# On Sampling the Background Indoor Particulate Resuspension Factor

SAND2019-7493C

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64th Annual Meeting of the Health Physics Society
Hilton Orlando, Orlando, FL – July 9, 2017

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# I. INTRODUCTION

# Inhalation Exposure Pathway and Resuspension

- Radionuclides released into environment undergo complex series of transports
- Internal dose from inhalation depends upon available pathways of exposure from site
- Particulate resuspension must be considered when predicting future air quantity for risk assessment

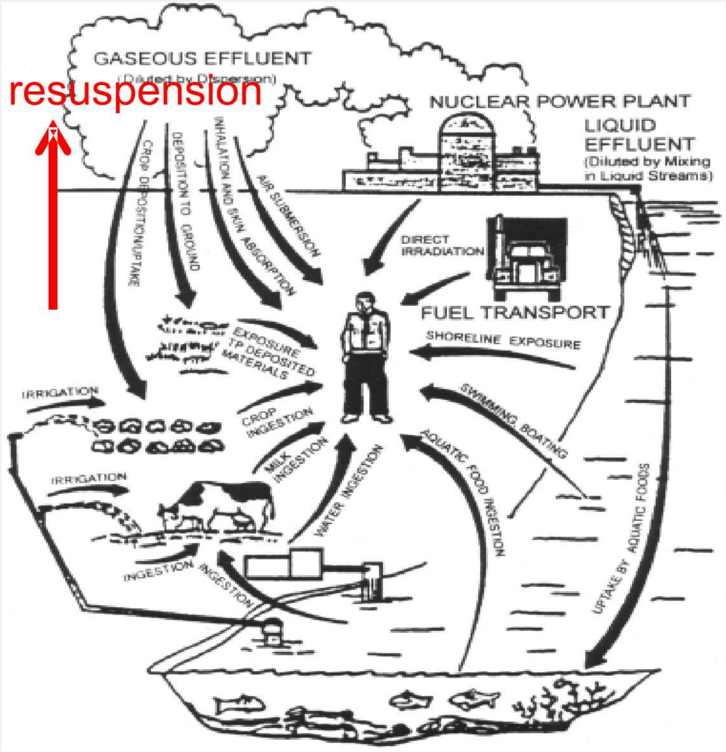


Fig 1. Potential exposure pathways in the event of a radionuclide release.*

*NRC, 2012

# Resuspended Inhalation Dose Prediction Model

- Dose due to inhalation of resuspended radionuclides*:

$$D_{inh} = C_{D,inh} \times \overline{f_B} \times KP,$$
$$KP = \int_{TP} Dp \times e^{-\lambda t} \times S_f(t)\, dt$$

Table 1. Formulaic breakdown of dose from inhalation of radionuclides.

| Term | Description (units) |
|---|---|
| $C_{D,inh}$ | inhalation committed dose coefficient (Sv $Bq^{-1}$) |
| $\overline{f_B}$ | activity-averaged human breathing rate (~0.92 $m^3$ $h^{-1}$) |
| $KP$ | resuspension parameter during time phase (TP ) (Bq s $m^{-3}$) |
| $Dp$ | initial areal deposition (Bq $m^{-2}$) |
| $\lambda$ | radionuclide decay constant ($s^{-1}$) |
| $S_f(t)$ | empirical resuspension factor ($m^{-1}$) |

*SNL, 2015 (simplified)

# Resuspension Factor Development

- Current FRMAC model*:

$$S_f(t) = 10^{-9} + 7 \times 10^{-9} e^{-0.002t} + 5 \times 10^{-6} e^{-0.07t}$$

- Semi-empirical model based on data ranging orders of magnitude
  - Did not differentiate nuclide, environment, or conditions
- Motivated $S_f(t)$ reassessment**

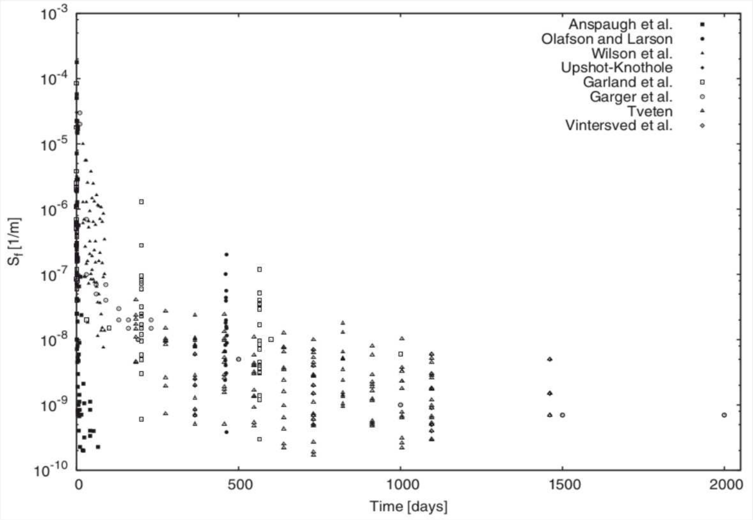


Fig 2. Historical resuspension factors from real/synthetic particle releases.*

*Maxwell and Anspaugh, 2011; **Marshall et al, 2018

# II. METHODOLOGY

# Catenary Kinetic Resuspension Model

- Fractional population of air (A), surface (S), ground (G) compartments:

$$\overset{k_{A\rightarrow}}{\leftarrow} \boxed{A} \underset{k_{A\leftarrow S}}{\overset{k_{A\rightarrow S}}{\rightleftarrows}} \boxed{S} \underset{k_{S\leftarrow G}}{\overset{k_{S\rightarrow G}}{\rightleftarrows}} \boxed{G} \overset{k_{G\rightarrow}}{\rightarrow}$$

$$X_A(t) = X_0 e^{\omega_0 t} + X_1 e^{\omega_1 t} + X_2 e^{\omega_2 t}$$

Table 2. Kinetic rate constant ($s^{-1}$) definitions for three-compartment catenary model.

| Term | Description |
|---|---|
| $k_{A\rightarrow}$ | Weathering rate: local removal via dispersion and sampling |
| $k_{A\rightarrow S}$ | Settling rate: gravitational enhanced by wet deposition |
| $k_{A\leftarrow S}$ | Resuspension rate: electrostatic drift enhanced by meteorology |
| $k_{S\rightarrow G}$ | Infiltration rate: based on ground porosity and colloidal properties |
| $k_{S\leftarrow G}$ | (Bio)turbation rate: mixing by decontamination, biota or long-term geology |
| $k_{G\rightarrow}$ | Migration rate: local removal via infiltration enhanced by wet deposition |

# Air Sampling Chamber

- Corresponds to model: $\overset{k_{A\rightarrow}}{\leftarrow} \boxed{A} \underset{k_{A\leftarrow S}}{\overset{k_{A\rightarrow S}}{\rightleftarrows}} \boxed{S}$

- Release mass $m_0$ of 1 $\mu$m $Eu_2O_3$ particles

- Sampled with low-volume sample rate $f$, exchanged at regular intervals $t_s$

Table 3. Experimental parameters for measuring indoor air samples.

| Parameter (units) | Value |
|---|---|
| $m_0$ (g) | $1, 5$ |
| $f$ ($\mathrm{m}^3/s$) | $3.33 \times 10^{-5}$ |
| $t_s$ (h) | $1, 24, 168$ |

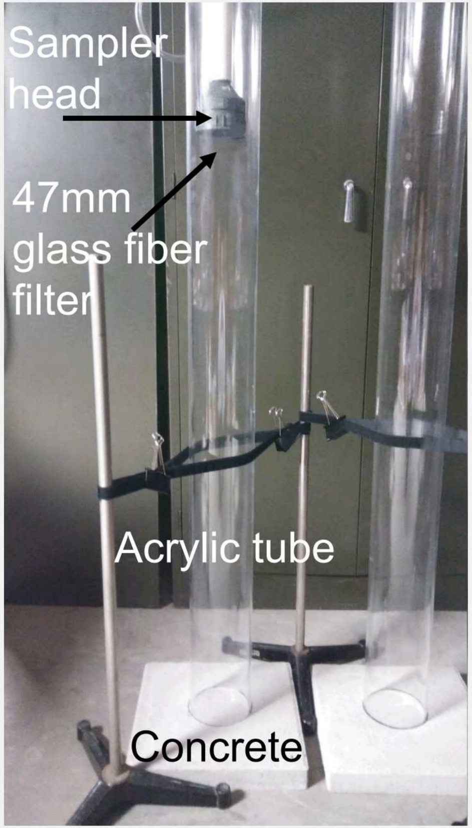


Fig 5. Resuspension chamber with vacuum pump head.

# Thermal Neutron Activation

- Filters positioned at neutron beam portal and irradiated for interval $\tau$
- Neutron flux $\phi$ calibrated with Au foil
- Solid water used to increase flux and decrease detection limit

Table 4. Experimental parameters for activation analysis of sampler filters.

| Parameter (units) | Value |
|---|---|
| $\tau$ (h) | $2, 8, 24$ |
| $\phi$ (n cm$^{-2}$ s$^{-1}$) | $1-20\times10^{7}$ |

