Validation of Dispersion Model of RTARC-DSS Based on ‘Manno Validation Kit’ Field Experiments

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1 Introduction

RTARC is a computer code (Stubna, 1983) developed at the VUJE Trnava Inc., Slovak Republic to calculate and predict atmospheric transportation and off-site radiological consequences in the event of a nuclear accident or radiological emergency during the early phase. The code is used by nuclear facilities for basic emergency response planning and preparedness, real time dose projection and dispersion calculations during an accident, and for post-accident analysis.

The ‘Manno Validation Kit’ (MVK) is a collection of three experimental data sets from Kincaid, Copenhagen, Lillestrom and supplementary Indianopolis experimental campaigns (TRC, 1986). The validation of the RTARC dispersion model has been performed on the basis of the maximum arc-wise concentrations using the Bootstrap resampling procedure (Hanna, 1991). Validation was performed for the short-range distances.

The maximum observed concentrations at each arc are compared with the estimated maximum concentrations at same arc. The model evaluation contains: 1) Quantitative statistical model evaluation (performance measures and statistical parameters), 2) Scientific evaluation of residual plots (values of the residual are plotted versus values of any variables) and 3) Estimation of model uncertainty components (roughness length, class stability).

From a statistical point of view the overall performance of the model is comparable to other models that have been applied on the ‘MVK’ fields experiments, where all the dispersion models face difficulties due to the stochastic nature of observations. The results of validation have shown that the outputs of the RTARC dispersion model are very sensitive to the accurate estimate of the roughness length and that model exhibits a tendency to underestimate the measured concentrations.

2 Model description

The task of RTARC dispersion model is to calculate space- and time-dependent air and ground concentrations of radionuclides, which represent the core inventory of the VVER type reactors. Dispersion model is straightforward Gaussian model, which simulate buoyant and mechanical plume rise (Briggs, 1976), reflection of plume on the ground and mixing layer, dry and wet deposition, radioactive decay, influence of geometric size of source and influence of surface roughness on the wind profile and vertical difussion parameter. Horizontal and vertical diffusion parameter are calculated according to the scheme Hosker (Hosker, 1974). Model calculates a values of time integrated concentrations.

The input parameters for model evaluation are following: wind speed, stability class, roughness length, mixing height, geometric size of source, averaging time of concentrations, exit velocity and initial buoyant flux of gas. A detailed description of the Model Validation Kit is given by Olesen (Olesen, 1994).

3 Evaluation tools

The most common evaluation procedure is to compare the predicted concentrations with the observed ones. In order to retrieve from an observed concentration pattern the appropriate data set for the validation of a dispersion model the arc-wise maximum (AM) method (Olesen, 1994) was applied in this study. The maximum observed concentrations at each arc are compared with the estimated maximum concentrations at the same arc, no matter where on the arc they occur. This study takes into account only those arcs where a maximum observed concentration could be relatively well-defined, i.e. data quality indicator equal to 3 (designed Q3 in the following).

The predicted ground level concentrations are compared with the observed data, using the BOOT, RESIDUAL and SIGPLOT codes (Hanna, 1991). The codes utilises ordered theoretical and experimental set of data and produces the following “performance measures”: normalized mean square error (NMSE), correlation coefficient (COR), factor of two (FA2), defined as the fraction of the data for which $0.5 \leq C_p / C_o \leq 2.0$, mean fractional bias (FB), fractional variance (FS) and other statistical parameters, as mean, sigma and bias. C_o and C_p are the observed and calculated concentrations, respectively.

The models’ behaviour is also examined qualitatively, through the scatter plots of the corresponding observed and predicted concentrations. Because it is important that the performance of a model should not show any trend with variables as distance from source, stability, buoyant flux and velocity, the so-called residuals plots are illustrated in this work. The residuals, defined as the ratios of the predicted versus the observed concentrations (Cp/Co), for two data sets (Kincaid and Indianopolis) are plotted against the above mentioned variables. The concentrations are distributed to certain regions of each variables, and the residuals are plotted using ‘box plots’. The boxes indicate five significant points: the 5, 25, 50, 75, 95-percentiles of the N points that belong to each region.

Regarding the fact that results of statistical validation are considerably dependent on estimate of roughness length, the simple analysis of uncertainties influence of input parameters on output results were carried out. Uncertainty analysis was made using Monte Carlo method with application Latin Hypercub Sampling procedure. The influence of uncertainties following parameters was examined: wind speed, mixing height, buoyant flux, class stability and roughness length. These calculation were done for 500 runs using the normal and uniform distribution for wind speed, mixing height and buoyant flux and piecewise distribution for class stability and roughness length. Correlation between input parameters weren’t taken into account.

