Correction of model predictions for the radioactive contamination of the environment with data assimilation

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INTRODUCTION

Model predictions for rapid assessment and prognosis of possible radiological consequences after an accidental release of radionuclides play an important role in nuclear emergency management. Besides from providing a snap-shot of the ongoing situation, radiological measurements (e.g., dose rate measurements) can be used to improve such model predictions. This paper describes a method for combining model predictions and measurements (data assimilation), assessing the radioactive contamination and quickly generating results that have both the spatial coverage provided by a model output and the confidence that comes from measurements. The method is under implementation in the European decision support systems RODOS (Rojas-Palma et al. 2003) and ARGOS. The data assimilation approach relies on the Ensemble Kalman Filter, a Monte Carlo variant of the Kalman filter. It is applied in two areas: monitoring of large scale deposition patterns and monitoring of complex deposition patterns in inhabited areas. Based on both numerical weather predictions and real meteorological measurements for several German NPP’s the use and benefit of the data assimilation approach will be demonstrated in realistic scenarios.

MODELING RADIOACTIVE CONTAMINATION AFTER CLOUD PASSAGE

Monitoring of large scale deposition patterns

One of the aims of introducing data assimilation into decision support systems (DSS) like RODOS and ARGOS is to improve the monitoring and prediction of large scale deposition patterns, since this data is one of the key parameters for predictions of radionuclide behaviour in the environment and resulting human exposure. The improvement is obtained by correcting model predictions for deposition of radionuclides onto the ground by assimilation of gamma dose rate measurements. The deposition model in RODOS bases on the radioecological model ECOSYS-87 (Müller and Pröhl 1993), extended by an atmospheric resistance model for dry deposition. A detailed description of data assimilation in the deposition model using the Ensemble Kalman Filter (EnKF) can be found in Gering (2007). The EnKF is especially suitable for very large, non-linear systems. A quantitative assessment of the uncertainties of model predictions and measurements is essential for data assimilation with the EnKF. In particular the uncertainty modelling for model predictions is one of the key factors which determines the performance of the data assimilation. Main source of uncertainty of model predictions in DSS’s is the uncertainty of the source term (i.e. the uncertainty of the released activities) as well as the uncertainty of the meteorological data. Both sources of uncertainty can be considered with the described EnKF approach.

For operational purposes the data assimilation capability for large scale deposition patterns
has been realised in the Deposition Monitoring Module DeMM. The application of the data assimilation approach in DEMM has been demonstrated with several realistic test scenarios (Gering 2007). It could be demonstrated that the EnKF has a high potential to simultaneously correct ground deposition for all radionuclides included in the source term with only a few (20-30) gamma dose rate measurements available. Output of DeMM can serve as input to the Inhabited Area Monitoring Module IAMM, which is described in the next section.

**Complex deposition patterns in inhabited areas**

In the case of a hypothetical release from a German NPP the maps for the surface contamination of a major city, calculated by DeMM, were relatively coarse (cell length 4 km) (Kaiser and Proehl 2007). Furthermore, DeMM processes GDR measurements which arise mostly from fixed monitoring stations. However in inner cities, much finer maps are needed for decision making and measurements will mainly arise from mobile devices. As a consequence of these observations the development of the Inhabited Areas Monitoring Module (IAMM) has been commissioned in the EURANOS project, financed by the European Commission with the Sixth Framework Programme.

The conceptual design of IAMM was developed in close cooperation with potential users and the following requirements have been identified:

Deposition patterns in inner cities or suburban areas show a high variability due to the complex structure of the surfaces where radioactive material has been deposited. Typically detectors collect photons within a radius of some ten meters. Especially after dry deposition the detector signals depends strongly on the measurement environment. To quantify the deviation of the signal strength to a hypothetical signal over an infinite lawn, Meckbach and Jacob (1988) have introduced the concept of location factors. With Monte-Carlo calculations they found that the influence of the measurement location, described by a dimensionless number, may vary by a factor of 20. Therefore, incoming measurements should be corrected with adequate location factors.

Immediately after the accident only a few measurements will be available. These measurements should be combined with the model predictions of DeMM. This combination of measurements and model results should be facilitated with data assimilation techniques.

If enough measurements are available some time after the accident, geo-statistical interpolation should be performed after correction with location factors. Model results would be no longer needed.

Considering the above-mentioned requirements IAMM operates in two different modes:

1) the data assimilation mode or
2) the geo-statistical interpolation mode,

which can be selected by a toggle button in the start-up window of the graphical user interface in Figure 1.

Input data to IAMM are a delineation of the mapped area together with a suitable grid, the nuclide vector for the accident, a set of location factors and a set of geo-referenced and dated GDR measurements. In the data assimilation mode a map of the surface contamination from a simulation model (i.e. DeMM) is also required. The geo-statistical interpolation can be
performed using nominal values for the radiological quantities without uncertainties. If uncertainties are provided for the input data, these can be propagated through the interpolation with Monte Carlo simulation. In the DA mode information of the uncertainty is mandatory. The endpoints are maps of either the GDR (mGy/h) or the surface contamination (Bq/m²) for a hypothetical reference surface of infinitely extended lawn. The maps can be produced for either the whole nuclide vector or for a single selected nuclide at arbitrary times after the accident.

Figure 1 shows the graphical user interface of the standalone version. A full technical documentation of the necessary input data, the file formats and a short user manual can be found in Kaiser (2007).

![Figure 1: Startup window of the IAMM graphical user interface in the standalone version.](image)

In the working group on urban modelling of the “Environmental Models for Radiation Safety” (EMRAS) project, sponsored by the International Atomic Energy Agency (IAEA), IAMM has provided the initial maps of the surface contamination for a scenario which treats the hypothetical explosion of a Radioactive Dispersion Device (RDD or “dirty bomb”) in the centre of a major North-American city (Thiessen 2007). Figure 2 shows the contour lines of the surface contamination which were calculated with inverse distance weighting algorithm. To date for an RDD explosion IAMM operates only in the mode of geo-statistical interpolation, since model results from DeMM will not be available. However, in the data assimilation mode similar maps will be produced as endpoints.
DeMM is currently being integrated into the RODOS DSS, IAMM into the RODOS and ARGOS DSS’s. Under the JRODOS, the Java-based version of RODOS which is currently under development, it will become a callable module with a user interface that provides the same functionality as the standalone version. In JRODOS the maps of surface contamination from IAMM can be fed seamlessly into the European Model for INhabited areas (ERMIN) (Jones et al. 2007). After the contamination of an urban environment the ERMIN tool allows the user to explore different recovery options and to refine countermeasure strategies. To date, only model results from DeMM, which is applied after large scale NPP accidents, are being processed by IAMM with data assimilation. To operate IAMM in the data assimilation mode after small scale RDD events, a coupling to an urban dispersion model is planned.

REFERENCES

Meckbach, R. and Jacob P. (1988), Gamma exposures due to radionuclides deposited in urban environments, Part II: Location factors for different deposition patterns, Radiation Protection Dosimetry 25, pp 181-190