ASSIMILATION OF GAMMA DOSE MEASUREMENTS IN A LAGRANGIAN MODEL DIPCOT

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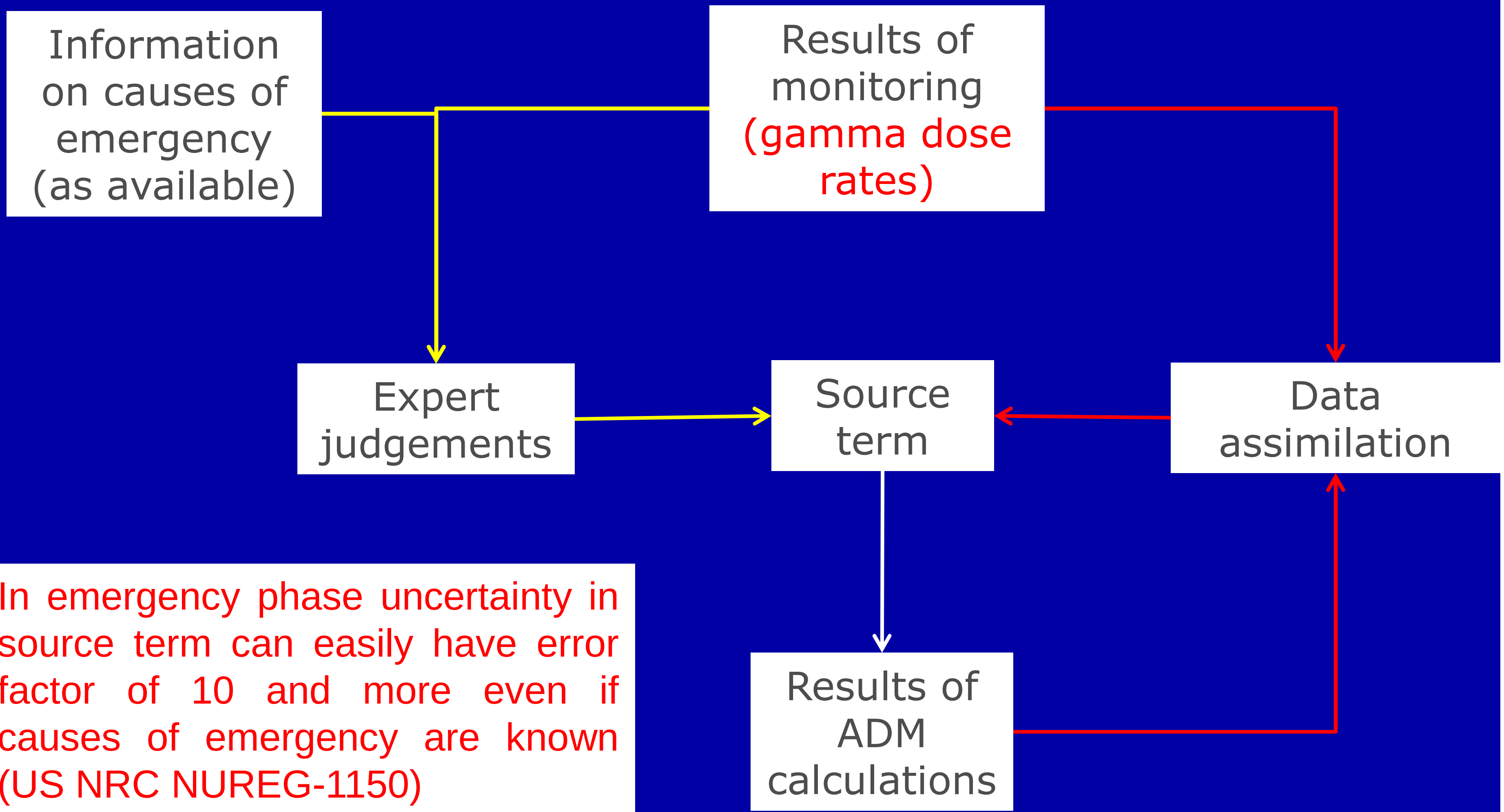
Source term assessment in emergency phase



