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TRADOS - AIR TRAJECTORY DOSE MODEL FOR LONG RANGE TRANSPORT OF RADIOACTIVE RELEASE TO THE ATMOSPHERE

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ABSTRACT

A model for estimating radiation doses resulting from long range atmospheric transport of released radionuclides in accidents is presented. The model (TRADOS) is able to treat changing diffusion conditions. For example the plume can be exposed to temporary rain, changes in turbulence and mixing depth. These can result to considerable changes in individual doses. The method is applied to an example trajectory and the doses caused by a serious reactor accident are calculated.

1. INTRODUCTION

Usually the primary interest of consequences due to radioactive release to the atmosphere is directed at effects occurring in the region from the vicinity of the release point to distances of up to hundred kilometres at the most. However, a large fraction of the total collective dose is accumulated from small individual doses at distances of hundreds of kilometres from the release point /1,2/. At present the importance of long range transport is well known for many conventional airborne pollutants.

During long range atmospheric transport changing dispersion conditions, such as turbulence, mixing depth, rain, wind speed and shear, and above all synoptic wind field variations, have to be taken into account. Short term changes during the transport path have strong influence on the doses. The amount of deposited material from the plume is of special interest.

This paper describes briefly how the trajectories and the dispersion conditions are determined. The atmospheric diffusion and plume depletion used in our model are described in chapter 3. Finally, the calculation of doses via different pathways is described, individual and collective doses are evaluated for an example trajectory, and the significance of changing dispersion conditions is examined.

2. CALCULATION OF THE TRAJECTORY AND DETERMINATION OF DISPERSION CONDITIONS ALONG IT

The trajectories have been calculated by the Finnish Meteorological Institute in a two-dimensional grid in one hour time steps with a mesh width of 150 km at 60^0N, using numerically analysed winds at the 850 mb pressure level. After every three hours a new trajctory is begun. Each trajectory is followed for six days, if it is not terminated due to its leaving the calculation area before that time. It is necessary to know the valid dispersion conditions to be able to estimate diffusion rates, intensity of removal mechanism etc. along the trajectory. In the analysis there were data of temperature, humidity and horizontal winds on standard constant pressure levels as well as mean vertical winds estimated for the layer 1000-500 mb. The stability classification is based on simulated netradiaton, character of terrain, and surface wind speed, according to a scheme of Pasquill-Turner type /3/. The occurrence of precipitation is calculated from the mean vertical wind in the layer 1000-500 mb.

Snow is assumed when surface air temperatures are below -5^{0}C. The mixing height is determined as a function of stability. Three values are employed; 250m for stable, 500 m for neutral, and 1500m for unstable situation. For high mountains the value 1500 m is used, regardless of stability.

3. SIMULATION OF THE RADIOACTIVE CLOUD

The second part of the TRADOS-model consists of a computer code which uses the information of dispersion conditions along a trajectory to simulate the radioactive cloud, and to estimate doses it causes via several dose pathways. As trajectories are calculated every third hour, it is assumed that each cloud is formed of three hour plume segments.

It is difficult to estimate cloud width at long distances, because synoptic scale wind field variations and shear effects are dominating. In the TRADOS model the plume width is determined utilizing the preceding and following trajectories, as shown in Fig. 1. In the case of a release of long duration the release is divided into several three hour trajectories, which are studied separately.

When long transport distances are being considered, dry deposition can be treated in a physically more acceptable way when using gradient-transfer theory modelling than when using Gaussian plume assumptions /4/. The gradient-transfer theory is used in the TRADOS-model to describe the vertical dispersion of radioactivity in the cloud. In the example presented, the dry deposition velocity v_d is given a value of 1 cm/s for particles and iodine. For noble gases no dry deposition is assumed. A comparison between the results of two models, the one using Gaussian and the other using gradient-transfer theory, has shown that over transport distances (< 100 km) more activity remains in the cloud to cause larger doses when gradient-transfer theory is applied /5/.

Relatively soon after release (within some hours in unstable and neutral conditions, and within about half a day in stable cases) the vertical distribution will reach a steady state shape. When this shape has been reached, the concentration of radionuclides is vertically uniformly decreased. Steady state shapes of vertical concentration profiles for several release heights have been calculated by a separate code to be used as input tables in the cloud simulation code.

