Wet and Dry Deposition of Fallout Materials at Kjeller

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Abstract

Daily measurements of fallout air activity and deposited activity at Kjeller, Norway, from 1 Sept. 1956 to 30 Sept. 1959 are given as monthly means for days with and without obvious precipitation. It seems that significant concentrations of fallout particles reach the earth about 3 months after high-yield test explosions. Dry deposition may reduce the amounts of fallout materials available for capture by precipitation.

1. Introduction

It has been thought for some time that particle sizes vary with yield (PROJECT SUNSHINE, 1953, p. 19), and this could have an important effect upon the general pattern of world-wide deposition. It is not an easy matter to measure particle sizes directly, and it is therefore interesting to see what might be deduced from routine measurements of air activity and deposited activity.

An apparent relationship between surface-air activity and deposition with precipitation has already been pointed out (STOREBÖ, 1957), and it might be important to see if dry deposition and surface-air activity are connected in any way. This could help in forecasting the extent of dry deposition in very dry periods.

It is shown here that wet and dry deposition and surface-air activity may all be interrelated, and that the amounts of fallout materials available for capture by precipitation may depend upon the amounts of materials removed from near-surface air layers by processes of dry deposition.

2. Measuring procedures

Daily samples of suspended particles are collected by drawing about 400 m³ of air through asbestos fibre filters at a height of about 2 m. The exposed filters are ashed and measured with an end-window beta counting tube after a delay of 48 hours. The counting arrangement is calibrated with potassium 40.

Samples of deposited materials are collected in open vessels which are emptied daily. When necessary the vessels are washed-out with distilled water. Samples are dried by infra-red lamps and measured in the same way as air dust samples. Precipitation amounts are determined from wet sample volumes.

3. Basic data

Daily measurements made at Kjeller during the period 1 Sept. 1956—30 Sept. 1959 have been divided into two groups, covering days with and without obvious precipitation. Monthly means of air activity and deposited activity have been calculated for each of these groups. Monthly means of deposition velocity

$$\left(\frac{\text{rate of deposition of activity per unit area}}{\text{conc. of activity per unit volume of air}}\right)$$

and air to precipitation activity ratios for equal volumes, have also been calculated. Average precipitation activity and average daily air activity have been determined for different total amounts of daily precipitation.

Measurement data for Kjeller have been published in several earlier reports (HVINDEN,

Table 1. Mean daily values of air activity and deposition on apparently dry days for each month between 1 Sept. 1956 and 30 Sept. 1959.

	1956		1957		1958		1959	
	average air activity (dry days) μμc/m³	average daily deposition on dry days μμ/cm²						
Jan.			0.61	173	0.35	204	1.23	1161
Feb.			0.43	89	0.59	119	2.71	1147
Mar.			0.73	230	1.59	478	3.08	1324
Apr.			1.11	469	2.32	1132	3.04	1195
May			1.95	868	1.60	1354	4.50	1629
June			1.13	516	2.50	764	2.12	538
July			0.45	564	2.54	843	1.55	436
Aug.			0.70	166	0.57	432	0.53	256
Sept.	0.76	2254	0.84	290	1.11	1012	0.28	119
Oct.	0.97	803	1.30	325	1.86	2408		
Nov.	0.61	761	0.45	218	2.18	2532		
Dec.	0.67	728	0.34	210	1.43	793		

1959), but are treated in a new way in this report. Daily routine measurements were started in the Spring of 1956, but results for the first 6 months have not been used in the investigation because of uncertainties in distinguishing between wet and dry days. A new system of recording data was started in Sept. 1956.

A number of measurements from March 1959 have been rejected because of minor accidental releases of I—131 from a nearby isotope laboratory.

4. Dry deposition

Monthly means of air activity and deposited activity on apparently dry days are given in table 1, the values being plotted in fig. 1.

Most of the points in figure 1 lie quite close to a line drawn through the point determined by the average values of air activity and deposited activity for the whole period. There are however a few points which obviously do not follow the general trend, and it might be important to find out why this is so.

