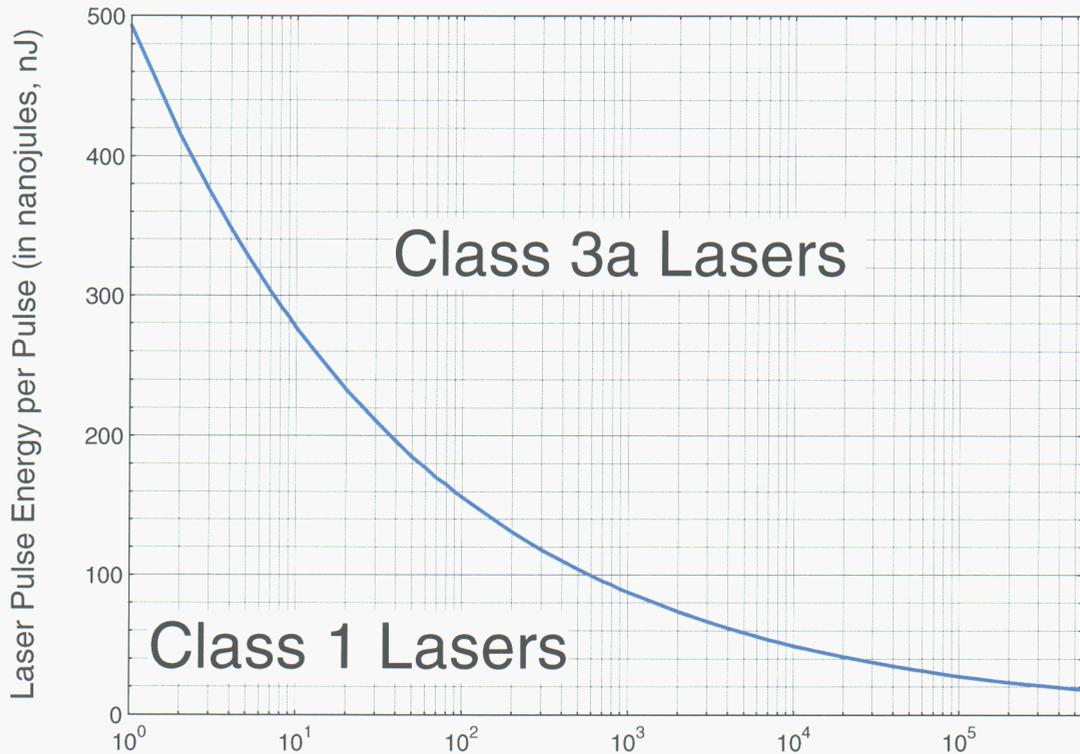


Figure 10.

Class 1 AEL for 905 nm for Small Source Viewing

Notes to the above curve:

The Critical Frequency (f_c) for this laser ($400 \text{ nm} < \lambda_{\text{laser}} < 1.050 \text{ }\mu\text{m}$) is 55,000 Hz [ANSI Std.z136.1-2000 (8.2.3.2)(note)].

For $\text{PRF} < f_c$ -Rule 3 applies [ANSI Std.z136.1-2000 (8.2.3.2)(note)].

Maximum number of laser pulses in a 10-second exposure for rule 3 to apply is < 550,000 pulses.

When the PRF is above the Critical Frequency the laser exposure is considered to be from a continuous wave, CW, laser and rule 2 applies.

IR lasers with radiant outputs greater than the Class 1 AEL but less than 5 times that value limit are considered laser hazard Class 3a.

$$\text{Class 1 AEL} < \text{Class 3a Lasers} < 5 \times \text{Class 1 AEL}$$

The number of laser pulses in each of the appropriate exposures to the four modes of laser operation for the M203PI GLS is applied to Rule 3 and is presented in the table below.

Table 6

Specific AEL(s) for the Various Modes of Operations (Small Source Viewing)

Laser Unit	Mode of Operation	Number Of Pulses	Per Pulse AEL
M203 LAT	Single Fire	22	$228 \times 10^{-9} \text{ J}$
M203 LAT	Rapid Fire	44	$192 \times 10^{-9} \text{ J}$
M203 LAT	Auto Align	60	$178 \times 10^{-9} \text{ J}$
M203 LAT	Auto Fire	220	$128 \times 10^{-9} \text{ J}$
Umpire Gun	Single Trigger Pull	165	$138 \times 10^{-9} \text{ J}$
Umpire Gun	Rapid Trigger Pull	825	$92.3 \times 10^{-9} \text{ J}$

B. Class 3a Allowable Exposure Limit

The Class 3a AEL is defined by the ANSI Standard to be:

$$\text{Class 3a AEL} = 5 (\text{Class 1 AEL})$$

Lasers, which have radiant outputs greater than the Class 3a AEL but less than the Class 3b AEL are considered laser hazard Class 3b.

$$\text{Class 3a AEL} < \text{Class 3b Lasers} < \text{Class 3b AEL}$$

C. ANSI Std. z136.6-2000 Force-On-Force Radiant Energy Limit (Q_{limit})

The radiant energy is limited to 2 times the Class 3a AEL, which in turn is related to the Class 1 AEL.

$$Q_{limit} = 2 \text{ (Class 3a AEL)}$$

$$Q_{limit} = 2 \text{ (5 x Class 1 AEL)}$$

$$Q_{limit} = 10 \text{ (Class 1 AEL)}$$

Hence, the radiant energy limit is 10 times the *small source* Class 1 AEL as depicted in the graph below.

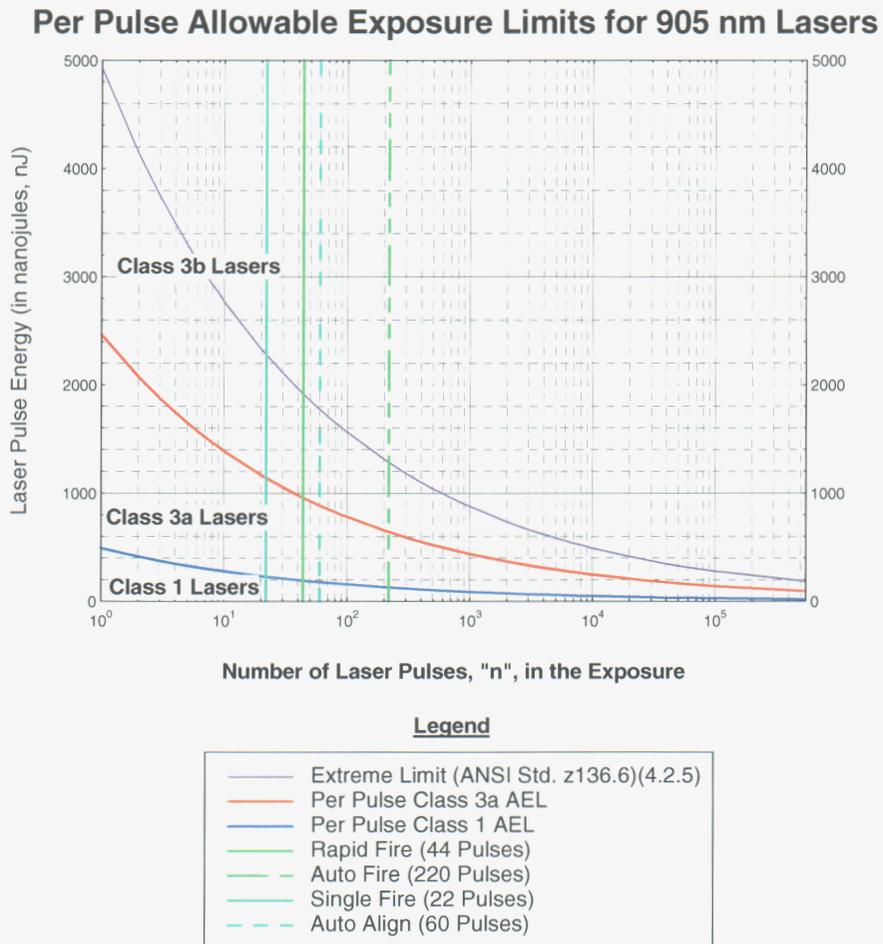


Figure 11.

