Sci Notebook 413
Resuspension Literature Review

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

Project Title: Literature Review on Resuspension of Radionuclides from Soil and Volcanic Ash

SwRI Project #: 20-01402-771

Div. 20 POC: Jim Weldy x 6800

Task: collect and review articles on the resuspension of radionuclides attached to soil particles or volcanic ash (deposited 20 km from source).

- particle tracking, 0-100 μm (split @ 10 μm)
- look at saltation, erosion
- need equations and numbers
- end result: exposure @ 20 km @ breathing level

Approach: I will obtain copies of articles pertaining to this subject. I will read them, underlining key points, equations, numbers, assumptions, and caveats. Then, I will put the title of each article @ the top of a page in this notebook and record significant findings, if any. If there is nothing good about an article, I will briefly state the reason.

Currently, I have received about 45 of 63 articles, and I have read about 35 of them.

R Ehlers 9/11/00

Robert C Ehlers 9/11/00

RE
9/25/00

Alzona, J., B.L. Cohen, H. Rudolph, H.N. Jow, and J.O. Frohliger. 1979. Indoor-outdoor relationships for airborne particulate matter of outdoor origin. *Atmospheric Environment* 131: 55-60.

R Ehler
9/12/00

From abstract:

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

- The contaminants of concern were Ca, Fe, Zn, Pb, and Br.
- Residence time of only a few hours.
- The article does not mention anything about size distribution or plutonium (or any radionuclides for that matter).
- It does have a few references to nuclear topics.
- The main conclusion to draw from this is that the infiltration indoors of plutonium should be studied. It may be that only fine particulates can infiltrate through cracks (w/ doors and windows closed), in which case, large particles w/ plutonium attached would not infiltrate, if the findings in other articles in this review are correct in stating that most plutonium that is resuspended is attached to coarser particles.
- Other conclusion is that a person outdoors will be exposed to more Pu anyway; so, that should be considered the worst case scenario. This is mentioned, b/c some gaseous pollutants have been known to exist in higher concentrations inside than outside.

Robert C Ehler 9/25/00

p57 –

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed on page 3 of this notebook.

RE 9/27/00

Robert Ehlers 9/27/00

Amato, A.J. 1976. Theoretical resuspension ratios. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 891-905. R Ehlers 9-12-00

Resuspension ratio is R = AR/AD, where AR is the portion of the air concentration of contaminants attributed to resuspension upwind, while AD is that which comes directly ~~f the~~ RE 9/25/00 from the source.

Conclusions of report:

p897 " 1.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

(Fig. 2).

2.

(Fig. 4). (Fig. 3). (Fig. 6).

3.

(Fig. 2 through 6)

These points all ~~may~~ RE 9/25/00 make sense intuitively, except, perhaps the second one in regard to the low windspeed. Resuspension is lower at low windspeed (as found in other reports & articles), but, apparently, AD ~~more~~ RE 9/25/00 decreases more, since AR/AD decreases w/ windspeed. This makes sense; if wind speed is low, then the contaminants will not be ~~disp~~ RE 9/25/00 carried downwind as far, so AD decreases, e.g. when deposition is considered.

→ The graphs should be useful, if the conditions at NTS are similar. If not, then the equations can be used with the parameters changed. The bottom of page 897 lists the values of parameters used to generate the graphs. ⟶

Robert Ehlers 9/25/00

The equations used are given on pages 895–897.
The assumptions are given on page 892.
The purpose of this model was to include meteorological and geological parameters, b/c the resuspension factor ignores them.
Questionable assumptions are:
① surface horizontal? ⑦ saltation + creep are ignored
⑥ Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 5 of this notebook.
interval is 1 meter long and layer is only 1 cm deep.
This 20 study, h > 1 cm, so contamination distribution may not be homogeneous, esp. if the source is aged (plutonium particles migrate in soil).
⑧ Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 5 of this notebook.
interval is only 1 meter long.
Volcanic ash would certainly cover a much larger area.
We would have to add a term for initial contamination for each interval in which there is ash on the surface AND where there is soil but no ash. Probably the soil term would be lower than the ash term (regarding Pu level).
9. Steady state conditions prevail in the final formulation.
From abstract: Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 5 of this notebook.

makes sense, since $R = A_R' / A_D$; just looking at the relative contributions.
Overall: This model is somewhat useful, but neglects too many processes due to the simplifying assumptions.
Robert C Ehlen 9/25/00

Anspaugh, L.R. and P.L. Phelps. 1976. Experimental studies on the resuspension of plutonium from aged sources at the Nevada Test Site. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 727-43. 9-12-00 RCEhlen

- "Aged" in this report is considered many years. The measurements were done 20 years after the contaminating event.
- saltation was "generally not significant"
- "saltation fluxes at this site are ordinarily very low"
- largest height measured for saltation flux was 40 cm, whereas we're concerned w/ respirable particles at breathing level.
- based on Healy's model of transport and diffusion
- displacement plane = 0.44 m = D
- surface roughness = 20 mm = Z_0
- substantially higher concentrations are downwind during high windspeeds
- At the center of the source, concentrations were directly proportional to the square of the friction velocity.

$$\chi = 3 \times 10^{-12} U_*^2 \qquad U_* [=] \text{mps}; \chi [=] \mu Ci/m^3$$

- Question: validity of correlating χ to U_*^2 under all meteorological conditions b/c of outliers (stable, calm regime or dust devil).

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

(pg. 735)

(next page)

Robert C Ehlen 9/25/00

The attempt to analyze the data using the Healy approach for GMX site, which consisted of using 50 Gaussian line sources, was not successful except when close to the source and at heights less than 1m.

Resuspension rates varied from 2.7×10^{-12} to 4.8×10^{-10} sec^{-1}.

Pulmonary deposition is 25 to 15%.

There is only a little justification (see p. 738) for using the resuspension factor ~~which~~ concept. RE 9/25/00

RE 9/25/00

Robert C Ehler 9/25/00

Anspaugh, L.R., J.H. Shinn, P.L. Phelps, and N.C. Kennedy. 1975. Resuspension and redistribution of plutonium in soils. *Health Physics* 29(10): 571-82.

9-12-00 R Ehler

Information potentially subject to copyright protection was redacted rom this location. The redacted material is from the reference above.

pg. 572

— for $F = -\rho K u_* X$, F = flux, ρ = constant, u_* = friction velocity, and X = airborne @ height z

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

this should caveat the data.

— pg. 576 lists general conclusions regarding earlier radionuclide resuspension studies: RE 9/25/00

1) half time increases as time after detonation increases

2) Information potentially subject to copyright protection was redacted from this location. Th redacted material is from the reference above.

(p. 7)

(p. 728).

The Pu probably migrates downward, too.

3) Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

— This paper overlaps the Anspaugh 1974 paper regarding the attempt to fit the data to Healy's model. The resuspension values for the NTS varied from 2.7×10^{-12} to 4.8×10^{-10} sec^{-1} (rates) →

Robert C Ehler 9/25/00

saltation ⇒ 50 to 500 um. suspension ⇒ <100 um.
creep ⇒ large, but <2 mm.

The model still does not account for weathering, so this paper doesn't serve much use as far as numbers and equations are concerned.
The general conclusions that it made for earlier resuspension studies are well-taken.
Overall, this paper doesn't add much to the 1974 paper.

RE 9/28/00

Robert C. Ehlers 9/28/00

Anspaugh, L.R. 1974. Appendix A. Resuspension Element Status Report: The Use of NTS Data and Experience to Predict Air Concentrations of Plutonium Due to Resuspension on the Enewetak Atoll. Lawrence Livermore Laboratory, California; Bio-Medical Division. 9-12-00 R Ehlers

Ordered 9/25/00. Unable to locate 10/2/00

RE 10/4/00

Robert C Ehlers 10/4/00

RE 10/4/00

Robert C Ehlers 10/4/00

Anspaugh, L. R., P.I. Phelps, N.C. Kennedy, J. H. Shinn, and J.M. Reichman. 1976. Experimental studies on the resuspension of plutonium from aged sources at the Nevada test site. *Atmosphere-Surface Exchange Particulate Gaseous Pollutants*, ERDA Symposium Proceedings 38: 727-43.

RCEhlers 9-12-00

Duplicate of article on pg. 7.

RE 9/25/00

Robert C. Ehlers 9/25/00

RE 9/25/00

Robert C Ehlers 9/25/00

Aylor, D.E. 1976. Resuspension of particles from plant surfaces by wind. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 791-812. RCEhlers 9-12-00

This article is interesting, but probably not useful.
Too many concerns:
1) plutonium different from pollen + spores
2) wind measurements are diff. from direct observations
3) leaf angles are assumed constant
4) leaf flapping → negligible nevada RE 9/25/00
5) types of plants (corn or pine in ~~Utah~~ ?)
6) relative humidity too high compared to ~~Utah~~ nevada 9/25/00 ?
7) gustiness or turbulence more important than mean wind speed

RE 9/25/00

Robert C Ehlers 9/25/00

RE

9/25/00

Robert C Ehler 9/25/00

Birenzvige, A. 1992. Inhalation hazard from reaerosolized biological agents: a review. *Chemical Research, Development & Engineering Center Report CRDEC-TR-413.* Aberdeen Proving Ground, Maryland: U.S. Army Armament Munitions Chemical Command: 55 pp.

R Ehler 9-12-00

p. 17

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

- Decrease in RF due to migration of Pu into soil and stronger attachment of traces to crustal particles
- When using or reporting RF's, must specify the depth of surface layer and the height at which air conc. was measured.
- pg. 21 Chepil reported that 15–25% of resuspended particles are in the respirable range.
- pg. 23 Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above. — ?! goes against findings of other authors
- pg. 25 Belly reported threshold friction velocity is related to moisture by:

$$V_{*t} = A(1.8 + 0.16 \log(w)) \sqrt{gd/\rho}$$

- p. 29 – Chepil reported that particles smaller than 20 µm are evenly distributed between heights of 2 and 20 ft. Goes ag. p. 23 statement. This statement is more correct, but wonder about "2–20 ft" part
- p. 31 mentions Anspaugh NTS Resusp rate = 2.7×10^{-12} to 4.8×10^{-10} s^{-1} of 20 yr. old Pu particles at NTS; 15–25% respirable mass conc.
- same site (NTS) Shinn found that resuspended particles had max. @ 4–5 µm. and conc. decreased by order of magnitude for 1 and 10 µm. total mass conc. increased by 6th power of wind.
- p7 respirable is 0.5 to 3.5 µm.

Robert C Ehler 10/2/00

p 34 Cowherd report that between 60 and 85% of the particle mass resuspended from roads is larger than 3.5 um.

- spends a large amount of time on roadway dust including EPA's model
- pg. 39 Healy reports that resuspension rate from agricultural activities are 10^{-6} to 10^{-8} s^{-1}!

Article mentions 17 articles already in the lit. review, but does not look at them critically. Author just presents very brief info. from each article in the review. The bibliography is good b/c it has 135 references.

Conclusion — not much use.

