

**RIH / RAIH Certification 2023**  
**IH Formulas**

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**1. Gases / Vapors**

**Idea Gas Law**

$$PV = nRT \quad T \text{ is in degree K}$$
$$P = \rho RT/MW \quad \rho \text{ is the density of air}$$

**Density correction factor (d)**

$$\rho_2 = \rho_1 \times \left\{ \left( \frac{T_1}{T_2} \right) \times \left( \frac{P_2}{P_1} \right) \right\} = \rho_1 \times d$$
$$d = \left( \frac{T_1}{T_2} \right) \times \left( \frac{P_2}{P_1} \right)$$

**Volume and mass concentration**

$$\text{ppm} = \frac{\text{mg/m}^3 \times 24.5}{MW} \quad @ \text{ STP } (25^\circ\text{C} \ \& \ 1 \ \text{atm})$$

**Saturation concentration**

$$\text{SC (\%vol)} = \frac{VP \ \text{mmHg}}{760 \ \text{mmHg}} \times 100$$

$$\text{SC (\%vol)} = \frac{VP \ \text{kPa}}{101.3 \ \text{kPa}} \times 100$$

**Dalton's Law**

Partial Pressure (PP) = % vol x total pressure of a mixture

**Raoult's Law**

PP of A = molar fraction of A x VP of A  
PP of B = molar fraction of B x VP of B

**Henry's Law**

The amount of a gas (in moles) dissolved in a liquid (C in mole/liter) is proportional to the partial pressure (PP in atm) of the gas in the gas phase above the liquid.

$C = k \times PP$        $k = \text{Henry's Law constant}$

**Absorption of gases/vapors through respiratory system**

$$A \text{ (mg)} = R\% \cdot V(\text{m}^3/\text{min}) \cdot C(\text{mg}/\text{m}^3) \cdot T(\text{min})$$

**2. Aerosols**

**Terminal settling velocity for  $Re < 1$  (laminar flow particle)**

$$V_{ts} = \rho_p d^2 g / 18\eta \quad \text{for particle } > 1\mu$$

$V_{ts}$  is in cm/s

$\rho_p$  is in  $\text{g}/\text{cm}^3$

$d$  is in cm

$g = 980 \text{ cm}/\text{s}^2$

$\eta = 1.81 \times 10^{-4} \text{ dyne}\cdot\text{s}/\text{cm}^2$

$$V_{ts} = \rho_p d^2 g C_c / 18\eta \quad \text{for particle } < 1\mu$$

$$C_c = 1 + (2.67/Pe_p)[6.23 + 2.01e^{-0.0821Pe_p}]$$

**Terminal settling velocity for  $Re > 1$  (turbulent flow particle)**

$$V_{ts} = Re / (6.6 d)$$

**Aerodynamic diameter**

$$d_a = d_s \sqrt{\rho}$$

$$d_a = d_e \sqrt{\rho_p / \chi} \quad \text{for non-spherical particles}$$

**Brownian diffusion**

$$x = \sqrt{2 D t}$$

**3. Gas Detection**

**Detector tubes**

$$L = KCV$$

$L = \text{length of stain}$

$C = \text{concentration of contaminant}$

$V = \text{volume of air sampled}$

$K = \text{a constant}$

**Beer-Lambert Law**

$$I_t = I_o \exp(-KCL)$$

$I_t = \text{intensity of transmitted radiation}$

$I_o = \text{intensity of incident radiation}$

$C = \text{concentration of gas}$

$L = \text{length of gas path}$

$K = \text{absorption coefficient}$

$$\text{Absorbance} = \log(I_t / I_o) = KCL$$

**Flammable gas detectors**

$$V = K \times H \times D \times C$$

$V = K \times D \times C / \text{LEL}$  for most flammable gases  $H$  is approximately proportional to  $1/\text{LEL}$ .

