MODELLING EXTERNAL RADIATION DOSES IN CONTAMINATED URBAN AREAS: IMPLICATIONS FOR DEVELOPMENT OF DECONTAMINATION STRATEGIES

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ABSTRACT

The Chernobyl accident in 1986 highlighted the need for contingency strategies for identification and mitigation of the potential long-term consequences of a radioactively contaminated (essentially with ^{137}Cs) urban environment.
To satisfy this need, the PC model URGENT has been developed. The model predicts, as a function of time, the dose rate in urban environments of various population densities. Input parameters for the model, together with associated uncertainties, were derived mostly from in situ measurements following the Chernobyl accident.

The model shows that in the case of dry deposited fallout, indoor surfaces can make a significant contribution to the total radiation dose. This is addressed in terms of 'location factors' which describe potential fractional dose inside the buildings.

In principle, URGENT can be used to describe any decontamination procedure and assess its effectiveness at any time after deposition. Worked examples of how the calculations can be exploited in the development of decontamination strategies are given.

INTRODUCTION

The PC model URGENT for calculation of the time-dependence over longer periods of the dose-rate contributions from different ^{137}Cs contaminated surfaces in the urban environment is essentially based on a set of coupled first order differential equations. However, the time-dependence can not be adequately described by this system for all radiocaesium migration processes. For instance, the weathering processes for roofs, roads, pavements and walls have been modelled by two component functions, as it was clear from the in situ measurement data recorded after the Chernobyl accident, that different fractions of the radiocaesium initially deposited to these surfaces were weathered off with different half-lives (1).

Where possible, the dynamic model has been based on measured data from investigations reported by other workers as well as measurements made by the Contamination Physics Group at Risø. The calculations of the resulting gamma dose rates are currently made using the dose conversion factors presented by Meckbach et al. (2).

The structure of the model, where the various compartments represent different fractions of the deposited radiocaesium on the surfaces in different states (loosely held, fixed, penetrated, etc.) allows a simulation of practically any dose reduction countermeasure by removal of a part of the contents of one or several compartments.

RESULTS/DISCUSSION

In the following is given an example of an application of the model. Consider a scenario, where a dry deposition of ^{137}Cs has occurred in the early spring (when deciduous trees were in leaf) to a highly populated area in the city, consisting of two-storey row-houses, paved areas, roads, and also some green areas with a few trees.

The relative initial distribution pattern of radiocaesium on different surfaces can be assumed not to differ significantly from the typically recorded values for urban dry deposition (3). Based on a limited local Danish poll, the assumption has been made that the average person spends 85 % of the time indoors and 15 % of the time outdoors. The general validity of this assumption has been indicated by the results of a recent state-wide survey of the activity patterns of Californians (4). It is assumed that the time spent indoors is equally distributed between the two residential floors of the building. However, in detailed strategy formation, the dose rates to people on the individual floors of a multi-storey building should also be considered, as for instance the contamination on the roofs of these buildings may give a large contribution to the dose rate to people living on the top floor, but at the same time give a negligible contribution to the inhabitants of the ground level flats.

Using the above assumptions the URGENT model can be used to estimate the dose rates or accumulated doses to an average person in the considered type of environment at different times following contamination.

Through the years following the Chernobyl accident numerous clean-up procedures have been investigated (5), and the most promising of these were recently investigated in semi-large scale in the Novo Bobovitsi settlement in Russia. Although a strategy certainly may not include decontamination operations for all types of surface, it was found from the field investigations that for environments such as that under consideration, the most cost-effective means of decontamination of the individual surfaces were probably to use a specially developed roof-washer (5) for roofs, high pressure water treatment for walls, cutting of trees and bushes, sweeping of roads and a 'triple' manual digging procedure (5) for grassed areas and bare soil, whereby the top layer containing most of the contamination is buried under shielding layers of soil. These procedures have been simulated by the model.

Table 1 shows the calculated percentage dose reduction achievable by these methods if they are initiated 6 months or 10 years after the deposition took place. Figures are given for both the reduction of the total accumulated life-time dose over 70 years by application of a method and for the reduction in dose-rate at the particular time when the method is applied. Also given is an estimate of the costs of the procedures.