RE 10/2/00

Robert C Ehlen 10/2/00

Bridge, J.S. 1983. Critical appraisal of fluvial facies models. *Bulletin* 673. American Association of Petroleum Geologists: 429. RCEhlen 9-12-00

This article is about river deposition, has no numbers or equations, is only two paragraphs long, and doesn't serve any purpose for this literature review.

RE 9/25/00

Robert C Ehlen 9/25/00

RE 9/25/00

Robert C Ehler 9/25/00

Engelmann, R.J. 1976. The relation between soil contamination and lung burden, and implications to resuspension experimental design. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 945-59.

RCEhler 9-12-00

This paper has no real value for this study. It makes points that can be found in other papers.

RE 9/25/00

Robert C. Ehler 9/25/00

RE 9/25/00

Robert C. Ehlers 9/25/00

Engelmann, R.J. 1976. Summary and concluding comments to deposition-resuspension 1974. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Engelmann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 960-63.

9-12-00
REhlers

- need better instrumentation to avoid breakage of particles upon collection
- LMFBR EIS model + numbers were omitted
- soil stabilizers were not mentioned in conference
- measure other soil and air attributes
- try other chemical tracers, esp. conservative ones
  use in combination
- get size and activity distribution, not just mass (soil)
- multi-layer deposition model
- plume depletion model of Horst, good
- power law + coefficients need more development for
  $K = aU_*^b$
- fire, vegetation succession, vegetation erosion cycle – need study
- ★ look at extensive soil erosion work by Chepil, Skidmore USDA
- resuspension ratios should be determined for size intervals
  not just total airborne activity.
- ✓ respirable resuspension by windspeed classes
- inside/outside exposure

Conclusion – some of these are addressed by authors outside of this conference. This test shows how complex resuspension really is.

RE 9/25/00

Robert C. Ehlers 9/25/00

RE 9/25/00

Robert C Ehler 9/25/00

Fogh, C.L., J. Roed, and K.G. Andersson. 1999. Radionuclide resuspension and mixed deposition at different heights. *Journal of Environmental Radioactivity* 46(1). Elsevier: 67-75.

RE 9-12-00

no Pu or Am, only Cs and Be.

This article just gives resuspension factors and deposition velocities; so the numbers are probably not that useful since resuspension factors are flawed (the concept is anyway). However, some of the points made in the article are good

— average resuspension factor for Cs during 3½ year study was 3.6×10^{-10} m^{-1}; Cs had high dry deposition velocity (~ 0.02 m/s) (corresponding to sedimentation vel of large particles, about 28 µm), and it showed little or no correlation to precipitation.

— Be had a smaller dep. vel. of 5.6×10^{-4} m/s, had strong dependence on precipitation and showed dep. vel. similar to long-range-transport particles.

— p. 72

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

This comment supports the assertion made by me regarding unpaved roads in reviewing Hodgin's article (p. 47-48) that resuspension by vehicles (esp. unpaved roads) could be significant.

— p. 72

Information potentially subject to copyright protection was redacted from his location. The redacted material is from the reference above.

This shows that resuspension factors really are not very good to use. →

— p. 74

Information potentially subject to copyright protection was edacted from this location. The redacted material is from the reference on page 25 of this notebook.

RE 9/25/00

— The last two points (previous) show that deposition has to be considered in the calculation of resuspension b/c the two processes are related.

RE 9/25/00

— The last point shows, or confirms, other articles that state that most radionuclide suspension is from larger particles than those found in the respirable fraction.

— p. 68

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 25 of this notebook.

This supports other findings that resuspension rates change with time and "weathering" should be included in any resuspension model.

RE 9/25/00

Robert C Ehler 9/25/00

Fowler, W.B. and W. Lopushinsky. 1986. Wind-blown volcanic ash in forest and agricultural locations as related to meteorological conditions. *Atmospheric Environment* 203: 421-5. R Ehler 9/25/00

Site: Mount St. Helens, WA

downside — all sites were grass covered, forest and agricultural locations; so, numbers won't apply to Nevada, but perhaps method will.

— 1980 eruption of Mt St. Helens — ash deposited >240 km

— This article does not mention resuspension per se, but it does have some results for wind tunnel erosion studies.

— exponential increase in suspended material with increasing wind speed, referenced Bauer (1972) that rate of wind erosion increases w/ third power of drag velocity.

— ash types

	ash types	threshold vel. (km/h)
newly deposited	loose, air dried, smooth surface	11.4-11.7
	w/ slightly irregular surface	9.0-9.3
	moderately irregular	5.8-7.1
consolidated	wetted, air dried	>69
	wetted, air dried, disturbed	22.5

— "on a daily basis, highest winds always produced a greater rate of ash accumulation." — logical

— moisture content (of ash) and other factors were not examined.

Overall conclusion: not very useful.

RE 9/25/00

Robert C Ehler 9/25/00

R.E. 9/25/00

Robert C. Ehlers 9/25/00

Fowler, E.B. 1976. Sampling of soils for radioactivity: philosophy, experience, and results. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 709-26.

R. Ehlers 9-12-00

Too general and no useful data

R.E. 9/25/00

Robert C. Ehlers 9/25/00

RE 9/25/00

Robert C Ehlers 9/25/00

Garcia-Olivares, A., and E. Iranzo. 1997. Resuspension and transport of plutonium in the Palomares area. *Journal of Environmental Radioactivity* 37(1): 101-14.

RCEhlers 9-12-00

This article presents a compartmental model of resuspension and transport that depends on the division of windspeed into classes to more accurately determine resuspension rates

- eight classes of windspeed and 12 classes of wind direction. The balance (steady state conditions) was found for each windclass according to their probabilities (weighted).

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

balance of activity in volume element (p. 3) is

$$\frac{d(hc)}{dt} = t_r C_s(x,y) - v_g c - hv \cdot \nabla c - h D_z \nabla^2 c$$

Anspaugh 1975 → $t_r = a u_*^3$, where $a = 10^{-10}\ s^2 m^{-3}$, and t_r is suspension rate

after using assumptions and further algebra + calculus, the equation is $c = \exp(-v_g l / hv) \int_0^{l} \frac{t_r C_s(l')}{hv} \exp(v_g l'/hv)\, dl'$

Solving this eq. for all wind speeds + directions for each cell in the grid gives annual averages for each grid cell. so it yields order of magnitude answers.

→ Wide variability in air concentrations. This model, on closer inspection, ~~still~~ RE 9/26/00 is not very much better than a simple resuspension factor. It does include wind classes, but the variation is too wide when annual averages are used. →

Robert C Ehlers 9/26/00

There are a few good points to mention from the article:

RE 9/26/00

1)

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(Sehmel, 1984). — These seem like common sense but they show that their model did not consider these things within the model, at least, not adequately.

— pg. 110 Contributions to air contamination

particle size	percent
<40 µm	52
40-63 µm	32
63-200 µm	16

— pg 112

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 31 of this notebook.

— pg. 113 author suggestions — 1) use daily meteor. values
2) no annual averaging ⇒ go together, but still leaves a lot to be desired.

Conclusion: Use findings of general nature but don't use actual model b/c too many factors are excluded.
Any model that is used by Div. 20, should try to use wind classes (speed & direction).

RE 9/26/00

Robert C Ehler 9/26/00

Garger, E. K., F.O. Hoffman, K.M. Thiessen, D. Galeriu, A.I. Kryshev, T. Lev, C.W. Miller, S.K. Nair, N. Talerko, and B. Watkins. 1998. Test of existing mathematical models for atmospheric resuspension of radionuclides. *Journal of Environmental Radioactivity* 42(2-3). Elsevier: 157-175.

R Ehler 9-26-00

These mathematical models attempt to account for both local and regional scales as well as seasonal variations; however, they are really just resuspension factor models. As mentioned in reviews of other articles, the resuspension factor models are not good b/c they don't normally account for weathering or many other factors.

These empirical models depend on the selection of the proper initial resuspension factor, based on local conditions. These models can be used if the initial value is determined and the correct weathering term is used; however, it still would not be enough. Dust devils, monthly or daily met conditions, soil characteristics, etc. need to be considered.

From the report, it appears that for all of the sites tested, the overall best model is Nair; however, it may not be best for NTS at Yucca Mountain.

— Table 1 is nice though; it lists the models used by the study's participants.

RE 9/26/00

Robert C Ehler 9/26/00

Rε 9/26/00

Robert C Ehler 9/26/00

Gay, D. D., and J.R. Watts. 1982. Particle size distribution of airborne plutonium near a chemical separations facility. *Report DP-1610.* Aiken, SC: Savannah River Laboratory: 15 pp.

RCEhler 9-22-00

Ordered on 9/25/00. Rec'd 10/2/00.

The facility is the Savannah River Plant in South Carolina. We can't really take data from one site and use it at another, like the Nevada Test Site. However here are the findings of note from this small study:

1)

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference above.

pg 7

- The air concentrations were all measured at 1.1 m off ground.

Conclusions There is not much detail in this study, and it is not useful to any significant degree.

Rε 10/3/00

Robert C. Ehler 10/3/00

RE 10/3/00

Robert C Ehlers 10/3/00

Gilbert, R.O. 1976. Statistical design aspects of sampling soil for plutonium. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 689-708. RCEhlers 9-12-00

nothing about resuspension

RE 9/25/00

Robert C Ehlers 9/25/00

RE 9/25/00

Robert E Ehlen 9/25/00

Gillette D.A. 1974. The influence of wind velocity on size distribution of aerosols. *Journal of Geophysical Research* 79 (27): 4068-75. RE Ehlen 9-12-00

field measurements and wind tunnel simulations

Interesting points:

1) p 4068 '

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

— but, they'll average out; depends on the time-scale of the mean speed and how that compares to the time-scale of the period of interest.

2) pg. 4070

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

— good explanation; pertains to dust devils too.

— ratio of sedimentation vel. to friction vel. = V_{sed}/U_*.

suspended ~~soil~~ aerosol (RE 9/26/00), $V_{sed}/U_* = 0.12$

settling aerosol, $V_{sed}/U_* = 0.68$

— Chepil (1951)

Information potentially subject to copyright protection was redacted rom this location. The redacted material is from the reference listed above.

Robert E Ehlen 9/26/00

— There was also little difference bet 1.5 m and 6m heights aboveground.
Tristron velocity measurements found in the wind tunnel were 113.5 cm/s, 96.5 cm/s and 74 cm/s (Figure 7). average = 95 cm/s
compare to Fowler + Lopushinsky value of 72 km/h for (ash) = new soil and 69 km/h for consolidated soil (ash).

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 39 of this notebook.

this study's answers same order of magnitude.
Authors conclusion: sandblasting of soil surface is the dominant mechanism of fine erosion once saltation has started.
Their study did not look at saltation per se, and other reports (Anspaugh, 1976) state that saltation is negligible at NTS.
So, this author's conclusion doesn't hold much weight, since the sandblasting of soil was not even simulated.
→ These soils are in Big Spring, TX, which are different from those found in Nevada, confirmed by (Anspaugh, 1976) which states that the texas soil is highly erodible, while the GMX soil is stable.
Conclusion : General comments, theoretical, maybe useful but probably none of the graphs.

