APPENDIX A.14.2. MPE Calculations and Limits

Eye exposure to a CW Nd:YAG laser

Wavelength (λ) = 1.064 μm = 1,064 nm
Assume accidental eye exposure (probably from specular or diffuse reflection).
Exposure duration t = 10s (since not in 400 to 700 nm visible range)
From Table A, MPE = 5.0 Cc x 10-3 W/cm2 .
Using CC = 1 from Table C for λ = 1.064 μm, MPE = 5.0 x 10-3 W/cm2 or 0.005 W/cm2 .

Skin exposure to a CW Nd:YAG laser

Assume exposure duration is 10 s or longer.
Using Table B for skin exposure, MPE = 0.2 CA W/cm2 .
From Table C, CA = 5.0 for λ = 1.064 μm.
MPE = 1.0 W/cm2

Eye exposure to single-pulsed Ruby laser λ = 694 nm

Pulse duration 30 ns,
FWHM Using Table A for pulses between 10-9 and 18 x 10-6 seconds,
MPE = 0.5 x 10-6 J/cm2

Eye exposure to Repetitively-Pulsed Nd:YAG laser

Pulse Repetition Frequency (PRF) = 30 hz (pulses per second)
Variable pulse width, from 7 to 30 ms
Rule 1 – No single pulse in a chain may exceed the MPE.

For worst case, use smallest pulse width (7 ms)
For λ = 1.064 μm, MPESP = 9.0 CC t 0.75 x 10-3
From table C, CC = 1.0,
so MPESP = (9.0)(1.0)(7x10-3) 0.75 x 10-3 J/cm2 MPE1 = 0.218 mJ/cm2 .

Rule 2 – Average Power MPE The exposure from any group of pulses delivered in time T must not exceed the MPE for time T.
For infrared region T = 10 seconds.
Divide MPE for a 10-second exposure by the number of pulses, n, during the 10-second period.
For this example, n = 300, so MPE/pulse = ((9.0)(1.0)(100.75) mJ/cm2)/300)
MPE2 = 0.169 mJ/cm2 .

Rule 3 – Multiple-Pulse MPE For thermal injury, the exposure for any single pulse within a group of pulses must not exceed the single-pulse MPE multiplied by a multiple-pulse correction factor CP.
From Table 3, CP = n-0.25, where n is the number of pulses in Tmax = 10 seconds.
CP = 300 -0.25 = 0.240

MPE3 = 52.3 μJ/cm2 .

Conclusion: Rule 3 produces the most limiting case, so MPE/pulse = 52.3 μJ/cm2 To express the limit as average irradiance MPE, multiply by the PRF = 30 Hz MPEE = 1.57 mW/cm2 or 1.57x10-3 W/cm2 .

Table A: MPE for Ocular Exposure (Intrabeam Viewing)

