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## LASER SAFETY

Martin J. Valente

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The system proposed for pointing the GBT will result in many accessible beam paths to which personnel may be exposed. The exposure of personnel to these beam paths necessitates that safety precautions be taken. As a guideline for the safety precautions, I referred to the safety regulations outlined by the American National Standards Institute's document, "Safe Use of Lasers" ANSI Z136.1 (1). It should be noted that federal agencies are required to consider this standard as regulatory. Presented here is a general overview of the ANSI regulations which I believe are applicable and appropriate to the GBT pointing system.

An individual must be designated as the Laser Safety Officer (LSO) with the authority and responsibility to monitor and enforce the control of laser hazards. The responsibilities of the LSO will be:

- 1) classification of laser system
- 2) hazard evaluation of work areas
- 3) assure prescribed control measures are in effect
- 4) approve standard operating procedures
- 5) recommend and audit protective equipment
- 6) approve wording on area signs and equipment labels
- 7) approve laser installation facilities and equipment prior to use
- 8) assure adequate safety education and training for laser area personnel

The laser used in the GBT pointing system operates at a wavelength of 780 nm with an output rated at 1mW maximum. These specifications fall under the classification IIIb for continuous wave lasers. This class includes lasers with a wavelength range of 0.7 to 1.4 microns with an output power of 0.5W. Note that this class IIIb also includes the 1.3 micron wavelength and that ANSI requires the same regulations be followed as with the 780 nm wavelength.

In order to determine the safety hazards involved, the maximum permissible exposure (MPE) for direct viewing of the laser had to be determined. The exposure limit was calculated by using the charts in figures 1 and 2 (2). For a wavelength of 780 nm, and an exposure time of 18 microseconds to 1000 seconds, the exposure limit formula is:  $1.8 \cdot (C_a) \cdot (t/t^{\wedge}.25) \text{ mJ/cm}^2$ .

From figure 2,  $C_a = 1.4$ . Assuming a very long exposure time of 30 seconds (direct viewing) with the eye at the exit aperture of the laser, and a circular beam with a diameter of 2mm, the energy density on the eye is  $954.9 \text{ mJ/cm}^2$ . The maximum permissible exposure under these circumstances is calculated to be  $32.3 \text{ mJ/cm}^2$ , therefore the MPE is exceeded under these conditions and a safety hazard exists. The energy density on the eye using a 1.3 micron laser is also  $954.9 \text{ mJ/cm}^2$  for the same output power and beam dimensions. The MPE for the 1.3 micron laser at 30 seconds of exposure is  $115.4 \text{ mJ/cm}^2$ , therefore the MPE is exceeded and likewise a safety hazard exists. See appendix page 1 for calculations.



The next step in analyzing the safety hazards is to determine the distance at which the laser can be viewed directly yielding an energy density on the eye equal to the MPE. The laser beam has a divergence of 1mrad, and therefore the beam cross sectional area increases with path length. The energy density on the eye will then decrease with longer path length. Using this information, the energy density on the eye equals the MPE at a distance of 4.5 meters from the point of divergence, which is approximately 4.5 meters from the exit aperture of the laser (approximating the beam waist to be at the exit aperture). A more realistic exposure time, e.g. 2 seconds, yields a distance of approximately 2 meters to equal the MPE limit. Since the most likely viewing distance of the laser will be at a distance of 100 m, it is appropriate to determine the length of time required for a person to reach the MPE limit from this distance. By using the previous MPE formula, the amount of time is effectively infinity. The criterion for using the previous formula is a time range between 18 $\mu$ s and 1000 s, therefore the formula for the highest time range was used:

$$\text{MPE} = 320 \cdot (C_a) \mu\text{W}/\text{cm}^2$$

At a distance of 100 m, the power density of the laser beam is 3.15  $\mu\text{W}/\text{cm}^2$ , which is well below the MPE. See appendix page 2 for calculations. The purpose of determining the MPE limits is to establish nominal hazard zones. These nominal hazard zones (NHZ) will indicate that the maximum permissible exposure is exceeded in these areas and safety precautions must be taken to prevent eye damage. The control steps that are to be taken within the NHZ area include:

- 1) restricting access by posting warning signs
- 2) performing operations using only qualified and authorized personnel
- 2) wearing protective eyewear
- 3) following outdoor control measures such as:
  - a. establishing NHZ areas
  - b. excluding unprotected, untrained, and unauthorized personnel from the beam path within the designated NHZ
  - c. disabling laser when not in use
- 4) following administrative and procedural controls such as:
  - a. standard operating procedures
  - b. education and training
  - c. alignment procedures

All classes of lasers require a protective housing. The housing may be removed under certain circumstances. Under these circumstances, the same control steps taken within the NHZ must be followed. The protective housing must be provided with an interlock system. The interlock should activate when the protective housing is removed during maintenance and operation. The interlock must not be defeated or overridden during operation. If the interlock is defeated during maintenance or service, a warning label with appropriate indications must be located on or near the interlock.



