1.17 SENSITIVITY AND UNCERTAINTY ANALYSES OF THE ATMOSPHERIC DISPERSION MODEL NPK-PUFF

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INTRODUCTION

In the early repression phase of a large-scale nuclear accident real-time air dispersion modelling is an integral part of the quantitative risk estimate on which a countermeasure strategy is based. Due to the stochastic and chaotic nature of the atmosphere the calculation of air dispersion is complicated and the accuracy of the spatial and temporal distributions is limited due to uncertainties in the algorithms, model parameters, and atmospheric input. A lack of knowledge of the magnitude and composition of the radioactive release into the environment will further add significantly to the uncertainty in the overall result of the calculation. A clear understanding of uncertainties in the model and the model parameters is of key importance in the decision process. This paper presents a preliminary analysis of uncertainties in the Dutch atmospheric dispersion model, NPK-PUFF. Uncertainties due to the meteorological fields are not all taken into account in this study.

DISPERSION MODEL

NPK-PUFF is the Dutch long-range Lagrangian puff model (*Verver, G.H.L. and F.A.A.M. de Leeuw*, 1992) that is operational in the Dutch nuclear emergency management organisation. From this model a short-range version was developed and validated (*Eleveld, H.*, 2002). This version allows the required handling of small and flexible time steps and facilitates output on grid sizes below 1 km^2. In this study the short-range version of NPK-PUFF calculated air and ground concentrations at receptor points using single-station hourly updated meteorological fields.

SENSITIVITY ANALYSIS

To understand the propagation of uncertainties of model and scenario parameters into radiation dose prognoses, a sensitivity analysis of the atmospheric dispersion and deposition models was carried out. Based on the modelled processes in NPK-PUFF, we have identified parameters contributing to the variation of the model outcome. However, not all parameters could be included in the sensitivity analyses. For the moment, restrictions apply for modelling of horizontal dispersion and stability-related parameterisations. More specifically, the Monin Obukhov length, which is calculated by NPK-PUFF using the sensible heat flux and some other parameters, cannot be directly adjusted. Additionally the horizontal dispersion is internally calculated by time and wind shear (*Verver, G.H.L., F.A.A.M. de Leeuw and H.J. van Rheineck-Leyssius*, 1990). As a preliminary investigation we have chosen to vary the horizontal parameterisation by the characteristic Lagrangian time scale t_{Lh} and the initial size of the isotropic horizontal plane σ_y.

To quantify the sensitivity of the various input parameters we applied the ranking number from the Model Validation Tool (MVT) of RIVM (*Eleveld, H. and H. Slaper*, 2002). The measured time-integrated concentration in air is compared with the NPK-PUFF results after varying a specific input parameter. The better the agreement, the lower the MVT ranking. The time-integrated air concentrations are taken from a particular day from the Kincaid data set.

An example of a sensitivity analysis is shown in Figure 1. The observed mixing layer height increases from 484 to 2274 m. An adjustment on the mixing layer height is made through a multiplication by f_{mh} of 0.3 to 2 per model run. An optimum is found for f_{mh} = 0.9, i.e. close to one, demonstrating that the Kincaid mixing heights agree well with our dispersion calculations.

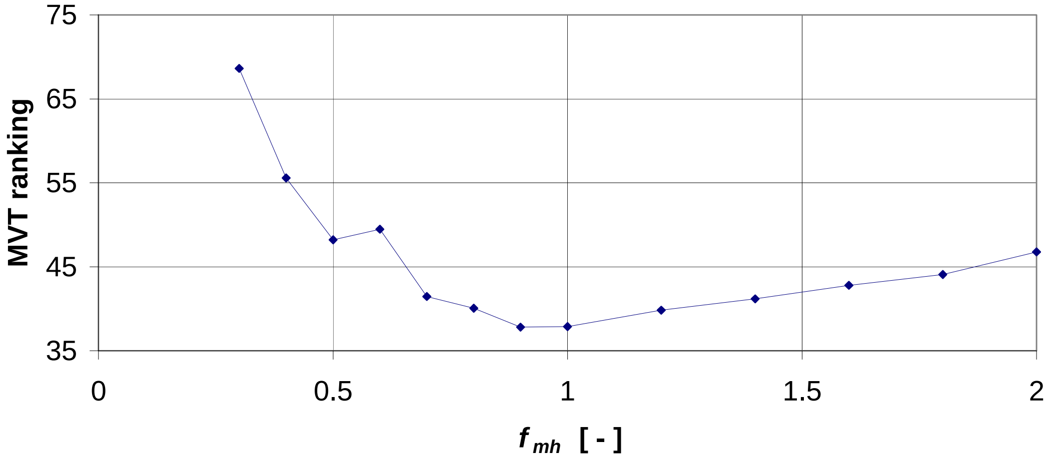

Figure 1. Sensitivity of the mixing layer height. Fraction f_{mh} is a multiplication factor applied to the mixing height. An optimal MVT ranking is found at f_{mh} = 0.9.

