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ROSATOM STATE CORPORATION FOR ATOMIC ENERGY

CTBT: Science and Technology 2017 Conference
26-30 June 2017, Vienna, Austria

**Express-Method for Identification of Underground Nuclear
Explosion-Generated Radionuclide Seepage Area
during On-Site Inspection**

Igor V. Markov

Gennadi V. Orlov

Dmitry A. Sagaradze

Andrei A. Ustselemov

1. Objective and tasks of express-method



Computation of contamination area and coordinates of radionuclide source on the basis of results of field gamma-measurements in several (up to ten) points.

Solution of inverse task

of atmospheric transport of UNE-generated radionuclides (backtracking) with application of engineering model of Gaussian plume.

2. Seepage, transport and deposition scenario



- Heated radionuclide mixture seeps out of UNE epicenter area.
- It rises up to unknown height, then transported with the wind to a certain unknown distance and finally deposits onto the ground surface.
- Distribution of activity of deposited radionuclides in cross-wind direction is considered to be Gaussian one.

Simplifications used in the presentation:

- Seepage of heated radionuclide mixture is one-time release from a single source.
- Transport is induced with the wind with constant direction and speed;
- Mixture composition – one-component gas.

3. Atmospheric transport model



The Gaussian plume model presented in **Procedural Instructions 2.6.1.28-06** of the Russian Federal Medical and Biological Agency is used:

- Distributions of particles in release cloud in vertical and cross directions are independent and close to normal one.
- When activity Q is released into the atmosphere time-integral **concentration** in ground-surface layer is:

$$C(x, y, z = 0) = \frac{1}{\pi\sigma_y\sigma_z} \cdot \frac{Q}{U} \exp\left[-\frac{y^2}{2\sigma_y^2} - \frac{h^2}{2\sigma_z^2}\right] \cdot F \quad (Bq \cdot c/m^3). \quad (1)$$

- Here $F(x)$ is **depletion factor** of contamination component during **dry deposition**

