Laser Safety:
Safe clinical application of laser radiation

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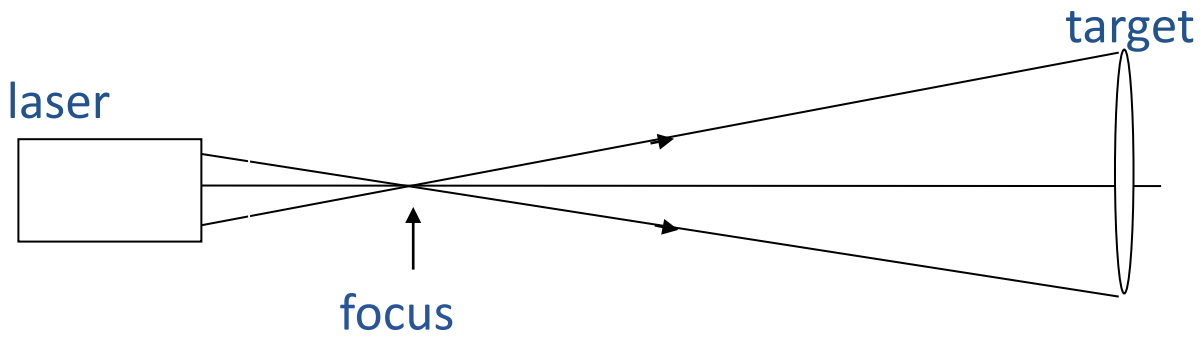
NOHD: Nominal Ocular Hazard Distance

- NOHD: safe distance to avoid eye damage
- Standard distance for safety: **0.25 m**
  for **10 s** exposure time.
- If laser intensity [W/m^2] at the standard distance is too high:
  protection glasses compulsory.

Damage of excessive laser exposure to eye and skin

	eye			skin	
Wave-length	Photo-chemical	Retina	Thermal	Erythema formation	Thermal
< 400 nm	+	-	+	+	+
400-600	+	+	+	-	+
600-700	-	+	+	-	+
> 700	-	-	+	-	+

NOHD: Nominal Ocular Hazard Distance



- Safety condition at target:
- Intensity ***I*** ≤ Maximum Permissible Exposure ***MPE***
- ***I*** and ***MPE*** in W/m^2
- ***NOHD*** is minimum distance where ***I ≤ MPE***

MPE: maximum permissible exposure

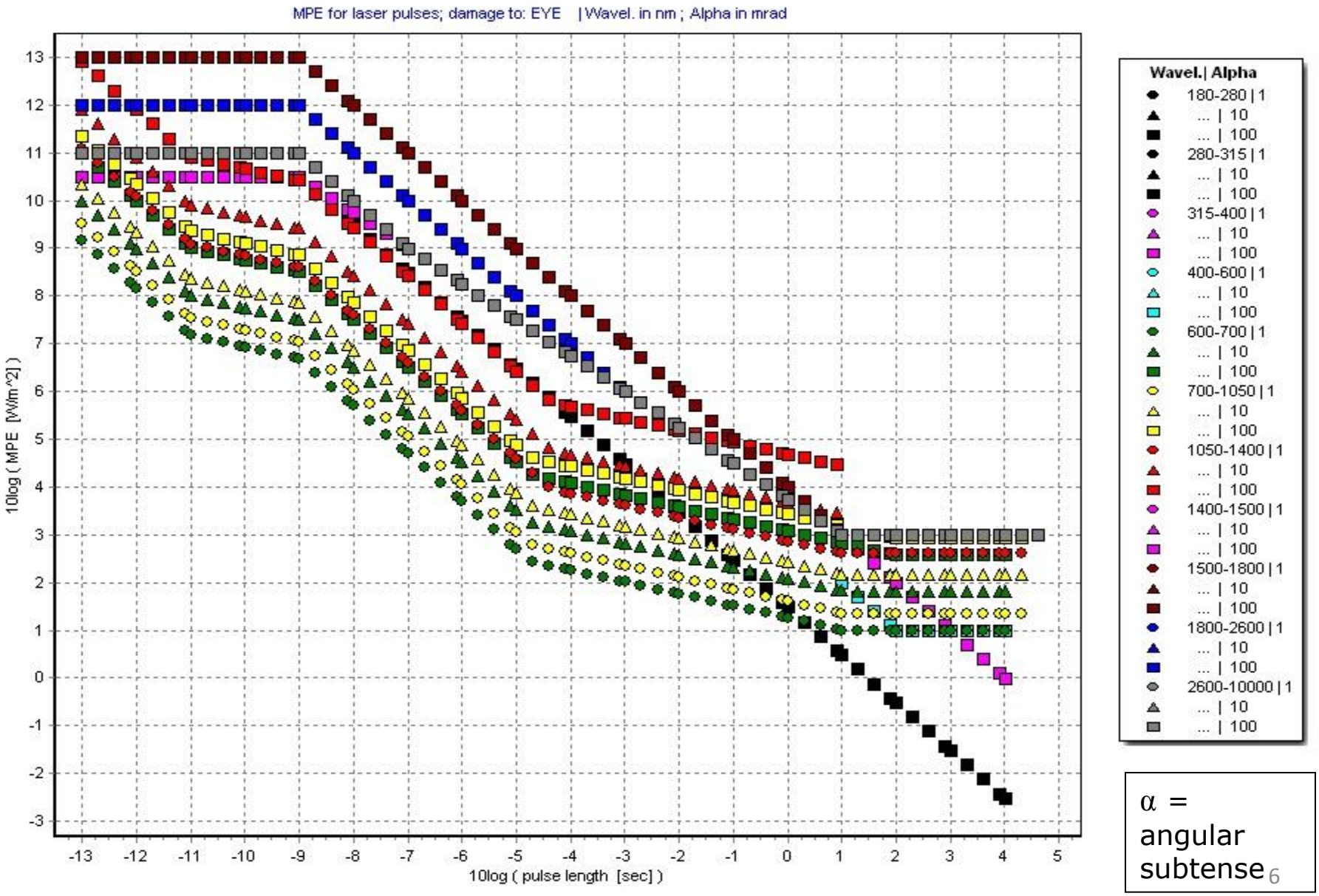
MPE is a function of:

