EXTENDED KALMAN FILTER ANALYSIS OF SHORT-RANGE ATMOSPHERIC DISPERSION OF RADIONUCLIDES

Bent Lauritzen and Martin Drews
Risø National Laboratory, P.O. Box 49, DK-4000 Roskilde, Denmark,

INTRODUCTION

The emissions of ^{41}Ar from the Belgian BR1 nuclear research reactor are assessed by means of a recently proposed Kalman filter method for source term estimation based on off-site gamma measurements. Argon-41 is produced in the air-cooled reactor by neutron capture on atmospheric argon, and during normal operations at 700 kW thermal effect the radioactive isotope is released from the reactor's 60-meter stack at a rate of approx. 1.5×10^{11} Bq h^{-1}.

In a recent double tracer experiment, a white aerosol tracer was added to the continuous emissions of ^{41}Ar. The gamma radiation from the decay of ^{41}Ar was measured at distances up to 1.5 km from the emission stack while simultaneous measurements of the wind field and the dispersion parameters were performed by means of lidar scanning of the aerosol plume. In addition, direct measurements of the ^{41}Ar release rate were obtained from permanent monitoring equipment in the emission stack. From a total of approx. 6 hours of measurements, four time series of synchronized one-minute radiation and meteorological data were generated (*Lauritzen et al.*, 2003; *Rojas-Palma et al.*, 2004).

KALMAN FILTER ANALYSIS

The gamma radiation data is analyzed by an Extended Kalman Filter (EKF) method, recently proposed for the reconstruction of the source term and the characteristics of the atmospheric dispersion during a nuclear accident situation (*Drews et al.*, 2004; 2005). In this method, the time evolution of the parameters describing the radioactive plume, X_t, is governed by an autoregressive stochastic system equation while the measurement data are coupled to the state vector by a static, non-linear measurement equation, *viz*.

$$X_t = A_t X_{t-1} + w_t \tag{1}$$

$$Y_t = h\left(X_t\right) + v_t \tag{2}$$

where v_t and w_t are uncorrelated Gaussian white noise terms. A Gaussian plume model, $h(\cdot)$, is employed in parametrizing the short-range downwind atmospheric dispersion and the radiation field from the plume. In the state space model (1)-(2), the state vector X_t consists of the unknown plume parameters including the source term, while the remaining parameters needed to describe the plume are being externally forced. The measurement vector, Y_t, in the present study comprises the gamma radiation data and the observed wind direction.

The Extended Kalman Filter provides a best estimate of the plume parameters conditioned upon all previously measured data. The performance of the filter is controlled by the embedded parameters of the state space model, in particular the system and measurement error covariances, V[w_t, v_t]. These parameters are here determined by a maximum likelihood method based on the measured data, making the analysis essentially free of external parameters.

Two different versions of the state space model are applied in analyzing the results of the atmospheric dispersion experiment, cf. Table 1. In the first model, the state vector given by the source term (the radionuclide release rate divided by the wind speed, q/u), the plume height (h), and the plume advection direction (θ) obeys a simple random walk process, *i.e.* A_t = **1**. In Model II the plume height is externally forced, given by Briggs formulas for a buoyant plume. This height was found to correspond well to the height of the plume centroid measured by lidar scanning during the experiment.

Table 1. State space model parameters

Model	X
I	$q/u, h, \theta$
II	$q/u, \theta$

RESULTS

In Figure 1 the results obtained from the EKF analysis in the two models are compared to the measured source term. The symbols (+) and (o) correspond to two out of the four time series of the experiment, for which the gamma detectors spanned the plume in the crosswind direction. In the upper panels of the figure, the measurements include the observed wind direction measured by an on-site weather mast, while for the two lower panels the wind direction measurements were omitted from the analysis.

The source term obtained with the Kalman filter is found in all cases to be approx. 80% larger than the measured source term, although with some scatter around the mean trend values. In Model I, the correlation coefficient between the estimated and the observed source term is 0.85, while in Model II the correlation coefficient is 0.90. The higher correlation found in Model II indicates a better estimate of the source term in this model. The source term estimate is in rough agreement with previous deterministic model calculations, which underestimate the measured radiation field by almost a factor of two, based on the measured source term (*Lauritzen et al.*, 2003).

CONCLUSIONS

The two models provide consistent results for the ^{41}Ar source term; in both cases, however, the estimated source term exceeding the measured values. Slightly better agreement between measured and estimated values are obtained when, as in the present case, a reliable estimate of the plume height is available. Including direct measurements of the wind direction in the analysis does not significantly improve the source term estimate.