Small Source Viewing AEL(s) for 905 nm lasers.

D. The Radiant Energy Output of the Umpire Gun (measured) Compared to the Class 1 AEL.

The radiant energy output of the Umpire Gun is graphically present below compared to the small source Class 1 AEL.

**Per Pulse Allowable Exposure Limit for 905 nm Lasers
With Output Of the Umpire Gun**

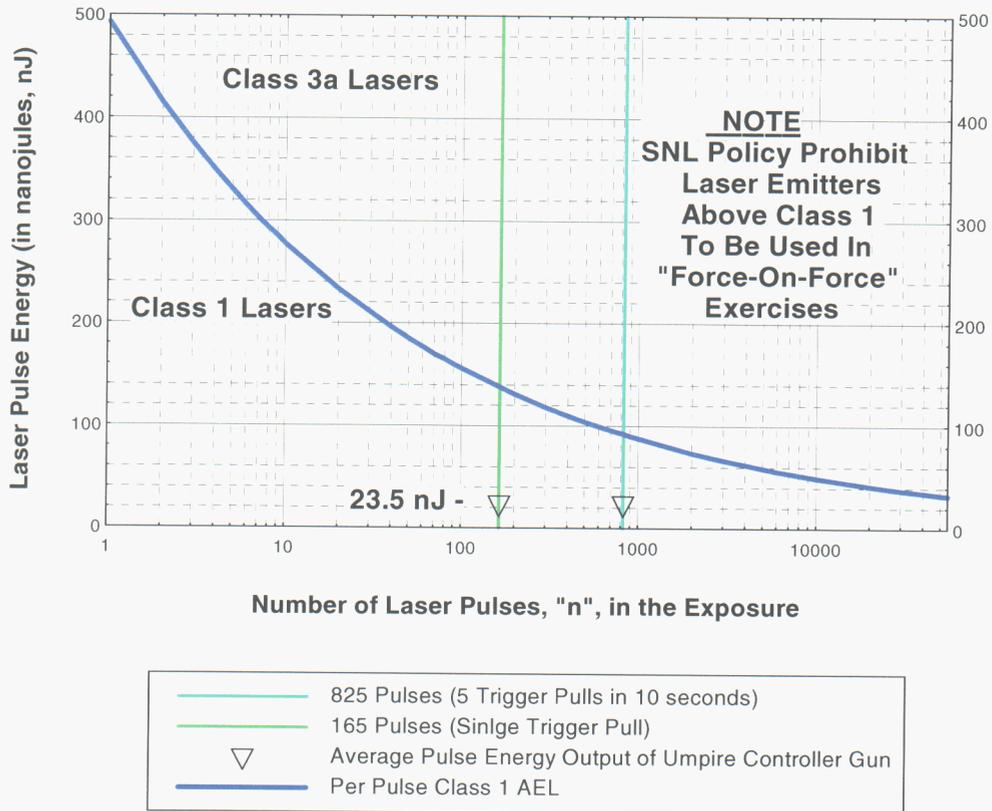


Figure 12.

Radiant Energy Output of “God Gun” versus small source Class 1 AEL

The radiant energy output of the Oscmar Umpire Gun for all modes of laser operation is less than the *small source* Class 1 AEL. The Umpire Gun is laser hazard Class 1. There are no restrictions, under either the ANSI Std. z136.6-2000 or SNL policy for its use in “force-on-force” exercises.

E. Radiant Energy Output (measured) of the M203PI GLS LAT.

The radiant energy output for each mode of LAT laser operation for the M203PI GLS is graphically presented below along with the *small source* Class 1 AEL, the *small source* Class 3a AEL, and “twice the *small source* Class 3a AEL”.

Per Pulse Allowable Exposure Limits for 905 nm Lasers

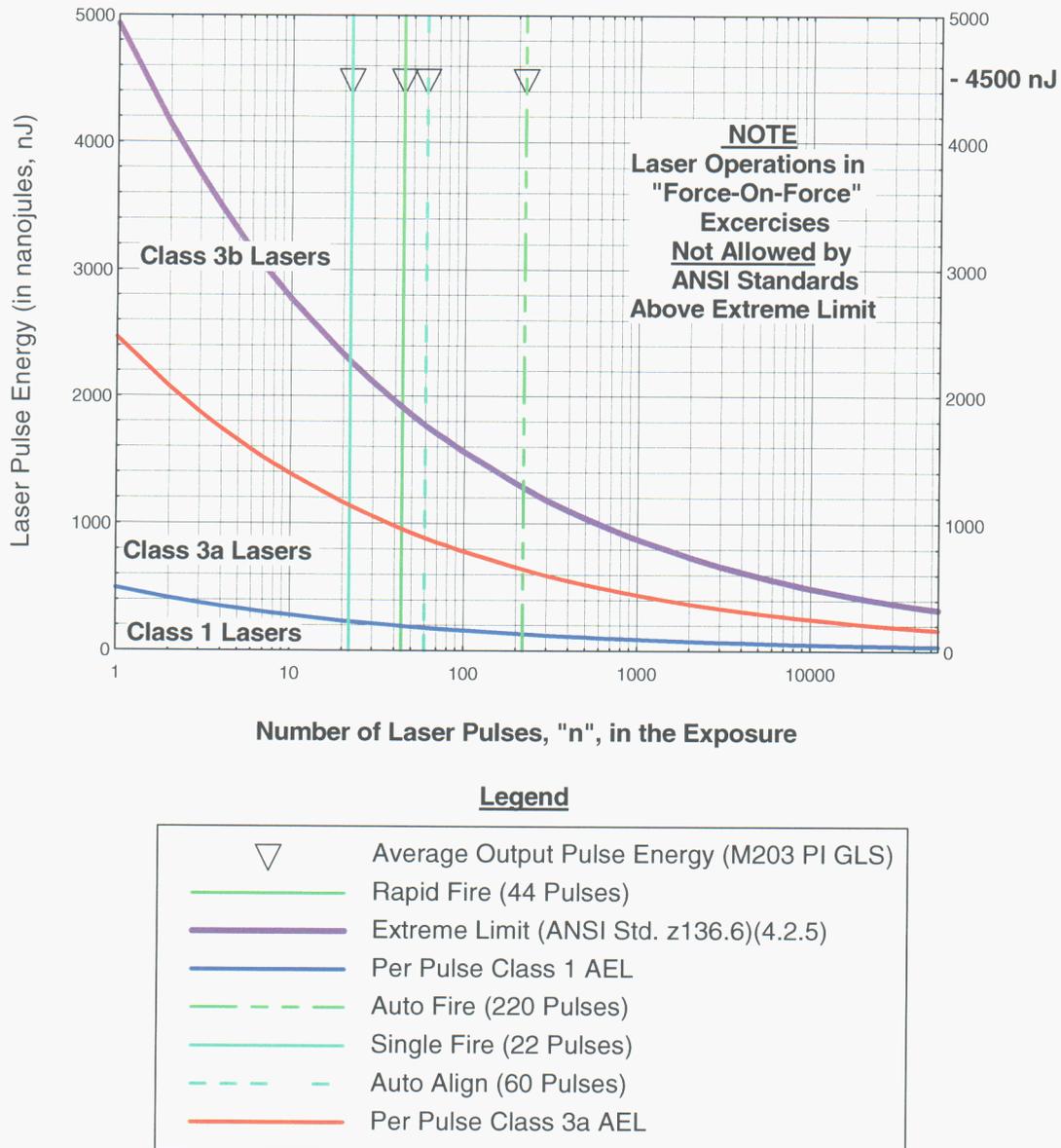


Figure 13.

M203PI GLS LAT Output versus (“Small Source” Viewing) AEL(s) for 905 nm.

The radiant output of the M203PI GLS LAT is clearly well into the Class 3b laser hazard for “small source viewing”. It exceeds the “twice the small source Class 3a AEL” limit of the ANSI z136.6-2000. This is consistent with the manufacturer’s listing in the user’s manual and the unit labeling as a “Class 3b Laser Product”.