Wavelength (μm)	Exposure Duration, t (s)	MPE	
		(J cm^{-2})	(W cm^{-2})
Ultraviolet			
0.180 to 0.302	10^{-9} to 3 x 10^{4}	3 x 10^{-3}	
0.303	10^{-9} to 3 x 10^{4}	4 x 10^{-3}	
0.304	10^{-9} to 3 x 10^{4}	6 x 10^{-3}	
0.305	10^{-9} to 3 x 10^{4}	10 x 10^{-3}	
0.306	10^{-9} to 3 x 10^{4}	16 x 10^{-3}	
0.307	10^{-9} to 3 x 10^{4}	25 x 10^{-3}	
0.308	10^{-9} to 3 x 10^{4}	40 x 10^{-3}	
0.309	10^{-9} to 3 x 10^{4}	63 x 10^{-3}	
0.310	10^{-9} to 3 x 10^{4}	0.1	
0.311	10^{-9} to 3 x 10^{4}	0.16	
0.312	10^{-9} to 3 x 10^{4}	0.25	
0.313	10^{-9} to 3 x 10^{4}	0.40	
0.314	10^{-9} to 3 x 10^{4}	0.63	
0.315 to 0.400	10^{-9} to 10	0.56 $t^{0.25}$	
0.315 to 0.400	10 x 3 x 10^{4}	1.0	
NOTE: To calculate MPE, use the J/cm^2 value shown or 0.56 $t^{0.25}$, whichever is lower.			
Visible and Near Infrared			
0.400 to 0.700	10^{-9} to 18 x 10^{-6}	0.5 x 10^{-6}	
0.400 to 0.700	18 x 10^{-6} to 10	1.8 $t^{0.75}$ x 10^{-3}	
0.400 to 0.450	10 to 100	1.0 x 10^{-2}	
0.450 to 0.500	10 to T_1		1 x 10^{-3}
0.450 to 0.500	T_1 to 10^{2}	C_B x 10^{-2}	
0.400 to 0.500	100 to 3 x 10^{4}		C_B x 10^{-4}
0.500 to 0.700	10 to 3 x 10^{4}		1 x 10^{-3}
0.700 to 1.050	10^{-9} to 18 x 10^{-6}	5.0 C_A x 10^{-7}	
0.700 to 1.050	18 x 10^{-6} to 10	1.8 C_A $t^{0.75}$ x 10^{-3}	
0.700 to 1.050	10 to 3 x 10^{4}		C_A x 10^{-3}
1.050 to 1.400	10^{-9} to 50 x 10^{-6}	5.0 C_C x 10^{-6}	
1.050 to 1.400	50 x 10^{-6} to 10	9.0 C_C $t^{0.75}$ x 10^{-3}	
1.050 to 1.400	10 to 3 x 10^{4}		5.0 C_C x 10^{-3}
Far Infrared			
1.400 to 1.500	10^{-9} to 10^{-3}	0.1	
1.400 to 1.500	10^{-3} to 10	0.56 $t^{0.25}$	
1.400 to 1.500	10 to 3 x 10^{4}		0.1
1.500 to 1.800	10^{-9} to 10	1.0	
1.500 to 1.800	10 to 3 x 10^{4}		0.1
1.800 to 2.600	10^{-9} to 10^{-3}	0.1	
1.800 to 2.600	10^{-3} to 10	0.56 $t^{0.25}$	
1.800 to 2.600	10 to 3 x 10^{4}		0.1
2.600 to 10^{3}	10^{-9} to 10^{-7}	1.0 x 10^{-2}	
2.600 to 10^{3}	10^{-7} to 10	0.56 $t^{0.25}$	
2.600 to 10^{3}	10 to 3 x 10^{4}		0.1

Notes:
1. For multiple pulses, apply correction factor C_P given in Table C.
2. For information on correction factors T_1, C_B, C_A, C_P and C_E, see Table C

General Notes:
1. The MPE for diffuse reflections at wavelengths between 0.400 and 1.400 μm is obtained by multiplying the corresponding MPEs above by C_E (see Table C for correction factors and T_1).
2. For repeated (pulsed) exposures see ANSI Z136.1-2000, section 8.2.3.

