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COMPARISON OF OPERATIONAL ATMOSPHERIC DISPERSION MODELS IN GERMANY

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Abstract: Within nuclear emergency planning and preparedness, atmospheric dispersion models are used as central tools for decision support in order to recommend disaster control measures. These measures are closely linked to reference levels for specific dose quantities which are obtained as model results. This paper gives an overview of a comparison of dispersion models being in operation in Germany, which have been optimized for the specific responsibilities of the authorities involved. Results for air concentrations, soil contaminations and the most important dose parameters are collated for different meteorological conditions.

Key words: *Model comparison; nuclear emergency; radiological protection*

INTRODUCTION

After the Fukushima accident, the German Commission on Radiological protection (SSK) started various projects concerning lessons learned on emergency planning and preparedness within the operation of nuclear power plants. One of these projects is the comparison of currently implemented atmospheric dispersion models in Germany and Switzerland in the area of nuclear emergency situations. Due to the federal structure and different responsibilities of the authorities involved, dispersion models are applied within different scopes. This is expressed by their spatial and time resolution, the calculated result parameters (e.g. air concentrations, deposition or doses) and the implementation of the algorithms describing the atmospheric dispersion or the calculation of doses. With respect to the application of models within the radiological emergency management, it is demanding, to evaluate the band width in the results for intervention levels which are defined for measures like stable iodine prophylaxis, shielding or evacuation.

Nine different models are considered in the comparison, starting with the short scale model LASAIR (Walter H., Heinrich G. 2011) used in the context of terroristic attacks (dirty bombs) and ending up with the LPDM model chain of the German Weather Service (Fay, B. et al. 2004), which describes the dispersion on a larger scale. In the mesoscale regime, the three models contained in the operational RODOS system (Rimpuff (Thykier-Nielsen, S., Deme, S., Mikkelsen, T. 1999) , Atstep (Päsler-Sauer 2006) and Dipcot (Andronopoulos, S. et al. 2010)) and three Lagrange particle models have been included: The ABR-system (Scheuermann, W. et al. 2011), which is integrated in some remote monitoring systems of nuclear power plants, the ARTM system (GRS 2007), whose conventional part is essentially based on the current implementation of the German Guidelines for Technical Instructions on air quality control, and the Swiss system ADPIC (ENSI 2014). Finally, with SAFER a Gaussian plume model which is based on the German Guidelines for Radiological Protection (SSK 2004) is taken into account.

In the first part of the project, the most important properties of each model including the parameters and formalisms were summarized, which is essential in order to understand differences in model results. Eight benchmark scenarios, from simple meteorological conditions to realistic weather situations are formulated to define the boundary conditions for the calculations. Whereas the RODOS models as well as the ABR participle in all scenarios, the other systems take part only as far as applicable for the respective scenario. Since ADPIC has been optimized for the Swiss plant sites, this system was involved in the documentation part of the project only. This paper gives an essential overview of the results of the comparison, which might lead to a better judgment of important features and for correct applications of the models.

SCENARIOS WITH SIMPLE BOUNDARY CONDITIONS

The model comparison starts with simple meteorological conditions. Here, a constant wind speed (3m/s) and wind direction (135°), both defined at 10 m above ground at the location of source, a flat topography and a release height of 150 m are assumed. Calculations are performed for unstable, neutral and stable conditions corresponding to the diffusion categories B, D and E, respectively. In addition, the influence of precipitation and roughness of the surface (which is not discussed in this paper) are considered. The source term is chosen to be quite simple as well and consists of three single nuclides: $1*10^{17}$ Bq Xe-133, $1*10^{15}$ Bq I-131 (50% organic and elementary), and $1*10^{13}$ Bq Cs-137 with constant emission rate. However, due to the importance of these nuclides as reference nuclides for the groups of noble gases, iodine and aerosols, a first estimation of the consequences for dose calculations is possible. The most important exposure pathways are considered, i.e. the external ground shine and cloud shine doses as well as the effective dose and the inhalation dose for adults. In each model, these quantities are calculated based on the predicted air concentrations and ground deposition. Thereby, additional differences are expected due to the deployment of different dose coefficients or methods of calculation.