Changes in atmospheric stability have influence on the vertical distribution of radioactive material. The value of the stability class index (unstable, neutral or stable), determined by the trajectory calculation code, is used in the cloud simulation code along the trajectory, using three hour travel timesteps. When stability changes towards stable, causing the mixing layer to decrease, part of the material remains above the mixing layer unaffected by dry deposition. When weather again becomes less stable, radioactive material spreads vertically to fill the increased mixing layer, taking with it the part above the former mixing layer.
Depletion of radioactive material from the cloud by wet deposition during rainfall is taken into account in the TRADOS-model. Contrary to dry deposition, wet deposition removes material also above the mixing layer. For radionuclides, like noble gases, which are not affected by deposition, a value of zero for the washout coefficient is assumed.

4. ASSESSMENT OF RADIATION DOSES

The radioactive decay and build-up of daughter nuclides are taken into account dynamically during dispersion and after deposition in the TRADOS-model. The dynamical consideration is based on decay schemes of up to three nuclides, as described in /5/. The essential fraction of longer decay schemes, when calculating the doses, can easily be described by three nuclides for the most common situations.

Doses, caused by radioactive release, are calculated in the TRADOS-model via four main pathways: external radiation from the cloud; inhalation of radioactive material; direct radiation from the contaminated ground; and ingestion of contaminated food products. Vertical distribution of radioactive material during the whole trajectory is taken into account in the calculation of external exposure from the cloud /5, 7/. Doses via inhalation are estimated from the concentration of radionuclides in the air close to the ground; and external exposure from fallout is calculated from activity in the ground taking into account migration processes from the surface /6/. A newly developed AGRID-submodel is used to evaluate doses via nutrition pathways, determining the deposited activity on plants and activity in the soil /8/. Agricultural products are divided into five separate pathways: milk, meat, green vegetables, grain and roots. Large variations in doses, depending on the season of the release, are taken into account /8/. For the calculation of collective doses population and different agricultural yields are used in combination with an average dose in each grid square determined along the whole trajectory.

5. EXAMPLE CASE

One example trajectory is considered, mainly to demonstrate phenomena which can be described with the TRADOS system. The radioactive release studied is from WASH-1400 /1/, where all noble gases and a high fraction of volatile fission products and a smaller fraction of ruthenium and lanthanium type elements of the reactor core are released into the environment. The reactor is assumed to be sited in Central Europe close to the North Sea.

The dose pathways considered are direct gamma dose from the plume with an average shielding factor of 0.5, 50 years' dose due to inhalation, and gamma dose from the deposited activity in the ground integrated over 30 years with an average shielding factor of 0.25. Internal dose factors are based on ICRP-30 /9/ models, and external dose factors on data published by Kocher /10/. Ingestion doses are not considered here, if the release takes place during the growing season, the dose rates due to ingestion of contaminated food, mainly milk, are so high that the contaminated food product is temporarily interdicted.

The route of the trajectory passed over the Baltic Sea to the Gulf of Bothnia, where it turned to Central Finland and continued in north-east direction to the Barents Sea. The corresponding individual dose is shown in Fig 2. At first the dispersion conditions are stable, unstable and stable, after which there is a neutral period of about two days. During the second stable period the decreased mixing height (250 m) compared with that under unstable conditions (1500 m) decreases the dose rapidly. About 90% of the total dose is caused by fallout at this distance. During the following neutral conditions the radioactive material is divided into two layers: one in the neutral turbulent layer close to the ground and subject to dry deposition, and the other above this turbulent layer not subject to deposition. Immediately after the change of stable to neutral condition, the dose increases due to the fact that radioactive material above the stable mixing layer can reach the ground and increase concentration close to the ground and, thus, deposition. During the neutral period there are four periods of rain. It can be clearly seen that the doses are considerably increased due to wet deposition. However, simultaneously, doses are more steeply decreased as a function of distance due to very effective removal of radioactive material from the cloud.

The collective dose caused by the trajectory is presented in Fig. 3 accumulated as a function of travelled distance in Finland. The trajectory has already travelled about one thousand kilometers when reaching the Finnish coast, and the first rain fall is still continuing. Neutral dispersion conditions dominate during the transport over Finland. After a dry period of three hours, rain occurs again causing the collective dose to accumulate relatively rapidly. During the third rain period the trajectory is over low populated area, and the contribution to the total collective dose is insignificant. Relatively great distances can be seen to contribute to the collective dose.

