The Role of Air Cleaning in Reducing Radon Related Risk

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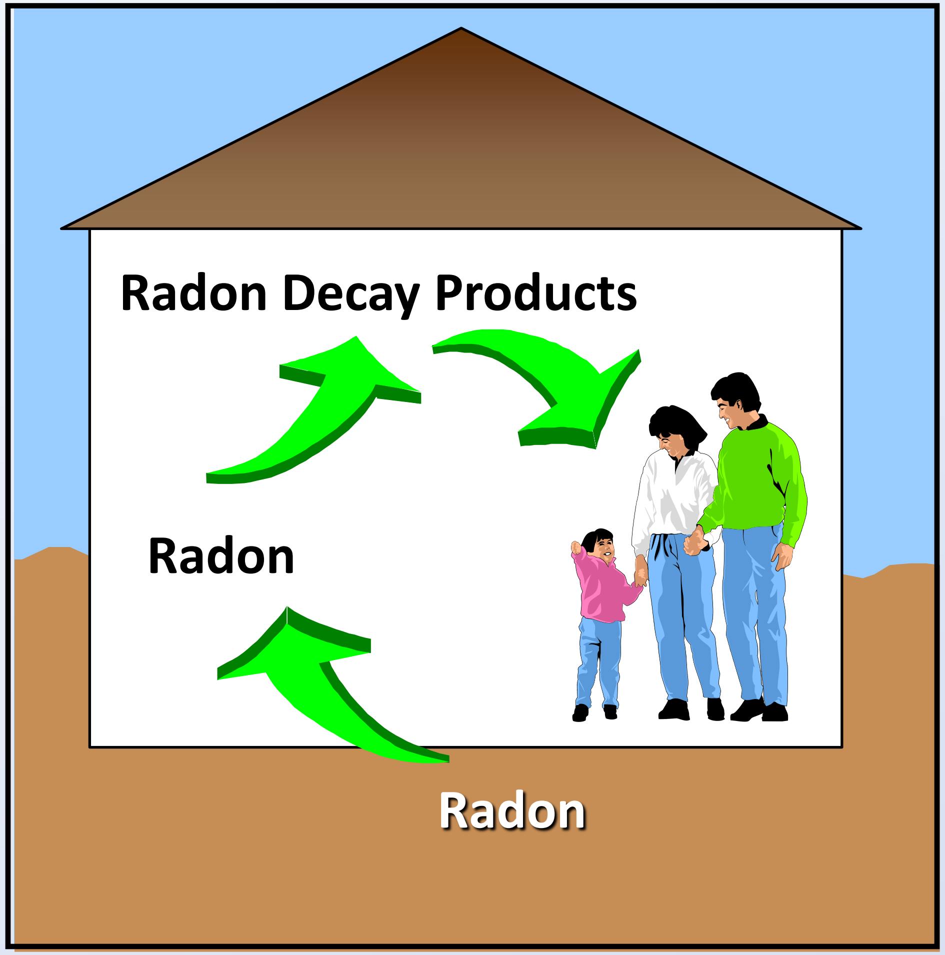
Delivered at the
Indoor Environments 2025 Radon and Vapor Intrusion Symposium – October 2025 – Fort Worth, TX

Questions to be Addressed
Answers to be Presented

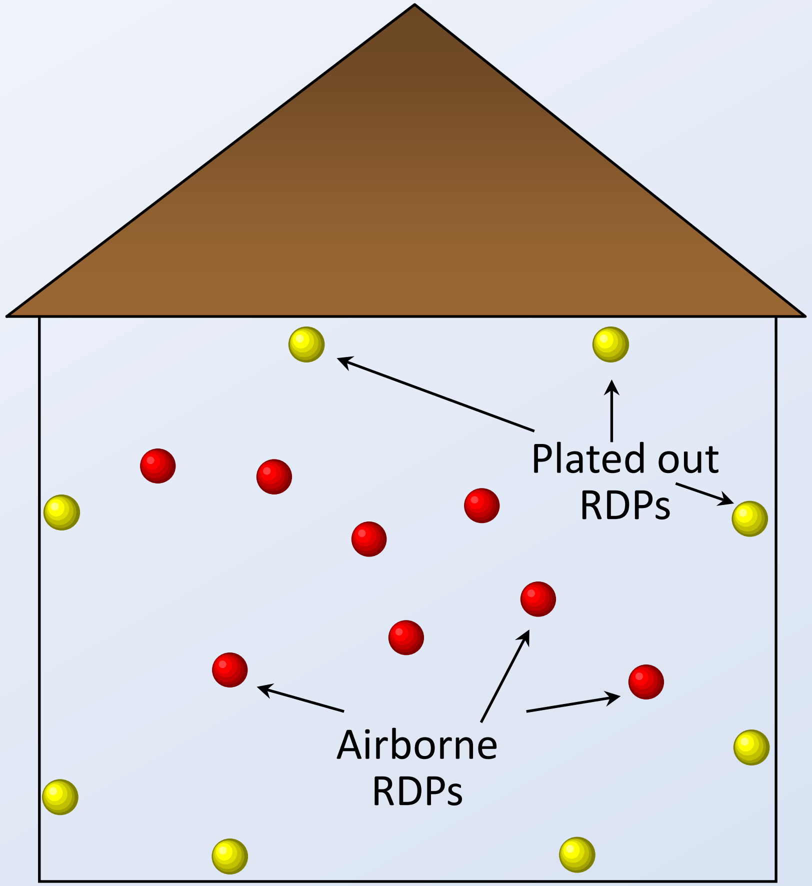
Questions	Answers
Does air cleaning or filtration reduce radon gas?	**NO -** Radon is an inert gas and passes right through filter
Does air cleaning reduce radon related exposure and Dose?	**YES -** Based upon ICRP dose model
Does air cleaning increase dose at low equilibrium factors?	**NO -** Dose Conversion Factors increase but delivered Dose drops
Can air cleaning work in conjunction with Active Soil Depressurization?	**YES -** The two together can significantly reduce Dose
Are there additional benefits of air cleaning?	**YES -** Asthma trigger reduction, etc.

So why is radon a concern?



- Radon decays into radioactive particles known as Radon Decay Products (RDPs).
- These particles are easily inhaled and deposited in the lungs where they can damage sensitive lung tissue.
- Radon Decay Products are the primary health risk

Equilibrium Factor (F)*



The equilibrium factor is the fraction (or percentage) of RDPs suspended in the air relative to the total RDPs created:

$$F = \frac{\text{Airborne RDPs}}{\text{Total RDPs}}$$

* Nomenclature: Equilibrium Ratio (ER) = Equilibrium Factor (EF) or (F)

Exposure vs Dose

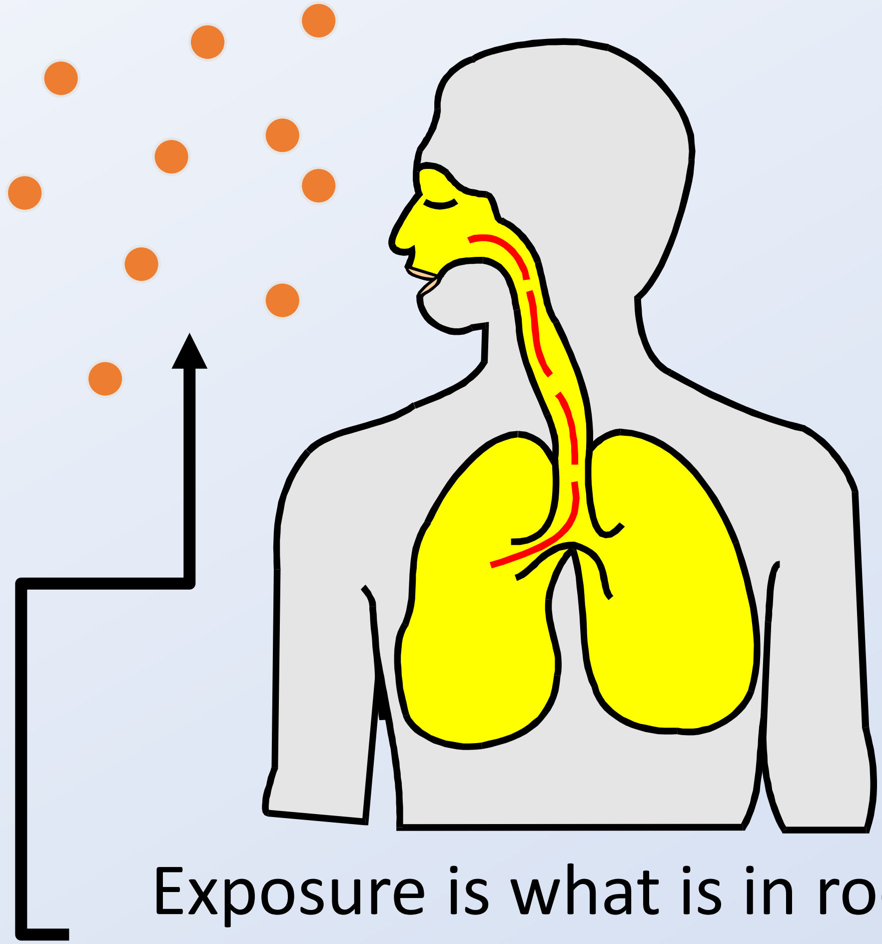
What is the goal?

