THE CODE ROM FOR ASSESSMENT OF RADIATION SITUATION ON A REGIONAL SCALE DURING ATMOSPHERE RADIOACTIVITY RELEASES

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Abstract. A new approach for assessment of radiation situation outside industrial sites of objects at radiation risk has been developed in the last few years. This approach is based on performing of multiple calculations using real time series of weather condition parameters. The code was applied for analysis of various hypothetical emergency scenarios typical for fast reactors. It was demonstrated that the algorithm of reduction of overlapping parts of calculations is efficient.

Key Words: atmospheric releases of radioactivity, realistic radiation situation, weather conditions variability, multivariant calculations of long-term releases.

1. Introduction

An important objective one has to gain in designing and building nuclear energy facilities is their safety validation. In order to accomplish this atmospheric dispersion models are actively used along with other tools. At the present time there exist a few approaches to modelling of radionuclides transport in the atmosphere. One of them employs three-dimensional Lagrangian stochastic dispersion models (LSDM). Models of this type embedded into many software packages have been widely used for modelling dispersion in the atmosphere. Those packages are exemplified by popular products as LODI [1], MINERVE-SPRAY [2] et cetera [3-6].

The model ROM (Nuclear Safety Institute) belongs to just this category. It is based on a LSDM verified against numerous analytical solutions and vast data of field experiments [7]. The results of verification are presented in [8-9]. Based on the results it was concluded that the calculated maximum of concentration on the centerline of the plume does not deviate from the experimental magnitude more than three times with probability 90%.

In safety analysis multivariant calculations are often conducted under such assumptions about atmospheric dispersion parameters that lead to overestimation of exposure doses at given distances from the source. For different distances from the source these parameters are chosen independently, whereas meteorological parameters are kept constant during an accident.

For small durations of releases (within a few hours) such an approach gives a rather accurate estimate of exposure doses at a given distance from the facility. For long-term releases (over a few days and above) the constant atmospheric parameters assumption turns out to be incorrect. Hence, its application for calculations of radioactive contamination may lead to too conservative estimates of exposure doses.

One way to reduce the conservatism of estimates and to approximate them to more realistic values is utilization of real time series of the atmospheric parameters directly influencing radioactive tracer transport. Plume traces cannot be subjected to classification. An ensemble approach can be considered as a realistic way out of the situation.

Now an approach using multivariant calculations taking into account inhomogeneous wind fields, anisotropic turbulence has been used with increasing frequency. Finnish package SILAM [10,11] is one of the most widespread software applying such an approach.

It consists in performing series of calculations with different dates of the onset of release using real meteorological parameters obtained by a measurement grid during a few last years. Then, the most conservative result is selected for every point from the ensemble of solutions.

2. The computational code ROM

The computational code ROM is intended for estimation of exposure doses to the population outside the area of a nuclear facility at radiation risk.

The code has the following features:

- the vertical wind and turbulence intensity profiles are drawn from scanty information using the model [12,13]. Weather conditions variability can be taken into consideration. The initial information in order to start a calculation:
    1) the velocity of wind and its direction at a height of 10 m;
    2) the stability class of atmosphere with accordance to Pasquill–Turner stability classification (A−G), specifying turbulent processes in atmospheric boundary layer (on the base of a few special models);
    3) the roughness of underlying surface;
    4) the intensity and type of precipitation;
- modelling dry and wet (due to precipitation) deposition of radionuclides on the underlying surface of various structures (vegetation, water surface, urban areas);
- modelling radionuclide decay chains (it is possible to vary the intensity of the radioactivity release in time and the height of the source);
- modelling exposure doses from radioactive plumes, from contaminated surfaces, via inhalation, via food chains;
- possibility of automatic executing series of calculations with various combinations of constant meteorological parameters and of subsequent selection of the maximum value of the exposure doses in every node of the computational mesh;
- the maximum of exposure doses is calculated at a given distance from the source via automatic exhaustive search among the points situated at a given distance from the source;
- multivariant calculations of releases of arbitrary duration with varying dates of the onset of accident using real time- and site-specific series of meteorological parameters;
- calculations of exposure doses caused by routine releases;
- futhermore, add-ons have been introduced into the code ROM that extend its applicability on fast reactors:
    1) ^{210}Po aerosol deposition data and dose coefficients have been added
    2) a model estimating deposition rates of hydroscopic aerosols of sodium combustion products in a moist atmosphere has been embedded.

