NUMERICAL SCHEME FOR DAUGHTER PRODUCTS BUILT-UP DURING ACCIDENTAL RADIOACTIVITY RELEASES

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Development of environmental system HARP for assessment of nuclear accident consequences continues in IITA within grant project GAČR No. 102/07/1596. Main objective of the project is improvement of reliability of model predictions on basis of advanced statistical techniques of assimilation of model results with observations incoming from terrain. Parallelly, an improvement of radioactivity transport submodels is in progress. One partial refinement related to capability of atmospheric dispersion model (ADM) to simulate significant decay chains more realistically is described thereinafter.

CURRENT METHODS

Radioactive decay chain scheme for time evolution of activities accounts for decay as well as production of daughter elements. It is expressed by system of differential equations:

$$\frac{da^i(t)}{dt} = -\lambda^i \cdot a^i(t) + \lambda^i \cdot \sum_{j=1}^{i-1} \beta^{j\to i} \cdot a^j(t) - Q^i(t) \cdot a^i(t) \qquad (1)$$

Here λ are decay constants, β denotes branching ratio (fraction of decays of parent *j* that produce daughter *i*), Q is production/depletion function for isotope *i*. Rewriting (1) for isolated system for simple isotope decaying ***parent (p)*** $\rightarrow$ ***daughter (d)*** $\rightarrow$ ***stable***, the equations of genetic activity balance for this particular case lead to well-known resulting time evolution expressions (e.g. [1]):

(2)

$$\frac{da^p(t)}{dt} = -\lambda^p \cdot a^p(t) \quad \Rightarrow \quad a^p(t) = a_0^p \cdot e^{-\lambda^p t}$$

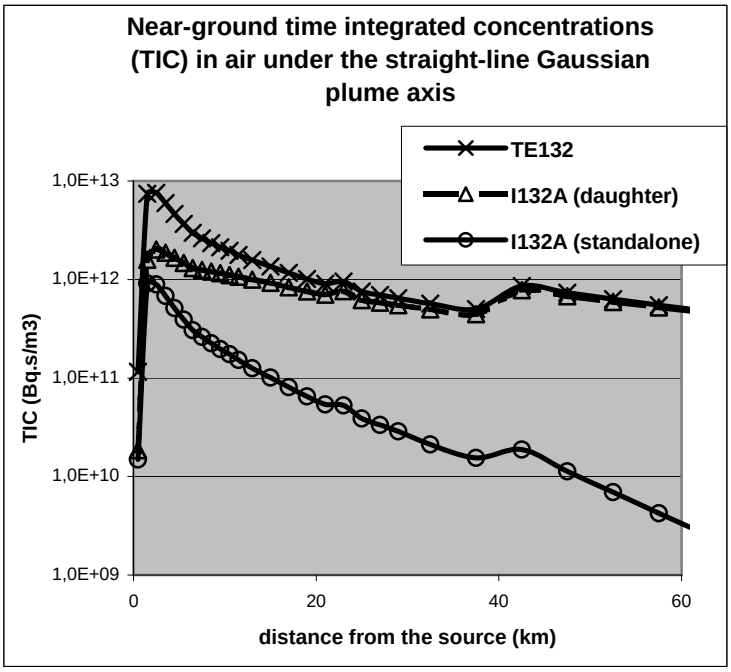
$$\frac{da^d(t)}{dt} = -\lambda^d \cdot a^d(t) + \lambda^d \cdot \beta^{p\to d} \cdot a^p(t) \quad \Rightarrow \quad a^d(t) = a_0^p \cdot \beta^{p\to d} \cdot \frac{\lambda^d}{\lambda^d - \lambda^p} \cdot \left(e^{-\lambda^p t} - e^{-\lambda^d t}\right) + a_0^d \cdot e^{-\lambda^d t}$$

It is clear, that eq. (2) stands also for isolated control volume of air inside of radioactive plume advecting over the terrain or for time evolution of activity deposited on the ground in latter phases of accident after the cloud has left the terrain. For analysis of early stage of accident we should account for the plume activity depletion besides decay also the processes of dry fallout and washout caused by atmospheric precipitation. The task gains new dimension when spatial distribution of dry

deposition (in dependency on land use characteristics) and time changes of wind directions and possible local precipitation changes have to be taken into account. An analytical expression can be found only making some problematic simplifications. For example straight-line Gaussian model (GPM - the simplest option of ADM module of the HARP system), which uses "source depletion" approach, introduces for the total effect of depletion mechanisms (radioactive decay, dry fallout and washout) from the point of source to position *x* the following expression:

$$F_{depl}^{TOT}(x) = F_{dry} \cdot \frac{\lambda^d}{(\lambda^p + \Lambda^p) - (\lambda^d + \Lambda^d)} \cdot \left\{ \exp\left[-\frac{(\lambda^d + \Lambda^d)}{\bar{u}} \cdot x \right] - \exp\left[-\frac{(\lambda^p + \Lambda^p)}{\bar{u}} \cdot x \right] \right\} \quad (3)$$

It stands for straight-line propagation of the plume in direction *x* with constant mean velocity $\bar{u}$, F_{dry} is original GPM expression for dry fallout. But (3) holds true only for case, when dry deposition velocities for parent and daughter are the same. Respective radiological outputs (activity concentrations and its time integrals) are recalculated by multiplying their isolated values by the total F_{depl} .