In emergency phase uncertainty in source term can easily have error factor of 10 and more even if causes of emergency are known (US NRC NUREG-1150)

Objective of the study

To develop numerically efficient and accurate method of source term estimation with assimilation of gamma dose measurements suitable for application with Lagrangian stochastic model DIPCOT in emergency phase of nuclear accident

Description of the DIPCOT (Anrdonopoulos, et.al., 2009)

Two versions were used: stochastic (Lagrangian puff) and deterministic (Gaussian puff)

Particles are assumed to follow the mean and fluctuating (only in stochastic version) wind flow

$$x_i^{n+1} = x_i^{n} + \left(\overline{u_i} + u_i'\right)\tau$$

Turbulent velocity fluctuations are based on the assumption that turbulent diffusion can be modelled as a Markov process, using Langevin equation

$$C(x_o, y_o, z_o, t) = \frac{1}{(2\pi)^{3/2}} \sum_{i=1}^{N} \frac{q_i \tau \exp\left(-\lambda\left(t-(i-1)\tau\right)\right)}{\sigma_x \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\frac{(x_i - x_o)^2}{\sigma_x^2}\right)$$
$$\exp\left(-\frac{1}{2}\frac{(y_i - y_o)^2}{\sigma_y^2}\right)\left\{\exp\left(-\frac{1}{2}\frac{(z_i - z_o)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2}\frac{(z_i + z_o - 2z_g)^2}{\sigma_z^2}\right)\right\}$$

Concentration calculations: Gaussian-shaped density kernel in both stochastic and deterministic modes (Yamada and Bunker 1988)

Gamma dose calculations in DIPCOT

Fluence rate

$$\Phi(x_0, y_0, z_0) = \frac{1}{4\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{Be^{-\mu r}c(x,y,z)}{r^2}dx\,dy\,dz$$

(general formula is too time consuming)

Another calcultion method is used which is based on the work of **Gorshkov, (1994)** as adapted for the use in DIPCOT in **Andronopoulos and Bartzis, (2010)**. New coordinate system is introduced which origin coincides with puff's center and z-axis intersects sensor point. After certain integral transformations 3D integral is reduced to 1D

$$\Phi_i(0,0,h_i) = \frac{1}{4\pi}\frac{Q_i}{\sigma'_{xi}\sigma'_{yi}\sigma'_{zi}}\frac{1}{\mu}(A_1 + \kappa A_2)$$

A_1 A_2 are functions of 4 variables: μh_i h_i/σ'_{xi} h_i/σ'_{yi} h_i/σ'_{zi}

Statement of data assimilation problem

Variational formulation

Cost function to be minimized

$$J_1 = \sigma_B^{-2}\left(\overline{q} - \overline{q}^b\right)^T \left(\overline{q} - \overline{q}^b\right)$$

$$J_2 = \sigma_O^{-2}\sum_{n=1}^{N_O}\sum_{k=1}^{K}\left(d_k^o(t_n) - \tilde{d}\left(\overline{r}^k\right)\right)^2 = \sigma_O^{-2}\left(\overline{d}^o - \underline{\underline{G}}\overline{q}\right)^T\left(\overline{d}^o - \underline{\underline{G}}\overline{q}\right)$$

$$J = \left(\sigma_O / \sigma_B\right)^2\left(\overline{q} - \overline{q}^b\right)^T\left(\overline{q} - \overline{q}^b\right) + \left(\overline{d}^o - \underline{\underline{G}}\overline{q}\right)^T\left(\overline{d}^o - \underline{\underline{G}}\overline{q}\right)$$

Subject to $\overline{q} \geq 0$

Calculation of elements of the matrix G

$$g_{li} = \frac{1}{4\pi}\sum_{ig=1}^{4} f_{ig}\,\frac{\mu_{\alpha,ig}E_{\gamma,ig}}{\rho\mu}\,\frac{\left[\tau\exp\left(-\lambda\left(t_l - (i-1)\tau\right)\right)\right]}{\sigma'_{xi}\sigma'_{yi}\sigma'_{zi}}\left(A_{1,ig,i,l} + \kappa_{ig}A_{2,ig,i,l}\right)$$

