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MATHEMATICAL MODELLING AS A TOOL FOR DECISION SUPPORT MANAGEMENT

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Abstract. The paper presents the results achieved in the joint research project in the field of modelling of radioactive releases and their propagation through the living environment. Various pathways of radionuclide transport to human body are taken into account including local, regional or national specific features of the problem. Primary concern is given to localisation of atmospheric, hydrological and food-chain and dose modules of European decision support system RODOS. Main endpoint is to achieve harmonisation of the off-site nuclear emergency management methodology with EU conventions and integration of the Czech Republic within international cooperation. Status of customisation of the RODOS system is shortly described with accent on online connection with meteorological data. At the same time additional research results being in progress in IITA are presented, which are focused on special particular scenarios having character of "worst cases" when looking from view of radiological burden of population.

1 Customisation of RODOS system for its use in nuclear emergency management in CR

Reliability of predictions depends both on sophisticated algorithms of mathematical modelling and on relevant input data, which has to reflect all local-specific features. The RODOS system demands large amount of local input data for modelling of radioactive releases into atmosphere and hydrosphere with successive propagation of radioactivity through food-chain pathway in direction to human body. It concerns model parameters, geographical information, radiological and meteorological online data and various environmental characteristics. The customisation activities are running under cooperation of State Office for Nuclear Safety (SONS), Czech Hydrometeorological Institute (CHMI) and Institute of Information Theory and Automation (IITA , Czech Academy of Sciences).

1.1 Propagation of radioactive pollutants in atmosphere and deposition on the ground surface

1.1.1 Methodology overview

A certain compromise between complexity of description and size of the analysed area is usually accepted. Simple models come out from Gaussian solution for puff or plume model and various formulations are used for particular situations. Near-range elongated puff model ATSTEP is used in the RODOS system for purposes of quick prognosis of radiological consequences of accidental radioactive releases into atmosphere. The model requires relatively simple meteorological forecast data related to the location of the source of pollution. In this model only 24-hour forecast for wind speed and direction (at 10 m height), category of atmospheric stability and potential intensity of precipitation is inevitable. More precise modelling in larger area needs more detailed initial and boundary condition specification. The local scale puff diffusion model RIMPUFF (developed at RISO National Laboratory in Denmark) generates real-time simulations of radioactivity propagation taking into account time and space dependant changes in meteorological conditions. The local scale domain varies from 20 to 160 km around the source and 48-hours weather forecast on space grid around the source of pollution is necessary and then more intensive online data transmission is invoked.

The most complex situation occurs for case of modelling the transport and radioactive fallout for long distances on national and European scales. Hybrid Lagrangian-Eulerian model

MATCH (Multi-scale Atmospheric Transport and Chemistry) has been developed at Swedish Meteorological and Hydrological Institute (Lenart Robertson at al.) and integrated into the RODOS system. Meteorological input has to provide consistent data for atmospheric state and motion on a synoptic scale. The NWP (Numerical Weather Prediction) database using HIRLAM or ALADIN forecast model meets this requirements. Computational grid around the source is very large (order of 1000 km) and then special GRIB (Gridded Binary) format is used for online data transition.

All atmospheric dispersion models (ADM) mentioned above are connected with built-in pre-processor of incoming primary meteorological measurements and forecast which provides the models by diffusion and deposition parameters and local scale wind fields for plume and puff transport and thus integrates the ADM with micro-meteorological pre-processing algorithms. When plume is leaving the outer bounds of the local scale domain (from 20 to 160 km), advection and diffusion specific parameters from nested RIMPUFF model are passed to long-range simulation represented by MATCH module. Selection of the specific AD model depends also on the local topography and other local data availability.

