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RUN-OFF FROM ROOFS

Jørn Roed

Abstract. In order to find the run-off from roof material a roof has been constructed with two different slopes (30^o and 45^o).

Beryllium-7 and caesium-137 has been used as tracers.

Considering new roof material the pollution removed by runoff processes has been shown to be very different for various roof materials.

The pollution is much more easily removed from silicon-treated material than from porous red-tile roof material. Caesium is removed more easily than beryllium.

The content of caesium in old roof materials is greater in red-tile than in other less-porous roof materials.

(Continued on next page)

INIS Descruptors: BERYLLIUM 7; BUILDING MATERIALS; BUILDINGS; CESIUM 137; DECONTMINATION; PRECIPITATION SCAVENGING; RAIN WATER; REVIEWS; RUN-OFF; TRACER TECHNIQUES; WEATHERING.

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However, the measured removal from new material does not correspond to the amount accumulated in the old. This could be explained by weathering and by saturation effects. This last effect is probably the more important.

The measurements on old material indicates a removal of 44-86% of the caesium pollution by run-off, whereas the measurement on new showed a removal of only 31-50%.

It has been demonstrated that the pollution concentration in the run-off water could be very different from that in rain-water.

The work was part of the EEC Radiation Protection Programme and done under a subcontract with Association Euratom-C.E.A. No. SC-014-BIO-F-423-DK(SD) under contract No. BIO-F-423-81-F.

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CONTENTS

1. INTRODUCTION

Run-off is that excess of deposited rainwater that is not retained on the area receiving the rainfall. This phenomenon has been extensively studied in the context of hydrology (Chow 1964).

As run-off water can carry away a part of the deposited radioactive material from roofs and roads through sewers it clearly could have an important impact on consequence calculation, in that material deposited in urban areas may not all be retained there, thereby reducing the dose to the urban population.

2. RUN-OFF IN URBAN AREAS

The total run-off can consist of surface run-off and infiltration, i.e. the flow of water through the soil surface.

Infiltration is dependent upon the type of surface. Artificial materials comprising most surfaces in urban areas, are sufficiently impervious to prevent infiltration.

For these surfaces the following equation will be valid

$$Q=P-I_a \qquad 2.1.$$

where Q is the actual direct run-off in mm, P the total rainfall in mm, and I_a the initial accumulated rainfall in mm until run-off occurs.

Ritchie et al. (1976) assumed for an urban area that run-off from artificial surfaces would be virtually 100% for all rainfall above an initially accumulated 3 mm. If there has been rain within the previous hour the run-off will occur sooner. In order to allow for patches of grass, etc. in the urban areas the amount of run-off was reduced to between 70 and 95%.

In their model Ritchie et al. made the assumption that the concentration of radioactive material in the run-off water is equal to the concentration in the rainwater.

The relation between rainfall and maximum run-off has been represented by many empirical and semiempirical formulas (Chow, 1962). The so-called rational formula is one of the most commonly used formulas for estimating maximum rate of surface run-off:

$$Q=C\cdot p\cdot A \qquad 2.2.$$

Where C is the run-off coefficient, p the rainfall intensity, and A the area considered. The rational method assumes that the rainfall intensity is uniform over the area during the duration of the storm.

The reasoning of the method states that after some time the run-off rate pr. unit area reaches a maximum

$$\frac{Q}{A} = C\cdot p \qquad 2.3$$

C then represents the part of the rainfall that runs off.

From the Handbook of Principles of Hydrology the following table gives run-off coeffecients for urban areas:

Description of Area	Runoff Coefficient
Flat, residential, with about 30% of area impervious	0.40
Moderately steep, residential, with about 50% of area impervious	0.65
Moderately steep, built up, with about 70% of area impervious	0.80

Table. 2.1. From Horner and Flynt (1936). Relation between rainfall and run-off frc urban areas.

In the Handbook of Applied Hydrology C values are given as reported by a joint committee of the American Society of Civil Engineers and the Water Pollution Control Federations. These values are applicable for heavy storms that occur only once every 5 to 10 years.