The three-dimensional air concentration of the radioactive particles is the basic quantity with respect to the meteorological features of the models. Near ground level, this quantity is directly related to the inhalation dose, which is one of the most important exposure pathways. For the simple boundary conditions mentioned above, each model predicts Gaussian-like shapes as expected. However, significant differences are found in the shape of the plumes which are caused by the different treatment of turbulent diffusion and the underlying assumptions for the vertical wind profiles (the assumed release height is 150 m compared to a measured wind of 3 ms^{-1} at 10 m above ground) leading to a different concentration near ground level and a different travel time of the radioactive cloud. For a better quantitative comparison, the behaviour of the time integrated concentration along the propagation direction is shown in Figure 1. Apart from the differences near to the source, the agreement for the concentration for neutral conditions is reasonable (here the deviations are less than a factor of five), especially when differences in the spatial resolution of the models is taken into account. To this end, for the ABR and ARTM models, two calculations with resolutions of about 1km and about 250 m have been included. As expected, the calculation with higher resolution produces higher concentration values near the source location. For larger distances, the results converge for of both models. So, at least for simple meteorological conditions a nesting is recommendable, as is done in the RODOS system. For unstable conditions, the agreement is even better for distances smaller than 10 km whereas an increasing deviation is found for larger distances. Note, that ARTM is closer to the RODOS models here. For stable conditions, however, larger differences between the model results are found. The implemented turbulence parameterization in ARTM which is taken from the German guidelines for Air Control favours extremely narrow plumes, horizontally as well as vertically. Thus, ARTM predicts a maximum at larger distances whereas ABR and RODOS are found to be quite similar. The magnitude of the maxima is similar for all models.

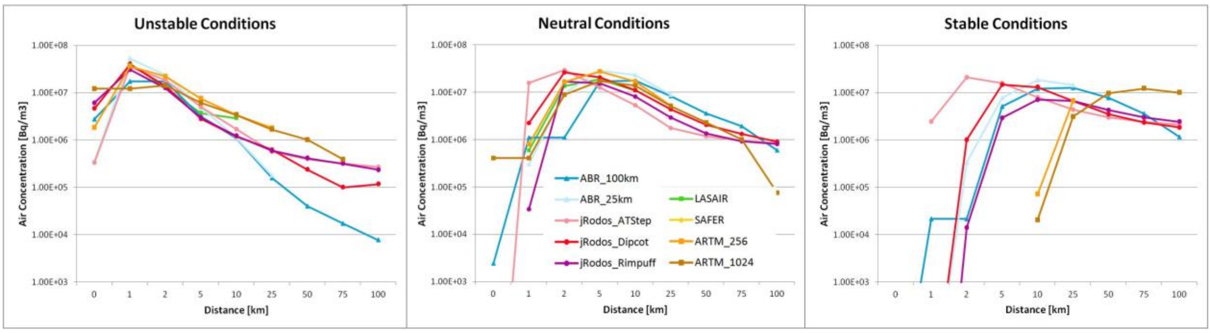

Figure 1. Xe-133 air concentration near ground level along the main wind direction for unstable (left), neutral (middle) and stable conditions (right) as predicted by the models.

Besides the radioactive decay, the concentration of the noble gas Xe-133 is not influenced by other physical or chemical processes. For iodine as well as for the group of aerosols the wet and dry deposition lead to a depletion of the concentration in the cloud. Additional model dependencies – e.g. expressed by the deposition velocities depending on the size of the particles and the washout factors - are relevant. In the models considered in the comparison, similar methods are applied, but partly different parameters are used. As a consequence, this leads to a slightly larger deviation of the model predictions for the dry deposition compared to the concentration discussed above as is indicated in the left part of Figure 2. In total, a discrepancy of a factor 10 is observed. On the other hand, in case of the wet deposition the agreement is found to be much better. Only at short distances large differences are observed. Taking into account that the wet deposition is modelled to be proportional to the integral of the concentration over the vertical direction this implies that the total concentrations above ground are quite similar. For small distances, however, large differences are found, which are partly caused by the different spatial resolution of the models. Note, that the washout is considerably larger than the dry deposition as expected for the underlying precipitation rate of 2mm/h. This demands to use high resolution precipitation data or forecasts in the model calculations. Furthermore, when comparing measured deposition data near the source location, models with high resolution should be used.

