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REAL-TIME SOFTWARE FOR MULTI-ISOTOPIC SOURCE TERM ESTIMATION

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Abstract. Consideration is given to development of software for one of crucial components of the RODOS - assessment of the source rate (SR) from indirect measurements. Four components of the software are described in the paper. First component is a GRID system, which allow to prepare stochastic meteoro-logical and radioactivity fields using measured data. Second part is a model of atmospheric transport which can be adapted for emulation of practically any gamma dose/spectrum detectors. The third one is a method which allows space-time and quantitative discrepancies in measured and modelled data to be taken into account simultaneously. It bases on the preference scheme selected by an expert. Last component is a special optimisation method for calculation of multi-isotopic SR and its uncertainties. Results of a validation of the software using tracer experiments data and Chernobyl source estimation for main dose-forming isotopes are enclosed in the paper.

1. Introduction

The paper presents results of the joint Russian-Belgian research in the area Data Assimilation And Source Term Estimation of Joint Study Project 1 in 1993-1995. Consideration is given to development of software for one of crucial components of the RODOS[1] - a decision making support subsystem for an early stage of an accident. To calculate one of the most important criteria, population dose, data about dynamics of spatial fields of concentrations and radiation of dose - forming radioisotopes. Such assessments can not be made promptly without using a geophysical model for atmospheric transport and deposition of radioactivity (ATM). In turn, the reliability of model assessments depends on input parameters, primarily a source rate (SR) because it determines the extent of the accident. It is obvious that it is not always possible to measure directly the dynamics of the SR at the time of an accident. This makes important the task of reconstruction of these relationships from measurements of radioactivity around the source.

2. Problem statement

First of all, we suppose that SR may be presented as a piecewise-constant dynamic function with time step Δt. During Δt meteorological and radioactivity measurements are a constants also. These data are processed by Grid system, which prepares the meteorological fields needed for ATM and tests and deletes outliners from the radioactivity data set. The SR value is the ATM parameter. It is estimated with special method - ATOS, which allows to calculate the best degree of agreement of measured and calculated by ATM characteristics of radioactivity contamination of the atmosphere and surface ground. To evaluate the SR values for all time steps jointly and to take into account possible additional information we use multi-time&isotopic source solver - the optimisation method based on projective geometry. We use estimated SR in ATM calculations and then Grid system for presentation of the dose/concentration fields in the final stage of the algorithm. Using these fields and GIS for the vicinity of the source we can calculate Risk values for possible countermeasures strategies. The chart of this process is presented on Fig. 1.

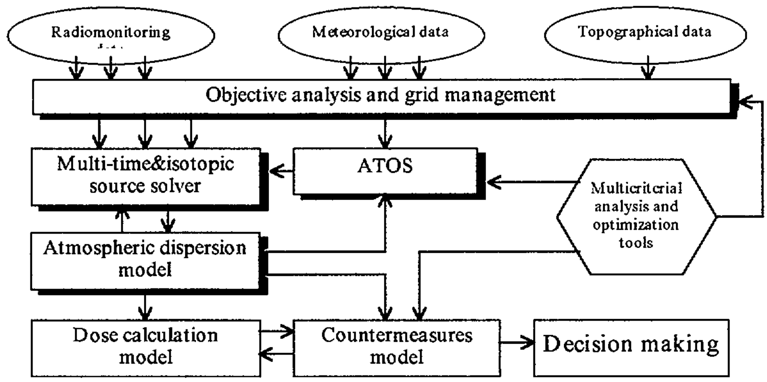

Figure 1. The chart of the interaction of the software components.

3. Grid system

The system of generation, management and visualisation (Grid) is the main tool for data exchange between software components. In addition to this function, it deals with the tasks of assessment of radiation situation in a populated point, presentation of results of modelling predictions and assimilation and evaluation of reliability of meteo/radioactivity measurements. Each of these problems has its specific features and it is impossible to elucidate all of them in one article. A more complete information about Grid can be found in [2]. In this paper we just underlay that Grid can calculate stochastic scalar/vector space-dynamic fields (including variance fields and semi-correlation functions).

4. Model for atmospheric transport and deposition of radioactivity (ATM)

Specific feature of the early stage of a radioactive accident is that measured gamma dose rate (GDR) and/or gamma-spectra are main data types that can be used for source term estimation (STE). In this particular case we need to simulate the detected GDR values with maximum accuracy. Calculation methods based on the semi-infinite cloud model may lead to large errors in the short range and are not suited in this situation. Because we use the RIMPUFF transport model [3] in our STE algorithm, it is natural to use a spherical reference system to describe the concentration field. On the other hand, as the STE method described below requires at least a ground-level data field, space integration process may be impossible in on-line mode. A compromise in this case is to use interpolation tables for normalised GDR for some energy intervals. The software includes the data bank containing radioisotopes spectra, decay chains and dose rate conversion coefficients. Therefore, ATM can emulate:
- instantaneous and time averaged concentrations of radioisotopes in the air;
- instantaneous and time averaged gamma-doses from a radioactive cloud;
- instantaneous and time averaged spectra of gamma shining from a radioactive cloud;
- time and/or space integrated concentrations of radioisotopes on the ground surface;
- time and/or space integrated gamma-spectra from the surface contamination,

and can be adapted for emulation of practically any measurement system.