1.1.2 Availability of relevant input meteorological data for ADM in the Czech Republic

The meteorological input consists of set-up input and dynamical data processed during run time. Two kinds of real-time meteorological databases are used in the RODOS system:

- Real-time database – comprise real-time met-tower (or sodar) on-line meteorological observations from net of meteorological towers. The data are accessible via network connection for purposes of automatic mode of RODOS system operation when prognosis of radiological situation during emergency is continually improved by assimilation with measured meteorological and radiation data.
- Real-time on-line accessible NWP (Numerical Weather Prediction) database, containing numerical weather predictions on space and time grid. The data are automatically downloaded from operational NWP model (HIRLAM or ALADIN – the latter one is in use in the Czech Hydrometeorological Service).

Especially huge amount of data requires 3-dimensional hybrid Lagrangian-Eulerian atmospheric model MATCH. The model grid is automatically adopted to changes in the input weather data grid. The model solves numerically the continuity equation for passive admixtures and accounts for advection, turbulent mixing in the boundary layer and deposition of admixtures induced by dry and wet fallout. The transport is treated by a mass conservative, positive definite advection scheme and boundary layer mixing is described by a mass consistent implicit vertical diffusion scheme based on K-theory. Boundary layer parameters like sensible heat flux, friction velocity, boundary layer height and other atmospheric stability parameters are generated from primary dynamical meteorological inputs by built-in preprocessor of online incoming data. Nested local-scale outputs based on particle clouds description initially treated by Lagrangian particle model RIMPUFF initialise the Eulerian long range module MATCH. A typical grid selection in MATCH scheme is 100x90 grid cells in the horizontal and 13 vertical layers. The extent of the grid does not permit to store the results directly in internal RODOS database and then visualisation of results is realised by means of a special tool.

1.1.3 Summary of requirements of the modul MATCH on primary meteorological data

The horizontal and vertical parameters of the computing grid

The meteorological forecast data on a large spatial grid centered on the pollution source are converted by the MATCH data pre-processor to the internal formats relevant to the medium-scale and large-scale radionuclide dispersion modelling (in an European scale). Numerical weather prediction models HIRLAM or ALADIN are the primary source of these data.

Originally, RODOS was linked to the model HIRLAM when 31 levels (33m, 106m, 188m, 308m,…) were used in the vertical and the rotated-pole geographical projection grid with the step 0.15° in the horizontal in the European scale. The computing grid of the model MATCH is directly derived from the input grid of the meteorological data. One can only set a sub-domain by setting corner indices via the parametr file NameList.

While porting MATCH for NPPs at the Czech Republic it was necessary to use NWP model ALADIN, operated by the Czech Hydrometeorological Institute. ALADIN uses similarly to HIRLAM the hybrid vertical coordinate system with its levels following in the troposphere the smoothed model topography. The data are transferred in the form of 2-dimensional fields on 21 vertical levels spanning from around 21 m to 5 km above the ground.

Unlike in vertical the ALADIN differs more from HIRLAM in the horizontal geometry. Whilst HIRLAM uses a rotated geographical grid, ALADIN runs on a conformal projection plane (preferring the Lambert tangent conic projection but still supporting the polar stereographic or cylindric Mercator projections). Fortunately, in the latest version PV5 of RODOS the module MATCH has been adopted to run on a Lambert map as well. The fact was used in the current porting for the Czech Republic.