4 Results

Quantitative statistical model evaluation has been performed for all four field experiments. Two calculations with the different roughness length (RL) has been performed for each experiment. Straight Co a Cp comparison was selected for the purposes of the quantitative evaluation. Results of quantitative evaluation for the Kincaid and Indianopolis data sets are summarised in the tables 1–2.

Table 1 Kincaid data set; statistics for maximum arc-wise concentrations $\mu g/m^3$; based on data subset Q3; 280 observations; the estimate of RL = 0.6 m.

Model	Mean	Sigma	Bias	NMSE	COR	FA2	FB	FS
C_OBS	0.71	0.53	0.00	0.00	1.000	1.000	0.000	0.000
RL 0.1m	0.35	0.26	0.36	1.80	0.099	0.468	0.676	0.684
RL 1.0m	0.53	0.33	0.18	0.82	0.335	0.629	0.295	0.468

Table 2 Indianopolis data set; statistics for maximum arc-wise concentrations ng/m^3 ($ng = 10^{-9} g$); based on data set Q3; 168 observations; the estimate of RL = 1.0 m.

Model	Mean	Sigma	Bias	NMSE	COR	FA2	FB	FS
C_OBS	1341.82	948.87	0.00	0.00	1.000	1.000	0.000	0.000
RL 1.0m	948.06	538.66	393.76	0.98	0.096	0.482	0.344	0.552
RL 4.0m	1317.10	745.01	24.72	0.65	0.216	0.494	0.019	0.241

The values FA2 a NMSE clearly indicate that the model RTARC has a tendency to underestimate the observed values in the cases Kincaid and Indianopolis data set. This is indicated by the values of FB = 0.295 (RL = 1 m) for Kincaid and FB = 0.019 (RL = 4 m) for Indianopolis.

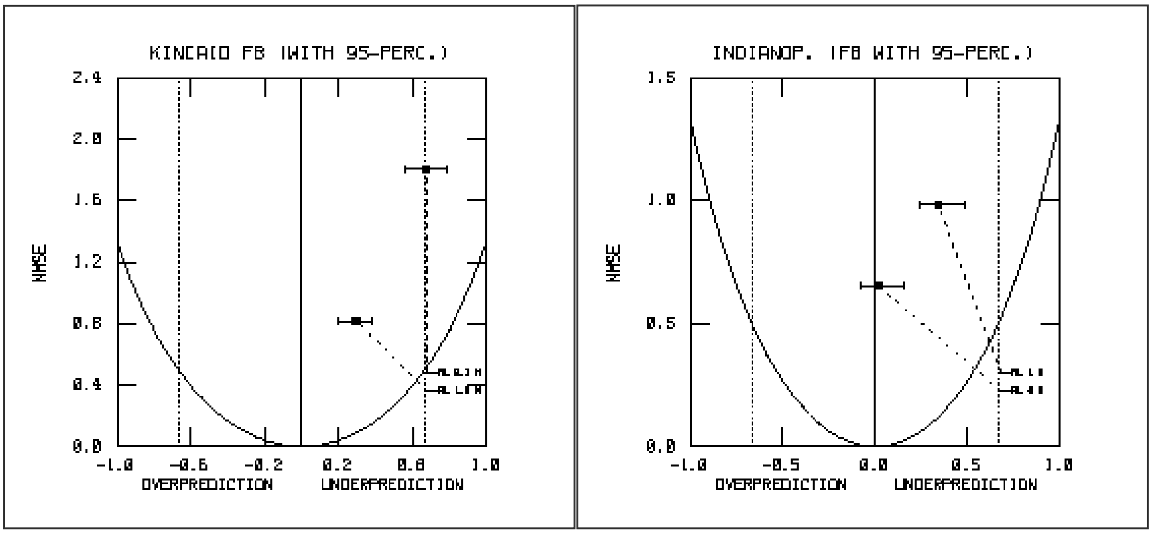

Figure 1 Error bar plots for Kincaid (left side) and Indianopolis experiment (right side).