5. Adequate transformation of observation space (ATOS)

The main technique of the STE is calculation of distance F between vectors of measured and model quantities (The Objective function). F is minimised via varying the ATM parameters. Note that in any case, F change can be superimposed on segment [0,1], with F=0 corresponding to a complete coincidence of model and measured quantities and F=1 - their complete noncoincidence. In this sense most of Objectives behave as a normalised Objective function of the Normalised Least Squares Method (NLSM). Note than main reason of failures in application of this method to the STE problem is uncertainties in meteorological parameters that can not be eliminated.. To improve the quality of results in this cases we use a method of Adequate Transformations of Observed Space (ATOS). Let us explain the main principles of the method.

In simple methods under simple meteorological conditions, minimising of F is achieved by including the effective wind direction in the list of parameters to be estimated. However, it is very difficult and time-consuming to seek the effective three-dimensional dynamic wind field under complex meteorological conditions. Therefore, we have decided to do otherwise: instead of varying the input model parameters, we modify the observed space (a ground level plane in the simplest case) using a series of affine transformations:

a) rotation around the source;
b) parallel transfer along the axis of the mass centre of measurements (MCM) - source;
c) proportional change of area around the mass centre of measurements;
d) ellipsoid change in the shape relative to the point of MCM and the axis MCM - source.

Without going into details, we note that these transformations are quite well defined in input model parameters.

By varying the degree of transformations, we obtain quite a small value of F and a good approximation of the source term.

However, two points should be emphasised. The value of transformation in the optimum with respect to F point determines the degree of uncertainty in the model prediction. A decrease in F, when it is already small enough, is explained by incidental reasons and does not correlate with the degree of reliability of the result.

With this in mind, we think that the optimisation problem should be stated as follows: *to find a rather small F at a rather small transformation.*

In this case, the quality of the solution must be evaluated by two criteria, i.e. two goals should be pursued at the same time. Note that the problem is made more difficult by the fact that the significance of criteria changes with the change in absolute estimates of variants by these criteria. For example, in the region of large values of F and small transformation it is essential to reduce the value of the objective function by, probably, more drastic transformation, while in the region of small values of F and large transformation it is more important to reduce the value of the latter.

In solving the problem of multicriteria optimisation, under these conditions the approximation approach [4] based on real preferences of a decision maker proved to be effective. The software for this approach (M-Crit) developed for application in decision making support system RODOS allows the structure of decision maker's preferences to be identified, fixed and saved for further use in interactive and automatic mode.

The proposed algorithm is implemented by multiple generation of random variants of transformation parameters, determining the rank of the variant by using a developed scheme of decision maker's preferences and selection of a variant corresponding to a minimum rank.

We have tested ATOS using tracer experiments data[5]. For simplifying we divided SR results on four groups 5(excellent), 4(good), 3(not good), 2(bad). Value TM in the Tab. 1 means the transformation magnitude and for F, TM and Rank we give average values.

Table 1. Summary results for different approaches to the source rate estimation.

Method used	Numb. of mark '2'	Numb. of mark '3'	Numb. of mark '4'	Numb. of mark '5'	F	TM	Rank
NLSM	14	10	13	40	0.67	0.00	17437
OP Transf.	4	4	18	51	0.29	0.76	19150
ATOS	4	3	9	61	0.40	0.28	11722

6. Multi-time&isotopic source solver

The necessity to take account of various information for the best possible determination of quantitative characteristics of the source term has led to development of a special optimisation method. It bases on application of the projection geometry methods to solving the restricted minimisation problem. It is worth noting that the algorithm not only estimates of the SR, but also gives its statistical evaluation, i.e. uncertainties related to optimal estimates can be evaluated.

The presented method was successfully used for reconstruction of the composition of the Chernobyl radionuclide fallout and external radiation absorbed dose of the population on the areas of Russia. All dose forming nuclides were subdivided in 6 groups and for each group "leader" was chosen (the dynamics of other nuclides reconstructed using the correlation relationship with the leader). These groups and leaders were:

1. ^{137}**Cs** - group ^{137}**Cs,** ^{136}**Cs,** ^{134}**Cs,** ^{125}**Sb**, 2. ^{131}I - group ^{131}**I,** ^{132}**Te,** ^{133}**I,**
3. ^{140}**Ba**- group ^{140}**Ba,**^{140}**La**., 4. ^{95}**Zr** - group ^{95}**Zr,**^{95}**Nb,**
5. ^{106}**Ru**- group ^{106}**Ru,** ^{103}**Ru**, 6. ^{144}**Ce**- group ^{144}**Ce,** ^{143}**Ce,** ^{141}**Ce**.

Results of STE and doses calculation can be found in [6]. The similar task was solved immediately after Tomsk accident. These materials were published in [7].

7. Conclusion

The main algorithms for assessment of the radiation situation and their validation and successful application for analyses in some radioactive accidents was described. Note that the presented software is a part of RECASS[2] - Russian national scale DMSS for cases of a radioactive accident.

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