- Wavelength
- Pulse duration (or continuous)
- Pulse frequency
- Angular subtense (viewing angle of light source from target)

MPE-formulae are tabulated in

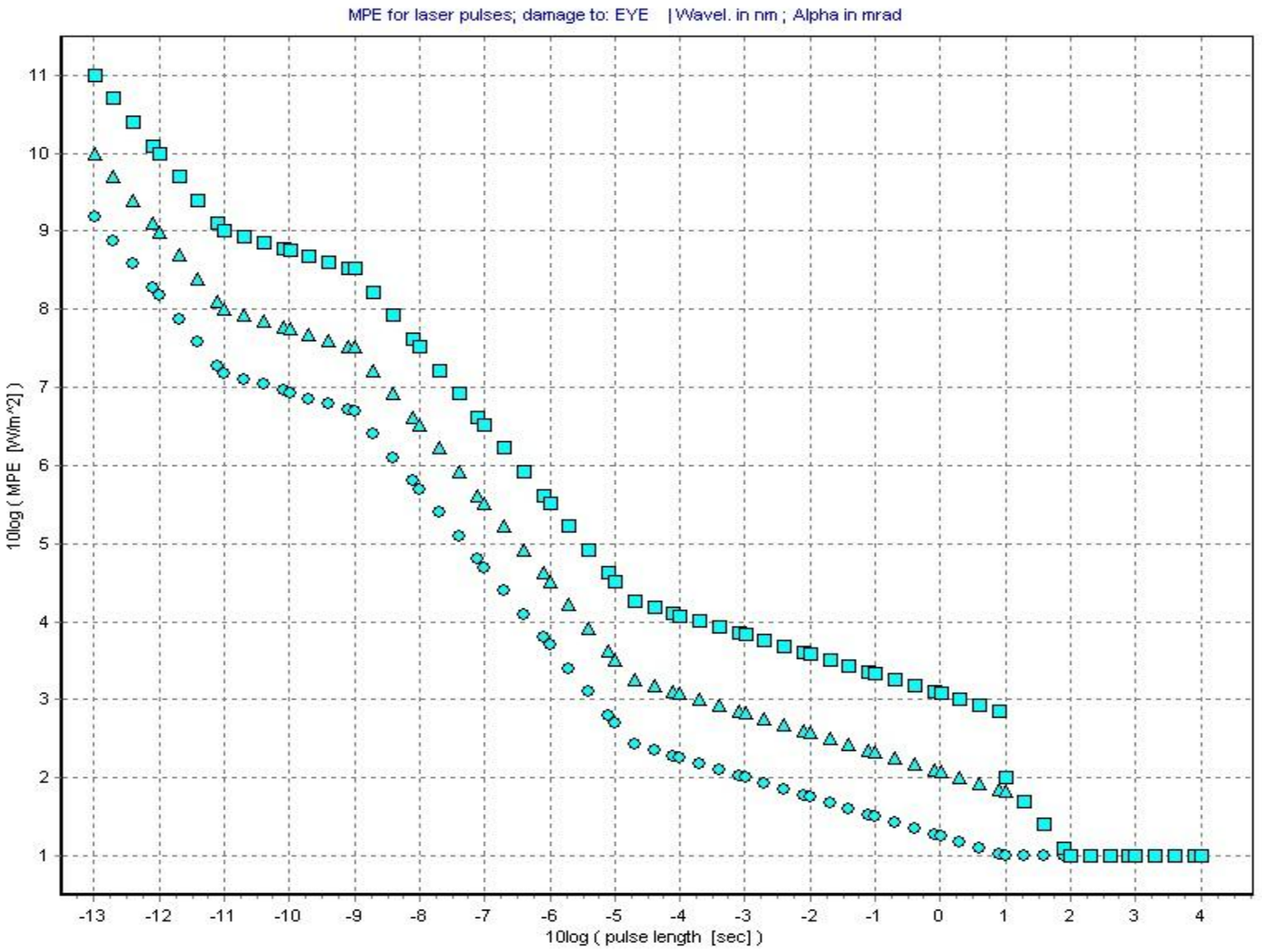
- Directive 2006/25/EU of European Parliament and Commission
- IEC 60825-1
- NEN 60825-1