The results provide a first validation of the proposed Kalman filter method for source term estimation from off-site gamma radiation measurements. Because of the rather simple models and analysis employed, the method has a strong potential for application in nuclear emergency management as a means for on-line, recursive estimation of the release and atmospheric dispersion of radionuclides, both during routine operations and in an emergency situation. The method is essentially parameter-free and therefore well suited for real-time applications in decision support systems.

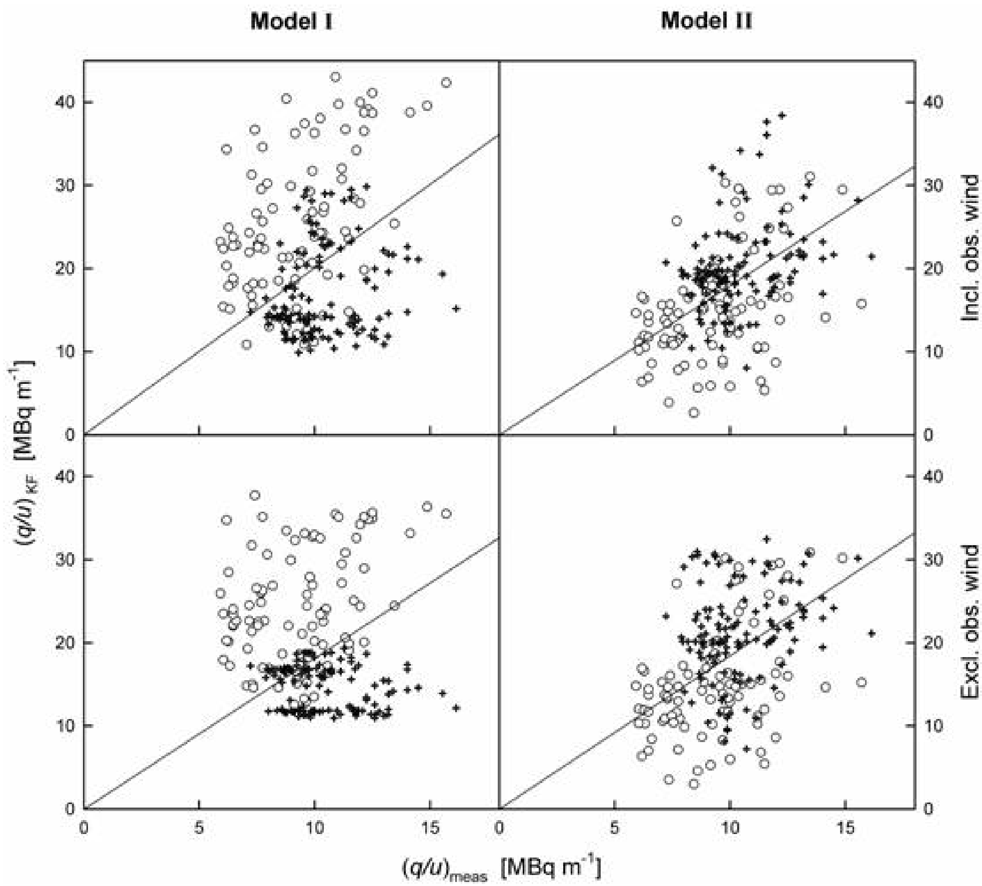

Fig. 1. Estimated vs. measured source term

REFERENCES

Drews, M., B. Lauritzen, H. Madsen, and J.Q. Smith, 2004: Kalman filtration of radiation monitoring data from atmospheric dispersion of radioactive materials. *Rad. Prot. Dos*. **111**, 257-269.

Drews, M., B. Lauritzen, and H. Madsen, 2005: Analysis of a Kalman filter based method for on-line estimation of atmospheric dispersion parameters using radiation monitoring data. *Rad. Prot. Dos*. **113**, 75-89.

Lauritzen, B. et al., 2003: Atmospheric dispersion of argon-41 from a nuclear research reactor: Measurement and modelling of plume geometry and gamma radiation field: *Int. J. Environment and Pollution* **20**, 47-54.

Rojas-Palma, et al., 2004: Experimental Evaluation of Gamma Fluence Rate Predictions from argon-41 Releases to the Atmosphere at a Nuclear Research Reactor Site. *Rad. Prot. Dos*., **108**, 161-168.