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Laser Safety Evaluation of the MILES and Mini MILES Laser Emitting Components

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Laser Safety Evaluation of the MILES and Mini MILES Laser Emitting Components

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Abstract

Laser safety evaluation and output emission measurements were performed (during October and November 2001) on SNL MILES and Mini MILES laser emitting components. The purpose, to verify that these components, not only meet the Class 1 (eye safe) laser hazard criteria of the CDRH Compliance Guide for Laser Products and 21 CFR 1040 Laser Product Performance Standard; but also meet the more stringent ANSI Std. z136.1-2000 Safe Use of Lasers conditions for Class 1 lasers that govern SNL laser operations. The results of these measurements confirmed that all of the Small Arms Laser Transmitters, as currently set ("as is"), meet the Class 1 criteria. Several of the Mini MILES Small Arms Transmitters did not. These were modified and re-tested and now meet the Class 1 laser hazard criteria. All but one System Controllers (hand held and rifle stock) met class 1 criteria for single trigger pulls and all presented Class 3a laser hazard levels if the trigger is held (continuous emission) for more than 5 seconds on a single point target. All units were Class 3a for "aided" viewing. These units were modified and re-tested and now meet the Class 1 hazard criteria for both "aided" as well as "unaided" viewing. All the Claymore Mine laser emitters tested are laser hazard Class 1 for both "aided" as well as "unaided" viewing.

Summary of Results:

All the SNL MILES laser emitters are or have been made to be Class 1 Lasers (as is) in accordance with the ANSI standard and no control measures or medical surveillance are applicable or required.

Table 1: "As Is" Results with Fixes

	Model #	Weapon	Transmitter Type	# of Units	Unaided/Aided Laser Hazard Class "Semi"	Unaided/Aided Laser Hazard Class "Auto"
1	AM5000A	Rifle/ M-16	SALT	36	1	1
2	AM5000B	Rifle/M203	SALT	4	1	N/A
3	AM5010A	Light Machine Gun	SALT	14	1	1
4	AM5020A	Heavy Machine Gun	SALT	3	1	1
5	AM6002A	Rocket Propelled Grenade	SALT	2	1	N/A
6	AM6006B	Claymore	SALT	3	1	N/A
7	AM3000	Pistol	SAT	39*	1	N/A
8	LTE2055	Controller Gun	LT	1	1	1
9	LTE2056	Controller	LT	4	1	1

* One unit inoperative

Recommendations:

1. To maintain Class 1 laser operation and prevent Class 3a laser controls being imposed, amend "Rules of Engagement" to:

   a. Restrict "Automatic" Fire of the Rifle and the Light Machine Gun (LMG) to a maximum range setting of 800 meters. For range setting of 1000 meters the output of the laser emitter falls within the Class 3a category.

   b. Restrict "Automatic" Fire of the Heavy Machine Gun (HMG) to a maximum range setting of 1600 meters. For range setting of 2000 meters the output of the laser emitter falls within the Class 3a category.

   c. Put in place administrative controls, such as an Operation Procedure (OP), to:

      1. Restrict the maximum range setting of the Rifle and LMG SALT units to 800 meters.

      2. Restrict the maximum range setting of the HMG SALT units to 1600 meters.

      3. Verification that the attenuation filters installed on the modified SAT units associated with specific weapon (pistol) numbers is still intact prior to issue.

      4. Verification that the "near limiting" apertures, associated with the Controllers are still intact prior to use.

2. Batteries should be removed from all *MILES* laser-emitting components when not in use in order to conserve battery life and prevent corrosion damage to the units.

3. For future purchases of laser emitters associated with MILES operation specify that, "the lasers shall meet Class 1 Laser criteria in accordance with the most current ANSI Std. z136.1 in addition to CDRH and 21 CFR 1040".

Detailed Laser Safety Evaluation and Measurements

I. Overview of the Multiple Integrated Laser Engagement System (MILES):

A. Small Arms Laser Transmitters (SALT):

1. The MILES employ the Small Arms Laser Transmitter (SALT). The SALT laser is an Infrared (IR) laser diode operated at a primary wavelength of 904 nanometers (nm). The model AM5000A SALT is mounted on the rifle (M-16). The model AM5000B is a rifle mounted grenade simulator (40 mm grenade), the model AM5010A is used with the Light Machine Gun (LMG), the model AM5020A used with the Heavy Machine Gun (HMG) and the model AM6002 (RPG) is used with the Rocket Propelled Grenade. The SALT emits a coded laser pulse train, which indicates weapon fire and identifies the weapon ID (person firing the weapon). This laser pulse train consists of a series of time coded laser pulses within an approximate 500 milliseconds (ms) event time window. Information in regard to weapon type, rate of weapon fire, the ammunition type, ammunition load and weapon range are programmed and are carried on a radio frequency (RF) link. The SALT manufacturer, Schwartz Electro-Optics (SEO), claims the proper operation of the SALT units fall within Class 1 laser hazard category as defined by the Food and Drug Administration (FDA) Center for Device and Radiological Health (CDRH) Compliance Guide for Laser Products and the 21 CFR 1040 Laser Product Performance Standard. These units do not have (laser) warning labels, consistent with a Class 1, laser hazard classification [ANSI Std. z136.1-2000 (4.7)].

B. Small Arms Transmitters (SAT):

1. The *Mini MILES* (Pistol) uses a Small Arms Transmitter (SAT) model AM3000, with a pulsed diode laser operated at a wavelength of 904 nm. The SAT emits a train of laser pulses (*Mini MILES* word), time coded for each specific unit, at each "fire" event (blank fire). The SAT unit screws into a modified Sig Sauer exercise pistol barrel, threaded to receive the model AM3000. The shock impact of the blank round discharge causes the model AM3000 laser to fire. The SAT units are not programmable. The SAT units do not have laser warning labels, indicating that the manufacturer considers these units to be Class 1 lasers as defined by the FDA CDRH and the 21 CFR 1040.

C. Other Laser Transmitters (LT):

1. The model AM6006 Claymore Mine uses a similar laser diode transmitter, also at a wavelength of 904 nm that emits a coded pulse train swept through 60 degrees of arc. The manufacturer claims the operation of the model AM60006 Claymore is laser hazard Class 1; however, these units do have laser hazard warning labels, although these are not the labels prescribed by ANSI Std. z136.1-2000 (4.7.5).

2. The model LTE 2056, hand held system controller and the model LTE 2055, Controller Gun ("*God Gun*"), have IR laser outputs, at 904 nm, to interact with the various *MILES*

components. The laser outputs consists of time coded pulse trains to interrogate and control the various *MILES* components. The manufacturer considers these laser transmitter units to be laser hazard Class 1 as defined by the CDRH and the 21 CFR 1040. Class 1 lasers do not require laser hazard warning labels.

D. Concerns:

1. The vendor claims these units are Class 1 lasers under CDRH and 21 CFR 1040. More importantly, are the laser outputs of the SALT, SAT and LT units **eye safe** (laser hazard Class 1) under ANSI Std. z136.1-2000?

2. Are all SALT units properly adjusted according to the maintenance and repair manual?

II. Approach for Evaluating the Laser Safety of the SALT, SAT and LT units (was to):

A. Determine the appropriate Allowable Exposure Limit (AEL). SNL laser operations are governed by the American National Standards Institute (ANSI) Standard z136.1-2000: for Safe Use of Lasers. A laser safety evaluation of these units specifically entail, the determination of the appropriate Maximum Permissible Exposure (MPE) and the Allowable Exposure Limit (AEL) as defined by ANSI Standard z136.1-2000 (our governing document).

B. Perform measurements (laboratory and field) of laser transmitter output emissions to determine empirically, by comparison to the appropriate AEL, these lasers' hazard classification, in accordance with ANSI Std. z136.1-2000, (9.2.1 & 9.2.2).

C. Report findings and recommendations.

III. MILES Laser Emitter Models Evaluated:

Table 2

MILES and Mini MILES Laser Emission Components Requiring Evaluation

	Model #	Weapon	Type	Transmitter	# of Units
1	AM5000A	Rifle/ M-16	Semi/Automatic	SALT	36
2	AM5000B	Rifle/M203	Single Shot	SALT	4
3	AM5010A	LMG	Semi/Automatic	SALT	14
4	AM5020A	HMG	Semi/Automatic	SALT	3
5	AM6002A	RPG	Single Shot	SALT	2
6	AM6006B	Claymore Mine	Sweep	SALT	3
7	AM3000	Pistol	Semi	SAT	40
8	LTE2055	Controller Gun	Semi/Automatic	LT	1
9	LTE2056	Controller	Semi/Automatic	LT	4
				total	107 units

IV. Diode Laser Parameters (from manuals):

Wavelength (λ) = 904 nm
Pulse width (t_p) = 80 to 120 nanoseconds (ns)

Exposure Time ($T_{exposure}$) = time for the completion of the pulse train (number of pulse in the event), not to exceed 10 seconds [Standard IR exposure time, ANSI Std. z136.1-2000 (8.2.2)].

V. Class 1 Lasers and Class 1 Laser Operations:

A. Governing Documents:

There are various industry and government documents that define Class 1 laser operations. The following is a list of documents that deal with defining this class 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

B. Assumptions:

For the purpose of this evaluation it was assumed that the use of MILES equipment, for force on force exercises, would constitute laser operations. These laser operations would be **outdoors**, involving personnel **without eye protection** and initially "unaided" viewing (no binocular use) but a later requirement for "aided" viewing (binocular use) was added. Additionally; it was assumed that these operations would not be conducted in areas adjacent to airports or produce laser propagation in navigable air space, governed by FAA 7400.2D, Chapter 34. Should this be necessary Federal Aviation Administration (FAA) coordination and approval would have to be added to the National Environment Protection Act (NEPA) documentation covering this activity. It was further assumed that these laser operations would occur on SNL controlled sites and would therefore be governed by ANSI Std.z123.1-2000.

C. Compliance:

The manufacture of lasers and laser systems must at minimum comply with the CDRH Compliance Guide for Laser Products and the 21 CFR 1040 Laser Product Performance Standard. Sandia National Laboratories (SNL) laser operations are governed by the more stringent ANSI z136.1-2000 standard. It is possible to meet the conditions of Class 1 laser operation under CDRH and 21 CFR 1040 and **not meet Class 1** conditions under ANSI Std. z136.1-2000.

D. CDRH, Compliance Guide for Laser Products and 21 CFR 1040, Laser Product Performance Standard:

CDRH cites 21 CFR 1040.10(b)(5) and 1040.10(d)(Table I) and states, "Class 1 limits apply to devices that have emissions in the ultraviolet, visible and infrared spectra and are limits below which biological hazards have not been established. In the visible and near infra-red spectra there are separate Class 1 limits for radiant energy (power) and integrated radiance (radiance); both limits must be exceeded for the device to *be* moved from Class 1". These limits are presented in 1040.10(d)(Table I).

From 1040.10(d)(Table I):

1. Radiant Energy:

Class 1 limit = $2.0 \times 10^{-7} k_1 k_2$ Joules $\quad [400 \text{ nm} < \lambda < 1400 \text{ nm}]$ $\quad [1 \times 10^{-9} \text{ sec} < t < 2.0 \times 10^{-5} \text{ sec}]$

where;

$k_1 = 10^{\{\lambda-700/515\}}$ $\quad [800 \text{ nm} < \lambda < 1060 \text{ nm}]$

$k_2 = 1.0$ $\quad [t < 100 \text{ sec}]$

Class 1 limit = $2.0 \times 10^{-7}\ 10^{\{904-700/515\}}$ Joules

Class 1 limit = $2.0 \times 10^{-7}\ (2.49)$ Joules

Class 1 limit = 498×10^{-9} Joules

2. **Radiant Power** for T seconds:

Class 1 limit = $3.9 \times 10^{-7} k_1 k_2$ (Joules) / T (seconds) $\quad [400 \text{ nm} < \lambda < 1400 \text{ nm}]$ $\quad [10 \text{ sec} < t < 10^4 \text{ sec}]$

T=10 seconds (Standard IR Exposure):

$$\text{Class 1 limit} = 3.9 \times 10^{-7} (10^{\{904-700/515\}})/10 \quad \text{Watts}$$

$$\text{Class 1 limit} = 3.9 \times 10^{-3} (2.49)/10 \quad \text{Watts}$$

$$\boxed{\textbf{Class 1 limit} = 971 \times 10^{-6} \ \textbf{Watts}}$$

3. **Integrated Radiance**:

$$\text{Class 1 limit} = 10\, k_1 k_2 t^{1/3} \ \text{J/cm}^2\text{-Sr}$$

[400 nm < λ < 1400 nm]
[10 sec < t < 10^4 sec]

$$\text{Class 1 limit} = 10\,(2.49)\,\{10^{-7}\}^{1/3} \ \text{J/cm}^2\text{-Sr}$$

$t=10^{-7}$ seconds

$$\boxed{\textbf{Class 1 limit} = 116 \times 10^{-3} \ \textbf{J/cm}^2\textbf{-Sr}}$$

Table 3

CDRH Class 1 Limits for 904 nm Lasers

Radiance	**498 x 10^{-9} Joules** **971 x 10^{-6} Watts**
Integrated Radiance	**116 x 10^{-3} J/cm^2-Sr**

Note: Neither CDRH nor 21 CFR 1040 consider limits (sub-threshold cumulative thermal injury) for multiple pulse exposure.

