Improving Exposure Judgment with Exposure Models

Brent Altemose, Ph.D., CIH, CSP
Owner & Principal Consultant, ALTIH LLC
brent@altih.com

Advancing Our Science AND Practice TO BETTER PROTECT WORKERS and Communities

Four Exciting Initiatives:

Initiative	Purpose
AIHA – ACGIH Defining the Science	Advance our science to improve the ability of practitioners to protect workers and communities.
Standards of Care	Define minimum practice performance expectations for ensuring acceptable worker protection.
State of the Art vs. Practice	Implement a continuous improvement strategy to close gaps between current practice and the state of the art and minimum standards of care.
AIHA – ACGIH Improving Exposure Judgements	Accelerate adoption of the use of IH statistical and other tools to improve the accuracy of worker exposure assessments.

Learn More Here

AIHA / ACGIH Initiative:

Improving Exposure Judgment Accuracy

Improve Practice to Align with Current Science

Drive a significant shift in the OEHS practice paradigm: from one where tools and activities to improve exposure judgment accuracy and interpretation are rarely or sporadically used, to one where their use is routine and expected.

Public Web Page

Improving Exposure Judgment with Exposure Models

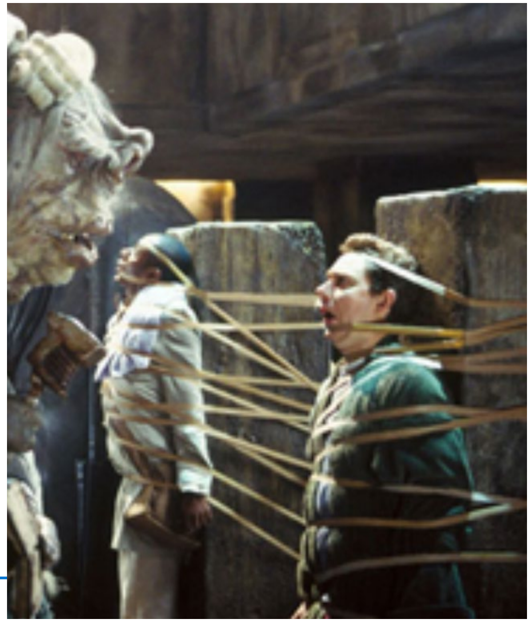
A Hitchhiker's Guide to Modeling

Where We Are Today…

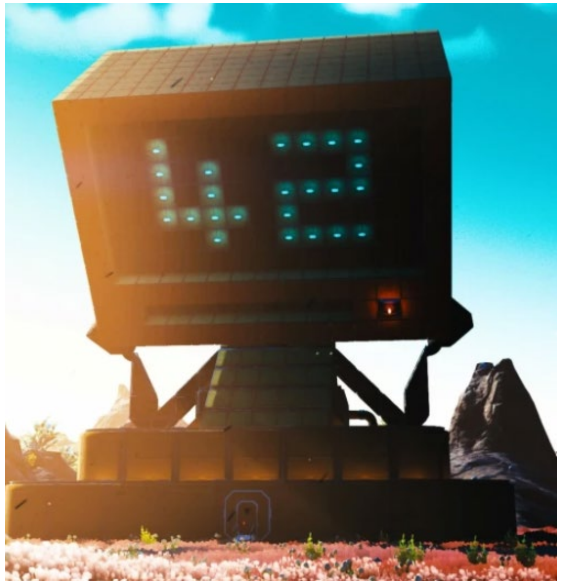
- Despite advances in monitoring and the use of statistical analysis and tools, “professional judgment” still rules the day
- The most common number of samples collected to make an assessment of exposure is ZERO
- The majority of tasks with potential exposure are never monitored

Barriers to Adoption of Modeling Tools

- Inertia
- Overconfidence/ The Expert Myth
- Compliance approach to monitoring
- May IHs view models as time consuming and complicated with limited application/utility



The Expert Myth



- We tend to believe that a correlation exists between depth of knowledge and our ability to forecast exposures
- Sometimes may be true, but often results in overconfidence in qualitative exposure judgments. So, there are glaring flaws in “professional judgment”[1]:
  - *Difficult to explain objectively*
  - *Typically not supported by quantified facts relating cause & effect*
  - *Not amenable to technology transfer*
  - *Insufficient as evidence for concerned workers or in litigation*

[1]Kiel et at. 2018. Mathematical Models for Estimating Occupational Exposure to Chemicals. 2nd edition. Fairfax, VA: American Industrial Hygiene Association (AIHA).

Advantages of Modeling

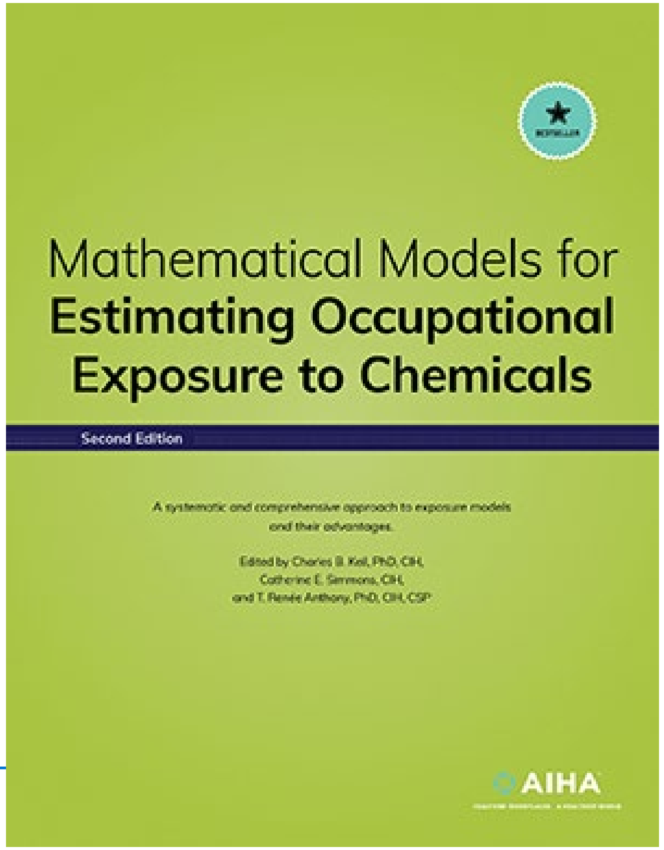
- Can't measure everything; may save time and money compared to collecting measurements
- Formalizes qualitative hypothesis with transparency and a real description of uncertainty
- Early warning about potential exposures and "put to rest" very low or trivial exposures
- Allows prospective and retrospective estimates of exposure
- Focuses on predictors of exposure, links cause and effect
  - *Provides context for measurement results*
  - *Estimate the effect of changes*
- Learn and apply incrementally

Refs: Kiel et at. 2018. Mathematical Models for Estimating Occupational Exposure to Chemicals. 2nd edition. Fairfax, VA: American Industrial Hygiene Association (AIHA); Jayjock and Hawkins 2022. Exposure Modeling: the Next Generation. *The Synergist*. June/July 2022.

