# Evaluating Audience Scanning Effects

Making Shows Safe
And Enjoyable

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Armed with the proper equipment and an understanding of the theory behind laser exposure limits, it is possible to determine whether a show that deliberately scans the audience is safe. In past *Laserist* articles, I have reviewed safety measurement devices. This article discusses the basics of how to evaluate effects and shows. For more detailed, step-by-step instructions (including formulas used in MPE calculations and tips for use in the field), please see an expanded version of this article at the ILDA Web site: *www.ilda.wa.org*.

One fundamental safety concept is that the eye needs time to recover from bright light. For example, if you view an audience scanning show, pay close attention to your vision as various effects cross your eyes. Effects that leave a strong afterimage are artistically unpleasant and detract from the show. In general, effects that leave afterimages may also exceed safety limits.

These limits are expressed by safety authorities as "Maximum Permissible Exposure" (MPE) levels. There is no single "safe level." For audience scanning shows, the key MPE levels are: Single-Pulse MPE, Multiple-Pulse MPE, and Average MPE. The show must be under all three limits to be considered safe.

## Evaluating a Tunnel

To understand why these three factors are used, consider a simple effect such as a laser tunnel—a circle projected onto the audience. The safety level of this effect can be determined from the beam power, the beam diameter (a spread-out beam is safer than a tight beam), and the scan rate (how quickly and often the beam scans the eye).

For this example, let's say the laser beam power is 250 mW, its diameter at the closest audience access point is 55mm, and the circle is scanned 60 times per second.

For safety analysis, consider your pupil diameter to be 7mm, the internationally recognized diameter for a dark-adapted eye. Since the beam diameter is larger than 7mm, only a portion of the beam enters the eye. Our first task is to calculate the power of the laser's light entering a 7mm pupil. This irradiance, or power in a given area, is 10.5mW/cm$^2$. Thus, we have 10.5 mW/cm$^2$ entering a pupil 60 times per second.

## Single Pulse Exposure

The circle effect can be considered another way, as a single laser source pulsing on and off. Each time the beam scans across the eye, we have a "pulse" of laser light. The "pulse width" is the length of time the light is in the eye. When viewing a scanned effect, your eye is typically exposed to multiple pulses because the laser projector scans the same pattern over and over again.

Pulses are important for two reasons: the eye can withstand more power if the pulse width is shorter; and the eye needs time to recover from each pulse. A single powerful, short pulse can be safe if the retina does not absorb a lot of energy. But if pulses come too quickly there is insufficient time to recover. This is why there is a Multiple-Pulse MPE as well as a Single-Pulse MPE.

Average power is also important. In the circle example, 250 mW is spread out by scanning over a large area. If the circle circumference is 7 meters, or 1,000 times the 7mm pupil aperture, the average power received at the pupil is 1,000 times less, or 0.25 mW. Average power, along with the total time an effect lasts, is used when determining the Average MPE.

To properly evaluate whether a show meets the three MPE limits, it must be played back on a computer. Taped shows (e.g., ADAT) cannot be used since effects cannot be paused to allow precise measurements to be taken.

To evaluate a show, it must first be run a number of times to determine particularly bright and hazardous effects. Then, the effects are paused and the brightest part of each effect (emphasized corners or overlapping lines) is measured.

It is easiest to use specialized meters that take measurements and automatically compare them to the MPE limits. All you do is place the detector in the brightest part of the effect; the readout provides numeric results, plus a "pass/fail" indication. Such meters reviewed in the last two issues of the Laserist are: the Laser MPE by Precision Optical Engineering and the LMS-2 by LOBO electronic.

If you do not have one of these meters,

you can use a calibrated power meter, a fast silicon detector, an oscilloscope and a calculator to determine these key factors: irradiance (raw laser power divided by area); pulse width (single pulse length); and pulse repetition rate (pulses per second). The results are then "plugged into" the MPE formulas to see if the effect exceeds the limits. If any MPE limit is exceeded, the effect is considered unsafe.

In the circle example, the irradiance is 10.5 mW/cm$^2$, the pulse width is 100 microseconds (the time it takes the beam to scan once across the pupil) and the pulse repetition rate is 60 pulses per second.

## Using the Formulas

Applying the Single-Pulse MPE formula, the limit for a 100 microsecond pulse is found to be 18 mW/cm$^2$. Since the irradiance of the beam is only 10.5 mW/cm$^2$, this test is passed. Applying the Multiple-Pulse MPE formula, the limit at 60 Hz is reduced to 3.6 mW/cm$^2$. Our effect exceeds this, as the irradiance is 10.5 mW/cm$^2$ for each pulse. We don't have to continue, since the effect exceeds the Multiple-Pulse MPE and is therefore considered unsafe. However, for completeness we'll calculate the Average MPE as well.

## Total Exposure Time

We previously determined the average power was 0.25 mW. To see if this is below the Average MPE we must consider how long the circle effect lasts, since there are different Average MPE limits for different exposure times. Ten seconds is the maximum time used for this calculation.* Applying the formula gives an Average MPE limit for 10 seconds of 1 mW/cm$^2$. Since the average power of this effect is 0.25 mW, this test is passed.

If an effect exceeds an MPE limit (as our circle does), you can lower the laser beam's power, enlarge the beam diameter, or spread the light out more by adding more complexity to the image.

Enlarging the beam is more effective than reducing the laser's power. This is because of the inverse square law: doubling the beam size makes the irradiance four times lower; tripling the size makes the irradiance nine times lower. The beam may appear "fuzzier" to the audience, but less light will enter the pupil at any one time.

Remember that MPE measurements are only part of the total safety package. You must also consider possible failure modes and provide appropriate control measures. These include keeping the audience from getting too close to the projector (before the beam has sufficiently diverged) and incorporating scan-fail interlocks that shut off the beam in case scanning stops.

** Strictly speaking, exposure times for the multiple-pulse MPE and average MPE should be for the whole show, which could be an hour or more. This is impractical to measure or enforce for a typical show as it would require a measurement of every effect in the show for the length of that effect and a tabulation of the total exposure time for all effects. Instead, British experts have concluded that a 10-second window per effect is sufficient. If none of the measured effects exceed the MPE for a 10-second exposure, then the entire show can reasonably be assumed to be below the MPE (see Web article for more details).*