The laser safety representative for SEO claims that these units comply with CDRH Class 1 laser criteria. SEO contends that these units do not exceed either of the CDRH values (presented above) and are therefore Class 1 lasers. That is, no single pulse in the pulse train exceeds the single pulse radiant energy limit and the average power over the exposure time does not exceeds the radiant power limit; therefore, the units are considered Class 1.

E. ANSI Standard z136.1-2000: <u>for Safe Use of Lasers</u>:

The ANSI Standard z136.1-2000 (1.2) states that, "…a Class 1 laser system is considered incapable of producing damaging radiation levels during operation and is, therefore, exempt from any control measures or other forms of surveillance". A Class 1 laser is defined to be a laser with an output emission not to exceed the appropriate AEL. The appropriate AEL for a particular laser is a function of the MPE, and a "limiting" aperture of ANSI Std. z136.1-2000 (3.2.3.4.1)(1). Both the MPE and the AEL are functions of the laser emission wavelength or wavelength range (Tables 5a & 8 of ANSI Std. z136.1-2000).

Class 1 $\leq$ AEL = MPE x (area of limiting aperture) [ANSI Std.z136.1-2000 (3.2.3.4.1)(2)]

1. <u>Determination of appropriate MPE</u>:

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 **<u>smallest</u>** of the MPEs determined by **Rules 1, 2 & 3.**

<u>Rule 1</u>: *Single Pulse*

$MPE_{s.p.} = 5.0\, C_A \times 10^{-7}\ J/cm^2$

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

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

[Table 6 of ANSI Std. z136.1]:
$700\ nm < \lambda < 1050\ nm$

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

$$MPE_{s.p.} = 5\,[10^{2(0.904-0.7)}] \times 10^{-7}\ J/cm^2$$

$$= 5 \times 2.56 \times 10^{-7}\ J/cm^2$$

$$\mathbf{MPE_{s.p} = 1.28 \times 10^{-6}\ J/cm^2}$$

<u>Rule 2</u>: *Average Power MPE for Thermal & Photochemical Hazards*

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

[Table 5a of ANSI Std. z136.1]:
$700\ nm < \lambda < 1050\ nm$
$T > 10\ sec$

$$C_A = 10^{2(\lambda-0.7)}$$ [Table 6 of ANSI Std. z136.1]: 700 nm < λ < 1050 nm

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

$$MPE_{CW} = 10^{2(0.904-0.7)} \times 10^{-3} \text{ w/cm}^2$$

$$\mathbf{MPE_{CW} = 2.56 \times 10^{-3} \text{ w/cm}^2}$$

Per Pulse MPE:

$$\mathbf{MPE_{CW(PP)} = 2.56 \times 10^{-3} / (PRF) \quad J/cm^2}$$

where,

PRF = Pulse Repetition Frequency

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

The appropriate MPE_{rp} is determined by the total number of laser pulses emitted in the exposure time.

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

Where;

PRF = Pulse Repetition Frequency

The maximum exposure time considered for normal, not forced, viewing for IR lasers (904 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 904 nm, laser is given as 55 KHz [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).

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

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

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

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

$$\mathbf{MPE_{r.p.} = (n^{-0.25}) \times (1.28 \times 10^{-6}\ J/cm^2)^{*}}\quad \text{(per pulse)}$$

*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 4

ANSI Std. Z136.1-2000: MPE(s) for 904 nm Lasers

Rule	MPE	Comments
Rule 1	$\mathbf{1.28 \times 10^{-6}\ J/cm^2}$	
Rule 2	$\mathbf{2.56 \times 10^{-3}\ w/cm^2}$	
Rule 3	$\mathbf{(n^{-0.25})\ (1.28 \times 10^{-6})\ J/cm^2}$	**Smallest value**

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

2. Determination of Class 1 AEL:

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

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

$D_{lim} = 0.7$ cm [Table 8 of ANSI Std. z136.1]
400 nm $< \lambda <$ 1400 nm

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

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

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

Rule 1 (Single Pulse):

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

$$AEL = (0.385\ cm^2)\ (1.28 \times 10^{-6}\ \ J/cm^2)$$

$$\mathbf{AEL_{rule\ 1} = 493 \times 10^{-9}\ \ Joules}$$

Rule 2 (CW):

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

$$AEL = (0.385\ cm^2)\ (2.56 \times 10^{-3}\ /PRF\ \ J/cm^2)$$

$\mathbf{AEL_{rule\ 2} = 986 \times 10^{-6}\ /\ PRF}$ **Joules** (per

Rule 3 (Multiple Pulse):

$$AEL\ per\ pulse = (C_p) \times (MPE_{s.p.}) \times \pi\ (0.7\ cm)^2 / 4$$

$$AEL = (n^{-0.25}) \times (1.28 \times 10^{-6}\ \ J/cm^2) \times (0.385\ cm^2)$$

$\mathbf{AEL_{rule\ 3} = (493 \times 10^{-9})\ n^{-0.25}}$ **Joules** (per pulse)

Note: **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 904 nm Lasers

Rule		MPE	AEL	Comments
Rule 1	Single pulse	1.28×10^{-6} J/cm^2	493×10^{-9} Joules	
Rule 2	CW	2.56×10^{-3} w/cm^2	986×10^{-6} W	
Rule 2	cw per pulse	2.56×10^{-3} /PRF J/cm^2	986×10^{-6} / (PRF) J	
Rule 3	per pulse	$(1.28 \times 10^{-6})(n^{-0.25})$ J/cm^2	$(493 \times 10^{-9})(n^{-0.25})$ J (see chart below)	Smallest value

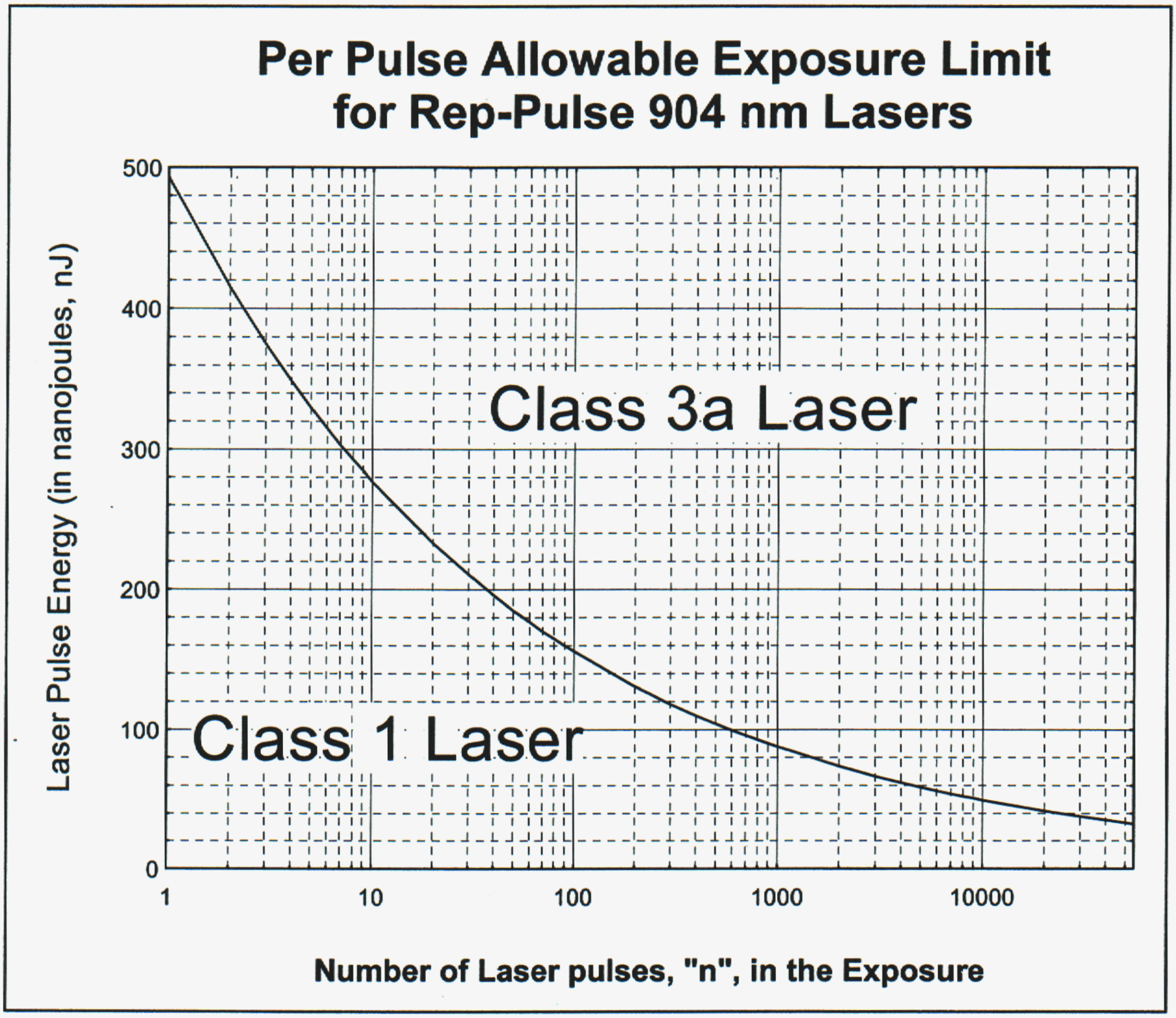
Appropriate AEL is the **smallest** value determined by rule 1,2, & 3.

Table 6

Comparison of CDRH and ANSI Std. z136.1-2000 Class 1 AEL Values for 904 nm Lasers

Type	CDRH & 21 CFR 1040	ANSI & ACGIH
Single pulse	498×10^{-9} Joules	493×10^{-9} Joules
CW	971×10^{-6} Watts	986×10^{-6} Watts
Multiple Pulse	Not considered by these standards	$(493 \times 10^{-9})(n^{-0.25})$ J (see chart below)

Rule 3 AEL determination:



Rep-Pulse Laser Per Pulse

<u>Notes:</u>

The Critical Frequency (f_c) for this laser (400 nm < λ_{laser} < 1050 nm) is 55,000 Hz *.

For PRF < f_c -Rule 3 applies *.

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

*ANSI Std.z136.1-2000 (8.2.3.2)(note)

VI. Evaluation of SALT, SAT and LT units:

A. Small Arms Laser Transmitter (SALT) Settings (Maintenance And Repair Manual):

The laser output pulse energy (in ergs) of the SALT is selectable according to weapon type and range and is given in the Maintenance And Repair Manual, *table II and III* (reproduced below) for the Rifle (M-16), LMG and HMG Laser Transmitters. The output energies (in ergs) were converted to joules for comparison to the AEL and are included in the tables below.

$$\text{Ergs} = \text{Joules} \times 10^{-7}$$

Hence;

$$1 \text{ Erg} = 100 \text{ nanojoules}$$

From: Maintenance and Repair Manual Rifle, Light Machine Gun and Heavy Machine Gun Laser Transmitter:

Maintenance And Repair Manual- Table II

Rifle and Light Machine Gun

Laser Output Settings for Weapon Ranges

SETTING	RANGE (meter)	OUTPUT (ergs)*	OUTPUT (nanojoules)*
0	400	0.22	22
1	600	0.37	37
2	800	0.60	60
3	1000	1.3	130

* +/- 10% accuracy

Maintenance And Repair Manual- Table III

Heavy Machine Gun

Laser Output Settings for Weapon Ranges

SETTING	RANGE (meter)	OUTPUT (ergs)*	OUTPUT (nanojoules)*
0	400	0.20	20
1	600	0.35	35
2	800	0.55	55
3	1000	1.3	130

* +/- 10% accuracy

B. Field / Laboratory Measurements:

SALT units that were not already attached to weapons (exercise M-16 rifles) and RPG, M203, LMG, HMG and Claymore mines were evaluated in the laboratory. Units that were attached to weapons (M-16 rifles) were evaluated in the field. The purpose of these evaluations was to measure the laser output pulse energies of the various SALT, SAT and LT units. Physical measurements of all unit outputs were made and compared to the appropriate AEL to determine laser hazard classification and also to verify that the outputs of the SALT and SAT units were properly adjusted (*table II and III*) and had not exceeded the appropriate AEL. Keeping in mind, "When comparing measured results to the MPE or AEL the combined uncertainty due to all sources of inaccuracy shall not exceed +/- 20%" [ANSI Std. z136.1-2000, (9.1)]. Laser emitter units, which exceeded the appropriate AEL were annotated.

C. Measurement Instruments:

1. Ophir Optronics Incorporated, model **PD10 Head**, serial number: 100556, calibration due: 5 February 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)].