The fig.1 presents the integration domain of the model ALADIN and the MATCH sub-

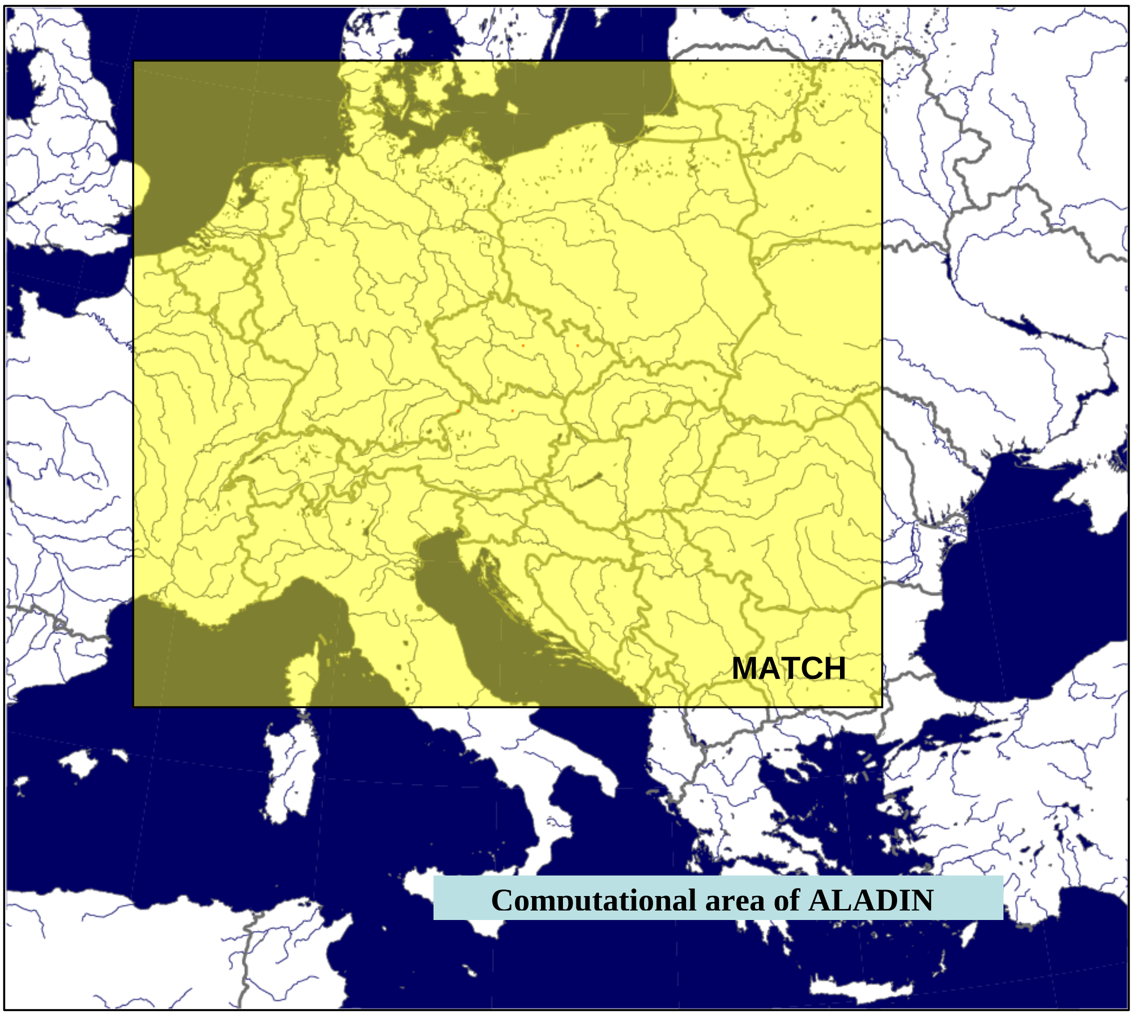


Figure 1. Geographical subarea of MATCH analysis

domain. The sub-domain was chosen so that it covers the Czech neighborhoods and it is roughly comparable to the domain of the model MEDIA (CHMI).

The original ALADIN 9km-grid appeared to be too dense. An interpolation to 25x25 km grid is therefore performed which reduces both the memory demands and computing time of the

MATCH simulation. The first experimentation showed up that while using the original 9 km grid the MATCH overflowed its internal array bounds. The resolution decrease to 25 km grid is therefore both technically necessary and appropriate for the large-scale air pollution modelling. However, the developers have announced further improvement for the fine grid.