Reduce potential risk or reduce delivered dose?
Or BOTH!

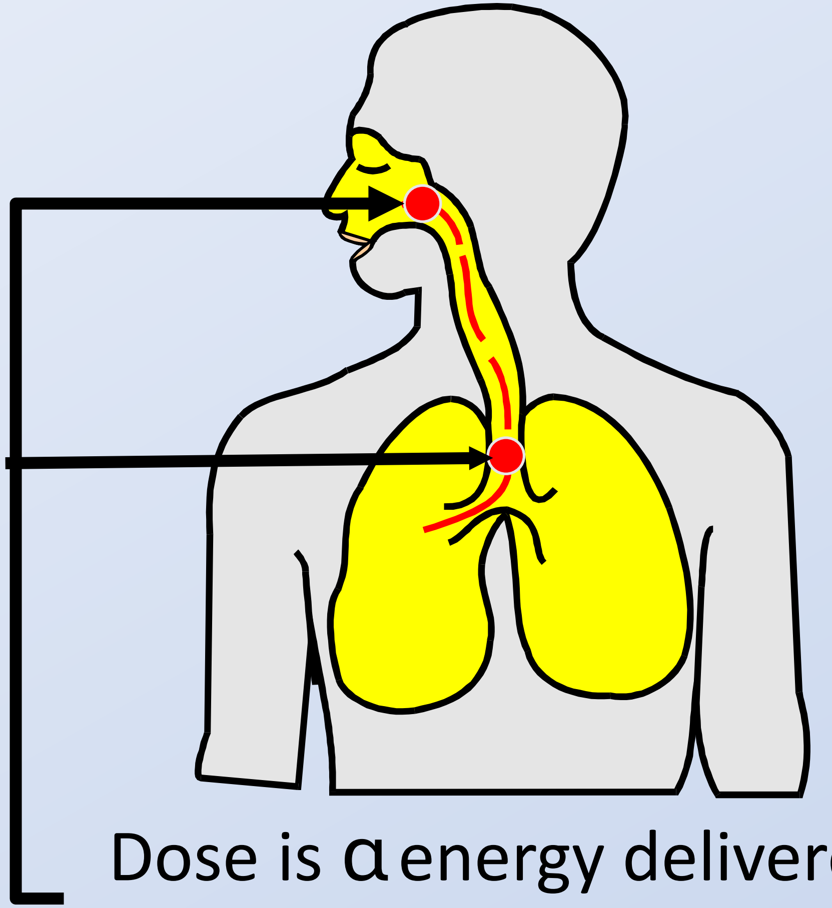
The biggest concern with epidemiological studies is mischaracterizing dose.

Bill Field - conversation with D Kladder circa 2010

Exposure VS Dose



Exposure is what is in room and available for inhalation



Dose is α energy delivered to lung from inhaled RDPs

Particle Size is Important in Dose Determination

- Smaller particles/clusters more easily enter the lung.
- Scientists have broken size of RDPs into two basic categories of health concern.

UNATTACHED RDPs: approx. 1 – 10 nm

ATTACHED RDPs: approx. 100-1000 nm

Dose Determination

Product of Exposure and Dose Conversion Factor

- **Exposure:** How much RDP activity is indoors x time of exposure
  - Working Level Months/year
- **Dose Conversion Factor (DCF):** Dose per exposure
  - Milli Sieverts per Working Level Month
- **Delivered Dose:** Energy imparted to lungs over time of exposure
  - Milli Sieverts/year

$$\text{Delivered Dose/year} = \overbrace{\frac{X\ \ mSv}{WLM}}^{\text{(DCF)}} \ x\ \overbrace{\frac{Y\ \ WLM}{Year}}^{\text{(Exposure)}} = \underline{\ Z\ }\text{ mSv/year}$$

ICRP 137 Dose Conversion Factor
(Table A.12 Indoor workplace)

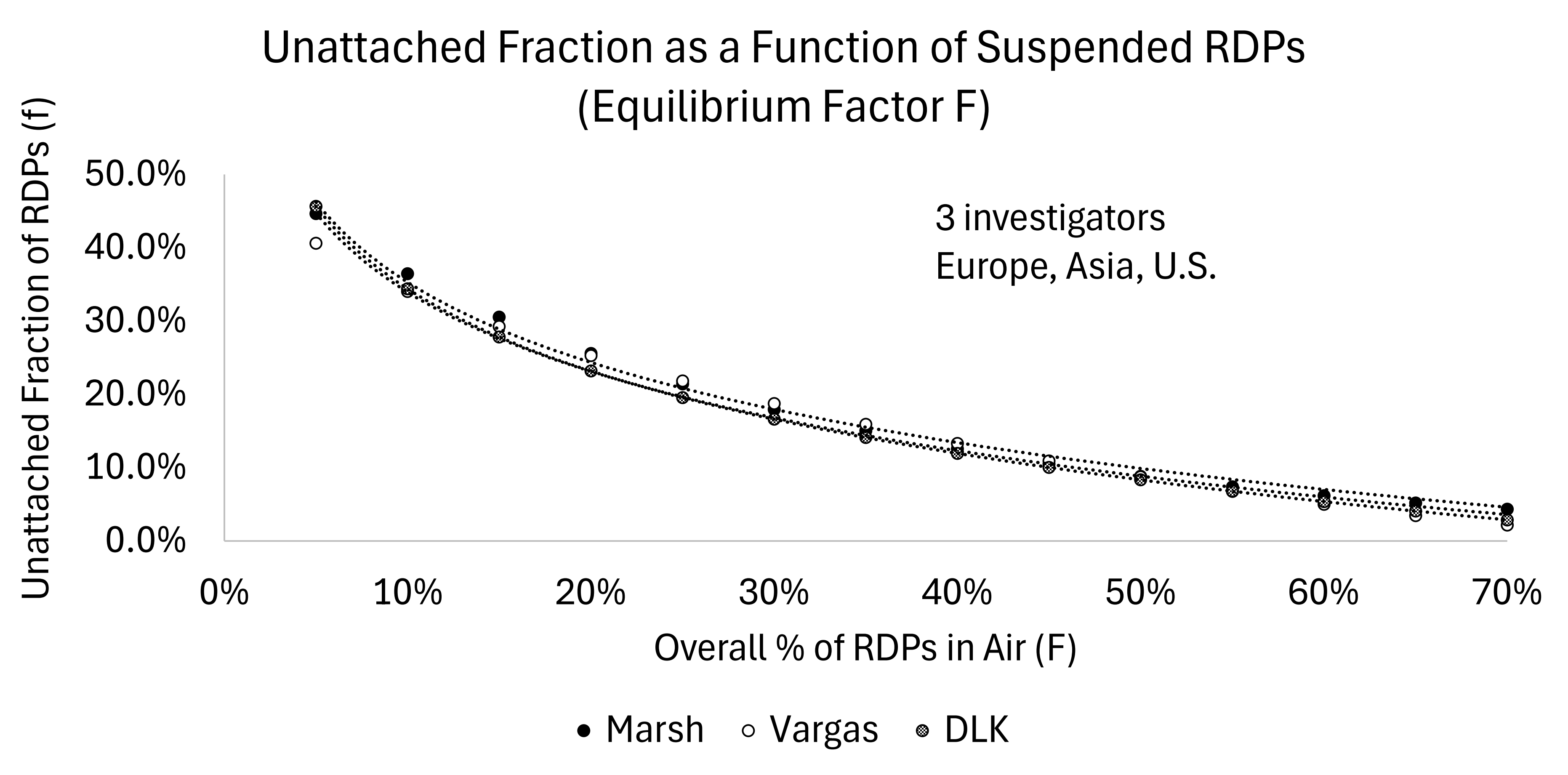
- DCF, which provides amount of dose per exposure is dependent upon unattached fraction (f_p).

$$DCF\ (mSv/WLM) = 86 \times f_p + 14 \times (1 - f_p)$$

Where f_p = unattached fraction

- Unattached fraction (f_p) can be measured but can also be estimated since it is inversely proportional to Overall Percentage of decay products in air (F).

