Implementation of a method for source term estimation based on measurements and atmospheric dispersion modelling for use in decision support systems

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Framework

- Collaborative Project “Innovative integrative tools and platforms to be prepared for radiological emergencies and post-accident response in Europe” – PREPARE
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Basic principles

- Advanced technique
- “Top-down” / measurement-based / “source inversion” algorithm
- Calculate radionuclide emission characteristics:
  - Released inventory / isotopic composition of release
  - Emission rate and its time-variation
  - Release height
- Adjust emission characteristics (as modelled) so that results of the atmospheric dispersion model best match the available measurements

Mathematical formulation

- Variational methodology: minimization of a "cost" function
- Cost function formulated on differences between:
  a) model predictions and measurements
  b) "first-guess" and estimated source term

$$J(\mathbf{x}) = (\mathbf{y} - g(\mathbf{x}))^T \mathbf{R}^{-1} (\mathbf{y} - g(\mathbf{x})) + \left(\mathbf{x} - \mathbf{x}^B\right)^T \mathbf{B}^{-1} \left(\mathbf{x} - \mathbf{x}^B\right) = J_1 + J_2$$

Important issues

- What kind of measurements to assimilate?
- Releases of multiple nuclides: estimate nuclide composition of release
- Uncertainties in model predictions and measurements, matrix **R**
- First-guess source term, vector x^B , and related uncertainties, matrix **B**
- Release height or vertical distribution of release

Implementation issues

- Source-Receptor Functions – SRF (or sensitivities – SRS) to express model predictions as linear functions of the source term

$$J(\mathbf{x}) = (\mathbf{y} - g(\mathbf{x}))^T \mathbf{R}^{-1} (\mathbf{y} - g(\mathbf{x})) + (\mathbf{x} - \mathbf{x}^B)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}^B)$$

$$g(\mathbf{x}) = \mathbf{M} \cdot \mathbf{x}$$

- Implementation for Lagrangian puff dispersion models – for calculating the SRF
- Modes of operation in the frame of JRODOS

Measurements

- *Gamma dose rate from monitoring network*: relatively fast, dense, frequent; but does not distinguish between nuclides
- *Activity concentration, ground deposition*: nuclide specific; but less dense, not immediately available, poor time resolution
- The algorithm should be able to take both into account, maybe in different time phases

First-guess source term

- Second term in cost function—regularization term— to assure convexity of the cost function and unambiguity of the solution
- Assignment by the user
- Library of existing source terms in JRODOS …
- Vector x^B consists of Lagrangian dispersion model puffs contents (activity of different nuclides)

Uncertainties in first-guess source term

- Matrix **B** – diagonal matrix
- Expert judgment: method of calculation – range of uncertainties
- “Robust” simplification: magnitude of error equal to maximum value of prior estimation

Multiple nuclide releases

- Nuclide-specific activity concentrations need to be used for this purpose
- If only bulk gamma dose rate measurements are available:
  - Pre-defined ratios of nuclides release rates

$$1/b_i \le x_i / x_1 \le a_i$$

    Values of b_i and a_i estimated by accident studies, core inventory analysis and/or expert judgment.

  - "Barrier-protection" functions (non-linear) or linear inequality constraints

Observation and model errors

- Observation and model errors combined in – diagonal – matrix **R**
- Observation errors: proportional to measured value, plus a "background" threshold
- Model error:
  - Statistics of ensemble model calculations
  - Model input parameters
  - Model calculations at a number of points around the point of interest

Release height

- Unknown for uncontrolled releases, important for buoyant releases
- Method for its inverse estimation:
  – Vertically distributed release, Lagrangian puffs emitted at different heights
  – Simplification: divide vertical release interval into a – small – number of subintervals
  – If Lagrangian model can treat multiple sources then source-receptor matrices can be calculated in 1 forward run
  – Minimization of cost function for each subinterval