Where to Start

- “Mathematical Models for Estimating Occupational Exposure to Chemicals” (AIHA – Kiel et al. 2018, 2nd ed.)
- Hewett and Ganser – “Models for every occasion” (Parts I to IV, JOEH 2017)
- IHMOD™ (latest version: 2.015, January 2023)
- IHSkinPerm™ (latest version: 2.4, October 2021)

AIHA Risk Assessment Tool Download



Improving Exposure Judgment with Exposure Models

Case Study #1 – Isoflurane Exposure

Modeling Case Study #1

- Exceeded company's internal OEL for isoflurane
  - 2 ppm (1-hour TWA)
- First attempt to install local exhaust ventilation was unsuccessful due to low flow rates achieved
- Biosafety Cabinet was not considered in initial design

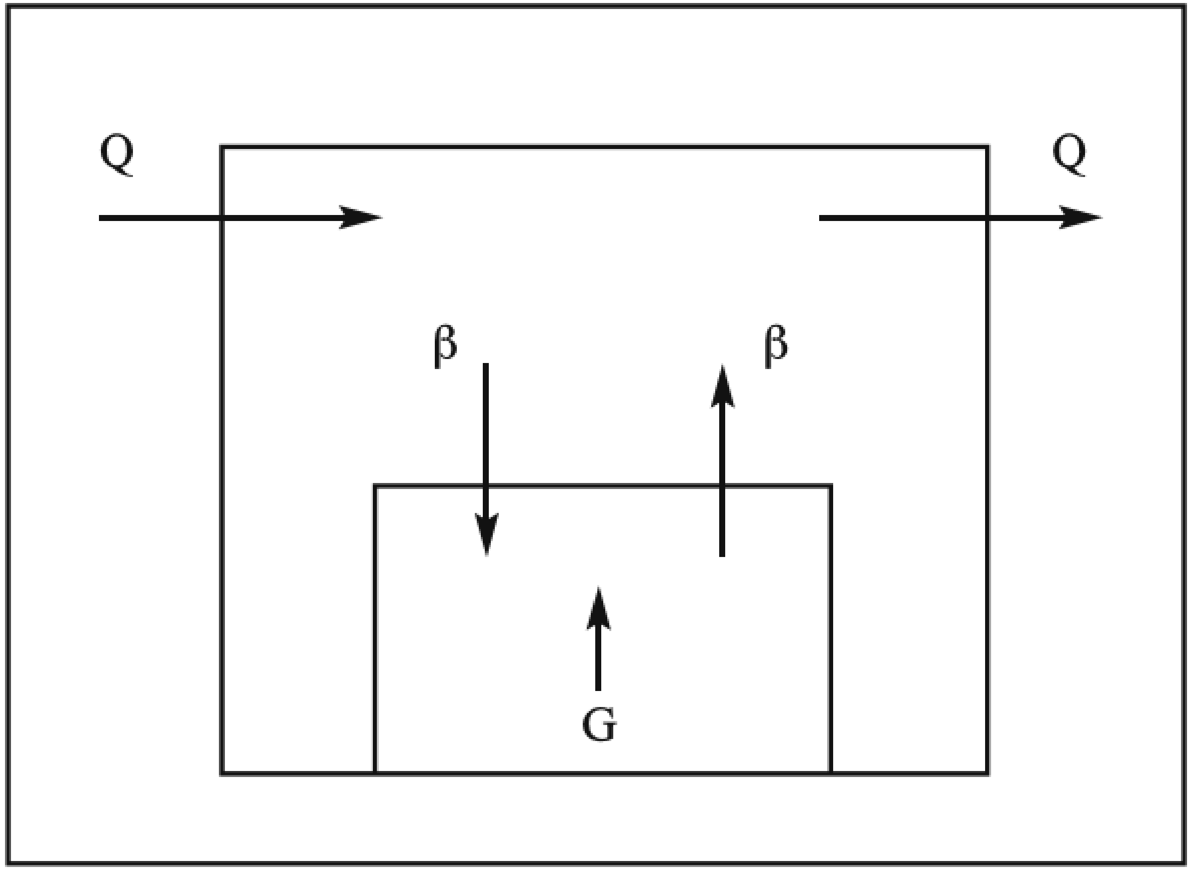

fair

“Before” Exposure Data

Category	n	GM (ppm)	Max (ppm)
All exposures	19	1.6	20
Biosafety Cabinet	2	17	20
Large Animal w/Tube	4	0.67	1.3
Small Animal w/Mask	1	1.4	1.4
Large Animal w/Mask	8	2.7	5.0
Large Animal Prep	2	1.1	1.3

n=number of samples; GM = geometic mean;
ppm = parts per milion

Two-Box Model



Source: Keil et al., ed., Mathematical Models for Estimating Occ Exp to Chemicals, 2nd ed. 2009.