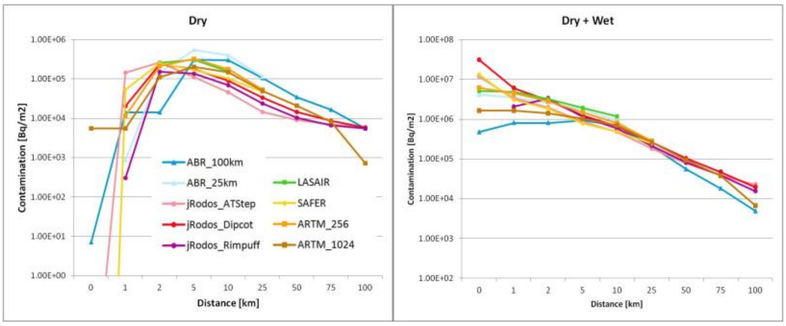

Figure 2. Deposition of Iodine 131 in Bq/m² for neutral conditions: Dry deposition (left) and washout (right). Here, a homogeneous precipitation rate of 2 mm/h has been assumed.

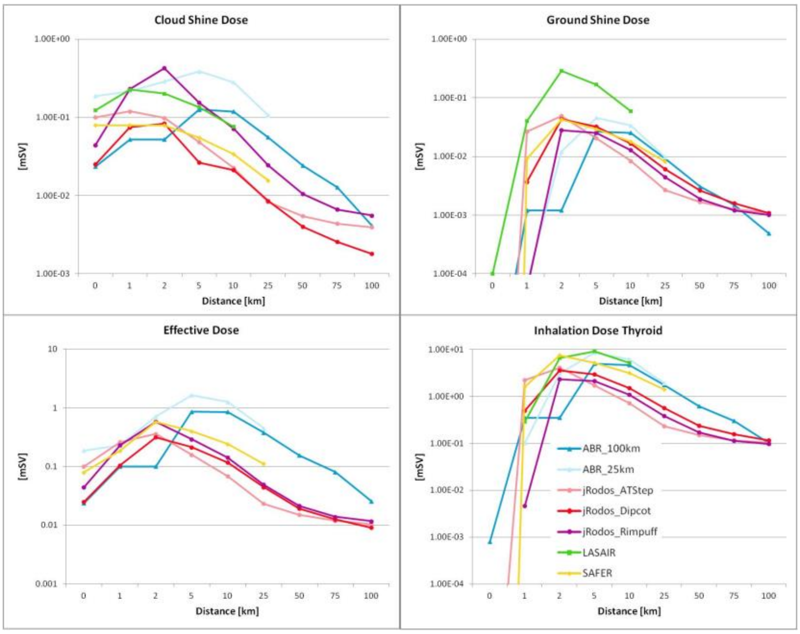

Figure 3. Xe-133 air concentration near ground level along the main wind direction as predicted by the models.

Within nuclear emergency protection, the quantities of major interest are the doses caused by the radioactive radiation of the particles. Figure 3 shows the results for neutral conditions for the external cloud shine and ground shine doses as well as for the thyroid inhalation dose and the effective dose. Obviously, for all quantities diagramed the discrepancy is larger than expected from the results for the concentration and deposition. In case of the cloud shine dose, the predictions of Rimpuff, ABR and Lasair are larger than Safer, Atstep and Dipcot. The ground shine doses are similar apart from the larger values of Lasair which are originated by a larger Caesium contamination caused by the use of heavier aerosol particles leading to additional sedimentation on the surface. Regarding the effective dose, the ABR predicts higher values compared to the other models, which is a consequence of the cloud shine and (effective) inhalation dose. In case of the thyroid inhalation dose, the RODOS results are systematically below the other model predictions. At first glance, this is a little surprising, since this parameter is directly proportional to the air concentration discussed above. The reason for the deviation is the utilization of different dose coefficients and inhalation rates.