Source-receptor functions

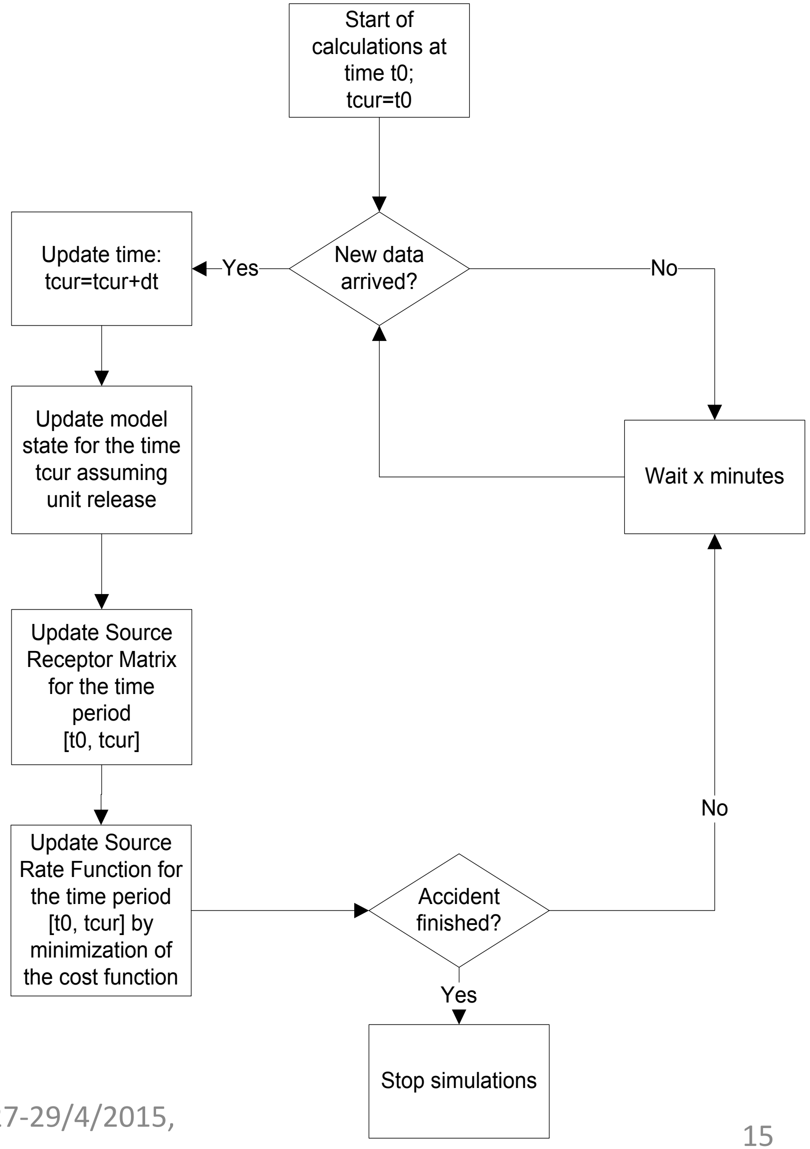
- Sensitivity of a receptor to a source
- Model: operator transforming sources to measurements $\mathbf{y}^{M} = g(x) + \boldsymbol{\varepsilon} = \mathbf{M} \cdot \mathbf{x} + \boldsymbol{\varepsilon}$
- Linear operator in respect to source rate: passive tracers (non chemically reactive, non buoyant)
- SRFs can be calculated by forward or backward model runs
- Mathematical formulation: depends on model formulation – Lagrangian puff model DIPCOT has been adapted to calculate SRFs

Other issues

- Reduction of “control vector” size
- Smoothness of solution in time
- Positivity of solution
- Software for solving minimization problem:
  - Non-commercial
  - Taking into account “double” inequality constraints
- Test cases