$V = \text{signal across the Wheatstone Bridge}$

$H = \text{heat of combustion}$

$D = \text{coefficient of diffusion of flammable gas}$

$C = \text{concentration of flammable gas}$

$K = \text{a constant}$

$\text{LEL} = \text{lower explosive limit}$

#### 4. Air Sampling

##### Active sampling

Mass corrected = mass concentration / (flow rate x sampling time)

Measured mass concentration = measured mass collected / (flow rate x sampling time)

Minimum sampling volume (liters) = analytical sensitivity ( $\mu\text{g}$ ) / {PEL ( $\text{mg}/\text{m}^3$ ) x desired fraction of PEL}

Required sample time (min) = Minimum sample volume / Sample rate (liters/min)

##### Passive sampling

Mass collected = Concentration x Sampling rate x Time

Sampling rate = D (A / L)

D = diffusion coefficient ( $\text{cm}^2 / \text{min}$ )

A = cross-sectional area of the diffusion path ( $\text{cm}^2$ )

L = diffusion path length (cm)

##### Combined efficiency

E = efficiency of 1<sup>st</sup> sampler + (100 – efficiency of 1<sup>st</sup> sampler) x efficiency of 2<sup>nd</sup> sampler

% Error of measurement = {(measured value – true value) / true value} x 100%

Cumulative error E =  $\sqrt{E_1^2 + E_2^2 + \dots}$

##### Time-weighted average (TWA)

$$\text{TWA} = \frac{C_1 \times T_1 + C_2 \times T_2 + \dots + C_n \times T_n}{T_1 + T_2 + \dots + T_n}$$

##### Combined exposure index

$$\text{Combined exposure index} = \frac{C_1}{\text{PEL}_1} + \frac{C_2}{\text{PEL}_2} + \dots + \frac{C_n}{\text{PEL}_n}$$

#### 5. Biostatistics

##### Normal distribution

Mean

$$\bar{X} = \frac{\sum X_i}{n}$$

Standard deviation

$$S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n - 1}}$$

One-sided distribution formula for lower and upper 95% confidence limits.

For  $n > 30$

$$UCL = \bar{X} + 1.645 S / \sqrt{n}$$

$$LCL = \bar{X} - 1.645 S / \sqrt{n}$$

For  $n < 30$

$$UCL = \bar{X} + tS / \sqrt{n}$$

$$LCL = \bar{X} - tS / \sqrt{n}$$

##### Log-normal distribution

Geometric mean

$$\bar{X}_g = \sqrt[n]{X_1 \times X_2 \times \dots \times X_n}$$

$$= \text{anti log} \left( \frac{\sum \log X_i}{n} \right)$$

Geometric standard deviation

$$S_g = \text{anti log} \sqrt{\frac{n \sum \log^2 X_i - (\sum \log X_i)^2}{n(n-1)}}$$

For  $n > 30$

$$\log UCL = \log \bar{X}_g + \left[ \frac{1.645 \log S_g}{\sqrt{n}} \right]$$

$$\log LCL = \log \bar{X}_g - \left[ \frac{1.645 \log S_g}{\sqrt{n}} \right]$$

For  $n < 30$

$$\log(UCL) = \log \bar{x}_G + \frac{(t^* \log S_G)}{\sqrt{n}}$$

$$\log(LCL) = \log \bar{x}_G - \frac{(t^* \log S_G)}{\sqrt{n}}$$

### Probability

For events that are not mutually exclusive i.e. they can occur alone or at the same time,

$$P(X \text{ or } Y) = P(X) + P(Y) - P(X+Y)$$

For events that are mutually exclusive i.e. they can occur alone but cannot occur at the same time,

$$P(A \text{ or } B) = P(A) + P(B)$$

## 6. Epidemiology

$$\text{Prevalence rate per 1,000} = \frac{\text{No. of existing events}}{\text{Population at risk}} \times 1,000$$

$$\text{Incident rate per 1,000} = \frac{\text{No. of new events during a time period}}{\text{Population at risk}} \times 1,000$$

**Infection rate** = number infected / population at risk of being infected

**Attack rate** = cases of disease / population at risk of being infected

**Fatality rate** = fatal cases / all cases of disease

**Pathogenicity** = cases of disease / total number infected

**Virulence** = cases of severe and fatal disease / all cases of disease

**Odds Ratio** or cross-product ratio estimates the chance of a particular event occurring in one population in relation to its rate of occurrence in another population.