For a multivariant calculation, using real time series of meteorological parameters, a varying parameter is the date of the onset of release, which determines a scenario of variability of the meteorological parameters during the period of release (the velocity and the direction of wind, the precipitation intensity, stability class of the atmosphere). The longer the period is, the

more calculations can be performed thereby leading to a larger data sample and, accordingly, to better statistical reliability.

A time-scenario of variability of the meteorological parameters has a fixed time increment equal to three hours. Hence, the onset of release in every calculation is shifted three hours ahead. Within each three-hour interval, the meteorological parameters are considered constant.

In a multivariant calculation with shifted onsets of release, every node of the computational mesh stores the maximum value of exposure doses of all calculations. Applying such an approach an upper (though realistic) value of the exposure dose is obtained.

The run of a multivariant calculation requires substantial time costs, especially in case of long-term releases (from a few days up to tens of days). Therefore, a time-reducing algorithm has been developed. This algorithm is used only for calculations of long duration accidents since there is no need for it to be applied to short-term releases.

2.1. Omitting recalculations in order to reduce the time cost of calculations of long-term releases

The performance of series of calculations with the same release but a variable onset of the release can be significantly increased taking into account that part of the three-hour intervals of a release period shifted three hours from another release period occur under the same meteorological. If the intensities and nuclide compound of the release are the same for all three-hour intervals then exposure doses in all nodes will be the same assuming the same meteorological conditions. Hence, it is not necessary to recalculate the atmospheric transport of contamination. If the parameters of the release can be different for separate intervals then a dose recalculation, while omitting that of the atmospheric transport of contamination under the same meteorological conditions, is needed.

Doses from a cloud and inhalation can be estimated from the time-integrated concentration while doses from the surface and via food chains – from the density of depositions. Omitting of recalculations is especially efficient with long-term releases which duration exceeds many times a three-hour interval. The maximal gain in performance is equal to T/3, where T– the duration of release in hours. Such a gain is achieved since in the subsequent calculation only the last three-hour interval of the release period is recalculated as opposed to the recalculation of the whole release period. Let us consider the recalculation procedure in more detail.

Let us divide the period of a release into N three-hour intervals with in general different nuclide compounds. In every calculation, a part of the period of the release occurs under the same meteorological conditions as another part of the period of the release in the prior calculation. In *FIG.1.* the scheme of conducting two subsequent calculations denoted by numbers 1 and 2 is shown. The release period is divided into five subsequent three-hour intervals. The onset of release in the second calculation is shifted three hours ahead from the beginning of the first calculation.

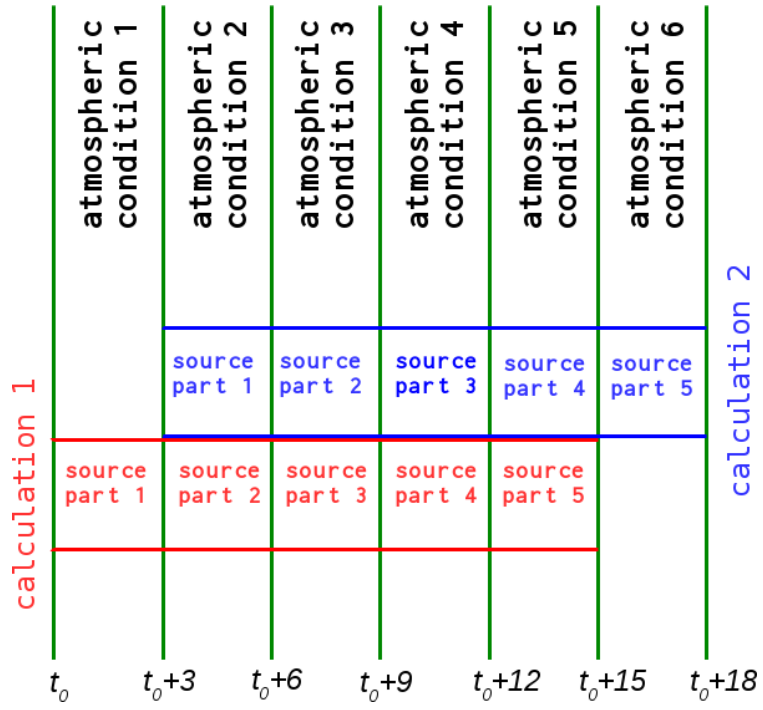

FIG. 1. Calculation scheme.