AIHA
HEALTHIER WORKPLACES
A HEALTHIER WORLD

Exposure Assessment
Strategies Committee

IH Mod 2.0™

Deterministic | Monte Carlo

HELP | HELP

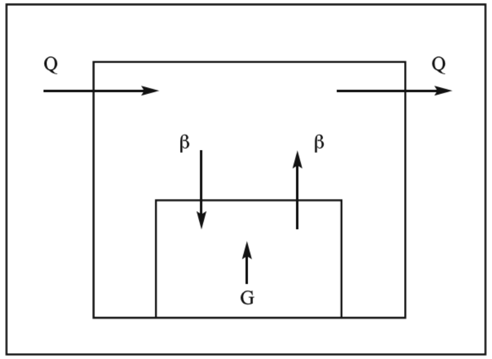
		Deterministic	Monte Carlo
1	*Well -Mixed Room Model*		
2	*Well-Mixed Room Model with Backpressure*		
3	*Well-Mixed Room Model Purging Equation*		
4	*Well-Mixed Room Model Decreasing Emission Rate, Spill Model*		
5	*Turbulent Eddy Diffusion without Advection following a Pulse Release*		
6	*Turbulent Eddy Diffusion without Advection with a Constant Emission Rate*		
7	*Turbulent Eddy Diffusion with Advection following a Pulse Release*		
8a	*Two-Zone Model with a Constant Emission Rate*		
8b	*Two-Zone Mode with a Decreasing Emission Rate*		
10	*Turbulent Eddy Diffusion with Advection with a Constant Emission Rate*		
11	*Near and Mid - Field Plume Models*		

PDF

Version 2.012, August 2022

This file has been created by Daniel Drolet and Tom Armstrong with review by Michael Jayjock

Two-Box Model



$$\beta = \frac{1}{2} FSA \; x \; S \qquad C_{N,SS} = \frac{G}{Q} + \frac{G}{\beta} \qquad C_{F,SS} = \frac{G}{Q}$$

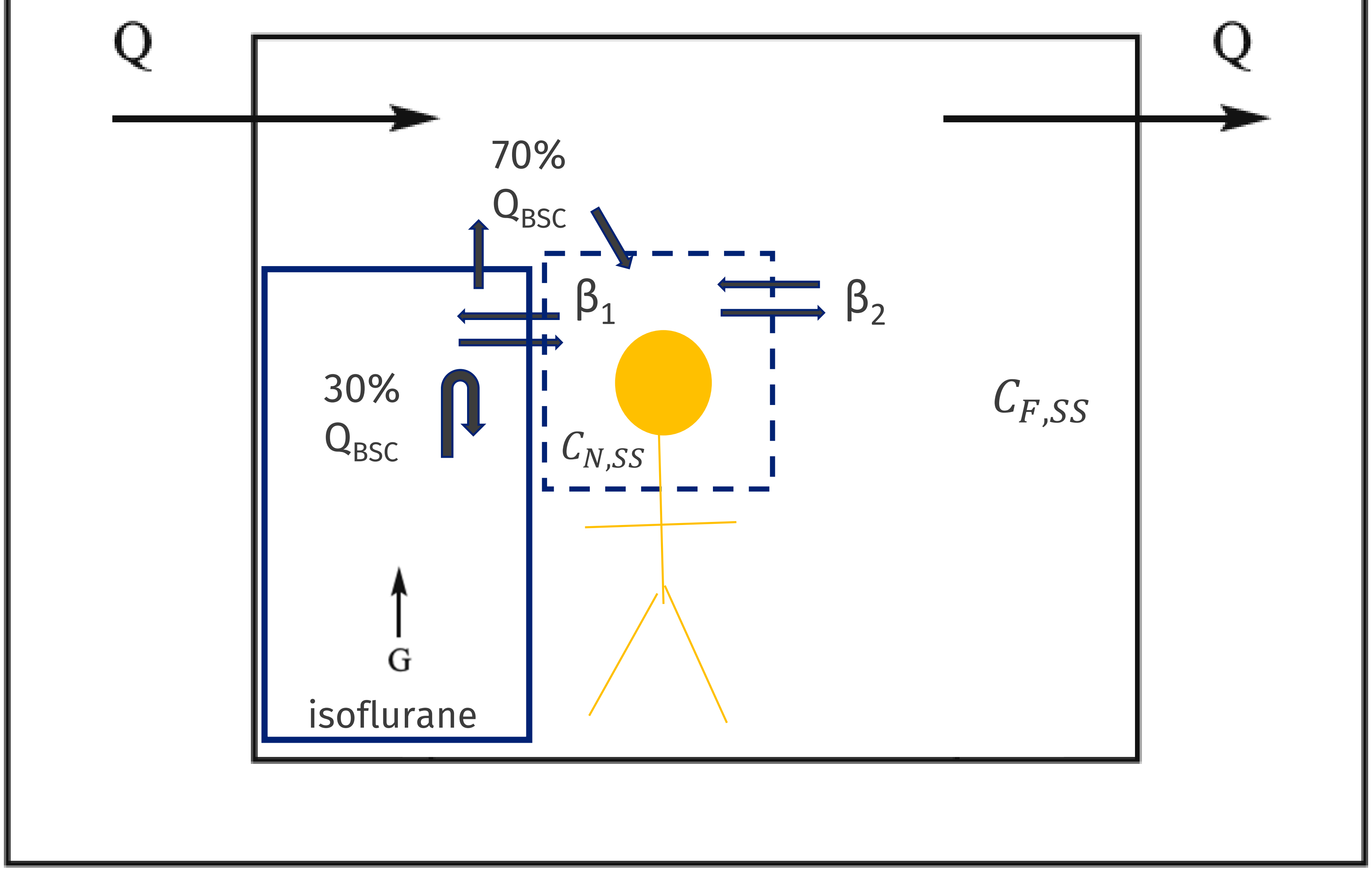
Need for the model:

V_r = room volume, m^3
V_n = near field volume, m^3
G = mass emission rate, mg/min
β = air flow rate between the near and far fields (m^3/min)
Q = room air flow rate (m^3/min)
FSA = free surface area of near field, m^2
S = random air speed, m/min