**Sensitivity** is the proportion of the results classified as true positives that actually are positives

**Specificity** is the proportion of the results classified as true negatives that actually are negatives

## 7. Local Exhaust Ventilation

$$Q = V \times A$$

$$A = \pi (D/2)^2$$

$$R_e = \rho \times D \times V / \mu$$

$$TP = SP + VP$$

$$V \text{ fpm} = 4,005 \sqrt{\{VP'' \text{ w.g.} / d\}}$$

$$V \text{ m/s} = 4.043 \sqrt{\{VP \text{ mm w.g.} / d\}}$$

$$V \text{ m/s} = 1.29 \sqrt{\{VP \text{ Pa} / d\}}$$

### Density correction factor

$d = d(\text{temperature}) \times d(\text{elevation}) \times d(\text{static pressure}) \times d(\text{moisture})$

$$= \frac{T_{std}}{T_2} \times \frac{BP_2}{BP_{std}} \times \frac{(BP_{std} \pm SP)}{BP_{std}} \times \frac{(1+w)}{(1+1.607w)}$$

**Mass balance**

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

$$\rho_1 Q_1 = \rho_2 Q_2$$

**Energy balance**

$$TP_1 + \text{losses} = TP_2$$

$$(SP_1 + VP_1) + \text{Losses} = (SP_2 + VP_2)$$

**Momentum balance**

$$m_{in} \times V_{in} = m_{out} \times V_{out}$$

$$\rho_{in} A_{in} V_{in}^2 = \rho_{out} A_{out} V_{out}^2$$

**Dalla Valle Equation**

Free hanging plain opening, tapered hood and bell-shaped hood

$$Q = V (10 X^2 + A) \quad \text{without flanging}$$

$$Q = 0.75 V (10 X^2 + A) \quad \text{with flanging}$$

**Hood resting on workbench**

$$Q = V (5X^2 + A) \quad \text{without flanging}$$

$$Q = 0.75 V (5X^2 + A) \quad \text{with flanging}$$

**Free hanging slot hood**

$$Q = 3.7 V \times L \quad \text{without flanging}$$

$$Q = 2.6 V \times L \quad \text{with flanging}$$

**Hood static pressure**

$$SP_h = VP + h_e$$

$$= VP + (f \times VP)$$

$$= VP (1 + f)$$

**Coefficient of entry**

$$C_e = \sqrt{VP/SP_h} = \sqrt{\{1 / (1 + f)\}}$$

**Compound hood**

Indirect Take-off

$$SP_h = (VP_s + 1.78 VP_s) + (VP_d + f \times VP_d)$$

Direct Take-off

$$SP_h = (VP_s \text{ or } VP_d \text{ whichever is higher} + 1.78 VP_s) + (f \times VP_d)$$

**Equivalent diameter**

$$(L \times W)^{0.625}$$

$$D_{eq} = 1.3 \frac{(L \times W)^{0.625}}{(L + W)^{0.25}} \quad \text{for rectangular duct}$$

$$4 A$$

$$D_{eq} = \frac{4 A}{P} \quad \text{for irregular shape}$$

**Fanning or Darcy Equation**

$$V^2 \quad L$$

$$F = f \frac{V^2}{2g} \times \frac{L}{D}$$

**Loeffler Equation**

$$a V^b$$

$$F = \frac{a V^b}{Q^c} \times L \times VP$$

$$Q^c$$

$$= k \times L \times VP$$

Elbow (SP) loss = k x VP

Branch entry loss = k x VP

Duct contraction

$$SP_2 = SP_1 - (1 - L) (VP_2 - VP_1)$$

Duct expansion

$$SP_2 = SP_1 + R (VP_1 - VP_2)$$

### Fan pressures

$$\begin{aligned}
 FTP &= SP_{outlet} - SP_{inlet} + VP_{outlet} - VP_{inlet} \\
 &= SP_{outlet} + ISP_{inlet} + VP_{outlet} - VP_{inlet} \\
 &= SP_{outlet} + ISP_{inlet} \quad \text{if } VP_{outlet} = VP_{inlet}
 \end{aligned}$$

$$\begin{aligned}
 FSP &= SP_{outlet} - SP_{inlet} - VP_{inlet} \\
 &= SP_{outlet} - ISP_{inlet} - VP_{inlet}
 \end{aligned}$$