RE 9/26/00

Robert C. Ehlers 9/26/00

Hammer, R.J. 1983. Analysis of resuspension source area impacts at Rocky Flats surveillance air samplers S-7 and S-8, July 25-August 25, 1983 and September 8-October 4, 1983. *Report.* Golden, CO: Rockwell International Corp., Golden, CO: 19 pp. RCEhlers 9-12-00

Ordered on 9/25/00. Received 10/2/00

Only four sets of data. No real correlation w/ site-specific parameters for meteorology, soil conditions, or size distribution.
Don't use.

RE 10/3/00

Robert C Ehlers 10/3/00

RE 10/3/00

Robert C Ehler 10/3/00

Hayden, J.A. 1976. Characterization of environmental plutonium by nuclear track techniques. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 648-60.

R Ehler 9-12-00

nothing on resuspension

RE 9/25/00

Robert C Ehler 9/25/00

RE 9/25/00

Robert C Ehler 9/25/00

Healy, J.W. 1980. Review of Resuspension Models. *Transuranic Elements in the Environment DOE/TIC-22800*. Washington, DC: U.S. Department of Energy.

R Ehler 9-12-00

Ordered on 9/25/00. Rec'd 10/2/00.

Excellent paper. Easy to understand.

Refers to 12 papers reviewed in this notebook.

No new data b/c it's a review, but will use it to compare w/ my own reviews.

Go to other side.

RE 10/6/00

Robert C Ehler 10/6/00

- States that Mishima's values of RF are for various conditions and times and that's why RFs vary over so many orders of magnitude.
- Anspaugh (1974) states that previously published models of resuspension rates should not be used many years after contaminating event.
- Anspaugh — desert area only
- Okaza-Chocimowski model does not have data to make adequate choices for a given area.
- Sehmel & Lloyd (1976) (Particle resuspension rates) and Sehmel (1977, Battelle Experiments) — "preaged" by applying water, that's why they did not have weathering
- RF — based on short term experiments → crude
- Resuspension rates — describe conc. @ any pt. around nonuniform contaminated area by use of point-source dispersion and deposition equations and integration over the area — use soil erosion data
- Chepil — particles < 5 um don't exist in ordinary soils b/c of aggregation ⇒ contaminants, as fine particles or aggregated onto soil, will behave as soil particles; moisture impt factor

Travis model incorporates studies only of eroding agricultural soils so should be applied only to similar soils.

- sandblasting breaks up aggregates + causes vertical flux at power of friction velocity = three. GMX: $F = 0.73 u_*^{3.09}$ (Shinn 1976)
  - use of soil erosion index (Fig. 2, pg. 222)
- Shinn (1977) GMX desert, crust, erosion only of disturbed mechanically. NTS has bulk of activity in 20 to 53 um range; activity in < 20 um is 3-5 times.

★ Healy likes resuspension rates w/ dispersion & deposition, matches meas data.

Robert C Ehlers 10/6/00

Hodgin, C. R. 1983. Mechanical resuspension of plutonium-239 from unpaved roads. *Precipitation Scavenging, Dry Deposition, Resuspension: Proceedings of the 4th International Conference* 2. New York, NY: Elsevier: 1175-84.

RCEhlers 9-12-00

- Site - Rocky Flats, CO
- A road dust resuspension model was developed.
- Road dust contained trace quantities of plutonium.
- An emulsified petroleum dust suppressant (Coherex) was used at this site and provided an overall annual control efficiency of 0.59.
- Emission factors and a line source model (Gaussian) was used with estimated parameter values for both.
- Confidence interval was 1.0 to 7.0 ug/m³ (inhalable particulates, or 0.115 to 1.08 uBq/m³ (^{239}Pu) was found for Gunnery Range Road and 2.0 to 9.0 ug/m³ and 0.281 to 1.30 uBq/m³ for the SE Perimeter Road.
- Gunnery Range Road: impact = 2.1% of observed annual concentration at samplers onsite (Rocky Flats) w/ 95% confidence interval of 1.1 to 7.9%.
- SE Perimeter Road: impact = 3.8% (2.0 to 9.1%)
- Combined: impact = 5.9% (3.2 to 17.0%)

Conclusions: Fugitive emissions (plutonium) from the two roads are not substantial contributors to Pu concentrations observed at site samplers.

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my opinion on next page ⟶

Robert C Ehlers 9/26/00

With 59% dust control efficiency,
the combined effect of the two roads was
5.9% (3.2 to 17% for 95% confidence interval).
The conclusions state that w/ control at 90%, the
site atmospheric Pu concentration would be reduced
by only four percent.
So, $5.9 - 4 = 1.9\%$

assuming linearity $\Rightarrow \frac{90-59}{1.9-5.9} = \frac{31}{-4} = -7.75$

$\frac{59-0}{5.9-x} = -7.75 \Rightarrow 59 = -45.725 + 7.75x$

$x = 13.5\%$ contribution from the roads if the
dust control efficiency is 0% (no dust
suppressant used, and no rain)
This is not an insignificant contribution, esp.
w/ a 95% confidence interval goes up to 17% when
dust control was 59%.)
So, RE 9/25/00
Also, the parameter values were just estimates w/o
any real knowledge of each parameter's independent
variance (see pg. 1182).
Conditions are different at NTS, and dust from
unpaved roads could be a very significant Pu concentration
source for the overall atmospheric concentration at the
site or the vicinity. At 20 km, RE 9/25/00 the existence of
unpaved roads would have to be determined to see if they
would contribute to the scenarios in the project's scope.

Robert C. Ehlen 9/26/00

Horst, T.W. 1982. The Estimation of Airborne and Surface Contamination Resulting from the Deposition-Resuspension Process. *Health Physics* 43(2): 269-272. R Ehlen 9-22-00

Horst explains why resuspension factor should
only be used in the immediate vicinity of the maximum
surface contamination, if the factor is applied at all.
This note points out the theoretical inadequacy of the
resuspension factor model. It recommends that

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That article is
reviewed on pg. 51 of this notebook.
Also says that resuspension rate model is also inadequate due
to lack of data on resuspension and weathering rates.

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C_r is direct airborne contamination due to resuspension
C_d is direct airborne contamination due to deposition (accounting
for it, that is)
C_o is airborne contamination concentration with no resuspension or deposition
Essentially: Horst wants to ignore resuspension rates
b/c they vary from 10^{-12} sec^{-1} to 10^{-4} sec^{-1} (Sehmel, 1980),
and take no credit for deposition losses.
So, we just have a very conservative concentration estimate.
Conclusion: Good for debunking resuspension factor and
rate models + theory but doesn't provide any
real alternative.

Robert C Ehlen 9/26/00

RE 9/26/00

Robert C. Ehlen 9/26/00

Horst, T.W. 1979. The Annual-Average Effect of the Deposition-Resuspension Process on Airborne Contamination Near the Surface. *Atmospheric Environment* 13: 791-6. R. Ehlen 9/26/00

- He ignores resuspension and deposition in his calculations in order to find an upper limit on the ground-level (1m) concentration
- He ignores weathering to "avoid the need to parameterize this highly variable process." (convenient)
- He assumes steady-state in order to continue his theoretical manipulations.
- Annual-average is too long a time period for our concern; we'll need something of much shorter time scale.

Good points: explanation of deposition-resuspension cycles (except, they occur simultaneously at times)
- discusses variable wind direction (sect. 5) (however, he talks about annual average, so why not use annual average wind direction?).

In the abstract, Horst states that

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The "mixing" part makes sense, but the ground-level contamination refers to cause or effect? He says cause, but should probably be effect. It all depends on receptor height (which Horst denies) and particle size distribution (which he says is respirable size and smaller, pg. 792). → see Frango (65).

Conclusion: too theoretical and too many limitations and assumptions. Don't use.

Robert C. Ehlen 9/26/00

RE 9/26/00

Robert C. Ehlers 9/26/00

Horst, T.W. 1978. Estimation of air concentrations due to the suspension of surface contamination. *Atmospheric Environment* 124: 797-802.

RE Ehlers 9-26-00

This article describes a method to use the Gaussian plume model for an area source, accounting for resuspension and a set of ~~Pasqu~~ RE 9/26/00 diagrams based on Pasquill-type dispersion coefficients.

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(p.802) → limitation

It compares well with the exact solution, agreement is best for Pasquill A and large x and worst for class F and small x. ← low windspeed, high insolation

Eq. 21 gives crosswind-integrated, Gaussian area source concentration,

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The eq. contains simplifications that are explained in the article. Eq. 21 includes resuspension and deposition.

Error (compared to exact solution) is 10 to 20%. Agreement is poorer beyond 5σ downwind since the two contributions to Eq. 21 continue to increase while difference decreases.

Conclusion: This model is good if a Gaussian plume model has to be used. The values for Vd and Λ (deposition and resuspension) can be determined using equations from other models, thereby combining the two/three models. Eq. 21 does not account for weathering or soil characteristics → Perhaps too general for Div. 20 model.

Robert Ehlers 9/26/00

~~RE 9/26/00~~

Robert C Ehlers 9/26/00

Iranzo, E., A. Espinosa, and J. Martinez. 1994. Resuspension in the Palomares area of Spain: a summary of experimental studies. *Journal of Aerosol Sciences.* 25(5): 833-41. REhlers 9-12-00

Resuspension factors are based on measurements of Pu contamination in the top 2 cm of soil. Resuspension factor (RF) appears to be higher in those areas with the lowest initial deposits. Horst, pg. 51 notebook stated something very similar, that ~~resuspension was higher with~~ RE 9/26/00 RE 9/26/00 the contaminant is preferentially resuspended during periods of greater average mixing and lower ground-level contamination. No one seems to yet have an explanation for this; it seems counterintuitive. It would seem that the greater the ~~ground~~ RE 9/26/00 soil concentration of Pu, the greater the flux of Pu into the air for a given windspeed. Contaminant flux is usually driven by the difference in concentration between two areas or two media. But, the RF is air concentration / soil concentration, so, if the soil concentration is lower for a given air concentration, then RF increases. Perhaps, with greater (or shorter) initial concentration, the initial RF applies for a longer period, then weathering starts to play an important part in the overall resuspension process. So, the ~~initial~~ RE 9/26/00 period for the initial RF may be dependent on the initial deposit. Also, air concentration depends on resuspension and deposition from upwind; so the old RF problem! Another possibility: in larger deposits, perhaps the Pu migrates downward out of the top two cm of soil, thereby lowering the RF, b/c soil is not uniformly contaminated. There may also be a weathering rate, too, that also "weathers" or

Conjecture

Robert C Ehlers 9/26/00

changes w/ time. In other words, migration into the soil may ~~have~~ RE 9/26/00 be just as complex as resuspension, b/c you do have temperature, moisture, water, etc.

$K(m^{-1}) = 1.29\times10^{-9} \exp[-0.00976t]$, is the reduction with time of the resuspension factor.