This has to be kept in mind when using model predictions as a basis for the assessment of the radiological situation in case of nuclear emergency because it implies that the use of different models may lead to different recommendations for counter measures for the same boundary conditions.

In addition to the simple scenarios discussed so far, further boundary conditions like rotating wind directions and wind shear have been investigated (SSK 2014). The basic findings remain unchanged. However, wind shear scenarios indicate the limitations of plume and puff models especially when the wind direction changes below the emission height.

A SCENARIO WITH REALISTIC WEATHER CONDITIONS

The scenario considered in this section is based on the location of the Biblis nuclear power plant which is located south west from Frankfurt in the Rhine valley. The weather situation has been chosen to be quite typical for that region, i.e. a south wind near the surface accompanied by a west wind flow above the boundary layer. At emission height, the wind direction is mainly from south west. During the emission phase of six hours, a precipitation front is passing the region in east direction. In the calculations, the meteorological data is taken from the numerical weather forecast of the June 30 2013 (COSMO-DE) of the DWD. Figure 5 gives an overview of the meteorological situation in the third hour of the emission phase in the vicinity of the plant site.

The results for the total ground contamination for I-131 are shown in Figure 6. The shape of the plumes – which looks quite similar for all models - is the same as for the air concentrations, but the spatial distribution of the deposition magnitudes differ due to the inhomogeneous precipitation involved. All models include the three dimensional wind field as predicted by the COSMO model which leads to more similar wind profiles in the models. Since the emission height (here 100 m) is below the height for the vertical rotation (Ekman spiral), the puff models, which show more narrow plumes, yield a similar description of the dispersion. The observed differences are mainly caused by the different turbulence parameterizations as well as the treatment of the topography. Whereas the ABR and Rimpuff results emphasize a north-north-west region of enhanced values in the region near the plant (following the wind field near ground) Dipcot favors a north-west-west direction. Concerning the maxima, Atstep is quite similar to the large scale LPDM model of the DWD. At larger distances, all plumes are dominated by the west wind regime of the weather forecast. These results can be directly expressed into predictions of the doses. Again, the deviations are found to be larger than for the concentrations. Qualitatively, however, all models yield a similar description of the radiological situation. Also, the maximum values or found to be similar, but located at different positions. When considering a specific location, the results partly differ by more than two orders of magnitude.

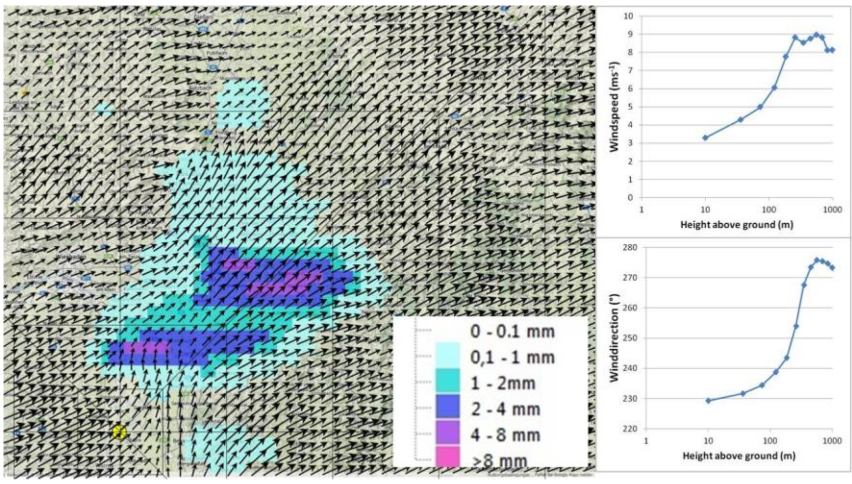

Figure 4. Meteorological data (COSMO-DE) for the realistic scenario (third hour): wind field (height 73 m) and precipitation (left). The plant is marked with a yellow dot. The right side shows the vertical profile for wind velocity and wind direction at the plant site up to 1000 m over ground level.