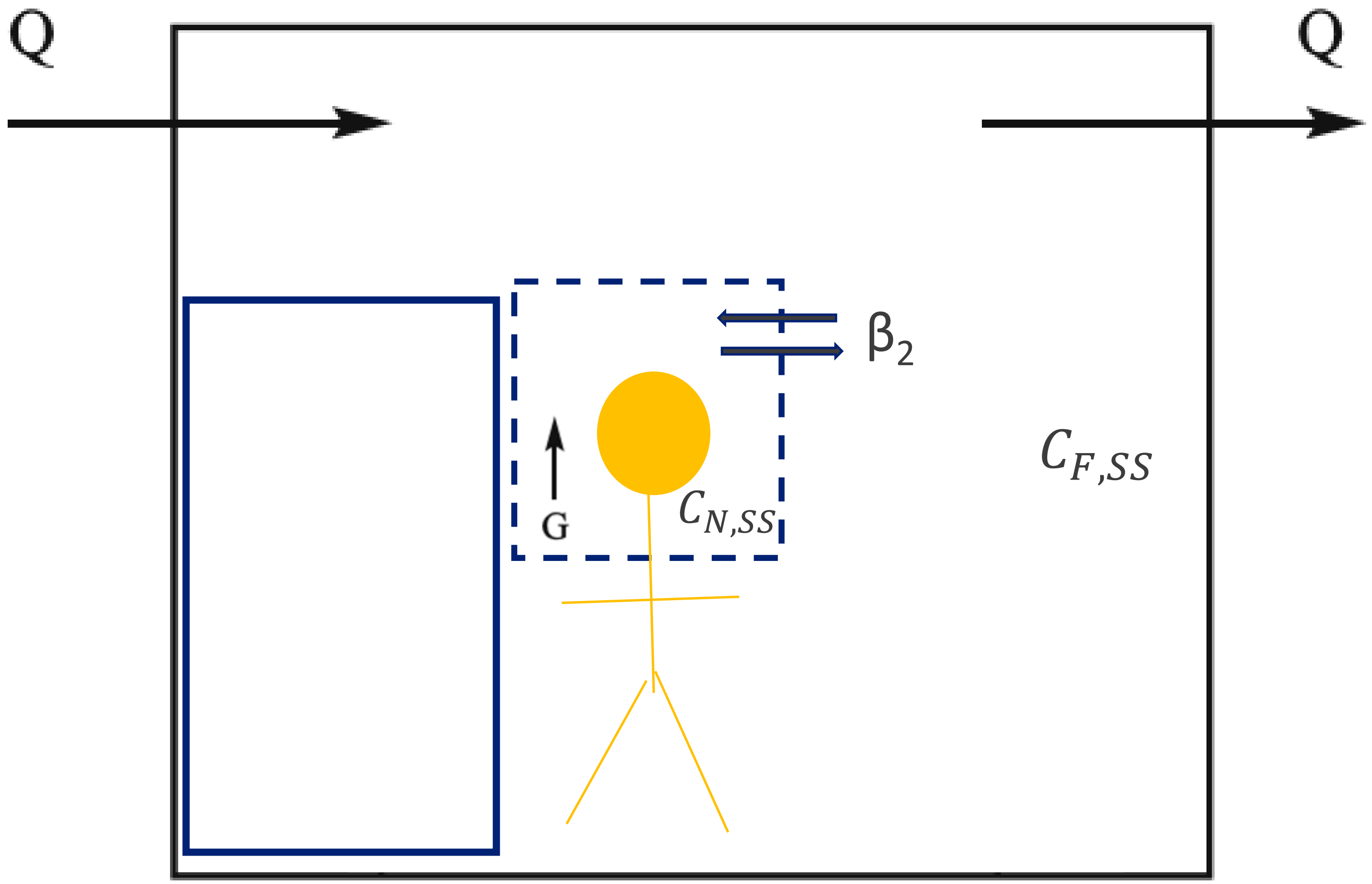
Output variables:

$C_{N,SS}$ = near field steady state concentration, mg/m^3
$C_{F,SS}$ = far field steady state concentration, mg/m^3

"Before" Model



“Before” Simplified



Input Parameters – "Before"

- G = 200 mg/min
- Q (room) = 300 cfm = 8.5 m^3/min (10 ach)
- V_r = 50 m^3
- V_n = 0.125 m^3
- $\beta_2 = \frac{1}{2} FSA \; x \; S = \frac{1}{2}(1.25m^2) \; x \; 3.05 \; m/min = 1.91 \; m^3/min$

Model Results – "Before"

- $C_{N,SS}$ = 128 mg/m^3 = 17 ppm
- $C_{F,SS}$ = 23.5 mg/m^3 = 3 ppm

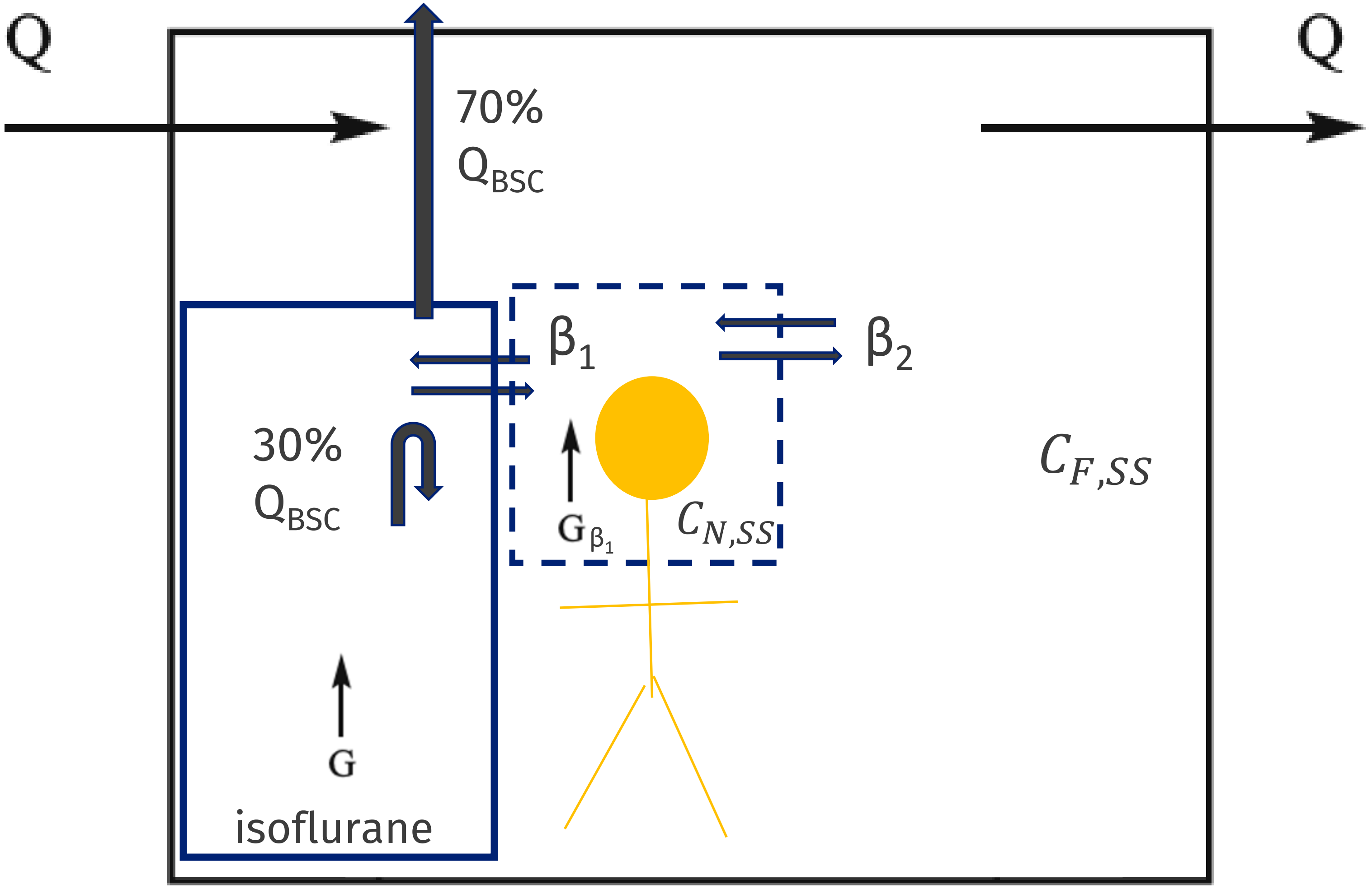
"Before" Exposure Data Compared to Model