2. Ophir Optronics Incorporated, model **NOVA digital meter**, serial number: 47407, calibration due: 28 June 2002, electrical accuracy: +/- 0.3 %

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

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

   b. 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)].

3. 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.

4. Tektronix **Model TDS 684C Digital Real Time Oscilloscope**, serial number: B020210, calibration due: 15 September 2002. Used to determine pulse width, Full Width at Half Maximum (FWHM).

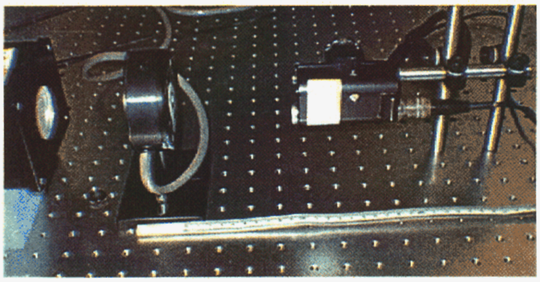
5. Tektronix **Model 7104 Oscilloscope**, serial number: B074120 with Tektronix model **7A24** Dual 50 Ω Vertical Amplifier, serial number: B133863, calibration due: 11 March 2002 and Tektronix model **7B15** Delaying Time Base, serial number: B035526, calibration due: 7 March 2002. Used to determine the number of *MILES* words in a "fire" event and pulse to pulse energy variations.

D. SALT Laser Output Measurements:

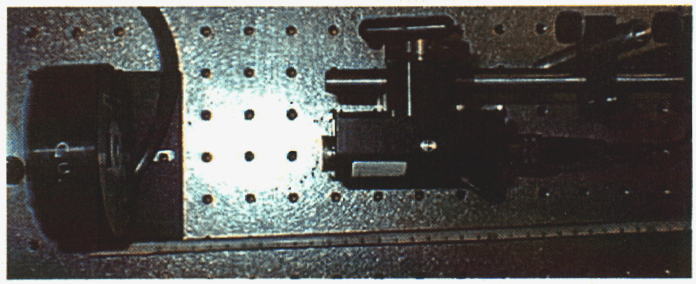
1. Model AM5000A (M-16 rifle):

a. **Laboratory measurements** of the model AM5000A rifle SALT consisted of placing the PD10 Head with a 7 mm "limiting" aperture 10 cm from the SALT exit window. A test jig was assembled to allow for consistent placement of the SALT units relative to the PD10 Head. A post collar was secured to the SALT mounting post and maintained the 10 cm distance. The alignment of the laser output to the PD10 head was adjusted using an "IR viewing" card.

This test jig (below) was used for all the SALT types: Rifle, 40 mm Grenade, LMG, HMG, and the PRG (by interchanging the mounting plate with a rifle unit).



Side View of SALT Test Jig
SALT mounted 10 cm from PD10 head



Top View of SALT Test Jig
SALT mounted 10 cm from PD10 head with 7 mm aperture.

b. **Field measurement** of the model AM5000A rifle SALT (already mounted on exercise rifles) was necessary because of the time that would be involved in re-sighting the SALT output beam to the rifle sight (unit to target alignment) if these units had been removed from the rifles for testing in the lab. Field measurements, generally involved greater uncertainties and less accuracy than those measurements made in the lab due to inconsistencies in holding the weapon to the PD10 head and maintaining alignment when measuring the SALT output.

c. The measured SALT output pulse energies were compared to the output settings of the model AM5000A listed in *Table II* of the Maintenance and Repair Manual. These measured values were used to determine the "as is" setting. The vendor default range setting is 400 meters (22 nJ per pulse).

The M-16 rifle can "fire" single shot (semiautomatic) or automatic (continuous fire while the trigger is depressed). Under the current "rules of engagement" for tactical exercises conducted at SNLA, the M-16 rifle is operated only in the semiautomatic mode. *Exercise M-16 rifles* will be modified in the future to prevent the automatic fire mode of operation. Until these modifications have been completed, the automatic fire mode of operation must be considered in the laser safety evaluation of the model AM5000A SALT. The magazine for the M-16 rifle has a maximum load of 30 rounds, although, loads of 28 rounds during exercises are typical. For the current laser safety analysis, magazine loads of 30 rounds were considered.

The maximum rate of fire for the M-16 rifle is given by the weapon documentation as 800 rounds per minute.

$$\text{Rate}_{max} = (800 \text{ rounds/min})(1 \text{ min}/60 \text{ sec}) = 13.3 \text{ rounds/sec}$$

With a full, 30 round magazine at the automatic rate of fire, the magazine is expended in 2.25 seconds.

$$T_{fire} = (30 \text{ rounds})/(13.3 \text{ rounds/sec}) = 2.25 \text{ sec}$$

For the M-16 rifle operated "single" fire (semiautomatic) the model AM5000A SALT output pulse train has been measured and consists of five "*MILES* words" or clusters of coded laser pulses emitted over 0.5 seconds. When the M-16 rifle is operated in the "auto" fire mode the first word (kill identifier) is repeated every 0.1 seconds until the last round is expended, allowing a complete "fire" sequence of words to be emitted. At the automatic mode of fire, the SALT emits laser pulses for duration of 2.75 seconds.

$$T_{exposure} = T_{fire} + T_{code}$$

$$T_{exposure} = 2.25 \text{ sec} + 0.5 \text{ sec} = 2.75 \text{ sec}$$

The **maximum exposure** time for this condition is **2.75** seconds. An **actual exposure** is expected to be <u>much less</u> because it is unlikely that a full magazine (30 rounds) will be expended on a single "target". Additionally; it is unlikely that all pulses will arrive at the same point (in this case the eye) due to the natural movement of the body when using hand held weapons and the recoil from discharged blank loads. Similarly there is likely to be movement of the "target" in response to the reports from the weapon firing at it and the *MILES*- Man Worn Laser Detector (MWLD) harness' audio response to "laser" hits.

The selection of the maximum exposure time constitutes the "worst case" and provides for conservative analysis weighted heavily on the side of laser safety and provides a built-in safety factor.

The maximum output laser pulse repetition rate (PRF), one pulse in every pulse position for the model AM5000A SALT is given by the vendor at 480 Hz (480 sec^{-1}).

The number of pulses can be calculated from the product of the Pulse Repetition Frequency (PRF) and the pulse train duration or exposure time ($T_{exposure}$). The maximum number of laser pulses in a:

Single Shot fire event is:

$$n_{max} = (PRF_{max}) (T_{exposure})$$

$$n_{max} = (480 \text{ sec}^{-1}) (0.5 \text{ sec}) = \mathbf{240 \ pulses}$$

For an **Automatic** fire event the maximum number of pulses is:

$$n_{max} = (PRF_{max}) (T_{exposure})$$

$$n_{max} = (480 \text{ sec}^{-1}) (2.75 \text{ sec}) = \mathbf{1320 \ pulses}$$

The number of output laser pulses in an exposure is critical in determining the appropriate AEL, the limit of Class 1 laser operation under ANSI Std. z136.1-2000 (8.2.3)(**Rule 3**), for pulse rate less than the critical frequency. The number of laser pulses in the coded laser output pulse-train will always be less than the maximum number of pulses determined above because the *MILES* code will necessarily require several vacant pulse positions per *MILES* word.

The maximum number of laser pulses (n_{max}) in a single fire event and in an auto fire event, constitute the "worst" case boundaries for each. Actual pulse rates are determined by calculating the Pulse Repetition Frequency (PRF) from the ratio of the measure average power to the measured average pulse energy and then multiplying by the exposure time or pulse train duration.

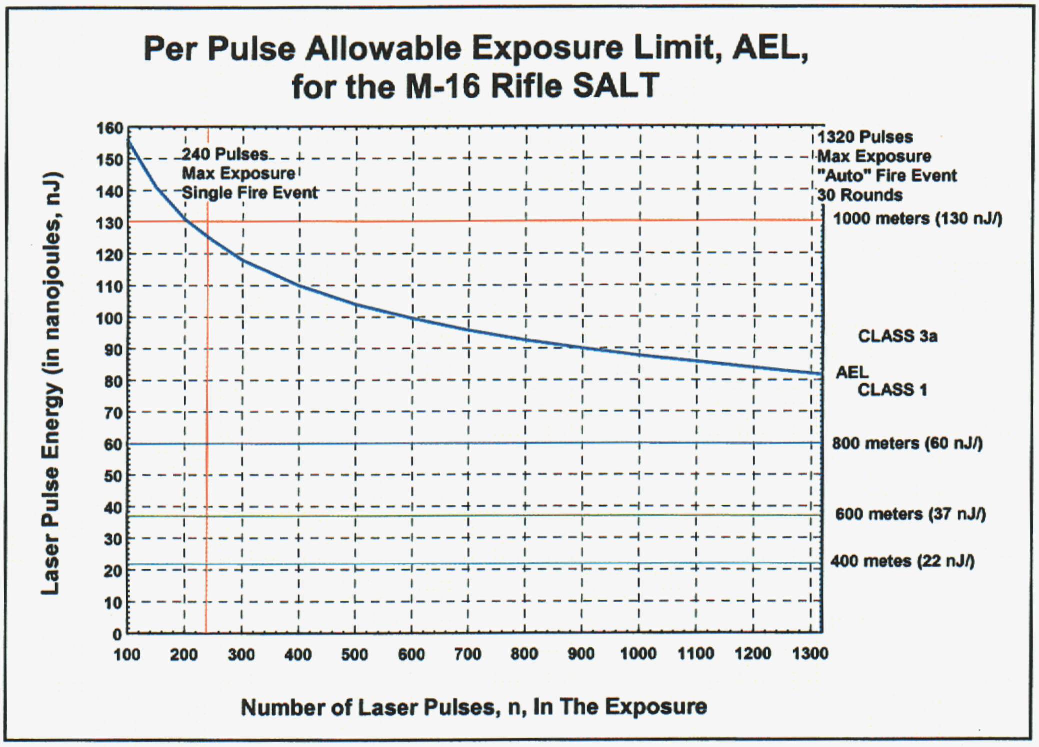
$$PRF (\text{sec}^{-1}) = P_{avg} (\text{J/sec}) / Ep_{avg} (\text{J})$$

$$n_{actual} = PRF (\text{sec}^{-1}) \times T_{exposure} (\text{sec})$$

Average values for output power and pulse energy are measured during an "auto fire" event using the dry-fire switch depressed and held to simulate the automatic fire of the M-16 rifle.

The appropriate per pulse AEL is a function of the actual number of laser pulses in the exposure.

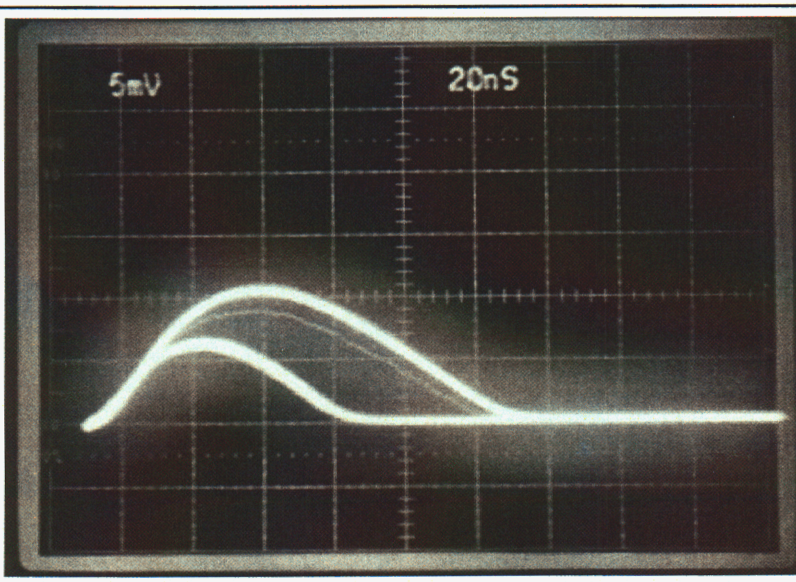
$$\text{Class } 1 \leq \text{AEL (per pulse)} = (493 \times 10^{-9}) \ n^{-0.25} \text{ (Joules)}$$



Laboratory and Field Measurement / Test Results:

Twenty-one, model AM5000A rifle, units were evaluated in the lab and fifteen (mounted on exercise M-16 rifles) were evaluated in the field. All units were operated using the "dry fire" cable. All units were tested "as is".

The laser emissions varied in pulse energy (pulse to pulse) in the pulse train. The variation in laser pulse energy was as great as plus or minus 40% as indicated below.



AM5000A Rifle SALT Output
Composite – "NORM" scope trigger
Ep ~ Vp x T_{FWHM}

The average outputs were measured "as is", and found to have laser emissions less than the appropriate AEL(s) and are therefore laser hazard Class 1.

Individual unit results are presented in the table below.

