ILLUSTRATION OF PROBABILISTIC APPROACH IN CONSEQUENCE ASSESSMENT OF ACCIDENTAL RADIOACTIVE RELEASES

Petr Pecha[1], Radek Hofman[1], Petr Kuča[2]
[1] Institute of Information Theory and Automation, AV CR, Prague
[2] National Radiation Protection Institute, Prague

MOTIVATION

We are describing a certain application of uncertainty analysis of environmental model HARP applied on atmospheric and deposition submodel. Simulation of uncertainties propagation through the model is basic inevitable task bringing data for advanced techniques of probabilistic consequence assessment and further improvement of reliability of model predictions based on statistical procedures of assimilation with measured data. The activities are investigated in the institute IITA AV CR within the grant project supported by GAČR (2007-2009). The problem is solved in close cooperation with section of information systems in institute NRPI.

The subject of investigation concerns evaluation of consequences of radioactivity propagation after an accidental radioactivity release from nuclear facility. Transport of activity is studied from initial atmospheric propagation, deposition of radionuclides on terrain and spreading through food chains towards human body. Subsequent deposition processes of admixtures and food chain activity transport are modeled. In the final step a hazard estimation based on doses on population is integrated into the software system HARP (more detailed description is published in [2.]). Extension to probabilistic approach has increased the complexity substantially, but offers much more informative background for modern methods of estimation accounting for inherent stochastic nature of the problem.

FROM DETERMINISTIC CALCULATIONS TO PROBABILISTIC APPROACH

Deterministic calculations did not comply with the inherent uncertain character of the problem and offer only single values of resulting target quantities. It relates to a certain deterministic single set of model input parameters based on the “best estimate” procedure or conservative “worst case” choice. On the other hand probability codes introduce capability to define a measure of confidence in model predictions. It allows progress from former deterministic calculations towards the generation of probabilistic answers on assessment questions. Quantitative reliability statements can determine a level of confidence with regards to exceeding of postulated limits and then provide much firmer basis for qualitative statements in the field of emergency management. The probabilistic tool offers support related to estimation of conservatism or adequacy of results.

Reliable and up to date information represents basic inevitable condition for effective management of intervention operations targeted on consequence mitigation during emergency situations. Advanced statistical methods of assessment require more profound uncertainty and sensitivity studies and model errors description. Within the frame of applied models, many uncertainties related to imperfections of both conceptual model (parametrization errors, uncertain submodel parameters, stochastic nature of some input data) and computational scheme (step of computation net, averaging land-use characteristics, averaging time for dispersion parameters, uncertainty in release scenario etc) are involved. In consequence of the inherent uncertainties the output radiological quantities have a random character. Thus, the processing and interpretation have to be based on probabilistic bases. Our first results coming out from point estimation of Monte Carlo samples are given in [4.]. In this article we proceed to interval estimation of confidence bounds with attempt to visualise this in 2-D representation using interactive graphical subsystem of the HARP code.

EXAMPLE OF PROBABILISTIC EVALUATION OF A HARMFUL RELEASE

Hypotetical scenario of radioactivity release

Illustration of probabilistic estimation is tested for scenario *MELK-STEP II* (our traditional trial configuration for testing of the new HARP functions) which was formulated for joint Czech – Austrian negotiations *STEP II b* within so called “MELK PROCESS”. Real dynamics for severe LOCA accident with partial fuel cladding rupture and fuel melting (from RODOS ST2 source term) is split up to 6 equivalent 1-hour segments. For prediction have been used retrospective meteorological forecast sequence “*CASE2*” from June 28, 2002 with release start at 00 UTM. We have implemented segmented Gaussian plume model (SGPM) for description of admixtures propagation in atmosphere and their deposition on terrain. SGPM is capable to synchronize stepwise time dynamics of the release and hourly changes of meteorological conditions provided by the Czech meteorological service. In the further calculations we have introduced a certain simplifications assuming only 1-hour release of 1.32E+12 Bq of ^{137}Cs in the 1^{-st} equivalent segment, rain occurs only from hour 5 to 6 after the release start (random rain intensity has uniform distribution U < 0 ; 6 mm.h^{-1} >). Release height is 60 m, SCK/CEN dispersion formulae for rural-type of terrain roughness are used.