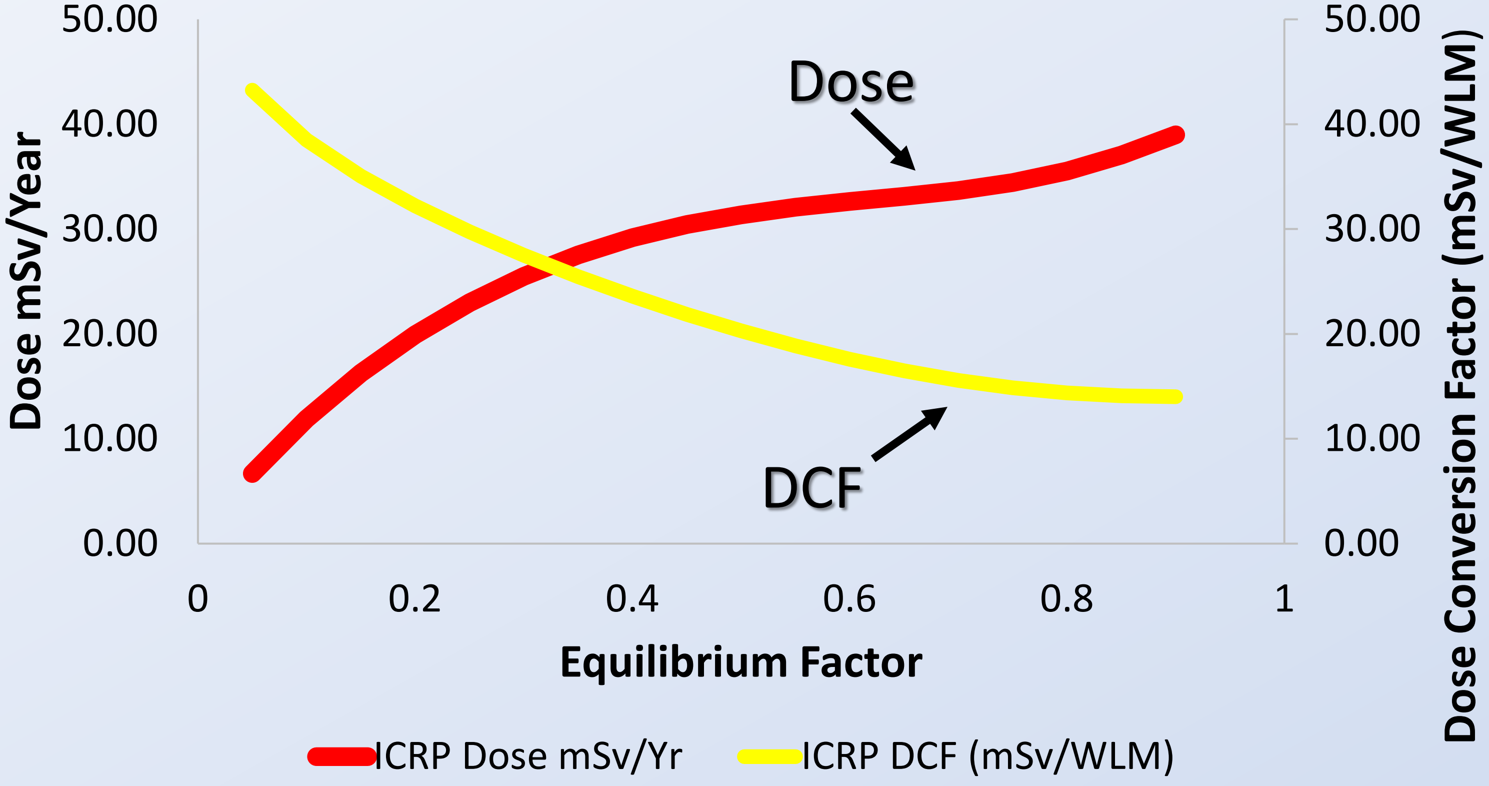
Unattached Fraction as a Function of Equilibrium Factor (F)



Correlation allows estimation of unattached fraction from concurrent RDP and Radon Measurement.

Effect of Equilibrium Factor (F) Reduction on DCF and Dose

DCF and DOSE at Different Equilibrium Factors with Radon Constant at 300 Bq/m³



- Dose Conversion Factor increases as F decreases
- Exposure goes down as F decreases
- Overall dose goes down as F decreases

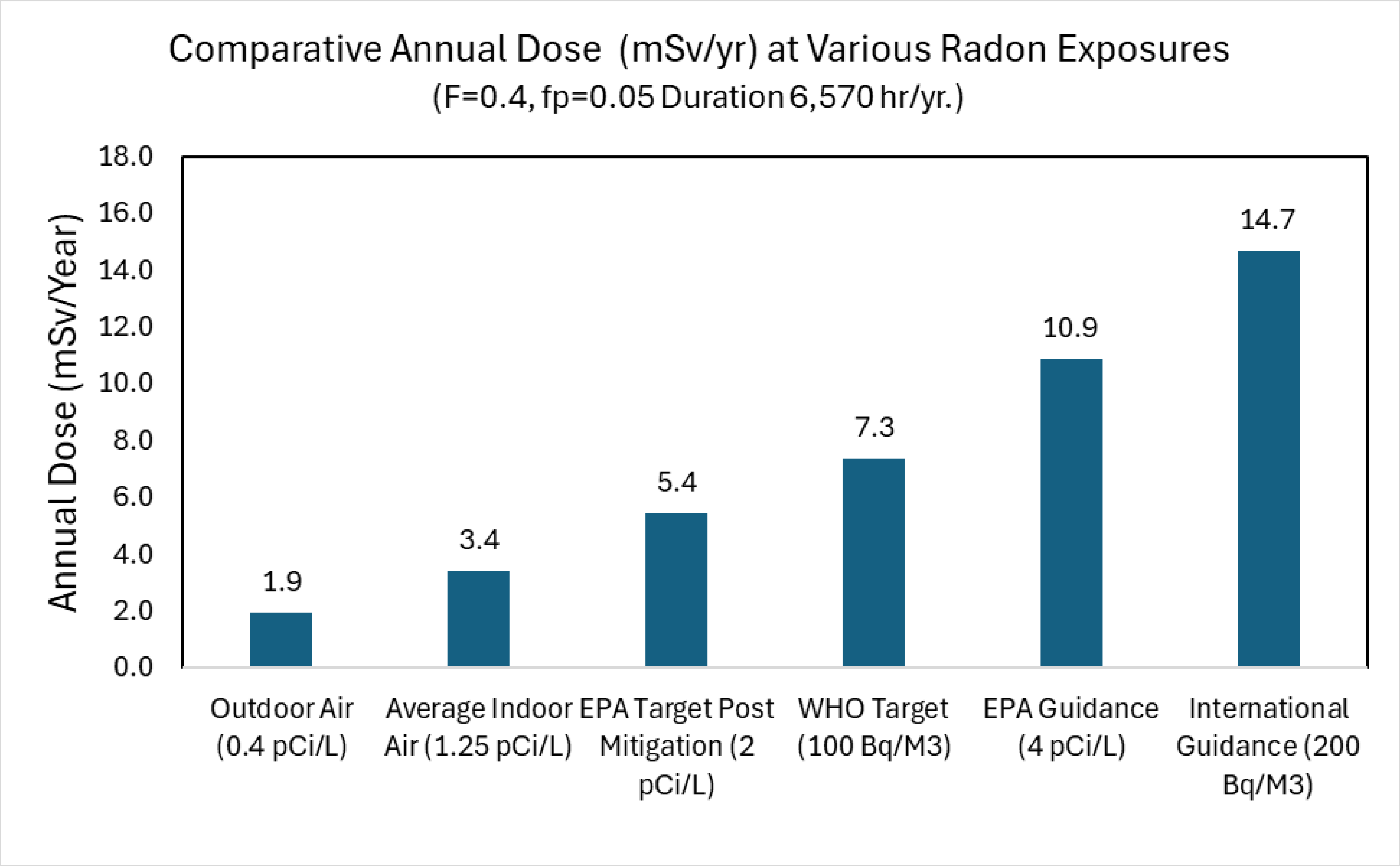
$$DCF\ (mSv/WLM) = 86 \times f_p + 14 \times (1 - f_p)$$