The meteorological data production

The meteorological data production for the module MATCH is implemented to the operational suite of the model ALADIN at CHMI. The forecasts are run twice a day from the atmospheric state analyses at 00 and 12 UTC. The forecast is run up to 48 hours storing every 3 hours the raw results in the so-called historic files. Then a special post-processing of these raw data is performed producing the fields for the module MATCH which are then converted to the GRIB format. The whole post-processing procedure is implemented on the supercomputer NEC SX-6 at CHMI and uses around 560 s of the processor time and 2,4 GB of memory.

The result files are then sent via the dissemination server of CHMI to the Crisis Coordination Centre (CCC) of the State Office for the Nuclear Safety by a dedicated communication link. The incoming files are stored in the local database at CCC. The MATCH data preprocessor then ingests the data from the database.

Input GRIB data parameters

The input atmospheric fields and constant ground parameters for the model MATCH are encoded in the WMO FM92 format GRIB with the following geographic parameters:

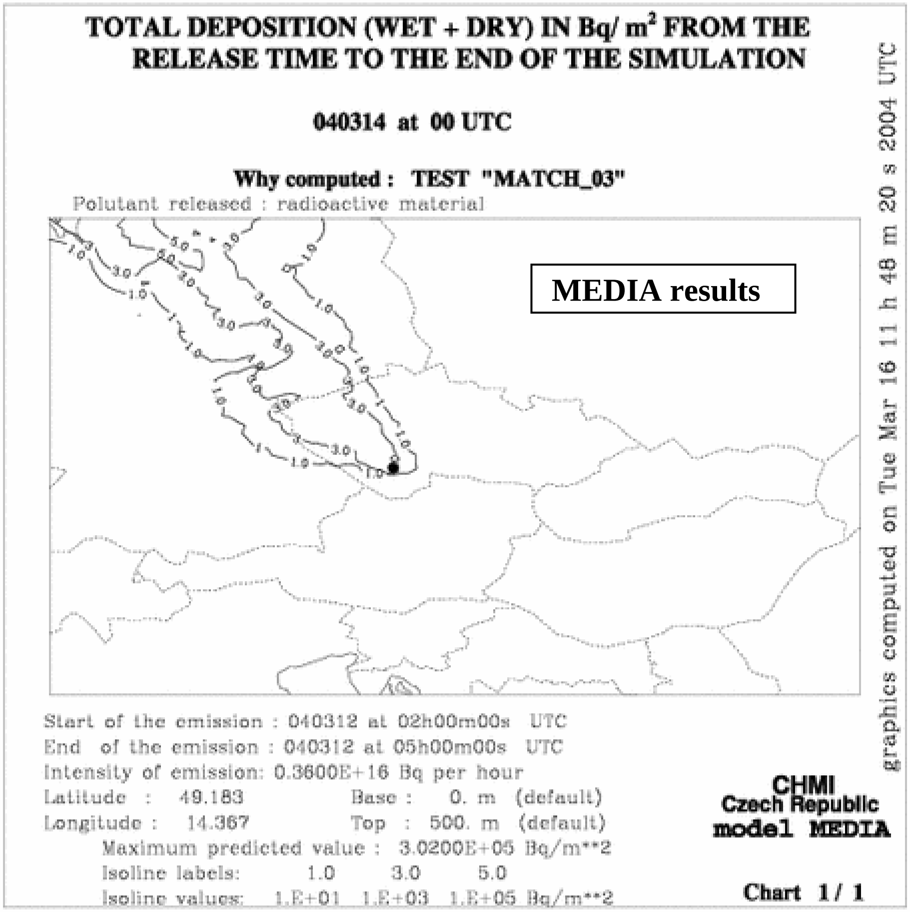
- the Lambert projection map with the tangent latitude 46.266°N and the vertical reference meridian 17°E
- 75x65 grid points
- 25 x 25 km horizontal grid step size
- the bottom-left corner 41.053°N and 4.223°E

Following the FM92 standards all parameters are given in the SI units. Every ALADIN model run produces 17 GRIB files each containing the complete data valid for one forecast range.