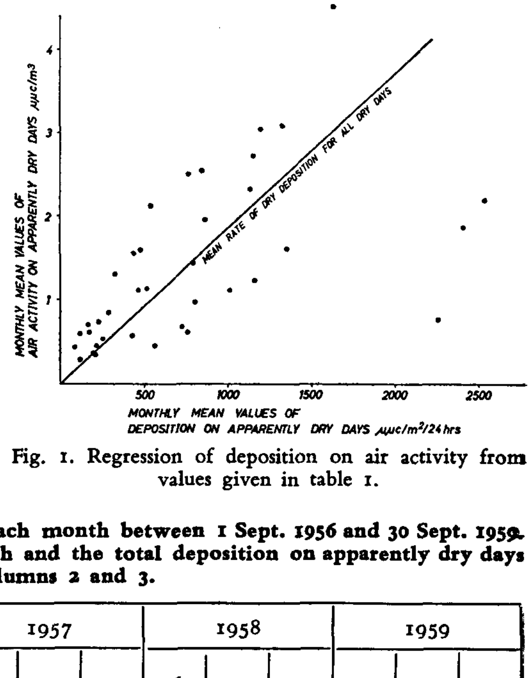

Fig. 1. Regression of deposition on air activity from values given in table 1.

Table 2. Mean values of deposition velocity for each month between 1 Sept. 1956 and 30 Sept. 1959. The number of apparently dry days in each month and the total deposition on apparently dry days are given in columns 2 and 3.

	1956			1957			1958			1959		
	deposition velocity cm/sec	number of dry days	deposition of dry days mc/km²									
Jan.				0.33	20	3.5	0.67	17	3.5	1.09	17	19.7
Feb.				0.23	11	1.0	0.23	14	1.7	0.49	23	26.4
Mar.				0.36	22	5.1	0.36	25	12.0	0.50	16	21.2
Apr.				0.49	23	10.8	0.56	17	19.2	0.45	16	19.1
May				0.51	18	15.6	0.98	18	24.4	0.42	25	40.7
June				0.53	11	5.7	0.35	20	15.3	0.29	22	11.8
July				1.45	14	7.9	0.38	18	15.2	0.33	17	7.4
Aug.				0.27	17	2.8	0.88	16	7.0	0.56	24	6.1
Sept.	3.43	21	47.3	0.40	10	2.9	1.05	18	18.2	0.49	26	3.1
Oct.	0.96	22	19.7	0.29	10	3.2	1.50	15	36.1			
Nov.	1.44	19	14.5	0.56	12	2.6	1.34	14	35.4			
Dec.	1.25	9	6.6	0.71	23	4.8	0.64	15	11.9			

As shown in table 2 and figure 2, monthly mean values of deposition velocity seem to increase almost invariably about 3 months after reported high-yield test explosion series (STRONTIUM PROGRAM 1959), possibly due to the arrival near the surface of rather large particles. (The high value of deposition velocity in Sept. 1956 could be due to the American high yield tests carried out in the Summer of 1956.)

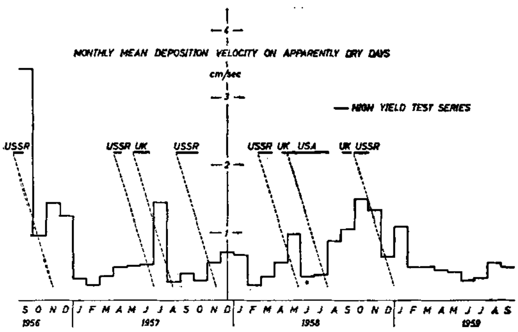

Fig. 2. Variations of deposition velocity from values given in table 2.

It can be deduced from table 1 that an average depth of about 500 m of surface air must have been emptied each day to account for the sampled amounts of deposited materials. It is interesting that particles of about 6—7 micron diameter which would fall from 20 km in about 3 months (PROJECT SUNSHINE, 1953, p. 86), would fall several hundred meters in still surface air in the course of a day or so. In fact the diurnal variation of fallout air activity reported from measurements at Kjeller (SMALL 1959), may be due to settling of rather large particles into surface-air layers.

Fallout air activity which is reduced during the daytime by turbulent removal of fallout particles, tends to increase during the nighttime because of continued settling of particles into calmer air.

It might be important to investigate a possible diurnal variation of dry deposition rate. Such an investigation would probably provide some information about the way in which particle sizes near the ground change as a result of weather conditions etc. The possibility of important health effects in this connection has been pointed out from observations of I—131 accidentally released to the atmosphere (SMALL and STOREBÖ, 1959).

The values of deposition velocity given in table 2 (approx. 0.2—3.4 cm/sec) are substantially larger than the value of 0.07 cm/sec obtained by STEWART ET AL. (1957). The British measurements were made using gummed surfaces and sampling funnels, and there is no apparent reason for the discrepancy. It might be suggested that fallout materials at Kjeller have contained a greater proportion of large particles.