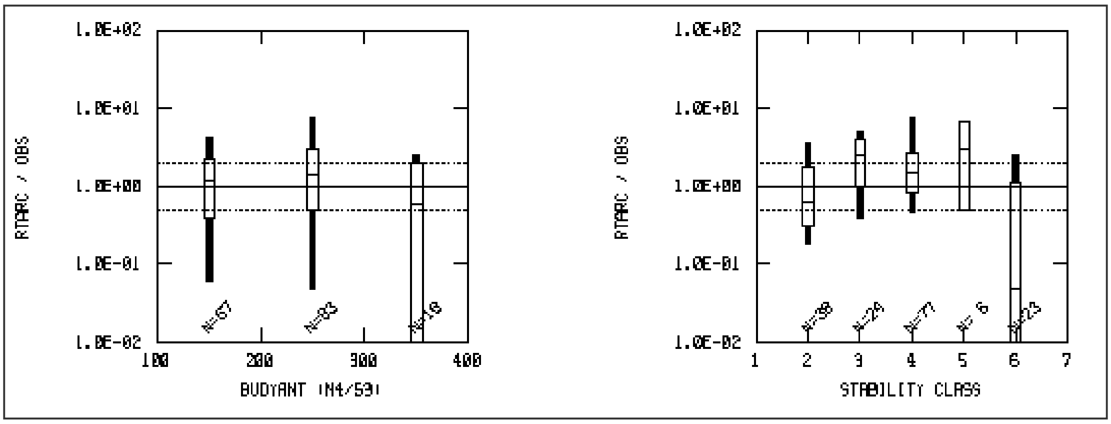

Figure 2 Indianopolis experiment: residual plots for distance from source (XDIS), wind speed (U), initial buoyant flux and PG stability class.

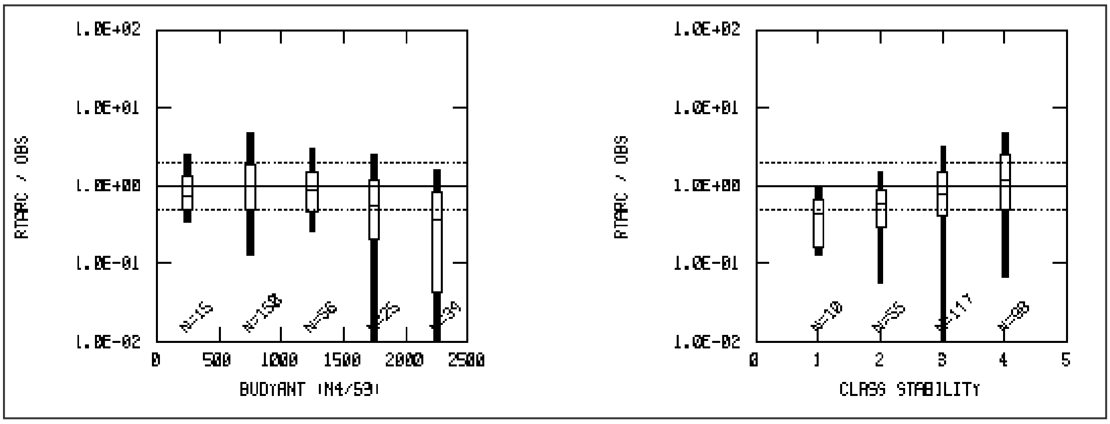

Figure 3 Kincaid experiment: residual plots for distance from source (XDIS), wind speed (U), initial buoyant flux and PG stability class.