MPE: maximum permissible exposure : eye



α = angular subtense

MPE: maximum permissible exposure : eye



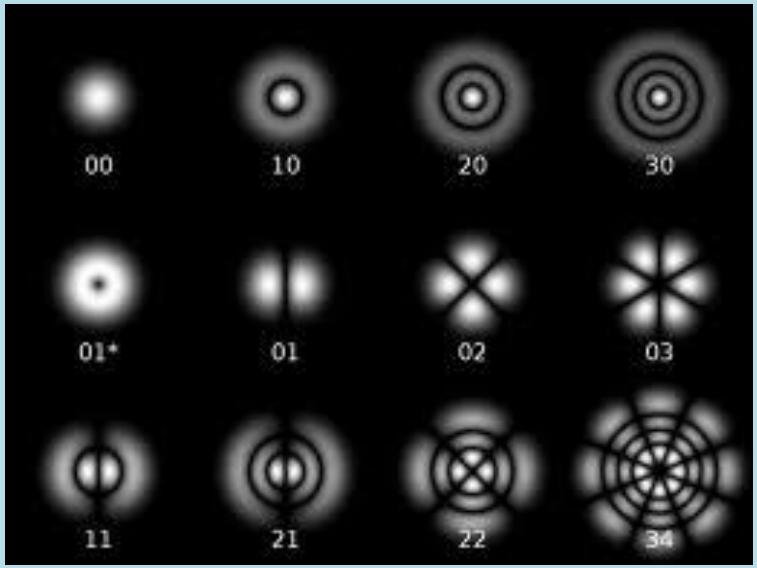
α = angular subtense

NOHD: Nominal Ocular Hazard Distance

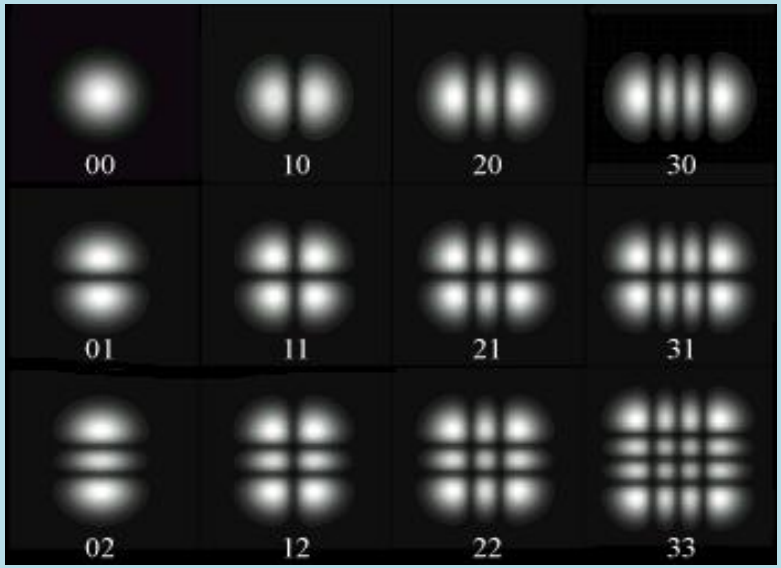
- Safety condition: $\boldsymbol{I \leq MPE}$ in W/m^2
- With $\boldsymbol{I = P.PC / S}$
- $\boldsymbol{I}$ = intensity [W/m^2]
- $\boldsymbol{P}$ = laser power [W]
- $\boldsymbol{PC}$ = laser Profile Correlation Factor [-]
- $\boldsymbol{S}$ = target area [m^2]

PC: Profile Correlation Factor

PC depends on laser mode structure



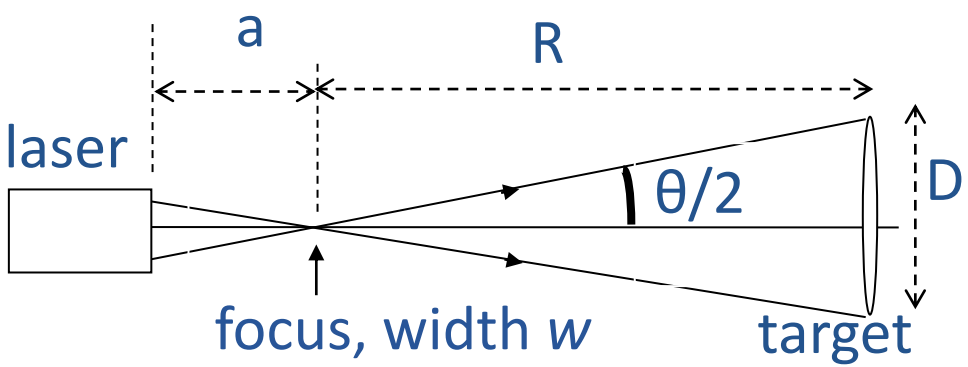