Besides mixing height, various parameters were subjected to the sensitivity analysis. Parameters with large responses with respect to the model outcome include the effective emission height, the time step (see also *Eleveld, H.*, 2002), and the cell size of the equidistant grid. Less sensitive parameters are the initial horizontal sigma σ_y, vertical sigma σ_z, surface resistance r_c, roughness length z_0, and the Lagrangian time scale t_{Lh}. After optimising and fixing the time step and the output grid size, the remaining parameters were included in the uncertainty analysis.

UNCERTAINTY ANALYSIS

In the uncertainty analysis parameters identified in the sensitivity analysis are varied according to an individual probability distribution function (pdf). We have made initial guesses for the pdf's assigned to the key parameters. The parameters included in the uncertainty analyses are given in Table 1. The computer program UNCSAM (*Janssen, P.H.M., P.S.C. Heuberger and R. Sanders,* 1992) enables the sampling of input parameters according to user-defined distribution functions. UNCSAM follows the Latin hypercube approach, which reduces the required number of model runs significantly. Furthermore, it calculates the ranking of the input parameters with regard to the contribution in the overall uncertainty. We used the partial rank correlation coefficient (PRCC), which accounts for a linear correlation with other parameters.

Scenarios

Four scenarios with a 4-hour emission are analysed; a dry and a wet (2 $mm.h^{-1}$) day, for low (10–20 m) and high (200–600 m) effective emission heights. The uncertainty ranges selected in this preliminary analysis represent cases with a maximum of uncertainty. The large uncertainty range in the high emission source represents an unknown plume rise due to thermal processes. The arbitrary strength of the release is not considered variable, since it will have a linear effect on the model outcome. Model calculations are performed under the same meteorological conditions as used in the sensitivity analyses. A fraction for the mixing layer profile is included, since it is modelled in NPK-PUFF.

Table 1. Parameter estimates and distribution functions for the four scenarios

Model parameter NPK-PUFF	Central value	Range (pdf)
Roughness length z_0 [m]	0.25	0.001 – 3 (triangular)
Fraction mixing layer profile f_{mh} [-]	0.65	0.3 – 1 (uniform)
Source height h_{em} [m] low source	15	10 – 20 (uniform)
high source	400	200 – 600 (uniform)
Fraction σ_z [-]	1.25	0.5 – 2 (uniform)
Initial σ_y [m]	130	10 – 250 (uniform)
Lagrangian time scale t_{Lh} [min]	90	1 – 180 (uniform)
Surface resistance r_c [s.m^{-1}] ^{131}I	120	60 – 200 (triangular)
Scavenging coefficient Λ [s^{-1}] ^{131}I		*Mixing and reservoir layer*
(Rain only)	5.8E-5	1E-5 – 1E-4 (triangular)

RESULTS

The deposition of radioactive contaminants after 6 hours and the maximum air concentration reached within this 6-hour period are calculated at three monitoring stations at 4, 8, and 36 km from the release point. Figure 2 shows the results for deposition at 4 km from the source. On the left we show results for two times 50 ‘dry’ runs and on the right two times 75 ‘wet’ runs. The resulting model outputs are sorted in increasing order and normalised to unity to represent a (subjective) probability distribution $P(Y \leq y)$. The uncertainties in input parameters roughly show model results that differ by not more than a factor of 10. It should be noted that important contributors to the model uncertainty, the horizontal dispersion process and the variability of the wind field data, are not fully considered in the analysis so far.

In Table 2 to 5 the partial rank correlation coefficient (PRCC) is presented. PRCC values are given at 4, 8, and 36 km from the release point. The fraction f_{mh} ranks first for the dry and low release scenario, closely followed by the surface resistance r_c for the dry scenario with a low source (Table 2). Fraction f_{mh} is outranked only for high releases with a large uncertainty in this parameter (Table 3). If rain is introduced in the analysis (Table 4 and 5) the scavenging parameter in the mixing layer is ranked as most sensitive. The scavenging parameter for the reservoir layer is ranked only in these scenarios for high and large vertical uncertainty sources. This is to be expected since a concentration in the reservoir layer is required to contribute in the wet deposition process (Table 5). Although the results, that depend on the choice of the parameter ranges, have some generic meaning, it is clear that any specific outcome of the ranking of parameters depends on a particular condition (e.g. stability) of the atmosphere.

