THE EFFECT OF ELECTRIC FIELD ON THE DEPOSITION OF RADON DAUGHTERS

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1. Background

• Conventional treatment

Deposition velocity of unattached daughters $u_g^f = 2...15$ cm/s.

Porstendörfer, J. (1994) Properties and behavior of radon and thoron and their decay products in the air. *J. Aerosol Sci.*.25, 219–263.

Jonassen, N. (1988) Ions, electric fields and radon daughters effects of filtration and electrostatic plateout. In *Seventh Int. Congr. Int. Radiat. Prot. Assoc.* , 377–380, Sidney.

• Example by Wilkening

Wilkening, M.H. (1977) Influence of the electric fields of thunderstorms on radon-222 daughter ion concentrations. In *Electrical Processes in Atmospheres*, 54–59, Steinkopff, Darmstadt.

• Examples by Henshaw

Henshaw, D.L., A.N. Ross, A.P. Fews, and A.W. Preece (1996) Enhanced deposition of radon daughter nuclei in the vicinity of power frequency electromagnetic fields. *Int. J. Radiat. Biol.*, **69**, 25–38.

• Electrostatic migration in normal atmospheric electric field

Electrical mobility of unattached daughters is about 1 $\mathrm{cm}^2/(\mathrm{V \cdot s})$.
Normal electric field is about 1..2 V/cm and directed down to the ground.
Corresponding migration velocity 1..2 cm/s is 10..100% of u_g^f.

Special cases: *thunderstorm, tops of trees, HV power lines*.

2. A rough model

Model: a thin horizontal wire of diameter d spanned over the flat ground on the height H.

- **Diffusion deposition**
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Symbols:

d – diameter of the wire, m

u - air flow velocity, m/s

λ – heat conductivity, W/(m·K)

D – coefficient of diffusion, m^2/s

ν – cinematic viscosity, m^2/s

a – temperature conductivity $a = \lambda/c_p\rho$

h – coefficient of heat transfer, W/(m^2·K)

u_D – velocity of diffusion deposition, m/s

Method:

Nondimensional heat transfer equations can be translated into the diffusion deposition equations replacing:

Nusselt number $\mathrm{Nu} = \dfrac{hd}{\lambda}$	with	Sherwood number $\mathrm{Sh} = \dfrac{u_D d}{D}$
Prandtl number $\mathrm{Pr} = \dfrac{\nu}{a}$	with	Schmidt number $\mathrm{Sc} = \dfrac{\nu}{D}$
Reynolds number $\mathrm{Re} = \dfrac{ud}{\nu}$	remains	Reynolds number $\mathrm{Re} = \dfrac{ud}{\nu}$

Eckert, E.R.G. *Introduction to the transfer of heat and mass*. McGraw-Hill, 1950.

Equations:

If the condition Re·Pr > 0.2 is satisfied, the Churchill-Bernstein equation of heat transfer offers a good approximation:

$$\mathrm{Nu} = \left(0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}}{\left(1+(0.4/\mathrm{Pr})^{2/3}\right)^{1/4}}\right)\left(1+\left(\frac{\mathrm{Re}}{282000}\right)^{5/8}\right)^{4/5}.$$

When translated into the terms of diffusion it gives the Sherwood number and the velocity of deposition

$$\boxed{u_D = \frac{D}{d}\mathrm{Sh} = \frac{D}{d}\left(0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Sc}^{1/3}}{\left(1+(0.4/\mathrm{Sc})^{2/3}\right)^{1/4}}\right)\left(1+\left(\frac{\mathrm{Re}}{282000}\right)^{5/8}\right)^{4/5}}$$

***Example** (of diffusion deposition)*:

assume $d = 1$ mm, $u = 5$ m/s, $D = 0.03$ cm^2/s (unattached fraction), and standard conditions

obtain Re = 380, Sc = 4.4, Sh = 19.5, $\boxed{u_D \approx 6 \text{ cm / s}}$.