Table 7

Model AM5000A Rifle

Unit Serial #	Lab/Field Tested	Average Power (μw)	Average Pulse Energy (nJ)	Average Pulse Width (ns)	Pulses Per Second	AEL/pulse semi (nJ/)	AEL/pulse auto (nJ/)	Laser Hazard Class
1698	Field	6.5	20	-	325	138	90.2	1
1700	Field	5.5	19.2	-	286	143	93.1	1
1701	Field	10	30.4	-	329	138	89.9	1
1868	Lab	7.3	24	68	304	140	91.7	1
1869	Lab	7.38	24.2	68	305	140	91.6	1
1870	Field	10.6	42	-	252	147	96.1	1
1871	Lab	7.1	23.3	72	305	140	91.6	1
1872	Field	9.7	27.5	-	353	135	88.3	1
1873	Lab	8	26.1	70	307	140	91.5	1
1874	Lab	7.5	24.4	68	307	140	91.5	1
1875	Lab	8.2	23.2	70	353	135	88.3	1
1876	Field	8.36	26.2	-	319	139	90.6	1
1877	Field	6.4	22.4	-	286	143	93.1	1
1878	Field	8.5	25.8	-	329	138	89.9	1
1879	Field	6.8	26.2	-	260	146	95.4	1
1880	Lab	8.85	28.8	70	307	140	91.5	1
1881	Lab	8.73	27.8	70	314	139	90.9	1
1882	Lab	7.7	25	80	308	140	91.4	1
1883	Lab	8.8	28.3	70	311	140	91.2	1
1884	Lab	7.6	24.9	70	305	140	91.6	1
1885	Lab	6.3	20.2	52	312	140	91.1	1
1886	Field	10.6	27.5	-	386	132	86.4	1
1887	Field	6.8	19.3	-	352	135	88.4	1
1888	Lab	8.2	26.8	78	306	140	91.5	1
1889	Field	6.6	19.6	-	336	137	89.4	1
1891	Lab	8.8	28.7	66	307	140	91.5	1
1892	Lab	8.3	27.0	70	307	140	91.5	1
1894	Lab	7.68	26.1	68	294	142	92.5	1
1896	Field	6.4	24.8	-	258	146	95.5	1
1897	Lab	7.8	25.5	53	306	140	91.5	1
1898	Lab	8.8	28.7	70	307	140	91.5	1
1899	Field	11.7	30	-	390	132	86.2	1
1904	Field	10.6	28.9	-	368	134	87.4	1
1905	Lab	8.27	26.4	70	313	139	91.0	1
1906	Lab	9.1	29.7	72	306	140	91.5	1
1907	Lab	8.28	26.9	70	308	140	91.4	1

Semiautomatic Fire:

The appropriate per pulse AEL(s), for the units presented above, ranged from 132 nJ to 147 nJ. The maximum output pulse energy (selectable by the model LTE 1004A System IR Controller), as given in *table II,* set for the maximum range (1000 meters) is 130 nJ. *Table II* gives the default range setting (400 meters) value as 22 nJ per pulse.

In the semiautomatic mode, **all** of the model AM5000A Rifle SALT(s) tested are laser hazard **Class 1.** "Eye safe" for **all** authorized ranges indicated in *table II* of the maintenance and repair manual. Average output pulse energies varied from 20.2 nJ to 29.7 nJ (-8.2%,+35%) "Lab" and 19.2 nJ to 42 nJ (- 12.7%,+91%) "Field" compared to the nominal 22 nJ per pulse given in *Table II.*

Automatic Fire:

It is important to mention again that under current rules of engagement the M-16 rifle is operated in the semiautomatic mode only and that the rifles are to be modified in the future to prevent the automatic mode of fire. But until this modification is complete a laser hazard analysis must be considered for the automatic mode of fire.

The appropriate per pulse AEL(s), for full magazine (maximum time) exposure for the units presented above ranged from 86.1 nJ to 96.1 nJ. With reference to *table II* of the maintenance and repair manual, these units would be laser hazard **Class 1** for range settings up to 800 meters (~ 60 nJ).

At the **1000 meters** setting the output pulse energy would exceed the appropriate per pulse AEL(s) and would enter laser hazard **Class 3a** (as shown below) and may present an eye hazard to personnel within the hazard zone. Additionally, Class 3a laser controls would apply.

Table 8

Laser Hazard Class vs. Range Settings

Rifle

Laser Output Settings for Weapon Ranges

OUTPUT Setting	RANGE (meter)	OUTPUT (ergs)*	OUTPUT (nanojoules)*	Laser Hazard Class (Semi)	Laser Hazard Class (Auto)
0	400	0.22	22	1	1
1	600	0.37	37	1	1
2	800	0.60	60	1	1
3	1000	1.3	130	1	**3a**

* +/- 10% accuracy

Class 3a Laser Controls:

Class 3a lasers require a warning label, the posting of the area of laser operation, laser safety eyeware for personnel in the laser operation area (for t > 0.25 sec) and laser safety training (LAS 110) for the laser operator. Medical surveillance is not required. [ANSI Std. z136.1-2000, ANSI Std. z136.6-2000 & MN471001, ES&H Manual (Chapter 6, section G)].

It is important to note here that the laser operator (weapon user) does not exercise control over the output energy level of the SALT. The laser operator cannot adjust the output energy level of the SALT once it is set; therefore, the laser operator cannot adjust the SALT from laser hazard Class 1 to a laser hazard Class 3a.

SALT Unit Adjustments:

The SNL Security Training Section has exclusive control over the SALT unit settings. The Training Section has possession and positive control over the model AM1100A Hand Held System Controllers. The model AM1100A controller (through a RF link) can select and adjust the SALT settings, such as weapon type, mode of operation, ammo type, shock, fire source, number of rounds and the **range**.

Administrative Control:

The Training Section (through an Operating Procedure (OP) for setting SALT output energy levels) can administratively maintain these SALT units as Class 1 lasers. This procedure could administratively restrict the maximum range setting to 800 meters for the model AM5000A rifle SALT (automatic mode of fire).

2. Model AM5000B (M203) Rifle mounted 40 mm Grenade:

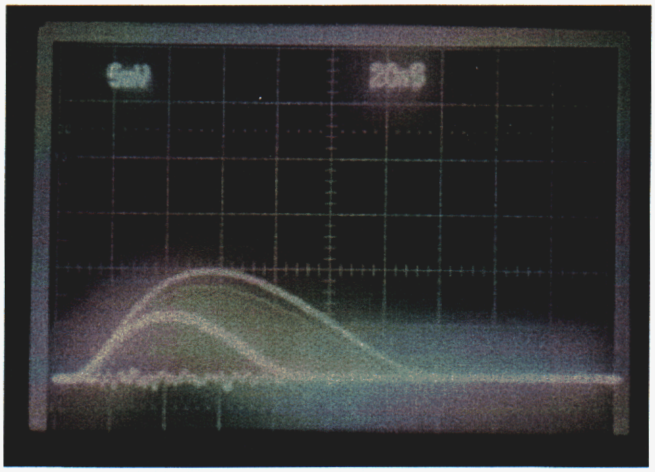
The rifle mounted 40 mm- grenade is a single "fire" event type weapon. The model AM5000B rifle/M203 was programmed to simulate a 40 mm- grenade, single fire, at a range of 400 meters. As with the model AM5000A the appropriate per pulse AEL(s) of all SALT units is a function of the number of laser pulses in the "fire" event exposure.

$$\text{Class 1} \leq \text{AEL (per pulse)} = (493 \times 10^{-9})\ n^{-0.25}\ \text{(Joules)}$$

Laboratory Measurement / Test Results:

Four, AM5000B rifle/ M203, units were programmed as 40 mm- grenades and were evaluated in the lab. All units were operated using the "dry fire" cable. All units were tested "as is". The laser emissions varied in pulse energy (pulse to pulse) in the pulse train. The variation in laser pulse energy was as great as plus or minus 50 % (as indicated below). The AM5000B rifle/M203 units emitted 7 (*MILES*) words in just under 0.7 seconds. The spot size at 10 cm was

8 mm x ~ 5 mm, rectangular with the major axis in the horizontal plane (opposite of the AM5000A, which has the major axis in the vertical plane).



AM5000B 40 mm- Grenade SALT Output
SN 1956
Composite – "NORM" scope trigger
$E_p \sim V_p \times T_{FWHM}$
$\Delta E_p \sim +/- 50\ \%$

The average outputs were measured and found to have laser emissions less than the appropriate per pulse AEL(s) and are therefore laser hazard Class 1.

Individual unit results are presented in the table below.

Table 9

Model AM5000B Rifle/M203 (40 mm Grenade)

Unit Serial #	Lab or Field Tested	Average Pulse Energy (nJ)	Average Pulse Width (ns)	Number of Pulses (n)	Exposure Time (sec)	AEL / pulse (nJ/)	Laser Hazard Class
1955	Lab	19.4	80	303	~0.7	118	1
1956	Lab	33.7	84	276	~0.7	121	1
1957	Lab	33.8	70	307	~0.7	118	1
1958	Lab	34.4	50	294	~0.7	119	1

3. Model AM5010A (LMG):

The Light Machine Gun has a maximum rate of fire similar to the M-16 rifle (800 rounds per minute). The LMG has magazine loads up to 100 rounds. There are currently no LMG at SNLA. The model AM5010A LMG SALT; however, can be mounted on an *exercise M-16 rifle* to simulate the LMG in exercises because of the similar rates of fire, but with only a 30 round magazine (no 100 round magazine are available for the M-16 rifle).

The laser safety analysis was similar to the parameters given above for the M-16 rifle. As with the model AM5000A rile analysis, the actual exposure of "target" personnel to the number of laser pulses would be less than the total due to natural movements of the person firing the LMG and the "target" motion.

Laboratory Measurement / Test Results:

Fourteen AM5010A LMG units were evaluated in the lab (as if mounted on an M-16 rifle). The model AM5010A LMG exhibited pulse to pulse energy variations similar to that of the model AM5000 rifle. The average pulse energies and the number of laser pulses in the exposure were determined in like manner as the model AM5000A rifle SALT units. All units were measured "as is" and found to have, output emissions (average) less than the appropriate per pulse AEL(s) and are therefore, laser hazard Class 1. Average output energy (from SALT unit to SALT unit) varied from 26.3 nJ to 32.8 nJ (up to 49% deviation) compared to the default range setting (400 meters) of 22 nJ per pulse given in *table II.*

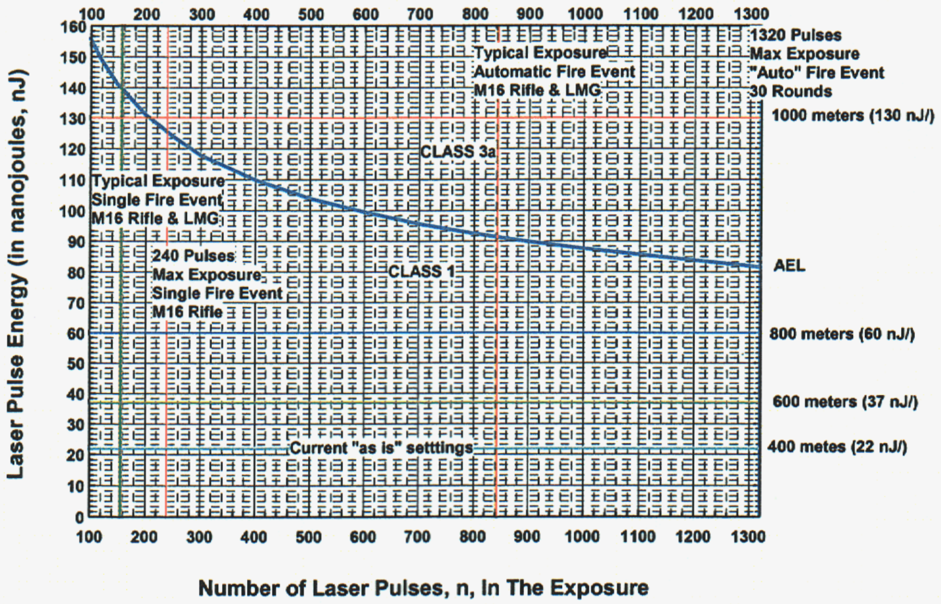
Individual unit results are presented in the table below.

Table 10

Model AM5010A LMG

Unit Serial #	Average Power (μw)	Average Pulse Energy (nJ)	Average Pulse Width (ns)	Pulses Per Second	Event Time max (sec)	Total Number Of Pulses	AEL/pulse Auto (nJ/)	Laser Hazard Class
3681	8	26.3	70	304	2.75	836	91.7	1
4016	8.05	26.4	72	305	2.75	839	91.6	1
4017	9.44	30.6	50	308	2.75	847	91.4	1
4019	8.96	29.3	70	306	2.75	841	91.5	1
4020	8.52	27.3	64	316	2.75	869	90.8	1
4022	8.4	27.4	68	307	2.75	844	91.5	1
4023	8.7	28.3	64	307	2.75	844	91.5	1
4027	9.42	30.1	68	313	2.75	861	91.0	1
4029	8.1	26.6	70	305	2.75	839	91.6	1
4104	8.9	29.3	72	304	2.75	836	91.7	1
4107	8.3	27	68	307	2.75	844	91.5	1
4109	9.52	31.2	70	305	2.75	839	91.6	1
4110	10.1	32.8	72	308	2.75	847	91.4	1
4113	9.7	31.8	72	305	2.75	839	91.6	1

Per Pulse Allowable Exposure Limit, AEL, for the M-16 Rifle & LMG SALT



As depicted above, the model **AM5000 Rifle** and the model **AM5010A LMG** are **Class 1** laser hazards, **except** for the conditions of **automatic fire** set for **maximum range** (1000 meters) **full exposure time** which moves these units into laser hazard **Class 3a** and therefore**,** Class 3a controls would apply.