— The duration of each wind class also influences the amount of resuspended material (pg. 839). So, even if the average wind speed or wind direction is the same in two cases, the one with longer durations ~~would have~~ RE 9/26/00 of high windspeeds might have a higher corresponding resuspension of material, driving up the RF?

Conclusions of authors: (1) RF decreases exponentially w/ time, from initial RF = order of $10^{-7}\ m^{-1}$ to $\sim10^{-9}\ m^{-1}$ a few months later, to 10^{-9} to 10^{-10} some years later. (2) Dust concentration due to resuspension averaged $93 \pm 39\ \mu g/m^3$ in cultivated area and $100 \pm 32\ \mu g/m^3$ in built-up area. (3) Plant surfaces showed highest dust concentration that had best characteristics for interception and retention of particles. (4) Built-up area had 0.76 correlation between frequency of windspeed >5 m/s and Pu concentration in air.

Conclusions: Interesting report, but may not apply to NTS. RF still has problems even w/ weathering included. ~~not specific enough to any other~~ RE 9/26/00 not general to be used elsewhere.

RE 9/26/00

Robert C Ehler 9/26/00

Johnston, P.N., G.A. Williams, P.A., and J.B. Cooper. 1993. Plutonium resuspension and airborne dust loadings in the desert environment of Maralinga, South Australia. *Journal of Environmental Radioactivity* 20(2): 117-31.

~~R Ehler 9-12-00~~

RFs again! (Table 2 - mass + activity dist.)

former nuclear weapons test site at Maralinga in the Great Victoria Desert, South Australia. (Deposits aged for 25 years)

Summary: RFs are typically $10^{-10}\ m^{-1}$ in calm conditions, but may increase 3 orders of magnitude during dust storms w/ wind speed >10 m/s. Overall geometric mean $= 4\times10^{-10}\ m^{-1}$. These RFs apply to Pu deposited during trials involving single point (non-nuclear) detonation of a nuclear weapon in a simulated accident. Similar results for low-yield test (1 kton).

Points: areas w/ no mechanical disturbance, most activity in top 1 cm. Where ploughing occurred, activity mixed through full depth. There's little soil in the area + it's rarely >10 cm deep.

— These RFs don't compare directly w/ stratospheric fallout b/c of different particle size distributions. Fallout is very fine particles, while Pu in this study is incorporated into larger, unresuspendable particles. Two fractions, AMAD of 5 µm and one >11 µm (Cooper) (pg 127)

— Assumed that particles < 75 µm is resuspendable, 42% of surface activity

— Plumes tend to vary greatly in cross-section over distances of tens of meters (See Horst 1978 for eg. for cross wind conc)

— States Healy (1980) gives RF of $10^{-9}\ m^{-1}$ for NTS. factor of 2.5.

— Under calm conditions, "substantial ~~factor~~ RE 9/27/00 fraction of airborne activity is associated w/ particles < 10 µm in size.

— maximum long term $PM_{10} = 5\ \mu g/m^3$

Author conclusion: activity + dust loading are very low + averages driven by dust storms.

Conclusion: May be able to use RF for ball-park figure for NTS. Table 2, also.

Robert Ehler 9/27/00

RE 9/27/00

Robert Ehlen 9/27/00

Krey, P.W., R. Knuth, and L. Toonke. 1976. Interrelations of surface air concentrations and soil characteristics at Rocky Flats. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 744-56.

REhlen 9-12-00

From abstract:

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

[So, 2.5 x 40% = 1% of total mass and activity concentrations, respirable, are from local soil surfaces!] → RF not a good concept for this site. $RF = 3 \times 10^{-9}$ m?

"Hot particle" concept – pg. 748, Pu activity is not uniform

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→ This is an argument for using annual-average for RF. Also, these hot particles are probably not respirable, due to their "tens of micrometer range." This hot particle theory would help explain some of the scatter in data and RFs, but it is only a theory and is not the only factor in the wide variation of RFs.

— no apparent correlation of respirable fraction w/ any meteorological parameter or w/ location in contaminated area

— Rocky Flats: soil activity median diameter = 50 um, while mass median diameter = 200 um.

Robert Ehlen 9/27/00

respirable range is ≤ 7 um.

3.8% of mass is respirable

13% of Pu activity is respirable

ratio Pu/mass = 13/3.8 = 3.4

CAVEAT

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— Atmospheric dilution = (activity/gram) soil / (activity/gram) air

[=] (dpm/g) soil / (dpm/g) air

= 38

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(pg. 753).

RF = 3×10^{-9} m^{-1} applied to Rocky Flats summer, moist soil, and low wind speed.

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RF is mass/volume or area; while ADF is activity/gram (mass).

Conclusions: a couple of interesting comments, but can't use the numbers for NTS. The new concept of hot particle, diff definition of respirable fraction, and the ADF could be used with other models or to refine other models.

RE 9/27/00

Robert C Ehler 9/27/00

Langer, G. 1986. Dust transport: wind blown and mechanical resuspension, July 1983 to December 1984. *Technical Report: RFP-3914*: 21 pp. RCEhler 9-12-00

Ordered on 9/25/00. Received 10/2/00

Findings: Rocky Flats RS grass, litter

— 70% reduction bet. 1 and 10 m in concentration of coarse and inhalable Pu particles; respirable particle conc. = at 1 and 10 m.

— respirable (<3 um); inhalable (3-15 um); coarse (>15 um)

— respirable Pu-239 is near Denver background levels

— Pu 239 is attached to larger particles; 70-80% on particles >15 um.

— no weathering over two years

— winds at Rocky Flats, sometimes 140 mph, and 50 mph for days

— as soil moisture for bare areas nears 30%, resuspension ceases at once

— wind tunnel dust and Pu resuspension rates — quadratic fits are poor, 0.60 and 0.33, respectively. — supports field obs RE 10/3/00 observations that high winds resuspend increasing amounts of dust but these release rates are not sustained for a long period of time; the available loose surface dust is exhausted in time.

— For modeling resuspension rates after 60 min. should be used to estimate the release of dust over prolonged periods.

— grass plus litter (decayed grass) has seven times the activity of grass only; grass & litter have 1/20th the activity of bulk soil (Table 4)

— litter has 1/30 the activity of the bulk soil (Table 4).

— above the litter level, grass blades carry fairly constant amt of Pu (w/in factor of 2). Whole blade has Pu available.

— at low windspeeds grass appears to be only source of Pu (<20 mph)

— mechanical resuspension not a factor b/c no traffic on soil

— rainsplash may resuspend soil particles + transfer them to plant surfaces

— Table 7 — dust and Pu release from grass blades only →

Robert C Ehler 10/3/00

was about 1 to 4% of that from a litter surface.
— quotes Gregory, small droplets are formed when drops hit the surface

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— "horiz distance = 1 m
— up to 5000 droplets / splash
— droplets range 5 um to 2.4 mm (median = 70 um).

conclusions: support for idea that resuspension is caused by other things besides just saltation
— grass litter, rain splash

Average dust conc at 1 m: (ug/m^3)

Resp. (<3 um)	Inh. (3-15 um)	Coarse	Total
8.2	11	28	47
(17%)	(23%)	(60%)	

Average Pu conc @ 1 m. (aCi/m^3)

Resp.	Inh	Coarse	total
3.9	18	91	113
(3%)	(16%)	(81%)	

Most of Pu on coarse particles, only 3% on respirables
similar to results in other studies

RE 10/3/00

Robert C Ehler 10/3/00

Langer, G. 1985. Wind Resuspension of Trace Amounts of Plutonium Particles from Soil in a Semi-Arid Climate. Golden, Colorado: Rocky Flats Plant, Rockwell International. RCEhler 9-12-00

Ordered on 9/25/00.
Technical Report: ~~RFP-3914: 21 pp.~~ RE 9/25/00
RFP-3633: 6 pp.

— Rate of dust and activity release varied as power of 3 of windspeed; 88% of activity was in dust particles >15 um.
— The empirical approach of using a wind tunnel was used

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

— no clear relation bet. suspension rates and soil surface conditions, such as soil type and grass cover ⇒ wrong!
— effects of soil moisture only discernible when moisture exceeded 15% in top 1 cm of soil and resuspension ceased.
— resuspension of dust (ug/m^2·min) = −18 + 0.45 × windspeed
Pu-239 resuspension (nCi/m^2·min) = −13 + 0.59 × windspeed.
These are obviously linear and do not correspond to other scientists findings that resuspension ~ u_*^3. AND, these equations are only good for time periods ≤ 15 min. Obviously, if u = 0, then dust and Pu cannot be negative in actuality.
— Critical finding: resuspension occurs even at low windspeeds but saltation starts when windspeed ≥ 30 mph ⇒ so, resuspension occurs not just by saltation, but also by re-entrainment from vegetation and rain splash
— Pu-239 concentration was 4.5 ± 3.3 aCi/m^3 in respirable dust at 1 m
— Pu 239 conc was 9.3 ± 11 aCi/m^3 in respirable dust at 10 m.
→ 3.9% of total Pu-239 conc at 1 m; 83% was in coarse particles
→ 20.7% total Pu-239 conc at 10 m; 64% was in coarse particles

Robert C Ehler 10/2/00

— respirable particles are mostly combustion pollutants from city and vehicle exhaust
— In the wind tunnel resuspended dust,
60-80% of activity was in >75 um fraction
— airborne tower dust had 4-12% in particles >75 um (coarse)
airborne dust had most activity in 15-45 um fraction
⇒ author's conclusion = activity conc. proportional to mass conc.

Problems:
respirable, inhalable, coarse fraction sizes are not given; conclusions are contradictory or inconsistent; can't match this data to NTS, b/c ~75% of ground is covered w/ grass
Good: confirmation that other mechanisms are used to resuspend dust besides saltation → consistent w/ findings from other reports & articles.

RE 10/3/00

Robert C. Ehlers 10/3/00

Langer, G. 1984. Wind resuspension of trace amounts of plutonium particles from soil in a semi-arid climate. *Technical Report No. RFP-3633:* 6 pp.

RCEhlers 9-12-00

Duplicate of pg. 63

RE 9/25/00

Robert C. Ehlers 9/25/00

RE 9/25/00

Robert C Ehlers 9/25/00

Langer, G. 1983. Activity, size, and flux of resuspended particles from Rocky Flats soil. *Precipitation Scavenging, Dry Deposition, Resuspension: Proceedings of the 4th International Conference* 2. New York, NY: Elsevier: 1161-73.

RCEhlers 9-12-00

Table 1, p.1164

Size Fraction µm	Dust Conc. µg/m³	% of total	Dust activity conc Bq/g Pu^{239}	Am^{241}	Airborne activity µBq/m³ Pu	Am
<3	6.7	14 } 24	0.12	0.022	0.81	0.15
3-~~6~~10 (RE 9/27/00)	4.6	10	—	0.074	—	0.33
10-15	6.6	14	0.48	0.096	3.2	0.63
>15	29	62	1.5	0.18	44	5.2

Size Fraction µm	% of total Pu	% of total Am	% of total Pu	% of total Am
<3	5.7	5.9 } 25.8	(1.7)	(2.4) } 7.6
(RE 9/27/00) ~~3-6~~ 3-10	Ø ~~27~~ (RE 9/27/00)	19.9	Ø	5.2
(RE 9/27/00) ~~6-10~~ 10-5	22.9	25.8	6.7	10.0
>15	71.4	48.4	(91.6)	(82.4)

— Most of airborne activity is carried by particles >10 µm.