Implementation in JRODOS

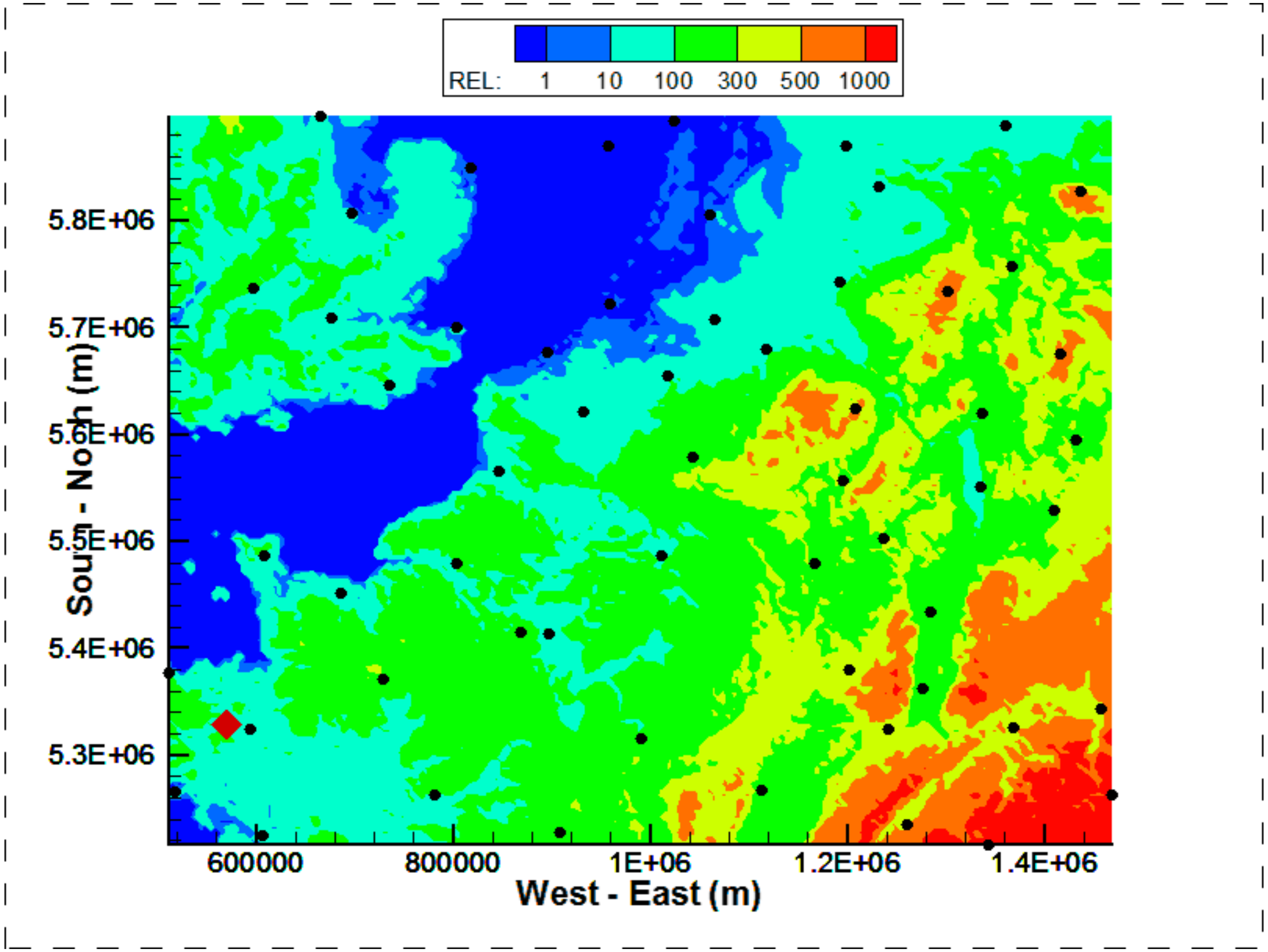
- Requirement: sequential implementation
- Similar to “diagnosis” mode of dispersion calculations in JRODOS



Test case: description

- Geographical domain – meteorology – topology of sensors – source location: ETEX European Tracer Experiment
- Hypothetical release of 21 nuclides, 2 release phases of 0.5 and 4 h, separated by 2h of no release (source term Muehleberg-1 from flexRISK, http://flexrisk.boku.ac.at/)
- Release rates from 0 to 10^{12} Bq/s
- Vertically distributed release, described by 10 vertical levels with Gaussian profile (0–100m, mode at 50m)