1.1.4 Current state and first results of AD models customization for the Czech Republic

All three main atmospheric dispersion modules of the RODOS system are now operational and online supplied twice daily by actual meteorological forecast data. In dependence on extent of area being considered and required precision of analysis the respective modules need specific detailed structure of the online incoming input data:

- Module QuickProgno (algorithm ATSTEP) for fast prognosis of radiological situation after radioactive release into atmosphere in the near area from the source of pollution – it needs simple time series of meteorological forecasts related to one point. It means that two separate data are transmitted twice daily for localities of nuclear power plants Dukovany and Temelin.
- Module ALSMC (more precise algorithm RIMPUFF) for modelling in short and medium distances from the source of pollution requires for the prognosis the forecast meteorological data on the spatial grid. The data are text files in HIRLAM format, generated from ALADIN model separately for surrounding area of each nuclear power plant.
- Module MATCH for modelling of radionuclide propagation in long distances which needs huge amount of binary gridded meteorological forecast data described above. The grid covers area in continental scale.



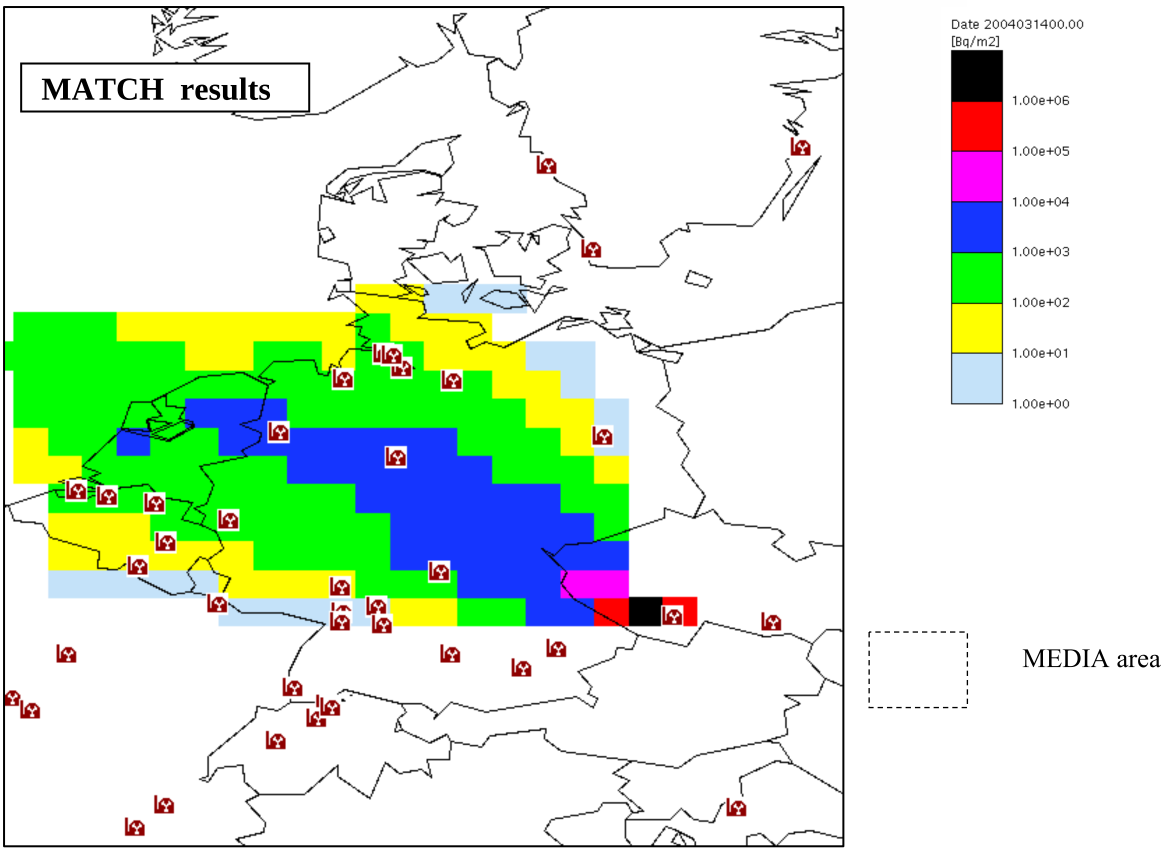


Figure 2. Deposition of Cs137 in European scale, hypothetical radioactive release on March 14, 2004 at 00.00 UTC; latest actual meteo forecast is used