Under current SNL Force-On-Force Policy only Class 1 lasers can be used. The M203PI GLS LAT unit output exceeds the 2 times the small source Class 3a AEL.

Under “Small Source Viewing” conditions this M203PI GLS unit cannot (by either SNL policy or the ANSI Standard) be employed in a “force-on-force” exercise.

F. Laser Hazard Analysis For The M203PI GLS LAT.

ANSI Std. z136.6-2000 (3.3.1), for the safe use of lasers outdoors requires a hazard analysis for all lasers, “exceeding Class 3a”. Additionally, “a hazard evaluation should be performed on invisible Class 3a lasers before they are to be intentionally pointed at personnel”. The laser hazard evaluation for the M203PI GLS LAT should include the following:

1. The Environment In Which The M203PI GLS Is Used.

“Following laser or laser system classification, environment factor require consideration” (ANSI Std. z136.1-2000). This includes such factors as how the laser is to be used (application), location (indoors or outdoors), laser operating conditions, the proximity of personnel to the laser, “the probability of personnel exposure to hazardous laser radiation”, and other such factors should be considered when evaluating the laser hazards.

2. Intended Use of the M203PI GLS LAT.

The system is intended for outdoor use.



Figure 14.

M16 Rifle with M203 Grenade Launcher (GLS not inserted in the tube)

In one application the M203 Grenade Launcher is mounted under the barrel of the M16 rifle as depicted above. The M203PI GLS (LAT) is mounted inside the

launch tube of the M203 Grenade Launcher to simulate the firing of a 40 mm grenade round, as depicted below.

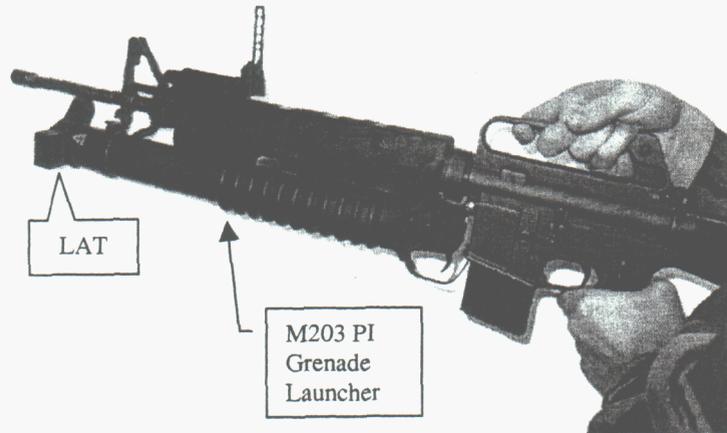
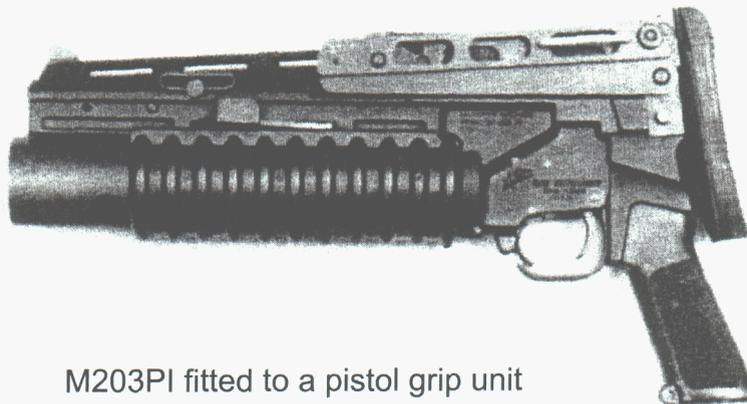


Figure 15.

M203PI GLS mounted in the M203 Grenade Launcher Tube

The M203PI GLS LAT is embedded in the M16/M203 rifle system. The rifle barrel, muzzle and flash suppressor extend some distance, greater than 6 cm, beyond the M203PI GLS LAT output window. It is physically possible to view the laser at a distance of 10 centimeter from the LAT.

Another configuration fits the M203PI Grenade Launcher to a pistol grip (as depicted below) can also be viewed at 10 centimeters from the LAT.



M203PI fitted to a pistol grip unit

Figure 16.

Large Area Beam.

The output beam is designed to have a “large” divergence, to simulate a large effective blast area of the 40-mm grenade round. The manual indicates that the effective area covered by the laser at the target distance has a diameter of 15 meters at a range of 300 meters. This output is not a collimated beam.

Small Source Viewing versus Extended Source Viewing.

Extended source viewing occurs when the viewing angle (α) of an observer looking back up the laser beam subtends an angle greater than the minimum viewing angle (α_{\min}), which ANSI Std. Z136.1-2000 (9.2) defines as 1.5 mr (1.5×10^{-3} radians). Extended source viewing conditions are **applicable to diode lasers** and diode laser arrays in situations where the viewing angles are **greater than 1.5 mr**, from the minimum viewing distance to the point where the viewing angle is equal to 1.5 mr (the range where small source viewing conditions would then apply from that point on). The minimum viewing distance is defined to be 10 centimeters (ANSI Std. z136.1-2000).

The exit diameter, d , at the M203PI GLS LAT was measured at 4 mm with the aid of an IR viewing card. At a 10-centimeters (100 mm) minimum viewing distance (R_{\min}) the viewing angle (α) is:

$$\alpha = \tan^{-1} [d / R_{\min}]$$

$$\alpha = \tan^{-1} [4 \text{ mm} / 100 \text{ mm}]$$

For angles less than 5 degrees (87.3×10^{-3} radians) the “small angle approximation” applies:

$$\alpha = 4 \text{ mm} / 100 \text{ mm}$$

$$\alpha = 0.04 \text{ radians}$$

$$\alpha = 40 \times 10^{-3} \text{ radians}$$

$$\alpha = \mathbf{40 \text{ mr}}$$

Applying the criteria of section 9.2 (ANSI Std. z136.1-2000):

$$\alpha_{\min} < \alpha$$

$$1.5 \times 10^{-3} \text{ radians} < 40 \times 10^{-3} \text{ radians}$$

At the minimum viewing distance **Extended Source Viewing applies** and will remain in effect until the viewing angle at some greater distance is equal to 1.5 milliradians. The distance at which the viewing conditions switches to Small Source can be found as follows:

$$R_S = d / \alpha_{\min}$$

Where:

R_S is the distance from the laser where viewing conditions switch to small source.

d is the exit diameter of the beam.

α_{\min} is the “minimum-viewing” angle for Extended Source Viewing conditions.

$$R_S = 4 \text{ mm} / 1.5 \times 10^{-3} \text{ radians}$$

$$R_S = 2.67 \times 10^3 \text{ mm}$$

$$\mathbf{R_S = 2.67 \text{ meters}}$$

Based on measured values Extended Source viewing conditions would apply to all viewing distances greater than 10 centimeters but within 2.67 meters of the M203PI GLS LAT.

The Consequence of Extended Source Viewing:

The Small Source MPE and the AEL values are modified by an “Extended Source” **correction factor** (C_E) for ranges where “extended source viewing” is applicable. The appropriate “Extended Source” **correction factor** is presented in table 6 (ANSI Std. z136.1-2000) as follows.

$$C_E = \alpha / \alpha_{\min}$$

$$\alpha_{\min} < \alpha < 100 \text{ mr}$$

At the minimum viewing distance (10 cm) the extended source correction factor for the M203PI GLS LAT is:

$$C_E = 40 \times 10^{-3} / 1.5 \times 10^{-3}$$

$$C_E = 26.7$$

The appropriate MPE for “extended source viewing” condition is:

$$MPE_{es} = C_E MPE_{ss}$$

Where:

MPE_{es} is the appropriate Extended Source MPE.

C_E is the Extended Source Correction Factor.