Control vector reduction

Problems that arise in straightforward implementation of DA

1. Poor convergence with very large number of puffs
2. In stochastic model elements of G-matrix are random variables

Assume that during time interval Δt source function is constant

In operational practice: $\Delta t \sim 10^3 \div 10^4\, s$ $\tau \sim 0.1 \div 100\, s$ ⇒ $\Delta t / \tau = \Pi >> 1$

Puffs are joined in $P=N_p/\Pi$ groups (later reffered also as CVR parameter)

Minimizing with respect to the reduced control vector $\underline{\tilde{q}}$ of the size P is performed.

Elements of $\underline{\tilde{q}}$ represent source rate for each group of puffs.

Elements of the reduce G-matrix $\underline{\underline{G}}^r$ are calculated by formula:

$$g_{lj}^r = \sum_{m=1}^{\Pi} g_{l((j-1)\Pi+m)}, \forall l,\ 1 \le l \le N_o K, 1 \le j \le P$$

From Central Limit Theorem and following the condition Π>>1 elements g_{lj}^r of the reduced G-matrix converge to statistically stable values

Experiment on ^{41}Ar dispersion in Mol, Belgium

Drews, et.al., (2002)

•Was carried out at the BR1 research reactor of the Belgium Nuclear Research Centre (SCK-CEN) in Mol

•Two experiments were simulated, Wednesday, 3^{d} Oct. 2001, Thursday, 4th Oct. 2001

Available measurements

•measured ^{41}Ar emission rate from the stack (average value was 1.5×10^{11} Bq/h)

•meteorological data by a weather mast (10 minute averages);

•monitoring of the gamma radiation field (fluence rate)

Basic setup of DIPCOT

•The meteorological data were preprocessed by MPP FILMAKER to prepare input meteorological fields for DIPCOT

•Time interval between puffs releases $\tau\approx3$ s

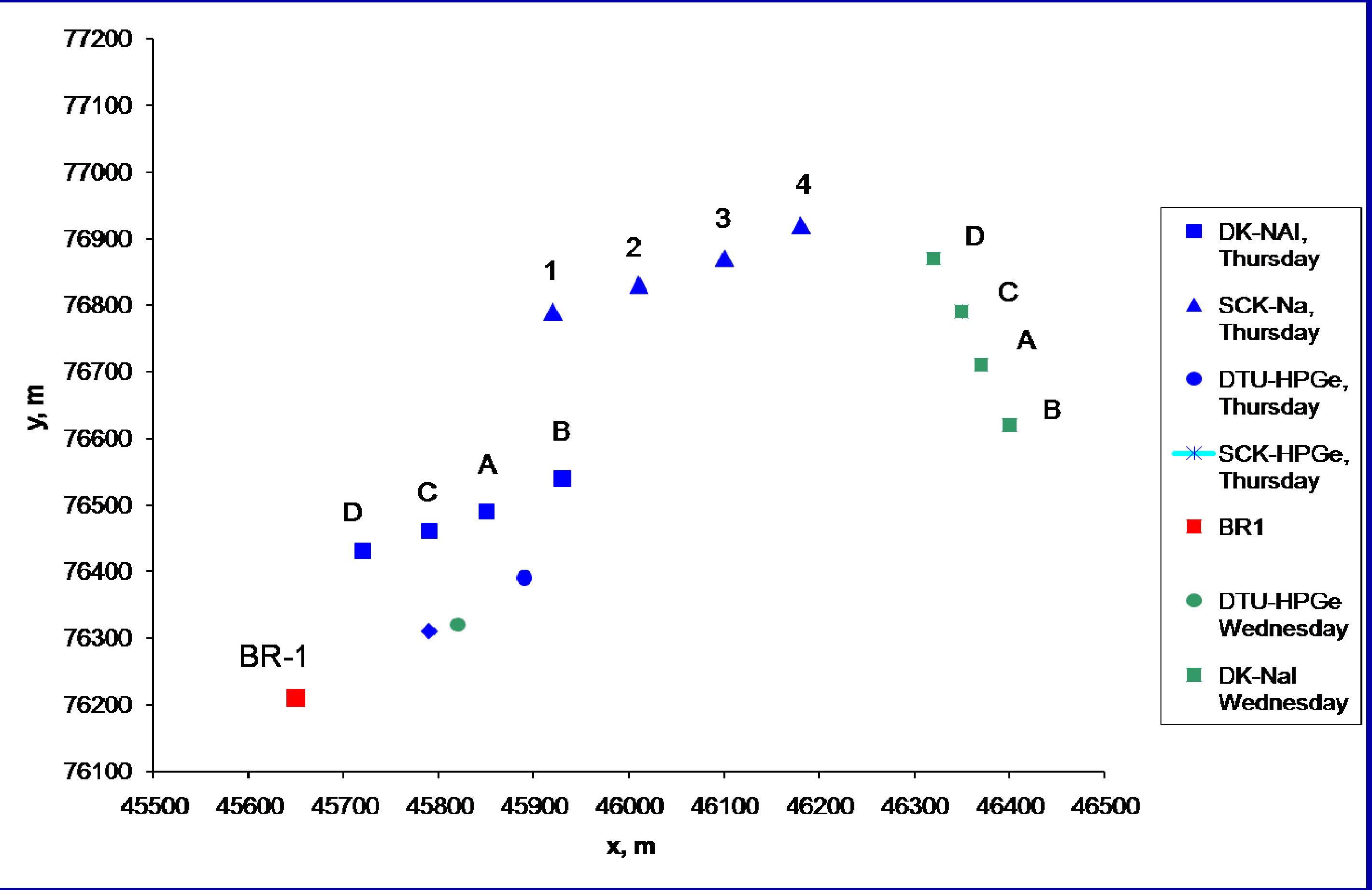
•First guess source function was by the factor of 10 greater than the true;