Time is plotted along the horizontal in *FIG. 1.* In the period of time from t_0 to t_0+3 atmospheric conditions denoted by 1 are kept, in the period of time from t_0+3 to t_0+6 – atmospheric conditions denoted by 2 are kept etc. It can be drawn from the *FIG. 1.* that in the first calculation during the time intervals from 2nd to 5th the meteorological conditions (from 2nd to 5th) are the same as those from 1st to 4th in the second calculation. Hence, the time integrated surface concentrations of nuclides will be proportional to one another. Let us denote the time integral of surface concentration of nuclide *r* within *i*th interval of the release period (in some computational node) in the first calculation $I_c(r,i)$, in the second –$I'_c(r,i)$. The amounts of activity released within *i*th and (*i*+1)th intervals are denoted as – $A(r,i)$ и $A(r,i+1)$ accordingly. Thus the integral of surface concentration is equal to (not taking into account radioactive decay):

$$I'_c(r,i) = I_c(r,i+1)\frac{A(r,i)}{A(r,i+1)}. \quad (1)$$

The depositions $P'(r,i)$ in the second calculation are obtained in the same manner. Therefore, in order to get the integral of concentrations and depositions in every calculation of the series except the first one, one need to calculate the transport of contamination only for the last three-hour interval of the release period while the integral of concentrations and depositions in other three-hour intervals of the release period should be recalculated.

2.2. The access to and usage of data pertinent to transport atmospheric conditions

In order to conduct multivariant calculations with varying dates of the onset of release, time series of meteorological parameters (WMO data archives) for a particular location of the object.

In Russia as pertinent data, the standard hydrometeorolgical observations at the near meteorological stations for a past period are regarded as well as the data of reanalysis referring to the coordinates of those stations.

In accordance with [14] the measurements are conducted every three hours and at distances of tens of kilometers from the measurement point.

The input file with the parameters needed for calculations by the code ROM is compiled on the base of the data measured at surface meteorological stations in the last few years. Some parameters like the stability class of the atmosphere or the intensity of precipitations are not included in the file and derived from other parameters. The stability class is estimated according to Turner taking into account synoptic data [12, 13]. In order to calculate the stability class the following parameters are used: the latitude of the station, the universal time at the station, the velocity of wind at a height of 10 m, the cloud okta at the scale from 0 to 10, the lower height of the cloud layer, the visibility, the snow cover data. The stability class is calculated for every station with subsequent interpolation from all stations into the object location with weighted coefficients $1/r_i^2$, where r_i– is a distance to *i*th station.

2.3. Dose computations in a multivariant calculation

In an ordinary calculation dose from a cloud, the surface and via inhalation is determined through numerical integration of dose rate in time for every computational node. At the same time, a change in surface concentrations and depositions due to radioactive decay is taken into account. For a multivariant calculation with omitting recalculations the initial data for the calculation are time integrated surface concentration and nuclides deposition. For dose calculation from the surface, the same time-integrated deposition field is used. Hence, in case of varying in time intensity of the release the decay is approximately calculated under the following assumption: increase of concentration caused by the part of the release within a three-hour interval is considered constant from the onset of this part of the release until it leaves the calculation domain. Thus, a dose from the three-hour interval and nuclide r is calculated as follows:

$$D(r,i) = \kappa_r \int_{t_0}^{t_0+\delta T} C(r,i,t)\exp(-\lambda_r(t-t_0))dt \approx \kappa_r \frac{I_c(r,i)}{\delta T}\frac{1-\exp(-\lambda_r \delta T)}{\lambda_r}. \quad (2)$$

Where κ_r – the dose coefficient, Sv ·m^3/(Bq ·s); λ_r – the decay constant; $C(r,i,t)$– the time dependent surface concentration of nuclide *r* within the *i*th three-hour interval; t_0 – the onset of the *i*th three-hour interval; δT – the period while the part of the release within the three-hour is within the computational domain. Dose via inhalation is obtained in a same manner substituting the inhalation dose coefficient for the dose coefficient κ_r in the formula 2. The increase in activity is due to the presence of parent nuclides as well as spontaneous decay. Dose via food chains depends only on the depositions at the time of harvest and is calculated precisely according to [15].