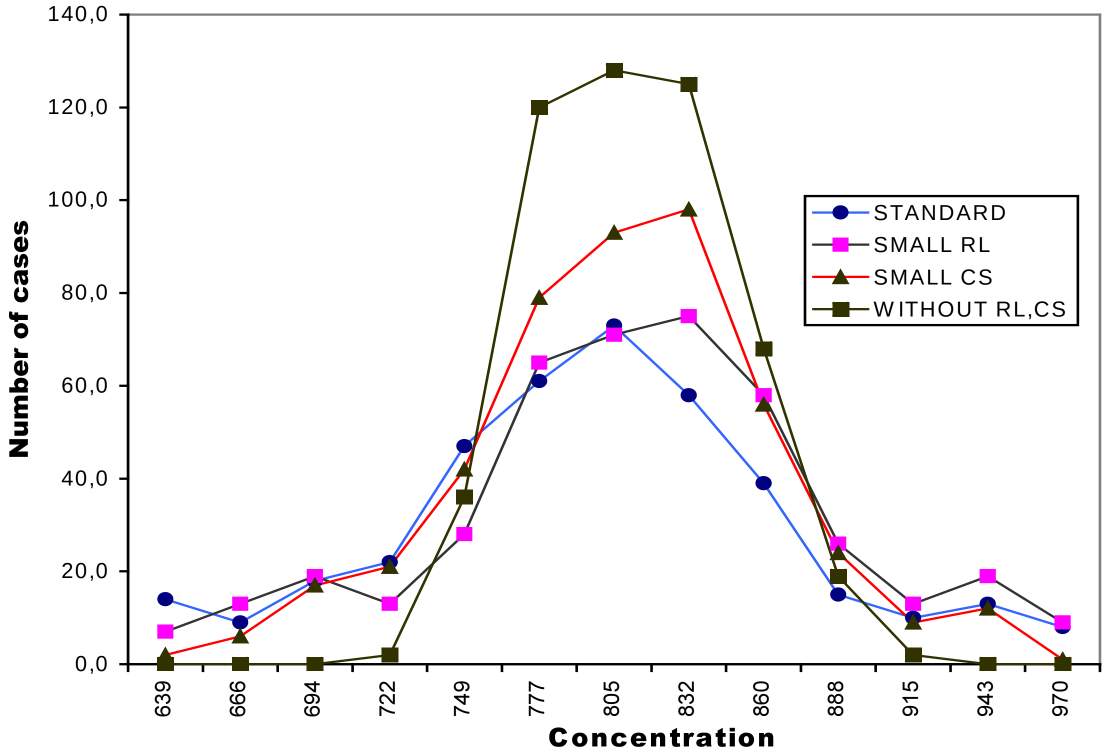

Figure 4 Function of frequencies for calculations with different uncertainties of roughness length (RL) and class stability (CS).

The underestimates and overestimates of the model are very good presented in Figure 1 (for Kincaid and Indianopolis experiment) by error bar plots. A detailed analysis of the model results is presented in Figures 2 and 3, which show residual plots for Kincaid and Indianopolis experiment data sets and for roughness length, which is great than estimated one. The bars in the box plots represent the percentiles of distributions of the N points (where N was defined on the basis of data sets of measurements for the responsible interval of values on the x-axis).

Propagation of parameter uncertainties is presented in Figure 4. The calculations were done for distance 10 km from source, wind speed 2 m/s, initial buoyant flux 270 m^4/s^3, mixing height 800 m, PG class stability B and roughness length 1.0 m. For the case so-called STANDARD was used piecewise distributions for class stability (probabilities for A=0.25, B=0.5, C=0.25) and roughness length (probabilities for 0.4 m = 0.25, 1.0 m = 0.5, 4.0 m = 0.25). For the cases so-called SMALL RL and SMALL CS were used in opposite to case STANDARD different probabilities for RL and CS: 0.10, 0.80 and 0.10. The so-called WITHOUT RL, CS was made using of deterministic values for RL and CS.

Analysis of uncertainties refer to the fact that model is the most sensitive towards uncertainty of class stability and only afterwards on roughness length. Uncertainties of both parameters influence upon the results throughout the exponent of vertical wind profile.

5 Conclusions

In the framework of this study, the performance of the model RTARC was assessed using ‘Kit’ field experiments. The validation was based on the evaluation of data sets which were determined according to the maximum of the arc-wise concentrations. The model exhibits a tendency to underestimate the measured concentrations under conditions, when initial buoyant flux is great than

1500 m^4/s^3 (Figure 3) or stability conditions are very stable (6 stability class – Figure 2). The ‘slight’ underprediction of the model in the case of very unstable conditions can be seen on Figures 2 and 3 – PG class stability 2 and 1. Nevertheless, this information could be used to guide future modifications of RTARC (plume rise model). When the RL values are equal estimated ones, the very ‘strong’ tendency of the underestimation of the model can be seen. Because the ‘Kit’ experiments covers mostly unstable and neutral conditions, it is important to carry out further test at data sets (including stable conditions too).

Generally, this model is very sensitive to the accurate estimate of roughness length (see Figure 1) and class stability. The difference between statistical evaluation for different RL is caused by dependence of exponent (vertical wind profile) on the value RL and class stability (urban or rural terrain). In the future, there will be need to examine the model sensitivity on the uncertainty of the vertical wind profile. Doing the calculations using Monte Carlo method, it will be necessary to take into account correlation between input parameters as well (for example between PG class stability and wind speed).

6 references

1. Stubna, M., Kusovska, Z., (1993), ‘RTARC: A computer code for radiological severe accident consequence assessment – Models and code description’, *Radiation Protection Dosimetry*, Vol. 50, Nos 2-4, pp. 135-139, 1993.
2. Briggs G.A., (1976), ‘Plume Rise Prediction’, In: Haugen, D. A.,: Lectures on Air Pollution and Environmental Impact Analyses, 59-111. American Meteorological Society, Boston, Mass., U.S.A., 1976
3. Hosker R.P., (1974), ‘Estimates of dry deposition and plume depletion over forests and grassland’, Oak Ridge, U.S.A., IAEA-SM-181/19, pp. 291-308.
4. Olesen H. R., (1994), ‘Model Validation Kit for the workshop on ‘Operational Short-Range Atmospheric Dispersion Models for Environmental Impact Assessments in Europe’’, Compendium of materials. NERI, Denmark.
5. Hanna S.R., Strimaitis D.G., Chang J.C., (1991), ‘Hazard response modeling uncertainty (a quantitative method). Vol. I: User’s guide for software for evaluating hazardous gas dispersion models’, Sigma Research Corporation, Westford, Ma.
6. TRC, (1986), ‘Urban power plant plume studies’, EPRI Report EA-5468, EPRI, 3412 Hillview Ave, Palo Alto, Ca 94304.