•Tests with both stochastic and deterministic versions of DIPCOT

•Tests with different value of CVR parameter P

•Special Note: results published in extended abstract don't agree with the results presented here because they were calculated with significantly larger $\tau\approx12$ s

Sensors locations in Mol experiments



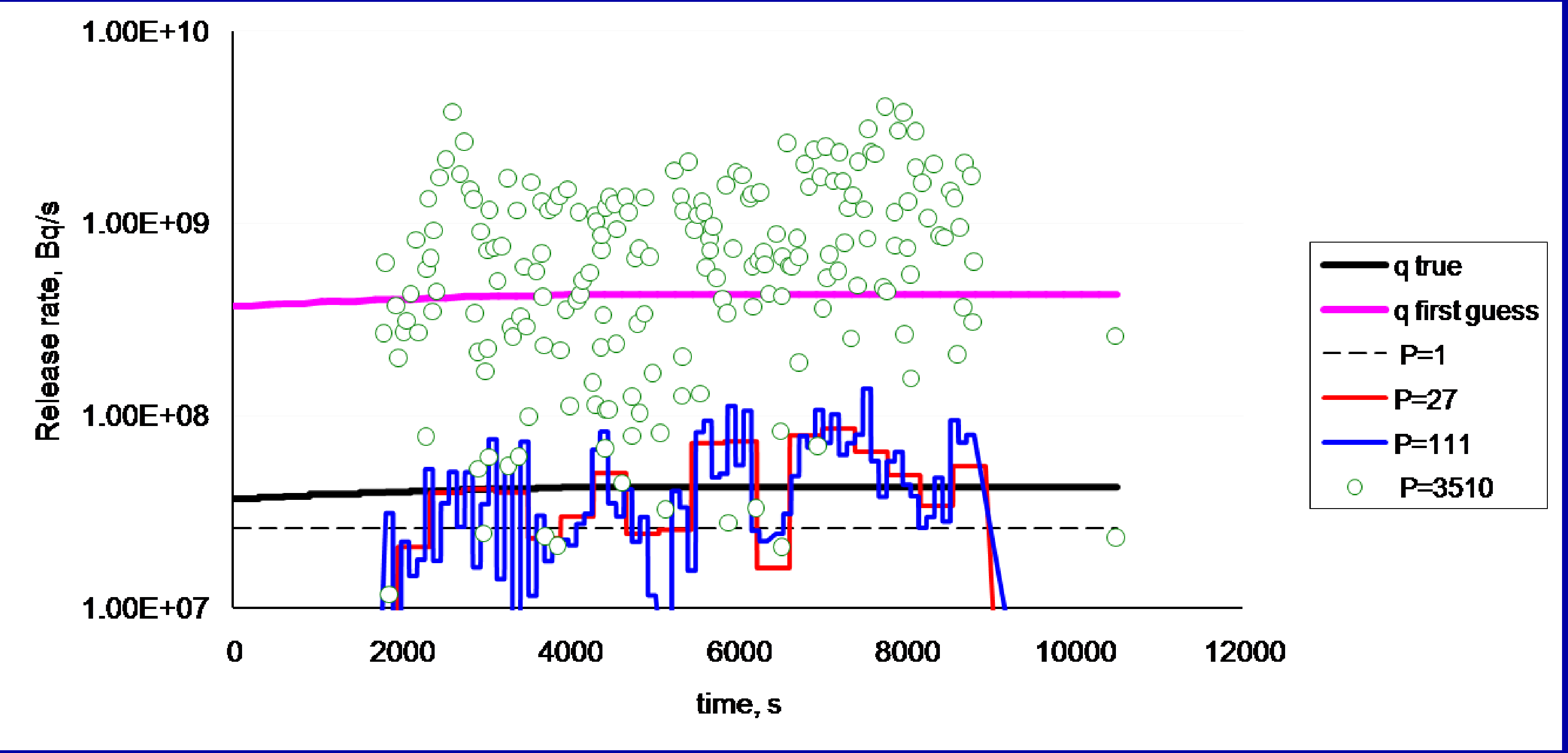
Data from sensors DK-NaI A-D – were used in DA

Data from other sensors were used in validation

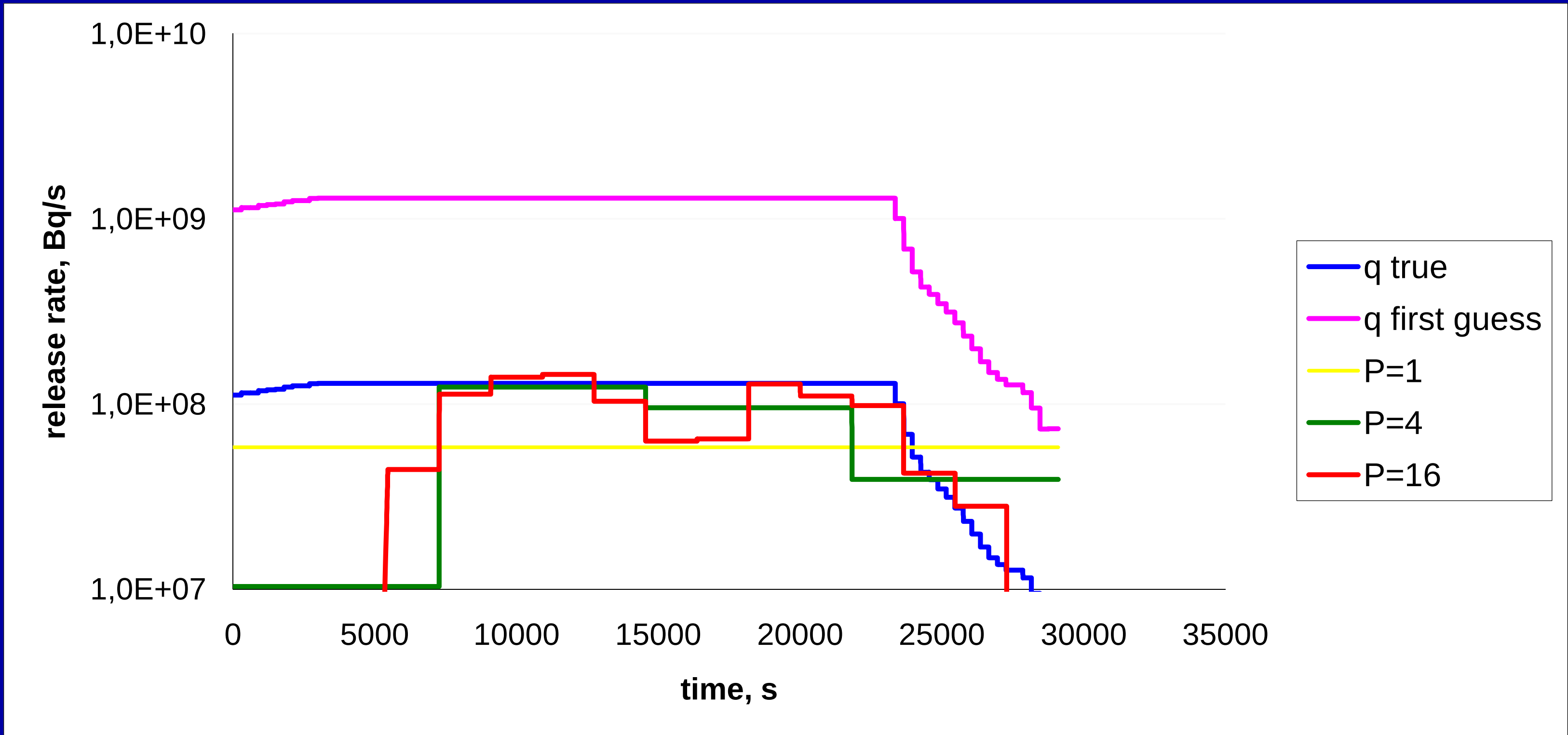
Detectors belonged to: Belgium Nuclear Research Centre (SCK-CEN);