6. DISCUSSION

The described assessment model is applicable for calculating long range transport of radioactive matter taking into account dispersion conditions. Changing dispersion conditions are taken into account by the gradient transfer approach. Thus dry and wet deposition and especially vertical distribution of the dispersing material are considered in a physically acceptable way. Short term changes, as shown in the example, have great influence on the dose.

Hitherto we have employed the model for the estimation of radiation doses due to short accidential release of radioactivity. We have, however, tried to develop the TRADOS model to be so fast running that it can be used even for investigations when a large number of trajectories has to be considered, as in probalistic risk studies. Also, by means of dispersion statistics the model is well applicable also to the estimation of individual and collective doses due to radioactive releases over a longer time period, for instance due to normal operation of a nuclear power plant.

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REFERENCES

1. Reactor Safety Study. An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. WASH-1400, 1975. (Washington D.C.: Nuclear Regulatory Commission).

2. Nordlund G., Partanen J.P., Rossi J., Savolainen I. and Valkama I., "Radiation doses due to long range transport of airborne radionuclides released by a reactor accident; effects of changing dispersion conditions during transport", to be published.

3. Turner D.B., 1964, "A diffusion Model for an Urban Area", J. Appl. Meteor. 3, 83.

4. Calder K.L., 1960, "Atmospheric Diffusion of Particulate Material, Considered as a Boundary Value Problem"", J. Meteor. 18, 413.

5. Nordlund G., Savolainen I. and Vuori. S., 1979, "Effect of Application of Surface Depletion Model on Estimated Reactor Accident Consequences", Health Phys. 37. 337.

6. Savolainen I. and Vuori S.,1977, "Assessment of Risks of Accidents and Normal Operation at Nuclear Power Plants". Electrical and Nuclear Technology, Publication 21. (Espoo: Technical Research Centre of Finland).

7. Vuori S., 1978, "Fast Correction of Cloud Dose Data Files Due to Changes in Dispersion Parameters", Health Phys. 34. 727.

8. Partanen J.P and Savolainen I.,"Seasonal Effects of Nutrition Dose Pathways on Ractor Accident Consequences", Technical Research Centre of Finland, to be published.

9. International Commission on Radiological Protection, 1979. "Limits for Intakes of Radionuclides by Workers". ICRP Publication 30. (Oxford: Pergamon Press).

10. Kocher D.C, 1980, "Dose-rate Conversion Factors for External Exposure of Photon and Electron Radiation from Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities", Health Phys. 38, 543.