Test case: description



Test case: modelling

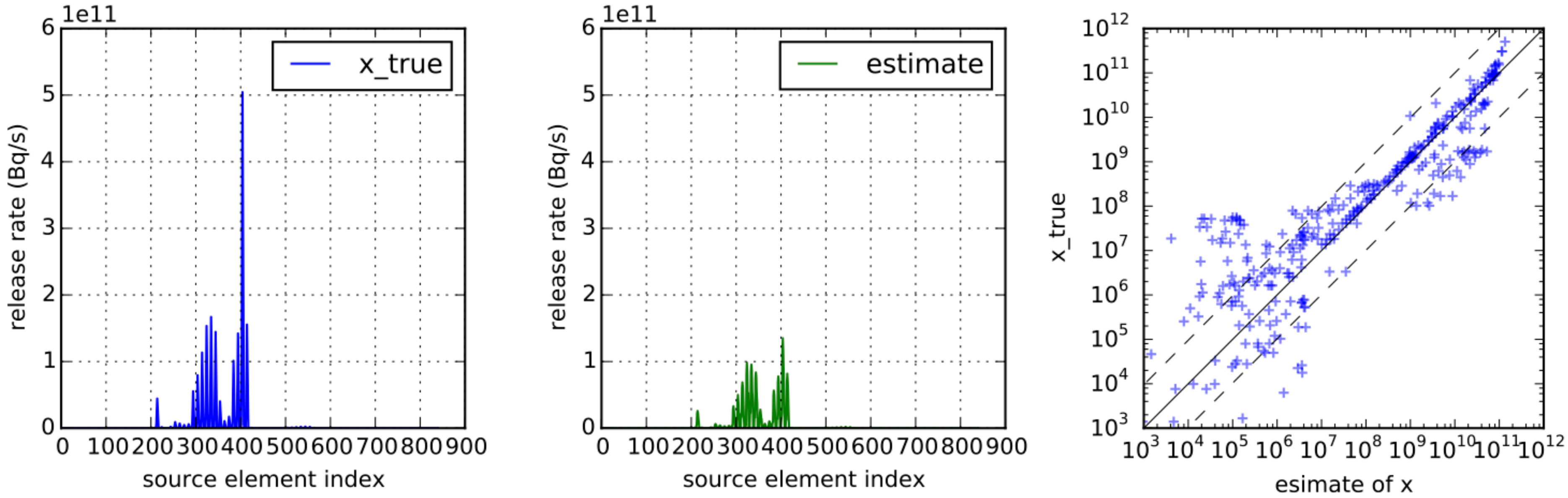
- Synthetic measurements produced by running Lagrangian puff dispersion model DIPCOT with "true" source term:
  - 10-min gamma dose rate "measurements" from 59 stations
- 4 time-phases for the description of the release: 2h before 1st release, 1st release, 2nd release, 2h after 2nd release
- SRFs have been calculated by DIPCOT and exported to module solving inverse problem
  - Time step of 0.5 h
- Ratios of nuclide release rates enter the mathematical problem as additional linear equations; corresponding error variances allow controlling enforcement of prescribed values

Test case: solution experiments

- Influence of time resolution used for the description of the release
  - 1st experiment: release rate of each nuclide constant in each of the 4 phases
  - 2nd experiment: release rate of each nuclide varies in each of the 4 phases with a time step of 0.5 h

