KfK 3421
November 1982

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ISSN 0303-4003

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Abstract

In several recent analyses of reactor accident consequences, it is assumed that all atmospherically deposited radionuclides remain in place initially and then undergo a relatively slow attenuation. As most early radiation fatalities are currently predicted to result from external exposure due to rain-deposited radionuclides, a more realistic representation of the relationship between rainfall levels and radionuclide deposition/removal processes may significantly reduce the number of predicted early fatalities. This report presents a brief overview of the possible development of a model for the attenuation of radionuclide concentrations in urban environments due to rainfall/runoff relationships. The following sequence of actions is suggested: (1) preliminary review, (2) exploratory modeling, (3) detailed literature review, (4) development of mathematical model, (5) development of computer model, and (6) model review including verification and sensitivity analysis. To facilitate the initiation of the indicated efforts, an introduction to the relevant literature is provided. Further, the following topics are also briefly discussed: (1) radionuclide transport and removal in the terrestrial environment, (2) need for a description of the chemical and physical forms of the radionuclides released in a reactor accident, and (3) potential importance of surface-water contamination.

Vorschlag für die Entwicklung eines Radionuklid-Washoff-Modells für die "Deutsche Risikostudie Kernkraftwerke"

Kurzfassung

Bei einigen neueren Untersuchungen zu Reaktorunfallfolgen wird angenommen, daß die aus der Abluftfahne abgelagerten Radionuklide am Ort der Ablagerung verbleiben und dort relativ langsam abnehmen. Da in den meisten Fällen Frühschäden (Tod durch akutes Strahlensyndrom) aus externer Bestrahlung durch Radionuklide resultieren, die bei Niederschlägen naß abgelagert werden, kann eine realistische Modellierung der Beziehungen zwischen Niederschlagsintensität und Radionuklidablagerung/Radionuklidtransport die Anzahl der vorhergesagten Frühschäden erheblich reduzieren.
Dieser Bericht gibt einen Vorschlag für die Entwicklung eines Modells zur Beschreibung der Abnahme der Radionuklidkonzentration in Stadtlandschaften auf der Basis von rainfall-runoff Beziehungen. Die folgenden Untersuchungsschritte werden vorgeschlagen: (1) vorläufiger Überblick, (2) exploratorisches Modell, (3) detaillierte Literaturstudie, (4) Entwicklung eines mathematischen Modells, (5) Entwicklung eines Rechenmodells und (6) Modellüberprüfung einschließlich Verifikation und Sensitivitätsanalyse. Um den Einstieg in die Untersuchungen zu unterstützen wird eine Einführung in die relevante Literatur gegeben. Weiterhin werden die folgenden Gesichtspunkte diskutiert: (1) Radionuklidtransport und -abnahme in der terrestrischen Umgebung, (2) Notwendigkeit der Beschreibung der chemischen und physikalischen Form der Radionuklide, die bei einem Unfall freigesetzt werden, und (3) mögliche Bedeutung der Kontamination von Oberflächenwasser.

Content

1. Introduction

In the analysis of reactor accidents, both the Reactor Safety Study (USN75) and the German Risk Study (Bu79) assume that all atmospherically deposited radionuclides remain in place initially and then undergo a relatively slow attenuation. As most early radiation fatalities result from external exposure due to rain-deposited radionuclides, a more realistic representation of the relationship between rainfall levels and radionuclide deposition/removal processes may significantly reduce the number of predicted early fatalities for reactor accidents. It is also possible that more realistic modeling of these processes may reduce predicted evacuation requirements and predicted latent health effects. The preceding is particulary true for urban areas, where much of the land surface is covered by various impervious toppings. The potential importance of rainfall/runoff relationships is indicated in preliminary work by Ritchie et al. (Ri76, Ri78).

This report presents a brief overview of how one might proceed in the development of a model for the attenuation of radionuclide concentrations in urban environments due to rainfall/runoff relationships. A general discussion of the steps that might be followed in the development of a model is given in Section 2. Then, radionuclide transport and removal in the terrestrial environment is discussed in Section 3, and the need for a description of the chemical and physical forms of the radionuclides released in a reactor accident is indicated in Section 4. Finally, the potential importance of surface-water contamination is briefly reviewed in Section 5.

2. Model Development

The possible steps in the development of a model to represent rainfall/runoff relationships in an urban environment for radionuclides released in a reactor accident are indicated in Figure 1. The first step is to conduct a preliminary review of the problem and such pertinent literature and data as may exist. To develop a more realistic representation for radionuclide concentrations resulting from wet deposition than is currently used in reactor safety studies, it is necessary to consider the following interrelated processes:

(1) Rate and distribution of rainfall,
(2) Rainout and washout of radionuclides from plume,
(3) Transport and deposition of radionuclides in terrestrial environment.

