DEVELOPMENT OF A STRATEGY FOR DECONTAMINATION OF AN URBAN AREA

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Abstract

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The Chernobyl accident in 1986 lead to high level contamination in urban areas in different parts of Europe and showed the importance of preparedness in the optimisation of any mitigatory interference. To meet this demand, a method for development of a decontamination strategy for urban areas has been developed based on measurements of radionuclide distribution in the urban environment after the Chernobyl accident, calculations of dose and experimentally obtained data on effectiveness and cost of practicable clean-up procedures. The approach highlights where decontamination would be of greatest benefit in terms of dose reduction and cost.

1. INTRODUCTION

The Chernobyl accident showed that releases from nuclear power plants may give rise to high levels of contamination, also in rather remote city areas, subject to the weather conditions during the passage of the cloud carrying the radioactive material. The single most important radionuclide concerning the long-term external exposure of urban populations was found to be ^{137}Cs. The measurements made after the Chernobyl accident, however, also provided a data base, which could be used to deduce guidelines concerning countermeasures to reduce the collective doses received by urban populations due to such releases [1-5)]. In the following, a stepwise approach for the development of such a contingency strategy is given.

2. DEVEOPMENT OF A STRATEGY

2.1. Identification of initial source term

The first step in the development of such a plan must be the identification of the relative initial levels of contamination on different surfaces in the urban environment. Here it is important to distinguish between the various possible modes of deposition. If deposition occurs in precipitation, the resulting distribution pattern will be very different from that caused by dry deposition. Again, there can be variations within a particular mode of deposition. For instance, a light shower giving very little surface run-off will lead to a different deposition pattern from that produced by prolonged heavy rain. Concerning dry deposition, Roed [6)] found that the deposition velocities to urban surfaces were very small compared to those previously recorded for rural areas.

Estimates by Roed et al. [7)] based on measurements of Chernobyl fallout in areas which received solely dry deposition and in areas in which deposition took place with heavy rain, lead to the typical relationships shown in Table I between radiocaesium concentration levels per unit area of different types of outdoor surface. These findings are consistent with measurements made in various parts of Europe [8-10)]. If such information is used in the strategy development, it will only be necessary to actually measure the deposition to, for instance, a grassed area.

TABLE I. RELATIVE SOURCE STRENGTHS FOR VARIOUS SURFACES SHORTLY AFTER DEPOSITION OF CHERNOBYL FALLOUT CAESIUM, RELATIVE TO A CUT LAWN, WHERE THERE IS NO PENETRATION IN THE SOIL.

Surface type:	**Dry deposition**	**Wet deposition**
Gardens and park areas	1.00	0.80
Roofs of buildings	1.00	0.40
Walls of buildings	0.10	0.01
Streets, pavements and walkways	0.40	0.50
Trees in leaf	3.00	0.10

TABLE II. EXTERNAL LOCATION AVERAGED DOSES (MGY) FROM DIFFERENT CONTAMINATED OUTDOOR SURFACES ACCUMULATED OVER 1 AND 10 YEARS FOLLOWING A WET OR DRY DEPOSITION ON 26. APRIL OF 1 MBQ/M^2 ^{137}CS IN FOUR DIFFERENT ENVIRONMENTS DESCRIBED BY MECKBACH ET AL. (1988). CONTAMINATION ON INDOOR SURFACES IS NOT INCLUDED HERE.

Wet deposition 1 year	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det. house	0.72	0.034	—	0.098	8.20
2-storey semidet. house	0.39	0.010	—	0.026	3.13
2-storey terrace houses	0.15	0.008	0.320	0.022	1.89
5-storey block of flats	0.006	0.008	0.434	0.011	1.34
Wet deposition 10 years	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det. house	2.58	0.250	—	0.133	55.6
2-storey semidet. house	1.39	0.076	—	0.036	22.3
2-storey terrace-houses	0.54	0.061	0.822	0.031	13.1
5-storey block of flats	0.022	0.057	1.119	0.015	9.55
Dry deposition 1 year	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det. house	1.79	0.34	—	2.93	9.01
2-storey semidet. house	1.16	0.13	—	0.79	3.53
2-storey terrace-houses	0.37	0.08	0.26	0.68	2.04
5-storey block of flats	0.015	0.07	0.37	0.34	1.45
Dry deposition 10 years	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det. house	6.41	2.48	—	3.98	68.7
2-storey semidet. house	3.44	0.76	—	1.08	27.4
2-storey terrace-houses	1.34	0.61	0.75	0.93	14.9
5-storey block of flats	0.054	0.57	1.11	0.46	10.9

In some cases, where deposition occurs in the absence of precipitation, the doses from indoor deposited contaminant aerosol may be significant. The indoor contamination level will especially be high, if the rate coefficient of ventilation (the fraction termed λ_r of air exchanged per unit time), the rate coefficient to deposition (the fraction termed λ_d of aerosols in the building deposited per unit time) and the filtering factor f (the fraction of aerosols in air entering the building which is not retained in cracks and fissures of the building structure) are all high.