Where f_p = unattached fraction

$$\text{Delivered Dose/year} = \underbrace{\frac{X\ mSv}{WLM}}_{\text{(DCF)}} \times \underbrace{\frac{Y\ WLM}{Year}}_{\text{(Exposure)}} = \underline{Z}\ \text{mSv/year}$$

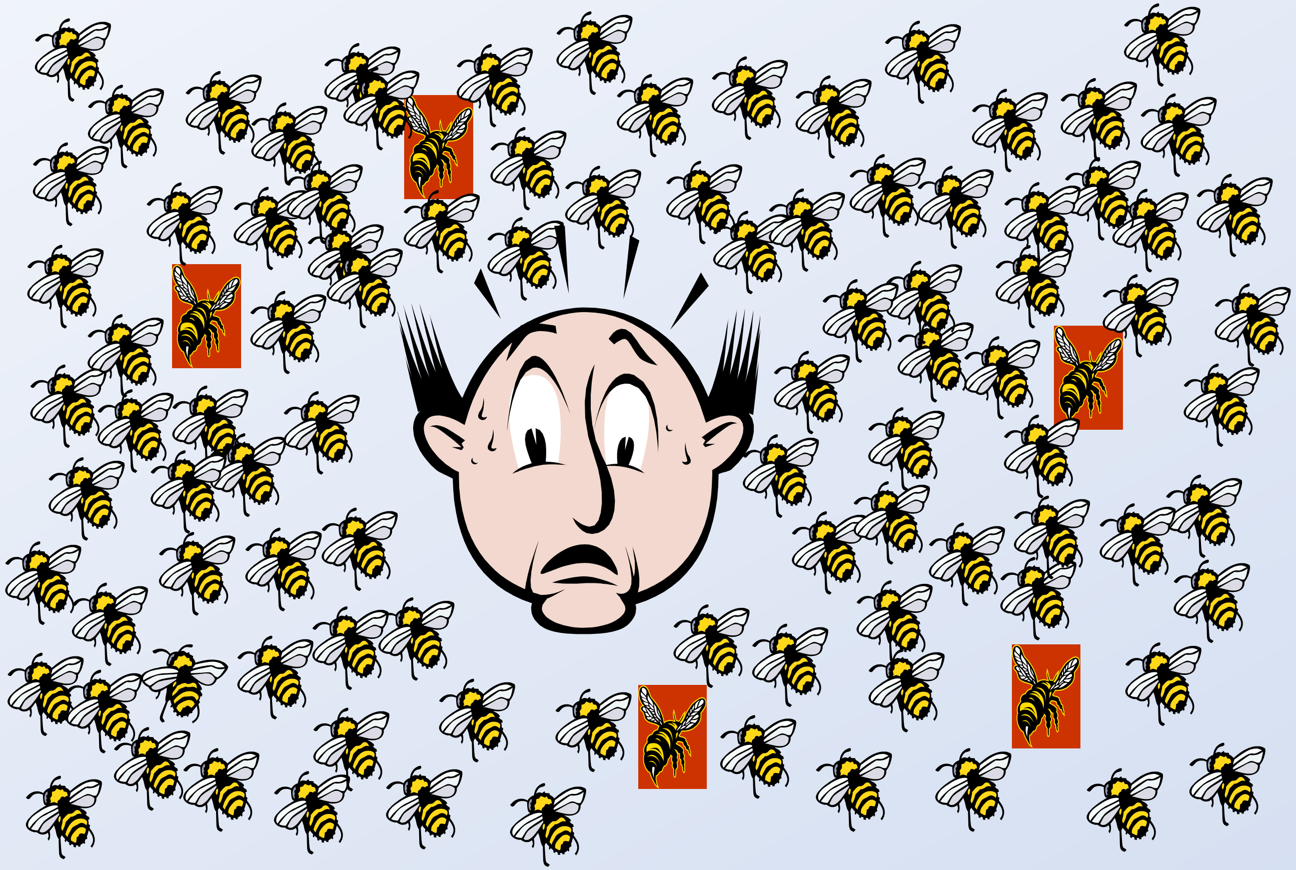
Based on ICRP 137, 6570 hours/year, Vargas Equation to estimate f

Putting Dose in Perspective



- Typical targets are 1 mSv/year over background.
  - ICRP-137 suggests 2.4 mSv/year
- 2/3 of radon induced lung cancers from exposures less than 4.0 pCi/L

Unattached vs Attached Analogy
No Air Filtration



100 Flying insects with stingers

95 Bees

<u>5 Wasps</u>

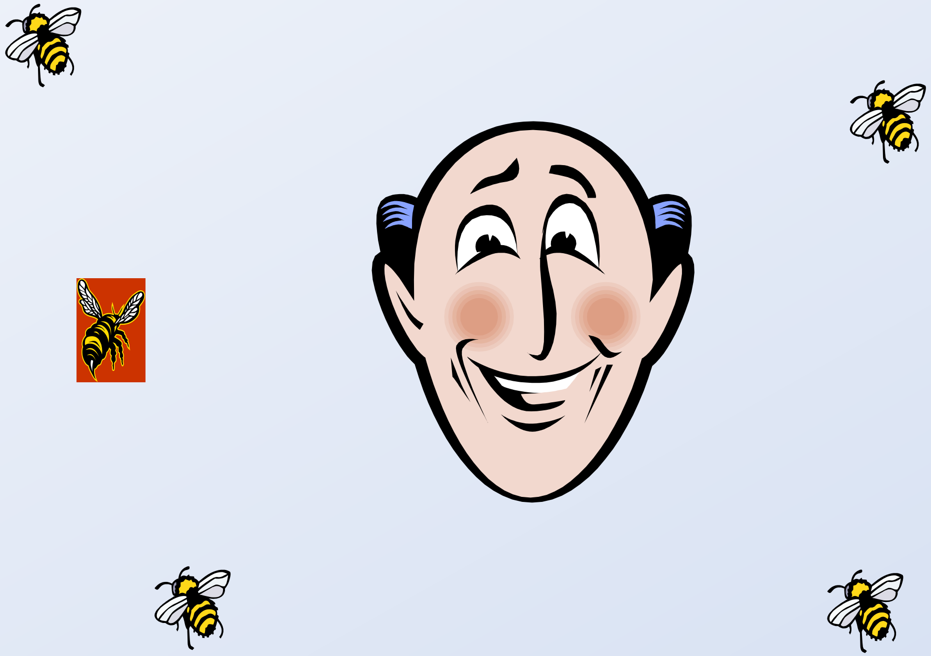
5% Wasps

≈ 5% unattached fraction

5% Commonly Assumed

Large number of flying insects with stingers, some nastier than others (wasps) high probability of being stung

Unattached vs Attached Analogy (contd.)
With Air Filtration



5 Flying insects with stingers:

4 Bees

<u>1 Wasp</u>

20% Wasps

≈ 20% unattached fraction

Although percentage of wasps has increased, actual number of wasps and bees has decreased; hence overall probability of being stung has decreased.