MPE_{ss} is the Small Source MPE

The extended source MPE at 10 centimeters is then:

$$\text{MPE}_{\text{es}} = (26.7) \text{MPE}_{\text{ss}}$$

Table 7

Specific MPE (Small & Extended Sources) for the Four Modes of Laser Operations at 10 cm

Laser Unit	Mode of Operation	Number of Pulses	Per Pulse MPE (Small Source)	Per Pulse MPE (Extended Source)
M203 LAT	Single Fire	22	$593 \times 10^{-9} \text{ J/cm}^2$	$15.8 \times 10^{-6} \text{ J/cm}^2$
M203 LAT	Rapid Fire	44	$499 \times 10^{-9} \text{ J/cm}^2$	$13.3 \times 10^{-6} \text{ J/cm}^2$
M203 LAT	Auto Align	60	$462 \times 10^{-9} \text{ J/cm}^2$	$12.3 \times 10^{-6} \text{ J/cm}^2$
M203 LAT	Auto Fire	220	$334 \times 10^{-9} \text{ J/cm}^2$	$8.92 \times 10^{-6} \text{ J/cm}^2$

Recall that the (Small Source) AEL is a function of the appropriate MPE.

$$\text{AEL}_{\text{ss}} = \text{MPE}_{\text{ss}} A_{\text{lim}}$$

For Extended Source viewing conditions.

$$\text{AEL}_{\text{es}} = \text{MPE}_{\text{es}} A_{\text{lim}}$$

Extended Source viewing at the minimum viewing distance (10 cm) of the M203PI GLS LAT:

$$\text{MPE}_{\text{es}} = (26.7) \text{MPE}_{\text{ss}}$$

$$\text{AEL}_{\text{es}} = (26.7) \text{MPE}_{\text{ss}} A_{\text{lim}}$$

$$\text{AEL}_{\text{es}} = (26.7) \text{AEL}_{\text{ss}}$$

Extended Source AEL as a function of the number of pulses is presented below.

**Per Pulse EXTENDED SOURCE Allowable Exposure Limit
for the M203PI GLS LAT (905 nm) at 10 cm ($\alpha = 40$ mr)**

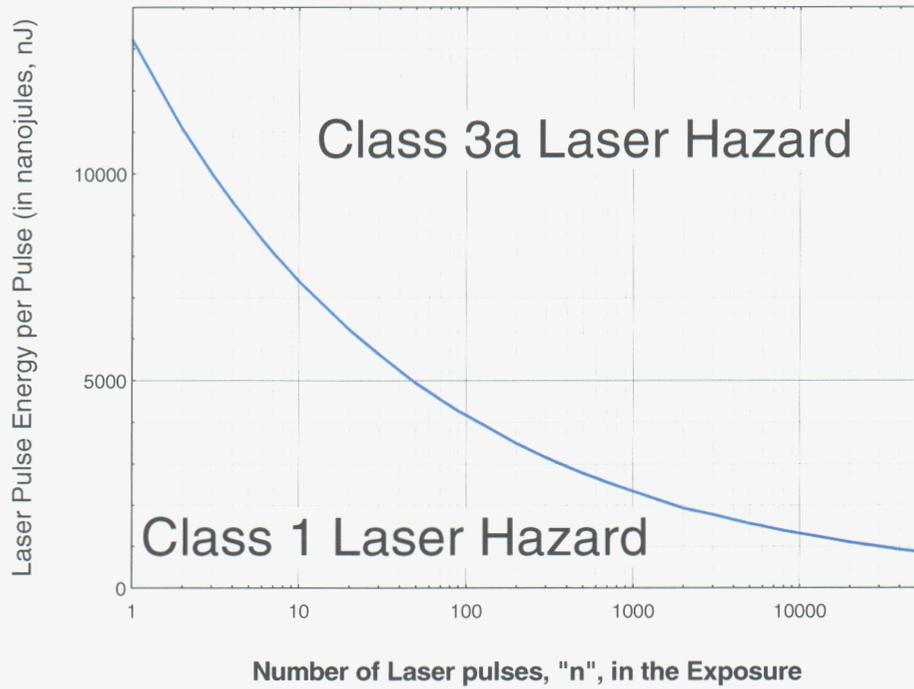


Figure 17.

Extended Source AEL at 10 cm for, $\alpha = 40 \times 10^{-3}$ radians

AEL(s) for Extended Source viewing condition at the minimum viewing distance is presented in the table below.

Table 8

Specific AEL(s) for the Four Modes of Operations
(Small Source and Extended Source Viewing) at 10 cm

Laser Unit	Mode of Operation	Number of Pulses	Per Pulse AEL (Small Source)	Per Pulse AEL (Extended Source)
M203 LAT	Single Fire	22	$228 \times 10^{-9} \text{ J}$	$6.09 \times 10^{-6} \text{ J}$
M203 LAT	Rapid Fire	44	$192 \times 10^{-9} \text{ J}$	$5.13 \times 10^{-6} \text{ J}$
M203 LAT	Auto Align	60	$178 \times 10^{-9} \text{ J}$	$4.75 \times 10^{-6} \text{ J}$
M203 LAT	Auto Fire	220	$128 \times 10^{-9} \text{ J}$	$3.42 \times 10^{-6} \text{ J}$

The radiant output of the M203PI GLS LAT was measured at 10 centimeters through a 7-mm diameter aperture and is added to the Extended Source AEL curve below.

**Per Pulse EXTENDED SOURCE Allowable Exposure Limit
for the M203PI GLS LAT (905 nm) at 10 cm ($\alpha = 40 \text{ mr}$)**

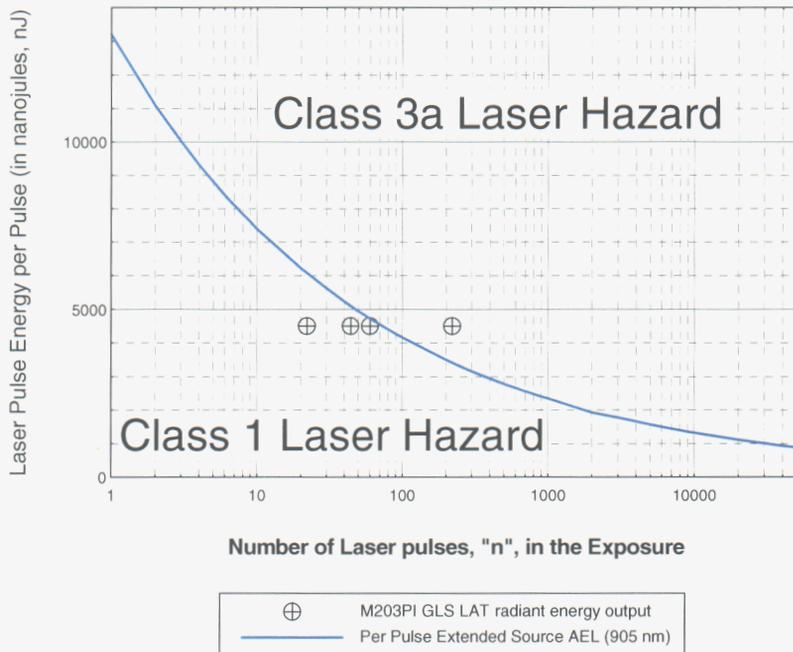


Figure 18.

Extended Source AEL @ 10 cm for $\alpha = 40 \times 10^{-3}$ radians with $Q_p = 4,500 \text{ nJ}$.

At minimum viewing distance (10 cm) the radiant energy output of the M203PI GLS LAT is laser hazard Class 1 for: Single Fire, Rapid Fire and Auto Align. The Auto Fire mode presents a Class 3a laser hazard at 10 centimeters.

