SAMPLE CALCULATIONS

-IONIZING RADIATION-

[redacted]

Activity-Exposure/Dose Calculation

A radionuclide source used as a level gauge has an activity of 240 mCi. The source emits a 0.89 MeV γ ray with each decay.

a.) Calculate the exposure rate at a distance of 8 ft from the source (assume point source geometry).

$$X = 6\ A\ E_\gamma\ n/(d)^2$$

X = exposure rate (mR/hr)
A = activity = 240 mCi
E_γ = γ-ray energy = 0.89 MeV
n = number of γ's per decay = 1.0
d = distance from source = 8 ft.

$$X = 6(240)(0.89)(1.0)/\ 8^2$$

$$X = 1282/64 = 20\ \text{mR/hr}$$

b.) Calculate the dose equivalent to a person who works at that location for 6 hr.

$$X = 20\ \text{mR/hr} \times 6\ \text{hr} = 120\ \text{mR}$$

$$DE = X\ (Q) = (120)(1) = 120\ \text{mrem}$$

c.) At what distance would the exposure rate be 2.5 mR/hr?

$$X_1(d_1)^2 = X_2(d_2)^2$$

$$(20)(8)^2 = (2.5)(d_2)^2$$

$$(d_2)^2 = 1280/2.5 = 512$$

$$d_2 = 22.6\ \text{ft}$$

Radioactive Decay Law

A. A radioactive source of ^{131}I has an activity of 280 mCi on the day it was received. What is the activity 47 days later (half-life is 8 d)?

$A_t = A_0 e^{-0.693t/T_{1/2}}$

$A_0 = 280$ mCi
$t = 47$ d
$T_{1/2} = 8$ d

$A_t = 280(e^{-0.693 \times 47/8}) = 280(e^{-4.07})$

$A_t = 280(0.017) = 4.78$ mCi

B. If you needed 12 mCi at that time, how much activity do you need at time zero?

$A_t = A_0 e^{-0.693t/T_{1/2}}$

$A_t = 12$ mCi
$t = 47$ d
$T_{1/2} = 8$ d

$A_t = 12 \text{ mCi} = A_0(e^{-0.693 \times 47/8}) = A_0(0.017)$

$A_0 = 12/0.017 = 705.9$ mCi

Exposure Rate and Shielding Calculation

For a 1-Ci source of ^{137}Cs, calculate (1) the exposure rate at a distance of 3 m and (2) the thickness of lead required to reduce the exposure rate to 2.5 mR/hr at that point.

1.) $X = 6\ A\ E_\gamma\ n/\ d^2$

$A = 1$ Ci
$E_\gamma = 0.66$ MeV
$n = 0.84$
$d = 3$ m $= 9.84$ ft

$X = (6)(1)(0.66)(0.84)/(9.84)^2$

$X = 3.33/96.8 = 0.034$ R/hr = [redacted]

2.) $I_t = I_0 e^{-\mu x}$

$I_t = 2.5$ mR/hr
$I_0 = 34$ mR/hr
$\mu = 1.16\ cm^{-1}$

$2.5 = 34\ e^{-1.16x}$

$2.5/34 = 0.074 = e^{-1.16x}$

To solve for x, take natural log (ln) of both sides.

$\ln 0.074 = \ln e^{-1.16x}$

$-2.61 = -1.16x$

$x = 2.61/1.16 = 2.25$ cm   h (HVL) half value layer TO

[redacted]

Laser Calculation

A helium neon laser has an output power of 10 mW. The beam diameter is 2 mm and the beam divergence is 0.3 milliradians. Calculate the irradiance at the exit port and at a distance of 1 km downrange.

Φ = output power = 10 mW = 10^{-2} W
a = exit beam diameter = 0.2 cm
ϕ = beam divergence = 0.3 mrad = 3×10^{-4} rad
r = 1 km = 10^{5} cm

Exit beam irradiance

$$E = 1.27\ \Phi/a^2$$

$$E = 1.27\ (10^{-2})/(0.2)^2 = 1.27 \times 10^{-2}/4 \times 10^{-2}$$

$$E = 0.32\ \text{W/cm}^2$$

Beam diameter at r = 1 km

$$D_L = a + r\phi = 0.2\ \text{cm} + (10^5\ \text{cm})(3 \times 10^{-4}) = 30.2\ \text{cm}$$