Cylindrical transverse modes



Rectangular transverse modes

Local intensity in modes is larger than averaged over the mode envelope.
→ **Profile Correlation Factor *PC***.

NOHD: Nominal Ocular Hazard Distance



Effective target area:

$$S = \frac{\pi}{4} D'^2, \quad D' = D + w$$

D' = effective diameter

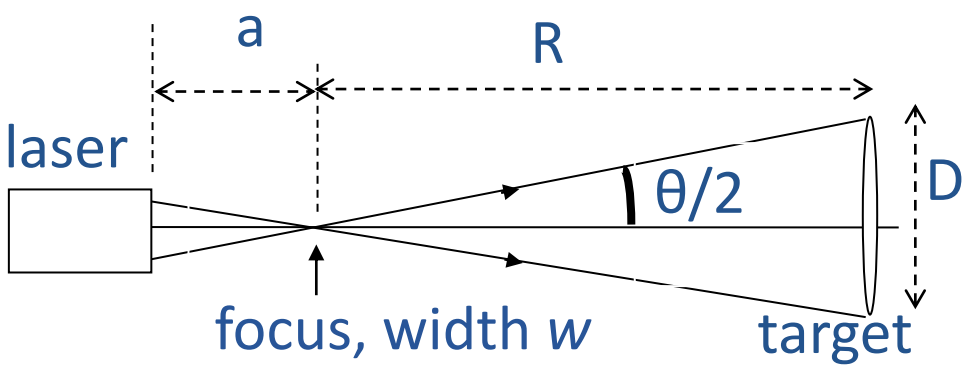
$$\frac{4S}{\pi} = D'^2 = (D + w)^2$$

Safety condition:

$$I = \frac{P.PC}{S} \leq MPE \quad \Rightarrow \quad S \geq \frac{P.PC}{MPE}$$

$$D = \sqrt{\frac{4S}{\pi}} - w \geq \sqrt{\frac{4P.PC}{\pi.MPE}} - w$$

NOHD: Nominal Ocular Hazard Distance



Effective target area:

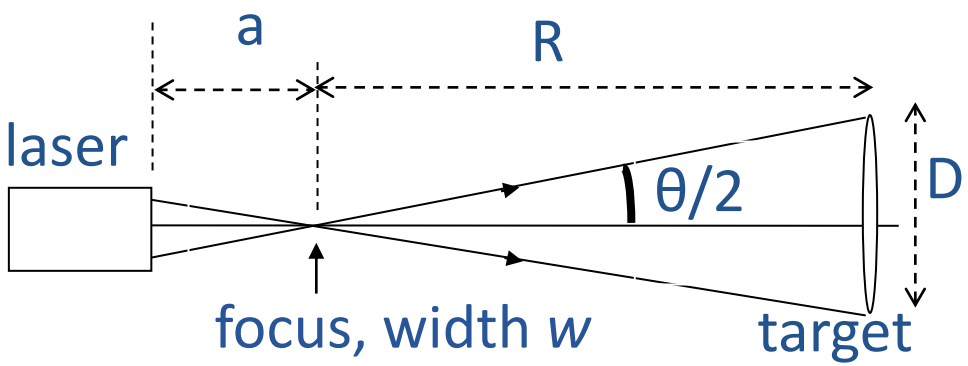
$$S = \frac{\pi}{4} D'^2, \quad D' = D + w$$

Safety condition: $$D \geq \sqrt{\frac{4S}{\pi}} - w = \sqrt{\frac{4P.PC}{\pi.MPE}} - w$$

$$NOHD = R + a = \frac{D}{2.\tan(\theta/2)} + a =$$

$$= \frac{1}{2.\tan(\theta/2)} \left[\sqrt{\frac{4P.PC}{\pi.MPE}} - w \right] + a$$

NOHD: Nominal Ocular Hazard Distance



NOHD depends on:

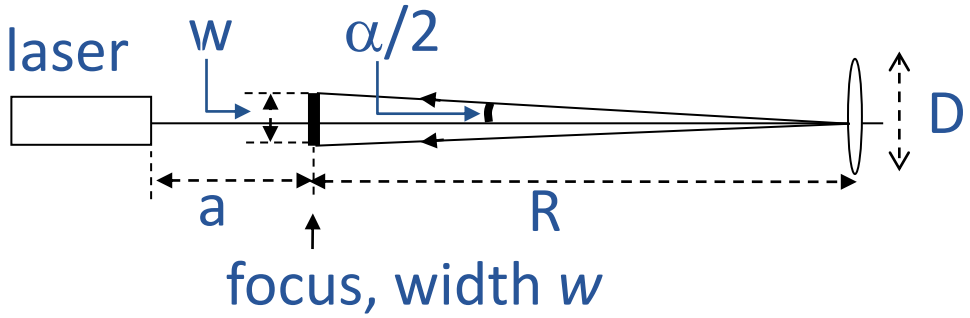
- *D*
- $\approx 1/\theta$
- $\sqrt{P}$
- $\sqrt{PC}$
- $\sqrt{1/MPE}$
- *-w*
- *a*

$$NOHD = R + a = \frac{D}{2.\tan(\theta/2)} + a =$$

$$= \frac{1}{2.\tan(\theta/2)}\left[\sqrt{\frac{4P.PC}{\pi.MPE}} - w\right] + a$$

NOHD: Nominal Ocular Hazard Distance

Focus as seen from the target



NOHD is also dependent on α : "angular subtense"

"angular subtense" = angle to view the source (= focus) from the target position

$$\tan\tfrac{1}{2}\alpha = \frac{\frac{1}{2}w}{R} = \frac{w}{2(NOHD - a)}$$

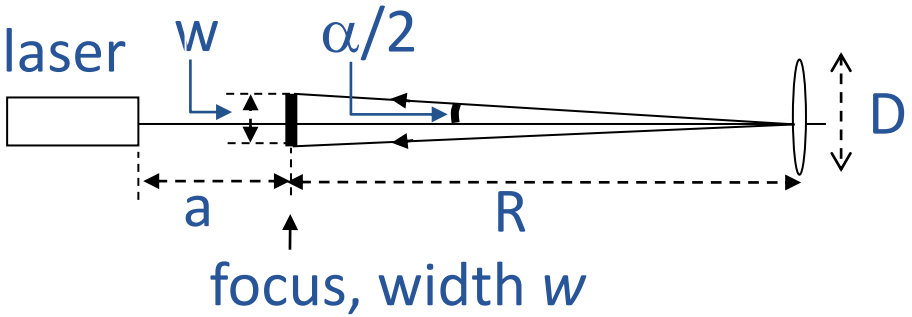
A smaller waist will lead to a sharper (intenser) spot on the target

