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Dry Deposition of Urban Surfaces

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DRY DEPOSITION ON URBAN SURFACES

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Abstract. In order to facilitate developing a model for deposition in urban areas, beryllium-7, created by cosmic radiation and fall-out cesium-137, have been used as tracers in measurements designed to find the dry deposition velocity on building surfaces.

A literature review has revealed that very little work has been done on deposition in urban areas; therefore, a major effort on measuring the deposition parameter is needed to construct reliable models in this field.

Deposition velocities in the range from 0.001-0.04 cm/s have been found.

INIS DESCRIPTORS: BERYLLIUM 7; BUILDINGS; CESIUM; DEPOSITION; FALLOUT DEPOSITS; REVIEWS; SURFACES; TRACER TECHNIQUES; URBAN AREAS; VELOCITY.

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CONTENTS

1. INTRODUCTION

The dry deposition velocity is a very useful parameter in calculating the long-term consequences of an accidental release of radioactive particles from nuclear reactors. (Thykier, 1980).

The object of this work is to investigate the dry deposition velocity on urban surfaces.

2. DRY DEPOSITION

2.1. Definition

Pollution in air can have diferent forms as liquid drops, reactive and non-reactive gas, and small solid particles. The dispersed pollutant can be removed from the air by different processes. Removal in the absence of precipitation is normally called dry deposition. This report will be restricted to the study of dry deposition of aerosol particles.

To describe aerosol deposition Gregory (1945) and Chamberlain (1953) introduced the concept of deposition velocity

$$V_d(z_d) = \frac{F(z_d)}{\chi(z_d)}, \qquad \text{where}$$

z_d is the height at which V_d is determined, $F(z_d)$ the downward flux of the contaminant towards the surface at height z_d and $\chi(z_d)$ is the concentration of the contaminant at height (z_d).

2.2. Deposition on rough and smooth surface

A smooth surface is one in which the roughness elements are so small that they do not penetrate the sublaminar layer created at the surface.

At rough surfaces the roughness elements are sufficiently large to be able to penetrate the sublaminar layer and this will cause a greater deposition than at smooth surfaces. (Ahmed 1979, Jonas 1978 and Underwood 1983)

2.3. Urban areas

The deposition in urban areas can be dealt with in two ways:

One is to consider the total urban surface as a rough surface with the buildings forming the roughness elements, and from this model find the total deposition to the urban area.

This way of dealing with deposition has some serious drawbacks: First, the distribution of the deposited material on the different vertical and horizontal surfaces are not found, and knowledge of this distribution is important in dose calculations. Secondly, when this sort of model is used the deposition velocities chosen are often those found from experiments in rural areas with a comparatively dense canopy, characterised by, e.g. friction velocity or roughness length.

The use of such deposition velocities in urban areas can greatly overestimate the deposition here.

To describe the deposition in urban areas properly it seems better to take another approach where the deposition processes in the canopy are looked at in detail, so that deposition on the separate roughness element are examined.

This type of model is developed for dense canopies by Thom (Thom 1967). Unfortunately, Thom's model cannot be used for calculating deposition in open canopies such as urban areas.

For describing deposition in urban area canopies it seems necessary to examine the air flows over the surface of the separate roughness elements and from these calculate the deposition on the different surfaces (roads, walls, roofs, etc.).

Although urban areas, as such, must be characterised as a rough surface, many of the separate surfaces within them are generally fairly smooth. The model must be able to cope with these characteristics.

3. EXPERIMENTS ON DRY DEPOSITION

The dry deposition velocity has been investigated in several laboratories and field experiments on different surfaces such as grass, bare soil, and metal.

Nearly all experiments dealing with vertical surfaces have been dedicated to finding the deposition velocities on smooth vertical tube surfaces. (Davies 1966, Sehmel 1970, 1973, Liu 1974, Slinn 1978, Friedlander and Johnston 1957).

Only a few of the wind tunnel experiments have dealt with vertical surfaces and a literature study has revealed only one (Roed 1983) field experiment with deposition on real urban surfaces.

Measurements of the overall deposition in urban areas are also very scarce and those found in the literature review all dealt with total deposition, dry as well as wet (e.g., Andersen 1978).