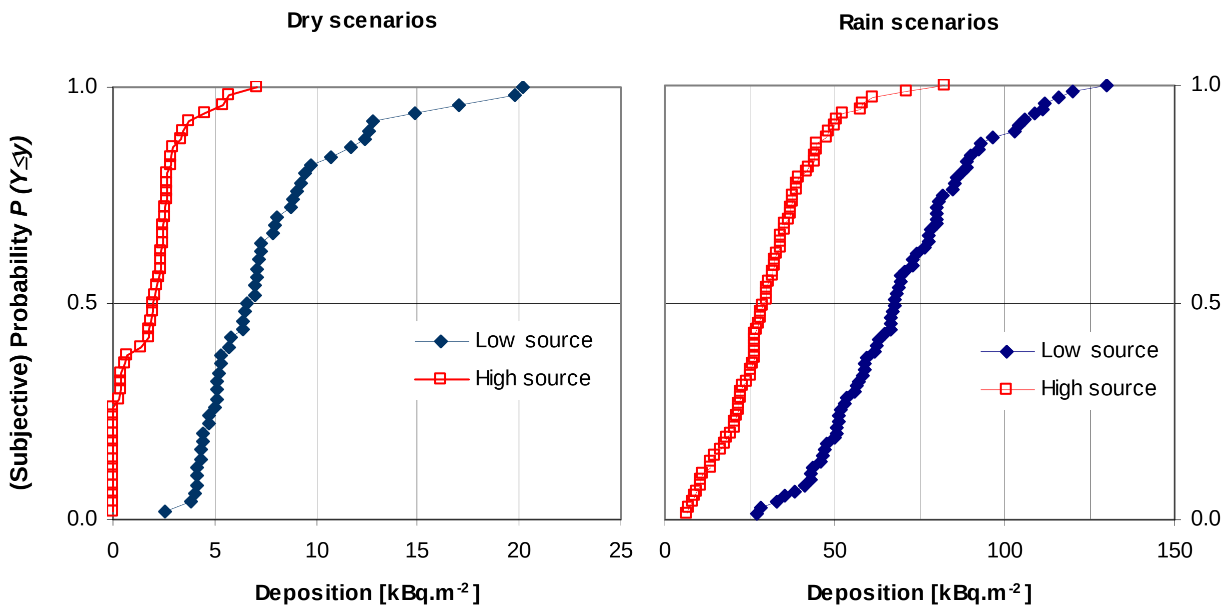

Figure 2. Cumulative distribution function of deposition calculations after 6 hours at 4 km from the source for the four scenarios.

Table 2. PRCC results for deposition in dry scenario with low h_{em}

Parameter	@ 4 km	rank	@ 8 km	rank	@ 36 km	rank
f_{mh}	–0.94	(1)	–0.95	(1)	–0.90	(1)
r_c	–0.79	(2)	–0.78	(2)	–0.62	(2)
z_0	0.46	(3)	0.26	(4)	–0.01	(7)
Fraction σ_z	–0.29	(4)	–0.09	(7)	0.03	(6)
t_{Lh}	0.10	(5)	–0.18	(5)	0.24	(3)
h_{em}	–0.04	(6)	0.28	(3)	0.19	(4)
Initial σ_y	–0.01	(7)	–0.09	(6)	–0.13	(5)

Table 3. PRCC results (truncated) for deposition in dry scenario with high h_{em}

Parameter	@ 4 km	rank	@ 8 km	rank	@ 36 km	rank
h_{em}	–0.74	(1)	–0.72	(1)	–0.71	(1)
f_{mh}	0.50	(2)	0.56	(2)	0.54	(2)
r_c	–0.22	(3)	–0.07	(6)	–0.20	(5)
Fraction σ_z	–0.10	(4)	–0.18	(4)	–0.22	(4)
z_0	–0.04	(5)	–0.18	(3)	–0.25	(3)

Table 4. PRCC results (truncated) for deposition in rain scenario with low h_{em}

Parameter	@ 4 km	rank	@ 8 km	rank	@ 36 km	rank
Λ_{mixing}	0.94	(1)	0.94	(1)	0.85	(1)
f_{mh}	–0.58	(2)	–0.64	(2)	–0.63	(2)
z_0	0.26	(3)	–0.09	(6)	–0.37	(3)

Table 5. PRCC results (truncated) for deposition in rain scenario with high h_{em}

Parameter	@ 4 km	rank	@ 8 km	rank	@ 36 km	rank
Λ_{mixing}	0.50	(1)	0.72	(1)	0.71	(1)
h_{em}	–0.34	(2)	–0.29	(4)	–0.25	(5)
$\Lambda_{reservoir}$	0.31	(3)	0.27	(5)	0.23	(6)
f_{mh}	–0.27	(4)	–0.37	(2)	–0.36	(2)
z_0	–0.18	(5)	–0.21	(6)	–0.32	(3)

CONCLUSION

We have carried out sensitivity and uncertainty analyses with the Dutch dispersion model NPK-PUFF and a simple scenario for a nuclear accident. It must be noted that certain important mechanisms for the atmospheric dispersion are not included yet. A full uncertainty analyses will include all horizontal dispersion parameters, the atmospheric stability parameterisation, and variability of the meteorological wind fields.

UNCSAM appears to be a valuable tool when analysing model behaviour and uncertainties in a complex parameter space. With the UNCSAM analysis we evaluated major contributors to the overall uncertainty of the model calculations. For dry scenarios these included: mixing layer height, effective emission height, roughness length, surface resistance and the vertical dispersion. For wet scenarios the scavenging parameters for the mixing and reservoir layers become more important.

The ultimate goal of the uncertainty evaluation program is to narrow the ranges of the input parameters under operational conditions. For the operational practices the current findings of an order of magnitude difference in model outcome may seem large and even disappointing. However, in view of the rather large uncertainty ranges chosen in the input parameters and the expectation of a considerable decrease of the uncertainty ranges by means of a parameter estimation method, it may well provide an acceptable basis for a quantitative decision process for countermeasures.

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