Uncertainty group of parameters of dispersion and deposition models

Let $\Theta \equiv \{\Theta_1, \Theta_2, \ldots, \Theta_M\}$ denotes a vector of M input random parameters Θ_m of SGPM model with corresponding sequence of distributions $D_1, D_2, \ldots, D_M$ which are usually selected on the basis of commonly accepted agreement of experts (range, type of distribution, potential mutual dependencies). The value of dimension M of input vector Θ is in general rather high. Further reduction of number M should be done on basis of sensitivity studies. For better understanding and perception of the problem we illustrate in Table 1 an uncertainty group and corresponding probability density functions derived on basis of extensive literature review and recommendations from elicitation procedures of experts.

Table 1. Default uncertainty group for dispersion and deposition model

param. id. and meaning	*pdf_type*	*param. id. and meaning*	*pdf_type*
ADM1: release intensity	lognormal$^{(*)}$	ADM8: mean wind speed $^{(***)}$	uniform
ADM2: σ_y - horizontal dispers.	lognormal$^{(*)}$	ADM9: wind profile exp.	normal$^{(*)}$
ADM3: horizontal wind fluct. $^{(**)}$	normal$^{(*)}$, discrete	ADM10: σ_z vertical dispersion	lognormal$^{(*)}$
ADM4: dry depo-elem iodine	loguniform	ADM11: mixing height correction	triangular
ADM5: dry depo-aerosol	loguniform	ADM12: thermal energy correrction	lognormal$^{(*)}$
ADM6: scavening coef.elem.iod.	loguniform	ADM13: precipitation intensity	uniform
ADM7: scavening coef. aerosol	loguniform	ADM14: time shift of precipitation	uniform discrete

$^{(*)}$ … *truncated ;* $^{(**)}$ … *horizontal wind direction fluctuation* $\Delta\varphi = ADM3*2\pi/80$ *(rad) ;*
$^{(***)}$ … *uncertain wind speed* $u=(1+0.1*ADM8)*u_{10} + 0.5*ADM8$; u_{10} *measured at 10 m*

Due to strong dependency on scenario type and subjective experts' opinion, the options from Table 1 have not general applicability. For this reason an independent subsystem is associated with probabilistic part of the HARP system for generating of multiple samples $\underline{k}$ (*k=1,…, K*) of input vector $\theta^k \equiv \{\theta_1^k,..., \theta_m^k ,…, \theta_M^k \}$ based on Latin Hypercube Sampling (LHS). At the same time the user can select from wide range of options related to changes of number of parameters M and type and extent of distributions.

Projection of uncertainties of input parameters of SGPM into output

Subject of interest is now examination of input parameter uncertainty propagation through SGPM towards resulting radiological quantities. Further discussion will be restricted to analysis of resulting random field of deposited activity of ^{137}Cs on terrain. The field is predicted by SGPM scheme such a random background vector ${}^{P}\mathbf{X}^{\mathbf{SGPM}} \equiv \{X_1, X_2, …, X_N\}$, where index p means “prediction”. The components X_i of vector **X** represent the random value of analysed output in each spatial node *i* of calculation grid. The calculation polar grid consists of 35 radial distances up to 100 km and 80 angle sectors, which means 2800 nodes in total. Computation simulation $\Re^{SGPM}$ based on SGPM approach enables to predict background vector according to general scheme

$$ {}^{P}\mathbf{X}^{\mathbf{SGPM}} \approx \Re^{SGPM}(\Theta_1, \Theta_2, …, \Theta_M) \qquad (1)$$

Adopted scheme of Monte Carlo modeling proceeds in two steps:

1. Generation of a particular *k-th* sample of input vector $\theta^k \equiv \{\theta_1^k,..., \theta_m^k ,…, \theta_M^k \}$, where θ_m^k is k-th realisation of m-th input random parameter Θ_m .
2. Propagation of the sample *k* through the model, it means calculation of the corresponding resulting *k-th* realisation of the background vector $\mathbf{x}^k$ according to $\mathbf{x}^k \approx \Re^{SGPM} (\theta_1^k,..., \theta_m^k ,…, \theta_M^k)$

The process yields K realizations of output background vector $[\ \mathbf{x}^k\ ]_{k=1, \dots , K}$. Provided that the value of K is sufficiently high (several thousands), statistical processing using methods of uncertainty analysis and sensitivity studies can be used as follows.