Table 11

Laser Hazard Class vs. Range Settings

Light Machine Gun

Laser Output Settings for Weapon Ranges

OUTPUT Setting	RANGE (meters)	OUTPUT (ergs)*	OUTPUT (nanojoules)*	Laser Hazard Class (Semi)	Laser Hazard Class (Auto)
0	400	0.22	22	1	1
1	600	0.37	37	1	1
2	800	0.60	60	1	1
3	1000	1.3	130	1	**3a**

* +/- 10% accuracy

As stated above the Training Section can administratively control and maintain these programmable SALT units as Class 1 lasers by restricting the maximum range setting to 800 meters.

4. Model AM5020A (HMG):

The Heavy Machine Gun (HMG) has a maximum rate of fire also similar to the M-16 rifle of 800 rounds per minute. The standard magazine load is 100 rounds. There are currently no HMG at SNLA and there are no plans to simulate it. Hence, the evaluation assumed a 100 round magazine and would apply should HMG(s) be acquired in the future.

$$Rate_{max} = (800 \text{ rounds/min})(1 \text{ min/60 sec}) = 13.3 \text{ rounds/sec}$$

$$T_{fire} = (100 \text{ rounds})/(13.3 \text{ rounds/sec}) = 7.50 \text{ sec}$$

$$T_{exposure} = T_{fire} + T_{code}$$

$$T_{exposure} = 7.5 \text{ sec} + 0.5 \text{ sec} = 8 \text{ sec}$$

$$n_{max} = (\ PRF_{max}\ )\ (T_{exposure}\ )$$

$$n_{max} = (\ PRF_{max}\ )\ (8 \text{ sec}\ )$$

The appropriate per pulse Class 1 AEL is a function of the number of laser pulses in the exposure.

$$\text{Class 1} \leq \text{AEL per pulse} = (493 \times 10^{-9})\ n^{-0.25} \text{ Joules}$$

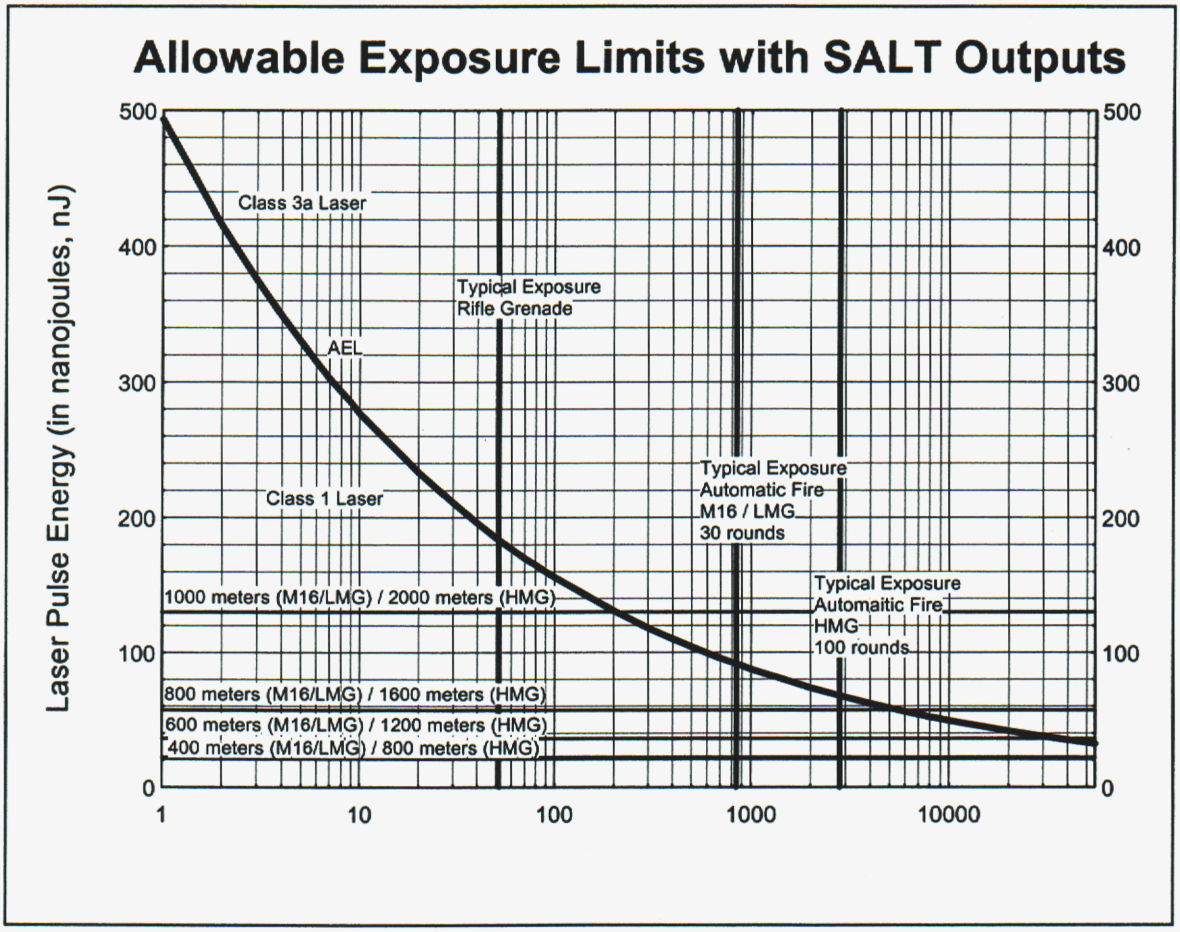
Laboratory Measurement / Test Results:

Three model AM5020A HMG units were evaluated in the lab. The variation in AM5020A HMG SALT output pulse energies were similar to those observed with the models AM5010 LMG and AM5000A rifle SALT(s). Measurement techniques were the same as for models AM5000A and AM5010A SALT(s). All units were measured “as is” and found to have emissions less than the appropriate per pulse, AEL(s) and are therefore laser hazard Class 1. The average output energy (from SALT to SALT) varied from 28.7 nJ to 47.6 nJ (up to 138% deviation) compared to the default range setting (800 meters) of 20 nJ per pulse given in *table III* of the manual.

Table 12

Model AM5020A HMG

Unit Serial #	Lab or Field Tested	Average Power (μw)	Average Pulse Energy (nJ)	Average Pulse Width (ns)	Pulses Per Second	Event Time max (sec)	AEL/pulse auto (nJ/)	Laser Hazard Class
4043	Lab	14.4	41.8	68	368	8	66.9	1
4077	Lab	9.5	28.7	48	331	8	68.7	1
4080	Lab	16.7	47.6	72	351	8	67.7	1



As depicted above, the model **AM5020A HMG** is a **Class 1** laser hazards, **except** for the conditions of **automatic fire** set for **maximum range** (2000 meters) **full exposure time** which moves these units into laser hazard **Class 3a** and Class 3a laser controls would apply.

Table 13

Laser Hazard Class vs. Range Settings

Heavy Machine Gun

Laser Output Settings for Weapon Ranges

OUTPUT Setting	RANGE (meter)	OUTPUT (ergs)*	OUTPUT (nanojoules)*	Laser Hazard Class (Semi)	Laser Hazard Class (Auto)
0	800	0.20	20	1	1
1	1200	0.35	35	1	1
2	1600	0.55	55	1	1
3	2000	1.3	130	1	**3a**

* +/- 10% accuracy

As stated above the Training Section can administratively control and maintain these programmable SALT units as Class 1 lasers by restricting the maximum range setting for HMG to 1600 meters.

5. Model AM6002A RPG:

The Rocket Propelled Grenade (RPG) is a **single fire event** type weapon. The weapon must be reloaded before it can be fired again. The model AM6002A RPG is mated with the weapon and simulates the RPG. The SALT emits five (*MILES*) words per "fire" event.

Laboratory Measurement / Test Results:

Two, model AM6002A RPG, units were evaluated in the lab. RPG units were setup as prescribed in the model AM6002A manual (section 6.1.2). The pulse to pulse variations (observed in the model AM6002A RPG SALT outputs) were similar to those observed in the other SALT(s) units tested. RPG SALT units were separated from RPG mount and a rifle mounting plate was attached to the unit so that it could be mounted on the test jig. The measurement techniques were the same as for models AM5000A, AM5010A and AM5020A SALT(s). All units were measured "as is" and found to have emissions less than the appropriate per pulse, AEL(s) and are therefore laser hazard Class 1.

Individual SALT unit results are presented in the table below.

Table 14

Model AM6002A RPG

Unit Serial #	Lab or Field Tested	Average Pulse Energy (nJ)	Average Pulse Width (ns)	# of Pulses In Exposure	Event Time (sec)	AEL/ pulse (nJ)	Laser Hazard Class
1222	Lab	71	70	200	0.5	131	1
1223	Lab	66.8	60	200	0.5	131	1

SEO SALT Calibration Procedures and Errors:

The SALT calibration procedure is given in 31829203: Maintenance and Repair Manual AM5000A, AM5010A, AM5020A Rifle, Light Machine Gun (LMG), & Heavy Machine Gun (HMG) Laser Transmitters, section (6.5.3.2) Measure and Calculate Laser Power. This is also applicable to all SALT units, including the model AM6002A RPG. The test instruments required consists of the model LTE-1003 Calibrator and an oscilloscope. The oscilloscope, typically either a fast analog storage scope or a fast, wide bandwidth digital scope) is used to measure the Peak voltage of the "intensity time" history from the LTE 1003 Calibrator. To determine the laser pulse energy (generally the first pulse): measure the peak amplitude, calculate the half peak value and then measure the time between the half peak value points (Time – Full Width at Half Maximum). The manual gives the pulse energy as the product of the following:

$$\text{Pulse Energy} = V_{peak} \times T_{FWHM} \times \text{ K factor}$$

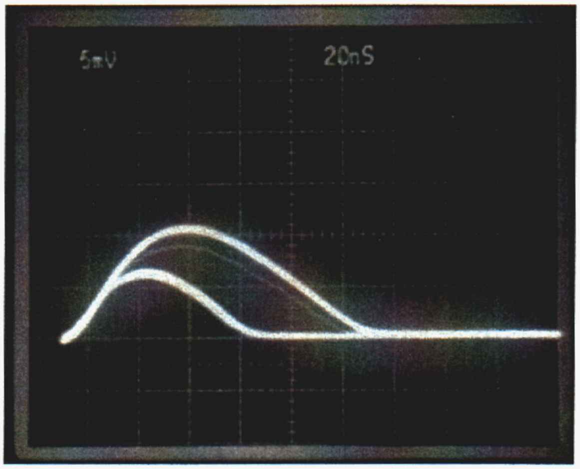
Where,

K factor is the calibration factor of LTE1003

This value of pulse energy (typically the first pulse) is compared to the pulse energy values presented in *tables II* and *III* of the maintenance and repair manual. The measured pulse energy can be adjusted up or down if the values are not within 10 % of table values. These energy adjustments can be performed by the (model AM1100A) Hand Held System Controller through the RF link.

The LTE-1003 Calibrator is a battery powered, fast photodiode, whose output has been previously calibrated. This unit does not have an "on/off" switch; hence, there is a continuous drain on the battery, which will have an effect on the unit's K factor (calibration factor) over time. The unit must be re-calibrated periodically. The unit is currently past due calibration check.

The result of observing composite laser pulses (intensity-time histories) for a SALT "fire event" make clear that the per pulse energy varies typically by +/- 40 %, and can vary by as much as +/- 50 %.



AM5000A Rifle SALT Output
Composite – "NORM" scope trigger
$E_p \sim V_p \times T_{FWHM}$
$\Delta E_p \sim$ +/- 40 %

Making energy measurements base on the first pulse could incur an error of as much as plus or minus 50 percent. This is quite a large error or uncertainty factor. Errors intrinsic with the prescribed calibration technique could have an impact on the proper range-energy settings for the SALT units. Output energy measurement errors on the order of 50% could allow for the improper range settings as a function of output pulse energy (*tables II & III*).

The uncertainty associated with SEO's calibration technique, described above, (as great as +/- 50 %) might explain the deviation observed in the SALT outputs energies and those presented in *table II* and *III* of the maintenance manual.