Table B:MPE for Skin Exposure

Wavelength (μm)	Exposure Duration, t (s)	MPE	
		(J cm^{-2})	(W cm^{-2})
Ultraviolet			
0.180 to 0.302	10^{-9} to 3 x 10^{4}	3 x 10^{-3}	
0.303	10^{-9} to 3 x 10^{4}	4 x 10^{-3}	
0.304	10^{-9} to 3 x 10^{4}	6 x 10^{-3}	
0.305	10^{-9} to 3 x 10^{4}	1.0 x 10^{-2}	
0.306	10^{-9} to 3 x 10^{4}	1.6 x 10^{-2}	
0.307	10^{-9} to 3 x 10^{4}	2.5 x 10^{-2}	
0.308	10^{-9} to 3 x 10^{4}	4.0 x 10^{-2}	
0.309	10^{-9} to 3 x 10^{4}	6.3 x 10^{-2}	
0.310	10^{-9} to 3 x 10^{4}	1.0 x 10^{-1}	
0.311	10^{-9} to 3 x 104	1.6 x 10^{-1}	
0.312	10^{-9} to 3 x 10^{4}	2.5 x 10^{-1}	
0.313	10^{-9} to 3 x 10^{4}	4.0 x 10^{-1}	
0.314	10^{-9} to 3 x 10^{4}	6.3 x 10^{-1}	
0.315 to 0.400	10-9 to 10	0.56 $t^{0.25}$	
0.315 to 0.400	10 x 10^{3}	1	
0.315 to 0.400	10^{3} to 3 x 10^{4}		1 x 10^{-3}
NOTE: 1. To calculate MPE, use the J/cm^{2} value shown or 0.56 $t^{0.25}$, whichever is lower.			
Visible and Near Infrared			
Wavelength (μm)	Exposure Duration, t (s)	MPE	
		(J cm^{-2})	(W cm^{-2})
0.400 to 1.400	10^{-9} to 10^{-7}	2C_A x 10^{-2}	
	10^{-7} to 10	1.1C_A $t^{0.25}$	
	10 to 3 x 10^{4}		0.2C_A
Far Infrared			
Wavelength (μm)	Exposure Duration, t (s)	MPE	
		(J cm^{-2})	(W cm^{-2})
1.400 to 1.500	10^{-9} to 10^{-3}	10^{-1}	
1.400 to 1.500	10^{-3} to 10	0.56 $t^{0.25}$	
1.400 to 1.500	10 to 3 x 10^{4}		0.1
1.500 to 1.800	10^{-9} to 10	1.0	
1.500 to 1.800	10 to 3 x 10^{4}		0.1
1.800 to 2.600	10^{-9} to 10^{-3}	0.1	
1.800 to 2.600	10^{-3} to 10	0.56 $t^{0.25}$	
1.800 to 2.600	10 to 3 x 10^{4}		0.1
2.600 to 10^{3}	10^{-9} to 10^{-7}	1 x 10^{-2}	
2.600 to 10^{3}	10^{-7} to 10	0.56 $t^{0.25}$	
2.600 to 10^{3}	10 to 3 x 10^{4}		0.1

Table C: Parameters and Correction Factors

Parameters/Correction Factors	Wavelength (μm)
$T_1 = 10 \times 10^{20(\lambda-0.450)}$ *	0.450 to 0.500
$T_2 = 10 \times 10^{(\alpha-1.5)/98.5}$ **	0.400 to 1.400
$C_B = 1.0$	0.400 to 0.450
$C_B = 10^{20(\lambda-0.450)}$	0.450 to 0.600
$C_A = 1.0$	0.400 to 0.700
$C_A = 10^{2(\lambda-0.700)}$	0.700 to 1.050
$C_A = 5.0$	1.050 to 1.400
$C_P = n^{-0.25}$ ***	0.180 to 1000
$C_E = 1.0$ $\alpha<\alpha_{min}$	0.400 to 1.400
$C_E = \alpha/\alpha_{min}$ $\alpha_{min}\leq\alpha\leq\alpha_{max}$	0.400 to 1.400
$C_E = \alpha^2/(\alpha_{max}\alpha_{min})$ $\alpha>\alpha_{max}$	0.400 to 1.400
$C_C = 1.0$	1.050 to 1.150
$C_C = 10^{18(\lambda-1.150)}$	1.150 to 1.200
$C_C = 8$	1.200 to 1.400

* $T_1 = 10$ s for $\lambda = 0.450$ μm, and $T_1 = 100$ s for $\lambda = 0.500$ μm.

** $T_2 = 10$ s for $\alpha < 1.5$ mrad, and $T_2 = 100$ s for $\alpha > 100$ mrad.

*** See ANSI Z136.1-2000 Section 8.2.3 for discussion of C_P and Section 8.2.3.2 for discussion of pulse repetition frequencies below 55 kHz (0.4 to 1.05 μm) and below 20 kHz (1.05 to 1.4 μm)

Notes:

1. For wavelengths between 0.400 and 1.400 μm: $\alpha_{min} = 1.5$ mrad and $\alpha_{max} = 100$ mrad
2. Wavelengths must be expressed in micrometers and angles in milliradians for calculations. The wavelength region λ_1 to λ_2 means $\lambda_1 \leq \lambda < \lambda_2$, e.g., 0.550 to 0.700 μm means $0.550 \leq \lambda < 0.700$ μm.