Table 9

M203PI GLS LAT Radiant Energy Output vs. Specific AEL(s) for the Four Modes of Operations (**Extended Source**) Viewing at 10 cm

Mode of Operation	Number of Pulses	Per Pulse AEL (Extended Source)	Radiant Energy Output	Extended Source Laser Hazard Class
Single Fire	22	$6.09 \times 10^{-6} \text{ J}$	$4.5 \times 10^{-6} \text{ J}$	1
Rapid Fire	44	$5.13 \times 10^{-6} \text{ J}$	$4.5 \times 10^{-6} \text{ J}$	1
Auto Align	60	$4.75 \times 10^{-6} \text{ J}$	$4.5 \times 10^{-6} \text{ J}$	1
Auto Fire	220	$3.42 \times 10^{-6} \text{ J}$	$4.5 \times 10^{-6} \text{ J}$	3a

The “Auto Fire” mode of operation for the M203PI GLS LAT simulates the firing of a 40-mm grenade round every second. This mode of LAT laser operation is normally not used and the M203PI GLS must be programmed to use this mode of operation. The “**Auto Fire**” mode is not needed and can be **administratively excluded** from the allowed modes of laser operations during force-on-force exercises or during system alignment. It is now assumed that the “Auto Fire” mode will be excluded and no longer considered a usable mode of operation.

The “viewing angle” varies as a function of the viewing distance from the M203PI GLS LAT as follows:

$\alpha(r)$:

$$\alpha = 4 \text{ mm} / r$$

Where:

α is the viewing angle

r is the viewing distance in millimeters.

The Extended Source correction factor for the M203PI GLS LAT would also vary as a function of the viewing distance.

$C_E(r)$:

$$C_E = \alpha / 1.5 \times 10^{-3}$$

$$C_E = (4 \text{ mm} / r) / 1.5 \times 10^{-3}$$

$$C_E = 2.67 \times 10^3 / r$$

The Extended Source AEL(s) of the M203PI GLS LAT for the various modes of laser operation is the product of the Extended Source correction factor and the Small Source AEL.

$$AEL_{es} = C_E AEL_{ss}$$

$$AEL_{es} = AEL_{ss} (2.67 \times 10^3 / r)$$

Where:

AEL_{es} is the Allowable Exposure Limit for Extended Source viewing.

AEL_{ss} is the Allowable Exposure Limit for Small Source viewing.

r is the distance from the M203PI GLS LAT in millimeters.

Below is the plot of the “Extended Source” AEL(s) for (Single Fire, Rapid Fire and Auto Align) modes of operation for the LAT laser as a function of the distance from the exit window.

EXTENDED SOURCE AEL(s) vs. Distance From M203PI GLS LAT

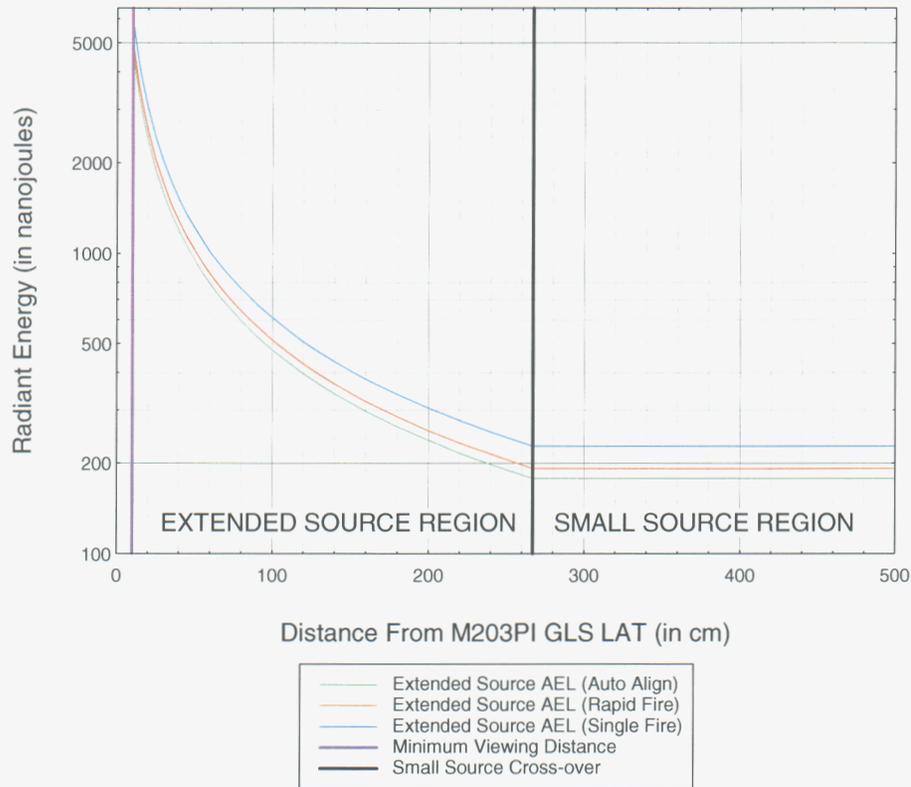


Figure 19.

Radiant Energy Output of the M203PI GLS LAT vs. Distance

The radiant energy was measured, through a 7-millimeter aperture (in the lab) at various distances from the LAT exit window, from 10 to 130 centimeters, in 10-centimeter increments. A new (different) battery was installed which, resulted in less radiant energy measured, at the 10-centimeter location, than the previously recorded 4.5 μJ . The radiant energy output appears to be somewhat dependent on the condition of the battery. At each measurement location, the “up-down” and “left-right” (vertical and horizontal) positioning micrometers (shown below) of the test jig were adjusted in order to get a maximum meter reading (beam center) of the radiant energy.

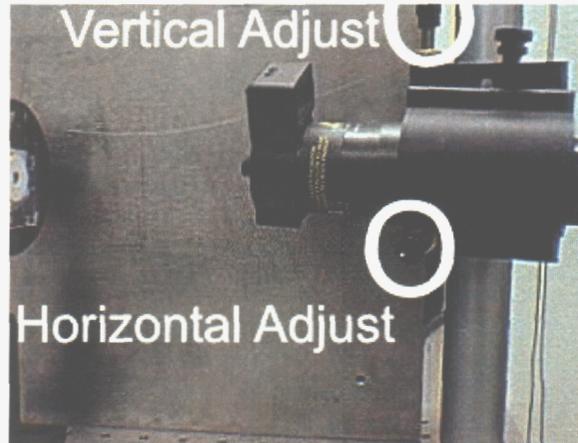


Figure 20.

The radiant energy measured at various distances from the M203PI GLS LAT is present in the table below.

Table 10

Radiant Energy Measured at various Distances from the M203PI GLS LAT

Distance From LAT	Radiant Energy
1.5 cm*	6.26 μ J
10 cm	3.56 μ J
20 cm	1.42 μ J
30 cm	636 nJ
40 cm	265 nJ
50 cm	129 nJ
60 cm	73 nJ
70 cm	46 nJ
80 cm	32 nJ
90 cm	25 nJ
100 cm	20 nJ
110 cm	17 nJ
120 cm	14 nJ
130 cm	12 nJ

* It was necessary to get a measurement of the entire radiant energy output of the M203PI GLS LAT in order to calculate the actual beam divergence from

comparison to the NOHD graphically obtained from the Radiant Energy versus Distance curves, presented below.

Radiant Energy Output of the M203PI GLS LAT Compared To EXTENDED SOURCE AEL(s) vs. Distance From The LAT