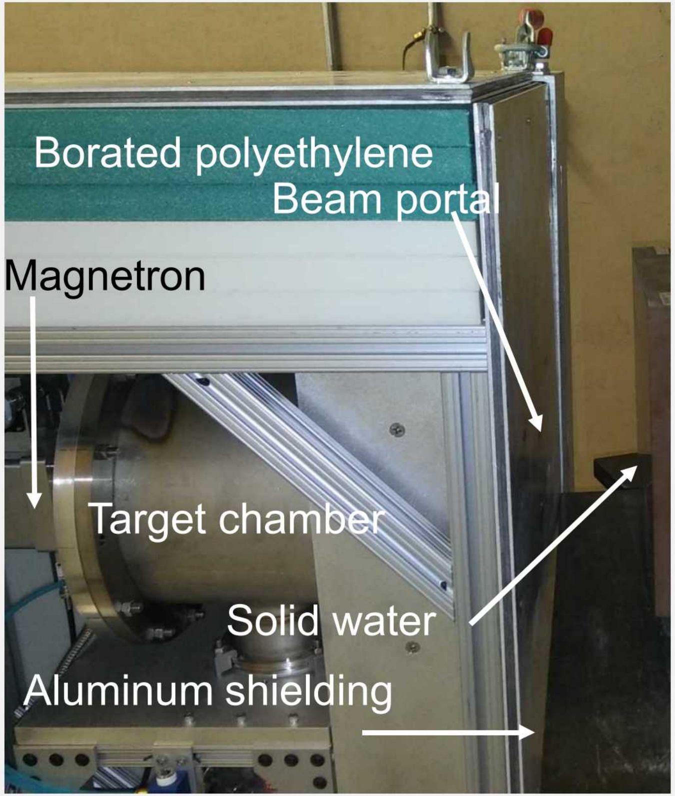


Fig 6. DD110M neutron generator beamline with solid water setup.

# Gamma Acquisition and Analysis

- Activated samples placed directly on Ge detector after delay $t_d$
- Obtained histograms with GENIE* pulse height analysis for interval $\Delta t$
- Pb shield reduced background and thus minimum detectable activity

Table 5. Experimental parameters for spectroscopic analysis of irradiated samples.

| Parameter (units) | Value |
|---|---|
| $t_d$ (h) | $0.1$ |
| $\Delta t$ (h) | $2, 8, 24$ |

*GENIE 2000, Canberra Industries, Inc., Meriden, CT

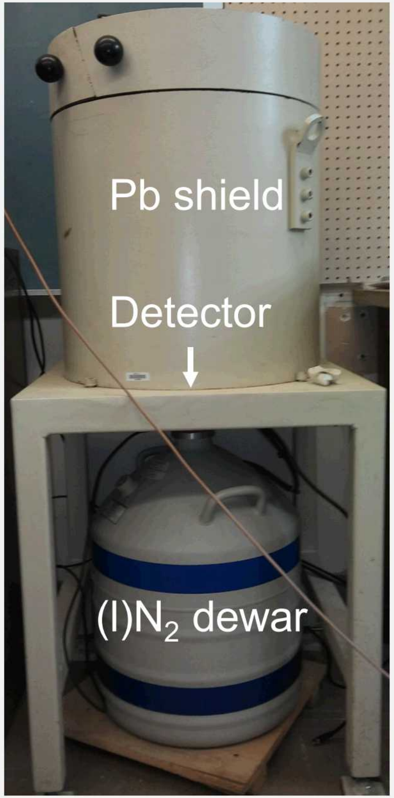


Fig 7. Ge(Li) gamma detector system with Pb shielding setup.