2.2. Time-integrated dose calculation

Having defined the initial source strength, the next step in the strategy would be to calculate the relative dose-rate at different locations, indoor and outdoor, due to a deposition on the various urban surfaces (e.g. roofs, walls, paved areas, grass, trees, bushes). As these dose-rate contributions change with time it is imperative to gain sufficiently detailed knowledge on how the deposited radioactive matter will migrate with time in an urban complex.

From the large amount of data from field measurements conducted after the Chernobyl accident of contamination levels on urban surfaces a computer model, URGENT, has been developed [11-12)]. This model calculates estimates of the dynamics of the radiocaesium migration processes which typically occur in a contaminated urban environment. The resulting gamma doses in a limited number of different urban complexes can be calculated from a library of dose conversion factors based on the calculations of Meckbach [13)].

As an example of this part of the strategy, the accumulated doses over 1 and 10 years from a 1 MBq/m^2 ^{137}Cs contamination of external surfaces in different urban environments have been calculated with the URGENT model. The results are given in Table II. In the calculations, the relative deposition on the different surfaces was assumed to be as given in Table I. It was further assumed that the average person living in one of the four environments modelled spends 85% of the time at indoor locations, equally distributed between the different residential floors, 10% of the time in the garden and 5% on the streets and pavements. The Table indicates the relative importance o the various contaminated urban surfaces as contributors to dose. It must however be stressed that such calculations are only valid for assessment of the average dose in the area. More detailed calculations are required if the purpose is to investigate the dose to people living on a particular floor of the building.

So far we have not included the contributions to dose from indoor deposition. With the terms given in Section 1 of this paper, the relationship between the average deposited contaminant concentration on indoor surfaces (D_i) and the deposited contaminant concentration on a smooth, cut lawn (D_o) immediately following deposition can be calculated from:

$$D_i / D_o = (V_d / V_{dg})\, f\, \lambda_r / (\lambda_r + \lambda_d),$$

where V_d is the average local indoor deposition velocity and V_{dg} is the average deposition velocity on a grassed outdoor surface [12)]. With the parameter values recorded by Roed and Cannell [14)] in a series of measurements of Chernobyl ^{137}Cs deposition in furnished Danish houses, the figures given in Table III were calculated for the first year doses received from an indoor ^{137}Cs contamination corresponding to an outdoor level of 1 MBq/m^2 on a smooth cut lawn.

2.3. Evaluation of effectiveness and costs of feasible countermeasures

The third and final step in the strategy is to consider practicable methods for removing the contamination and to find out which procedures are best suited for the specific scenario in terms of cost and benefit.

Table IV shows estimates of achievable dose reduction factors and costs of dose reduction (including transportation and final disposal) [15-17)]. In defining the appropriate specific surface. Table IV has been derived from a large number of decontamination experiments, both in situ and in the laboratory.

Combining Tables II and IV, values of cost and benefit of carrying out the procedures can be estimated. The result is presented in Table V. Here the total dose reduction achieved by cleaning each type of surfaces is given together with the individual cost.

The Table shows that following a dry deposition, street cleaning, removal of trees and shrubs and, especially, digging the garden are in practically all environments effective and inexpensive means of achieving very significant dose reductions and would therefore rank high in a list of priorities. Although the procedures for roofs and walls are shown not to be cost-effective on average, for instance roofs may in some cases be significant dose contributors to people living on the top floor of a building, and walls in certain city areas may also contribute significantly to dose.

TABLE III. ESTIMATED RECEIVED DOSES THE FIRST YEAR FOLLOWING CONTAMINATION (MGY), EQUIVALENT TO A TARGET POSITION 1M ABOVE GROUND IN A ROOM WITH HEIGHT 3 M AND IN THE CENTRE OF A 4M BY 4M GROUND AREA ASSUMING THE ABOVE MEAN INDOOR CONCENTRATIONS AND THAT 50 % OF THE TOTAL AMOUNT OF CAESIUM IS DEPOSITED ON THE FLOOR, WHILE THE REST IS EQUALLY DISTRIBUTED ON THE WALLS AND CEILING. RELATES TO A ^{137}CS CONTAMINATION ON A LAWN OF 1 MBQ/M^2.