4. THE DRY DEPOSITION VELOCITIES USED IN REACTOR SAFETY STUDIES

The problems of finding a convincing model for dry deposition in urban areas are reflected in the deposition velocities used in recent reactor safety studies.

The Rasmussen Report, WASH 1400, 1975, has used a constant deposition velocity of 1 cm/s independent of the weather situation, pollution form, and type of surface (rural or urban).

Later American studies as NUREG/CR-2239 (1982) and the German safety study (Deutshe Risikostudie 1979) have also used deposition velocities of 1 cm/s for rural as well as for urban areas.

The Swedish study (Statens Strålskyddsinstitutt 1979) has used a deposition velocity of 0.3 cm/s in both rural and urban areas.

In the latest British study (Kelly and Clarke 1982), the deposition velocities used are 0.1 cm/s for particles, 1 cm/s for inorganic iodine, and 0.001 cm/s for organic iodine for rough surfaces (roughness length 30 cm) independent of the density of the canopy, so that in urban as well as most rural areas these values will be used.

In the Swedish study of the consequences to Danish territory of a hypothetical reactor accident at the Barsebäck power plant (Forsvarets Forskningsanstalt 1983), the deposition velocities are chosen as 0.2 cm/s for particles, 0.5 cm/s for inorganic iodine, and 0.005 cm/s for organic iodine. These values are used for rural as well as urban areas.

Until now the only studies where different deposition velocities for urban and for rural areas have been used are the Danish ones. These reflect the work done at Risø National Laboratory in this field.

In the study of radioactive contamination on Danish territory (Gjørup et al. 1981) deposition velocities of 2 cm/s for rural and 0.2 cm/s for urban surfaces were used. It must be emphasized that the deposition velocity of 0.2 cm/s is used for all urban surfaces, horizontal, vertical, and sloping, so that the overall deposition velocity for the urban area will be about 0.3 cm/s.

In the study of the consequences of actual large reactor accidents calculated on the basis of empirical data (Gjørup et al. 1983) the values suggested by (Roed 1982) were used. That is, for rough rural areas 0.2 cm/s for particles and 1 cm/s for inorganic iodine, and for urban surfaces 0.04 cm/s for particles and 0.2 for inoganic iodine. As mentioned above, the deposition velocities for urban surfaces are used on the real surfaces, so that the overall deposition for the urban area will be about 0.06 cm/s for particles and 0.3 cm/s for inorganic iodine.

5. EXPERIMENTAL PART

5.1. Dry deposition on building surfaces

Our experimental work has been concentrated on investigating the deposition velocities on building sufaces.

Some of the surfaces are those on actual vertical building surfaces where the surface depositions of fall-out ^{137}Cs are measured.

Others are artificial surfaces that are mounted on buildings to investigate the deposition velocity of ^{7}Be.

5.2. Cesium-137 measurements

Some typical Danish houses, some with brick walls and others with plastered walls, are chosen for study.

An approximately 5-mm thick layer of the surface of removed bricks was sliced off, pulverised, and later analysed for its content of ^{137}Cs. The next 5 mm was also analysed for its content of this isotope. We found from these measurements that the ^{137}Cs was confined to the outermost layer.

The concentration of fall-out particles in Danish air has been measured continually from 1960 in our laboratory by Aarkog and Lippert (1983).

Before 1962 the concentration of ^{137}Cs in the air filters was measured by radiochemistry, accompanied by large errors.

From 1962 and after ^{137}Cs in the air-filters was measured by gamma-spectroscopy. As the highest precision before 1962 was obtained on ^{90}Sr fall-out, we used these measurements to find ^{137}Cs concentration.

To do this we assume that the mean concentration of ^{137}Cs in air over a long period is proportional to the total fall-out of ^{90}Sr in the same period.

We then use the period 1963-1982 to find the factor of proportionality, P (see Table 5.2.1.), as

$$P = \frac{5{\cdot}028}{1{\cdot}600} \cdot \frac{Bq{\cdot}^{137}Cs{\cdot}m^{-3}}{Bq{\cdot}^{90}Sr{\cdot}m^{-2}}$$

The decay-corrected time-integrated concentration until and including a given year is found by summation of the contributions for each year, decay corrected to the year considered.