Test case: results

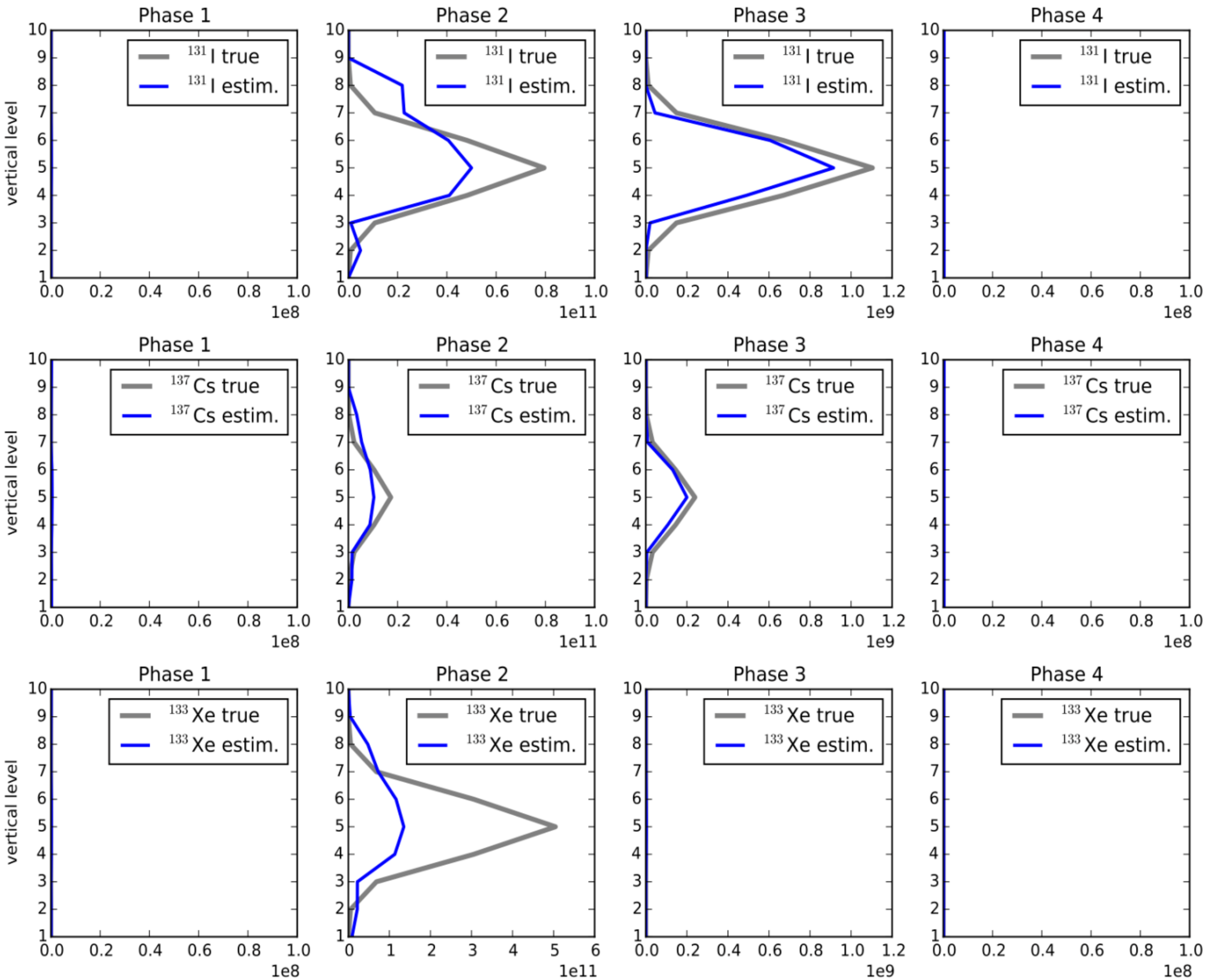
- 1^{st} experiment



- results are acceptable and resolve the most important features of the release (timing and magnitude of higher emissions)
- Differences in lower emissions are due to differences in emission in different vertical sources even in one phase

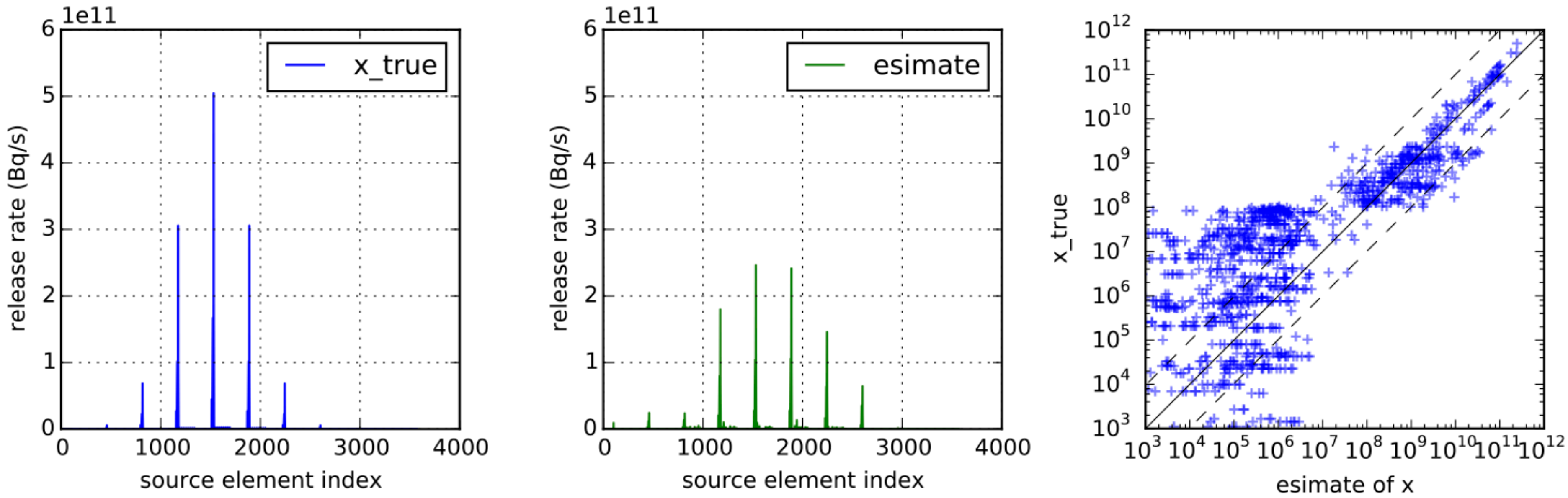
Test case: results

- 1st experiment: vertical profiles for emissions of selected nuclides in different phases



Test case: results

- 2nd experiment: more elements in source matrix



- Timing of releases was estimated correctly — periods with no releases were more or less preserved
- Better agreement for higher releases

Conclusions

- An advanced method for source term estimation based on measurements and Lagrangian puff atmospheric dispersion model is under development
- The method will be integrated in JRODOS in the framework of PREPARE Project.
- The first test results for realistic emission scenarios with multiple nuclides and vertically distributed releases are very encouraging