Beam irradiance at 1 km

$$E = 1.27\ \Phi/(a + r\phi)^2 = 1.27 \times 10^{-2}/9.12 \times 10^{2}$$

$$E = 1.4 \times 10^{-5}\ \text{W/cm}^2 = 14\ \mu\text{W/cm}^2$$

~23x larger than max. exposure

USEFUL FORMULAS

1. $\Phi\ (W) = \frac{Q(J)}{t(s)}$; $1W = 1J \cdot s^{-1}$

2. Irradiance (E): $E = \frac{\Phi}{\pi a^2/4} = \frac{1.27\Phi}{a^2}\ W \cdot cm^{-2}$ exit beam

3. Radiant Exposure (H):

$$H = \frac{Q}{\pi a^2/4} = \frac{1.27Q}{a^2}\ J \cdot cm^{-2}$$

4. Beam Diameter at Range r: $D_L = a + r\varphi$ (cm) ($\varphi \leq .37$ radians)

5. Irradiance at Range r: $E = \frac{\Phi e^{-\mu r}}{\pi \left(\frac{a+r\varphi}{2}\right)^2} = \frac{1.27\ \Phi}{(a+r\varphi)^2}\ W \cdot cm^{-2}$

6. Radiant Exposure at Range r: $H = \frac{Q e^{-\mu r}}{\pi \left(\frac{a+r\varphi}{2}\right)^2} = \frac{1.27\ Q}{(a+r\varphi)^2}\ J \cdot cm^{-2}$

7. Optical Density: O.D. = log E/E or log H/Hn

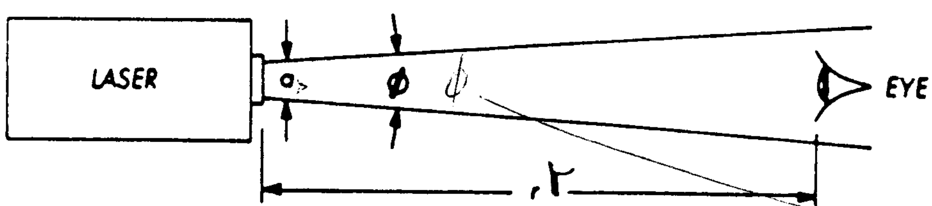

FIGURE B-3a. Intrabeam viewing — direct beam (primary beam).

ANSI laser Standard book

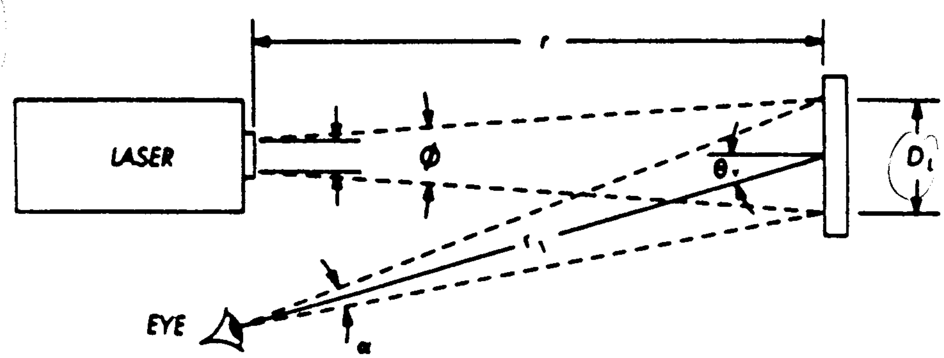

FIGURE B-4a. Extended source viewing — normally a diffuse reflection.

OPTICAL RADIATION
Sample Calculations

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Ultraviolet Radiation Exposure

The effective irradiance (E_{eff}) of a short arc lamp in the UV-B range (280-315 nm) is 28 μW/cm^2. How long can an unprotected worker be exposed to that intensity?

$TLV = 3\ mJ/cm^2 = 3 \times 10^{-3}\ J/cm^2$

$E_{eff} = 28\ \mu W/cm^2 = 2.8 \times 10^{-5}\ W/cm^2$

$t_{max} = TLV/E_{eff} = 3 \times 10^{-3}\ J/cm^2 / 2.8 \times 10^{-5}\ W/cm^2$

$t_{max} = 1.07 \times 10^2\ s = 107\ s$

What optical density filter plate is required to allow all day viewing?

$OD = \log E_{eff}/TLV = 28\ \mu W/cm^2 / 0.1\ \mu W/cm^2$

$OD = \log 280 = 2.5$

A black lamp (UV-A) used for inspection exposes a worker to an irradiance of 2.5 mW/cm^2. Can the worker be exposed to this lamp all day without protection? If not, what is the maximum allowed exposure duration?