For certain situations (e.g. visible light):

MPE depends on α (tabulated in EU-Directive), and thus on *NOHD*

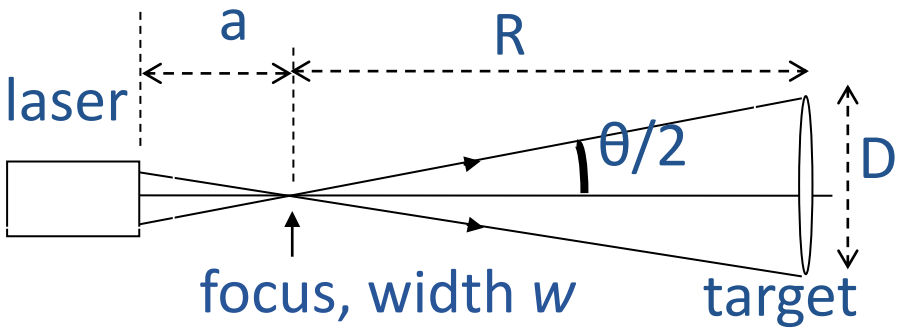
NOHD: Nominal Ocular Hazard Distance

Two relations between *NOHD* and *MPE :*



$$\tan\tfrac{1}{2}\alpha = \frac{w}{2R} = \frac{w}{2(NOHD - a)}$$

So, $NOHD = f(\alpha)$



But also:

$NOHD = f(MPE) = f(\alpha)$!

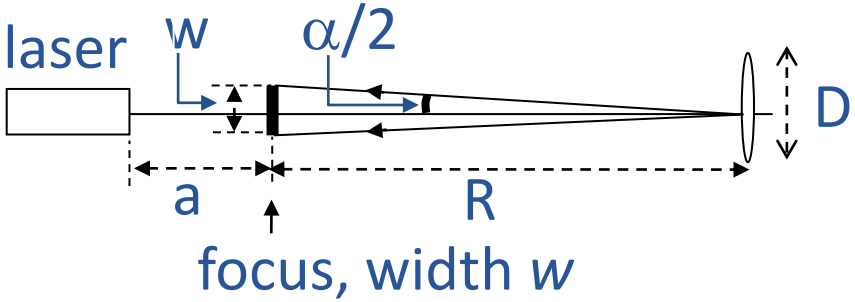
From Safety Condition: $I \leq MPE$

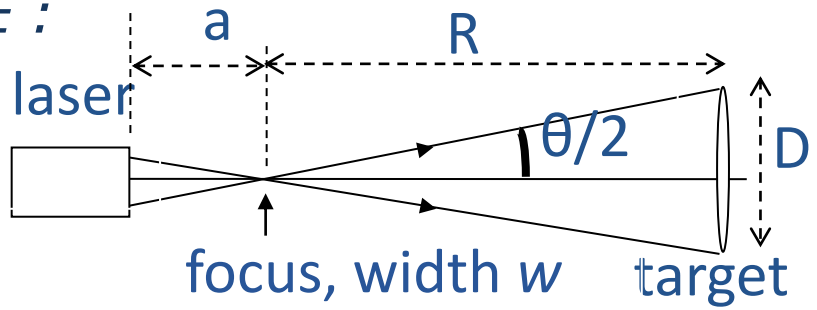
$$NOHD = R + a = \frac{1}{2.\tan(\theta/2)}\left[\sqrt{\frac{4P.PC}{\pi.MPE}} - w\right] + a$$

Thus: iterative approach necessary !!