Values of Runoff Coefficient *C*

Type of drainage area	*Runoff coefficient, C*
Lawns:	
Sandy soil, flat, 2%	0.05–0.10
Sandy soil, average, 2–7%	0.10–0.15
Sandy soil; steep, 7%	0.15–0.20
Heavy soil, flat, 2%	0.13–0.17
Heavy soil, average, 2–7%	0.18–0.22
Heavy soil, steep, 7%	0.25–0.35
Business:	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential:	
Single-family areas	0.30–0.50
Multi units, detached	0.40–0.60
Multi units, attached	0.60–0.75
Suburban	0.25–0.40
Apartment dwelling areas	0.50–0.70
Industrial:	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30
Streets:	
Asphaltic	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.95

Table 2.2. Some values of the run-off coefficient C reported by a joint commitee of the American Society of Civil Engineers and the Water Pollution Control Federation, (ASCE and WPCF, 1960).

3. RUN-OFF ON ROOF MATERIAL

Run-off is normally defined as the amount of water that is transported away from an area exposed to precipitation.

Evaporation is not included in the run-off mechanism.

To find the run-off from a roof, a construction has been built that allows measurement of the amount of water per m^2 horizontal projected area that runs off.

This is done by collecting the run-off water from the roof construction in a vessel as shown in Fig. 3.

The amount of rainwater per m^2 projected area is found by direct sampling of rainwater in a vessel.

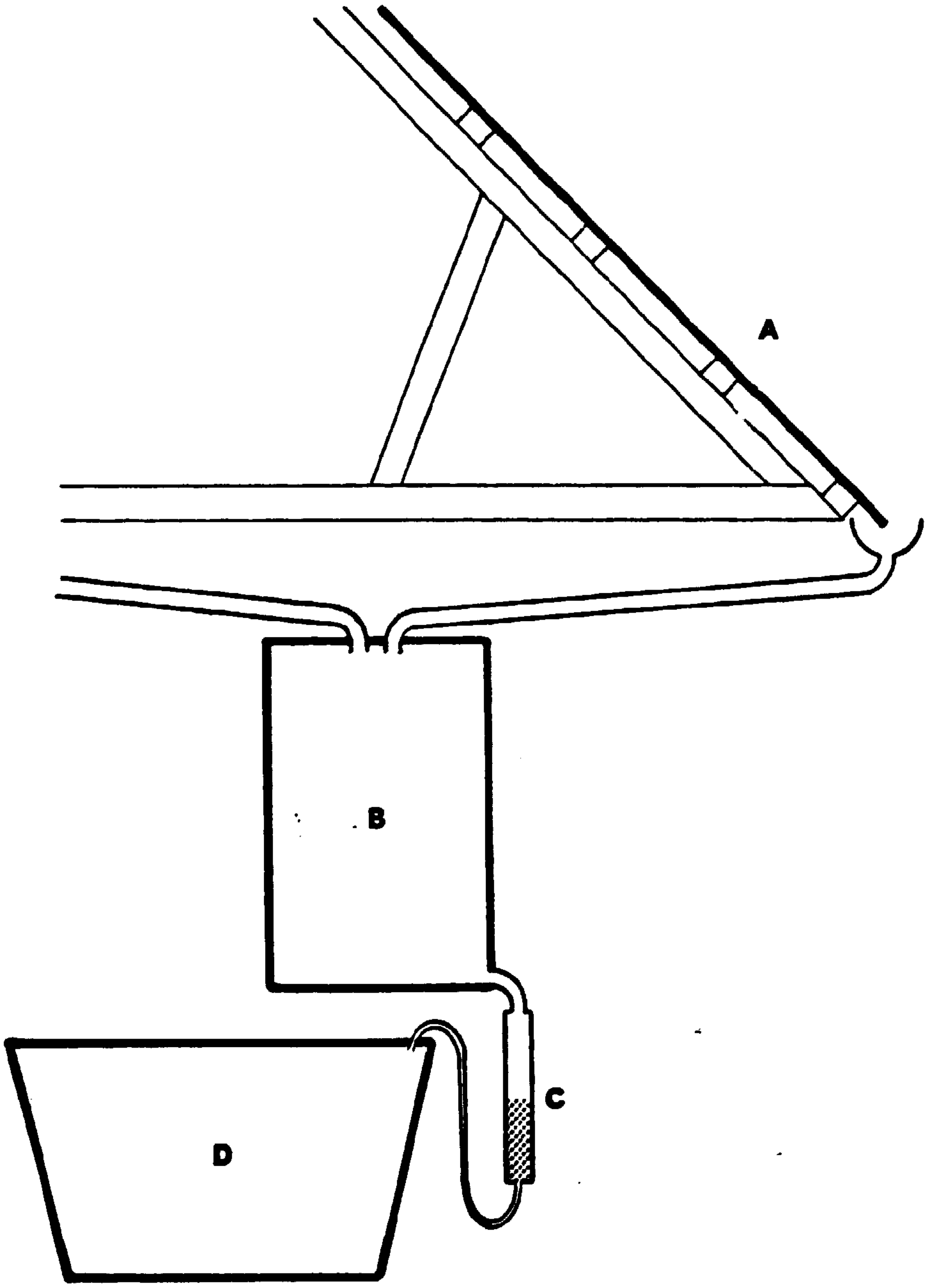
Some authors (Ritchie 1976) assume that the concentration of pollution in the run-off water is equal to the concentration in rainwater, so that the amount of pollution removed by the run-off processes can be found from knowledge of the amount of run-off water and the concentration of the pollution in rainwater.