TLV (UV-A)	= 1 mW/cm^2	$t \geq 10^3$ s
	1 J/cm^2	$t < 10^3$ s

$t_{max} = 1\ J/cm^2 / 2.5 \times 10^{-3}\ W/cm^2$

$t_{max} = 400\ s = 6\ min,\ 40\ s$

RADIOFREQUENCY/MICROWAVE RADIATION
Sample Calculations

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POWER DENSITY CALCULATION

Calculate the equivalent power density (P) for each of the following field strength values.

<u>Electric Field Strength</u>

$E^2 = 160{,}000\ V^2/m^2$

$P = E^2/3770\ mW/cm^2$

$P = 160{,}000/3770\ mW/cm^2$

$P = 42.4\ mW/cm^2$

<u>Magnetic Field Strength</u>

$H^2 = 0.12\ A^2/m^2$

$P = 37.7\ H^2\ mW/cm^2$

$P = 37.7\ (0.12)\ mW/cm^2$

$P = 4.5\ mW/cm^2$

DUTY FACTOR CALCULATIONS

A. RF Heater

An RF heater operating at 18 MHz is used to manufacture plastic holders. Each completed piece requires 2 seals and the RF power is on for 1.5 s for each seal. The operator makes 120 pieces per hour. Calculate the duty factor.

$DF = RF_{on}(hr)/0.1\ hr = RF_{on}(s)/360\ s$

RF_{on} = (time/seal)(# seals/piece)(pieces/hr)(0.1 hr)

$RF_{on} = (1.5\ s)\ (2)\ (120)\ (0.1) = 36$

$DF = 36/360 = 0.10$ unitless

B. Pulsed Radar

A pulsed radar operates at a frequency of 6.4 GHz. The pulse width is 12 μs and the unit generates 1500 pulses per second. Calculate the duty factor.

DF = PW x PRF

PW = pulse width = 12 μs = 1.2×10^{-5} s

PRF = pulse repetition frequency = 1500 Hz=1.5×10^{3}/s

$DF = (1.2 \times 10^{-5})\ (1.5 \times 10^{3}) = 1.8 \times 10^{-2}$

DF = 0.018 (1.8%)

RADIOFREQUENCY (RF) HEATER EXPOSURES

An RF heater operates at 65 MHz with a duty factor of 20% (DF = 0.2). The maximum field strength exposures measured at the operator's location are:

Electric (E) field - 15,000 V^2/m^2

Magnetic (H) field - 2.1 A^2/m^2

Is the operator exposed to field strengths exceeding the TLV? The TLVs are:

$E = 61.4$ V/m; $E^2 = 3770\ V^2/m^2$

$H = 16.3/f$ A/m = 0.251 A/m; $H^2 = 0.063\ A^2/m^2$

The duty-factor-corrected exposures are as follows:

E-field - $E = (15{,}000\ V^2/m^2)\ (0.20) = 3000\ V^2/m^2$

H-field - $H = (2.1\ A^2/m^2)\ (0.20) = 0.42\ A^2/m^2$

Exposures	TLV	Overexposure
3000 V^2/m^2	3770 V^2/m^2	No
0.42 A^2/m^2	0.063 A^2/m^2	Yes

If either the E or H field TLV is exceeded, there is an overexposure.

RF HEATER EXPOSURE CALCULATIONS

An RF heater operating at 22 MHz is used to seal notebook covers. Each cover takes 10 s to produce with an RF seal time of 2 s. The operator's exposures were measured to be 15,000 V^2/m^2 and 0.65 A^2/m^2. Is the operator overexposed? Calculate the equivalent power density for each exposure.

f = 22 MHz
RF_{on} = 2 s
Process time = 10 s

1. DF calculation

$$DF = RF_{on}/360 \text{ s}$$

$$DF = 2s \times 36/10s \times 36 = 72s/360s = 0.20$$

2. Duty-factor-corrected exposures

$$E^2 = 15{,}000 \ V^2/m^2 \ (0.2) = 3000 \ V^2/m^2$$

$$H^2 = 0.65 \ A^2/m^2 \ (0.2) = 0.13 \ A^2/m^2$$

3. TLV Calculation

$E = 1842/f = 83.7$ V/m $E^2 = 7010 \ V^2/m^2$

$H = 16.3/f = 0.741$ A/m $H^2 = 0.55 \ A^2/m^2$

4. Determination of overexposure

Both E^2 and H^2 are below the TLV.

Thus, the operator is not overexposed.

5. Equivalent Power Density

$$P = E^2/3770 = 3000/3770 = 0.8 \text{ mW/cm}^2$$

$$P = 37.7 \ H^2 = 37.7 \ (0.13) = 4.9 \text{ mW/cm}^2$$