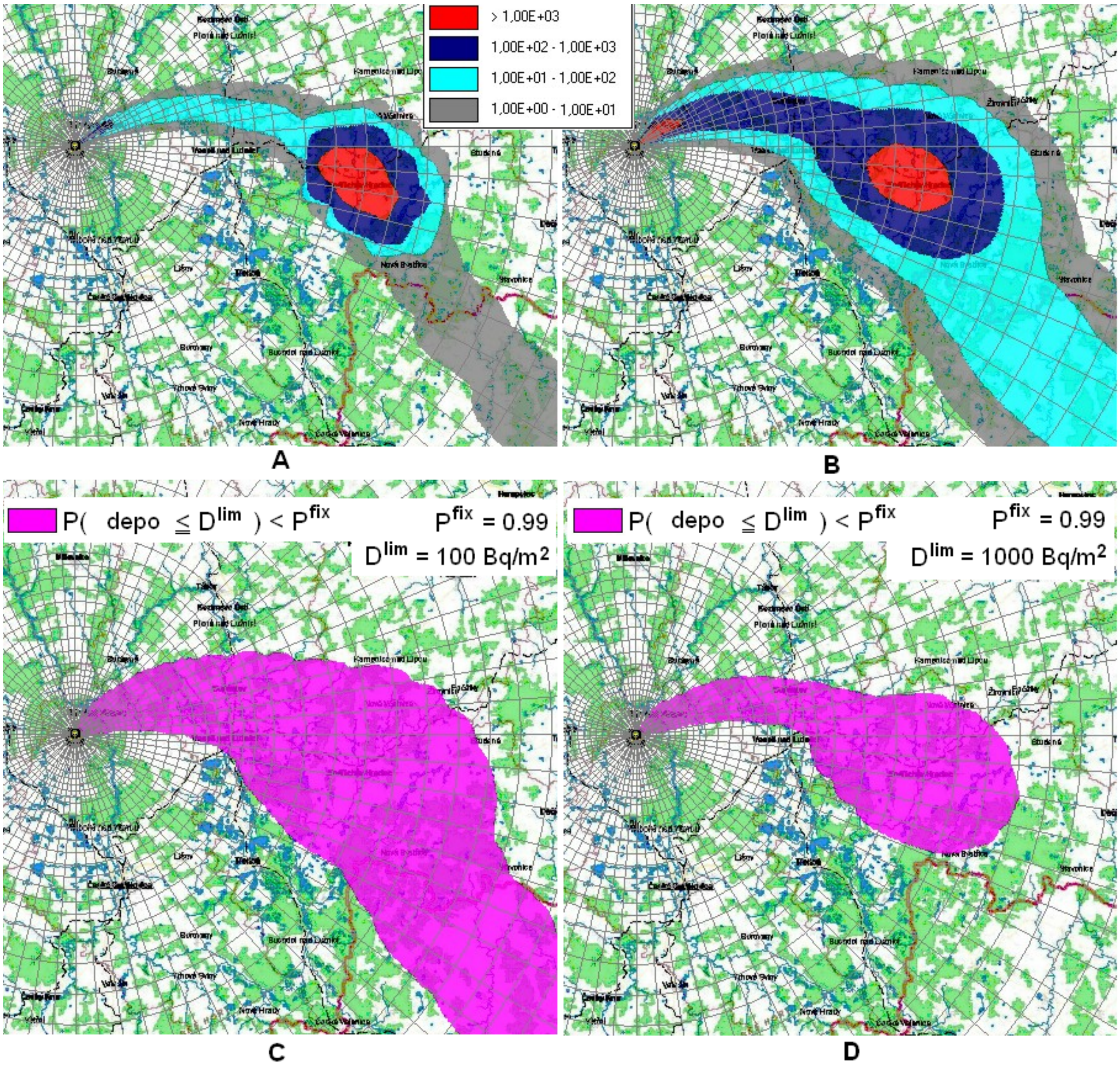
Interactive 2-D graphical presentation of probabilistic levels