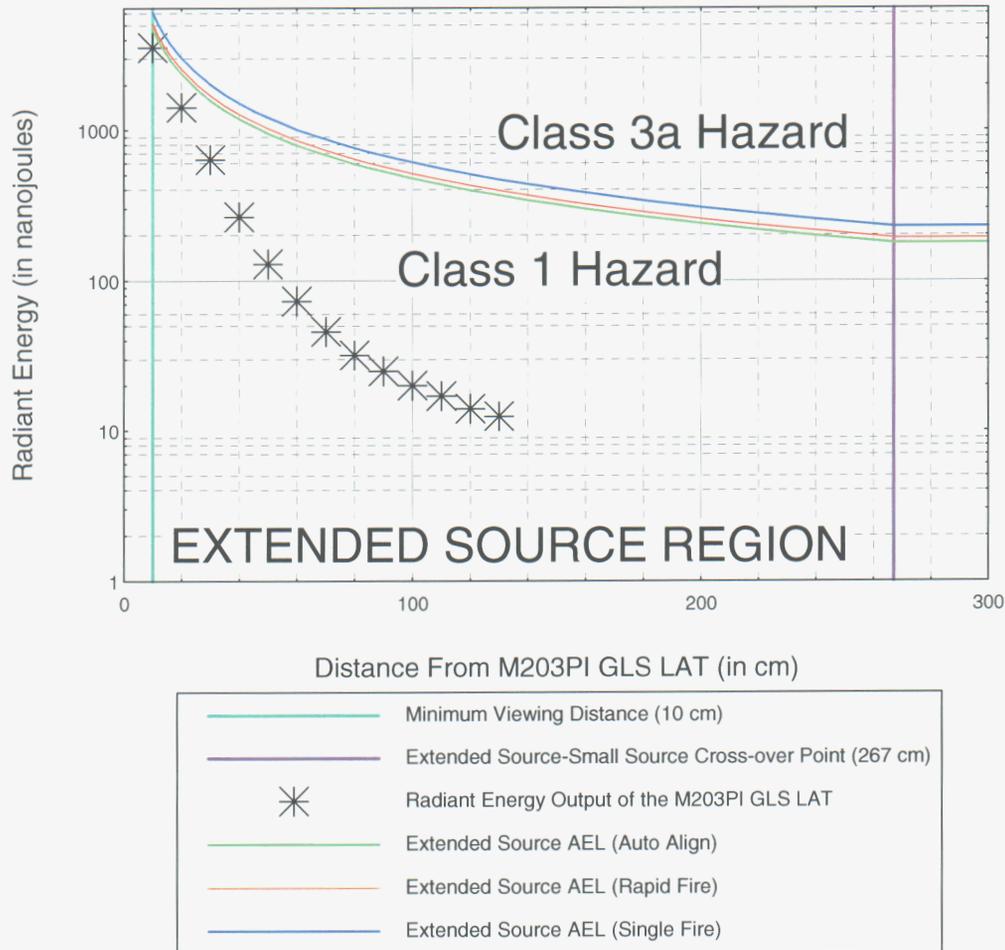


Figure 21.

The radiant output of the M203PI GLS LAT was **Extended Source Hazard Class 1** for the 3 (usable) modes of LAT laser operation.

To be considered a Class 1 laser hazard the M203PI GLS LAT radiant energy output must present a Class 1 hazard in the “Small Source” region as well as Class 1 hazard in the “Extended Source” region, for each of the 3 usable modes of laser operation.

In short, to be considered a **Class 1** Laser Hazard the M203PI GLS LAT laser **must** be:

- a. Extended Source Class 1 in the Extended Source Region.
- b. Small Source Class 1 hazard when it switches to the Small Source Region.

VI. Nominal Hazard Zone

The Nominal Hazard Zone (NHZ) is the area or region that the laser emission poses a threat to unprotected personnel exposed to the laser light. The NHZ is generally equal to the Nominal Ocular Hazard Distance (NOHD) for normal viewing or to the Extended Ocular Hazard Distance (EOHD) for aided viewing.

A. Nominal Ocular Hazard Distance

The NOHD is that distance from the laser after which the exposure to the laser light is considered to be “eye safe” (usually for small source viewing conditions). The appendix of ANSI Std. z136.1-2000 presents a formula for calculating this distance is:

$$R_{\text{NOHD}} = \theta^{-1} [(4Q_p / \pi\text{MPE}) - (d_o)^2]^{0.5} \text{ cm}$$

Where:

R_{NOHD} is the Nominal Ocular Hazard Distance in centimeters.

θ is the beam divergence in radians.

Q_p is the radiant energy in joules.

MPE is the appropriate Maximum Permissible Exposure in J/cm^2 .

d_o is the exit beam diameter in centimeters.

The NOHD (small source eye-safe distance) can be compared to the R_s (the distance where the viewing switches from extended to small source).

The radiant output is considered **small source Class 1** (eye-safe) if the following is true:

$$\text{NOHD} \leq R_s$$

Where:

NOHD Nominal Ocular Hazard Distance, after which “eye-safe” conditions exit.

R_s The distance where: viewing switches from “Extended Source” to “Small Source”.

Determination of the Beam Divergence.

The manual does not provide the beam divergence, a value needed to calculate the NOHD (see the equation presented above). To determine the beam divergence the exit diameter of the M203PI GLS LAT was measured, using an IR phosphorous imaging card. The exit diameter measured 4 mm (0.4 cm) and the beam diameter at 10 centimeters was measured as 8 mm. The beam divergence was calculated from these measured values as follows:

$$\theta = \tan^{-1} [\Delta d / \Delta r]$$

$$\theta = \tan^{-1} [(d_1 - d_0) / (r_1 - r_0)]$$

Small angle approximation for $\theta < 5$ degrees ($< 87.3 \times 10^{-3}$ radians)

$$\theta_1 = (d_1 - d_0) / (r_1 - r_0)$$

$$\theta_1 = (8 \text{ mm} - 4 \text{ mm}) / (100 \text{ mm} - 0 \text{ mm})$$

$$\theta_1 = 4 \text{ mm} / 100 \text{ mm}$$

$$\theta_1 = \mathbf{40 \times 10^{-3} \text{ radians}}$$

In like manner the diameter at 20 centimeters was measured and found to be 16 mm, which yields a beam divergence of:

$$\theta_2 = (d_2 - d_1) / (r_2 - r_1)$$

$$\theta_2 = (16 \text{ mm} - 8 \text{ mm}) / (200 \text{ mm} - 100 \text{ mm})$$

$$\theta_2 = 8 \text{ mm} / 100 \text{ mm}$$

$$\theta_2 = \mathbf{80 \times 10^{-3} \text{ radians}}$$

The beam cross-section geometry change from elliptical to circular during the first 10 cm but after 10 cm the spot appeared to remain circular. Hence θ_2 is probably the better value for the beam divergence of the two and θ_1 was rejected.

The user's manual implies an "effective" beam divergence of 50 mr (50×10^{-3} radians). But the beam divergence could be greater than this number.

To reconcile these different beam divergences an alternate approach was taken.

Using the radiant energy output (through a 7-mm aperture) versus distance curve (above), the NOHD distance (small source) can be determined graphically. The NOHD is the intersection of this radiant energy output versus distance curve with the small source AEL(s) represented by the dashed lines. The NOHD for the various modes of laser operation was determined this way.

Radiant Energy Output of the M203PI GLS LAT Compared To Extended & Small Source AEL(s) vs. Distance From The LAT

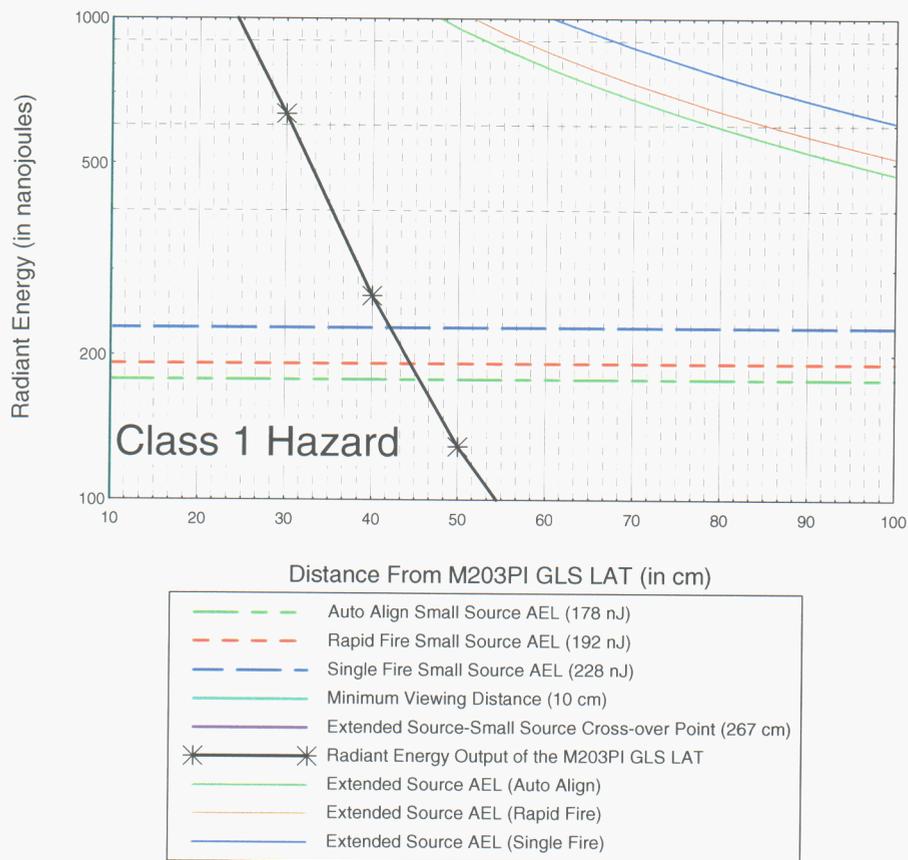


Figure 22.