The warning signs designating the NHZ areas must be in accordance with the American National Standard Specification for Accident Prevention Signs, ANSI Z35.1-1972. The protective eyewear must provide sufficient attenuation of the beam. The attenuation (optical density) required of the eyewear can be calculated by the following formula:

$D(\lambda) = \log (\text{energy density on eye} / \text{MPE})$  where  $D(\lambda)$  = optical density,  
 $\text{MPE} = 32.3 \text{ mJ/cm}^2$ , and energy density on eye =  $954.9 \text{ mJ/cm}^2$ . This yields a requirement of an optical density equal to 1.47 for the protective eyewear to be worn in the NHZ areas.

The ANSI standard also covers medical surveillance of personnel who risk exposure to radiation from a class IIIb laser. The purpose of the surveillance is to develop a medical baseline against which damage can be measured in the event of accidental injury. The medical examination must follow the protocol outlined in appendix E2.2 of the ANSI Z136.1 document. This document divides personnel into the categories of incidental and laser personnel. Incidental personnel are those whose work makes it possible (but unlikely) that they will be exposed to laser energy above the MPE. Incidental personnel need only be tested for visual acuity prior to participation in laser work and following any suspected laser injury. Laser personnel are those who work routinely in the laser environment and are ordinarily fully protected by the safety requirements outlined for NHZ areas. My understanding is that this description will not apply to personnel working on the GBT, and that the incidental personnel category is the most appropriate. However, in the event that someone does fit the laser personnel description, the baseline eye examination required is more extensive and can be referred to in the document, ANSI Z136.1-6.3.2.

As a result of this brief analysis, the following conclusions can be drawn:

- 1) The data from the hazard analysis points out that the MPE can be exceeded at varying distances, depending on the integration time. Therefore, by using a viewing time of 30 seconds to make the MPE calculations, we have a very large safety factor. This will aid in reducing the risk of eye injury to personnel.
- 2) At a distance of 100 m, the personnel have no risk of eye damage, regardless of the length of exposure.
- 3) The NHZ areas should be established in such a manner that they surround each laser by a distance of 5 meters in radius.
- 4) Proper safety precautions must be followed within the designated NHZ areas, as outlined in this paper.
- 5) The use of a 1.3 micron laser as opposed to a .78 micron laser is not beneficial in regards to reducing the safety measures required by ANSI.
- 6) The most appropriate classification of personnel at risk to laser exposure is the incidental category, and therefore the medical surveillance required should be a minimum of a visual acuity examination prior to the possibility of exposure.

FIGURE 1

TABLE 8-1. Exposure Limits for Direct Ocular Exposures  
(Intrabeam Viewing) from a Laser Beam