Tuning of the modules consisted from computation of number of various hypothetical release scenarios. In some cases a certain comparison with other codes was done. The most complicated situation has been found for modelling in long distances, when it was difficult to adjust inputs and interpret results with regard to slightly different algorithms, input data format and types of results. Nevertheless, comparison study between MEDIA and MATCH models has proved basic functionality of the MATCH module. Partial results from publication [4] are presented on figure 2 (MEDIA results vers. MATCH results) for case of global deposition of radionuclide Cs137 in continental scale. It relates to hypothetical release from NPP Temelin, which was simulated taking into account real meteorological forecast for date March 14, 2004 at 00.00 UTC.

1.2 Modelling of propagation of radioactive pollutants in ecosystem taking into account hydrological and food chain pathways

Let us resume the three main and most important pathways of radioactivity propagation through the ecosystem:

- Atmospheric pathway
- Hydrological pathway
- Ingestion pathway - transport activity through food chain in direction to human body due to prospective consumption of contaminated food

Al three areas are strongly interconnected and particular results from one area represents indispensable inputs to another one. For example atmospheric fallout on river basin represents radioactive source term for successive hydrological analysis. The results for atmospheric pathway analysis mentioned above should confirm good progress and relatively high level of AD models adaptation on national conditions of the Czech Republic. The last two topics are just in stage of treatment and problem definition.

The hydrological model chain of the RODOS system offers prediction of radioactivity concentration propagation in various water bodies. The problem consists in simultaneous solution of differential equations for:

⇒ hydraulics submodel

⇒ sediment transport

⇒ radioactive pollution transport

For each scenario a certain model is predetermined. The customisation activities in the field of hydrological modelling come out from the simple scenarios selected for introductory works which imply the selection of the corresponding suitable hydrological model from the module cluster of the RODOS system. Two scenarios were selected:

1. Part of Vltava river net from weir Korensko (potential inflow of liquid radioactive pollutant from NPP Temelin) up to Orlik reservoir (see scheme on fig. 3a.).
2. Propagation of radioactivity pollution in reservoir Orlik, where input is represented by results of previous river net modelling. The water body of Orlik is characterised by deep, narrow and very long (more then 20 km) complex shape (part of the body is drawn on fig. 3b).

System RODOS offers for the 1st case of the river net one-dimensional modul RIVTOX where stream hydraulics variables, transport of suspended sediments and radionuclide concentrations are averaged over the cross-section of the river. Diffusive wave approximation of Saint-Venant's equation describes the water discharge. Transport of suspended sediments is expressed according to advection-diffusion scheme taking into account dynamics of sedimentation and resuspension in the upper contaminated river bed. The final radionuclide transport submodel provides cross-sectionally averaged concentrations of activity in solution, suspended sediments and in the bottom deposition.