What Other Researchers Before Us Have Found With Filtration:

Year	Investigators	Citation / Source	F	fp	Dose
2017	Vaupotič, J., Bezak	*Radiation and Applications, Vol 2, Issue 2*	↓	↑	↓
2011	Wang, Tschiersch	*Sci Total Environ* 409: 3613–3619	↓	↑	↓
2008	Yasouka, Y. et al.	*Radiat. Prot. Dosim.* 130(4): 425–430	↓	↑	↓
2000	Vaupotič, J.	*Radiat. Prot. Dosim.* 87(3): 251–256	↓	↑	↓
1999	Vaupotič, J. & Kobal, I.	*J. Environ. Radioact.* 45:33–40	↓	↑	↓
1995	Hopke, Jensen, Montassier et al.	*Environ. Sci. Technol.* 29:1359–1364	↓	↑	↓
1994	Hopke et al.	*J Aerosol Sci* 25: 395–405	↓	↑	↓
1994	Hopke et al.	*Radiat Prot Dosimetry* 56: 55–59	↓	↑	↓
1993	Bigu, J.	*Ann. Ocup. Hyg, Vol 37. No5*	↓	↑	↓
1992	Li & Hopke (AIVC Report)	*Air Filtration and Radon Decay Product Mitigation*	↓	↑	↓
1991	Li & Hopke	*Health Phys* 61(6): 785–797	↓	↑	↓
1991	Harley, N.H. (DOE/NYU Reports)	*DOE/NYU Environmental Medicine Radon Progeny Studies* (1988–1991 series)	↓	↑	↓
1990	Harley, N.H. & Robbins, E.S.	*"Radon Progeny Dose Reduction by Air Cleaning,"* Radiation Protection Dosimetry, 32(1): 35–39	↓	↑	↓
1985	Rajala, Janka, Lehtimäki et al.	*Sci Total Environ* 45: 493–498	↓	↑	↓

- RDPs(EF) significantly reduced.
  - F to as low as 3%
- Unattached Fraction increased
- Dose is Reduced

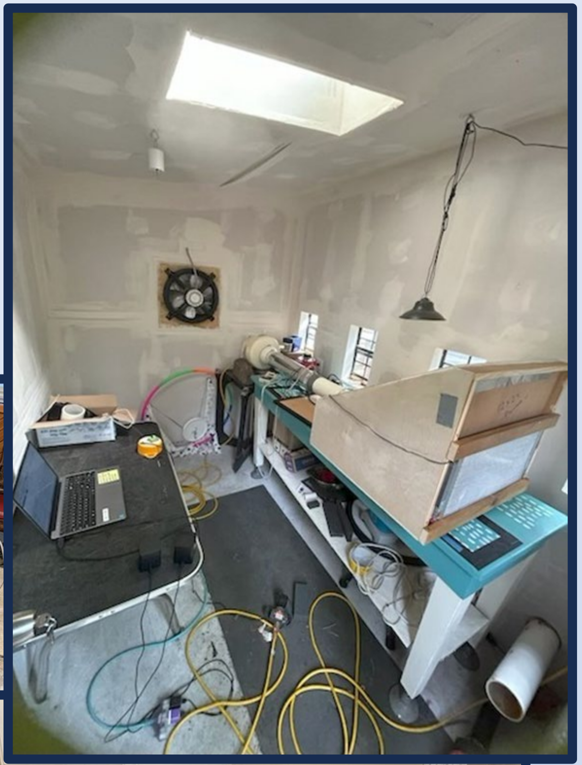
Dose reduction is not linear with RDP reduction due to increase in unattached, but net effect is reduction in Dose

2024-2025 Studies by Kladder and Waldron

- Three separate test locations on Front Range of Colorado
- Variables Measured:
  - Radon (CRM and EIC)
  - RDPs Multiple CWLMs calibrated in Germany and Saskatoon
  - Unattached Fraction RDPs (ERPISU)
  - Particles
  - Humidity
- Variations:
  - Different filter types
  - Varying filtration rates

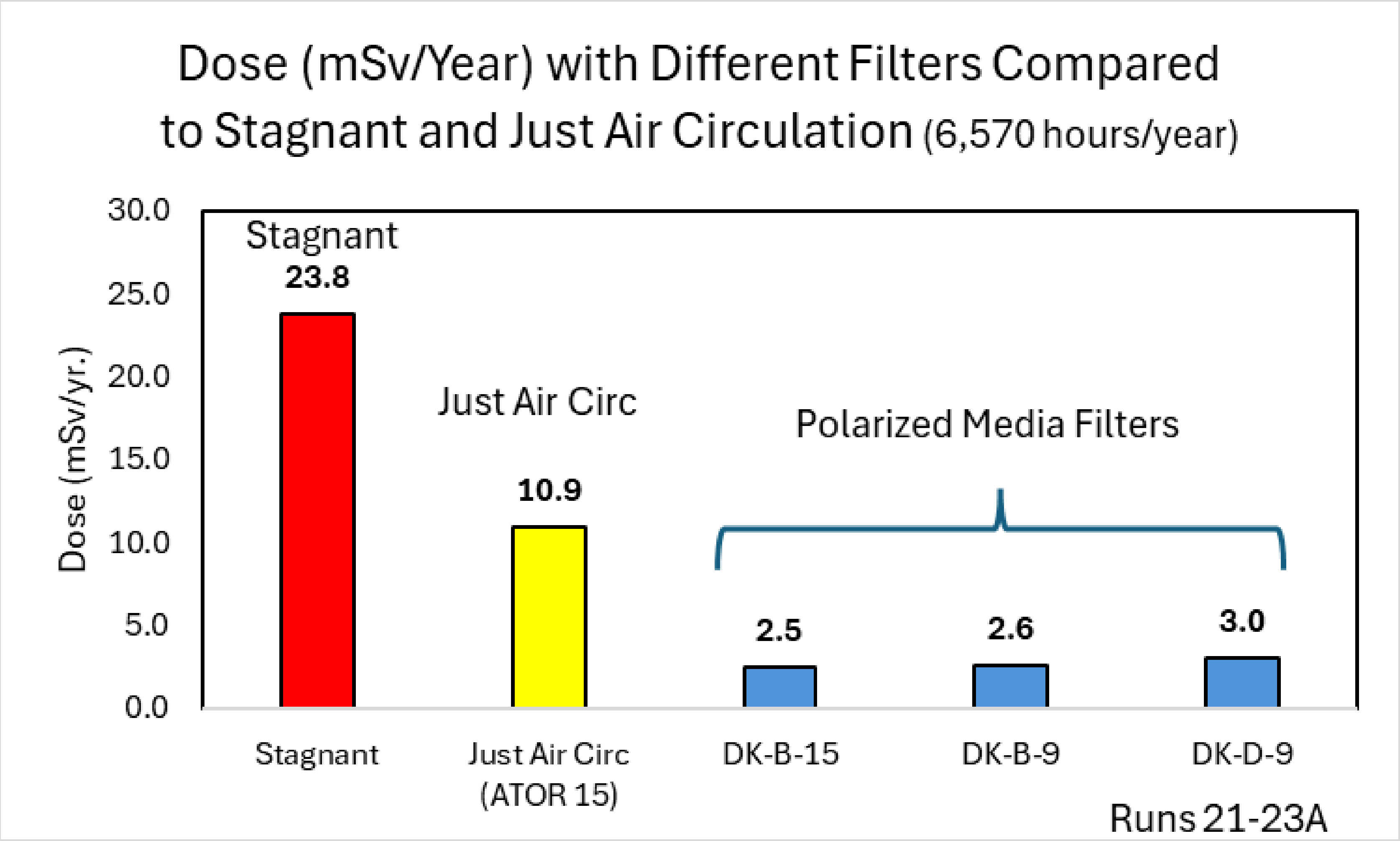
Group	Room	Radon	Air Circ (ATOR)
Group 1	81 m^3	4-8 Ci/L	2
Group 2	15 m^3	4-8 pCi/L	2-15
Group 3	12.2 m^3	38-42 pCi/L	2-8

ATOR: Air Turn Over Rate: - Volume of Location/hour (similar to CADR/V)