### Motor HP or kW

$$AkW = Q \text{ (cms)} \times FTP \text{ (mm w.g.)} / 102.2$$

$$AkW = Q \text{ (cms)} \times FTP \text{ (Pa)} / 1,000$$

$$BkW = AkW / ME$$

$$SkW = k_{dl} \times BkW$$

$$RHP > 1.33 \times SkW$$

$$AHP = Q \text{ (cfm)} \times FTP \text{ ("w.g.)} / 6356$$

$$BHP = AHP / ME$$

$$SHP = K_{dl} \times BHP$$

$$RHP = 1.33 \times SHP$$

### Fan laws at STP

Q varies directly as fan speed

TP & SP vary as the square of fan speed

HP or kW varies as the cube of fan speed

### Fan laws at non-STP

$$Q_{non-STP} = Q_{STP}$$

$$FSP_{non-STP} = FSP_{STP} \times d$$

$$kW_{non-STP} \text{ or } HP_{non-STP} = kW_{STP} \text{ or } HP_{STP} \times d$$

### Balancing at junction

$$Q_{corrected} = Q_{design} \times \sqrt{SP_{higher} / SP_{lower}}$$

$$VP_{resultant} = (Q_1/Q_3) VP_1 + (Q_2/Q_3) VP_2$$

### Pressure devices or aerodynamic velocity meters

$$V = 4005 \sqrt{VP / d}$$

$$\begin{aligned}
 &1 \\
 V_{corrected} &= V_{reading} \times \frac{1}{\sqrt{d}}
 \end{aligned}$$

### Thermal anemometers or thermodynamic velocity meters

$$\begin{aligned}
 &1 \\
 V_{corrected} &= V_{reading} \times \frac{1}{d}
 \end{aligned}$$

## 8. Dilution Ventilation

### Build-up stage

$$\begin{aligned}
 &G - QC_2 \quad -Q \\
 \log \frac{\quad}{G - QC_1} &= \frac{\quad}{2.303 k} (t_2 - t_1) \\
 &V \quad G - QC_2 \\
 t_2 - t_1 &= -2.303 k \frac{\quad}{Q} \log \frac{\quad}{G - QC_1}
 \end{aligned}$$

$$C_2 \text{ ppm} = \frac{G}{Q} (1 - e^{-(Q/kV)}) \times 1,000,000$$

**Steady state**

$$Q = k G / C$$

$$Q \text{ (lpm)} = \frac{24.1 \times E \text{ (gm per min)} \times k}{MW \times C \text{ (ppm)} \times 10^{-6} \times d}$$

$$Q \text{ (m}^3\text{/h)} = \frac{24.1 \times SG \times E \text{ (liter per hr)} \times k}{MW \times C \text{ (ppm)} \times 10^{-6} \times d}$$

**Purging**

$$t_2 - t_1 = \frac{2.303 kV}{Q} \log \frac{C_1}{C_2}$$

$$C_2 = C_1 e^{-Q(t_2 - t_1) / (kV)}$$

**Sensible heat**

$$Q \text{ (cmm)} = \frac{H_s \text{ (watt)}}{20 (T_i - T_o) \text{ }^\circ\text{C}}$$

$$Q \text{ (cfm)} = \frac{H_s \text{ (BTU / hr)}}{1.08 (T_i - T_o) \text{ }^\circ\text{F}}$$

**Latent heat**

$$Q \text{ (cms)} = \frac{H_i \text{ (watt)}}{45,000 \times \Delta h \text{ (kg water / kg dry air)}}$$

$$Q \text{ (cfm)} = \frac{H_i \text{ (BTU / Hr)}}{0.67 \times \Delta h \text{ (grains / lb)}}$$