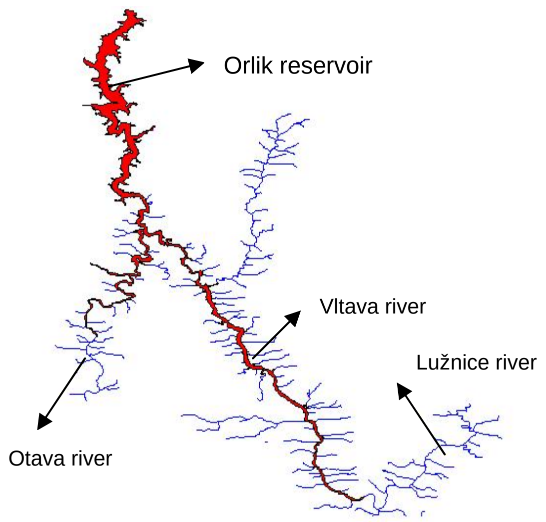


Fig. 3a) Part of Vltava river basin with Orlik reservoir selected for RIVTOX calculations

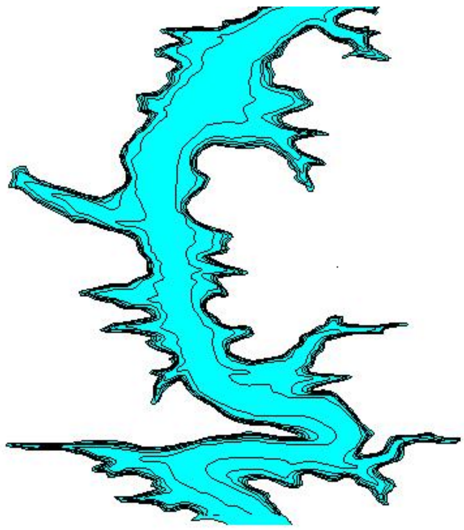


Fig. 3b) Part of complex shape of water body of Orlik reservoir (depth lines are drawn)

For the 2nd case of the reservoir Orlik the 3-dimensional modul THREETOX of the RODOS HDM system can be adopted. The model is suitable for simulating short and medium-term radionuclide advection and dispersion in a deep lakes and reservoirs. Inevitable input requirement is access to complete bathymetry of the water body. This problem for the Orlik reservoir is solved using detailed vector maps DMU 25 for the water layers of the Czech Republic which were released for use for purposes of the RODOS project customization by VTOP institute in Dobruska.

Let us notice that the process of collection of the local hydrological data necessary for adaptation of the RIVTOX resp. THREETOX models for both scenarios are now in progress and the first results will be available by the end of 2004 year.

As for modelling of radioactive transport through food chains the RODOS system offers again interactive software FDMT based on European dynamics models ECOSYS or FARMLAND. Before starting customization of RODOS FDMT, the results of atmospheric and hydrological pathways have to be available as an input. Moreover, ingestion pathway covers thematically extremely wide area requiring collection of miscellaneous local data. Due to this facts the activities in this field are in a halfway. First results are presented in [6].

2 Comments on additional research activities in the field

Alongside with the RODOS customisation process also own research activities in the field of risk assessment of some special particular scenarios of radioactive releases are in progress. The effort is concentrated on the areas that are not sufficiently covered by the commonly used general codes. In general, several issues in the field of atmospheric modelling remain so far essentially unresolved. The problems are connected with treatment of missing data periods, dispersion of admixtures during extreme weather situations, trends in long-term changes of climate and potential synergistic effects between physical-chemical forms of pollutants. More detailed analysis of the local scenarios accepting the latest knowledge is necessary for latter stage of an accident in relation to assessment of long-term doses from deposited activity, assessment of contribution of long-term of resuspension and update of the ingestion model. The response time for the new knowledge implementation should be fast and straightforward. Another area is opened by demands for sensitivity analysis and, in common, to transition from deterministic calculations to probabilistic assessment.