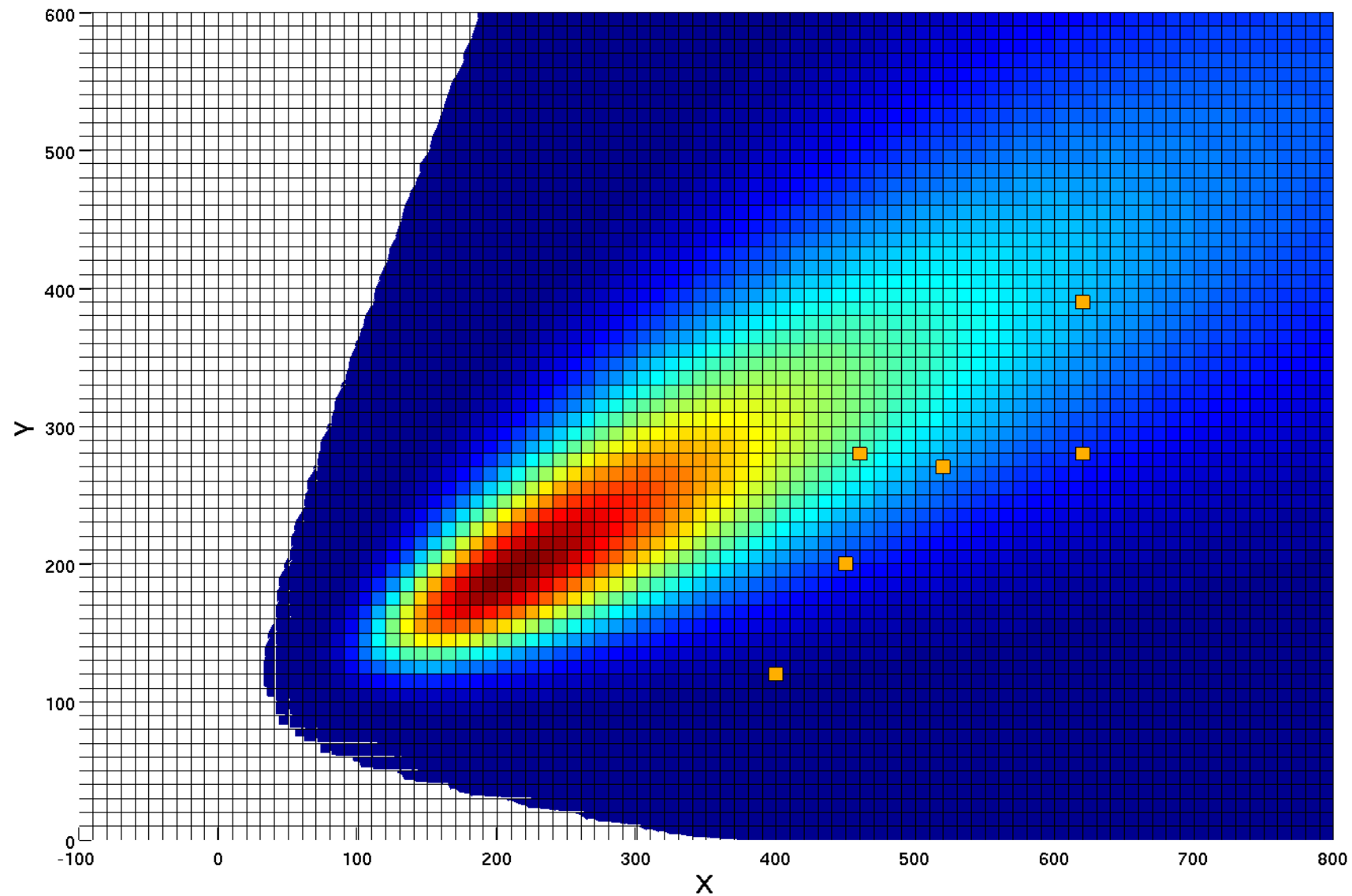
$$F(x) = \exp\left\{-\sqrt{\frac{2}{\pi}} \cdot \frac{w}{U} \cdot \int_0^x \exp\left(-\frac{h^2}{2\sigma_z(x)}\right) \frac{dx}{\sigma_z(x)}\right\}. \quad (2)$$

- **Surface density** of contamination by the component is:

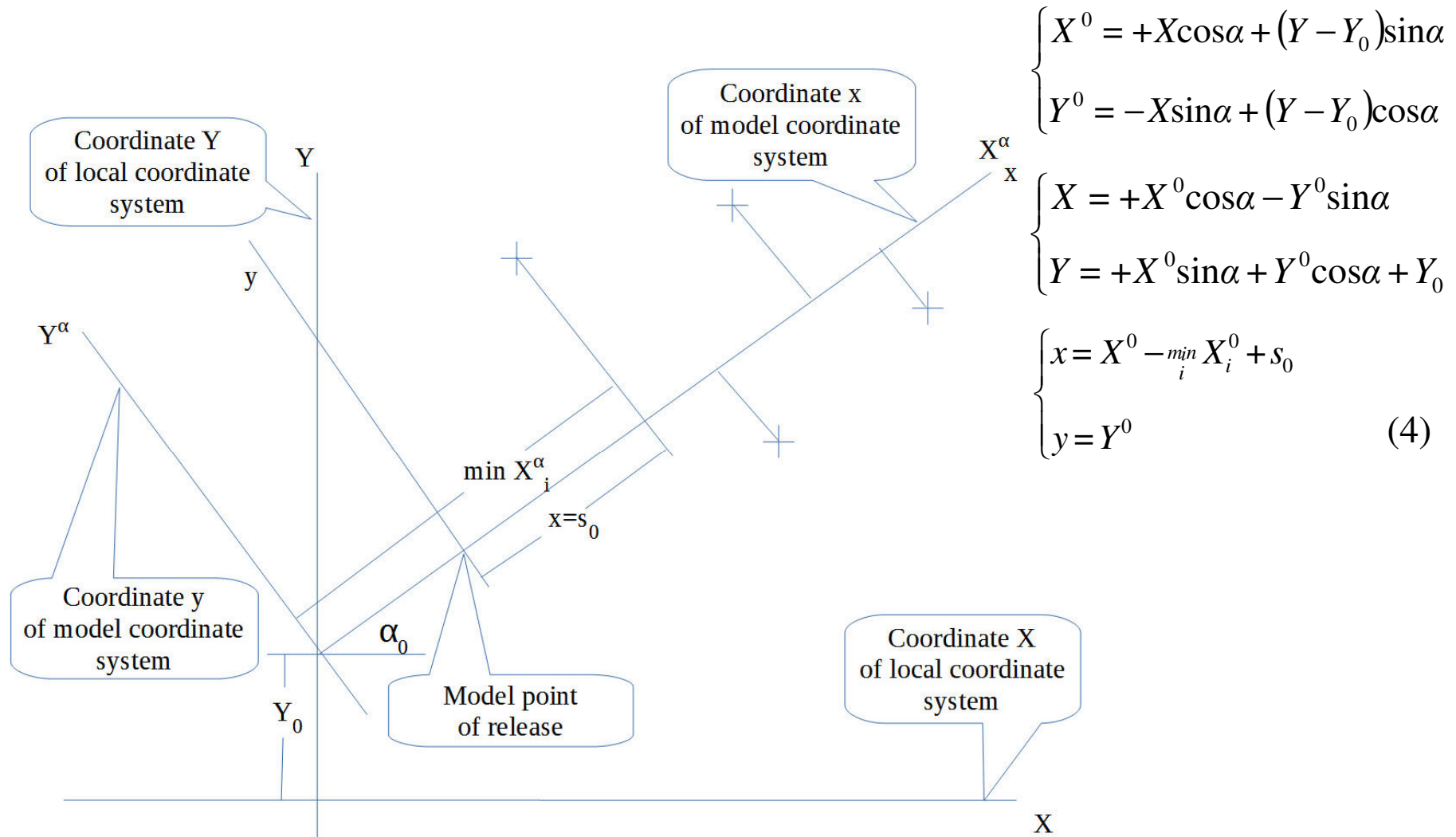
$$S(x, y) = w \cdot C(x, y, z = 0), \quad (3)$$

where w – rate of component deposition onto the underlying surface.

4. Example of contamination distribution



5. Transition from the field coordinate system to the model one



6. *Desired output parameters of the model*



Desired output parameters for the model are the following:

- Parameter P of atmosphere stability by Paskwill;
- Roughness z_0 of the underlying surface;
- Height h of source (release) of contamination;
- Ratio $Q_U = Q / U$ from (1).
- Ratio $w_U = w / U$ from (2). In this presentation $w_U = 0$ is accepted.
- Geometrical parameters α , Y_0 , s_0 , which specify position of the model coordinate system x , y with respect to local coordinate system X , Y .

Desired output parameters are determined from the condition of the best model interpolation (approximation) of measured radionuclide activity values.

7. Model deviation measure



Ratio (1) will be transformed as $C(x, y, z = 0) = Q_U \cdot D(x, y, z = 0)$, where $Q_U = Q / U$.

Deviation measure of model (1) of atmospheric transport $C(x_i, y_i)$ in each point $i = 1, 2, \dots, I$ of the field measurement x_i, y_i will be evaluated.

In order to align exponentially differing values of contamination the logistic difference of measured $C(x_i, y_i)$ and model $Q_U \cdot D(x_i, y_i)$ values in the same points will be taken:

$$\ln C(x_i, y_i) = \ln Q_{Ui} + \ln D(x_i, y_i), i = 1, 2, \dots, I. \quad (5)$$

It should be noted that these values allow to estimate unknown ratio Q_U :

$$\ln Q_U \approx \frac{1}{I} \sum_i^I \ln \tilde{N}(x_i, y_i) - \ln D(x_i, y_i) \quad (6)$$

that decreases by one the number of desired output parameters.