**9. Indoor Air Quality**

**Number of air changes**

$$N = 60 \times Q / \text{room volume}$$

**Outdoor air supply (Q)**

$$Q \text{ (m}^3\text{/s)} = \frac{n \times G}{C_e \text{ (ppm} \times 10^{-6}\text{)}} \quad \text{steady state (at equilibrium)}$$

*n is the number of occupants*

*G is the rate of generation of carbon dioxide per person (0.011 ft<sup>3</sup>/min or 5.3x10<sup>-6</sup> m<sup>3</sup>/s)*

*C<sub>e</sub> is the equilibrium concentration of carbon dioxide at steady state generated by the occupants*

*The calculated C<sub>e</sub> does not include the outdoor carbon dioxide concentration (currently 428 ppm)*

*Total CO<sub>2</sub> concentration measured = C<sub>e</sub> + 428 ppm*

**10. Noise**

$$I = \frac{W}{4\pi r^2}$$

$$I = \frac{p^2}{\rho C}$$

$$L_w = 10 \log \frac{W}{W_0}$$

$$W_0 = 10^{-12} \text{ w (1 piconWatt)}$$

$$L_p = 10 \log \frac{p^2}{p_0^2}$$

$$p_0 = 20 \text{ } \mu\text{Pa}$$

$$L_T = 10 \log \left[ \sum 10^{\frac{L_i}{10}} \right]$$

**Metric unit** (*R* in m<sup>2</sup> Sabins; *r* in m)

$$L_p = L_w + 10 \log \left[ \frac{Q}{4\pi r^2} + \frac{4}{R} \right]$$

**US unit** ( $R$  in  $\text{ft}^2$  Sabins;  $r$  in  $\text{ft}$ )

$$L_p = L_w + 10 \log \left[ \frac{Q}{4\pi r^2} + \frac{4}{R} \right] + 10.5$$

$$R = \frac{\alpha S}{1 - \alpha}$$

$$L_{p2} = L_{p1} - 20 \log (r_2 / r_1)$$

**Permissible exposure level**

$$\text{SPL} = 85 - 10 \log \{T / 8\}$$

**Permissible exposure time**

$$T = 8 / \{2^{(\text{SPL} - 85)/3}\}$$

**Noise dose  $D = t / T$**

$$D = \frac{t_1}{T_1} + \frac{t_2}{T_2} + \dots + \frac{t_n}{T_n} = \sum_{i=1}^n \frac{t_i}{T_i}$$

**Equivalent sound level ( $L_{eq}$ )**

$$L_{eq} = 10 \log \left[ \sum_{i=1}^n \frac{t_i}{T} \times 10^{\frac{L_i}{10}} \right]$$

$$L_{eq} = 85 + 10 \log \frac{D\%}{12.5 \times T}$$

$$L_{eq, 8 \text{ hr}} = L_{eq, T \text{ hr}} + 10 \log (T / 8)$$

**Mass Law**

Metric unit

$$\begin{aligned} \text{TL} &= 20 \log (f \times w) - 48 \\ &= 20 \log f + 20 \log w - 48 \end{aligned}$$

US unit

$$\begin{aligned} \text{TL} &= 20 \log (f \times w) - 33 \\ &= 20 \log f + 20 \log w - 33 \end{aligned}$$

**Transmission Loss (TL)**

$$\begin{aligned} \text{TL} &= 10 \log (1/t) \\ &= 10 \log (I_i / I_t) \\ t &= I_t / I_i \end{aligned}$$

**11. Vibration**

**Root-mean-square** vibration acceleration:  $a_{\text{rms}} = \sqrt{\{1/T\} \int a^2 (t) dt}$

$$\% \text{ Dose} = \{A(8)/A(8)_{\text{limit}}\}^2 \times 100$$

$$\% \text{ Dose} = \{a_{\text{rms}}/A(8)_{\text{limit}}\}^2 \times (T/8) \times 100$$