<i>Spectral Region</i>	<i>Wave Length</i>	<i>Exposure Time, (t) Seconds</i>	<i>Exposure Limits</i>
UVC	200 nm to 280 nm	$10^{-9}$ to $3 \times 10^4$	3 mJ/cm <sup>2</sup>
UVB	280 nm to 302 nm	"	3 "
	303 nm	"	4 "
	304 nm	"	6 "
	305 nm	"	10 "
	306 nm	"	16 "
	307 nm	"	25 "
	308 nm	"	40 "
	309 nm	"	63 "
	310 nm	"	100 "
	311 nm	"	160 "
	312 nm	"	250 "
	313 nm	"	400 "
	314 nm	"	630 "
	315 nm	"	1.0 J/cm <sup>2</sup>
UVA	315 nm to 400 nm	$10^{-4}$ to 10	$0.56 t^{1/4}$ J/cm <sup>2</sup>
	315 nm to 400 nm	10 to $10^3$	1.0 J/cm <sup>2</sup>
	315 nm to 400 nm	$10^3$ to $3 \times 10^4$	1.0 mW/cm <sup>2</sup>
Light	400 nm to 700 nm	$10^{-9}$ to $1.8 \times 10^{-5}$	$5 \times 10^{-7}$ J/cm <sup>2</sup>
	400 nm to 700 nm	$1.8 \times 10^{-5}$ to 10	$1.8 (t / \sqrt[4]{t})$ mJ/cm <sup>2</sup>
	400 nm to 549 nm	10 to $10^4$	10 mJ/cm <sup>2</sup>
	550 nm to 700 nm	10 to $T_1$	$1.8 (t / \sqrt[4]{t})$ mJ/cm <sup>2</sup>
	550 nm to 700 nm	$T_1$ to $10^4$	$10 C_B$ mJ/cm <sup>2</sup>
	400 nm to 700 nm	$10^4$ to $3 \times 10^4$	$C_B$ $\mu$ W/cm <sup>2</sup>
IR-A	700 nm to 1049 nm	$10^{-9}$ to $1.8 \times 10^{-5}$	$5 C_A \times 10^{-7}$ J/cm <sup>2</sup>
	700 nm to 1049 nm	$1.8 \times 10^{-5}$ to $10^3$	$1.8 C_A (t / \sqrt[4]{t})$ mJ/cm <sup>2</sup>
	1050 nm to 1400 nm	$10^{-9}$ to $10^{-4}$	$5 \times 10^{-6}$ J/cm <sup>2</sup>
	1050 nm to 1400 nm	$10^{-4}$ to $10^3$	$9(t / \sqrt[4]{t})$ mJ/cm <sup>2</sup>
IR-B & C	700 nm to 1400 nm	$10^3$ to $3 \times 10^4$	$320 C_A$ $\mu$ W/cm <sup>2</sup>
	1.4 $\mu$ m to $10^3$ $\mu$ m	$10^{-9}$ to $10^{-7}$	$10^{-2}$ J/cm <sup>2</sup>
	1.4 $\mu$ m to $10^3$ $\mu$ m	$10^{-7}$ to 10	$0.56 \sqrt[4]{t}$ J/cm <sup>2</sup>
	1.4 $\mu$ m to $10^3$ $\mu$ m	10 to $3 \times 10^4$	0.1 W/cm <sup>2</sup>

$C_A$  - See Fig. 8-8, Laser EL listing.

$C_B = 1$  for  $\lambda = 400$  to 550 nm;  $C_B = 10^{[0.015 (\lambda - 550)]}$  for  $\lambda = 550$  to 700 nm.

$T_1 = 10$  s for  $\lambda = 400$  to 550 nm;  $T_1 = 10 \times 10^{[0.02 (\lambda - 550)]}$  for  $\lambda = 550$  to 700 nm.

For  $\lambda = 1.5$  to 1.6  $\mu$ m increase EL by 100.

FIGURE 2

## Current Laser Exposure Limits

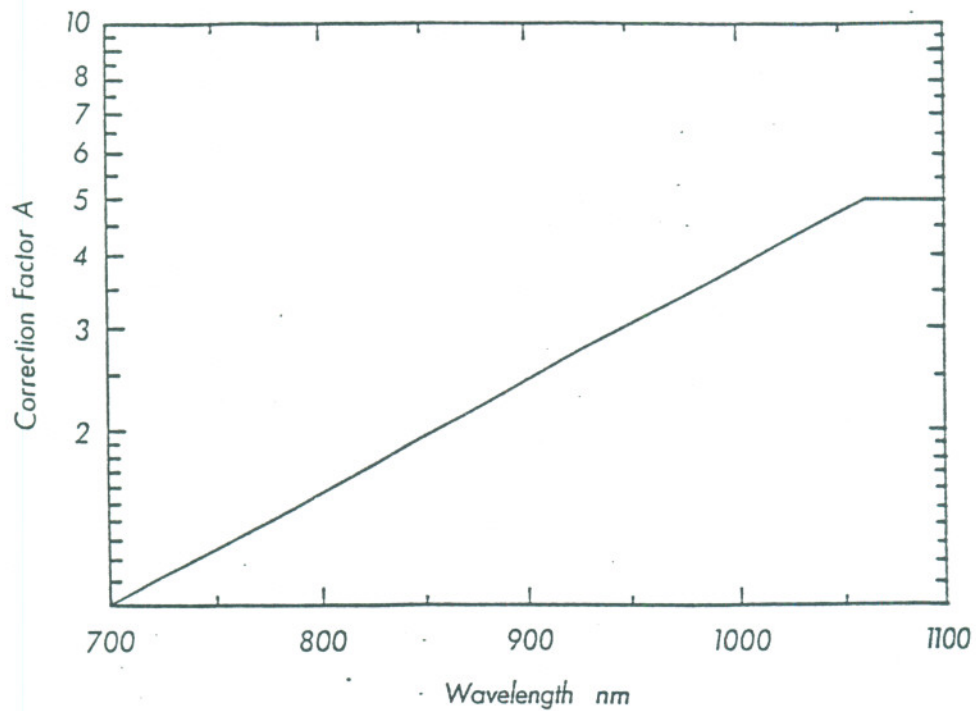


Figure 8-8. Correction Factor A,  $C_A$ . The formula for  $C_A$  is:  $C_A = 1$  for wavelengths ( $\lambda$ ) of 400 nm to 700 nm;  $C_A = 10 [0.002 (\lambda - 700 \text{ nm})]$  for  $700 \text{ nm} < \lambda < 1050 \text{ nm}$ ; and  $C_A = 5$  for  $1050 < \lambda < 1400 \text{ nm}$ .