$$Predicted\ C_{N,SS} = 17\ ppm$$

Category	n	GM (ppm)	Max (ppm)
All exposures	19	1.6	20
Biosafety Cabinet	2	17	20
Large Animal w/Tube	4	0.67	1.3
Small Animal w/Mask	1	1.4	1.4
Large Animal w/Mask	8	2.7	5.0
Large Animal Prep	2	1.1	1.3

n=number of samples; GM = geometric mean; ppm = parts per million

“After” Model



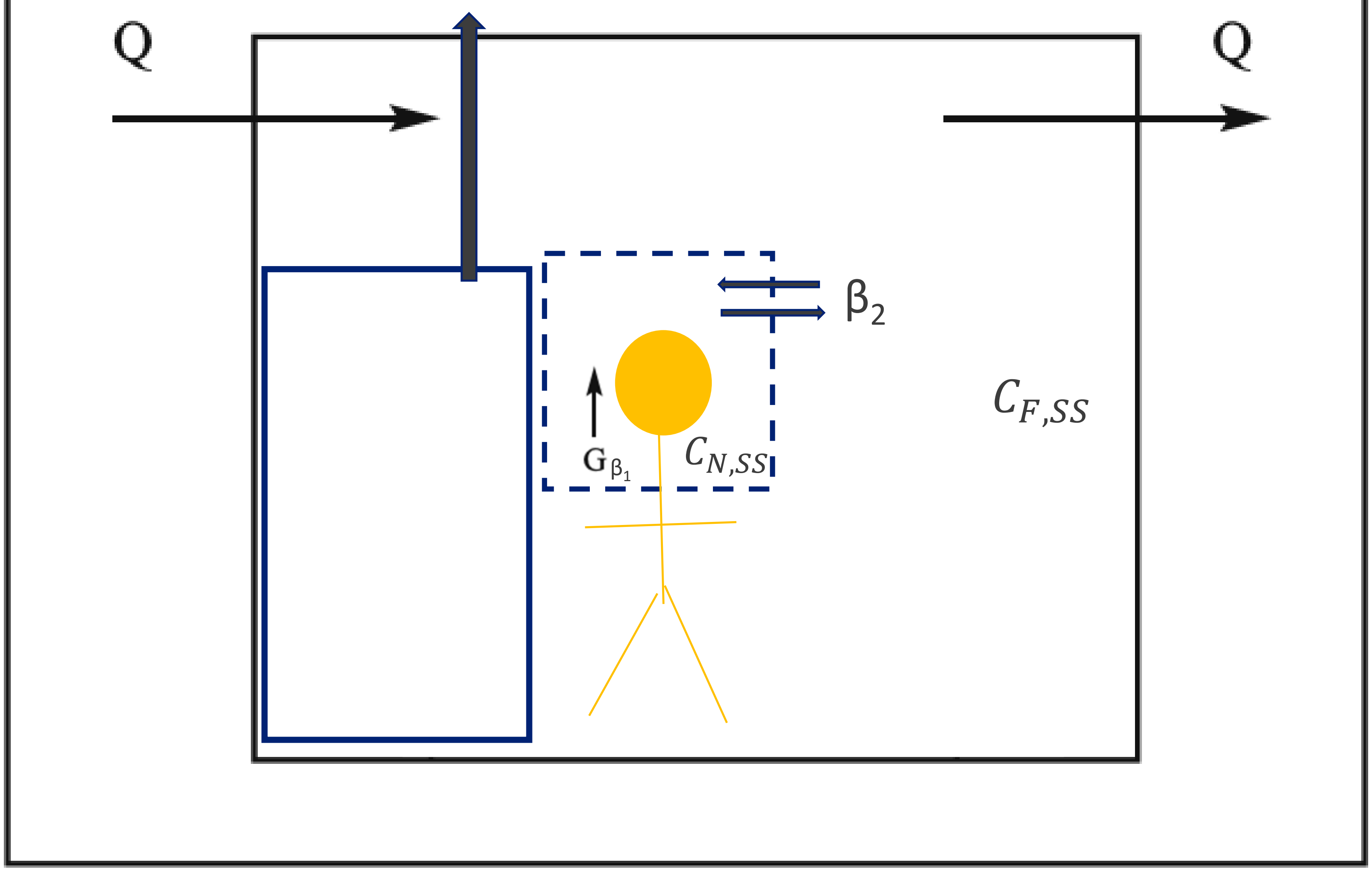
Generation Rate – "After"

- G = 200 mg/min
- Q_{BSC} = 300 cfm = 8.5 m^3/min

  70% Q_{BSC} = 6 m^3/min
- $\beta_1 = \frac{1}{2} FSA\ x\ S = \frac{1}{2}(3ft^2)\ x\ 10\ fpm = \frac{1}{2}(0.279m^2)\ x\ 3.05\ m/min$

  $\beta_1 = 0.43\ m^3/min$
- $G_{\beta 1}$ = 200 $mg/min \ \mathrm{x}\ \frac{0.43}{6.43} = 13.4\ mg/min$