**Vibration dose value:**  $\text{VDV} = \{\int a^4 (t) dt\}^{1/4}$

**Whole-body vibration**

TLV at Time  $T$  (hrs):  $\text{TLV} = 2.45 / \sqrt{T}$

AL at Time  $T$  (hrs):  $\text{AL} = 1.22 \sqrt{T}$

**Hand-arm vibration**TLV at Time T (hrs): TLV = 5.0  $\sqrt{(8/T)}$ AL at Time T (hrs): AL = 2.5  $\sqrt{(8/T)}$ **Transmissibility (T)**

$$T = \sqrt{\frac{1 + 4 (f / f_n)^2 \delta^2}{\{1 - (f / f_n)^2\}^2 + 4 (f / f_n)^2 \delta^2}}$$

*f* is the shaking force frequency, c/s*f<sub>n</sub>* is the natural frequency of the system, c/s*δ* is the damping ratio or factor – an indication of the ability of the isolator to dissipate energy**Isolation (I)**

$$I = (1 - T) \times 100\%$$

**Natural frequency (f<sub>n</sub>)**

$$f_n = 4.98 / \sqrt{d} \quad d \text{ is the static deflection in cm}$$

**Spring constant (K)**

$$K = W / d$$

*W* is the weight on each mounting point of the machine, kg*K* is the spring constant or stiffness of the isolator, kg/cm**12. Heat (Thermal Stressor)****Heat balance equation**

$$S = M \pm R \pm C - E$$

**Metric units**

(Temp °C, V m/s, Pa = mm Hg)

$$E_{\max} = 14 V^{0.6} (42 - P_a) \quad \text{kcal/hr}$$

$$C = 7.0 V^{0.6} (T_a - 35) \quad \text{kcal/hr}$$

$$R = 6.6 (T_w - 35) \quad \text{kcal/hr}$$

$$T_w = T_g + 1.8 V^{0.5} (T_g - T_a) \quad ^\circ\text{C}$$

**US units (mixed)**

(Temp °F, V ft/min, Pa mmHg)

$$E_{\max} = 2.4 V^{0.6} (42 - P_a) \quad \text{Btu/hr}$$

$$C = 0.65 V^{0.6} (T_a - 95) \quad \text{Btu/hr}$$

$$R = 15 (T_w - 95) \quad \text{Btu/hr}$$

$$T_w = T_g + 0.13 V^{0.5} (T_g - T_a) \quad ^\circ\text{F}$$

**WBGT indoor (without exposure to sun)**

$$\text{WBGT} = 0.7 T_{\text{nw}} + 0.3 T_g$$

**WBGT outdoor (with exposure to sun)**

$$\text{WBGT} = 0.7 T_{\text{nw}} + 0.2 T_g + 0.1 T_a$$

**Heat Stress Index (HSI)**

$$\text{HSI} = \frac{E_{\text{req}}}{E_{\text{max}}} \times 100 \%$$

**Allowable exposure time (AET)**

$$\text{AET (hr)} = \frac{58.6 \text{ kcal}}{(E_{\text{req}} - E_{\text{max}}) \text{ kcal/hr}}$$

**Minimum recovery time (MRT)**

$$\text{MRT (hr)} = \frac{58.6 \text{ kcal}}{(E_{\text{max at rest}} - E_{\text{req at rest}}) \text{ kcal/hr}}$$

### 13. Cold Stress

**Wind Chill Index (in C)** =  $13.12 + 0.6215 \times T - 11.37 \times V^{0.16} + 0.3965 \times T \times V^{0.16}$   
 T is the actual air temperature °C, V is the wind speed in km/h

**Wind Chill Index (in F)** =  $35.74 + 0.6215 \times T - 35.75 \times V^{0.16} + 0.4275 \times T \times V^{0.16}$   
 T is the actual air temperature in °F, V is the wind speed in mph.