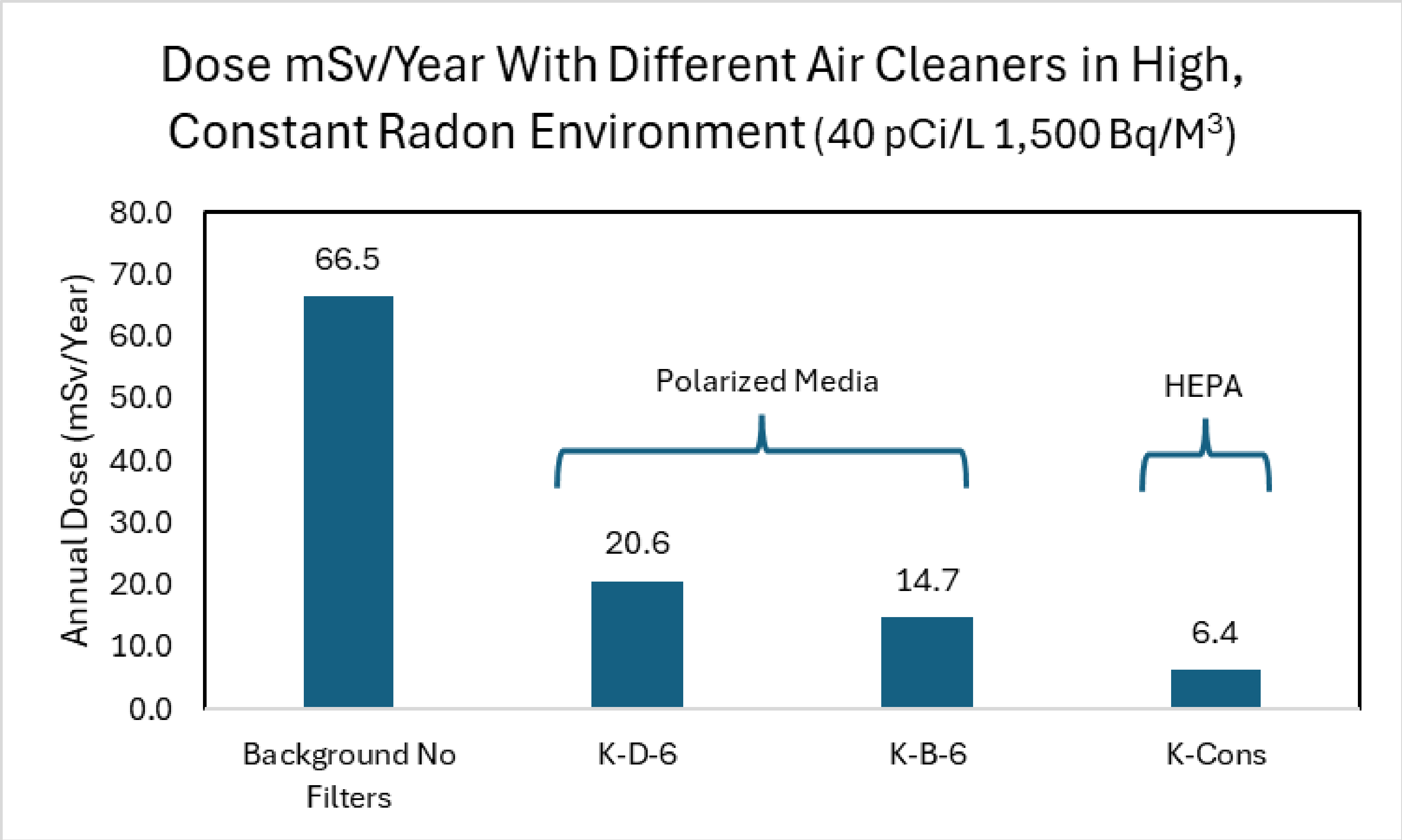
Air Circulation Plus Filters

Group 2 Smaller Room Moderate Rn ATOR 9-15



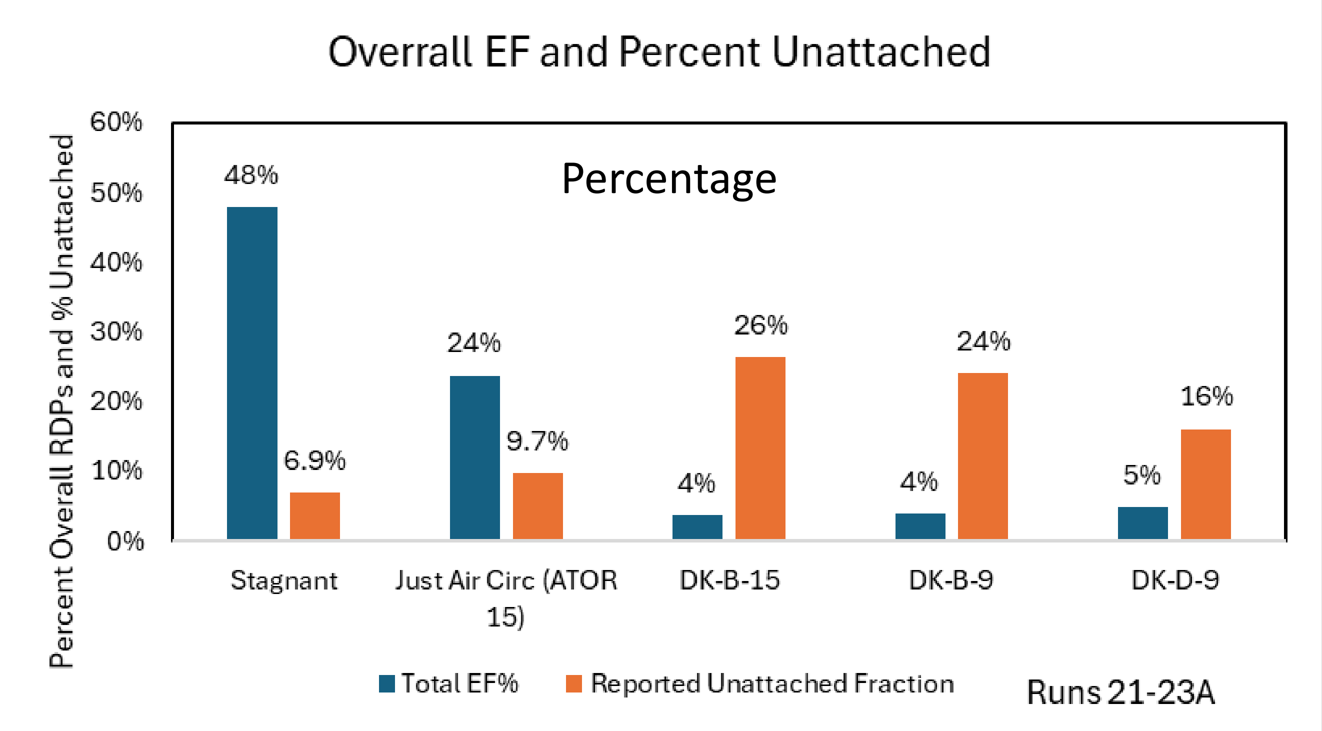
- Dose dropped in half with just air circulation
- 10-fold reduction in dose with air cleaners.

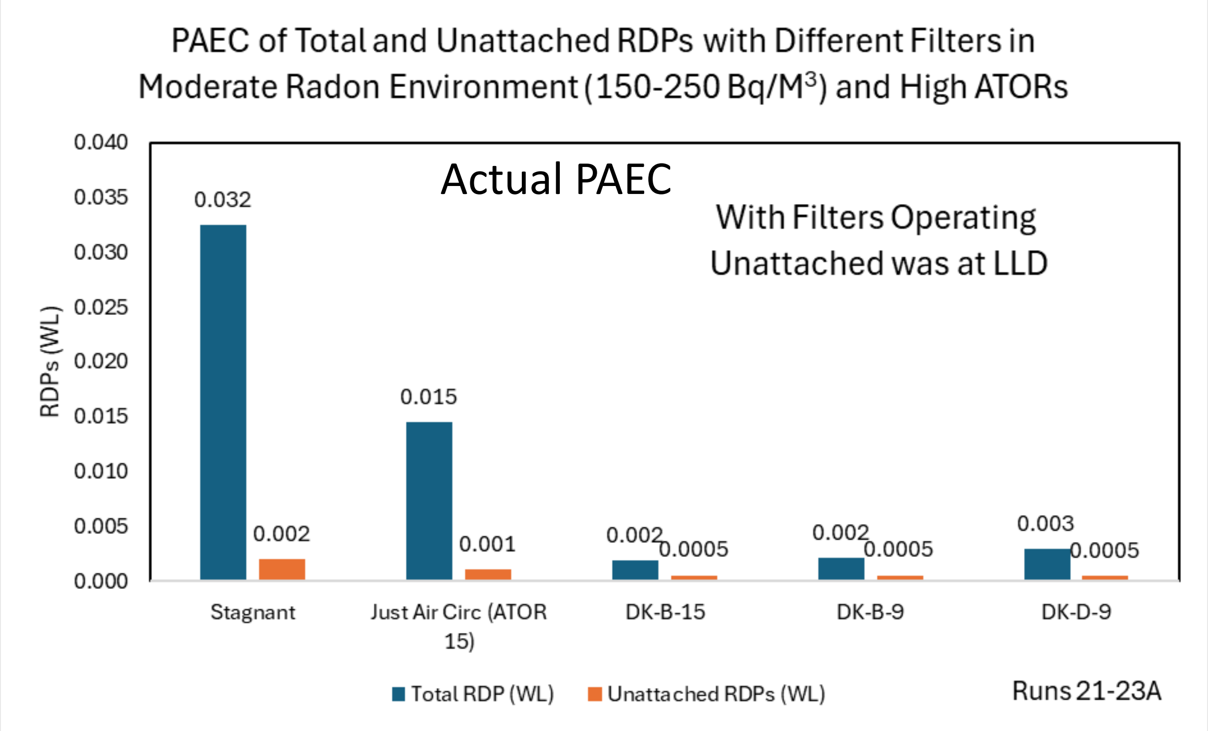
Group 3 Radon Chamber High Radon (~40 pCi/L) DOSE