# III. RESULTS

# Resuspension Factor Measurements

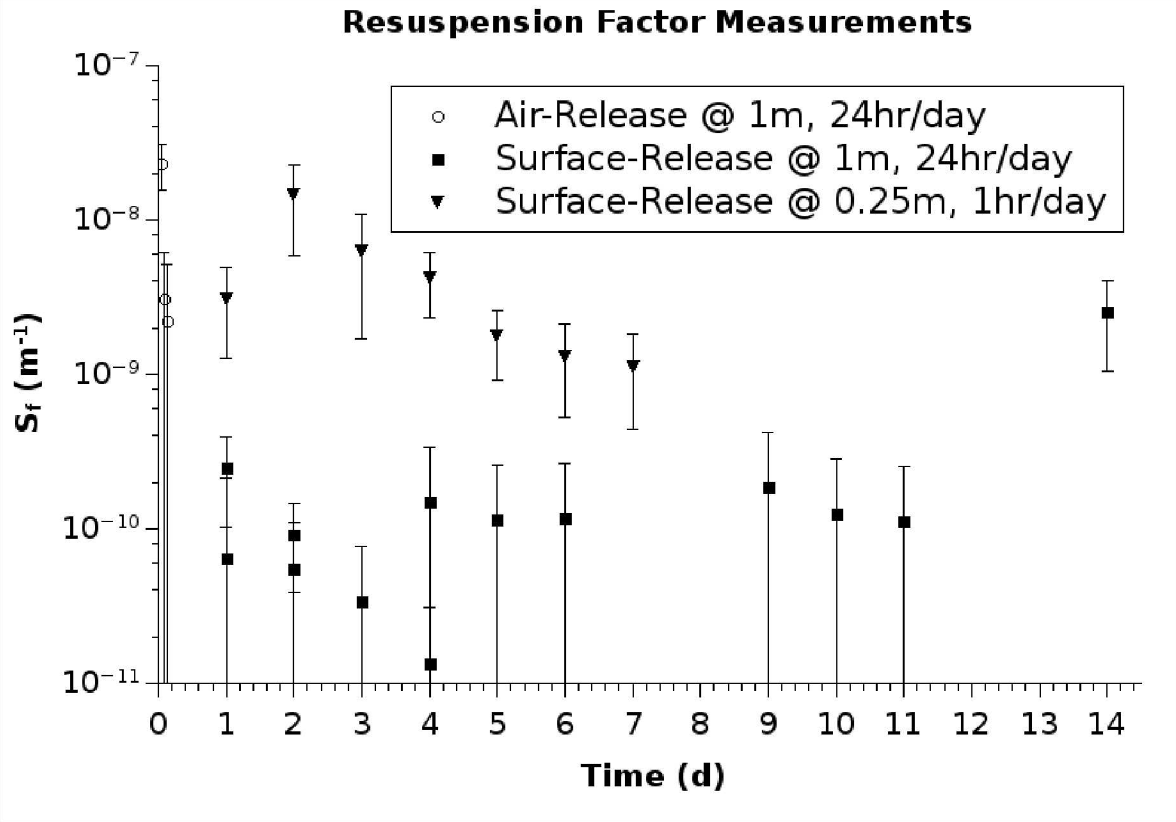


Fig 7. Measured resuspension factors from air and surface releases. The surface release datum at 14 d was sampled for two full weeks.

# IV. DISCUSSION AND FUTURE WORK

# Discussion

- NAA offers precise measure of resuspension factor $S_f$
    - $S_f$ was 100x lower than current model prediction for indoors
- Initial release height drastically affects $S_f$
    - Defining “resuspension” and “initial suspension” is critical for accurate dose predictions

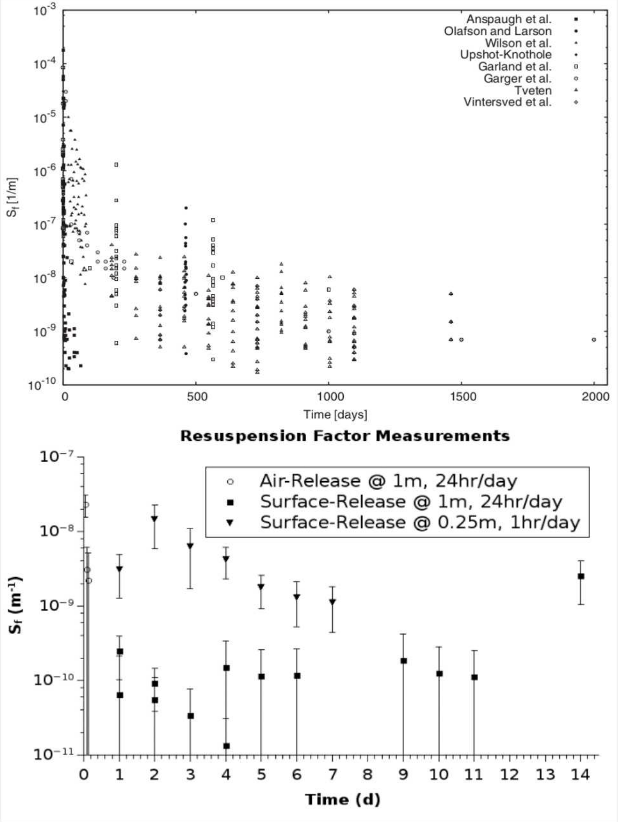


Fig 8. Comparison of historic dataset (above) and newly measured $S_f$ (below).

# Discussion (continued)

- Sampler height dramatically affects $S_f$ measurements
  - Required two-weeks of sampling for first surface-release datum @ 1m
  - $S_f$ highly sensitive to sampling time within time-phase window
- $S_f$ measurements point to possible "undersaturation" conditions
  - Depending on circumstances, agencies using current model may be overcounting dose

# Future Work

- Assess resuspension perturbation from contributing sources
  - Wind speed and gust frequency, other atmospheric conditions
  - Ground chemical identities and roughness
- Resuspension of other elements/isotopes
- (Initial) particle size distribution analysis

# References


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