The decay corrected time-integrated concentration of ^{137}Cs in air the years before 1963 is found by multiplying the decay-corrected accumulated ^{90}Sr fall-out in the considered year together with the factor of proportionality, P.

The contribution to the decay-corrected time-integrated concentration from the years after 1962 is found directly from the measurement of the air concentration of ^{137}Cs in the year considered.

Provided the same mean weather conditions prevail and ignoring weathering and resuspension the deposition velocity V_d is then found from the expression

$$D_t = V_d \cdot \bar{\chi} \qquad 5.2.$$

where D_t is the deposited amount per unit of area. $\bar{\chi}_d$ is the decay-corrected time-integrated concentration as given in Table 5.2.1, V_d is shown in the Table 5.2.2.

Table 5.2.1.

Year	^{137}Cs-concentration in air $\mu Bq \cdot m^{-3}$	Fall-out of ^{90}Sr:Bq·M^{-2} Single years	Accumulated	Decay-corrected ^{137}Cs time integrated concentration in air $\mu Bq \cdot m^{-3} \cdot y$
82	5.4	2.1		5.506
81	30	13.1		5.629
80	8.7	4.3		5.730
79	23	6.1		5.855
78	63	17.1		5.969
77	60	14.2		6.043
76	15.5	3.8		6.123
75	48	15.3		6.250
74	73	26.3		6.347
73	17.3	7.1		6.420
72	51	16.1		6.553
71	98	55.7		6.654
70	127	60.9		6.709
69	91	38.8		6.735
68	88	51.9		6.800
67	79	38.7		6.869
66	210	79.4		6.948
65	390	146.3		6.896
64	1150	385.2		6.657
63	2400	617.7		5.636
62			1054	3.312
61			806	2.532
60			772	2.426
59			749	2.353
58			542	1.703
57			397	1.248
56			292	917
55			185	581
54			97	305
53			29	91
52			11	35
51			4	13
50			1	3

Table 5.2.2.

Sample No	When built (year)	Area of surface (m^2)	Deposition of ^{137}Cs (Bq m^{-2}) Sample facing East	South	West	North	Combined North and South	Deposition velocity (cms $^{-1}$)
Brick wall								
82	1900	0.213	7.86					0.005
83	1900	0.221				25.96		0.015
81	1910	0.188	5.72					0.003
70A	1910	0.464				38.99		0.022
70B	1910	0.534				16.61		0.009
70C	1910	0.158		74.53				0.042
70D	1910	0.341		52.59				0.030
71A	1920	0.094		3.85				0.002
71B	1920	0.231				6.9		0.004
79A	1920	0.181	6.23					0.004
95	1930	0.327				26.72		0.015
80	1956	0.266		56.07				0.036
72	1958	0.132				65.08		0.044
73	1958	0.133					77.00	0.052
Plastered wall								
97	1900	0.120				58.81		0.034
90	1918	0.277				75.78		0.043
74	1920	0.153		36.71				0.021
75	1920	0.162				16.61		0.010
76	1920	0.115			26.39			0.015
79B	1920	0.061	8.35					0.005
96	1930	0.133	41.76					0.024
78	1940	0.226	20.63					0.011
85	1950	0.195			24.34			0.014
86	1950	0.294	6.75					0.004
87	1950	0.270				45.42		0.026

5.3. Beryllium-7 measurements

Plates were mounted on some houses in order to measure conveniently the ^{7}Be deposited.

Two types of plates were fabricated; the surface of one consisted of mortar based on beach sand to insure a low background of ^{7}Be. The other surface was made of rough wallpaper painted with a normal house paint.

The surface of each plate was protected against rain by mounting a shed roof over it.

After having been exposed to the air and its content of ^{7}Be particles for some months, the plates were brought to the laboratory and the surface was scraped off and measured for its content of ^{7}Be by means of a Ge(Li) gamma spectrometry set-up.

In the period of exposure air samples were collected weekly by a sampler that collects the air particles on 6 glass-fibre filters each 0.56 m x 0.48 m. The flow through the filters is approximately 275 000 m^3 per week.

The filters are also analysed in a Ge(Li) detector set-up.

The results of the measurement are shown in Table 5.3.1.