"After" Simplified



Input Parameters – "After"

- $G_{\beta 1}$ = 13.4 mg/m^3
- Q (room) = 8.5 m^3/min
- V_r = 50 m^3
- V_n = 0.125 m^3
- $\beta_2 = \frac{1}{2} FSA\ x\ S = \frac{1}{2}(1.25m^2)\ x\ 3.05\ m/min = 1.91\ m^3/min$

Model Results – "After"

- $C_{N,SS}$ = 8.6 mg/m^3 = 1.1 ppm
- $C_{F,SS}$ = 1.6 mg/m^3 = 0.2 ppm


WARNING
WARNING

“After” Exposure Data

$$Predicted\ C_{N,SS} = 1.1\ ppm$$

	Pre-Ventilation			Post-Ventilation			
Category	**n**	**GM (ppm)**	**Max (ppm)**	**n**	**GM (ppm)**	**Max (ppm)**	**p (Ho)**
All exposures	19	1.6	20	14	0.33	1.8	<0.001
Biosafety Cabinet	2	17	20	4	0.27	0.94	<1E-05
Large Animal w/Tube	4	0.67	1.3	2	0.19	0.22	<0.01
Small Animal w/Mask	1	1.4	1.4	3	0.28	0.57	n/a
Large Animal w/Mask	8	2.7	5.0	2	1.4	1.8	<0.1
Large Animal Prep	**2**	**1.1**	**1.3**	**2**	**1.4**	**1.8**	**n/a**

n=number of samples; GM = geometric mean; ppm = parts per million;
p (Ho) = probability that null hypothesis (means are equal) is true

Conclusions – Case Study #1

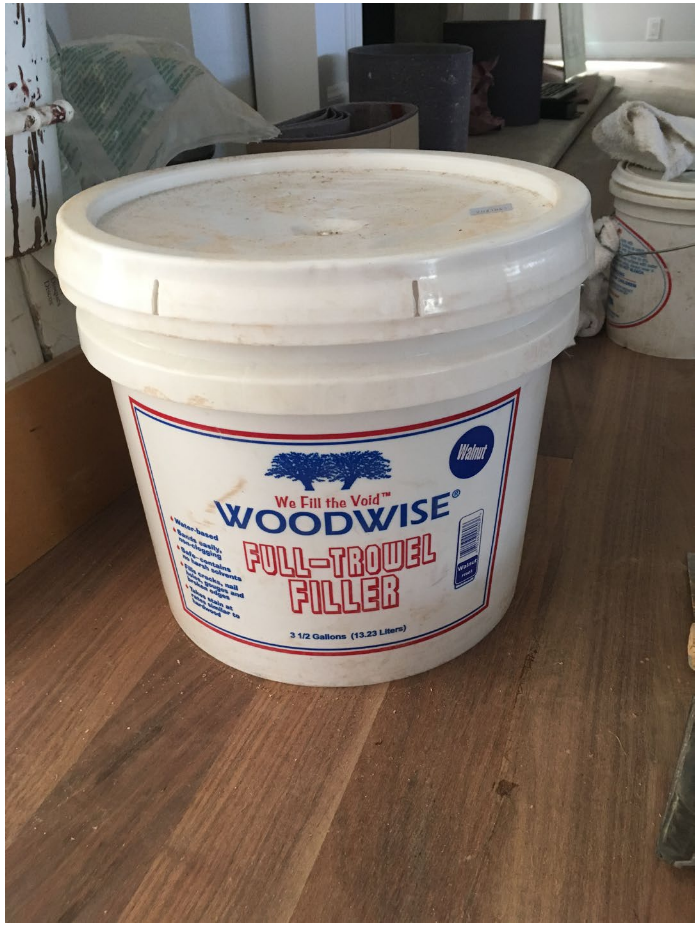
- Modeling predicted that the proposed modification (exhausting the biosafety cabinet outdoors) would reduce exposure below the internal isoflurane OEL of 2 ppm
- Exposure monitoring verified the proposed modification was successful and reduced exposure even more than predicted

Improving Exposure Judgment with Exposure Models

Case Study #2 – Silica Exposure

Modeling Case Study #2

- Objective: build a model to predict respirable crystalline silica (RCS) exposures for a wood filler product under a range of air exchange rates without local exhaust ventilation to determine if OSHA Action Limit and ACGIH TLV could be exceeded
- Results of this study are part of the public record for a Safe Use Determination under Prop 65 in California


Walnut
We Fill the Void™
WOODWISE®
FULL-TROWEL FILLER
• Water-based
• Sands easily, non-clogging
• Safe–contains no harsh solvents
• Fills cracks, nail holes, gouges and broken edges
• Takes stain at rates similar to hardwood
3 1/2 Gallons (13.23 Liters)

WOODWISE® Wood Filler Products Silica Composition

Product	Quartz	Respirable Quartz
Full-Trowel Filler	0.1-0.6%	0.1-0.2%
Wood Patch	0.1-0.6%	0.1-0.2%
Pre-Finish Filler	0.1-2.0%	0.1-0.2%
No Shrink Patch-Quick	0.1-0.6%	0.1-0.2%