8. Interpolation functional



For integral estimation of interpolation quality we determine the **set of seven parameters** $p = (Y_0, \alpha, s_0, P, z_0, h)$ and find minimum

$$S(p_{opt}) = \min_p S(p), \quad (7)$$

where the minimized functional is:

$$S(p) = \sum_{i=1}^I [\ln C_i - \ln D(x_i, y_i, p) - \ln Q_U]^2. \quad (8)$$

9. Numerical minimization stages



The task of numerical minimization (7) of multidimensional functional $S(p)$ is resolved in two stages:

1. Global stage – grid minimization on the basis of regular 6-dimension grid.
2. Local stage – optimization of found approximation in local optimization code.

In this case we apply local optimization code, which uses only the values of optimized functional without programming its partial derivatives.

10. Numerical modeling



Desired parameters:

- Parameter P of atmosphere stability by Paskwill;
- Roughness z_0 of underlying surface;
- Height h of contamination source (release);
- Geometrical parameters α , Y_0 , s_0 of the model coordinate system x , y .

Input data – measured contamination values $C_i(x_i, y_i)$ in points $i = 1, 2, \dots, I$.

It is considered that the field measurements of activity were made for radioactive gases in the near-ground layer of the atmosphere, in this case deposition rate is $w_U = 0$, deposition factor $F(x) = 1$.

For six computed parameters P , z_0 , h , α , Y_0 , s_0 it is necessary to have six measurement points as a minimum (see Slide 5).

METEOROLOGICAL DATA AT A POINT OF RELEASE TIME ARE NOT REQUIRED FOR THE COMPUTATIONS !!!

11. Results – global stage



- Number of global stage nodes: 3680820.
- Computation time: 81 seconds.
- Value of functional of interpolation quality: 2.146520e-04.

Initial Value of Parameter	Computed Value of Parameter	Error	Parameter Variation Limits and Interval
QU = 1	QU min = 1.00248	0.002477	
P = 2	P min = 2	+0	2.0 : 1.0 : 6.0
z0 = 6.7	z0 min = 5.2	-0.22388	4.0 : 0.2 : 9.0
h = 31.77	h min = 35	+0.10167	10.0 : 5.0 : 50.0
s0 = 366.8	s0 min = 360	-0.018539	0.0 : 20.0 : 500.0
Y0 = 72.3	Y0 min = 60	-0.17012	0.0 : 10.0 : 100.0
alfa0 = 31.17	alfa0 min = 32	+0.026628	25.0 : 1.0 : 35.0

12. Results – local stage



- Number of local stage nodes: 468.
- Computation time: 0.67 seconds.
- Value of functional of interpolation quality: $1.020250e-10$.

Initial	Computed	Error
Value of	Value of	
Parameter	Parameter	
QU = 1	QU opt = 1.00248	
P = 2	P opt = 2	
z0 = 6.7	z0 opt = 6.80647	+0.015892
h = 31.77	h opt = 31.8447	+0.0023513
s0 = 366.8	s0 opt = 366.788	-3.3858e-05
Y0 = 72.3	Y0 opt = 72.3024	+3.2572e-05
alfa0 = 31.17	alfa0 opt = 31.1694	-1.8592e-05

13. Conclusion



- This express-method enables resolution of inverse task of backtracking of atmospheric transport of radionuclides using minimal number of field gamma-measurements.
- Express-method restores meteorological conditions at a point of release time of UNE-generated radionuclides.
- Inverse task resolution with the express-method being presented (backtracking) provides plausible distribution of radionuclide activity on site and coordinates of point of their release into the atmosphere.
- With relevant software installed on inspector's personal computer (PC) this express-method enables the output of map of site contamination with UNE-generated radionuclides that provides an opportunity to enhance efficiency and safety of inspection group.



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Thanks a lot for your attention !