— Johnston pg. 127 quotes Cooper (1990) that artificial dust-raising experiments show the presence of two fractions of inhalable fractions, one w/ activity median aerodynamic diameter (AMAD) of 5-6 µm and one >11 µm, the larger fraction enhanced more by mechanical disturbance. This paper is on the (RE 9/27/00) ~~Mo Marlunga site, which is supposed to be similar to NTS and~~ (RE 10/10/00) has mass and activity loadings in table 2. This phenomenon of two fractions matches the Table 1 from Langer, where there is no activity in the 3-10 µm range, but there is <3 µm and >10 µm. Since particles ≥10 µm are inhalable, but not respirable, the respirable range of concern is really <3 µm.

— However Am + Pu concentrations increase w/ particle size (factor of 10 from 5 to 20 µm).

Robert C Ehlers 9/27/00

✓ ±1% RE 9/27/00

Only 2.4 % of airborne activity is from respirable particles, which is at the fallout level of Pu at Rocky Flats.

Previous studies (Sehmel 1980) had given numbers of 9 to 99%. The difference is traced through 8 large particles in cascade impactor used by past researchers. The large particles migrated through the impactor stages to the filter that collected fine particles.

– Wind tunnel resuspension varied as the ~~78~~ RE 9/27/00 2.8–4.2 power of wind speed for a soil moisture range of 14 to 1%, respectively. Little dust was resuspended when soil moisture was > 14%.

No measurable respirable particles were resuspended.

Conclusion: ~~Consider these points for NTS.~~ can't relate to NTS RE 10/6/00

RE 9/27/00

Robert C Ehlers 9/27/00

Langer, G. 1981. Radioactivity of aerosols resuspended from soil containing plutonium activity. *Transactions of the American Nuclear Society 39.* New York, New York: Academic Press: 97. RCEhlers 9-22-00

June 1980 – Rocky Flats (~~Hanford~~) (Colorado) RE 10/2/00

Concern: determine principal source of activity: road or field

1) portable wind tunnel test to determine surface susceptibility to wind erosion indicated that < 0.05% of the resuspended dust extended into the respirable range. (field)

2) Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

Conclusion: The conditions at RF seem to be fairly different from those at NTS; so, these findings may not be very useful. However, these findings do show that for these conditions, few particles from the road and field are respirable, so if there is any exposure to plutonium, it is from coarse particulates.

note: article is less than a page long.

RE 9/25/00

Robert C Ehlers 9/25/00

RE 9/25/00

Robert C. Ehler 9/25/00

Leighton, D. and A. Acrivos. Viscous resuspension. *Chemical Engineering Science* 416: 1377-84.

R Ehler
9/12/00

This only pertains to liquid suspensions, not gaseous. RE 9/25/00

RE 9/25/00

Robert C. Ehler 9/25/00

RE 9/25/00

Robert C Ehlen 9/25/00

Lem, P. N.; J.V. Behar, and F.N. Buck. 1977. Resuspension of plutonium from contaminated land surfaces: meteorological factors. *Technical Report No. PB-271645*: 36 pp.

R Ehlen 9-12-00

Ordered on 9/25/00 Received on 10/2/00

This is a review of some resuspension models w/ regard to meteorological factors.

Table 1 (pg. 3) lists all the factors influencing wind erosion (air related factors, meteorological factors, ground features, surface properties, soil characteristics, and particle properties). RE 10/4/00

— Chepil (1945) four soil types studied: Sceptre heavy clay, ~~Haverh~~ Haverhill loam, Hatton fine sandy loam, and fine dune sand.

55-72% by wt. of soil carried in saltation

3-38% " " in suspension

7-25% " " in creep (surface).

— Chepil (1945).

Information potentially subject to copyright protection was redacted from this location. The redacted material is from Chepil (1945)

suspension." → unless all of soil is small particles, then small particles will probably be resuspended at some point with larger particles.

~~→ This contradicts~~ RE 10/4/00. This concurs w/ some scientific findings that respirable particles will not resuspend. The areas of study must have been of very uniform soil or wind tunnels.

— As surface weathers and ages the deposited material becomes part of the surface soil, and surface behaves according to soil erosion concepts.

— min. wind speed is associated w/ predominant particle size range and is unaffected by surface roughness (Chepil)

— important to report simultaneous measurements of size dist. of airborne & surface soil.

Robert C Ehlen 10/4/00

- Weathered resuspension factor (Anspaugh 1974)

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initial value high enough to account for unusual disturbances.

- Horst (1974) → see articles mentioned in this notebook for updated info.
  → resuspension must balance redeposition, valid?
- Slinn — statistical analysis approach has major difficulties
- Travis (1976) assumes contaminants and host material have same properties → good assumption if most of contaminant is attached to soil, which would be the case w/ aged deposits, esp.
- Slinn (1975) suggests one way to improve the resuspension factor is to relate it to soil erodibility by using Chepil's eq: ~~$K = 3.5 \times 10^{-9}$ cm/s~~ RE 10/4/00 (pg. 11) ~~Ton/acre-mo~~

Info. potentially subject to copyright protection redacted from this location. The redacted material is from the reference on page 73 of this scientific notebook.

- resuspension rate: "accounts for how much material is removed from the surface and transported downwind"; few field measurements;
- Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 73 of this scientific notebook.
- resuspension ratios — Horst modified [illegible] model but there are still problems
- pg 15 — data obtained from wind tunnel studies can be applied to atmospheric calculations → supports finding in Garger 1986, pg. 8]
- erosive force of moist air is lower than that of dry wind.
- Stewart (1967) states that continuous changes in surface characteristics can severely limit usefulness of relationship bet. windspeed & resuspended material → soil has to be fixed, equilibrated, insoluble, & little movement
- supports need for further study on dust devils & [illegible] of potential for long range transport of fine particles
- "a satisfactory mathematical formulation of [resuspension] is not evident."

Robert C Ehlen 10/4/00

Nair, S.K., C.W. Miller, K.M. Thiessen, E.K. Garger, and F.O. Hoffman. 1997. Modeling the Resuspension of Radionuclides in Ukrainian Regions Impacted by Chernobyl Fallout. *Health Physics* 72(1): 77-85.

RCEhlen 9-12-00

See Garger et al. 1998.

This is the paper accompanying the Nair model as presented in Garger 1998, in which mathematical models were compared.

In an emergency w/ little data available, the Nair model can provide upper and lower-bound estimates of the unknown air concentration. For accurate predictions using sufficient data, the Garland/Nair model would provide better estimates.

~~The Nair model, in my review~~ RE 9/27/00

In my review of the models presented in Garger 1998, I suggested that Nair's model is the best.

RE 9/27/00

Robert C Ehlen 9/27/00

RE 9/27/00

Robert C. Ehlen 9/27/00

Nathans, M.W. 1976. Methods of analysis useful in the study of alpha-emitting and fissionable material-containing particles. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 661-74.

R Ehlen 9-22-00

not really useful

RE 9/25/00

Robert C. Ehlen 9/25/00

RE 9/25/00

Robert C Ehlers 9/25/00

Oksza-Chocimowski, G.V. 1977. Generalized model of the time-dependent weathering half-life of the resuspension factor. *Technical Report.* Las Vegas, Nevada, Office of Radiation Programs: 56 pp.

RCEhlers 9-12-00

→ Table 1 lists resuspension factors from Mishima 1964.
— There has been much new data since then. Some values of possible use are:

	RF (m^{-1})
average RF in accidents involving plutonium	RE 10/2/00 ~~4×10^6~~ 4×10^{-6}
vehicular traffic (Nevada)	RE 10/2/00 ~~7×10~~ 7×10^{-8}
proposed RF for plutonium oxide (outdoors moderate activity)	10^{-5}
plutonium sampled 1 ft above ground (vehicular dust)	5×10^{-45}

— Time-Dependent Half-Time Model Based on Anspaugh's Resuspension Factor:

$$R_f(t) = R_{f(0)} e^{-\lambda(t)t} = R_f(0)\, e^{-\frac{0.693}{T_{1/2}(t)}t} = R_f(t)$$

— Proposed Interim Model of Time-Dependent Half-Time:

$$T_{1/2}\left(t, R_f(0)/R_f(\infty)\right) = A \ln\left(1 + B + Ct^D\right) + \frac{0.693t}{\ln\left(\frac{R_f(0)}{R_f(\infty)}\right)}$$

A = constant coefficient, days
B = Constant [–] ; C = constant coefficient, day^{-D}
D = constant exponent [–]
$R_{f(0)}$ = initial RF, m^{-1}, at given location
$R_f(\infty)$ = final RF at same location t = time, days

— Table 3 and Figure 11 show plots of Anspaugh, Kathren, and Langham's RF models based on proposed ½ time method.
— Drawbacks are same as for RF model and the fact that data is compiled from different sites by different researchers. Limited data for NTS.
Recommendation = probably shouldn't use this; constants are arbitrary →

Robert C Ehlers 10/2/00

They constants were selected to make
proposed model results match the results of
the other models

p.19 Langham reported "attenuation factors"
of 35 and 40 days estimated at NTS, although
the time periods to which these are strictly applicable
are uncertain.

→ Half time of 35 to 38 days for 3-160 days after deposition.
→ Half-time ≈ 66 days for 77-315 days after deposition
Anspaugh

The Langham model used NTS data which showed
half time of 35 days. Proposed model calculated the
final value. $R_f(t) = R_f(0)\, e^{-\frac{0.693t}{T_{1/2}}}$
initial value = $10^{-4}\, m^{-1}$ final = 0
(see table 3).

Conclusion — too much theoretical manipulation
of data; fudge factors.

RE 10/2/00

Robert C Ehler 10/2/00

Porch, W. M., G.D. Greenly, and C.S. Mitchell. 1983. Update and inclusion of resuspension model codes. *Technical Report UCID-20071*. Livermore, CA: Lawrence Livermore National Laboratory: 19 pp. R Ehler 9-12-00

Ordered on 9/25/00 Rec'd 10/2/00
Not very useful.
Code dates from 1983, and written for Rocky Flats Co.

Information potentially subject to copyright protection was redacted from this location.
The redacted material is from the reference listed above.

Used smoothing parameters to fit data
The code estimates resuspension based on wind-blown dust fluxes.
derived for different soil types.
Conclusion: don't use.

RE 10/4/00

Robert C Ehler 10/4/00

RE 10/4/00

Robert C. Ehlers 10/4/00

Sehmel, G.A. 1982. Ambient airborne solids concentrations including volcanic ash at Hanford, Washington sampling sites subsequent to the Mount St. Helens eruption. *Journal of Geophysical Research* 8713: 11087-94.