#### Rate of heat loss from exposed skin

$H (W/m^2) = 1.16 (10 V_{air}^{0.5} + 10.45 - V_{air}) (33 - T_{db})$   
 $V_{air}$  in m/s;  $T_{db}$  in C ; 1 kcal/hr = 1.163 watt

### 14. Ergonomics

#### Body lever systems

$L \times l = F \times f$

#### NIOSH Lifting Equation

##### Recommended weight load (RWL)

$RWL = 23 \text{ kg} \times HM \times VM \times DM \times FM \times CM \times AM$

$HM = 25 / h \text{ cm}$  *horizontal multiplier*

$VM = 1 - 0.003 [(75 - v \text{ cm})]$  *vertical multiplier*

$DM = 0.82 + 4.5 / d \text{ cm}$  *distance multiplier*

$FM$ : from table *frequency multiplier*

$CM$ : 1.0(good), 0.95(fair), 0.9(poor) *coupling multiplier*

$AM = 1 - 0.0032 \times A$  *asymmetric multiplier*

ISO and Singapore use 25 kg is the max acceptable weight

#### Lifting Index (LI)

$LI = \text{Load} / RWL$

#### Muscle endurance time (T)

##### Static muscular effort

$\text{Log } T = 1.0 - \frac{1.96 \times \%MVC}{100}$

$T = \text{endurance time in minutes}$

$MVC = \text{max. voluntary contraction}$

##### Dynamic muscular effort

$\text{Log } T = 4.0 - \frac{4.0 \times \%MAC}{100}$

$T = \text{Endurance time in minutes}$

$MAC = \text{max. aerobic capacity i.e. max. oxygen a person can consume}$

#### Recovery time (RT)

Static muscular effort

$RT = 18 \left( \frac{t}{T} \right)^{1.4} \cdot \left\{ \frac{\%MVC}{100\%} - 0.15 \right\}^{0.5} \cdot t$

$t = \text{contraction or work time}$

$T = \text{endurance time in minutes}$

$MVC = \text{max. voluntary contraction}$

Dynamic muscular effort  
 $(\%MAC/100) - 0.33$   
 $RT = \frac{\quad}{0.23} \times t$   
*MAC = max. aerobic capacity*  
*t = work time*

**15. Ionizing Radiation**

**Radioactive decay**

$N = N_0 e^{-\lambda t}$   
*λ is the decay constant*  
 $\lambda = 0.693 / t_{1/2}$   
*t<sub>1/2</sub> is the ½ life*

**Dose** = Dose Rate x Exposure Time

**Inverse square law**

$D_1 / D_2 = r_2^2 / r_1^2$

**Dose equivalent** (rem or Sv) = Absorbed Dose (rad or Gy) x QF

**Quality factor (QF)**

Type of Ionising Radiation	QF
X-rays, gamma rays, beta particles	1.0
Thermal neutrons	2.0
Alpha particles, fast neutrons	10

**Internal dose rate for α and β emitters**

$D$  (rad/day)  
 $A (\mu Ci) \times 2.2 \times 10^6$  (dpm/μCi)  $\times 1440$  (min/day)  $\times E$  (MeV)  $\times 1.6 \times 10^{-6}$  (erg/MeV)  
 = -----  
 $W$  (gm)  $\times 100$  (ergs/gm/rad)

**Effective, physical and biological half-life**

$1 / T_{1/2 \text{ eff}} = (1 / T_{1/2 \text{ phy}}) + (1 / T_{1/2 \text{ bio}})$