For dose calculation from the surface, it is assumed that in the period from от t_0 to $t_0 + \delta T$ the amount of depositions is linearly dependent on time barring change in activity due to decay. Thus, dose from the surface is calculated according the formula 3:

$$D(r,i) = \kappa_r \int_{t_0}^{t_0+\delta T} P(r,i,t)\exp\big(-\lambda_r(t-t_0)\big)\,dt + \\ + \kappa_r P(r,i,t_0+\delta T) \int_{t_0+\delta T}^{t_0+\delta T+\Delta T} \exp\big(-\lambda_r(t-t_0-\delta T)\big)\,dt \approx$$

$$\approx \kappa_r \frac{2I_P(r,i)}{\delta T} \int_{t_0}^{t_0+\delta T} (t-t_0)\cdot\exp\big(-\lambda_r(t-t_0)\big)\,dt + \\ + \kappa_r P(r,i,t_0+\delta T) \int_{t_0+\delta T}^{t_0+\delta T+\Delta T} \exp\big(-\lambda_r(t-t_0-\delta T)\big)dt =$$

$$= \kappa_r \frac{2I_P(r,i)}{\delta T}\lambda_r^{-2}\left(1 - \exp(-\lambda_r \delta T)\,(1 + \lambda_r \delta T)\right) + \kappa_r P(r,i,t_0 + \delta T)\lambda_r^{-1}(1 - \exp(-\lambda_r \Delta T)) \quad (3)$$

where: κ_r – the dose coefficient, Sv·m^2/(Bq·s); $P(r,i,t)$ и $I_P(r,i)$ –the time dependent density of deposition of nuclide *r* and the time integral of it (at the moment when the *i*th three-hour part of the release leaves the computational domain); $t_0 + \delta T + \Delta T$ – the moment for which the dose from the surface is calculated. Dose from the surface is divided in two parts: the first part is obtained during the period of linear increase of depositions, the second –in the period after the leave of the three-hour part of the release up to an arbitrary forecast point in time. The error due to approximate account of decay manifest itself only in the first part.

2.4. Examples of application of the technique

The technique of omitting recalculations has been tested on a few releases of arbitrary duration. Results of dose calculations applying the technique were compared against results of direct calculations of a long-term release [15]. The following conclusion was drawn. The error of calculation of dose from a cloud, the surface and via inhalation is due to approximate account of decay. Moreover, an error due to the stochastic nature of the transport model is imposed on it. The error due to this factor is about 20–25% for a standard amount of Lagrangian particles (about 1000 particles) in the computational domain. The error caused by the first factor depends on the nuclide compound of release and increases as the impact of unstable (with half-live less than three hours) nuclides in the release on the exposure dose becomes larger. In order to estimate the impact of such errors a release of ^{132}I (half-life is about 2,3 hours) with a duration of three hours. The parameters of the release: the height – 50 m; the surface roughness – 0,1 m; the velocity of wind – 1 m/s. The error of the dose from a cloud was within 6% at a far distance from the source (up to 15 km) and within 10% near the source (up to 500 m). The error of the dose from the surface was within 10% at a far distance from the source and within 15% near the source [15].

Further, a comparison between the ordinary calculation of a release and the calculation under the assumption of the worst constant conditions for every node [15]. Dose calculation has been carried out using the ROM code.

The nuclide compound of release: ^{132}I (3,3e+12 Bq), ^{133}Xe (3,1e+14 Bq), ^{137}Cs (1,9e+13 Bq). The decay products were taken into account. The duration of the release – 24 hours, the height – 200 m. This accident is hypothetical and experimental data isn't available. A comparison of dose profiles obtained using different modes of calculation in the ROM code is below. Namely the calculated dose from a cloud against the distance from the source is plotted in the *FIG. 2*. Fig. 2 is intended to illustrate the tendency of calculations under oversimplified assumptions to overestimate the magnitude of dose in a given point of the contaminated area. We cross-verified simplistic approaches against a calculation made under more realistic assumptions about weather conditions.