f = 0.4	**$8_d = 0.36\ h^{-1}$**	**$8_d = 0.60\ h^{-1}$**	**$8_d = 1\ h^{-1}$**
$8_r = 0.3\ h^{-1}$	0.19	0.23	0.27
$8_r = 0.4\ h^{-1}$	0.22	0.27	0.33
$8_r = 0.6\ h^{-1}$	0.26	0.35	0.4
f = 0.6	**$8_d = 0.36\ h^{-1}$**	**$8_d = 0.60\ h^{-1}$**	**$8_d = 1\ h^{-1}$**
$8_r = 0.3\ h^{-1}$	0.29	0.35	0.41
$8_r = 0.4\ h^{-1}$	0.32	0.40	0.51
$8_r = 0.6\ h^{-1}$	0.39	0.53	0.65
f = 1.0	**$8_d = 0.36\ h^{-1}$**	**$8_d = 0.60\ h^{-1}$**	**$8_d = 1\ h^{-1}$**
$8_r = 0.3\ h^{-1}$	0.48	0.59	0.68
$8_r = 0.4\ h^{-1}$	0.54	0.68	0.84
$8_r = 0.6\ h^{-1}$	0.66	0.88	1.08

TABLE IV. ACHIEVABLE URBAN DOSE REDUCTION FACTORS AND COSTS OF DOSE REDUCTION IN AN URBAN AREA CONTAMINATED BY WET/DRY DEPOSITION. THE SUGGESTED METHODS ARE: FOR GARDEN AREAS : DIGGING. FOR STREETS: VACUUM SWEEPING. FOR TREES: CUTTING BACK OR REMOVAL. FOR ROOFS: HOSING OR SANDBLASTING. FOR WALLS: SANDBLASTING.

Surface type	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
DRF after dry deposition	1.9	1.9	2.0	50	10
DRF after wet deposition	1.5	1.2	1.7	10	8
Costs (ECUAm^{-2})	2	0.8	0.01	7	0.5

TABLE V. ESTIMATES OF COST AND BENEFIT OF DIFFERENT CLEAN-UP PROCEDURES FOR WET OR DRY CONTAMINATED URBAN ENVIRONMENTS. PERCENTAGE 1ST YEAR DOSE REDUCTION BY CLEANING THE SURFACES AND COSTS PER PERSON PER % DOSE REDUCTION (IN ECU).

Single-storey detached house	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep.)	2.8	0.1	—	1.7	78.3
ECU/person per % dosered.	22.50	218.00	—	237.36	1.01
% dose reduction (dry dep.)	5.2	4.1	—	23.7	42.3
ECU/person per % dosered.	16.21	7.43	—	11.97	1.87
Two-storey semidet. house	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep.)	3.8	0.1	—	1.2	76.2
ECU/person per % dosered.	16.57	458.08	—	160.87	0.59
% dose reduction (dry dep.)	8.8	1.0	—	24.1	45.4
ECU/person per % dosered.	10.71	45.31	—	7.12	1.05
2-storey terrace house row	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep.)	2.2	0.1	5.6	1.5	68.1
ECU/person per % dosered.	29.05	260.44	0.06	79.73	0.73
% dose reduction (dry dep.)	6.0	1.1	4.2	23.9	42.7
ECU/person per % dosered.	29.05	31.88	0.02	3.71	1.09
5 storey block of flats	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep.)	0.2	0.1	10.2	1.0	64.2
ECU/person per % dosered.	179.47	145.27	0.02	6.28	0.16
% dose reduction (dry dep.)	0.4	1.6	7.8	22.3	43.1
ECU/person per % dosered.	55.92	47.33	0.01	0.22	0.24

In the case of wet deposition, the garden areas would be given first priority since a considerable dose reduction (78%) may be achieved at a relatively low cost. Street cleaning would also be useful and very inexpensive.

If the actual conditions for indoor deposition, in terms of the previously mentioned parameters, are known the corresponding dose contribution can be deduced from Table III, and this can form the basis for an evaluation of the relative importance of indoor decontamination. A comparison of Tables II and III shows that the dose contribution from indoor surfaces can be significant in a dry deposition scenario.

3. CONCLUSION

A contingency plan for clean-up of contaminated urban areas has been outlined. From measurements following the Chernobyl accident, the typical distribution with time of radioactive matter in an urban complex has been identified. The resulting time-integrated doses have been found by computer modelling employing the large amount of data obtained from in situ Chernobyl fallout measurements. On this background, the effectiveness of practicable countermeasures in terms of dose reduction and costs has been evaluated.

The analyses of wet contaminated urban scenarios showed that decontamination of gardens should be given first priority, since a reduction of the total external dose by as much as 78% can be achieved by a special garden digging procedure (skim-and-burial digging). Street cleaning should be given second priority, as it can be performed very inexpensively. In dry deposition scenarios, also removal of the trees seems cost-effective. On average, the effect of decontamination of walls and roofs was found to be small, and clean-up of such surfaces would be given a low priority.

Such calculations, together with for instance the recommendations of the ICRP could form a set of guidelines on which procedures to follow subsequent to an accidental release.

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