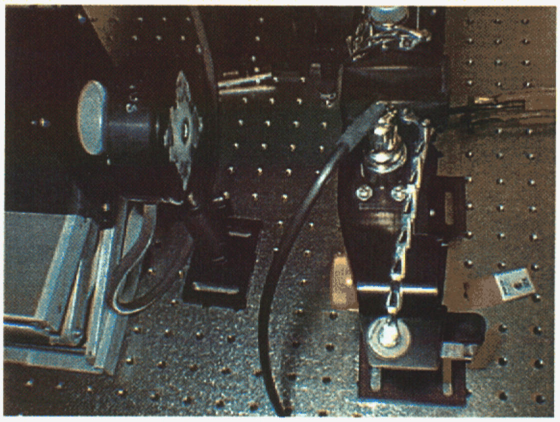
6. Model AM6006B Claymore Mine:

The model AM6006B simulates a Claymore Mine, electronically triggered by a switch closure (remote trigger cable). The Claymore Mine is a single fire event. The model AM6006B is operated semi-automatic, with one "fire" laser pulse train sequence per trigger. The AM6006B can be triggered up to four times (then the unit must be re-set by the Controller Gun). The laser output is swept through 60 degrees of arc. Again, the appropriate per pulse AEL is a function of the number of pulses exposed during the exposure.

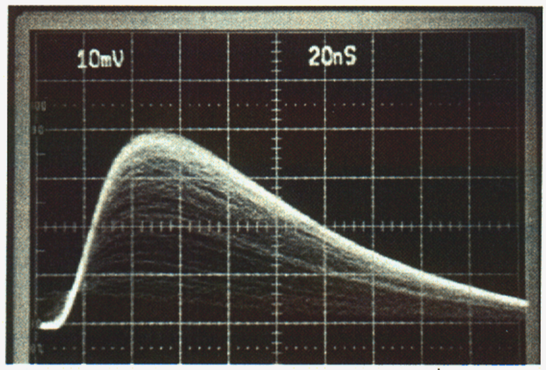
$$\text{Class 1} \leq \text{AEL per pulse} = (493 \times 10^{-9})\ n^{-0.25}\ \text{Joules}$$

Laboratory Measurement / Test Results:

Three model AM6006B Claymore Mine SALT units were evaluated in the lab. A test jig (presented below) was assembled to provide consistency, unit to unit, in test setup. The pulse to pulse energy variations, observed in the model AM6006B Claymore SALT outputs (presented below), were much greater than those observed in the other SALT(s) units. This is probably due, in part, to the dither mirror sweeping through the 60 degrees of arc with the energy measuring detector being fixed 10 cm from the Claymore on its frontal center line. Four (*MILES*) words were observed in approximately 2.5 seconds.



Test setup for AM6006B Claymore Mine evaluation.



AM6006B SALT Output
SN 2001
Composite – "NORM" scope trigger
$Ep \sim Vp \times T_{FWHM}$

All units were measured "as is" and found to have emissions less than the appropriate per pulse, AEL(s) and are therefore laser hazard Class 1.

Individual Claymore Mine unit results are presented in the table below.

Table 15

Model AM6006B Claymore Mine

Unit Serial #	Lab or Field Tested	Average Pulse Energy (nJ)	Average # of Pulses per Exposure	# of Scan Exposures Per Event	Average # Pulses Per Event	Pulse Width (ns)	Event Time (sec)	AEL Per pulse (nJ)	Laser Hazard Class
2000	Lab	5.6	62	4	248	80	~2.5	124.2	1
2001	Lab	1.4	61	4	244	100	~2.5	124.7	1
2002	Lab	1.0	63	4	252	100	~2.5	123.7	1

The laser hazard warning labels ("Caution") on these units are not required and are inconsistent with laser hazard Class 1.

7. Model AM3000 Mini MILES (Pistol –SAT):

The model AM3000 Mini MILES (Pistol –SAT) emits one *Mini MILES* word per "fire" event. The model AM3000 is not programmable and emits one predetermined *Mini MILES* word for each discharge of a blank round. It can also be "fired" by taping the side of the unit with the plastic handle of a screwdriver to test functionality. It was also observed that the laser unit could be "fired" by the "dry fire" hammer fall on an empty chamber.

The maximum number of pulse positions of the *Mini MILE* word is given by the specification data sheet as 35. The number of pulses per *Mini MILE* word were measured and found to vary from a minimum of 11 pulses per word to a maximum of 30 pulses per word.

The pulse energy was found to vary from pulse to pulse and also from "fire" event to "fire" event. The average pulse energy per event was measured and the average value for 10 such events were taken to represent the *average pulse energy* of the unit. This average value of pulse energy was used to determine laser hazard class.

As above, the appropriate per pulse AEL is a function of the number of laser pulses in the exposure.

$$\text{Class 1} \leq \text{AEL (per pulse)} = (493 \times 10^{-9})\ n^{-0.25}\ \text{Joules}$$

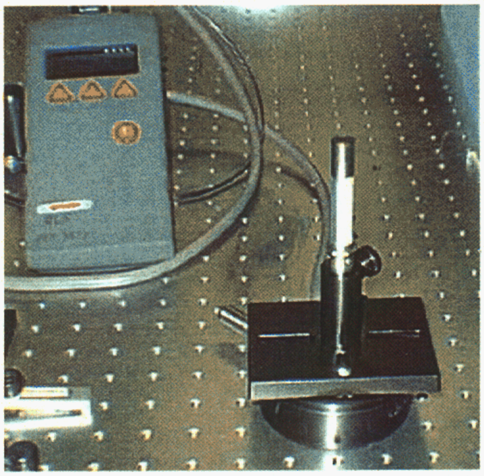
Laboratory Measurement / Test Results:

Forty AM3000 Mini MILES (Pistol) units were evaluated in the lab. Initially, all 40 units were found to be inoperative due to battery failures. The batteries (four-1.5 volt- type 384/392 in series) in all 40 units were replaced. All units were measured "as is".

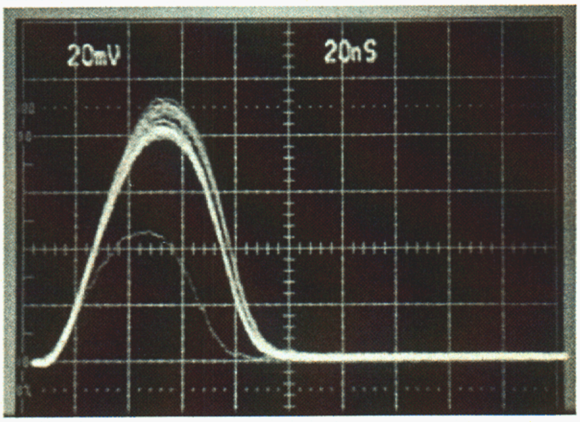
Eight of the units were found to have emissions less than the appropriate per pulse AEL(s) and are considered laser hazard **Class 1**.

Thirty-two of these units were found to have emissions in excess of the appropriate per pulse AEL(s) but less than 5 times the AEL (definition for entrance into laser hazard Class IIIb) and are therefore considered to be laser hazard **Class 3a**. Class 3a laser controls, in this case would apply.

The laser emissions varied in pulse energy (pulse to pulse) in the pulse train. The variation in laser pulse energy for a fire event was as great as plus or minus ~35 % as indicated below. The variation form "fire" event to "fire" event ranged from +/- 1.7% to +/- 12.7% (averaging +/- 5.6%). The unit to unit output variation was +/- 51 % of average.



Setup for measuring output energy of AM3000 SAT.



AM3000 Pistol SAT Output
SN 1074
Composite – "NORM" scope trigger
Ep ~ Vp x T_{FWHM}
ΔEp ~ +/- ~35 %

Individual model AM30000 unit results are presented in the table below.

Table 16

AM3000 Mini MILES – Pistol SAT

Unit Serial #	Lab Field Tested	Average Pulse Energy (nJ)	Number Of Pulses	Average Pulse Width (ns)	Event Time Exposure (ms)	AEL Per Pulse (nJ)	Laser Hazard Class
1013	Lab	241.5	24	38	15	222.7	3a
1026	Lab	306.9	21	46	19	230.3	3a
1027	Lab	275.7	24	42	15	222.7	3a
1028	Lab	340.6	24	44	15	222.7	3a
1029	Lab	336.4	24	44	7	264.9	3a
1030	Lab	147.5	24	48	15	222.7	1
1031	Lab	351.5	24	50	15	222.7	3a
1032	Lab	269.5	24	42	15	222.7	3a
1033	Lab	351.1	11	46	7	270.7	3a
1034	Lab	273.7	24	40	15	222.7	3a
1035	Lab	305.6	25	46	19	220.5	3a
1036	Lab	265	24	44	15	222.7	3a
1037	Lab	241.5	11	44	7	270.7	1
1038	Lab	115.2	11	48	7	270.7	1
1039	Lab	345.4	24	45	15	222.7	3a
1040	Lab	356.1	11	44	7	270.7	3a
1041	Lab	305.6	24	48	15	222.7	3a

Table 16, continued

AM3000 Mini MILES – Pistol SAT

Unit Serial #	Lab Field Tested	Average Pulse Energy (nJ)	Number Of Pulses	Average Pulse Width (ns)	Event Time Exposure (ms)	AEL Per Pulse (nJ)	Laser Hazard Class
1042	Lab	357.5	24	45	19	222.7	3a
1043	Lab	211.3	11	49	7	270.7	1
1044	Lab	352.2	24	42	15	222.7	3a
1045	Lab	138.8	11	40	7	270.7	1
1046	Lab	252.3	12	42	7	264.9	1
1047	Lab	266.7	30	40	20	210.7	3a
1048	Lab	254.4	18	40	20	239.4	3a
1049	Lab	341.4	24	44	14	222.7	3a
1050	Lab	256.4	24	40	20	222.7	3a
1051	Lab	334.9	23	44	15	225.1	3a
1052	Lab	331.2	22	46	16	227.6	3a
1053	Lab	334.5	12	45	7	264.9	3a
1055	Lab	330.1	12	44	7	264.9	3a
1056	Lab	235.3	11	44	7	270.7	1
1057	Lab	346.9	11	43	7	270.7	3a
1058	Lab	278	24	44	15	222.7	3a
1059	Lab	340.8	23	42	15	225.1	3a
1060	Lab	200.3	11	44	7	270.7	1
1061	Lab	355.8	12	44	7	264.7	3a
1062	Lab	260.8	24	42	18	222.7	3a
1074	Lab	330.9	20	44	18	233.1	3a
1100	Lab	320.3	11	43	7	270.7	3a
1189	Lab	324.4	25	54	15	220.5	3a

Class 3a Laser Controls:

Class 3a controls (given previously) would apply to model AM3000 use. Again, these units are not programmable and therefore the Security Training Section cannot adjust its output and administratively maintain these units as Class 1 lasers.

Based on discussions with SNL Security, Training Section - the Sig Sauer pistol (used in force on force exercise) engagement protocol calls for two shots to the body and one shot to the head. As a result of this intentional head exposure, with an accompanying possible eye exposure, it is absolutely necessary that the model AM30000 *Mini MILES* Pistol SAT be a laser hazard Class 1. As a result of this laser hazard **Class 1 use only** policy, no Nominal Hazard Zone (NHZ) was calculated for these Class 3a units. Instead, engineering controls to bring these Class 3a units into laser hazard Class 1 condition were investigated.

In was found that these **Class 3a** units could be brought into laser hazard **Class 1** by the introduction or installation of attenuation filter(s) in the output beam. The Minimum Optical

Density (OD_{min}) for attenuation filters necessary to bring these units into laser hazard Class 1 was calculated for each of the Class 3a AM30000 SAT units.

$$OD_{min} = \log [E_p/AEL]$$

The calculated values for OD_{min} ranged from 0.03 to 0.21.

Attenuation filters were fabricated out of Kapton (2, 3 and 4 layers) for three different ODs (0.17, 0.2 and 0.24) to cover the range needed to bring the laser hazard Class 3a units to laser hazard Class 1 (at relatively the same output level). The ODs of these fabricated attenuation filters, at 904 nm, were measured by a model 5000 Cary Spectraphotometer. The appropriate attenuation filters were installed and secured on the Class 3a SAT units with epoxy (pictured below).

These modified SAT units were re-tested. All units had laser emissions below the appropriate AELs and are now laser hazard Class 1 and do not require warning labels or other controls.

A representative "modified" unit was field tested for functionality and the electronic target (model LTE2020A Small Arms Alignment Fixture) indicated and recorded "dead center" hits at a range of 100 feet in day light.

Individual modified model AM30000 SAT unit results are presented in the table below.