**Total Dose** = 1.44 x  $D_0 \times T_{1/2 \text{ eff}}$

*D<sub>0</sub> is the initial dose rate/day*

**Shielding formula for X & Y Rays**

$I = I_0 e^{-\mu x}$

$I = I_0 e^{-(0.693 / HVL) x}$

*I = intensity or dose rate of a beam that penetrates a shield*

*I<sub>0</sub> = original intensity or dose rate*

*μ = linear attenuation coefficient = 0.693 / HVL*

*X = shield thickness*

**Beta radiation dose rate (D)**

$338,000 \times A$  (mCi)  
 $D$  (mrem/h) = -----  
 $r^2$  (cm)<sup>2</sup>

*A is the source activity in mCi*

*r is the distance in cm from the source*

**Gamma radiation dose rate (D)**

$r A$   
 $D = \text{-----}$

$$r^2$$

*D is the dose rate in R/h*

*r is the specific gamma ray constant in R/mCi-h at 1 cm*

*A is the source activity in mCi*

*r is the distance in cm from the source*

$$D = \frac{5,000 \times A \times E \times f}{r^2}$$

*D is the dose rate in mR/h*

*A is the source activity in mCi*

*E is the gamma photon energy in MeV*

*f is the fraction of disintegrations yielding the photon energy of E MeV*

*r is the distance in cm from the source*

## 16. Non-ionizing Radiation

### Speed

$$c \text{ (m/s)} = v \text{ (Hz)} \times \lambda \text{ (\mu m)}$$

### Energy

$$E \text{ (eV)} = h \times v \text{ (Hz)} = 1.24 / \lambda \text{ (\mu m)}$$

$$h = \text{Planck's constant } (6.6 \times 10^{-34} \text{ J}\cdot\text{sec})$$

### Infrared radiation

#### Stefan-Boltzmann Law

$$I = e \times \sigma \times T^4$$

*I = intensity or rate of energy flow in watt/m<sup>2</sup> or J/m<sup>2</sup>s*

*e = emissivity of the object (e = 1 for ideal radiator).*

$$\sigma = 5.6703 \times 10^{-8} \text{ watt/m}^2\text{K}^4$$

*T = absolute temperature (°K) of the object*

### UV radiation

$$\text{Dose (J/m}^2\text{)} = \text{Dose Rate (J/m}^2\text{/h)} \times \text{Exposure Time (h)}$$

$$\text{Standard erythemal dose (SED)} = \text{SED} = 100 \text{ J/m}^2$$

**UV Index** is expressed as dose rate

$$1 \text{ UV Index} = 90 \text{ J/m}^2 \text{ /hr}$$

**Sun protection factor (SPF)** = Sunburn radiation dose with sunscreen / Sunburn radiation dose without sunscreen

### Laser

$$\text{Optical density} = \log (I_i / I_t)$$

$$= \log (\text{potential exposure} / \text{maximum permissible exposure})$$

## 17. Visible Light (Lighting)

### Workplace Lighting

$$\text{Intensity } I \text{ (cd)} = \text{Flux } F \text{ (lumens)} / (4\pi) \text{ steradian}$$

$$\text{Illuminance } E \text{ (lux)} = \text{Flux } F \text{ (lumens)} / \text{Area } A \text{ (m}^2\text{)}$$

$$\text{Illuminance } E \text{ (footcandle)} = \text{Flux } F \text{ (lumens)} / \text{Area } A \text{ (ft}^2\text{)}$$

$$\text{Illuminance } E \text{ (lux)} = \text{Flux } F \text{ (lumens)} / (4 \pi d^2) \text{ m}^2$$

$$\text{Illuminance } E \text{ (footcandle)} = \text{Flux } F \text{ (lumens)} / (4 \pi d^2) \text{ ft}^2$$

$$\text{Illuminance } E \text{ (lux)} = \text{Intensity } I \text{ (cd)} / d^2 \text{ (m}^2\text{)}$$

Illuminance E (footcandle) = Intensity I (cd) / d<sup>2</sup> (ft<sup>2</sup>)

**Contrast** = 
$$\frac{\text{Luminance of Object} - \text{Background Luminance}}{\text{Background Luminance}}$$

**Brightness Ratio** = 
$$\frac{\text{Luminance of Object}}{\text{Background Luminance}}$$

**Reflectance** = 
$$\frac{\text{luminance (foot-lamberts)}}{\text{illuminance (foot-candles)}}$$

**Lighting design formula**

$E (\text{lux}) \times A (\text{m}^2) = N \times L (\text{lumen / lamp}) \times \text{CU} \times \text{MF}$

*CU is the utilization factor*

*MF is the maintenance factor*