



Comparing CW Argon Ion and Q-Switched Nd:YAG lasers

With the widespread interest in "YAG's", I thought it might be helpful to illustrate some of the differences between CW gas ion lasers, which most of us are quite familiar with, and the newer pulsed lasers, which are still uncommon.

For our comparison, let's say we have a 40 W Argon laser and a 40W Nd:YAG laser. The Argon laser delivers 40 Joules of energy per second ($J/s = W$), as does the Nd:YAG. However, the YAG laser delivers the 40 J in 25,000 very short packets called pulses. Each pulse is about 600 nanoseconds long (0.6 microseconds), and contains $(40/25000)$ 1.6 millijoules of energy. If we divide the amount of energy per pulse by the duration of the pulse ($1.6 \text{ mJ}/0.0000006$), we arrive at the peak power 2666 W, which is the power the laser would produce if it could run continuously.

Another way we can compare the two lasers is to take a "time slice" equal to the duration of one pulse. If we take a 600 nanosecond slice of the Argon beam, we have $(40W \cdot 0.0000006 \text{ S})$ or 24 microjoules. To compare the two lasers, divide the $1.6 \text{ mJ}/0.024 \text{ mJ}$, and we find the YAG laser delivers the energy 70 times "faster" than the Argon laser.

With an Argon laser, the primary damage mechanism for human tissue is thermal. The energy of the beam is absorbed by the melanin, water, and blood in the tissue, converted to heat, and "cooks" the tissue. With pulsed lasers, the energy is delivered so rapidly that normal thermal processes are overrun by an "Acoustic Shockwave" effect. The tissue doesn't cook, it pops like a popcorn kernel. If the injury is in the eye, the beam may not cauterize the eye, it may simply blow a hole in the retina, leading to massive bleeding, and generally total loss of vision in that eye. This is what really happens, just check the laser accident registry maintained by Rockwell Laser!

Recently there has been a report of some audience scanning done with a pulsed YAG at a major trade fair. I am amazed at the ignorance that would lead to such activity!!!

Audience scanning relies on "spreading out" the energy in a beam to a level within the limit for safe exposure (Maximum Permissible Exposure - MPE). If we scan a 1 watt Argon beam to 1000 discrete positions, each position will have $1/1000$ of the energy, or 1 milliwatt, approximately the MPE for a CW laser. This doesn't work the same way with a pulsed laser, however. The duration of the pulse is so short that the scanner effectively doesn't move while the pulse fires. The only thing we gain is fewer pulses in the eye, not weaker pulses.

Let's say the beam is scanning a line with a sawtooth waveform at 100 Hz. At the point of access, the scan is 10 feet (300 cm) wide. This gives a velocity of 30,000 centimeters/second. If we multiply the velocity of the beam by the duration of the pulse, we can see how far the beam travels during the pulse. $30,000 \times 0.0000006 = 0.018$ cm, which is about 1/40 of the diameter of the pupil. It basically doesn't move.

We can easily look up the MPE for a very short pulse in the tables provided by CDRH, ANSI, IEC and DIN. All the numbers are the same, except for some unit conversions (W/cm^2 vs. W/M^2). For duration's of less than 18 microseconds, the MPE for a single pulse is 0.5 microjoules/cm². With all Q-switched lasers, this MPE applies!

Finally, lets evaluate a "small" YAG laser, at 3 watts average power. If the beam is scanning so that only a single pulse is delivered to a specific location, this reduces the hazard to a single pulse evaluation. Given a 4 milliradian divergence, and a pulse energy of 0.3 millijoules (3 Watts/10,000 pulses/second), the beam will have to be 27+ cm across (600 cm²) to have the radiant exposure reduced to the single pulse MPE, which requires a range of about 70 meters (230 ft.). If the divergence is less, or the pulse rate slower, the hazard range will increase. And this is assuming that only a single pulse will enter the eye.

For multiple pulses, we use a correction factor of $n^{-1/4}$ power, where "n" is the number of pulses in the time of exposure. Usually we use 0.25 seconds, so we have 10,000 pps \times 0.25 s or 2500 as "n". This gives a value of $0.141(n^{-1/4})$ as the multiple pulse correction factor, which is multiplied with the single pulse MPE (0.141×0.5 microjoules), resulting in a corrected MPE value of 70 nanojoules/cm². Finally, this is multiplied by the number of pulses in the exposure duration (2500×70 nanojoules/cm²) for a MPE value of 0.17 milliwatts/cm², 14 times less than the MPE for a CW laser. Given our 4 milliradian divergence, we would have to be 370 meters (>1200 ft.) away from the laser to glance into the beam without injury. This compares to a range of 97 meters for an equivalent Argon laser (3 Watts at 4 milliradians).

In conclusion, any type of scanning of Q-switched lasers must be very carefully evaluated as to the potential hazard. It is a far more complex issue than presented by CW lasers, with potentially catastrophic consequences. For those of you who feel that these numbers are too conservative, I suggest that you examine the wealth of biological data based on hard research and accident analysis. The numbers are not made up!