Ritchie et al. (Ri78, Ri76) provide a brief introduction to current ideas on modeling the rate and distribution of rainfall within storm systems. Several recent reviews (Br81; Ho78, pp. 18-19) provide an introduction to the literature on rainout/washout calculations. Decriptions of models currently in use to represent urban hydrology furnish background on modeling the transport and deposition of pollutants in the terrestrial environment (USA76; Met 71, Hub75; Mc75, Ai75). The outcome of the preliminary review should be a general overview of the problem and some idea as to what modeling approaches might be appropriate.

1st step:	Preliminary Review
2nd step:	Exploratory Modeling
3rd step:	Detailed Literature Review
4th step:	Development of Mathematical Model
5th step:	Development of Computer Model
6th step:	Model Review - Part 1: Verification - Part 2: Sensitivity Analysis

Figure 1: Overview of Model Development for Radionuclide Attenuation in Urban Environments.

The second step is to perform exploratory modeling to help develop a better understanding of potential modeling approaches and the potential effects which such approaches might have on predicted accident consequences. In particular, guidance should be sought as to whether or not improved modeling of rainfall/runoff relationships in urban environments would sufficiently reduce predicted accident consequences to justify further effort in this area. The particular exploratory modeling performed will be guided by the results of the preliminary review performed in the first step. One way such modeling might be performed is by "patching-in" simplified models for rainfall/runoff relations into already existing models for the calculation of reactor accident consequences. It is also possible that simple "back of the envelope" type calculations may provide the needed guidance.

If the decision is made that the incorporation of more detailed modeling of rainfall/runoff relations into reactor accident consequence modeling is desirable, then the third step in the process should be a carefull and detailed review of the relevant literature and data. The object here is to develop sufficient knowledge to be able to make decisions as to exactly what relationships are to be modeled and also as to what might be appropriate methods to use in modeling these relationships. This is a prelude to the fourth step in process, which is the actual development of the mathematical models to be used. In turn, once the mathematical models have been developed, the fifth step in the process can be performed, which is the development of a computer program to implement the mathematical models.

The sixth and final step in the process is to review the model and computer program which have been developed. Such a review might have two parts. The first part would be to verify the predictive capability of the model. The most meaningfull approach would be to obtain data on the deposition and movement of some material similar to what might be expected in a release from a reactor accident and then to determine the extent to which the model can duplicate the observed behavior of this material. The second part would be to perform a sensitivity analysis of the model. It is possible that the final model will be relatively complex and require various input parameters which will be imprecisely known. It is important to be able to assess how much uncertainty exists in model predictions and also which model parameters are most important in giving rise to this uncertainty. How such an analysis might proceed is described by Iman et al. (Im81a, Im81b).

3. Radionuclide Transport and Removal in the Terrestrial Environment

Now that an overview of the possible development of a model for radionuclide removal in urban environments has been presented, some additional thoughts are given with respect to the part of the modeling effort which treats the actual transport and removal of deposited radionuclides. This is the third of the three topics suggested for preliminary examination in the first step of model development. The other two topics - rate/distribution of rainfall and rainout/washout of radionuclides from plume - will not be discussed.

Radionuclide removal probably has the potential to be important only for impervious areas (i.e., streets, sidewalks, roofs,..); for previous areas (i.e., yards, gardens, fields,..), existing data for both radioactive fallout (e.g., Carl78, Men74, Ja69a, St60) and agricultural chemicals (e.g., Leo79, Wau78, Caro76) indicate that rainfall-induced removal from the area of initial deposition will probably be small. Such limited removal would seem to be consistent with the concepts of the Hewlett runoff model (War75, pp. 247-250). Thus, for radionuclides initially deposited on or subsequently washed to previous areas, the basic question involves not their removal but rather the attenuation of their radiation field due to downward movement in the soil column. Both the Reactor Safety Study and the German Risk Study use a relatively simple model for such attenuation which is derived from radioactive fallout data (USN75, p. E-4). It is probably desirable to review this model with respect to any new data which maybe available and also any changes in overall sophistication for reactor consequence modeling.

The removal of deposited radionuclides from impervious surfaces is now considered. Obviously, this is dependent on both the properties of the rainfall and the properties of the surfaces. As already indicated, the removal of deposited radionuclides from pervious surfaces is usually small. However, it seems reasonable to suspect that such removal maybe large for impervious areas attached to storm drains. Conversely, for impervious areas for which the runoff travels only a short distance and then flows onto a pervious area, there maybe a very small removal from an overall area. It is convenient to divide the modeling of radionuclide removal from impervious areas into two parts: (1) water runoff and (2) radionuclide transport. Guidance on how these processes might be modeled can be gained from models currently in use for urban hydrology. These are discussed in the next two paragraphs.

The two most widely used models for urban hydrology are the Storage, Treatment, Overflow and Runoff Model (STORM) (USA76) and the Storm Water Management Model (SWMM) (Met71, Hub75, Ma76). The ILLUDAS model is also of interest (Han79). Such models use information of the following types in developing runoff predictions: nature of rainfall, percentage of total tributary area represented by different land-use categories, average imperviousness of each land-use category, and density of storm drains for each land-use category. From such information, the amount of runoff is predicted and then routed through a storm drainage system. It is such flows of water which are then used in predicting the removal and transport of various pollutants. Articles by McPherson (Mc75) and Aitken (Ai75) provide reviews and sources of additional information.