In order to investigate the validity of this hypothesis and determine the amount of material removed by run-off processes we have measured the concentration in rainwater as well as in run-off water.

To do this the run-off water is passed through an ion-exchanger in which the pollution is trapped.

The amount of beryllium-7 and caesium-137 is then measured by gamma-ray spectrometry by means of a Ge(Li)-detector.

Fig. 3



A: roof material

B: buffer container

C: ion exchanger

D: container

In the same way the collected rainwater is passed through an ion-exchanger to find its content of ^{7}Be and ^{137}Cs.

The roof construction used for the measurements has two different slopes and is divided in 6 sections, 2 with a 30^{o} slope and 4 with 45^{o} slope.

3.1. Measurements

The roof was covered with new roof material in the following way:

section 1	cement tile	45^{o} slope
section 2	red tile	45^{o} slope
section 3	corrugated eternite	45^{o} slope
section 4	silicon-treated eternite	45^{o} slope
section 5	corrugated eternite	30^{o} slope
section 6	silicon-treated eternite	30^{o} slope

Just after the roof material was mounted the total construction was covered with tarpaulins; the first measurement (Table 3.1.1.) was made when the construction was covered.

In this measurement the run-off water can easily pass from one section to another because of the tarpaulins so that the results should be treated as one for each slope.

From the measurement of run-off from tarpaulins we found that nearly all the rainwater runs off. However a substantial part of the contamination is retained by tarpaulins resulting in a lower concentration in the run-off water than in the rain water.

We found a strong dependence on the slope of the tarpaulin, so that about 50% of the pollution of caesium-137 and beryllium-7 are removed by run-off when the slope is 45^{o}, but only about 10% is removed with a slope of 30%.

Table 3.1.1.

Run-off from tarpaulin on roof

March 1984

Section No.	Concentration in run-off water $Bq m^{-3}$	Concentration in run-off water in % of concentration in rainwater	Run-off water m^3 per horizontally projected m^2	% of water that runs off	% material removed with run-off
	^{7}Be				
1	2174.20	68.8	0.0128	78.0	54
2	2030.87	64.2	0.0170	103.7	67
3	1015.33	32.1	0.0226	137.8	44
4	2366.37	74.8	0.0090	54.9	41
5	314.94	10.0	0.0178	108.5	11
6	296.15	9.4	0.0152	92.7	9
	^{137}Cs				
1	1.715	60.0	0.0128	78.0	47
2	1.582	55.3	0.0170	103.7	57
3	0.666	23.3	0.0226	137.8	32
4	2.287	80.0	0.0090	54.9	44
5	0.384	13.4	0.0178	108.5	15
6	0.319	11.2	0.0152	92.7	10