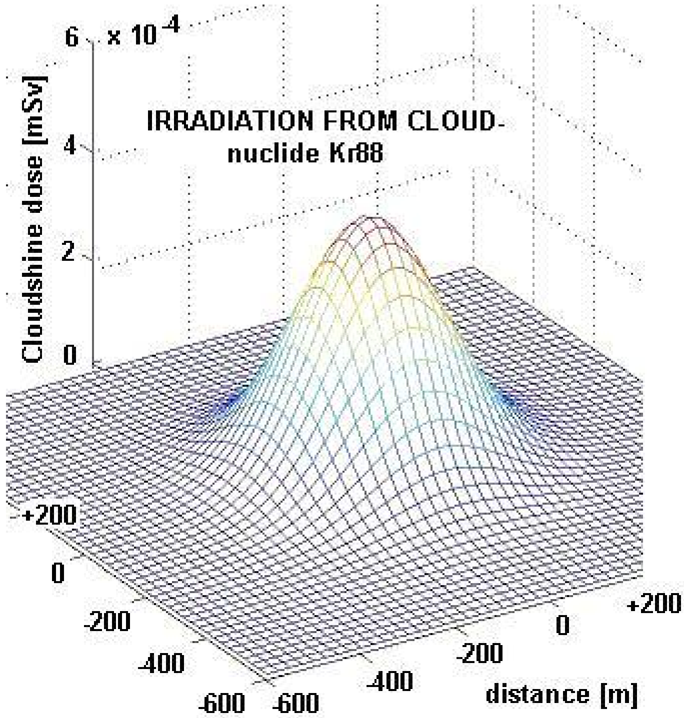


Fig. 4: Multiple puff simulations: cloudshine dose (adults) in miliSieverts [mSv] from Kr88 ($\lambda^{Kr88}=6.88\cdot10^{-05}$ s^{-1}), conversion factor for semi-infinite cloud=$1.02\cdot10^{-13}$[$Sv.s^{-1}.Bq^{-1}.m^{3}$], stable atm. stratification

Such an example of so called "worst case" analysis of the extreme weather situations is refered in paper [5] which deals with radiological consequence assessment of radioactive releases from nuclear facilities at low-wind speed (calm) atmospheric conditions. The developed technique anticipates evolution of situation taking into account possible cumulation of conditions in the most adverse way. Such information has great importance for decision support of nuclear emergency management, even if the occurrence of such extreme situations is less probable. During calm conditions the wind direction becomes undefined and the plume of admixtures can fluctuate anywhere or the puffs are diffused and grown at the point of release without being advected. The latter scenario can be especially hazardous and can lead to the highest peak ground level concentrations of radionuclides.

Proper techniques of mathematical modelling of calm conditions are resumed and recommended modifications of common models (namely Gaussian solution) are accepted in order to avoid possible pitfalls of their direct unqualified application. Two simple numerical approaches are adopted and applied in [5] to the hypothetical scenario of radioactive releases during the calm conditions. The first one is based on step-wise release of partial 3-D Gaussian puffs and superposition of results in all steps of release. Some partial results of this conservative assessment describing the effect of unmovable radioactive cloud "hanging" over the source of pollution (for calm conditions occurring during stable atmospheric stratification when ground level releases remain close to the surface and dilute slowly) is drawn on fig. 4. The second approach modifies semiempirical formulas of the commonly used Gaussian plume model (for dispersion coefficients and plume rise) according to the recommendations for low-wind speed conditions. A certain low wind speed is chosen in this case and periodic multiple plume travel over the point of release is modelled using segmented plume approximation. Detailed results for this plume approximation is given in [5].

Let us mention in the conclusion some facts related own activities in the field of radionuclide transport in food chains and calculation of internal doses due to ingestion of contaminated food. The former Czech local model ENCONAN has been updated and extended. The new food-chain transport model [7] for both accidental and long-term (normal) releases is introduced and enables more precise generation of annual activity intake. The dynamic model is adopted for the average Czech conditions taking into account local *consumption habits* (dependence on season and age), *agricultural production* scheme, average *agro-climatic conditions* and *phenologic characteristics* of the plants, *feeding diets* of animals, *time delays* during *processing, transport and storage* of foodstuffs and feedstuffs etc. The balance equations of the activity instantaneously or continuously deposited on the leaves and ground enable more precise modelling including sensitivity analysis of estimation of resulting ingestion doses for a given day of fallout due to vegetation periods.

Acknowledgement

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