- **Electrostatic deposition**
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Symbols:

u_E – velocity of electrostatic deposition, m/s

Z – electric mobility, m^2/(V·s)

E – electric field on wire surface, V/m

E_o – undisturbed atmospheric electric field

k – Boltzmann constant 1.38×10^{-23} J/K

T – temperature, K

e – ion charge 1.6×10^{-19} C

H – height of the wire, m

Equations:

$$u_E = ZE, \qquad Z = \frac{eD}{kT}, \qquad E = \frac{2H}{d \ln(4H/d)} E_o, \qquad u_E = \frac{eD}{kT} \frac{2H}{d \ln(4H/d)} E_o$$

Example:

assume $H = 1$ m, $d = 1$ mm, $D = 0.03$ cm^2/s, $E_o = 100$ V/m

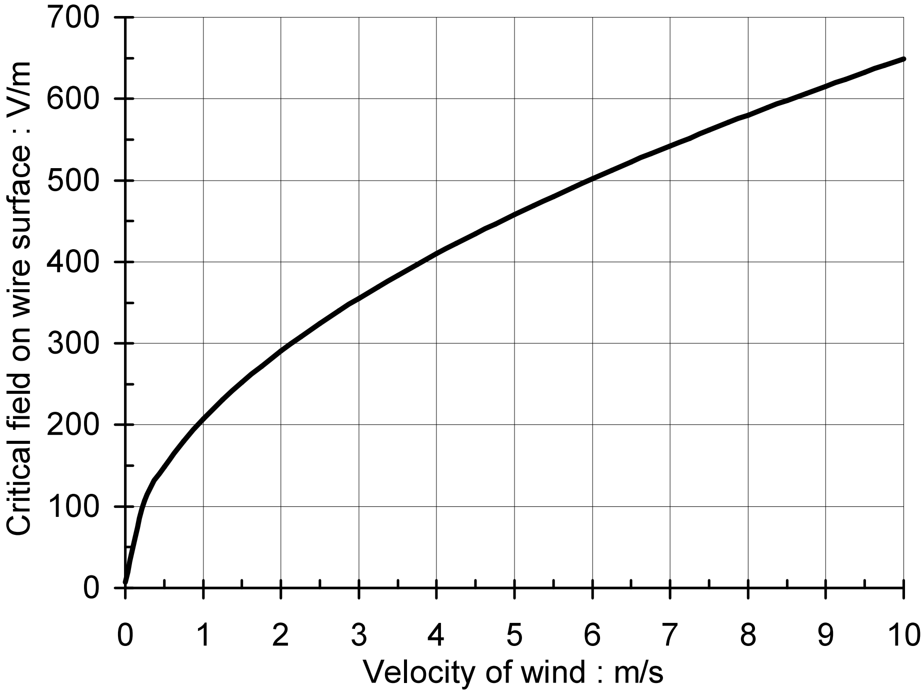
obtain $E = 24$ kV/m, $Z = 1.27$ cm^2/(V·s), $\boxed{u_E \approx 3 \text{ m / s}}$.

- **Comparison**

The electrical deposition equals to the diffusion deposition ($u_E = u_D$) when the electric field on the surface of the collector reaches the critical value

$$E_{cr} = \frac{kT}{ed}\mathrm{Sh}.$$

The critical field depends on the wind velocity u via the Reynolds number $\mathrm{Re} = ud/\nu$ and on the particle mobility via the Schmidt number $\mathrm{Sc} = \nu/D$. An example is given in the figure:



($d = 1$ mm, $D = 0.03$ cm^2/s, $Z = 1.27$ cm^2 V^{-1}s^{-1}, standard conditions)

Example:

Let the atmospheric electric field have a typical fair weather value of 200 V/m, the geometric factor for a well-exposed needle is $E/E_o = 100$, and the activity concentration of unattached ^{218}Po is 2 Bq/m^3.

It follows the equilibrium activity concentration on the surface of the needle about 1300 Bq/m^2 that dramatically exceeds the activity estimated when considering only the diffusion deposition.