5. Deposition with precipitation

Monthly means of average precipitation activity per litre and air activity for days with precipitation are given in table 3, and plotted in fig. 3.

Most of the points in figure 3 lie quite close to a line drawn through the point determined by the average values of air activity and average precipitation activity per litre for the

Table 3. Mean daily values of air activity and precipitation activity on obviously wet days for each month between 1 Sept. 1956 and 30 Sept. 1959

	1956		1957		1958		1959	
	average air activity (wet days) $\mu\mu c/m^3$	average precipitation activity $\mu\mu c/l$						
Jan.			0.61	785	0.40	400	1.17	670
Feb.			0.31	356	0.34	216		
Mar.			0.85	1120	1.22	914	2.67	3154
Apr.			1.88	4990	2.02	1746	2.27	2347
May			1.55	1915	1.88	1638	4.61	3625
June			0.69	576	1.77	1289	2.54	2736
July			0.64	896	1.03	878	1.19	698
Aug.			0.51	342	0.48	652	0.67	403
Sept.	0.91	2894	0.90	1026	0.87	1397	0.17	83
Oct.	1.00	4168	1.35	1339	1.68	2052		
Nov.	0.51	1364	0.51	680	2.53	4396		
Dec.	0.58	1393	0.28	583	0.97	2124		

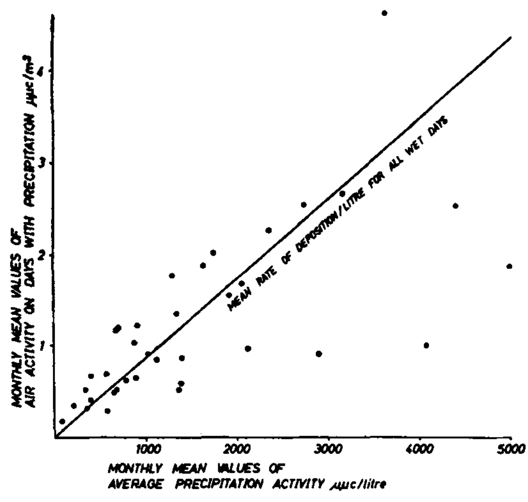

Fig. 3. Regression of precipitation activity on air activity from values given in table 3.

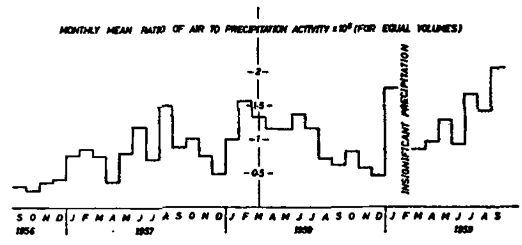

Fig. 4. Variations of air to precipitation activity ratio from values given in table 4.

whole period. Consequently in view of what has been pointed out in section 4, it is interesting to see if the obvious exceptions to the general trend in fig. 3 can be explained by changes in particle sizes.

Comparing the air to precipitation activity ratios given in table 4 and figure 4 with the deposition velocities given in table 2 and figure 2, it seems that when deposition velocity increases, the air to precipitation activity ratio falls and vice-versa. This might indicate that some fraction of fresh fallout particles is removed by processes of dry deposition rather than by precipitation. One way of explaining this is that precipitation processes involve an upward movement of air from near the surface, and that larger particles in particular tend to be removed near the surface. This leads to the simplified model shown in fig. 5.

Consequently the amount of fallout materials available for capture and removal by precipitation, may depend to some extent upon the amount of dry deposition from surface air layers.

The mean values of air to precipitation activity ratio in themselves provide material for speculation about precipitation processes, since droplet growth by condensation might be expected to produce higher values of air to precipitation activity ratio than growth by coalescence. It appears from fig. 4 that relatively fresh fallout materials tend to reduce the air to precipitation activity ratio, and it might be argued that coalescence effects are more important than usual when fresh fallout materials are available. Consequently the simple model shown in fig. 5, which is based upon dry removal effects, may have to be elaborated to include effects of fallout particles in the formation of precipitation elements.