Table 17

Model AM3000 Mini MILES – Pistol SAT

Re-Test Post Attenuation Filter Installation

Unit Serial #	Weapon #	OD Actual	Average Pulse Energy Post OD (nJ)	Number of Pulses	Pulse Width (ns)	Exposure (ms)	AEL Per Pulse (nJ)	Laser Hazard Class
1013	32	0.17	144.9	24	38	15	222.7	1
1026	5	0.17	139.3	21	46	19	230.3	1
1027	9	0.17	137	24	42	15	222.7	1
1028	12	0.2	182.4	24	44	15	222.7	1
1029	2	0.17	184.6	24	44	7	264.9	1
1031	38	0.24	176.4	24	50	15	222.7	1
1032	20	0.17	144.4	24	42	15	222.7	1
1033	18	0.17	199.7	11	46	7	270.7	1
1034	16	0.17	165.1	24	40	15	222.7	1
1035	30	0.17	*	25	46	19	220.5	*
1036	11	0.17	161.3	24	44	15	222.7	1
1039	8	0.24	175.8	24	45	15	222.7	1
1040	27	0.17	153.7	11	44	7	270.7	1
1041	36	0.17	183.3	24	48	15	222.7	1
1042	4	0.24	176.9	24	45	19	222.7	1
1044	19	0.24	178.1	24	42	15	222.7	1
1047	6	0.17	159.9	30	40	20	210.7	1
1048	3	0.17	135	18	40	20	239.4	1
1049	15	0.24	190.1	24	44	14	222.7	1
1050	34	0.17	145	24	40	20	222.7	1
1051	28	0.2	119.1	23	44	15	225.1	1
1052	24	0.2	176.7	22	46	16	227.6	1
1053	33	0.17	163.2	12	45	7	264.9	1
1055	37	0.17	190.6	12	44	7	264.9	1
1057	29	0.17	188.2	11	43	7	270.7	1
1058	1	0.17	151.5	24	44	15	222.7	1
1059	13	0.2	159.5	23	42	15	225.1	1
1061	17	0.17	198.5	12	44	7	264.7	1
1062	35	0.17	210	24	42	18	222.7	1
1074	10	0.17	167.2	20	44	18	233.1	1
1100	25	0.17	211.3	11	43	7	270.7	1
1189	40	0.2	158.8	25	54	15	220.5	1

*One model AM3000 SAT unit, serial number 1035, developed an internal electrical fault and is currently inoperable.

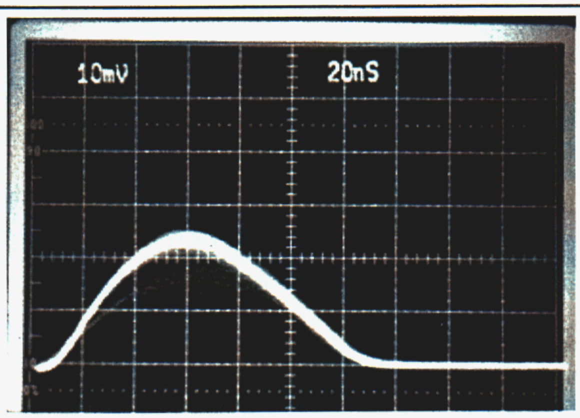
The Training Section can administratively check and verify that the SAT units associated with a particular "weapon number" indicated above, has affixed to its output the attenuation filter prior to issue and use for a training exercise and checked again on its return.

8. Model LTE 2055 Controller Gun:

   The model LTE 2055 Controller Gun is a *MILES* type umpire laser transmitter mounted on a short rifle stock. The LTE 2055 Controller Gun is used to interact with the various *MILES* elements. The LTE 2055 produces coded (selectable) laser emissions upon trigger pull.

Laboratory Measurement / Test Results:

The model LTE 2055 Controller Gun LE unit was evaluated in the lab. The pulse to pulse energy variations observed in the model LTE 2055 Controller Gun LE output (presented below) were on the order of +/-25 %. The model LTE 2055 Controller Gun LE emits 1 to 3 (*MILES*) words per trigger pull (Semiautomatic). The model LTE 2055 Controller Gun LE emits up to 35 (*MILES*) words per second for as long as the trigger is held. Because the model LTE 2055 can produce a laser output for as long as the trigger is held, the 10 second standard IR exposure must be used for the exposure time, as prescribed by ANSI Std. z136.1-2000 (8.2.2). Similar to the M16 rifle the **actual exposure** is expected to be much less then 10 seconds. It is unlikely that all pulses will arrive at the same point (in this case the eye) due to the natural movement of the body when using and directing hand held devices. Similarly there is likely to be movement of the "target" as well.



LTE 2055 Controller Gun Output
SN 1003
Composite – "NORM" scope trigger
$E_p \sim V_p \times T_{FWHM}$
$\Delta E_p \sim +/- \sim 25\ \%$

"Unaided" Viewing Measurements:

The exit beam size of the model LTE 2055 Controller Gun is on the order of 16 mm x 12 mm. For the "unaided" viewing measurements the average pulse energy was measured through a 7 mm, (limiting) aperture at a distance of 10 cm. It was assumed that the irradiance (energy density) was uniform across the beam cross-section. Since the exit beam diameter is greater than the limiting aperture, extended source conditions might exits if the viewing angle was greater than α_{min} (greater than 1.5 milliradians) [ANSI Std. z136.1-2000 (8.1)]. Personnel who could be exposed the model LTE 2055 output could be at a range of from less than 2 meters to as much as 2000 meters. Extended source conditions would revert to small source conditions at a viewing distance of ~ 9.3 meters.

Viewing angle (α):

$$D = R \tan(\alpha)$$

where;
D = diameter of source
R = range for source

$$D = R(\alpha)$$

for $\alpha < 5$ degrees

And;

$$D = \text{average}(d_M, d_m)$$

where;
d_M = diameter major axis
d_m = diameter minor axis

Range (R) at which extended source becomes small source:

$$R = D / \alpha_{min}$$

$$R = (16\text{ mm} + 12\text{ mm}) / 2 \times (1.5\text{ mr})$$

$$R = \sim 9.3\text{ meters}$$

Personnel within 9.3 meters of the laser exit would be exposed to an extended source and personnel at greater than 9.3 meters would be exposed to a small source. The MPE for a small source is smaller than the MPE for an extended source. As a result, small source conditions were assumed to exits throughout the range of possible personnel exposures. This is a conservative assumption favoring laser safety.

"Aided" Viewing Measurements:

Because of the relatively large output laser beam cross section, 16 mm x 12 mm, this might have a significant impact on laser safety should binoculars (7 x 50) be in use. Binocular use could range from 2 to 2000 meters.

The ANSI Std. z136.1-2000 (table 9) calls for a 50 mm "limiting" aperture for "aided" viewing measurements. The active area of the PD-10 head is a circle of 10 mm, diameter. For "aided" viewing measurements of the model LTE 2055 Controller Gun laser output, a collecting lens (in a 50 mm holder-aperture) was used to focus the entire energy output onto the PD-10 head's active area. This "aided" viewing evaluation assumed that binocular use might expose its user to the entire output of the model LTE 2055 Controller Gun LE for exposures up to 10 seconds (worst case). ANSI Std. z136.1-2000 (3.2.3.4.2-note) allows for the "aided" system (binocular) transmission factor of 0.7 for non-visible light. It was further assumed that the transmission loss through the collecting lens is on the same order as the transmission loss through the binocular optics. Therefore the energy measured by the PD-10 head was assumed to be on the same order as the energy that would be (transmitted through the binocular) to the eye of the "aided" viewer. This is a slightly conservative assumption favoring laser safety.

Unit results are presented in the table below.

<u>Table 18</u>

<u>Model LTE 2055 Controller Gun</u>

Unit Serial #	Lab Field Tested	Average Pulse Energy 7mm (nJ)	Average Pulse Energy Total (nJ)	Pulse Width (ns)	Number Of Pulses (Semi)	Maximum Number Of Pulses (10 sec)	Exposure Time Semi (ms)	AEL Per Pulse Semi (nJ/)	Maximum "IR" Exposure (sec)	AEL Per Pulse Auto (nJ/)	Laser Hazard Class (unaided) Semi/Auto	Laser Hazard Class (aided) Semi/Auto
1003	Lab	33.1	102.4*	80	19	6650	6	236.1	10	54.6	1/1	1/3a

*Measured average pulse energy with transmission loss through the collecting lens would equate to the loss through binoculars.

The 3a laser hazard classification for "aided" viewing of the model LTE 2055 Controller Gun occurs after 5 continuous seconds of laser emission on the same point. As a result, Class 3a laser controls (laser hazard warning labels, the posting the area of laser operation, laser safety eyeware) as well as laser safety training would apply. [ANSI Std. z136.1-2000, ANSI Std. z136.6-2000 and MN471001 (6G)].

Similar to the situation with the model AM3000 SATs, the NHZs were not calculated because of the "Class 1 laser use only" policy for laser emitters. Rather, an engineering approach was investigated to bring this unit into laser hazard Class 1.

The engineering approach taken was, to maintain the laser emitter unit as a Class 1 laser by introducing a "near limiting" aperture at the exit window of the unit. With the installation of this "near limiting" aperture the output spot size of the LT unit at 10 cm was measured and found to be on the order of ~ 8 mm in diameter compared to the 7 mm diameter limiting aperture defined in ANSI z136.1-2000 (table 8). "Aided" as well as "unaided" viewing measurements was again performed.

It was found that this unit was brought into laser hazard **Class 1** by the installation of the ~ 8 mm diameter aperture placed on the inside of the exit window.

Unit results are presented in the table below.

Table 19

Model LTE 2055 Controller Gun

Unit Serial #	Lab Field Tested	Average Pulse Energy 7mm (nJ)	Average Pulse Energy Total (nJ)	Pulse Width (ns)	Number Of Pulses (Semi)	Maximum Number Of Pulses (10 sec)	Exposure Time Semi (ms)	AEL Per Pulse Semi (nJ/)	Maximum "IR" Exposure (sec)	AEL Per Pulse Auto (nJ/)	Laser Hazard Class (unaided) Semi/Auto	Laser Hazard Class (aided) Semi/Auto
1003	Lab	33.0	36.1	80	19	6650	6	236.1	10	54.6	1/1	1/1

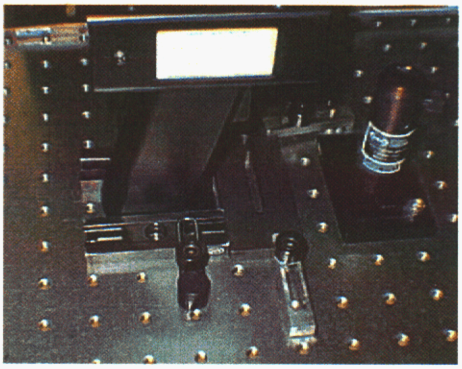
*Measured average pulse energy with transmission loss through the collecting lens would equate to the loss through binoculars.

9. Model LTE 2056 Controller (Hand Held-Pistol Type):

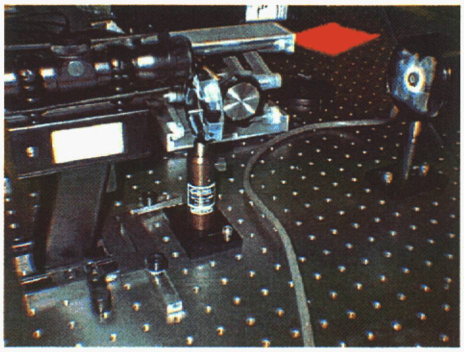
The model LTE 2056 Controller is a *MILES* type umpire laser transmitter in the form of hand-held *pistol* type housing. Like the model LTE 2055 Controller Gun, the model LTE 2056 Controller is used to interact with the various *MILES* elements. The model LTE 2056 produces a coded laser emission upon trigger pull.

Laboratory Measurement / Test Results:

Four model LTE 2056 Controller LT units were evaluated in the lab. A test jig (shown below) was assembled to allow for the consistent placement of the model LTE 2056 Controllers so that they would be in alignment with test and measurement instruments.

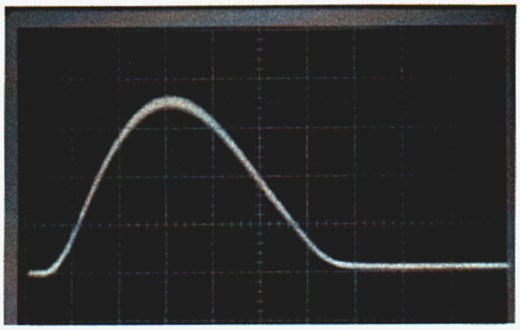


Test Jig for the LTE 2056 Controller (hand held) to consistently align it to the PD10 head, without the lens for "unaided" viewing tests.



Test setup with lens for collecting and focusing the total output and measurement of the output with the PD10 head for "aided" viewing

The pulse to pulse energy variations observed in the model LTE 2056 Controller LE output (presented below) were on the order of +/- ~ 5 %.



LTE 2056 Controller Output
SN 2019
Composite – "NORM" scope trigger
Ep ~ Vp x T_{FWHM}
ΔEp ~ +/- ~5 %

The model LTE 2056 Controller Gun LE emits 1 (*MILES*) word per trigger pull (Semiautomatic). The model LTE 2056 Controller Gun LE emits up to 5 (*MILES*) words per second for as long as the trigger is held. Because the model LTE 2056 can produce a laser pulse train output for as long as the trigger is held, the 10 second standard IR exposure must be considered for the exposure time, as prescribed by ANSI Std. z136.1-2000 (8.2.2). As with the model LTE 2055 Controller Gun the **actual exposure** is expected to be much less. It is unlikely that all pulses will arrive at the same point (in this case the eye) due to the natural movement of the body when using hand held devices. Similarly there is likely to be movement of the "target".