- Even in high radon environment the dose is decreased with air cleaning/filtration
- 3-10 fold reduction in Dose

Percent vs Measured Activity
Group 2 Smaller Room Moderate Rn ATOR 9-15

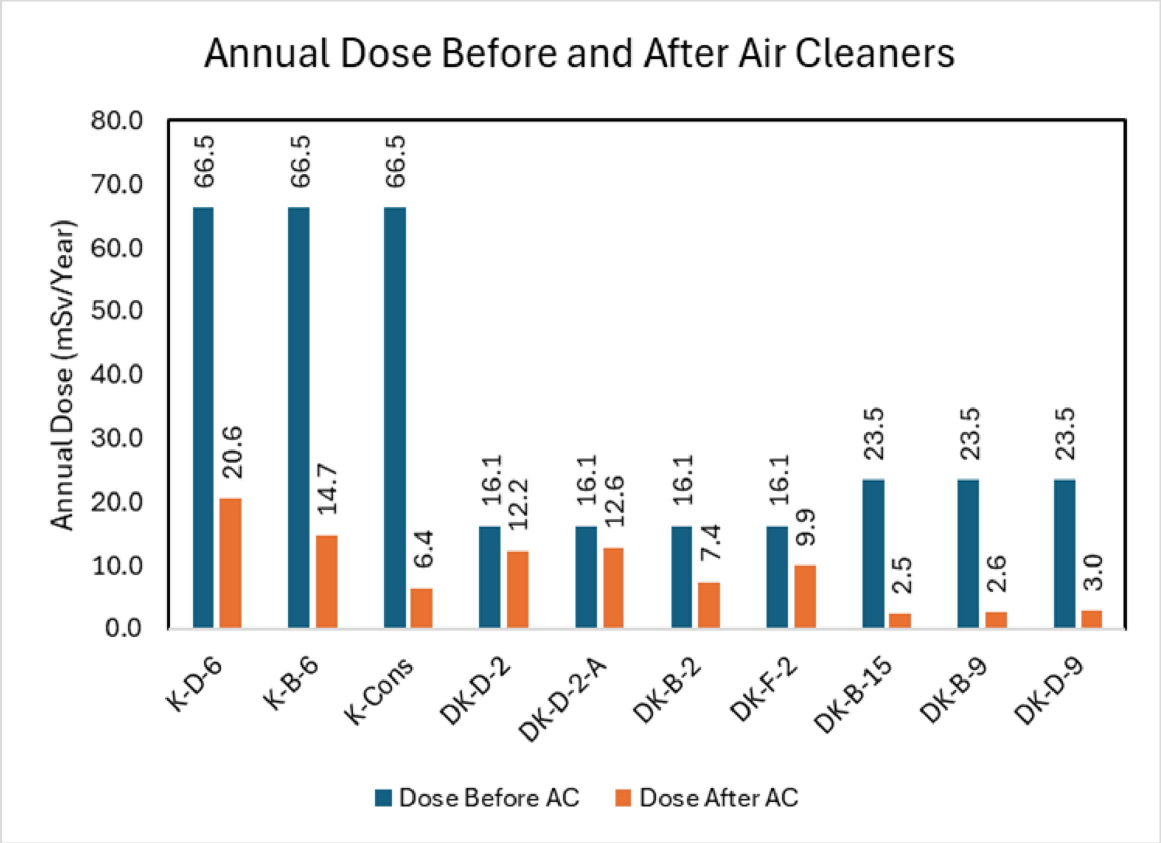


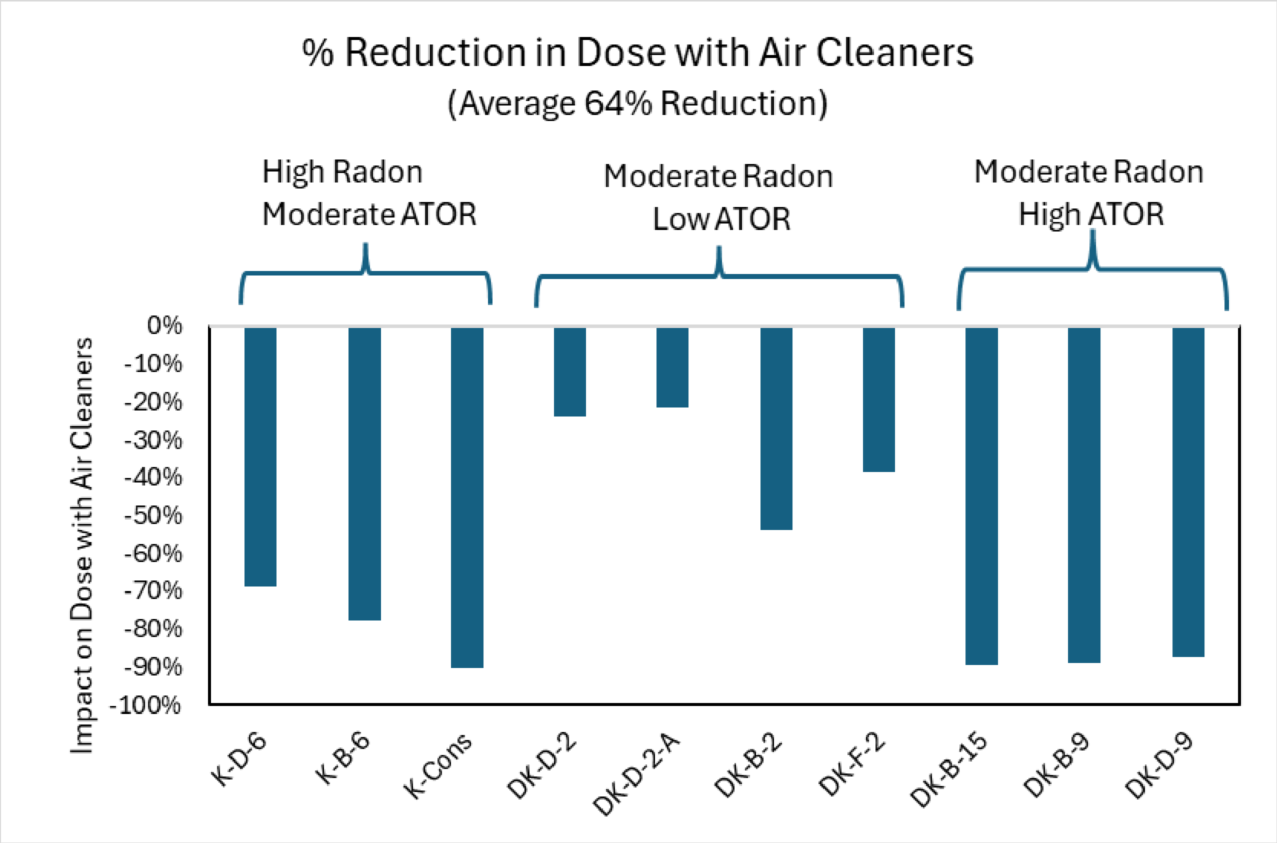


- Air circulation alone cut RDPs in half
- Filters further reduced EF
- Unattached fraction % increased with air circulation and filtration

- PAEC/Activity for unattached actually dropped to LLD.
- Likely due to high air movement and plate-out of diffusive unattached RDPs.