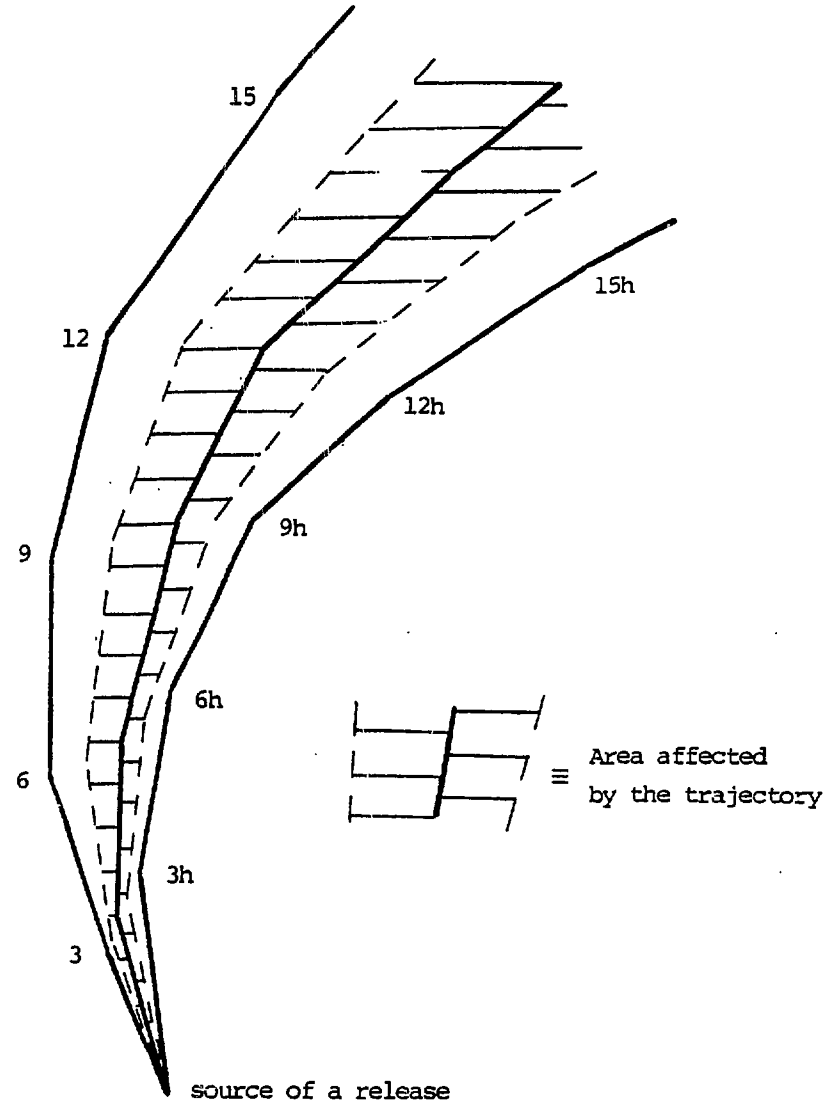

Fig.1 Affected area in the TRADOS model is determined by three subsequent trajectories.