Table 1. Costs and benefits of application of different clean-up methods in an urban row house environment. Percent reduction of accumulated doses over 70 years and of immediate dose rate reduction are given, assuming that clean-up is initiated 6 months or 10 years after deposition.

Surface:	Roofs	Walls	Roads	Trees	Soil
% 70-y dose red. (6 months after)	2.7	1.6	1.1	4.5	63.7
% dose rate red. (6 months after)	6.0	1.3	3.5	28.2	42.1
% 70-y dose red. (10 years after)	0.3	0.4	0.1	0.2	22.5
% dose rate red. (10 years after)	1.2	1.5	0.5	3.9	68.0
Costs (ECU/m^2)	2	1.7	0.1	7	0.5

From Table 1 it is clear that a cleaning of the areas of soil would give the greatest effect, both after 6 months and after 10 years. As the natural reduction of the dose rate from soil areas is rather limited compared to the effects of weathering on most of the other surfaces in the environment, the dose rate contribution from the soil will become relatively larger with time. As the cost of triple digging is relatively small, clean-up of grassed areas would be given first priority in a clean-up strategy for this scenario.

Even if 10 years go by before the garden is dug, it is still possible to reduce the total accumulated dose by almost one-fourth by digging the garden. However, it is clear that in urban centres with smaller garden areas, the other surfaces will be much more dominant. It is therefore important to tailor a strategy for use in a specific type of area. It should be mentioned that recent investigations in Russia have shown that the dose contribution from roofs after 9 years (and certainly earlier) may in some cases be much greater.

Calculations, in which URGENT output for dose rates inside and outside different buildings due to an outdoor deposition has been compared with a semi-empirical indoor deposition/dose model, have shown that in some dry deposition scenarios the indoor deposition may contribute greatly to the average dose-rate. The semi-empirical deposition model was based on the following equation:

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

where D_i is the average deposited contaminant concentration on indoor surfaces, D_o is the deposited contaminant concentration on a smooth, cut lawn, V_{dg} is the typical deposition velocity to a cut grassed surface, $V_d = \lambda_d v/A$ (where v is the indoor volume, A is the indoor surface area and λ_d is the rate coefficient of deposition, in other words: the fraction termed λ_d of aerosols in the building deposited per unit time). λ_r is the rate coefficient of ventilation (the fraction termed λ_r of air exchanged per unit time), and f is the filtering factor (the fraction of aerosols in air entering the building which is not retained in cracks and fissures of the building structure). Parameters for ^{137}Cs, which are believed to be realistic estimates, were found from practical investigations (3,6): $V_{dg} = 4.3\ 10^{-4}$ m/s, $\lambda_d = 0.8\ h^{-1}$, $\lambda_r = 0.4\ h^{-1}$, f = 1.0.

It was further assumed that the average indoor contamination level decreases to 70 % in 10 years. The effective dose rates were calculated at 1m above the floor of a room with a ground area of 4m by 4m and a height of 3m. The dose contributions from scattered radiation and deposition on indoor surfaces of neighbouring rooms were not included in the calculations, which were made for three different types of environment, where the essential difference is the shielding provided from outdoor contamination. The results in Table 2 are presented as location factors (defined as the ratio of the effective dose rate received indoors to that received outdoors following a uniform deposit of radiopollutants).

Table 2. Calculated location factors 10 years after a dry deposition of ^{137}Cs to different housing areas, assuming that no indoor deposition occurs and assuming that an indoor deposition does occur.

Location factor (t=10 years)	Without indoor deposition	With indoor deposition
Low shielding building	0.51	0.59
Medium shielding building	0.091	0.14
High shielding building	0.019	0.083

As can be seen from Table 2, the influence of indoor deposition on the location factor in dry deposition scenarios can be great. Indeed, in areas of buildings with a good shielding effect, this contribution may dominate. Similar calculations of location factors at other times after deposition have shown that the relationship between ^{137}Cs location factors with and without indoor deposition does not appear to change significantly with time.

CONCLUSIONS

The role of computer modelling in development of decontamination strategies has been demonstrated by an example of dry deposition to a row house area. It was found that the garden areas contributed most to the dose to people living in this type of area. Even after 10 years it is still possible to reduce the total accumulated dose significantly. A comparison between the URGENT model results and a semi-empirical indoor deposition/dose model has indicated that indoor deposition may in some cases contribute greatly to the average dose.

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