Summary of K&W Dose Impact of Filters



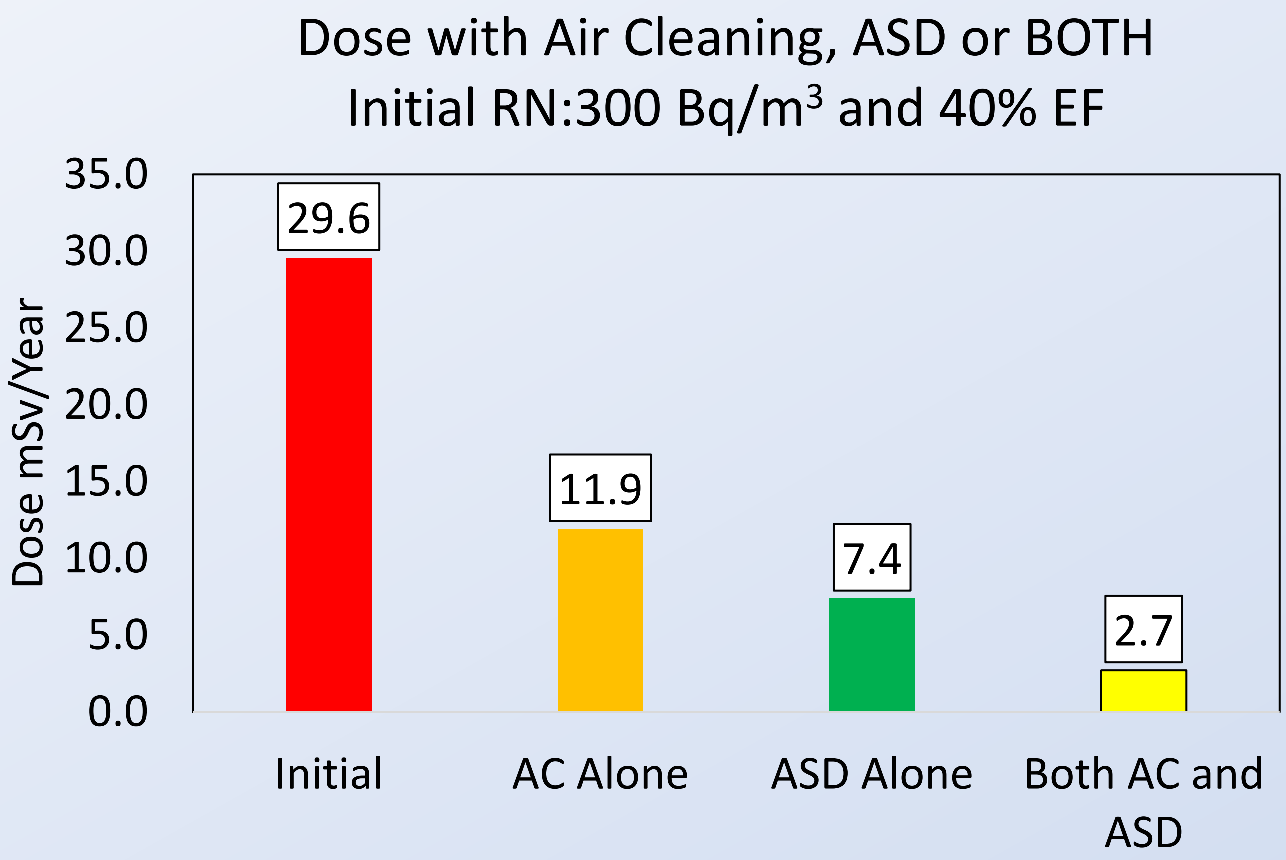


- In all cases, air cleaner reduced dose
- Dose reductions are greater when Radon is high and when air circulation is high

RDP Reduction Applications

- Where air handlers circulate air within the entire occupied space
  - Modular/console air cleaners only treat one room.
- Where Forced Air Unit would operate while building is occupied
  - Office buildings, schools
  - Homes with constantly operated forced air systems
- Tough to mitigate houses and buildings
  - Under slab returns, multiple foundations, etc.

Comparison of Dose Reduction with 75% reduction in RDPs (Air Cleaning) and 75% Reduction in Radon (ASD) or BOTH!



- Reduction of Source Rn (ASD) reduces dose
- Air Cleaning reduces dose
- The two together significantly reduce dose
  - To less than 3 mSv/yr target

Based on dose models

ICRP 137, Initial RN: 300 Bq/M^3 75% Reduction in either case, 6570 hr/yr

IAQ Collateral Benefit of Air Cleaning

Filter discs from Radon Decay Product Measurement Device
2-day measurements at 1.0 L/min

- Air passes through filter
- Traps particulates as well as RDPs
- Reduces airborne particulates
  - Asthma triggers
  - COVID

Why Consider RDP Reduction Now?

- Heightened awareness regarding the health benefits of reducing airborne particulates
  - Indoors
  - Outdoors (PM2.5 and PM10)
  - Asthma and other respiratory stresses
- Many buildings have or are incorporating particulate reduction measures
  - COVID was a large impetus for filter applications

Summary

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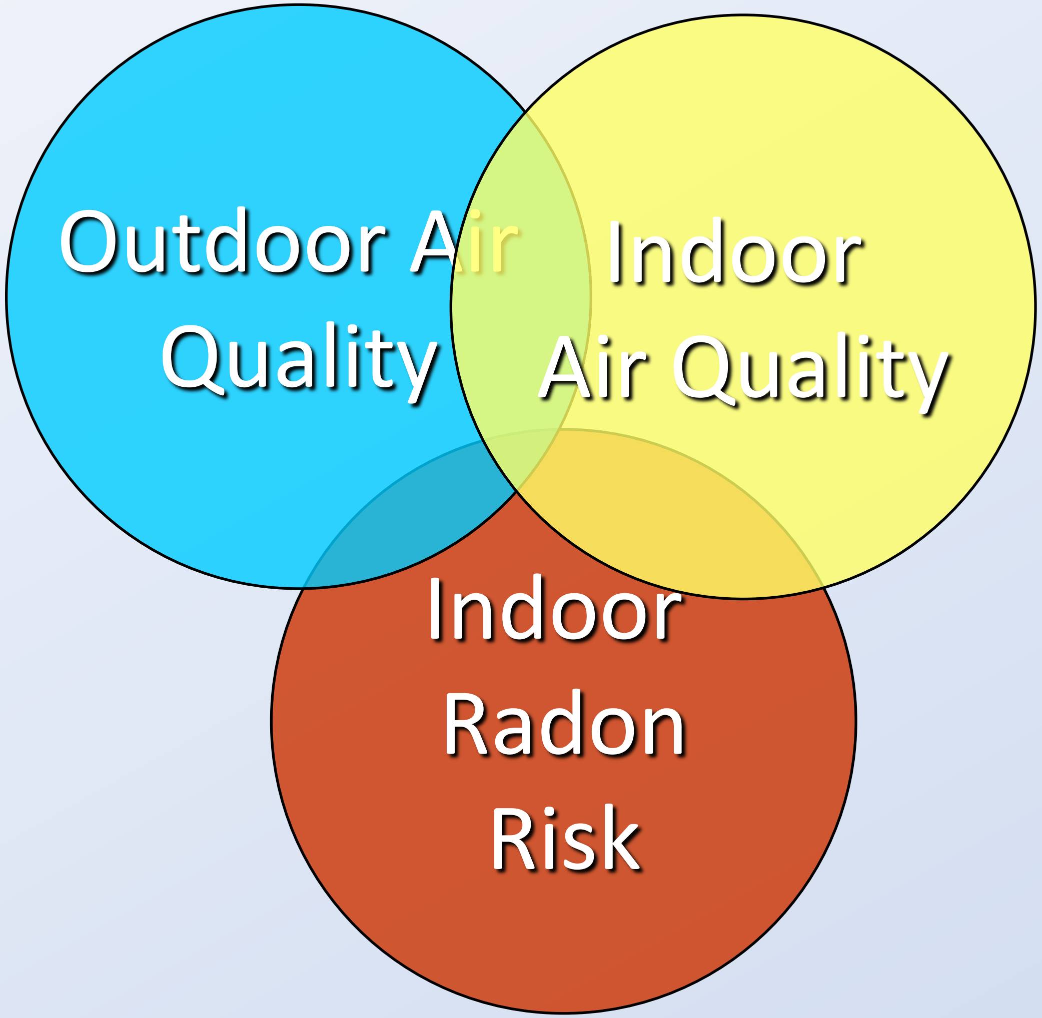
Particulate Reduction: Common Ground For Health Risk Reduction



Airborne particulates impact all three areas

Improvements in air quality can benefit radon dose

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