The preceding models treat pollutants which are already present in the surface environment rather than pollutants which are being brought in by the particular rainfall event which is generating the runoff. Thus, the nature of the problems which have been considered maybe more akin to washoff of dry-deposited radionuclides than runoff of rainfall-deposited radionuclides. However, many things involved in modeling these two processes are undoubtedly the same. The most common way to model pollutant removal from an impervious surface is to use an exponential washoff relationship related to rainfall intensity (Je78, Al81). Such an approach uses empirically determined rate constants to describe washoff. Another approach is to use more physically based models for washoff (El79); however, the data requirements for such an approach maybe prohibitive.

The models which have been developed for urban hydrology - and the attempts at their use and validation - should provide information and perspective as to how radionuclide washoff in urban environments might be analyzed. Hence, the discussion thus far has emphasized models of this type. However, there also exist models for general hydrology and mineral cycling (e.g., Cr66, Pa74, Lee76, Huf77), nuclear weapons fallout (e.g., Gru65, Gru66, Huf67a, Huf67b, Huf70), agricultural chemicals (e.g., Fr75, Fr78, Do77, Do79, USD80), airborne industrial effluents (e.g., Wag78, Wag79, Gre79), and other entities in the environment which may provide usefull information and perspective. Fleming (Fl75) provides an introduction to modeling techniques in hydrology. For investigations in Germany, the extensive study by Jacobi et al. on radioactive fallout and surface-water contamination will be of interest (Ja69a, Ja69b, Ja69c, Ja70).

4. Chemical and Physical Forms of Released Radionuclides

Important areas of uncertainty are the potential chemical and physical forms of radionuclides released in a reactor accident. Clearly, such properties will have great impact on radionuclide transport in the terrestrial environment. Chemical forms affect reactions which may take place with environmental substrates and thus prevent further movement. This is obviously important on pervious areas where various binding actions may rapidly prevent both vertical and lateral movement. Although one might reasonably expect impervious surfaces to be less reactive than pervious surfaces, the important question of how much less certainly remains. The physical properties of particles to which radionuclides maybe attached is also important. Such properties affect the manner in which particles are transported and deposited by flowing water. Such effects are not considered by Ritchie et al. (Ri78, Ri76); in their analysis, all radionuclides washed from the plume by a given volume of water are assumed to be lost from the environment if this water is removed by surface runoff. A review of current knowledge with respect to potential chemical and physical forms of radionuclides released in a reactor accident would be very usefull. Such information is important in an overall modeling effort.

If preliminary investigations indicate the potential importance of runoff/washoff relationships in urban environments and there is insufficient information available for the construction of appropriate models, then experimentation maybe desirable to develop the necessary background data. There should be no conceptual problem in designing experimental apparatus to study runoff/washoff relations for different rainfall intensities, different surfaces, and different transported entities. With respect to the overall relevance of information generated in this manner, the greatest uncertainty would seem to be in the selection of the appropriate entities to use as surrogates for radionuclides released during a reactor accident. Thus, as discussed in the preceding paragraph, it is important to have some idea as to what the chemical and physical forms of the released radionuclides might be.

The individual processes involved in radionuclide washoff in urban environments are quite complex, and thus a model which tries to duplicate these processes in detail maybe too unwieldy to be applicable. Thus, there is undoubtedly an upper bound on the level of complexity that can be meaningfully achieved in the modeling effort. Indeed, the most productive approach maybe to seek out some material which is released to the environment and whose behavior can be used as an analog for the behavior of radionuclides released during reactor accidents. If such an analog can be found, then it maybe possible to construct relatively simple empirical models from the observed behavior of the analog. This was done several times in the consequence modeling for the Reactor Safety Study (USN75); there, the behavior of fallout radionuclides from weapons testing was used to obtain empirical models for the behavior of radionulcides released in reactor accidents. Perhaps fallout data - collected on the appropriate scale - can again be used to construct empirical models. However, for this approach with fallout radionuclides or some other material to be reasonable, it is necessary to be able to justify the appropriateness of the selected analog. Due to the past use of fallout radionuclides as analogs for radionuclides released in reactor accidents, a review of the appropriateness of this usage would be valuable. The previously indicated experimental work may also provide important guidance in the development of empirical models.

5. Surface-Water Contamination

Thus far, the discussion has delt with the possible attenuation of radionuclide levels in urban environments due to runoff/wash-off relationships. As an adjunct to this, the question arises as to whether reduced human exposure due to radionuclide washoff might be offset by increased exposure from aquatic pathways into which the removed radionuclides could eventually enter. Several studies have considered the possibility of such exposure and have concluded that it is probably not important relative to other exposure pathways (e.g., Ja69c, Ng73, He82). This is also consistent with numerous analyses of the relative importance of different exposure pathways for fallout radionuclides (e.g., Aa71, Gu69, Har69).

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