Radiant Energy versus Small and Extended AEL

The region of intersections can be “zoomed-in” to give better resolution of the intersection points. The “x” coordinates of the intersections points represent the NOHD(s) for the various modes of LAT operation.

Radiant Energy Output of the M203PI GLS LAT Compared To Small Source AEL(s) vs. Distance From The LAT

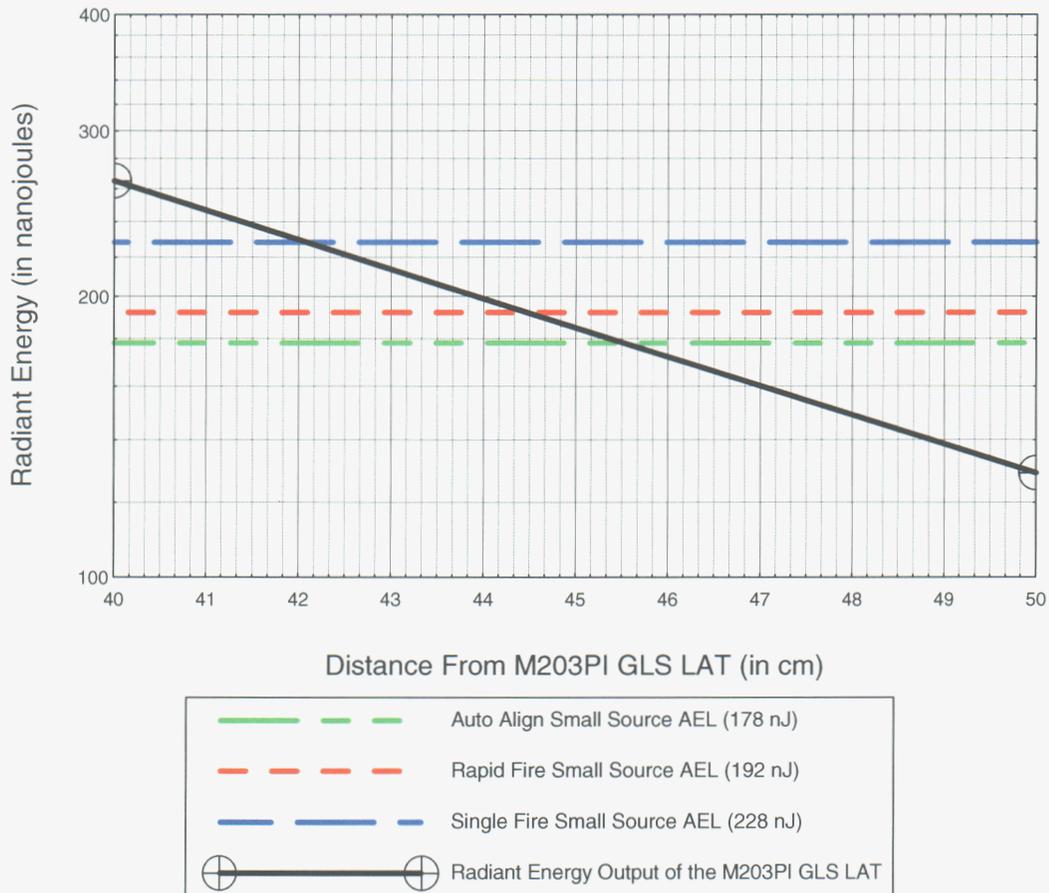


Figure 23.

NOHD(s) for the various modes are tabulated below.

Table 11

NOHD(s) Graphically Determined From Radiant Energy Output of the M203PI GLS
LAT for Small Source AEL(s)

Mode of Operation	AEL (Small Source)	NOHD
Single Fire	228 nJ	42.2 cm
Rapid Fire	192 nJ	44.5 cm
Auto Fire	178 nJ	45.5 cm

Based on the graphically determined **small source NOHD(s)** the radiant energy output of the M203PI GLS LAT becomes **eye-safe inside of 0.5 meters**.

Hence:

$$\mathbf{0.5\ meters \sim NOHD \leq R_s = 2.67\ meters}$$

M203 PI GLS LAT is Class 1 Laser Hazard (unaided viewing).

The M203PI GLS LAT can be considered a Class 1 laser hazard (for unaided viewing) because the radiant energy output is:

- a. **Extended Source Class 1** in the extended viewing region.
- b. **Small Source Class 1** at the point where viewing switches from “Extended Source” to “Small Source”.

Determination of the Beam Divergence (Continued).

These graphically determined values for the small source NOHD(s) present in table 11 and the measured radiant energy at the exit of the laser can be used to calculate the beam divergence. The “Single Fire” example follows.

Single Fire:

Recall the equation for the NOHD.

$$R_{NOHD} = \theta^{-1} [(4Q_p / \pi MPE) - (d_o)^2]^{0.5} \text{ cm}$$

Isolate and solve for, “ θ ”:

$$\theta = [(4Q_p / \pi MPE) - (d_o)^2]^{0.5} / R_{NOHD} \text{ radians}$$

Substitute measured and calculated values:

$$\theta = [\{ (4)(6.26 \times 10^{-6}) / \pi (593 \times 10^{-9}) - (0.4)^2 \}^{0.5} / 42.2 \quad \text{radians}$$

$$\theta = 86.4 \times 10^{-3} \quad \text{radians}$$

The calculated NOHD, for the various modes of laser operation, for the M203PI GLS LAT are tabulated below.

Table 12

Beam Divergence Determined from the NOHD(s)
For The Various Modes of LAT Operation

Mode of Operation	Per Pulse MPE	NOHD From graph	Beam Divergence
Single Fire	$593 \times 10^{-9} \text{ J/cm}^2$	42.2 cm	$86.4 \times 10^{-3} \text{ radians}$
Rapid Fire	$499 \times 10^{-9} \text{ J/cm}^2$	44.5 cm	$89.4 \times 10^{-3} \text{ radians}$
Auto Align	$462 \times 10^{-9} \text{ J/cm}^2$	45.5 cm	$90.9 \times 10^{-3} \text{ radians}$

The **average beam divergence** determined graphically was **88.9 (+/- 2.5) mr** [+/- 2.8 %].

B. Extended Ocular Hazard Distance (Aided Viewing)

The EOHD is that distance from the laser after which the exposure to the laser light through an optical viewing aid is considered to be “eye safe”. This distance is approximated by the following expression:

$$R_{\text{EOHD}} \sim [(\tau_{\text{atm}}) (\tau_{\text{aid}})]^{0.5} [d_{\text{aid}} / d_{\text{lim}}] R_{\text{NOHD}}$$

Where;

R_{EOHD} is the range of the Extended Ocular Hazard Distance.

R_{NOHD} is the range of the Normal Ocular Hazard Distance.

τ_{atm} is the atmospheric transmission factor for 905 nm laser light.

τ_{aid} is the transmission factor for the optical viewing to 905 nm laser light.

d_{aid} is entrance diameter of the optical viewing aid, in centimeters.

d_{lim} is the diameter of the limiting aperture, table 8 ANSI Std z136.1-2000, in centimeters.

The derivation of the above approximation is given in: SAND Report 2002-1315, May 2002, Approximation Methods for Estimating the Eye-Safe Viewing Distances, with or without Atmospheric Transmission Factors Considered, for Aided and Unaided Viewing Conditions.