V_d for ^{7}Be is found in the same way as was done in the case of ^{137}Cs by integrating the air concentration over the time in which the plates are exposed, correcting for decay (^{7}Be half-life is 53 days), and finding the total deposition per unit of area on the plates.

The deposition velocities are shown in Table 5.3.2.

Table 5.3.1.

Concentration of ^{7}Be in air at 1.5 m height at Riso

Year	Period	Concentration in air $\mu Bq\ ^{7}Be\ m^{-3}$	Year	Period	Concentration in air $\mu Bq\ Be\ m^{-3}$
1982	Nov 15 - Nov 22	1565	1983	Sep 12 - Sep 19	1389
	" 22 - " 29	1998		" 19 - " 26	2274
	" 29 - Dec 06	1777		" 26 - Oct 03	1895
	Dec 06 - " 13	1122		Oct 03 - " 10	1549
	" 13 - " 20	1057		" 10 - " 17	2111
	" 27 - Jan 03	1639		" 17 - " 24	2367
				" 24 - " 31	1938
1983	Jan 03 - Jan 10	1578		" 31 - Nov 07	1501
	" 10 - " 17	2127		Nov 07 - " 14	1843
	" 17 - " 21	1259		" 14 - " 21	1479
	" 24 - " 31	1761		" 21 - " 28	1173
	" 31 - Feb 07	1750		" 28 - Dec 05	2935
	Feb 07 - " 14	1590		Dec 05 - " 12	1574
	" 14 - " 21	2740		" 12 - " 19	1949
	" 21 - " 28	1308		" 19 - " 27	1453
	" 28 - Mar 07	928		" 27 - Jan 02	1754
	Mar 07 - " 14	2302			
	" 14 - " 21	1744	1984	Jan 02 - Jan 09	1403
	" 21 - " 28	1850		" 09 - " 16	1227
	" 28 - Apr 04	1778		" 16 - " 23	1284
	Apr 05 - " 11	1764		" 23 - " 30	1013
	" 11 - " 18	2841		" 30 - Feb 06	1498
	" 18 - " 25	1822		Feb 06 - " 13	1500
	" 25 - May 02	1396		" 13 - " 20	6066
	May 02 - " 09	1490		" 20 - " 27	2349
	" 09 - " 16	2950		" 27 - Mar 05	2405
	" 16 - " 30	1665		Mar 05 - " 12	2382
	" 39 - Jun 06	2293		" 12 - " 19	3425
	Jun 06 - " 13	3094		" 19 - " 26	3018
	" 13 - " 20	2207		" 26 - Apr 02	2235
	" 20 - " 27	3191		Apr 02 - " 09	1568
	" 27 - Jul 04	1354		" 09 - " 16	2018
	Jul 04 - " 11	3736		" 16 - " 24	2565
	" 11 - " 18	2939		" 24 - " 30	2879
	" 18 - " 25	1844		" 39 - May 07	2678
	" 25 - Aug 01	2169		May 07 - " 14	2945
	Aug 01 - " 08	1851		" 14 - " 21	2924
	" 08 - " 15	2728		" 21 - " 28	1456
	" 15 - " 22	1798		" 28 - Jun 04	1789
	" 22 - " 29	3157		" 04 - " 12	3757
	" 29 - Sep 05	3229			
	Sep 05 - " 12	1668			

Table 5.3.2.

Sample No.	Surface material	Area of sample (m^2)	Sample exposed from	to	Surface towards	Deposition ($Bq\ ^{7}Be\ m^{-2}$) Vertical	Horizontal	Deposition velocity ($cm\ s^{-1}$)
89	Plaster	2.98	11/16/82-	3/28/83	NE	0.635		0.0066
92	Plaster	2.98	3/28-83-	11/24/83	NE	0.611		0.0049
102	Paint	4.30	11/24/83-	2/9/84	NE	1.86		0.0158
103	Paint	4.30	8/15/83-	3/26/84	S	0.193		0.0013
104	Plaster	2.98	4/24/83-	4/9/84			9.21	0.066
105	Plaster	2.98	4/24/83-	4/9/84	N	0.305		0.0022
106	Plaster	2.98	1/10/83-	6/6/84	N	0.212		0.0013
107	Plaster	2.98	1/10/83-	6/6-84			0.458	0.0028

5.4. Discussion

The ^{137}Cs-deposition on the walls can be divided into dry and wet deposition.