RCEhlers 9-12-00

Figures 3+4 are quite interesting

- article considers source weathering
- Horn Rapids Dam + Hanford Meteorological Station
  - two sites, low ash deposits, 1-2 mm and 3-4 mm
- 0.5 to 1.5 cm of rain required to significantly reduce airborne solid concentrations for two months
- for a more aged resuspension source, 2 cm of rain had negligible effect
- monthly average threshold windspeed = 3.6 m/s = 8 mph
- for monthly average < threshold windspeed, airborne concentration decreased with time
- for four month period after eruption, half-life was on the order of 30 days, corresponding to weathering rate of 5.1 year^{-1}! ⇒ for windspeeds < 3.6 m/s

HRD: - respirable is < 5.5 μm diameter, 55% of total air solids

- the apparent increased effectiveness of rain reducing the resuspension of ~~ash from~~ the unaged source (RE 9/29/00) may have just been due to the monthly average windspeed was above the threshold windspeed ~~→ paper says above, maybe it should say "below"~~ — RE 9/29/00 (before the rain?)
- duration of airborne concentration reduction + crust integrity may be as short as a day; conc. increases as ground dried
- Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above. (p. 11092) — why not? wind dries soil + decreases time for resuspension to resume →

Robert C. Ehlers 9/29/00

and airborne concentrations (as well as resuspension factors and rates) increase with windspeed to a certain power, depending on site conditions

—

HMS: p. 11093

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 83 of this scientific notebook.

— half-life for any decrease in airborne concentration was > 4 months.

— weathering rate ≈ 0

→ for windspeeds > 3.6 m/s

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 83 of this scientific notebook.

Conclusion: some useful information about ash deposits and resuspension of ash during various meteorological conditions; however, no information about plutonium, b/c there was no Pu present, apparently; also, they didn't sample for Pu.

RE 9/29/00

Robert C Ehler 9/29/00

Sehmel, G.A. 1980. Particle Resuspension: A Review. *Environmental International* 4:107-127. REhler 9-12-00

Good review of resuspension knowledge and research needs for the time it was written.

resuspension = deposited from atmosphere, then re-entrained

suspension = deposited by nonatmospheric process (e.g., spill) then ~~se~~ RE9/29/00 entrained.

— In this article, resuspension = resuspension + suspension, b/c subsequent behavior can't be distinguished bet. resuspension & suspension. Have noticed the use of this term in this way in other articles.

— Resuspension rates are used as boundary conditions for atmospheric transport models.

— Lowest 1.5 m of atmosphere is generally neglected by ~~atm~~ RE 9/29/00 meteorological models.

— threshold speed increases w/ average particle size and decreases with a wider range of particle diameters in the soil

— duststorm sand movement, wind erosion equation, and sand transport rate are all proportional to u^3 (windspeed)

— wind tunnel results — air capacity to transport soil proportional to u_*^5 (friction velocity)

— pg. 109 — resuspension factor cannot be predicted accurately.

— article lists problems w/ RFs and resuspension rates

— pg. 111 talks some about the different types of meteorological models, but only in a footnote.

— particles < 3.5 um are considered respirable, smaller than < 7 um found in other articles. 3 < 15 um (inhalable).

Robert C. Ehler 9/29/00

p. 112

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 85 of this scientific notebook.

m

- particle-soil interaction study results have not been generalized to the more complex interactions of the environment."
- resuspension literature discusses arid/semiarid regions while soil erosion data is generally for agricultural areas
- effects of meteorological variables upon resuspension have not been quantified ⇒ Table 1 lists "all" variables that influence resuspension; The table is daunting; much study still to be done!

⇒ author states that predictions for resuspension rates + factors are very poor ("extremely"); Fig. 2 and Tables 2-4 give ranges of values for RFs, half-times (half-life times), air conc. dependency on wind, and resuspension rates.

There are numbers + ranges for NTS:

NTS range of RF (wind-induced) = 3×10^{-10} to $6 \times 10^{-4}\ m^{-1}$ (Fig. 2)

NTS half-life time: 35 days to ∞ (Table 2)

air concentration increases w/ windspeed to 2.2 power;

NTS resuspension rates = 10^{-12} to $6 \times 10^{-8}\ sec^{-1}$ (vary w/ year, month, wind speed, and particle diameter)

M) non-respirable average = $10^{-11}\ sec^{-1}$; (all) respirable = 10^{-11} to $10^{-7}\ sec^{-1}$

→ vehicle + pedestrian-induced resuspension — hazy conclusions

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference on page 85 of this scientific notebook.

— use a range of values!

Robert C Ehler 9/29/00

Sehmel, G.A. 1978. Plutonium concentrations in airborne soil at Rocky Flats and Hanford determined during resuspension experiments. *Airborne Radioact., Am. Nucl. Soc. Natl. Meet. Paper, ANS Winter Meeting*. American Nuclear Society: La Grange Park, IL: 81-101.

RCEhler 9-12-00

- ^{238}Pu suspended more readily relative to ^{239}Pu
- pg. 85

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

- pg. 87

→ too many orders of magnitude are spanned by the data.

- threshold windspeed of 5 m/s for resuspension
- most Pu was resuspended while attached to larger host soil particles
- Table 6 has conc. (in air + soil) of Pu. → orders of magnitude
- even the powers of windspeed varied from 1.5 to 6

Conclusion: very little new since Sehmel + Lloyd 1976.

Don't use.

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Re 9/28/00

Sehmel, G.A. 1977. Plutonium and tracer particle resuspension: an overview of selected Battelle-Northwest experiments. *U.S. Energy Res. Dev. Adm., Nevada Operations Office (Rep.) NVO-178*: 181-210.

REhler 9-12-00

Ordered on 9/25/00. Rec'd 10/2/00.

p. 184 lists the topics

- Pu from contaminated environmental surfaces at Rocky Flats (already covered in Sehmel, 1976 and '78)
- controlled inert tracer particles from selected surfaces on the Hanford Reservation (already covered in Sehmel (1980)
- soil particles, Hanford (also in Sehmel (1980)
- fallout particles in forest fire smoke (Sehmel and Orgill, 1976) – not covered in any of the other articles in this notebook (1 page of info., p. 191)

Release rates are unknown; calculations would require knowledge of the smoke plume's total volume and average smoke concentration as well as the contamination level in the burning forest.

Radionuclide Air Concentration: smoke/background (equal volumes)

Isotope	Conc. Ratio
^{7}Be	1.2
^{54}Mn	3.8
^{95}Zr	1.9
^{95}Nb	1.8
^{106}Ru	2.9
^{125}Sb	4.6
^{137}Cs	22.2
^{144}Cs	2.9

So, a fire will cause resuspension of radionuclides, but there is no information on release rates.

Conclusion: interesting, but may not be of much use, except as a factor.

Robert Ehler 10/4/00

Re 10/4/00

Robert C Ehler 10/4/00

Sehmel, G. A. 1977. Radioactive particle resuspension research experiments on the Hanford Reservation. *Technical Report No. BNWL-2081*: 47 pp. R Ehler 9-12-00

Ordered on 9/25/00. Rec'd 10/2/00

Early version of Sehmel, 1980 ~~+ later version of~~ and Sehmel 1978.

Don't need RE 10/4/00

Re 10/4/00

WRONG ARTICLE; switched w/ Sehmel 1977 (p 93 of notebook) RE 10/4/00

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RE 10/4/00

Robert C Ehler 10/4/00

Sehmel, G.A. 1977. Transuranic and tracer simulant resuspension. *Technical Report BNWL-SA-6236*: 84 pp. REhler 9-12-00

Ordered on 9/25/00. Rec'd 10/4/00
Wrong article, switched w/ Sehmel 1977
(pg. 91 of notebook). RE 10/4/00
Same as Sehmel ~~1980~~ 1978, but with details on americium + cesium. Not much else is different. The 1978 report condenses material and gets to the point, while including Rocky Flats data.

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Sehmel, G.A. and F.D. Lloyd. 1976. Particle resuspension rates. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 846-58.

R Ehlers 9-12-00

- wind velocity was slowed by sampler
- tracer used, molybdenum

Not useful

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Robert C Ehlers 9/28/00

RE 9/28/00

Robert C. Ehler 9/28/00

Sehmel, G.A. and F.D. Lloyd. 1976. Resuspension of plutonium at Rocky Flats. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 757-79.

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Rocky Flats

impactors collect respirable particles, while

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

— also mentions "hot" particles, causing, supposedly,

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— 2σ counting statistic error limits

— most Pu was resuspended while attached to larger host soil particles

— Below 10 m, concentrations decreased with height; Concentration increased from 10-30 m, possibly due to an elevated upwind source or a dust devil

— greater than respirable particles do penetrate into all impactor stages.

— airborne Pu conc. increased w/ windspeed to the 2.1 power

— Pu suspension rates increase w/ windspeed to the 5.9 power

— p. 776

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

Conclusions: Early paper, problems, doesn't really relate to NTS, depends on resuspension rates. Don't use

Robert C Ehler 9/28/00

R.E. 9/28/00

Robert C Ehlers 9/28/00

Shinn, J.H. 1992. Enhancement factors for resuspended aerosol radioactivity: effects of topsoil disturbance. *Precipitation Scavenging Atmosphere-Surface Exchange: Proceedings of the 5th International Conference.* Hemisphere,Washington, D.C.: Hemisphere; 3: 1183-93.

RCEhlers 9-18-00

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

We're not interested in worst case w/o considering meteorological conditions and soil characteristics, and weathering.
EF is not adjusted for size distributions in air or soil.
Table 1 lists NTS numbers from Shinn 1986 paper.
Conclusion: not useful.

R.E. 9/27/00

Robert C Ehlers 9/27/00

RE 9/27/00

Robert C. Ehlers 9/27/00

Shinn, J.H., D.N. Homan, and C.B. Hofman. 1986. A Summary Of Plutonium Aerosol Studies: Resuspension At The Nevada Test Site. *UCRL-90746*: 1-78. ~~RE 9-12-00~~

This paper was supposed to have been published in the Journal for Environmental Radioactivity or in a book of Proceedings, but apparently it was never published, b/c we could not find copies except from Dr. Dean Strom for the Pacific NW Nat'l Lab.

The authors' permission has not been received to ~~give~~ cite this paper. RE 9/27/00

Shinn replaces u_* with $\overline{u_*^3}/\overline{u_*^2}$, which has values of 1.6 to 2 times u_*. The bar denotes time average ~~of~~ RE 9/27/00 equal to time required for Pu-particle collection, usually 1-2 wks.

This was ~~only~~ RE 9/27/00 an attempt to correct for the nonlinear dependency of erosion on friction velocity by measure time averaged concentration (χ) and not the time averaged flux (F).

But, they find that the concentration profile fits a power law,

$$\frac{\partial \chi}{\partial z} = p\frac{\chi_1}{z_1}$$

, with p inherently dependent on geophysical processes at a particular site.