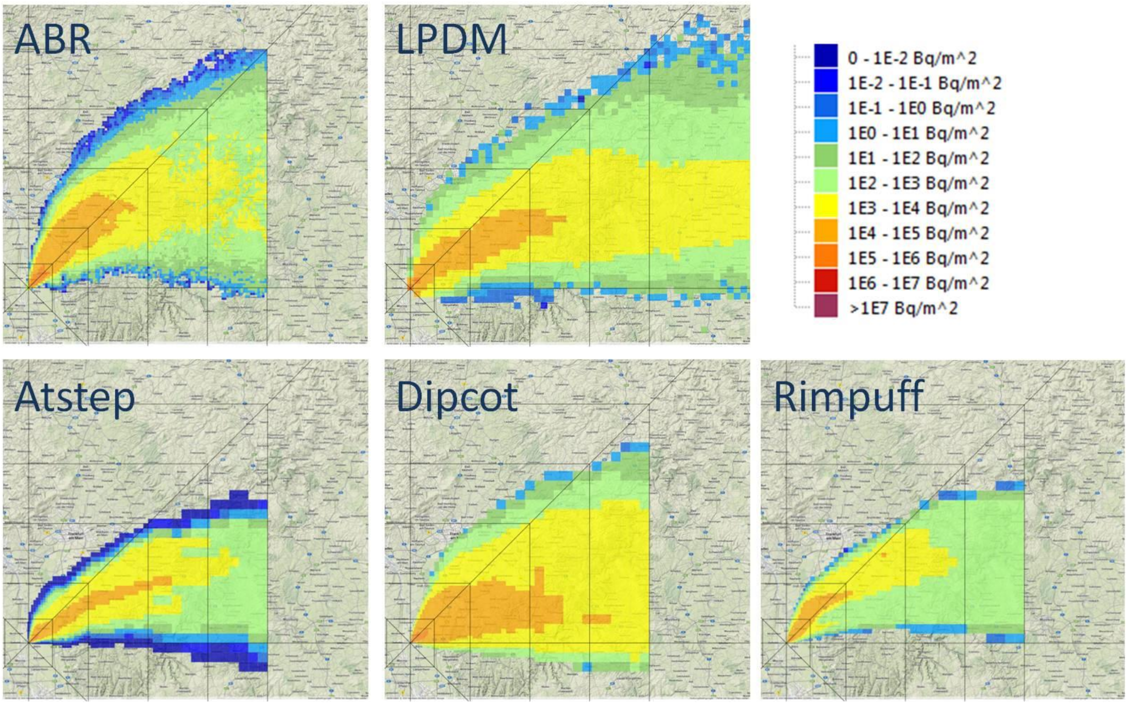

Figure 5. Total Deposition of I-131 for the models ABR, LPDM, Atstep. Dipcot and Rimpuff.

CONCLUSIONS AND OUTLOOK

In conclusion, it is found that the results of the models are qualitatively similar, especially with respect to the shape of the plumes as well as for the magnitudes of the maxima. For unstable and neutral conditions, the differences in the air concentrations are less than a factor of 5. For stable conditions, as expected, caused by different turbulence parameterizations the differences are larger. In addition, larger deviations are found in the contamination and the dose parameters, which can be partly explained by the deployment of different modeling parameters. Here, a harmonization of the models seems to be recommendable. For the cloud shine dose further analysis is necessary to explain the differences in the results.
For the future, further scenarios should be considered in order to understand the model behavior with respect to the influence of buildings and topography. In addition, more realistic source terms should be considered.

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