Danish Emergency Management Agency (DK); Technical University of Denmark (DTU)

Source function estimation for Wednesday exp.



Source function estimation for Thursday exp.



Statistical indicators of errors in s.f. estimation

$$MAE = \left\langle \left| q^a - q^t \right| \right\rangle / \left\langle q^t \right\rangle$$

$$MB = \left\langle q^a - q^t \right\rangle / \left\langle q^t \right\rangle$$

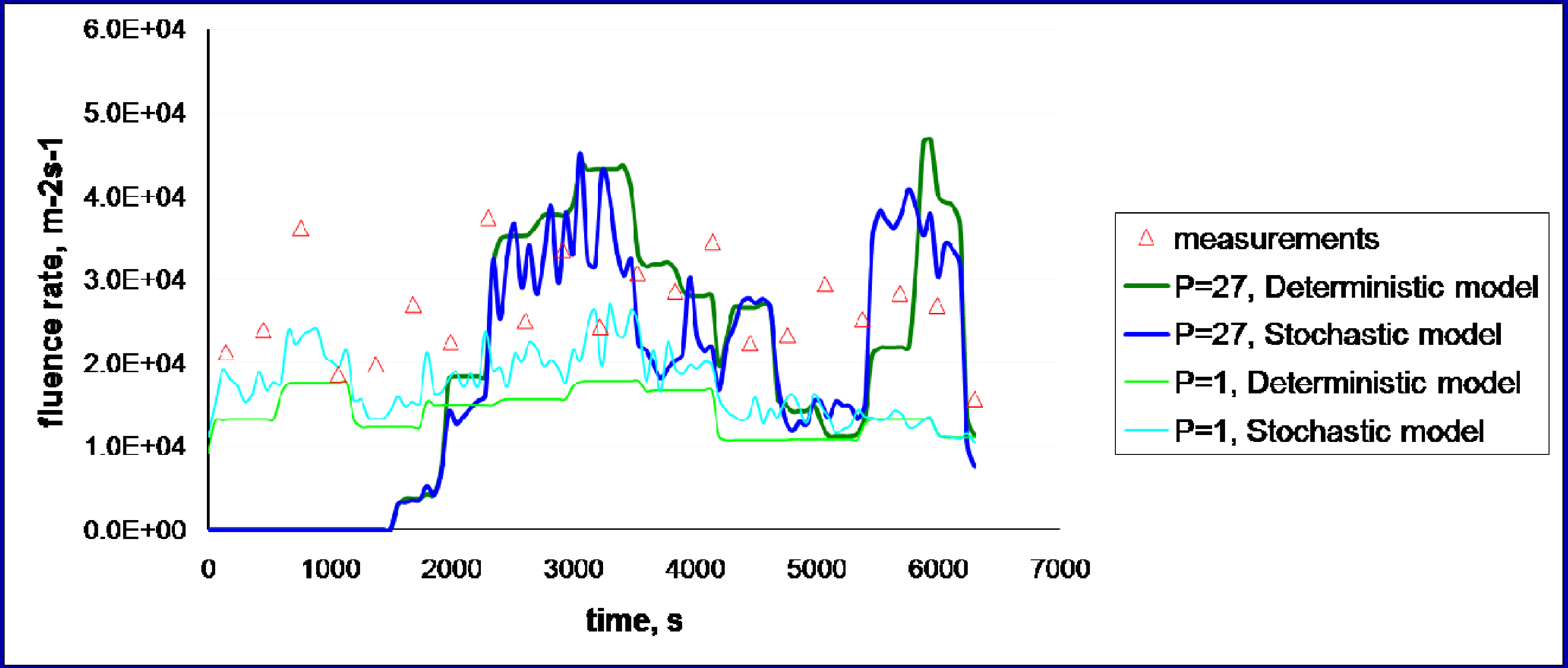
Wednesday

P	Stoch/Deter	MAE	MB
f.g.	S,D	9.0	9.0
27	D	0.51	-0.38
9	D	0.44	-0.38
1	D	0.50	-0.50
27	S	0.59	-0.28
9	S	0.45	-0.35
1	S	0.39	-0.39