Concentration of ^{7}Be in rainwater: 3162 $Bq\ m^{-3}$
Concentration of ^{137}Cs in rainwater: 2.86 $Bq\ m^{-3}$
Amount of rainwater: 0.0164 $m^3\ m^{-2}$

The first measurement of real roof material was made in April 1984; the results are shown in Table 3.1.2.

The main result is again that the concentration in run-off water is very much lower than the concentrations in rainwater, and that silicon-treated material showed the highest values for removed material. For beryllium the removal was 20% for a slope of 45^{o} and 10% for the 30^{o} slope.

For the more porous material the removal of the pollution was smaller. From cement tile about 7% was removed and from red tiles and eternite the removal was only a few percent.

The measurements made in May 1984 (see Table 3.1.3.) showed the same overall picture as those made in April.

From silicon-treated eternite the removal was 26% for beryllium and 50% for caesium independent of the slope.

From cement tile the removal was 6% for beryllium and 9% for caesium.

From red tile and eternite the removal of beryllium was 1-2% and of caesium 7-9%.

Beside the measurements on new roof material the amount of caesium trapped on old roof material was also measured.

The accumulated fallout of caesium in the trapped material was compared with caesium in the rain water during the period of exposure.

All the figures are decay corrected to the time of the sampling.

Table 3.1.2.

Run-off from roof material

April 1984

Section No.	Concentration in run-off water		Run-off water m^3 per horizontally projected m^2	% of water that runs off	% material removed with run-off
	Bqm^{-3}	in % of concentration in rainwater			
	^{7}Be				
1	219.94	7.24	0.0112	91.1	6.6
2	132.95	4.37	0.0031	25.2	1.1
3	76.56	2.52	0.0111	90.2	2.3
4	684.18	22.51	0.0113	91.9	20.7
5	60.16	1.98	0.0096	78.0	1.5
6	441.49	14.52	0.0085	69.1	10.0
	^{137}Cs				
1	1.933	8.06	0.0112	91.1	7.3
2	3.366	14.03	0.0031	25.2	3.5
3	0.949	3.96	0.0111	90.2	3.6
4	8.910	37.14	0.0113	91.9	34.1
5	0.618	2.58	0.0096	78.0	2.0
6	11.089	46.22	0.0085	69.1	31.9

Concentration of ^{7}Be in rainwater: 3039.52 $Bq\ m^{-3}$
Concentration of ^{137}Cs in rainwater: 23.993 $Bq\ m^{-3}$
Amount of rainwater: 0.0123 $m^3\ m^{-2}$

Section No. 1: Cement tile slope 45°
2: Tile slope 45°
3: Corrugated eternite slope 45°
4: Silicon-treated eternite slope 45°
5: Corrugated eternite slope 30°
6: Silicon-treated eternite slope 30°

Table 3.1.3.

Run-off on roof material

May 1984

Section No.	Concentration in run-off water $Bq m^{-3}$	in % of concentration in rainwater	Run-off water m^3 per horizontally projected m^2	% of water that runs off	% material removed with run-off
	^{7}Be				
1	282.85	13.97	0.0172	42.6	6.0
2	162.39	8.02	0.0082	20.3	1.6
3	121.71	6.01	0.0133	32.9	2.0
4	764.30	37.76	0.0285	70.5	26.6
5	83.20	4.11	0.0212	52.5	2.2
6	894.35	44.18	0.0240	59.4	26.2
	^{137}Cs				
1	0.460	21.77	0.0172	42.6	9.3
2	0.779	36.87	0.0082	20.3	7.4
3	0.575	27.21	0.0133	32.9	9.0
4	1.480	70.04	0.0285	70.5	49.3
5	0.414	19.59	0.0212	52.5	10.0
6	1.775	84.00	0.0240	59.4	49.8