3. Preliminary measurements

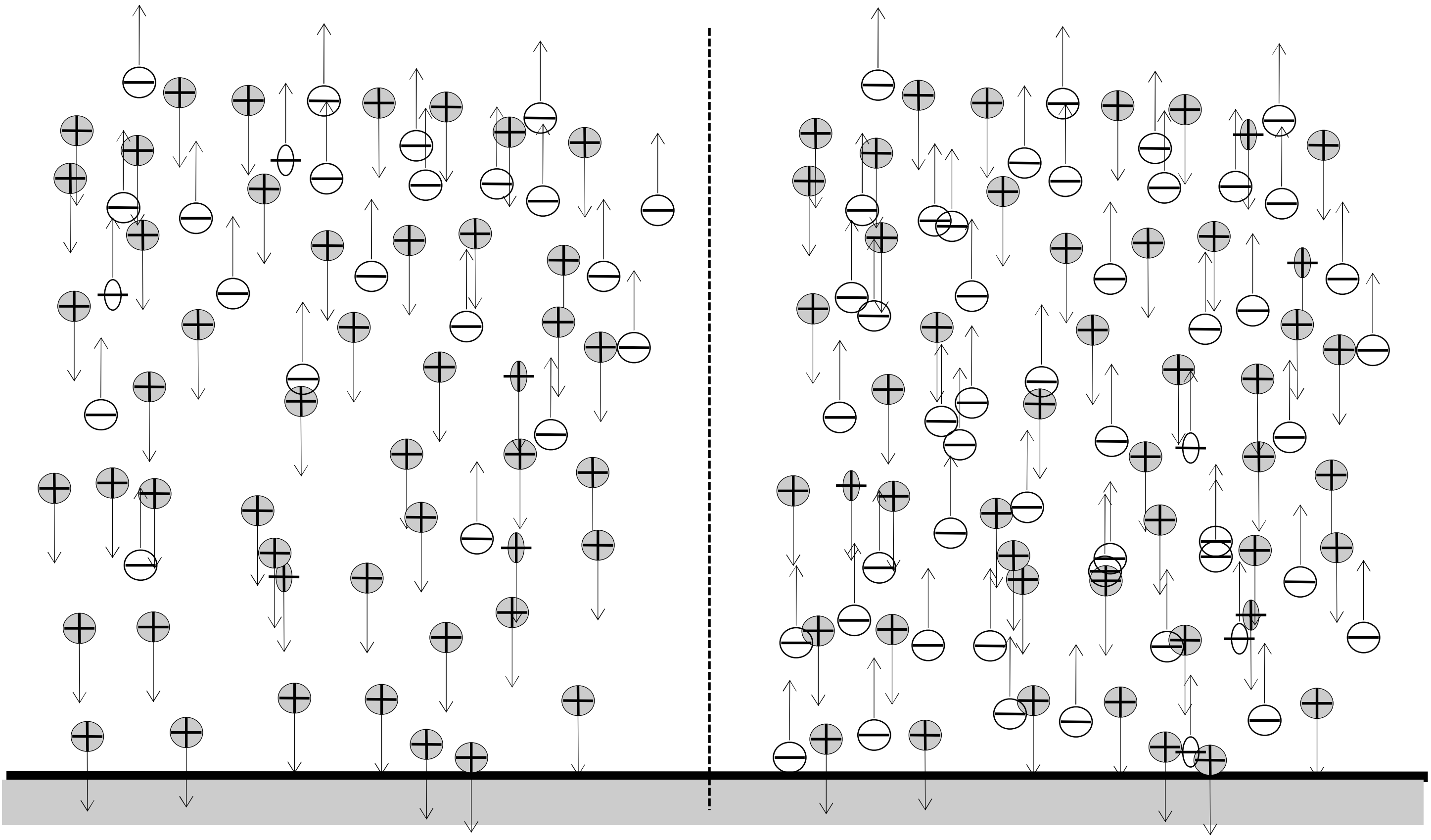
Hypothesis: The short-living radionuclides on the leaves and needles of trees originate from the dry deposition from the air after some period of fair weather. The effect of electric field is enhanced under HV lines. Near Tartu, a 330 kV AC lines approaches the transformer substation over a high (about 4 m) spruce hedge. Top branches of spruces a well exposed to the electric field and collect the radon daughters from the air.

Method: The top needles of spruces under HV line were picked and measured using EG&G Ortec HPGe detector GEM-35200 and analyzer 92x-W3 Spectrum Master. The thoron daughter ^{212}Pb was identified according to the 238.6 keV γ-line and radon daughter ^{214}Bi according to the 609.5 keV γ-line.

Results: Any essential difference in ^{212}Pb activity between the needles picked from different heights was not discovered. Probably, the vertical profile of the thoron concentration and the height profile of the electric field concentration factor on trees are compensating each other. The highest specific activity of ^{214}Bi up to 4 kBq/kg was measured on the top branches of a spruce situated close to the 330 kV line. The specific activity of lower branches has varied between 0.1 and 1 kBq/kg. The number of measurements is not big enough for a firm synopsis. A preliminary conclusion is that the measurements did not contradict the theoretical estimates proclaiming the essential role of the electrical field in the deposition of the radon daughters on the trees.

4. Environmental impact

• Atmospheric electric electrode effect



▨ Willett, J. (1985) Atmospheric-electrical implications of ^{222}Rn daughter deposition on vegetated ground. *J. Geophys. Res. D*, 90, 5901–5908 .

• Hypothetic biological effect