NOHD: Nominal Ocular Hazard Distance

Two relations between *NOHD* and *MPE :*

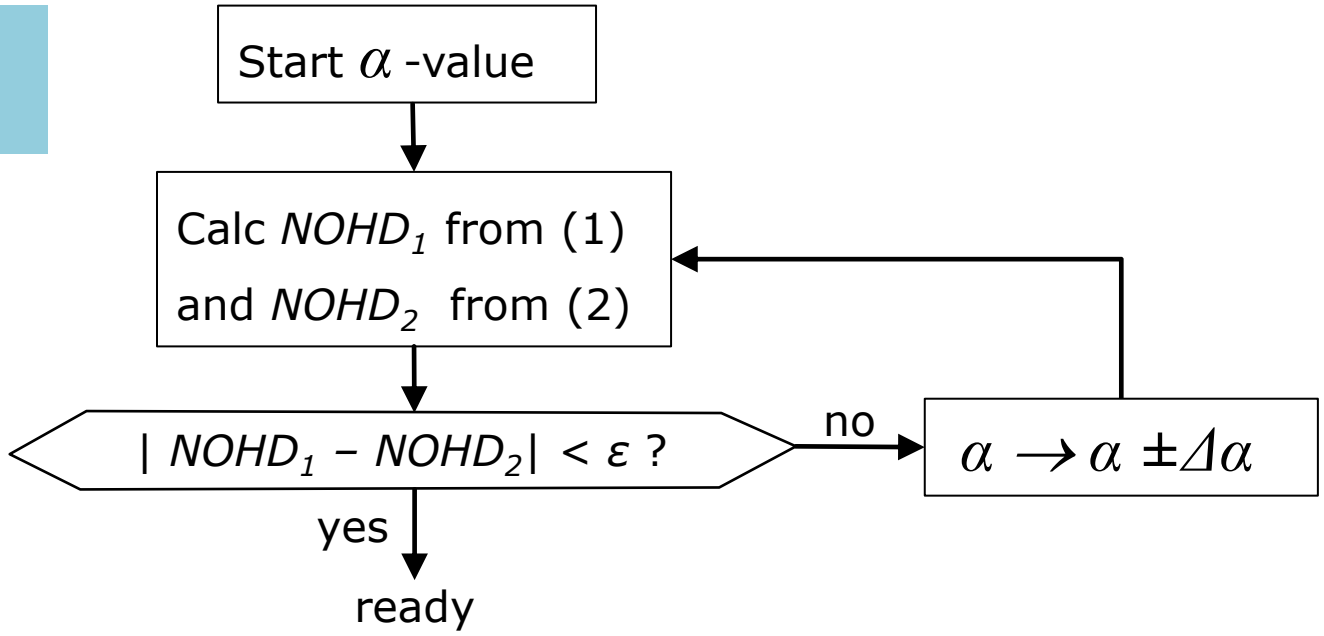




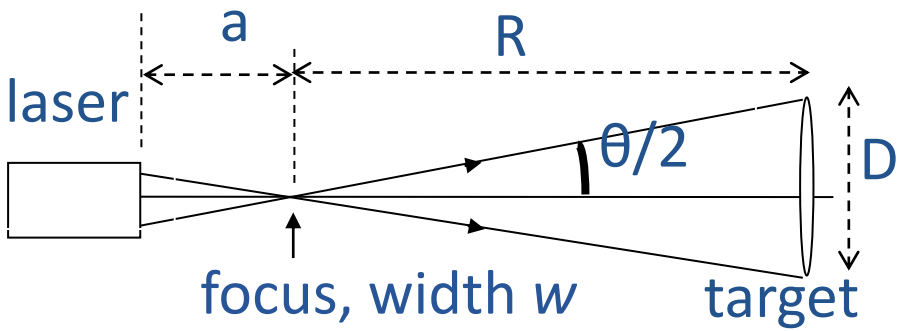
$(1)\colon NOHD = f(\alpha)$

$(2)\colon NOHD = f(MPE) = f(\alpha)$

Iterative approach:



Transmission of safety goggles



$NOHD = R + a$

In case *NOHD* > safety distance *b* (from focus):
safety goggles necessary!