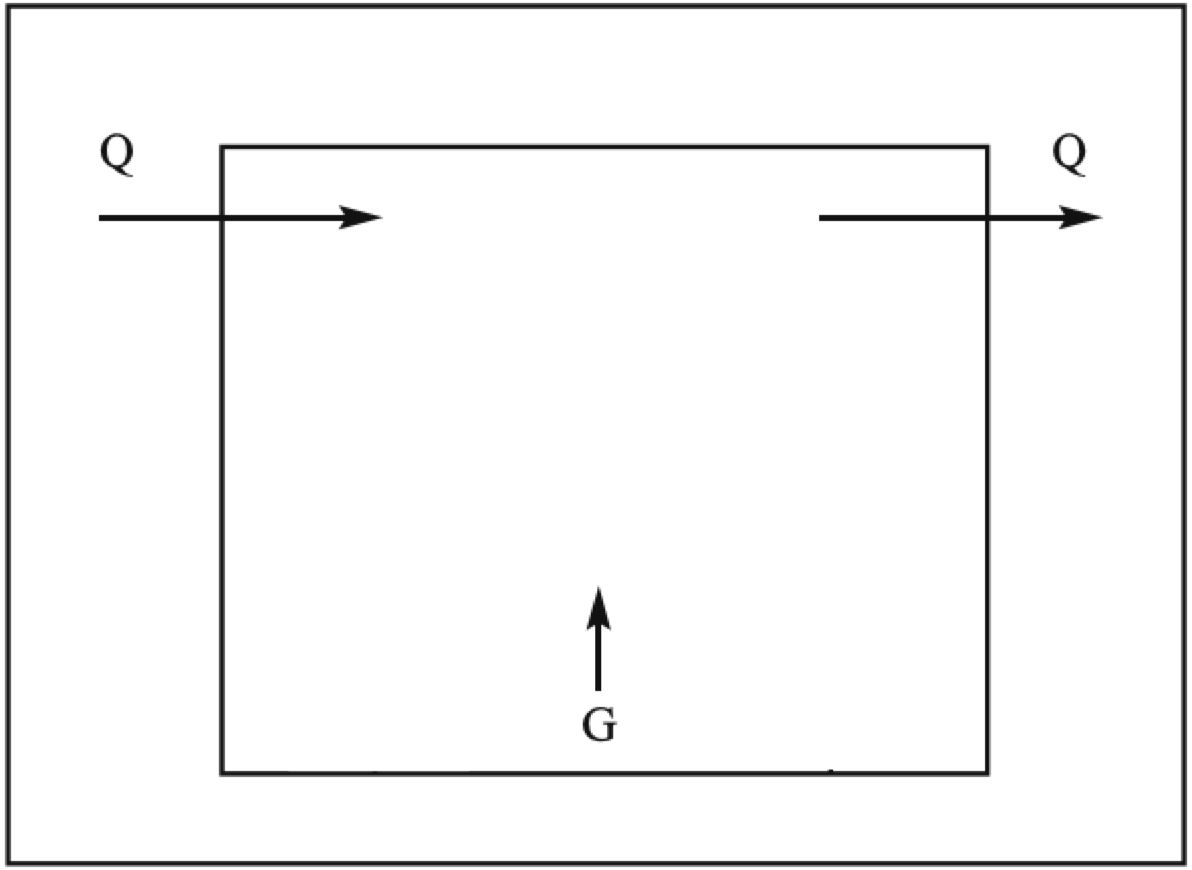
Source: Product Safety Data Sheets and Laboratory Analysis of Particle Sizing (highest presumed silica content based on the available data is shown)

Occupational Exposure Limits

Analyte	OEL	Type of OEL	Units
Respirable Crystalline Silica (RCS)	0.025 0.05 (0.025 AL)	ACGIH TLV-TWA OSHA and Cal/OSHA PEL-TWA	mg/m^3 mg/m^3

Key: OSHA = Occupational Safety and Health Administration; PEL = Permissible Exposure Limit; AL = Action level; TWA = time weighted average (over eight hours); ACGIH = American Conference of Governmental Industrial Hygienists; TLV = Threshold Limit Value; mg/m^3 = milligrams per cubic meter of air

One-Box Model



Source: Keil et al., ed., Mathematical Models for Estimating Occ Exp to Chemicals, 2nd ed. 2009.

Build up and Decay of Contaminants

$$C(t) = \frac{G}{Q} - (\frac{G}{Q} - C_o)e^{\left(-\frac{Q}{V}t\right)}$$

C(t) = concentration at time t, mg/m^3
t = time, min
G = generation rate, mg/min
C_o = initial concentration, mg/m^3
Q = effective or actual ventilation rate, m^3/min
V = room volume, m^3