Unaided" Viewing Measurements:

The exit beam size of the model LTE 2056 Controller is on the order of 20 mm by 16 mm, ellipse. For the "unaided" viewing measurements the average pulse energy was measured through a 7 mm "limiting" aperture. It was also assumed that the energy density is uniform throughout the beam cross-section. The same measuring techniques were employed as with the model LTE 2055 Controller Gun. Since the exit beam diameter is greater than the limiting aperture, extended source condition might exits if the viewing angle was greater than α_{min}, greater than 1.5 milliradians (mr) [ANSI Std. z136.1-2000 (8.1)]. Personnel who could be exposed the model LTE 2056 output could be at a range of from 2 meters to as much as 2000 meters. Extended source conditions would revert to small source conditions at a viewing distance of 12 meters.

Range (R) at which extended source becomes small source:

$$R = \text{average } D / \alpha_{min}$$

$$R = (20 \text{ mm} + 16 \text{ mm}) / 2 \times (1.5 \text{ mr})$$

$$R = 12 \text{ meters}$$

Personnel within 12 meters would be exposed to an extended source and personnel at greater than 12 meters would be exposed to a small source. As a result, small source conditions were assumed to exits throughout the range of possible personnel exposure. This is a conservative assumption favoring laser safety.

"Aided" Viewing Measurements:

Similar to the model LTE 2055 described above, because of the relatively large output laser beam cross section (20 mm x 16 mm, ellipse) compared to the 7 mm limiting aperture, this might have a significant impact on laser safety should binoculars be in use.

The same measuring techniques were employed as with the model LTE 2055 Controller Gun. For "aided" viewing measurements of the model LTE 2056 Controller output a collecting lens was used to focus the entire energy output into the PD-10 head. "Aided" viewing evaluation assumed that binocular use might expose its user to the entire output of the model LTE 2056 Controller LE (worst case). It is further assumed that the transmission loss through the collecting lens is on the same order as the transmission loss through the binocular.

Individual model LTE 2056 Controller LE units results are presented in the table below.

Table 20

Model LTE 2056 Hand Held Controller

Unit Serial #	Lab or Field Tested	Average Pulse Energy 7mm (nJ)	Average Pulse Energy Total (nJ)	Pulse Width (ns)	Number Of Pulses (Semi)	Max Number Of Pulses (10 sec)	Exposure Time Semi (ms)	AEL Per Pulse Semi (nJ/)	Maximum "IR" Exposure (sec)	AEL Per Pulse Auto (nJ/)	Laser Hazard Class (unaided) Semi/Auto	Laser Hazard Class (aided) Semi/Auto
2007	Lab	56.0	264.3	80	70	3500	0.025	170	10	64	1/1	3a
2009	Lab	54.1	240.5	84	75	3750	0.025	167.5	10	63	1/1	3a
2010	Lab	71.7	242.8	84	70	3500	0.025	170	10	64	1/3a*	3a
2019	Lab	57.6	250.8	72	70	3500	0.025	170	10	64	1/1	3a

*Note: The 3a laser hazard classification for unaided viewing of the model LTE 2056 Controller, serial number 2010, occurs after 5 continuous seconds of laser emission on the same point. For the aided viewing the laser Class 3a occurs within the first second of emission.

It is absolutely necessary that laser transmitters be laser hazard Class 1. As a result of this laser hazard Class 1 use only policy, no NHZs were calculated for the model LTE 2056 hand held controllers. Instead engineering means, to bring the laser hazard Class 3a units to laser hazard Class 1, "unaided" viewing for SN 2010 as well as all four units for "aided" viewing were investigated.

The engineering approach for the model LTE 2056 Hand Held Controllers was the same approach used for the model LTE 2055 Controller Gun. These units were made Class 1 lasers by introducing a "near limiting" aperture at the exit window of the units. The same "near limiting" aperture was used. The output spot size of the LT units at 10 cm are on the order of ~ 8 mm diameter compared to the 7 mm diameter "limiting aperture" defined in ANSI z136.1. Installing these apertures (~ 8 mm diameter) caused these unit to enter the laser hazard class 1.

It was found that these units were brought into laser hazard **Class 1** by the installation of the 8 mm diameter aperture on the inside of the exit window. "Aided" viewing as well as "unaided" viewing measurements were performed.

Individual modified model LTE 2056 Controller LE unit results are presented in the table below.

Table 21

Modified Model LTE 2056 Hand Held Controller with Exit Aperture

Unit Serial #	Lab or Field Tested	Average Pulse Energy 7mm (nJ)	Average Pulse Energy Total (nJ)	Pulse Width (ns)	Number Of Pulses (Semi)	Max Number Of Pulses (10 sec)	Exposure Time Semi (ms)	AEL Per Pulse Semi (nJ/)	Maximum "IR" Exposure (sec)	AEL Per Pulse Auto (nJ/)	Laser Hazard Class (unaided) Semi/Auto	Laser Hazard Class (aided) Semi/Auto
2007	Lab	36.1	53.7	80	70	3500	0.025	170	10	64	1/1	1/1
2009	Lab	36.3	48.1	84	75	3750	0.025	167.5	10	63	1/1	1/1
2010	Lab	41.6	42.2	84	70	3500	0.025	170	10	64	1/1	1/1
2019	Lab	35.1	35.8	72	70	3500	0.025	170	10	64	1/1	1/1

V. Additional Considerations due to the "Aided" Viewing Requirements:

A. Impact of Aided Viewing Requirement on SALT Unit Measurements:

As previously indicated the SALT output spot size at the measurement distance (10 cm) was ~8 mm by ~5 mm (major axis would rotate 90 degrees between rifle and M203). The difference in the total output energy and the energy measured through the "limiting" (7 mm) aperture would be approximately 14.3 %. That is the total energy output (E_{out}) would be ~14.3 % greater than that measured over the limiting aperture (E_m).

$$E_{out} = (1.143)\ E_m$$

However the transmission factor through the optical system (binoculars) is given as 0.7 [ANSI z136.1-2000 (3.2.3.4.2-note)]. Hence, an estimate of the level of exposure to an "aided" viewer's eye (E_{eye}) would be:

$$E_{eye} = (0.7)\ E_{out}$$

$$E_{eye} = (0.7)\ \text{x}\ (1.143)\ E_m$$

$$E_{eye} \sim (0.8)\ E_m$$

$$E_{eye} < E_m < AEL$$

$$E_{eye} < AEL$$

The eye exposure of the "aided" viewer (7 x 50 binocular) at 2 meters (or greater) would be less than the "unaided" viewer measurement at 10 cm, which was less than the AEL. Hence, the eye exposure from "aided" viewing is less than the appropriate AEL and presents a laser hazard Class 1. Therefore, the added requirement of "aided" viewing does not adversely impact or change the laser hazard classification of the various SALT units, which had been determined by the unaided viewing measurement method. These units are laser hazard Class 1 for "aided" as well as "unaided" viewing.

B. Impact of Aided Viewing Requirement on SAT unit measurements:

The spot size of the model AM3000 SAT (Pistol) at the head of the model PD-10 (10 cm measuring distance) was on the order of 4 to 5 mm on the major axis and 2 to 3 mm on the minor axis (beam waist at ~ 10 cm). The entire beam passes through the 7 mm "limiting" aperture; therefore, there **is no** impact for "aided" viewing. The units are laser hazard Class 1 for "aided" as well as "unaided" viewing.

C. "Aided" Viewing Unit Measurements of the Model AM6006B Claymore Mine:

The spot size of the previously measured Model AM6006B Claymore Mine output was much greater than the 7 mm, diameter "limiting" aperture at 10 cm. The output beam sweeps through an arc of 60 degrees. The ANSI Std. z136.1-2000 (table 9) prescribes that "aided" viewing measurements are made over a 50 mm limiting aperture at a minimum viewing distance of 2 meters.

Because of the larger beam size, actual measurements were conducted in accordance with the procedure prescribed by ANSI Std. z136.1-2000 (9.2.1.1). As previously noted the active area of the PD-10 head is a circular area of 10 mm, diameter. A 50 mm-diameter, collecting lens (of 25 cm focal length - in a lens holder) was placed at 2 meters from the model AM6006B Claymore Mine on the frontal center line. The PD-10 head was placed at 23 cm from the collecting lens. The transmission factor for the lens (~0.92) is assumed to be on the same order as the optical "aided" system (7 x 50 binoculars). Therefore eye exposure of the "aided" viewer would be on the same order of that measured.

Individual Claymore Mine unit results for "aided" viewing are presented in the table below.

Table 22

Model AM6006B Claymore Mine "Aided Viewing"

Unit Serial #	Lab or Field Tested	Average Pulse Energy (nJ)	Average # of Pulses Per Exposure	# Of Scan Exposures Per Event	Average # Pulses Per Event	Pulse Width (ns)	Event Time (sec)	AEL Per pulse (nJ)	Laser Hazard Class
2000	Lab	5.9	62	4	248	80	~2.5	124.2	1
2001	Lab	6.5	61	4	244	100	~2.5	124.7	1
2002	Lab	5.6	63	4	252	100	~2.5	123.7	1

All the model AM6006B Claymore Mine laser transmitters are laser hazard Class 1 for "aided" as well as "unaided" viewing. The attached "Caution" labels (implying laser hazard Class 3a) was not of the prescribed format [ANSI Std. z136.1-2000 (4.7.5)] and is not required for laser hazard Class 1 [ANSI Std. z136-2000 (1.2)(1)]. Since labeling would be inconsistent with Class 1 laser hazard classification these labels were removed.

VI. Summary:

1. All the SNL MILES laser emitters are or have been made to be Class 1 Lasers (as is) in accordance with the ANSI standard and no control measures or medical surveillance are applicable or required.

2. To maintain Class 1 laser operation and prevent Class 3a laser controls being imposed, amend "Rules of Engagement" to:

   a. Restrict "Automatic" Fire of the **Rifle** and the Light Machine Gun **(LMG)** to a **maximum range setting** of **800 meters**. For range setting of 1000 meters the output of the laser emitter falls within the Class 3a category.

   b. Restrict "Automatic" Fire of the Heavy Machine Gun **(HMG)** to a **maximum range setting** of **1600 meters**. For range setting of 2000 meters the output of the laser emitter falls within the Class 3a category.

c. Put in place administrative controls, such as an Operation Procedure (OP), to:

   1. Restrict the maximum range setting of the Rifle and LMG SALT units to 800 meters.
   2. Restrict the maximum range setting of the HMG SALT units to 1600 meters.
   3. Verification that the attenuation filters installed on the modified SAT units associated with specific weapon (pistol) numbers is still intact prior to issue.
   4. Verification that the "near limiting" apertures, associated with the Controllers are still intact prior to use.

4. Batteries should be removed from all *MILES* laser-emitting components when not in use in order to conserve battery life and prevent corrosion damage to the units.

5. For future purchases of laser emitters associated with MILES operation specify that, "the lasers shall meet Class 1 Laser criteria in accordance with the most current ANSI Std. Z136.1 in addition to CDRH and 21 CFR 1040".

VII. References:

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.

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

FDA CDRH Compliance Guide for Laser Products

SEO Technical Manuals:

1743920 Advance MILES Blank Fire Pistol Simulator

27309216 Operation and Maintenance Manual Model LTE 2055 Controller Gun

31829203 Maintenance and Repair Manual Rifle, Light Machine Gun and Heavy Machine Gun Laser Transmitter

31829204 Operator's Manual RPG Anti-Tank Laser System

31829208 Hand Held System Controller

31829218 Enhanced MILES Decoder/Controller User's Manual

Claymore Mine Operation & Maintenance Manual

VIII. Appendix

Glossary

ACGIH	American Conference of Government Industrial Hygienists
AEL	Allowable Exposure Limit
ANSI	American National Standard Institute
Auto	Automatic
CDRH	Center for Device and Radiological Health
CFR	Code of Federal Regulations
cm	Centimeter (10^{-2} meters)
Cp	Pulse correction factor
CW	Continuous Wave
D, d	Diameter
D_{lim}	Diameter of limiting aperture
E_{eye}	Energy at the eye
E_m	Measured energy
E_{out}	Output energy
Ep	Pulse Energy
ES&H	Environmental, Safety & Health
FAA	Federal Aviation Administration
f_c	Critical Frequency
FDA	Food and Drug Administration
FWHM	Full Width at Half Maximum
HMG	Heavy Machine Gun
Hz	Hertz (sec^{-1})
IR	Infrared
J	Joules
LE	Laser Emitter
LMG	Light Machine Gun
LT	Laser Transmitter
MILES	Multiple Integrated Laser Engagement System
min	Minute
MPE	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
R	Range
RF	Radio Frequency
RPG	Rocket Propelled Grenade
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
w	watt
α	Alpha- view angle
Δ	Delta- difference
λ	Lambda- wavelength
μw	microwatt (10^{-6} watts)
Ω	Omega- Ohms (unit of electrical resistance)
~	Approximate or "proportional to"

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