Transmission *T* of safety goggles and Optical density *OD:*

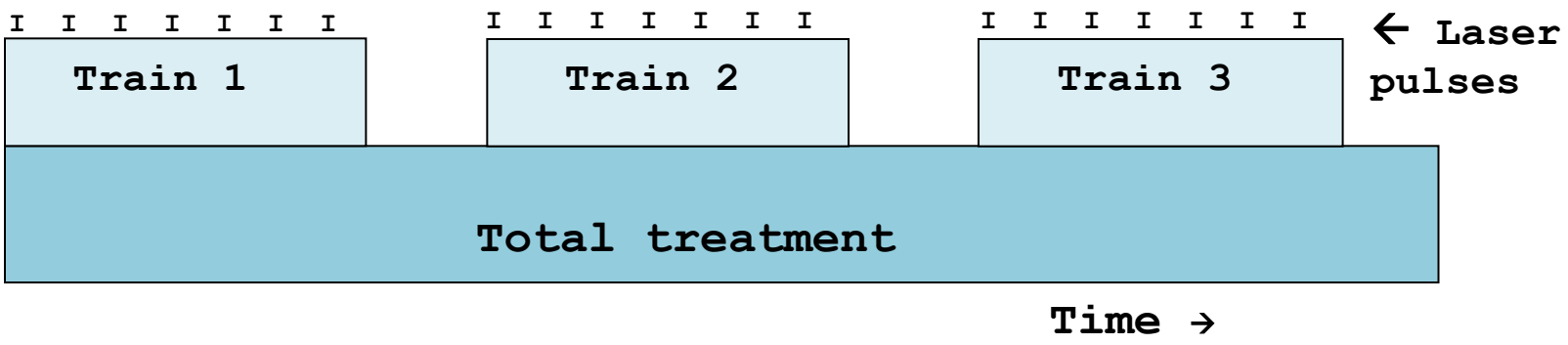
$$T = \left[\frac{b}{NOHD - a} \right]^2 \; ; \; OD = - \, {}^{10}\log T$$

target area $\sim R^2$

Standard safety distance = 0.25 m for 10 sec exposure.

Laser treatment

In general: pulsed laser treatment will consist of separate trains of separate pulses



Continuous laser: 1 long train of 1 long pulse.

Example

LASER INPUT DATA	VALUE	
Wavelength	532	nm
(full) Divergence angle	0.0125	rad
Profile correlation factor	2	-
Waist(spot)diameter	400e-6	m
Distance laser to focus(waist)	0.3	m
Basic pulse: pulse power	1.000E+06	W
...: pulse energy	5.000E-03	J
...: duration	5.000E-09	s
...: rep.freq.	1000	Hz
Train of pulses: power	5.000E+00	W
...: energy	5.000E+01	J
...: duration	1.000E+01	s
...: rep.freq.	0.100	Hz
...: pulse at end of train (yes/no=1/0)	0	-
...: nr. of pulses per train	10000	-
Total treatment: power	5.000E+00	W
...: energy	5.000E+01	J
...: duration	1.000E+01	s
...: nr. of trains in total	1	-
Safe distance from focus (for OD-glasses)	0.250	m

Example

OUTPUT of calculations:

For this wavelength the damage is:
EYE: photochemical and retina (thermal) and thermal
SKIN: thermal

RESULTS: (H in J/m^2 - E=MPE in W/m^2)

CALCULATION	formula	MPE [W/m^2]	alpha [rad]	NOHD [m]	T-glasses	OD-glass
eye: pulse	H=5E-3.CE	1.000E+06	3.133E-06	127.9	3.837E-06	5.416
..id. with CF1	.. N= 10000, CF= 1.000E-01	1.000E+05	9.906E-07	404.0	3.836E-07	6.416
..id. with CF2	.. N= 10000, CF= 1.000E-01	1.000E+05	9.906E-07	404.0	3.836E-07	6.416
eye: train	H=18.CE.t^0.75	1.012E+01	4.461E-06	89.99	7.769E-06	5.110
eye: total	H=18.CE.t^0.75	1.012E+01	4.461E-06	89.99	7.769E-06	5.110
skin: pulse	H=200.CA	4.000E+10	6.605E-04	0.906	1.700E-01	0.769
..id. with CF1	.. N= 10000, CF= 1.000E-01	4.000E+09	2.012E-04	2.286	1.584E-02	1.800
..id. with CF2	.. N= 10000, CF= 1.000E-01	4.000E+09	2.012E-04	2.286	1.584E-02	1.800
skin: train	H=1.1E4.CA.t^0.25	1.956E+03	6.230E-05	6.722	1.515E-03	2.819
skin: total	H=1.1E4.CA.t^0.25	1.956E+03	6.230E-05	6.722	1.515E-03	2.819

CF = correction factor, needed for thermal damage when >1 pulse in Tmin.
(Tmin is 1.8E-5 s for 532 nm).

the end