INTAKE FRACTION

* Intake fraction = IF (previously inhalation transfer factor)
* Simple but powerful tool (screening calcs; inhalation dose)
* IF = fraction pollutant mass emitted by single source that is inhaled.
  - inhaled by (a) individual or (b) population.
* Dose (inhalation) = IF × E × Δt
  (E: mass emission rate.)
* PIF = population intake fraction = $\sum_{\beta} IF$ (all individuals)
  - β = entire urban area; large building, etc.

Mathematically:

$$IF = \frac{\text{mass inhaled}}{\text{mass emitted}} = \frac{\int_{t_0}^{t_{f_2}} C(t)\, Q_\beta(t)\, dt}{\int_{t_0}^{t_{f_1}} E(t)\, dt}$$

$C(t)$ = mass concentration due only to specific source (mg/m^3)

$Q_\beta(t)$ = breathing rate (m^3/hr)

$E(t)$ = specific source emission rate (mg/hr)

t = time (hr) 0 = initial f = final note t_{f_1} vs. t_{f_2}

At steady-state

$$IF = \frac{C Q_\beta \int dt}{E \int dt} = \frac{C Q_\beta}{E} = \frac{\text{mass inhalation rate}}{\text{mass emission rate.}}$$

Recall mass balance model for C(t)

$$\frac{dC}{dt} = \lambda \cancel{C_0} - \lambda C + E/\forall \quad \therefore \frac{dC}{\lambda C - E/\forall} = -dt$$

($C_0 \approx 0$ (why?))

$$\ln\left\{\frac{\lambda C - E/\forall}{\lambda C_{(t=0)} - E/\forall}\right\} = -\lambda \int dt = -\lambda t$$

$$\ln\left\{1 - \frac{\lambda C}{E/\forall}\right\} = -\lambda t \quad \therefore \quad C = \frac{E}{\lambda \forall}\left(1 - e^{-\lambda t}\right)$$

or at steady-state $\quad C = \frac{E}{\lambda \forall}$

Dynamic Case:

$$IF = \frac{\int C(t)\Phi_B(t)\,dt}{\int E(t)\,dt} = \frac{\int \frac{E(t)}{\lambda \forall}\left(1 - e^{-\lambda t}\right)\Phi_B(t)\,dt}{\int E(t)\,dt}$$

- Assume $E, \lambda, \forall, \Phi_B$ constant.

$$IF = \frac{\frac{E}{\lambda \forall}\Phi_B \int \left(1 - e^{-\lambda t}\right)dt}{E(t_f - t_i)} = \boxed{\frac{\Phi_B}{\lambda \forall\, \Delta t}\int_{t_0}^{t_f}\left(1 - e^{-\lambda t}\right)dt}$$

Steady-state Case:

$$IF = \frac{C\Phi_B}{E} = \frac{\cancel{E}}{\lambda \forall}\frac{\Phi_B}{\cancel{E}} = \frac{\Phi_B}{\lambda \forall} = \boxed{\frac{\Phi_B}{\Phi_V}}$$

NOTES:

1. IF ≠ function (E) in either dynamic or S-S. cases!
2. IF depends on Φ_B, Φ_V (or $\lambda \forall$) and time (if dynamic)
3. Simple, but powerful.

A Closer Look at IF for steady-state

$$IF = \frac{\Phi_B}{\Phi_V} \simeq \frac{0.78\ m^3/hr}{\lambda\ V}$$

$\lambda \simeq 0.2 - 1/hr.$

$V \simeq 350\ m^3$ (varies a lot!)

$IF \simeq 0.0002 - 0.01$ (0.2% to 1% of mass emitted is inhaled)

* Assumes well-mixed environment (no personal cloud, etc.)
* Assumes no removal terms.

Comparison w/ outdoor sources

* $IF \simeq 10^{-12} - 10^{-10}$ (from literature, eg., Lai et al.)
* $IF(\text{indoor source}) / IF(\text{outdoor source}) \simeq 10^{7} - 10^{10}$.
* outdoor source must emit $10^{7} - 10^{10}$ more for same dose as indoor source (proximity / activity patterns)

EXAMPLE: $PM_{2.5}$ emissions from candle.

* $E_{candle} \sim 1 - 100$ mg/hr. (use Pagels candle 1 $\simeq$ 2.4 mg/hr)
* mass inhaled = mass emitted $\times$ (IF)
* want → outdoor source equivalent of 1 candle. ($PM_{2.5}$)

$$IF_{indoor} \times E_{candle} = IF_{outdoor} \times E_{source}.$$

mass inhalation indoors = mass inhalation outdoors

$$E_{source} = \frac{IF_{indoors}}{IF_{outdoors}} \times E_{candle} \simeq \frac{0.006}{10^{-11}} (2.4\ mg/hr)$$

$$= 1.4 \times 10^{9}\ mg/hr = 1.4 \times 10^{3}\ kg/hr = 1.4 \text{ metric tons/hr}$$

$\simeq$ 12,000 metric tons/year (wow!)

How does this compare w/ all major point sources in Texas?

* PM_{10} (2010) $\simeq$ 55,000 - 60,000 metric tons/year.
* All sources (major point)! & $PM_{2.5} < PM_{10}$!!

POPULATION INTAKE FRACTION (PIF)

INDOOR:

Dynamic: $$PIF = \frac{\sum_{i=1}^{N} \int C_i(t) \Phi_{Bi}(t)\, dt}{\int E(t)\, dt}$$

Steady-state: $$PIF = \sum_{i=1}^{N} \frac{C_i \Phi_{Bi}}{E}$$

N = # of building occupants

Removal of Indoor Pollutants: (Indoor source) w/ Removal

$$\forall \frac{dC}{dt} = Q\phi_0 - QC + E - \underbrace{\eta Q_c C}_{\text{control}} - \underbrace{v_d C A}_{\text{deposition/reaction on surfaces.}}$$

$$\frac{dC}{dt} = -\lambda C + \frac{E}{\forall} - \eta\frac{Q_c}{\forall} C - v_d \frac{A}{\forall} C$$

* ASSUME steady-state to simplify:
* Assume no control:

$$\phi = -\lambda C + \frac{E}{\forall} - v_d \frac{A}{\forall} C \quad \therefore \quad \phi = -(\lambda + v_d \tfrac{A}{\forall})C + \frac{E}{\forall}$$

$$C = \frac{E/\forall}{(\lambda + v_d \frac{A}{\forall})} \quad \therefore \quad \frac{1}{(1 + \frac{v_d A/\forall}{\lambda})} \times \frac{E}{\lambda \forall}$$

$$IF = \frac{C\phi_\beta}{E} = \frac{\frac{1}{(1 + \frac{v_d A/\forall}{\lambda})} \frac{E}{\lambda \forall} \phi_\beta}{E} = \frac{1}{(1 + \frac{v_d A/\forall}{\lambda})} \left(\frac{\phi_\beta}{Q_{vent}}\right)$$

$+ \frac{\eta Q_c}{\lambda \forall}$ (If control added back in)

NOTES:

* Effects of removal on IF
  - If $v_d A/\forall \approx \lambda$ IF down by 1/2.
* For OZONE: $v_d A/\forall > \lambda$ ($\sim 2-5\times$ as great)
  - IF lower than for inert pollutant.
* For particles: $v_d A/\forall = f_n(d_p)$
  - See results in Lai et al. (don't worry about this → I will show in lecture)
  - Discuss peak IF & why?

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* Discussion of Nazaroff (2008).