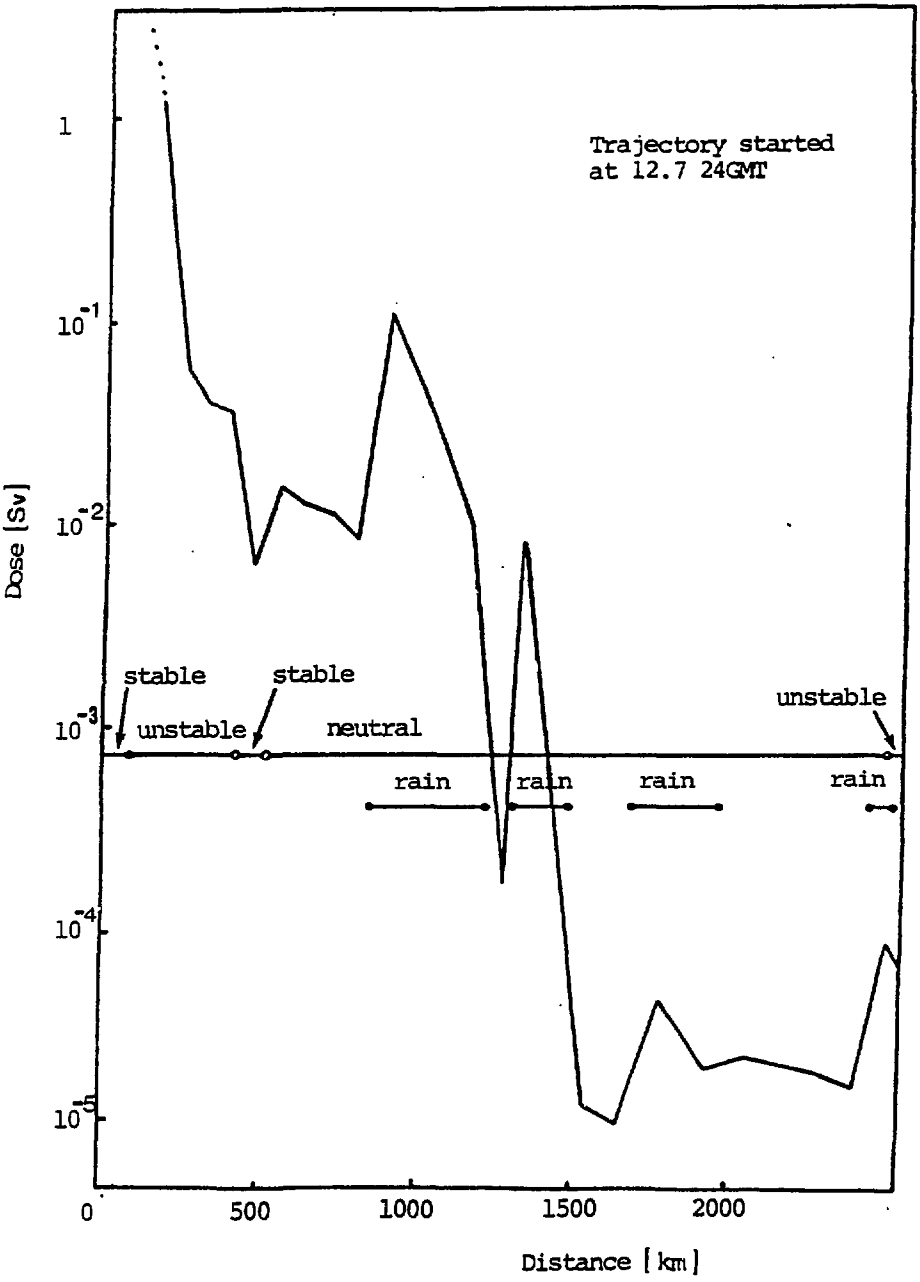

Fig.2 Total individual effective dose (plume γ, fallout γ (30a), inhalation) due to BWR-2 release. Atmospheric stability and rain occurrence are enclosed.

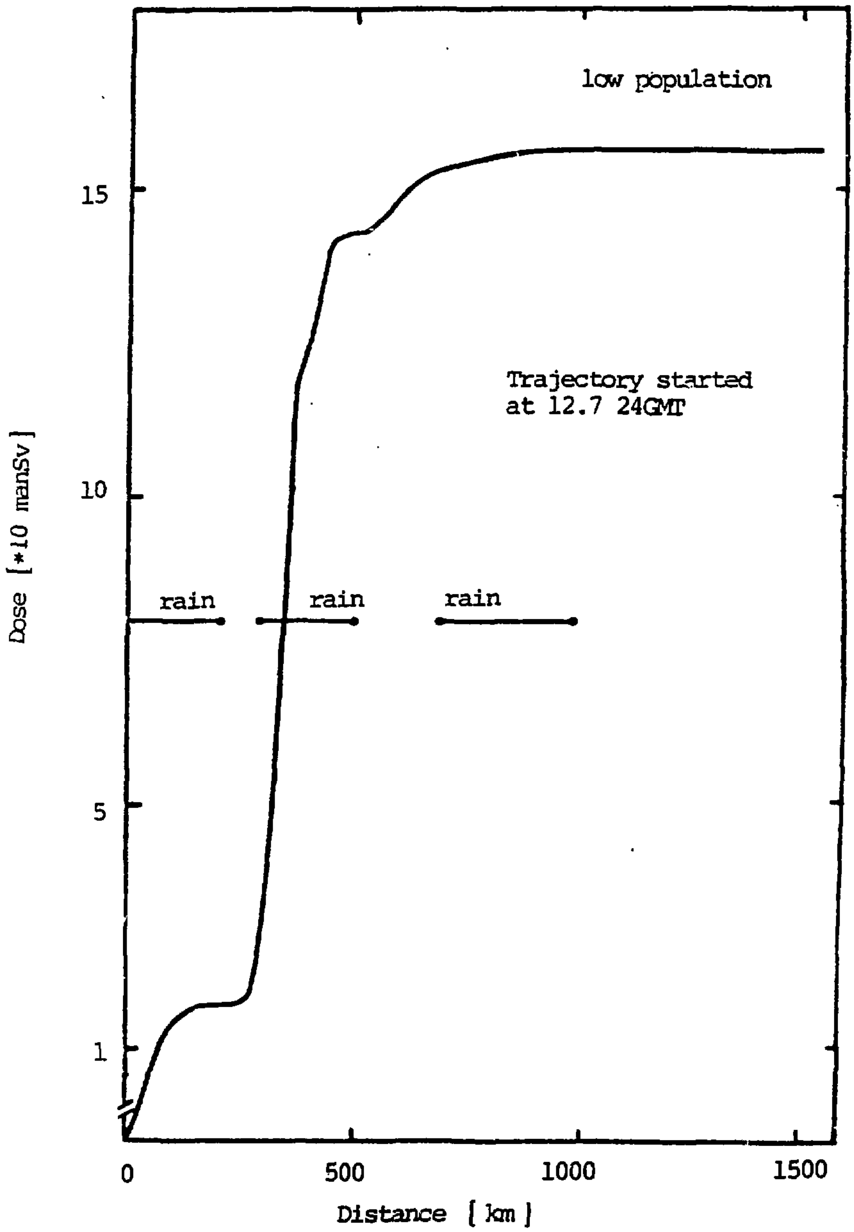

Fig.3 Total collective dose (plume γ, fallout γ, inhalation) accumulated in Finland due to BWR-2 release.