Concentration of ^{7}Be in rainwater: 2024.19 $Bq\ m^{-3}$
Concentration of ^{137}Cs in rainwater: 2.113 $Bq\ m^{-3}$
Amount of rainwater: 0.0404 $m^3\ m^{-2}$

Section No. 1: Cement tile slope 45°
2: Tile slope 45°
3: Corrugated eternite slope 45°
4: Silicon-treated eternite slope 45°
5: Corrugated eternite slope 30°
6: Silicon-treated eternite slope 30°

From the figures given in Table 3.1.4. we find that the ^{137}Cs material removed by run-off is 44-86% for red-tiles and from 84-99% for other materials.

This discrepancy can be explained in at least three ways:

First, the weathering cannot be neglected because of its efficiency during the more than 20 years that some of the roof material has been exposed to this effect. Yet it must be noted that in the case of eternite, as shown in Table 3.1.4. the trapped material in percent of the corresponding accumulated fallout seems not to be strongly dependent on the time of exposure; if so, the percent should be higher for a shorter exposure.

This gives us the reason for believing that the weathering effect is not essential for explaining the discrepancy.

The second possible explanation is that the new material traps the pollution more efficiently than the old. This could be due to a saturation effect that appears after a certain time has passed. This effect could be different for each type of roof material.

The third possibility is that the new material is so different from the old that the two can't be compared. This could certainly be true for most of the material, but not for red-tile which has been fabricated approximately the same way for decades. It must be emphasized that red-tile is the material that shows the closest agreement between the measurement on the new and the old material.

Table 3.1.4.

Run-off from old roofs

Sample No.	Slope of the roof degree	Built year	Area of sample m^{-2}	^{137}Cs-deposition on roof Bq m^{-2}	Percent [x)] of ^{137}Cs that runs off from roofs
RED TAIL					
38	45	1900	0,097	383 ± 23	78
15	20	1900	0.121	346 ± 29	85
34	45	1914	0,051	1037 ± 25	44
36	50	1914	0,108	217 ± 13	86
14	45	1952	0,083	430 ± 46	76
23	40	1952	0,096	267 ± 21	85
1	45	1956	0,048	726 ± 58	57
GLAZED TAIL					
30	45	1918	0,097	219 ± 17	87
7	45	before 1950	0,070	179 ± 21	90
CEMENT TAIL					
31	45	1910	0,166	212 ± 21	84
32	45	1935	0,116	182 ± 38	90
11	45	1943	0,106	131 ± 10	93
SLATE					
8	45	1906	0,251	112 ± 14	94
35	45	1918	0,277	161 ± 6	91
CORRUGATED ETERNITE					
13	15	1954	0,120	99 ± 7	95
5	5	before 1950	0,119	281 ± 11	87
6	45	before 1950	0,104	112 ± 9	94
2	45	1960	0,101	47 ± 7	97
3	45	1971	0,099	10 ± 7	97
ETERNITE "SLATE"					
33	20	1947	0,189	16 ± 2	99

x) calculated from the amount of ^{137}Cs on the roof and the corresponding content of ^{137}Cs in rainwater.

4. CONCLUSION

For new roof material the degree to which pollution is removed together with run-off is very different for various types of material.

The pollution is much more easily removed from silicon-treated material than from porous roof material that is in the form of red-tile.

Caesium is removed more easily than beryllium.

The content of caesium in old roof materials is greater in red-tile than in other less-porous roof materials.

However, the measured removal on new material does not correspond to the amount accumulated in the old material. This could be explained by a weathering effect, or by a saturation effect. The last effect is probably the most important in explaining the discrepancy.

The measurement on old material indicates a removal of 44-86% of the caesium pollution by run-off, whereas the measurement on the new material showed a removal of only 31-50%.

Further, it has been demonstrated that the pollution concentration in the run-off water could be very different from the concentration in rainwater.

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