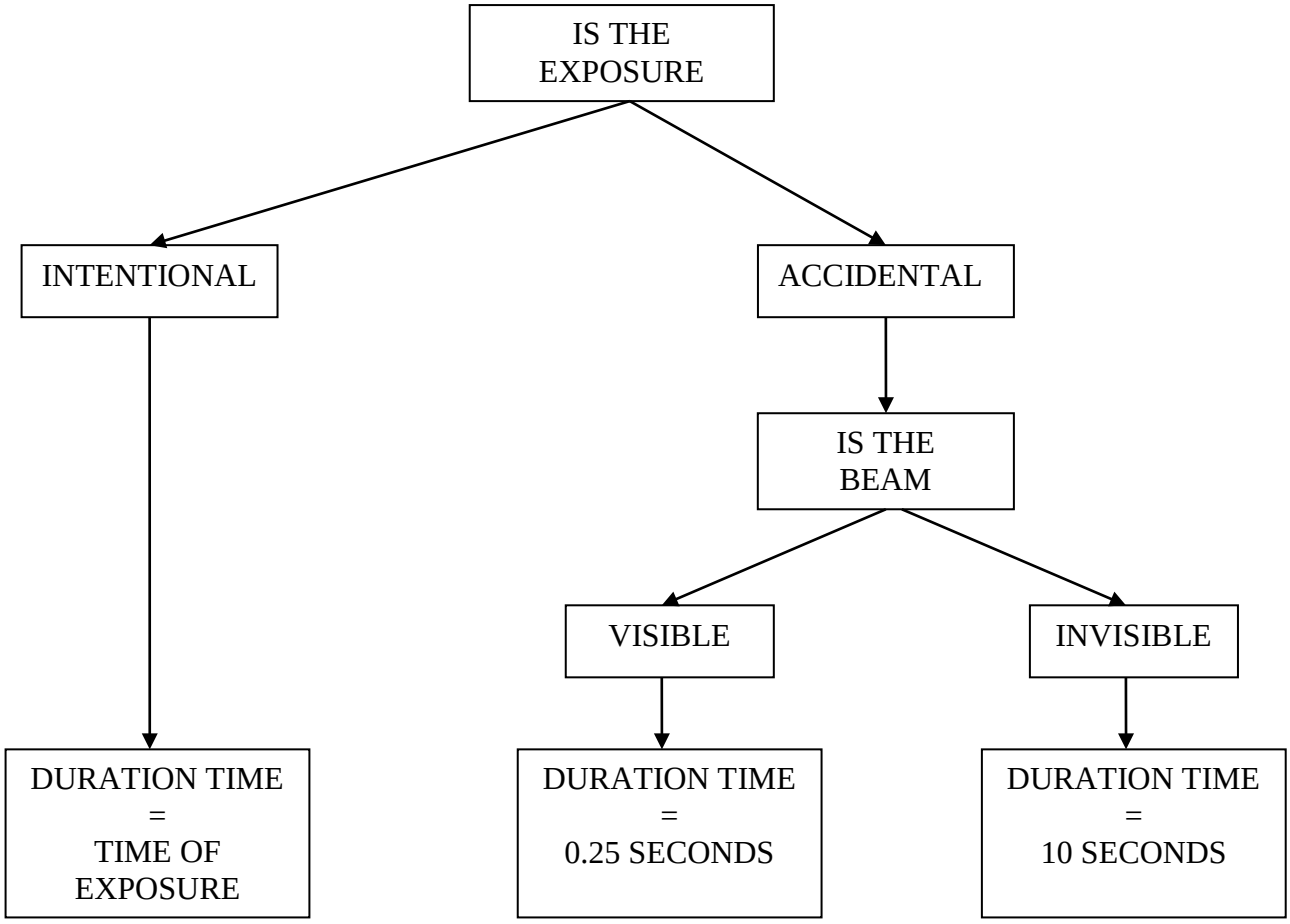
Appendix 1 - Maximum Permissible Exposure (MPE)

Non-pulsed Lasers

WORK OUT EXPOSURE TIME



USE THE APPROPRIATE TABLE TO GET THE MPE FORMULA USING EXPOSURE TIME (ALONG) AND WAVELENGTH (DOWN)

VISIBLE LASER	TABLE 1
UV LASER	TABLE 2
IR LASER	TABLE 3

INSERT DURATION TIME(t) INTO FORMULA TO GET RADIANT EXPOSURE MPE (in Jm^{-2})

IRRADIANCE (in Wm^{-2}) = MPE (in Jm^{-2})/ DURATION TIME IN SECONDS

NOTE: Ocular MPEs for accidental exposure to visible laser beams.