K realizations of output background vector $[\ \mathbf{x}^k\ ]_{k=1, \dots , K}$ have been generated for K=5000. Random character of parameters ADM12 and ADM14 from Table 1 was so far ignored. Each particular realisation *k* of vector $\mathbf{x}^k$ having dimension N stands for specific activity deposition of ^{137}Cs in all calculation points of polar grid in Bq/m^2. Sampling statistics important for estimation of release consequences can be generated from this K samples. An attempt to visualize spatially new probabilistic approach is illustrated in Figure 1. Deterministic “best estimate” prediction expressed by scheme $\mathbf{x}^{\mathbf{best}} \approx \Re^{SGPM} (\theta_1^{best},..., \theta_m^{best} ,…, \theta_M^{best})$ is in Figure 1A. Noticeable “red bull eye” is caused by washout of activity by atmospheric precipitation (nominal intensity 3 mm/hour between hour 5 to 6 after the release start). Spatial 2-D distribution of sample mean values is shown in Figure 1B. In Figure 1C respectively 1D are illustrated colored areas, where probability of not exceeding limit 100 Bq/m^2 respectively 1000 Bq/m^2 is lower than fixed selected value $P^{fix} = 0.99$. In other words (more familiar in the field of radiation protection), outside the colored areas the deposition limit will not be exceeded with probability lower than number P^{fix}. A certain analogy between shape in Figure 1B and probability lines in Figure 1C and 1D is understandable. The functions illustrated above are integrated into the HARP system. User can enter selected values of deposition limit D^{lim} and P^{fix} interactively with fast graphical response on screen. At the same time, numerical value of $P(depo \le D^{lim})$ is displayed on the screen for any mouse position in analyzed area.

CONCLUSION

Example of probabilistic assessment illustrated here is based on uncertainty analysis of input parameters of SGPM model. Predicted background field of ^{137}Cs deposition are labelled with index <u>*p*</u> as $^{P}\mathbf{X}^{\mathbf{SGPM}}$. Final goal is estimation of a certain unknown true background vector $\mathbf{x}^{\mathbf{true}}$, which accounts also for deficiencies of the SGPM formulation in itself insisting in insufficient description of reality. We must have on mind, that even if we know true values of all input parameters θ_m^{true} *(m=1,…,M)* of SGPM model, the $\mathbf{x}^{\mathbf{true}}$ still remain uncertain. One possibility how to approach reality insists in comparison of results of various models sometimes called as ensemble benchmark. More promising way is data assimilation process enabling stepwise incorporation of observations incoming from terrain. The latter alternative is our main task investigated within grant project No. 102/07/1596 supported by GAČR (first results in [3.]).

Figure 1. Spatial distribution of ^{137}Cs activity deposition on terrain [Bq/m^2]. Picture of deterministic „best estimate“ (see A); Sample mean (see B); Probability P(depo≤D^{lim}) < P^{fix} says: deposition limit D^{lim} will not be exceeded with probability lower then selected number P^{fix} ; for D^{lim} =100 Bq/m^2 , P^{fix} = 0.99 (see C); for D^{lim} =1000 Bq/m^2 , P^{fix} = 0.99 (see D)



REFERENCES

[1.] Saltelli A., Chan K. and Scott E. M., 2001: Sensitivity Analysis. John Wiley & Sons Ltd, ISBN 0-471-99892-3.

[2.] Pecha P., Hofman R. and Pechova E., 2007: Training simulator for analysis of environmental consequences of accidental radioactivity releases. 6th EUROSIM Congress on Modeling and Simulation (Ljubljana, Slovenia, September 9-13, 2007), ISBN 978-3-901608-32-2.

[3.] Hofman R. and Pecha P., 2007: “Integration of data assimilation subsystem into environmental model of harmful ….”. HARMO11 Conf., Cambridge, UK, July 2-5, 2007), 111-115.

[4.] Pecha P. and Pechova E., 2005: Modeling of random activity concentration fields in air …. HARMO10 Conf., Sissi (Crete),Greece, October 17-20, 2005, paper No. H11-069.