The mean value of air to precipitation ac-

Table 4. Mean values of air to precipitation activity for equal volumes for each month between 1 Sept. 1956 and 30 Sept. 1959. Precipitation amount and total wet deposition for each month given in columns 2 and 3

	1956			1957			1958			1959		
	$\frac{\text{air activity}}{\text{precip. activ.}} \times 10^{-6}$	mm precipitation	deposition on wet days mc/km²									
Jan.				0.78	49	38.1	1.00	49	19.4	1.76	108	71.7
Feb.				0.87	120	42.1	1.57	60	12.8			11.6
Mar.				0.76	37	41.8	1.34	9	8.2	0.85	45	140.0
Apr.				0.38	23	115.0	1.16	45	79.7	0.97	103	246.6
May				0.80	48	92.5	1.15	91	149.4	1.28	23	82.5
June				1.20	131	75.6	1.38	74	95.6	0.93	13	34.2
July				0.71	112	100.4	1.17	102	92.4	1.67	80	55.7
Aug.				1.50	137	46.9	0.72	71	46.7	1.42	34	13.6
Sept.	0.31	81	233.7	0.88	162	165.9	0.62	41	57.0	2.06	14	1.2
Oct.	0.25	27	110.6	1.01	71	95.5	0.82	110	224.9			
Nov.	0.37	42	57.3	0.75	61	41.7	0.58	55	241.1			
Dec.	0.42	46	64.4	0.48	4.5	2.6	0.46	78	166.5			

tivity ratio for the whole period, $0.9 \cdot 10^{-6}$ (implying that 0.9 gms of precipitation have on the average contained as much activity as 1 m^3 of surface air) might be used to form a rough picture of the average precipitation process at Kjeller. Since average precipitation clouds probably contain about 0.3—0.4 gms/m^3 of water droplets, it seems that a moderate degree of extra condensation is necessary before precipitation occurs. This is of course not surprising, since cloud water must be replenished in order to provide appreciable precipitation. It seems that there may in fact be a very high degree of correspondence

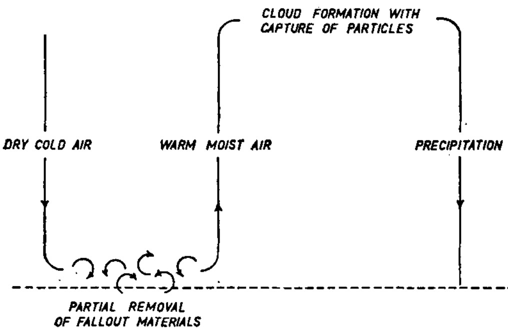

Fig. 5. Model showing connection between wet and dry deposition and surface air activity.

between the original activity of surface air/m^3 and the activity of condensed water/m^3 of clouds. It has for example been observed near Finse in the southern part of Norway at about 1,700 m above sea level, that the activity of hard rime during deposition was about the same as the activity of snow falling in clouds at the same height. This suggests that precipitation occurred as a result of droplet growth by condensation or sublimation followed by coalescence.

Although the amount of fallout materials in air which has come from near the surface may be overridingly important, extra amounts of materials could be mixed into the clouds from environmental air. This type of mixing is probably less important in the case of layer clouds than in the case of cumulus and cumulonimbus clouds.

For this reason fig. 6 showing the average volume activity of precipitation for different amounts of precipitation per day, might be explained in the following way. Observations

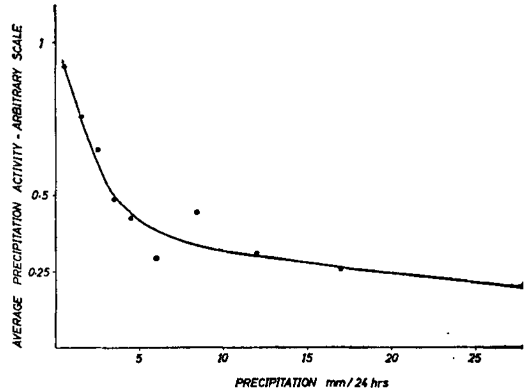

Fig. 6. Average precipitation activities for different daily amounts of precipitation.

covering days with small total amounts of precipitation are likely to be very much influenced by convectional precipitation, which although typically intense, tends to produce relatively small total amounts. However, the greater mixing with environmental air, and possibly greater coalescence in convection clouds, seem likely to produce precipitation which is more radioactive than orographic and cyclonic precipitation. On the other hand orographic and cyclonic precipitation tend to produce relatively large total amounts. Between these two extremes of small total amounts of convectional precipitation with relatively high volume activity and large total amounts of orographic and cyclonic precipitation with relatively low volume activity, occur different combinations of rain-