RADIANT EXPOSURE MPE = $6.36Jm^{-2}$
IRRADIANCE MPE = $25.4Wm^{-2}$

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<tr><th>Exposure time t(s)
Wavelength (nm)</th><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 10^{-9}</th><th>10^{-9} to
1.8×10^{-5}</th><th>1.8×10^{-5} to 10</th><th>10 to 10^2</th><th>10^2 to 10^4</th><th>10^4 to 3×10^4</th></tr>
<tr><td rowspan="2">400 to 600</td><td rowspan="3">$1.5 \times 10^{-4} C_6$ Jm^{-2}</td><td rowspan="3">$2.7 \times 10^4 t^{0.75} C_6$ Jm^{-2}</td><td rowspan="3">$5 \times 10^{-3} C_6$ Jm^{-2}</td><td rowspan="3">$18t^{0.75} C_6$ Jm^{-2}</td><td colspan="3">Retinal photochemical hazard</td></tr>
<tr><td>$100C_3$ Jm^{-2} using γ_p=11mrad</td><td>$1C_3$ Wm^{-2} using $\gamma_p = 1.1t^{0.5}$ mrad</td><td>$1C_3$ Wm^{-2} using γ_p=110mrad</td></tr>
<tr><td>400 to 700[d]</td><td colspan="3">AND[d]
Retinal thermal hazard
$\alpha \le 1.5$ mrad: $10 Wm^{-2}$
$\alpha > 1.5$ mrad
$t \le T_2$
$18t^{0.75} C_6$ Jm^{-2}
$t > T_2$
$18C_6 T_2^{-0.25}$ Wm^{-2}</td></tr>
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<tr><td>302.5 to 315</td><td>$t \dagger T_1$
C_1 Jm^{-2}
where $C_1 = 5.6 \times 10^3 t^{0.25}$
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where $C_2 = 10^{0.2(\lambda-295)}$
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$(10^4/t$ $Wm^{-2})$</td><td>$10 Wm^{-2}$
$(10t$ $Jm^{-2})$</td></tr>
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TABLE 2: *Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - UV section.*

<table>
<tr><th>Exposure time t(s)
Wavelength (nm)</th><th>10^{-13} to 10^{-11}</th><th>10^{-11} to 10^{-9}</th><th>10^{-9} to 10^{-7}</th><th>10^{-7}
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<tr><td>1050 to 1400</td><td>1.5×10^{-3} x C_6C_7 Jm^{-2}</td><td>$2.7 \times 10^5 t^{0.75} C_6C_7$ Jm^{-2}</td><td colspan="3">$5 \times 10^{-2} C_6C_7$ Jm^{-2}</td><td colspan="2">$90t^{0.75} C_6C_7$ Jm^{-2}</td></tr>
<tr><td>1400 to 1500</td><td colspan="2">10^{12} Wm^{-2}</td><td colspan="4">10^3 Jm^{-2}</td><td>$5600t^{0.25}$ Jm^{-2}</td><td colspan="2" rowspan="4">1000 Wm^{-2}</td></tr>
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TABLE 3: Maximum Permissible Exposure (MPE) at the cornea for direct ocular exposure to laser radiation - IR section.

Pulsed Lasers

Step 1
Calculate MPE_{single} for a single pulse using the pulse-length as the duration time, NOT 0.25s for visible lasers and 10s for invisible lasers as used in non-pulse lasers

Step 2
Calculate MPE_{train} for a train of pulses using the formula:
MPE $train = MPE_{single} \times N^{-0.25}$
Where N is the number of pulses in the duration time (i.e. 0.25s for visible lasers and 10s for invisible lasers)

Step 3
Calculate $MPE_{average}$ using the formula
$MPE_{average} = (MPE_{duration\text{-}time}) / N$
Where $MPE_{duration\text{-}time}$ = Radiant exposure MPE for a non-pulse laser.
And N is the number of pulses in the duration time (i.e. 0.25s for visible lasers and 10s for invisible lasers)
The most restrictive of MPE_{single}, MPE_{train} and $MPE_{average}$ is taken as the MPE.

Example
What is the MPE for accidental ocular exposure for a pulsed argon ion laser which emits 10 pulses per second at 488nm with a pulse duration of 1ms?

Step 1
Calculate MPE_{single}.
Using the duration time as the pulse length and using table 1 we see that the MPE is given by:

$MPE = 18t^{0.75} C_6 \, Jm^{-2}$
By putting the numbers in we get $MPE_{single} = 0.1Jm^{-2}$

Step 2
Calculate MPE_{train}.
We need to know the number of pulses, N, in the duration time, 0.25s. For 10 pulse per second this equals 2.5.
We use the formula:
$MPE_{train} = MPE_{single} \times N^{-0.25}$
To get:
$MPE_{train} = 0.08Jm^{-2}$

Step 3
Calculate $MPE_{average}$.
This is given by the MPE calculated with an exposure time of 0.25s divided by the number of pulses, or
$MPE_{average} = (MPE_{duration\text{-}time}) / N$
which is 6.36/2.5
$MPE_{average} = 2.54Jm^{-2}$

So $MPE_{single} = 0.1Jm^{-2}$, $MPE_{train} = 0.08Jm^{-2}$ and $MPE_{average} = 2.54Jm^{-2}$

We can now see that MPE_{train} is the most restrictive with a value of:
$MPE_{train} = 0.08Jm^{-2}$ So the MPE for this pulsed laser is **$0.08Jm^{-2}$**

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