For laser transmission under 200 meters the following approximation can be made,

$$\tau_{\text{atm}} \sim 1$$

So, the EOHD can be approximated as:

$$R_{\text{EOHD}} \sim (\tau_{\text{aid}})^{0.5} [d_{\text{aid}} / d_{\text{lim}}] R_{\text{NOHD}}$$

Table 9 of the ANSI Standard z136.1-2000 lists the transmission factor for the optical viewing aid as **0.7**.

Table 8 of ANSI Standard z136.1-2000 lists the diameter of the limiting aperture, for NIR light as 7 mm (0.7 cm).

The diameter of the entrance optic of a standard binocular is 50 mm (~2 inches).

Hence for a 905 nm laser the expression for the EOHD can be approximated as;

$$R_{\text{EOHD}} \sim (0.7)^{0.5} [50 \text{ mm} / 7 \text{ mm}] R_{\text{NOHD}}$$

$$R_{\text{EOHD}} \sim \mathbf{5.98 R_{\text{NOHD}}}$$

Table 13

NOHD(s) & EOHD(s) **Graphically Determined** From Radiant Energy Output Of The M203PI GLS LAT for Small Source AEL(s)

Mode of Operation	AEL (Small Source)	NOHD (Small Source)	EOHD (Small Source)
Single Fire	228 nJ	42.2 cm	2.52 m
Rapid Fire	192 nJ	44.5 cm	2.66 m
Auto Fire	178 nJ	45.5 cm	2.72 m

The minimum viewing distance for aided viewing is 2 meters (ANSI Std. z136.1-2000). Based on calculated values of the beam divergence and the graphically determined NOHD(s) and the EOHD(s) for the various modes of laser operations for the M203PI GLS LAT is greater than the minimum viewing distance (2 meters) for aided viewing. This indicates that, even with the large beam divergence, this unit does pose an **ocular hazard for aided viewing** at distances: greater than the minimum viewing distance of 2 meters **extending to about 3 meters**. In actuality it is highly unlikely that an observer would be using binoculars to view personnel within 3 meters (~ 9 feet) of his position. In addition **DOE Order 5480.16A**, Firearms Safety, (Chapter 1)(5)(a)(8)(d) **and DOE-STD-1091-96**, Firearms Safety Standard (Chapter 4-Exercises) already **prevents ESS laser engagement** of personnel (with or without binoculars), “**closer than 10 feet (3.05 meters)**”.

VII. Administrative Controls

The M203PI GLS LAT can be maintained as a hazard Class 1 laser through the use of a formal Standard Operating Procedure (SOP) or an Operating Procedure (OP), which excludes the “Auto Fire” mode of laser operation. The M203PI GLS LAT presented an Extended Source Class 1 laser hazard for: “Single Fire”, “Rapid Fire” (a multiple Single Fire event), and the “Auto Align” modes of laser operations. The Umpire Gun is used to set the mode of laser operation for the M203PI GLS LAT. The laser user (force-on-force player) does not have the means to change the LAT’s mode of operation and cannot change the LAT from Class 1 to Class 3a (for unaided viewing) once the mode of operation is set for the “force-on-force” exercise.

The rules of engagement are already set to prevent the intentional exposure of personnel using binoculars (aided viewing) inside of 3 meters from the LAT. DOE Order 5480.16A, Firearms Safety, (Chapter 1)(5)(a)(8)(d) and DOE-STD-1091-96, Firearms Safety Standard already prevents ESS laser engagement of personnel (with or without binoculars), “closer than 10 feet (**3.05 meters**)”.

VIII. Conclusions

Although the M203PI GLS LAT is labeled as a Class 3b laser (*Small Source*), because of the relatively large exit beam diameter of the laser diode and the large divergence optics employed the **Laser Hazard posed is actually Class 1** (Extended Source) and remains Class 1 at the distance that viewing switches to small source for 3 of the 4 modes of LAT laser operation. The 4th mode (Class 3a Hazard) can be administratively excluded because it simulates an Automatic Grenade Launch, which is not used in or needed for SNL “force-on-force” exercises.

Eye safety is insured by the strict compliance with existing DOE orders and Standards governing laser ESS “force-on-force” exercises.

IX. Reference

21 CFR 1040, Laser Product Performance Standard

ACGIH, 2001 Threshold Limit Values for Chemical Substances & Physical Agents & Biological Exposure Indices

ANSI Std. z136.1-2000: for Safe Use of Lasers, Published by the Laser Institute of America.

ANSI Std. z136.6-2000: for Safe Use of Lasers Outdoors, Published by the Laser Institute of America.

DOE Order 5480.16A, Firearms Safety.

DOE-STD-1091-96, Firearms Safety.

FAA 7400.2D Chapter 34, Outdoor Laser/High Intensity Light Demonstrations.

FDA CDRH: Compliance Guide for Laser Products.

M203PI Grenade Launcher Simulator (GLS) User Manual, © Osmar International Limited.

SAND 2002-1315, May 2002, Approximation Methods for Estimating the Eye-Safe Viewing Distances, with or without Atmospheric Transmission Factors Considered, For Aided and Unaided Viewing Conditions.

X. Appendix

Glossary of Symbols and Abbreviations

ACGIH	American Conference of Government 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
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
CW	Continuous Wave
D, d	Diameter
d _{aid}	Diameter of the entrance optic of viewing aid
d _{lim}	Diameter of limiting aperture
DOE-STD	Department Of Energy Standard
DR	Dummy Round
E	Irradiance (J/cm^2)
ES&H	Environmental, Safety & Health
ESS	Engagement Simulation System
FAA	Federal Aviation Administration
f _c	Critical Frequency
FDA	Food and Drug Administration
FWHM	Full Width at Half Maximum
GLS	Grenade Launcher Simulator
HMG	Heavy Machine Gun
Hz	Hertz (sec^{-1})
IR	Infrared
J	Joules
LAT	Large Area Transmitter
LE	Laser Emitter
LMG	Light Machine Gun

LT	Laser Transmitter
MILES	Multiple Integrated Laser Engagement System
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)
MWLD	Man Worn Laser Detector
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
P _{avg}	Average power
PRF	Pulse Repetition Frequency
Q	Radiant Energy in joules
Q _{eye}	Energy at the eye
Q _{limit}	The radiant energy limit value
Q _m	Measured energy
Q _{out}	Output energy
Q _p	Pulse Energy
R _{EOHD}	Range to the Extended Ocular Hazard Distance (eye safe distance)
RF	Radio Frequency
R _{NOHD}	Range to the Nominal Ocular Hazard Distance (eye safe distance)
RPG	Rocket Propelled Grenade
R _s	Range for extended source to small source cross-over point
SALT	Small Arms Laser Transmitter
SAT	Small Arms Transmitter
sec	Second
SEO	Schwartz Electro-Optics
Semi	Semiautomatic
SNLA	Sandia National Laboratories – Albuquerque
Sr	Steradian
Std	Standard

T, t	Time period
t _{exposure}	Exposure time or duration of exposure
t _{FWHM}	Pulse width (full width at half maximum)
t _{min}	The maximum exposure time for the MPE to be equal to MPE(1ns)
w	watt
α	Alpha- view angle
α_{min}	Minimum viewing angle (1.5×10^{-3} radians)
α_{max}	Maximum viewing angle (100×10^{-3} radians)
Δ	Delta- difference
λ	Lambda- wavelength
μw	Microwatt (10^{-6} watts)
μJ	Microjoule (10^{-6} joules)
Ω	Omega- Ohms (unit of electrical resistance)
τ	Transmission factor
τ_{aid}	Transmission factor for viewing aid (table 9 ANSI Std. z136.1)
τ_{atm}	Atmospheric transmission factor
~	Approximate or “proportional to”

X. Distribution

6	MS-1423	A. L. Augustoni, 1118
1	MS-1423	G. N. Hays, 1118
5	MS-0759	H. E. Metcalf, 5845
1	MS-0759	R. R. Page, 5845
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