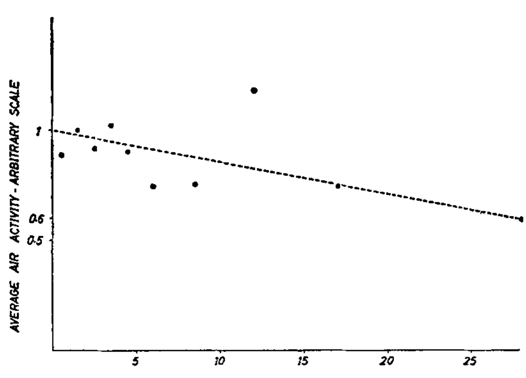

Fig. 7. Average air activities for different daily amounts of precipitation.

fall types and different degrees of mixing with environmental air.

Fig. 7 shows that air activity tends to be lowest on days with large total amounts of precipitation. This might be due to a large extent to differences in downward mixing rates near the surface, mixing being greatest when convectional clouds are formed. The rather haphazard grouping of points in the figure may point to significant variations in mixing rates between different days.

Figure 6 agrees very well with a corresponding figure given by STEWART ET AL. (1957), but does not show the steady increase reported by HINZPETER (1958), for precipitation amounts greater than 10 mm per day.

The values of air to precipitation activity ratio (0,2 · 10^{-6}—2.0 · 10^{-6} between Sept. 1956 and Sept. 1959) agree well with those reported by BLOK in Holland (1957), 0.4 · 10^{-6}—2.5 · 10^{-6} between Sept. 1955 and April 1957, but are lower than the value of 3 · 10^{-6} given by HINZPETER (1958) from measurements made in Germany in the period July—December 1957.

It might be suggested that Hinzpeter's measurements have been more influenced by convectional precipitation than corresponding measurements in England, Holland and Norway. This does not seem unlikely in view of the geographical and meteorological factors involved in precipitation processes.

6. General discussion of fallout deposition rates

Some of the deposition on days with obvious precipitation will have fallen without precipitation, but on the other hand some precipitation will have fallen and evaporated on apparently dry days. Consequently the measured dry to wet deposition ratio of about 1 : 6 deduced from table 6.1 may not be greatly in error for the open sampling vessels during this period.

To account for the total wet + dry deposition during the whole period an average depth of about 2,500 m of "surface" air must have been emptied each day. This probably corresponds to a depth of about 500 m of "average" tropospheric air, since air activity increases with height. This means that it would have been necessary to empty and refill the troposphere over Kjeller about once every 20 days in order to account for the measured deposition. Since deposition at Kjeller is not average on a worldwide scale, it might be reasonable to use figures for Sr-90 in soils to see how Kjeller compares with the rest of the Northern hemisphere. A rough average figure for most of the Northern hemisphere up to 1958 is about 10 mC/km², the value for Oslo being 28.6 (ALEXANDER, 1959). The 20 days tropospheric emptying time might then be multiplied by 3 to obtain a rough estimate of 60 days for the Northern hemisphere. This value can again be multiplied by 10 to obtain a rough estimate of 600 days for the average stratospheric emptying time over the Northern hemisphere, 10 being an approximate figure for the number of times "average" stratospheric air is more active than "average" tropospheric air (ENVIRONMENTAL CONTAMINATION FROM WEAPONS TESTS, 1958).

Assuming insertion heights of about 20 km, the average rate of downward transport in the stratosphere seems to have been about 15 m per day. It is very interesting that this is the same figure obtained by Storebö for the probable average rate of air subsidence in the Northern polar stratosphere (STOREBÖ, 1959).

7. Conclusions

Some fallout materials from test explosions have been deposited more quickly than expected, probably because of gravitational settling of relatively large particles.

Measurements show that there might be a rather acute deposition period beginning about

Table 5. Summary of wet and dry deposition data

1117 daily observations — 655 dry days + 462 wet days			
Total deposition on dry days	0.51	curie per km²	
» » » wet »	3.17	» » »	
Average air activity on dry days	1.43	micromicrocurie per m³	
» » » » wet »	1.15	» » »	
» » » for all »	1.31	» » »	

2—3 months after a large-number of high-yield air bursts, and lasting probably a few months.

It looks as though it might be possible to forecast both wet and dry deposition rates, given sufficient measurements of surface air activity over land and ocean regions.

Dry deposition might be greatly influenced by a diurnal variation of removal rates.

Acknowledgements

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