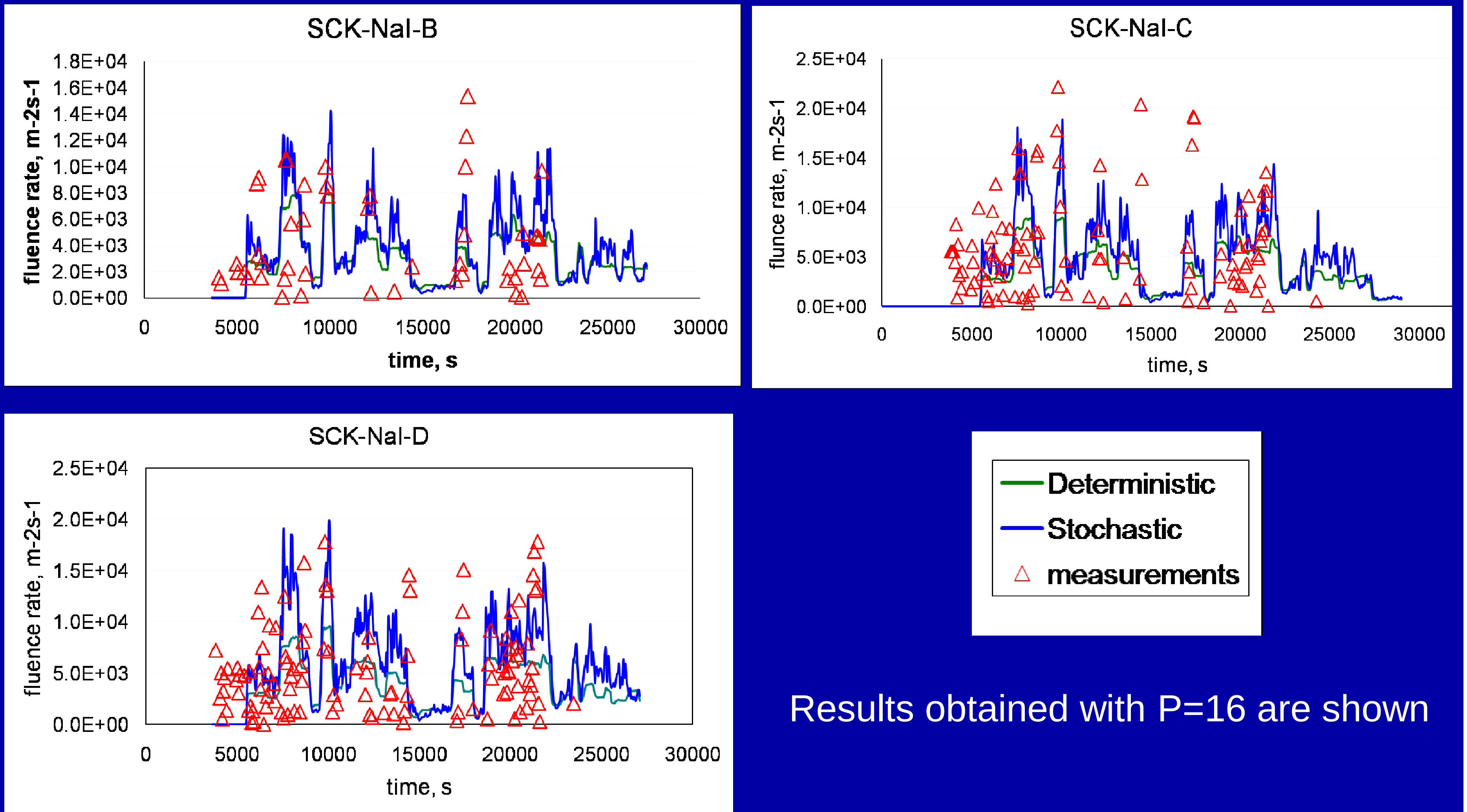
Thursday

P	Stoch/Deter	MAE	MB
f.g.	S,D	9.0	9.0
16	D	0.40	-0.36
4	D	0.42	-0.38
1	D	0.62	-0.52
16	S	0.42	-0.37
4	S	0.44	-0.38
1	S	0.58	-0.46

Comparison of calculated vs measured fluence rates for DTU-HPGe sensor, Wednesday



Comparison of calculated vs measured fluence rates for SCK-NaI sensors, Thursday



Results obtained with P=16 are shown

Statistical indicators (NMSE and FB) of errors in calculated fluence rates as compared to independent set of measurements

Wednesday

Case	Stoch/Deter	NMSE	FB
f.g.	D	8.94	0.83
True	D	0.62	0.2
P=27	D	0.51	-0.17
P=9	D	0.57	-0.19
P=1	D	0.48	-0.3
True	S	0.05	0.03
27	S	0.58	-0.218
9	S	0.61	-0.26
1	S	0.23	-0.21

Thursday

Case	Stoch/Deter	MAE	MB
f.g.	D	13	0.8
True	D	0.4	0.08
16	D	0.63	-0.059
4	D	0.85	-0.12
1	D	1.71	-0.33
True	S	0.53	0.2
16	S	0.58	0.039
4	S	0.73	-0.013
1	S	0.94	-0.17

Conclusions

1. An efficient algorithm was developed which allows for source function adjustment with data assimilation of gamma dose measurements in Lagrangian atmospheric dispersion model DIPCOT.
2. The proposed control vector reduction allows for substantial improvement in numerical efficiency and accuracy of the data assimilation method and makes it suitable for the use also with stochastic version of DIPCOT.
3. The developed method is validated against the measurements in field experiment on atmospheric dispersion performed in Mol. In all cases of DA runs the statistical indicators of errors of the estimated source function and fluence rates as compared to measurements were significantly reduced.
4. The results of assimilation runs obtained with the stochastic version of DIPCOT were generally better than the results obtained with the deterministic version. That improvement was especially revealed in prediction of the maximum concentrations.
5. The presented results demonstrate suitability of the developed algorithm for application in operational nuclear emergency response systems.

Acknowledgements

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Thank you for attention!