All of the soil + environmental conditions are wrapped up into one parameter, p, which is worse than a power constant dependent on velocity. → The derivation seems self-defeating & flawed. So, I'm not sure about these calculations. RE 9/27/00

≥ 90% of soilborne Pu was estimated to be in the top 5 cm at all ~~sites~~ locations. The RF of nuclear sites was ~~higher~~ RE 9/27/00 lower by order of magnitude than the non-nuclear because the glass beads containing most of the plutonium were not resuspendable.

— Resusp. rates were lower than those reported by Healy (1980).

— Seasonal peak of alpha radioactivity does not coincide w/ the

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seasonal peak of suspended soil.

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The redacted material is from the reference on page 101 of this scientific notebook.

↳ disagrees w/ other reports in which
disturbance causes resuspension of larger particles.

Interesting points:

1) pg. 12 – Thermal cycle frees particles for resuspension each morning.

2) pg. 12 – soil moisture cycle (daily) caused shrinking/swelling of clays and production of free particles. [Water vapor from deep soil layers and condensation]

Location type	average EF	avg. AMAD (µm)	avg. resp.%	avg. RF (m^{-1})	avg R rate (s^{-1})	ave R half time (y)
non-nuclear	0.96	5.6	10	4.1×10^{-10}	1.94×10^{-11}	13,780
nuclear	0.011	2.6	13.5	2.2×10^{-12}	3.03×10^{-13}	1,668,000

non-nuclear does seem to be greater concern wrt resuspension, but there were only two locations for each type, and the wind was not described for each one. Also,

non-nuclear: Pu soil (Bq/g) = 167; Pu aerosol (Bq/m^3) = 0.00278
nuclear: " " = 346 " " = 8.5×10^{-6}

$C = EF \times M \times A$ → aerosol conc = EF × dust conc × soil activity

So, weathering is not considered.

Conclusions: Instead of using these numbers, it would be better to take new measurements.

This article is not useful; that's why it wasn't published.
It does help in the review of EF article, Shinn 1992.

Robert Ehler 9/27/00

Shinn, Joseph H.; Homan, Donald N.; Gay, Don D. 1983. Plutonium aerosol fluxes and pulmonary exposure rates during resuspension from bare soils near a chemical separation facility. *Precipitation Scavenging, Dry Deposition, Resuspension: Proceedings of the 4th International Conference* 2. New York, NY: Elsevier: 1131-43.

R Ehler 9-12-00

Savannah River Plant, SC

– Pu flux didn't increase greatly as dust flux increased b/c Pu activity decreased with time to counteract the increased dust flux.

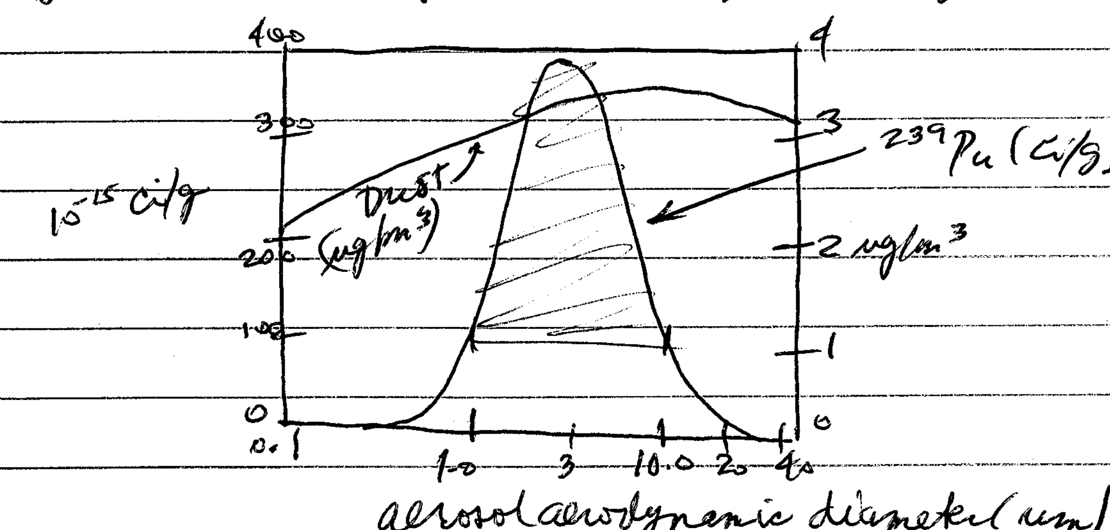
– average RF = 3×10^{-10} m^{-1}, compares well w/ weathered deposits in Nevada

– resusp rate = 3.8×10^{-7} day^{-1} → 1/2 time ≈ 5000 years

– max. Pu conc = 4.94×10^{-17} Ci/m^3 → inconsequential exposure

– Pu conc. 12% respirable

– Figure 1. most of Pu in 1–10 µm range.



Dust concentration + Pu activity particle size distribution

Conclusion: a little more useful than the other Shinn articles.

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Re 9/27/00

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Sibley, T.H. 1984. Comparative adsorption of selected radionuclides on different types of suspended particulates. *Technical Report.* USA JOURNAL: Comm. Eur. Communities, (Rep.) EUR 9214, Int. Symp. Behav. Long Lived Radionuclides Mar. Environ.: 189-99. RCEhler 9-12-00

ordered on 9/25/00. Rec'd 10/3/00

water sediments!

Re 10/5/00

Robert C Ehler 10/5/00

RE 10/5/00

Robert C Ehler 10/5/00

Sinclair, P.C. 1976. Vertical transport of desert particulates by dust devils and clear thermals. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 497-527.

R Ehler 9-12-00

7000 tons of desert dust and sand may be transported from an area 285 km^2 during an average dust devil season (May-Aug.)

$\frac{7000 \text{ tons}}{285 \text{ km}^2} \approx 25 \text{ ton/km}^2$

pg 503

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the reference listed above.

p 504

pg 509 GMX site of area 5 of NTS has 1 dust devil per minute during most active part of day. mean of 85 dd/day.

"Clear" dry thermals can ~~lift part~~ RE 9/27/00 have mixing up to 16,000 ft.

★→ There should have been NTS measurements on downwind transport.

Leapfrog effect can extend transport to 2600 miles.

Conclusion – This is something to think about including in the model depending on frequency at NTS, which apparently is high.

Table 1 and Figure 8 have good info.

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Robert C Ellers 9/27/00

Slinn, W. G. N., P.C. Katen, M.A. Wolf, W. D. Loveland, L.F. Radke, E.L. Miller, L.J. Ghannam, L. J., B.W. Reynolds, and D. Vickers. 1979. Wet and dry deposition and resuspension of AFCT/TECT fuel processing radionuclides. *Technical Report SR-0980-10*: 529 pp.

R Ellers 9-12-00

Ordered on 9/25/00. Rec'd 10/2/00

Large report. Read about 100 pages of it for resuspension info.

p. 41-55 is same (verbatim) as Slinn, 1978

Ch. VII has more detailed info. on experiment, talks about other researchers' findings.

p. 276 - RF is best for local resuspension for a small contaminated area (lab) or where air conc. is measured over very large area (approximating an infinite plane); most useful for mechanical disturbance.

This study sought to determine experimental values for Λ and α (resuspension rate and weathering rate). - pg 280

This study was done in Willamette Valley, OR. soil is diff. from NTS. OR soil probably has larger # of particles in 3 μm range than in desert studies.

average Resuspension Rates: u_* = friction velocity

silt loam soil: 2.3×10^{-8} sec.$^{-1}$, $\Lambda \propto u_*^b$ where $b = 0.49 - 3.18$

medium coarse gravel: 5.6×10^{-8} sec.$^{-1}$, $b = 0.35 - 3.08$

mown grass: 1.3×10^{-8} sec.$^{-1}$, $b = 0.86 - 2.44$

Weathering rates: soil, mown grass, gravel affected least to most

Except for mown grass, no trend of decreasing RR w/ time in any speed class or surface type.

weathering rate: time for rates to reach 1/e of initial values is ~~35 days, 120 years, two years~~ RE 10/5/00.

No conclusions regarding weathering rates. Conflicting data.

Robert C Ellers 10/5/00

— Figure 7 presents data from several other studies showing average Λ (RR) vs. roughness height (z_0).

— soil crusting can alter (reduce) RRs.

Error Analysis (pg. 321-24)

source strength = ±30%   wind stresses = ±10

mass loading of tracer = ±50 for low mass ; ±20% high

TOTAL = factor of 2 or 3.

Oregon soil = higher % of fines,

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The redacted material is from the reference on page109 of this scientific notebook.

→ diff from NTS.

— NTS may have low resusp. too, but for diff reasons.

* Procedure for estimating RR: (p. 327-328)

— varying power of RR due to surface moisture content

— RR decreased w/ increasing time steps

Conclusions, pg. 443-4: research terminated, tentative parameterizations, concept of weathering should be ~~re-ad~~ re-assessed and probably abandoned. (RA 10/3/00)

appendix A: micrometeorological consideration — useful surface boundary layer

A-8: little theoretical support exists, best we can hope for, given the complexity of trying to describe small scale motions so transient in space and time.

— Bagnold's derivation of flux ∝ u^3 law

— photographs of experiment

Recommendations: interesting comments, but can't really apply to NTS.

Robert C Ehler   10/3/00

Slinn, W.G.N. 1978. Parameterizations for Resuspension and for Wet and Dry Deposition of Particles and Gases for Use in Radiation Dose Calculations. *Nuclear Safety* 19(2): 205-19. RCEhler 9-12-00

p. 212-216 for resuspension

— emphasizes description of particles' resuspension from previously contaminated surfaces, ignoring simultaneous deposition and resuspension.

— discusses resuspension flux and jump discontinuity, (not useful)

→ erosion rate (Chepil) equation gives erosion flux, but the fraction that is resuspended has to be determined, still, because most erosion occurs by creep or saltation

→ variability in resuspension factors is due to:

1) great variability in erosion and weathering rates

2) averaging time: an example → 1/3 of material resuspended in hour (1 hr), then resuspension rate is 1/3 ÷ 3600 sec = 9.3×10^{-5} sec^{-1}

But if this is the only high windstorm during the year, then the annual-average $\Lambda = \frac{1}{3} \div 3.15 \times 10^{7} \approx 1.06 \times 10^{-8}$ sec^{-1}

Almost 4 ~~six~~ (RE 9/28/00) orders of magnitude difference, ~~solely~~ (RE 9/28/00) due to just a change in the averaging time!

Slinn's proposed alternative (in Summary comments section) is crude and does not address the accident case or the case in which the source is resuspended material.

Conclusion: nothing really useful, just a few good comments.

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RE 9/28/00

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Slinn,W.G.N. 1978. Erratum: Parameterizations for Resuspension and for Wet and Dry Deposition of Particles and Gases for Use in Radiation Dose Calculations. *Nuclear Safety* 19(3): 365-365.

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Inconsequential.