For the samples taken from walls that are well protected from rain, snow and hail the deposited material is due mainly to dry deposition. Sample nos. 71A, 71B 79A, 81 and 82 were taken from fairly well-protected surfaces, and the calculated deposition velocities are low (0.002-0.006 cm/s).

The rest of the samples were taken from houses with small eaves or none. For the last samples in particular there could be a surplus of ^{137}Cs from rain striking the wall surfaces, so that the calculated deposition velocity would then represent an upper limit of the dry deposition.

For the deposition velocities for ^{137}Cs, a major potential source of error is that weathering effects and the effect of cleaning buildings, removal of paint, etc. will eliminate a portion of the deposited ^{137}Cs.

Concerning the cleaning of walls and removal of paint the effect on the deposited caesium is probably small because there is no tradition in Denmark for regularly cleaning outer walls.

The likelihood that paint, etc. will be removed is greater for plastered houses; therefore, the samples from these surfaces were taken from areas of the walls where the old paint did not seem to have been removed by the redecoration processes.

The weathering effect is probably also fairly small as explained below.

Wiltshire and Owen (1965, 1966) used firehosing to clean paved areas. They found a decreasing effect for decreasing particle size. Even for smoothly textured surfaces they came to the conclusion that there was practically no decontamination effect for particle sizes of 10 µm or less. According to the measurement made by Sisefsky and Arntsing (1972), the fallout particles are smaller than 10 µm.

Also, the particles originating from a reactor accident are believed to be small (Albrecht and Wild 1982).

Corn (1961) stated that solid aerosols apparently adhere with great tenacity to solid surfaces. Even vigorous blowing on a surface will dislodge only few particles smaller than 10 µm.

The findings of Wiltershire and Owen, and Corns agree with our own decontamination experiment, where we tried to remove deposited ^{137}Cs fallout particles from roof material by vigorous blowing, followed by a washing procedure (Roed and Gjørup, 1984). We found no effect on smooth roof material.

The experiments referred to here are of short duration, whereas after 20 years of exposure the weathering effect could be more efficient.

However, if there should be such an enhanced effect the deposition velocity should be greater in the case of the ^{7}Be measurement, as the material used in these measurements are exposed to weathering for only less than one year.

As seen in Table 5.3.2. the deposition velocity calculated from the ^{7}Be measurements are generally smaller than those calculated from the ^{137}Cs measurement. However, all the surfaces used for ^{7}Be measurements are well protected against wet deposition, so these velocities should be compared with those of ^{137}Cs on a well-protected surface.

In this case we see that the deposition velocities of ^{7}Be are in the same range or smaller than those of ^{137}Cs.

So it can be concluded that the "short-term" deposition velocities of ^{7}Be are not greater than the "long-term" deposition velocities of ^{137}Cs.

Two horizontal surfaces have been investigated, sample No. 107 has been undisturbed, but the other (No. 104) shows clear signs of footprints from children and cats. So that a part of the ^{7}Cs has come from soil contaminated with wet deposited ^{7}Cs. The calculated dry-deposition velocity of that sample represents therefore an upper limit for the actual dry-deposition velocity.

6. CONCLUSION

The values of the deposition velocity of ^{137}Cs calculated in this work are in the range from 0.004 to 0.044 cm sec^{-1}. Some of the samples taken can also have been exposed to a portion of wet deposition. For these samples the calculated values of the deposition velocity is an upper limit. Some of the ^{137}Cs samples are taken from well-protected surfaces. At the protected surfaces the deposition velocities are in the same range as the velocities measured for ^{7}Be deposition. All the surfaces in the ^{7}Be measurement are well protected.

For the horizontal surfaces the deposition velocities for the one that is undisturbed are in the same range as the vertical.

The deposition velocities found are very small; this indicates that the deposition velocities in urban areas are considerably smaller than those measured in rural areas.

A literature review revealed an extensive need for developing a model for deposition in urban areas. Some attempt towards this has been made (Roed 1982, 1983 Jensen 1984).

To find data for this type of model it is necessary to direct a major effort to measuring of dry deposition in urban areas.

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