The line №1 – a calculation with varying combinations of every stability class and the velocity of wind (in a broad range). The line №2 – a calculation with varying the onset of the including about 50 runs (the meteorological data from the last half of the February 2010 were used). The line № 3 – an single ordinary calculation using the real meteorological data from the period from 20 to 21 February 2010 in Beloyarskaya NPP region.

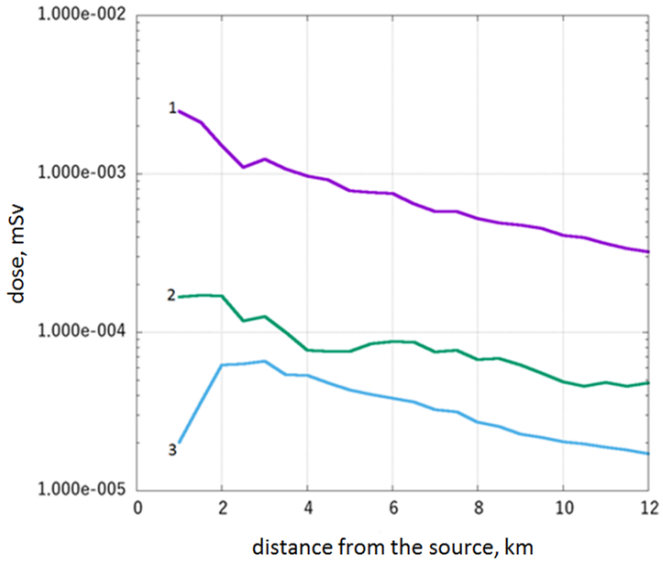

FIG. 2. Comparison of different methods of dose calculation.

Single calculation using the ROM code with real time dependent atmospheric conditions is expected to give the best (minimal) result as shown in the *FIG. 2*. The series of calculations with the constant artificial atmospheric conditions gives the worst (maximal) result. The series of calculations with real time dependent atmospheric conditions gives middle, more realistic result. This confirms the fact that application of constant weather conditions leads to an overestimation in comparison with the approach where real time-variable weather conditions are used.

In the *FIG. 3.* 2D field of dose from a cloud calculated using real meteorological fields is shown. The value of dose in every node is equal to the maximum value selected from those obtained in all calculations with the varying onset of release.

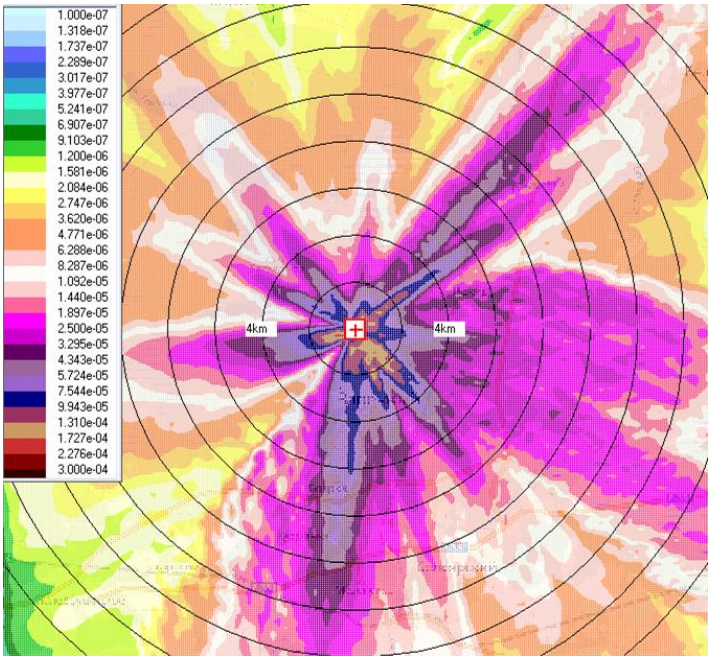

FIG. 3. Dose from a cloud in the calculation with varying the onset of release.

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