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Slinn, W.G.N. 1976. Formulation and a solution of the diffusion—deposition—resuspension problem. *Atmospheric Environment* 109: 763-8.

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This is a reformulation of some processes.
good point —

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the referencelisted above.

- does include something like a weathering rate, α, the rate at which G (pollutant's concentration in the surface) becomes fixed to the surface and unavailable for resuspension
- includes Gaussian distribution of concentration crosswind and vertically.
- Because of averaging time (as mentioned on p. 111), resuspension rate could be on the same order of magnitude of the deposition rate instead of 4 orders lower. RE 9/28/00

resusp rate = $\Lambda = v_r/\delta$; $\Omega = v_d/H$ = dep. rate

δ and H are approximate mixed depths in the surface and atmosphere, respectively.

This formulation looks good for its time and may still be quite useful but it still depends on a ~~time~~ RE 9/28/00 factor or rate. There is a great lack of experimental data to support this model.

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Robert C Ehlers 9/28/00

R.E. 9/28/00

Robert C Ehler 9/28/00

Slinn, W.G.N. 1976. Dry deposition and resuspension of aerosol particles-a new look at some old problems. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 1-40. RC Ehler 9-12-00

tour of particles

p.24 - states that particle size distribution in the lowest layer is determined by soil particle size dist., not the probability dist. of horizontal wind fluctuations.

⟹ if the horizontal wind is sufficient to dislodge some particles, it will dislodge all

⟹ other articles disagree w/ these two statements.

Chepil is quoted: 3-40% of ground is suspended
5-25% creep
50-75% saltation

— attacks problem of simultaneous resuspension and deposition when resuspension dominates. see Fig. 19.

— tries to figure out fraction of resuspension for real and sticky artificial grass, neither of which is for ~~NT~~ R.E. 9/28/00 NTS.

Because this was more of a (self-called) tour of a particles life than a thorough discussion of resuspension, and Slinn attacks all previous assumptions, he doesn't provide any solutions that are really supported by data. He just confirms the fact that resuspension is difficult to understand and that we need more data.

R.E. 9/28/00

Robert C Ehler 9/28/00

RE 9/28/00

Robert C Ehler 9/28/00

Smith, W.J., II, F.W. Whicker, F.W., and H.R. Meyer. 1982. Review and categorization of saltation, suspension, and resuspension models. *Nuclear Safety* 236: 685-99. REhler 9-12-00

suspension <50 um
saltation 80-1000 um } similar to Travis
creep > 1000 um

Excellent article, see Table 2 (pg 697), comparing all of the different types of models.

The combined suspension model by John R. Travis, see pg 121 of this notebook, looks like it will be the best one for the NTS site, volcanic - nuclear accident scenario w/ exposure 20 km from site (critical distance).

Recommendation ⇒ use Travis (combined suspension) model.

[The article shows that resuspension factors rates ratios should be avoided.]

RE 9/28/00

Robert C Ehler 9/28/00

R E 9/28/00

Robert C. Ehler 9/28/00

Travis, J.R. 1976. A model for predicting the redistribution of particulate contaminants from soil surfaces. *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants: Proceedings of a Symposium held in Richland, Washington, 4-6 Sept. 1974.* CONF-740921. Ed. Englemann, R.J. and G.A. Sehmel. Springfield, Virginia: National Technical Information Service: 906-44.

R Ehler 9-12-00

Excellent article, creep >1000 um, saltation 50-1000 um, suspension <50 um.
computerized model, uses Bagnold-Chepil horizontal flux formulation and modified Gilette vertical flux formulation, puff source Gaussian distribution in 3 dimensions demo — PuO_2 in highly erodable soils under dust storm conditions [Factor of 2 or 3.]
Too many good things, equations, etc. to write them here.
Conclusion: seriously consider using this model.
Excellent list of sources.

R E 9/27/00

Robert C. Ehler 9/27/00

RE 9/27/00

Robert C. Ehler 9/27/00

Vashi, V. D., P. Kotrappa, and S.D. Soman. 1980. Resuspension of plutonium from contaminated soils. *Radiat. Prot.: Proc. Congr. Int. Radiat. Prot. Soc., 5th* 1. Pergamon: Oxford, England: 592-5.

RCEhler 9-12-00

RFs for humid beach soils, not NTS-like soils.
RFs decreased as soil moisture increased.
One site (one of 4) had soil moisture ≅10%, but this sure particle size distribution is different from NTS.
Also, premonsoon and postmonsoon conditions were tested. Certainly not like NTS.

RE 9/27/00

Robert C. Ehler 9/27/00

Re 9/27/00

Robert C Ehler 9/27/00

Yuan, Y.C. and C.J. Roberts. Estimation of air concentration from resuspension of contaminated surfaces. *Trans. Am. Nucl. Soc.* 32: 106-107.

RCEhler 9-25-00

About 1 page long.

General findings:

1) resuspension factor increases w/ area of contamination, esp. for contaminants w/ small deposition velocities
2) resuspension factor reflects: particle size of contaminants, areal distribution, size of contaminated area, variation in suspension rates, and meteorological conditions
3) The example calculation indicates resuspension factor is too general.

Conclusion: Don't rely on resuspension factors.

Re 9/25/00

Robert C Ehler 9/25/00

RE 9/25/00

Robert C Ehler 9/25/00

Zimmer, S.L. and B.E. Dahneke. 1976. Resuspension of particles: the range of validity of the quasi-stationary theories. *Journal of Colloid Interface Science* 543: 329-338. R Ehler 9-12-00

Theoretical, includes
viscous and nonviscous (gases).
QSA only good for high values of $\Delta\phi$ KT.
too theoretical; hard to put into other models
(strongly bound particles), small escape rates (?)

RE 9/27/00

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RS 9/27/00

Robert Ehler 9/27/00

Recommendations for Modeling Resuspension:

[Use the Travis model, discussed on pages 121,133 in notebook.]

I will make brief comments on articles of note:

(These are either interesting or useful theoretically, or NTS data.)

1) Alzona (pg. 3-4 of this notebook): indoor dust exposure is 1/3 that of outdoor. (Plutonium was not studied, nor other radionuclides.) This ratio holds true when doors and windows are closed. Most of the dust is of smaller size; so, there would be little Pu exposure, since Pu is preferentially attached to larger particles.

2) Anspaugh (1975, 1976; pages 7-10 of notebook) contains resuspension rates for Nevada Test Site (NTS). I don't recommend the use of resuspension rates, factors, or ratios. Includes weathering.

3) Aylor (notebook pg. 15): Resuspension from vegetation can be significant; however, with so many variables (as mentioned on pg. 15), this process is probably too complex to include in the model right now, unless a conservative factor is used. It's probably best to just use the soil erosion equation for the NTS vegetation type.

4) Engelmann (pg. 23, notebook): mentions research needs for study of resuspension.

5) Fowler (notebook pg. 27): studied volcanic ash in forest and agricultural locations, esp. regarding the effect of weathering (new vs. aged deposits). Conditions are different for NTS, but this confirms that moisture would reduce resuspension of soil or ash.

6) Gilette (pg. 39-40, notebook): The theoretical comments may be useful, but in general, the data is not useful to NTS.

7) Healy (notebook pg. 45-46): A good review of resuspension models. Mentions NTS data and the Travis model, which I recommend. Healy prefers resuspension rates coupled w/ dispersion, deposition, soil

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(cont'd from pg. 129)

characteristics, and meteorological data. All of these are fine, except the resuspension rates.

8) Hodgin (pg. 47-48, notebook): Resuspension of plutonium from unpaved roads can be significant if no dust control measures are used. This should be considered in such a ~~go~~ RE 10/10/00 case.

9) Horst (1978; notebook pg. 53): Describes a method to use Gaussian ~~plume~~ RE 10/10/00 plume model for an area source. Deposition and resuspension rates can be determined using other models or equations. However, eq. 21 doesn't account for weathering or soil characteristics.

10) Krey (notebook, pg. 59): "Hot particle" concept. Also introduces ~~air dilut~~ RE 10/10/00 atmospheric dilution factor (ADF), which compares air conc to soil conc to yield ratio in units of activity/gram. Not very useful, though. "Hot particles" also mentioned by Sehmel (1976).

11) Langer (1986, p.61-62): Supports idea that resuspension can be caused by rain splash and can occur from grass and litter (decayed grass). This could be tied in w/ the Aylor article.

12) Lein (p.73-74): Review of resuspension model WRT meteorology. Confirms problems w/ resuspension rates, ratios, and factors. Mentions Travis' model; no problems with it.

13) Oksza-Chocimowski (pg. 79-80): Gives other models' attempts to include weathering of resuspension factor, including Anspaugh's.

14) Sehmel (1982; pg. ~~81-82~~ RE 10/10/00 83-84, notebook): Volcanic ash WRT meteorology and weathering. Ash concentrations in air are similar to dust storm air concentrations, except in 0.3-0.5 μm diameter range [small], in which ash conc was 4 times higher. [Of course, the soil for dust storm was from WA, not Nevada.]

15) Sehmel (1980; pg. 85-86): Good review of resuspension models; includes NTS data. Suggests using a range of RF values.

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(Cont'd from page 131)

16) Sehmel (1977, pg. 89): Gives radionuclide concentration ratios ~~(air/soil)~~ RE 10/10/00 for smoke/background for fallout particles from forest fires. If fire is considered, these ratios may prove useful; however, plutonium is not included. Release rates are not known.

17) Shinn (1986; pg. 101-102): Contains a little bit of data from NTS.

18) Sinclair (1976; pg. 107): Due to high frequency of dust devils at NTS, this paper should be considered, especially since leapfrog effect can transport fine particles many (100's) miles. However, since Pu is preferentially attached to large particles, their transport by dust devils is probably on the same order of magnitude as from regular wind resuspension.

19) Slinn (1979, pg. 109-110): Interesting, but not terribly useful.

20) Slinn (1976, pg. 115-116): This formulation for the diffusion-deposition-resuspension problem looks pretty good, but still depends on a resuspension factor or rate.

21) Slinn (1976)(pg. 117-118): Attacks all previous models and assumptions, but doesn't provide any real solutions. Maybe good for preparing defense of model selected for Div. 20 (Yucca Mountain).

22) Smith (pg. 119): Excellent article. Article shows that resuspension factors, rates, and ratios should be avoided. Seems to prefer the combined suspension model (Travis); has ~~not~~ RE 10/10/00 no problems with it.

23) Travis (pg. 121): Excellent article, good derivation and description of model. Includes soil characteristics, meteorology, resuspension, deposition, etc. Uses Bagnold-Chepil horizontal flux formulation and modified Gillette vertical flux formulation. Puff source 3-D Gaussian distribution. Includes dust storm, Pu, accidents. Use this model as the basis for the Yucca Mountain resuspension model. Code available.

Robert C. Ehler 10/10/00

This scientific notebook, which contains notes from a literature review on resuspension of radionuclides from soil and volcanic ash, is closed. The notes recorded herein are generally traceable to referenced documents and should be able to be replicated by a competent scientist or engineer.

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Element Manager PA

3/31/2003