## REFERENCES

- 1) Winburn, D.C. (1990). Practical Laser Safety, Marcel Dekker, Inc, New York
- 2) Sliney, D. and Wolbarsht, M. (1981). Safety with Lasers and Other Optical Sources, Plenum Press, New York

## APPENDIX



### Calculation of MPE and Energy density from laser

Laser wavelength = 780 nm    Power = 1 mW    Beam diameter = 2 mm    Divergence = 1 mrad

Exposure limit for direct viewing (MPE):

$$\text{MPE} = (1.8) \cdot (C_a) \cdot (t / (t^{.25})) \text{ in mJ/cm}^2$$

$$C_a = 1.4 \quad t = 30 \text{ seconds}$$

$$\text{MPE} = (1.8) \cdot (1.4) \cdot (30 / (30^{.25})) = 32.3 \text{ mJ/cm}^2$$

Energy density on the eye:

$$\text{from laser: } 1 \text{ mW} = 1 \text{ mJ/s} \Rightarrow \text{at } t = 30 \text{ seconds, we get } 30 \text{ mJ}$$

$$\text{area of beam} = (\pi) \cdot (d^2) / 4 = (\pi) \cdot (.2 \text{ cm})^2 / 4 = .0314 \text{ cm}^2$$

$$\text{Energy density} = (30 \text{ mJ}) / (.0314 \text{ cm}^2) = 954.9 \text{ mJ/cm}^2 \gg \text{MPE}$$

For laser wavelength = 1.3  $\mu\text{m}$     Power = 1 mW    Beam diameter = 2 mm

Exposure limit for direct viewing (MPE):

$$\text{MPE} = 9 \cdot (t / (t^{.25})) \text{ in mJ/cm}^2$$

$$t = 30 \text{ seconds}$$

$$\text{MPE} = 9 \cdot (30 / (30^{.25})) = 115.4 \text{ mJ/cm}^2$$

Energy density on the eye = 954.9 mJ/cm<sup>2</sup>  $\gg$  MPE



Calculating the distance,  $z$ , where the Energy density = MPE:

$$\text{Energy density} = \{t \text{ (in s)}\} * \{1 \text{ mJ/s}\} * \{1/[\pi * d^2 / 4] \text{ (in cm}^2)\}$$

At threshold of MPE  $\Rightarrow d = D_{th}$

$D_{th} = 2*(z)*(tan\theta) + .2 \text{ cm}$  from the beam divergence and geometry

Setting the Energy density = MPE  $\Rightarrow MPE = t*[4/(\pi*d^2)]$

Solving for  $d \Rightarrow d = \sqrt{4*t/(\pi*MPE)}$

Substituting for  $d$  and solving for  $z$  yields:

$$z = \{\sqrt{4*t/(\pi*MPE)} - .2\} / (2*tan\theta) \text{ in cm}$$

For  $t = 30 \text{ s}$   $\theta = .057 \text{ deg}$   $MPE = 32.3 \text{ mJ/cm}^2$

$$\Rightarrow z = \{\sqrt{4*30/(\pi*32.3)} - .2\} / (2*tan(0.057 \text{ deg})) = 450 \text{ cm}$$

For  $t = 2 \text{ s}$   $\Rightarrow MPE = 4.238 \text{ mJ/cm}^2$   $\theta = .057 \text{ deg}$

$$\Rightarrow z = 289 \text{ cm}$$

Calculating the exposure time at  $z = 100 \text{ m}$ :

Energy density =  $t*(.00315)$  in  $\text{mJ/cm}^2$

$$MPE = 2.52*(t / (t^{.25}))$$

Setting the Energy density = MPE and solving for  $t$  yields

$$t = (2.52/.00315)^4 \cong \infty$$

Using the formula:

$$MPE = 320*(1.4) \text{ in } \mu\text{W/cm}^2 = 448 \mu\text{W/cm}^2$$

from the laser, we have  $0.00315 \text{ mJ/(s*cm}^2) = 3.15 \mu\text{W/cm}^2 \ll MPE$