$$C(t) = \frac{G}{Q}(1 - e^{\left(-\frac{Q}{V}t\right)})$$

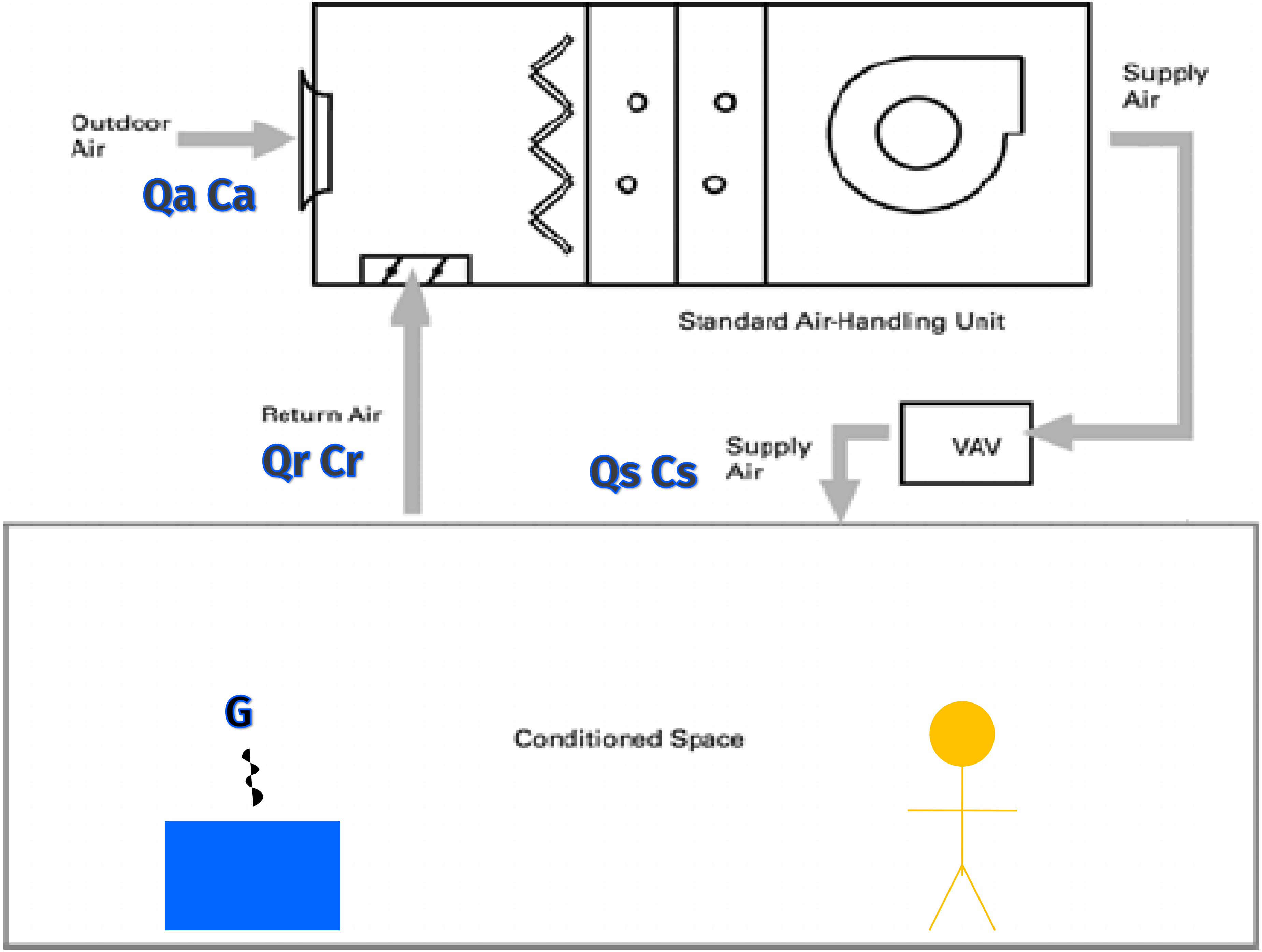
Build-up - No initial concentration

$$C(t) = C_o e^{\left(-\frac{Q}{V}t\right)}$$

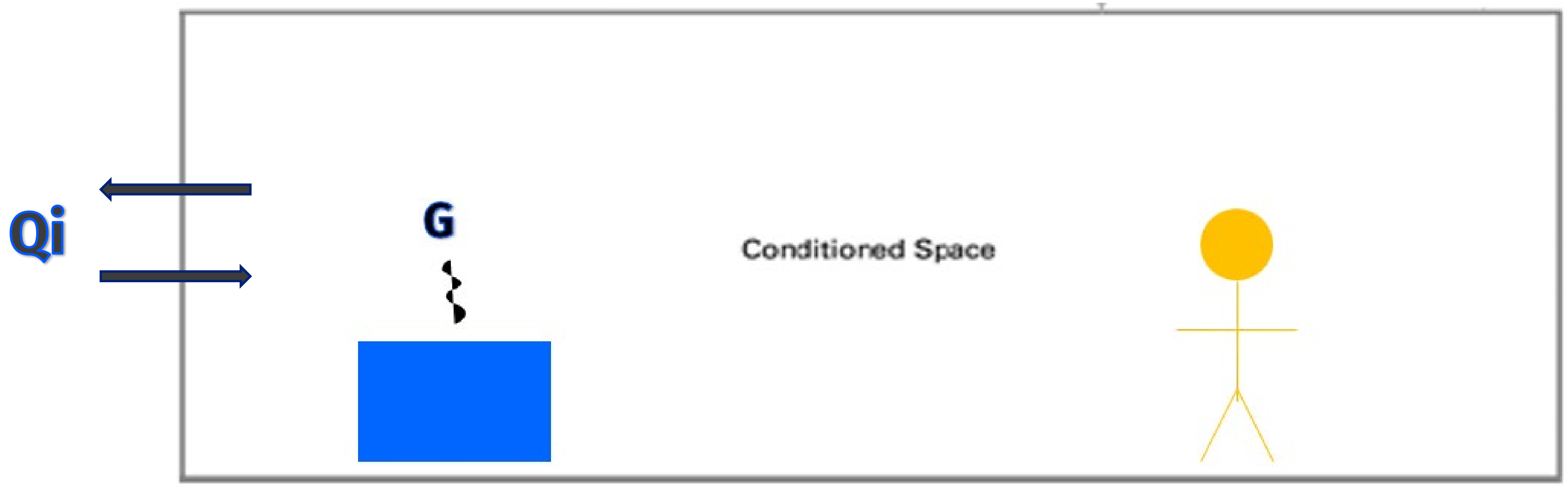
Decay - No generation or generation stops
(Well-Mixed Room Purging Equation)

One-Box Model

Which Q to use?



One-Box Model



What if no mechanical ventilation?

$$C(t) = \frac{G}{Q}\left(1 - e^{\left(-\frac{Q}{V}t\right)}\right)$$

$$C_{ss} = \frac{G}{Q}$$

Estimating "Q"

- Took CO_2 measurements on same day (but after) exposure monitoring to determine air exchange rates
- decayed from 489 ppm to background concentrations, 398 ppm, in 30 minutes (0.5 hours) with no one present

$$C(t) = C_o e^{\left(-\frac{Q}{V}t\right)}$$

$$398\,ppm = (489\,ppm)e^{\left(-\frac{Q}{V}(0.5hr)\right)}$$

$$\frac{Q}{V} = \frac{2.1}{hr}$$

Respirable Particulate and RCS Estimated Generation Rate

- Based on measured respirable particulate exposure levels and calculated air exchange rate, could estimate a generation rate for respirable dust and RCS during use of this product

$$C_{ss} = \frac{G}{Q}$$

$$79\ \mu g/m^3 = \frac{G}{\frac{2.1}{60\frac{min}{hr}}(85\ m^3)}$$

$$G = 235\ ug/min$$

$$G = 625\ ug/\min x\ 0.6\%\ RCS = 1.4\ ug/min$$

RCS Estimated Worst-Case Exposure

- Estimated RCS generation rate (1.4 µg/min)
- Average of the summer and winter median value for California residential homes (0.85 ACH)
- Small average room volume of 25 m^3 (EPA 2011)

$$C_{ss} = \frac{1.4\ \mu g/min}{\frac{0.85}{60\frac{min}{hr}}(25\ m^3)} = 4.0\ \mu g/m^3$$

Conclusions – Case Study #2

- Exposure monitoring results were below the predicted worst-case exposure
- Modeling along with exposure monitoring and an analysis of potential lifetime exposures for users of the products resulted in California issuing a Safe Use Determination under Prop 65

Improving Exposure Judgment with Exposure Models

Conclusions

Modeling – Know Where Your Towel Is

- The majority of tasks with potential exposure are never monitored
- You often can't rely on professional judgment alone
- Can save time and money compared to collecting measurements
- Allows prospective and retrospective estimates of exposure
- Focuses on predictors of exposure, links cause and effect
- These and other tools are out there an you CAN learn to use them!

IHMOD™ (latest version: 2.015, January 2023)

IHSkinPerm™ (latest version: 2.4, October 2021)

AIHA Risk Assessment Tool Download