The application of approximation according to (3) for the same physical-chemical forms (aerosols) of parent-daughter pair Te132→I132A is given in Fig. 1. Initial activity discharges for Te132= 1.48E+18Bq ($T_{1/2}$=77.7 h) and for I132A=3.92E+18 Bq ($T_{1/2}$=2.26 h) were selected from scenario STEP II-b (see [2]). Dependencies from Fig. 1 correspond with eq. (2) for case $T^p_{1/2} >> T^d_{1/2}$ and illustrate dissemination of dangerous iodine to far distances during the straight-line plume propagation.

Figure 1. Behaviour of I132(aerosol) such standalone or as a daughter of TE132 parent (release from JE Temelín in SE direction, HARP code calculations in its simple GPM option)

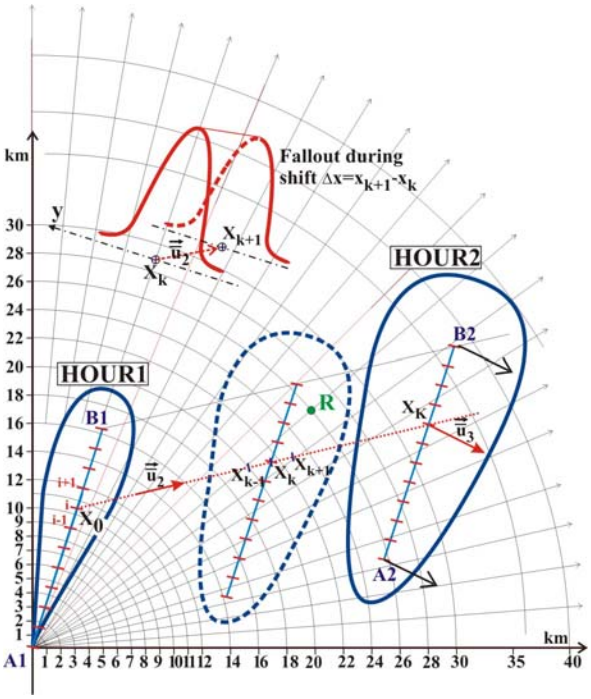
NUMERICAL APPROACH

In the further investigation the following realistic features of the task have to be accepted:

1. Actual changes of weather conditions (at least hourly meteorological forecasts)
2. Spatial changes of depletion/deposition characteristics due to land use categories
3. Possible different physical-chemical forms of parent and daughter nuclides

For accomplishment of the first two points the complicated scenario of release dynamics have to be synchronized with available meteorological forecasts so that drifting of radioactive plume over the

terrain can be satisfactorily modeled. For this purposes an approach of segmented Gaussian plume scheme (SGPM) has been adopted. Hourly changes of wind speed and direction, Pasquill class of atmospheric stability and precipitation are assumed to be available for the next 48 hours from the Czech meteorological service. Using assumption of activity conservation, the release dynamic is segmented into equivalent number of hourly segments. Each such segment is modeled in its all subsequent hourly meteo-phases when stepwise segment movement is driven by meteorological forecast for the corresponding hours. Fig. 2 illustrates such hourly shift between HOUR1 to HOUR2.



This 1-hour interval is divided on K elementary time shifts *k* (K=30÷50) and within each elementary shift k→k+1 of the hourly plume segment an increments of calculated radiological quantities are added in all receptor points R (in means in all points of calculation polar grid). More detailed description of the numerical algorithm of SGPM model is published in [4]. An advantage of the numerical SGPM scheme is its inherent capability to comply with the third requirement stated above which allows different physical-chemical forms for parent-daughter pairs.

Figure 2. Segmented Gaussian plume approach for numerical modeling of propagation of discharges in atmosphere

Activity concentrations $a^p(t_{k-1})$ and $a^d(t_{k-1})$ of the parent and daughter nuclid in the plume result from SGPM calculations in the previous elementary time shift $< t_{k-2}, t_{k-1}>$. Formation of contribution to daughter activity Δa^d just only due to parent decay during $< t_{k-1}, t_k>$ is assumed to be governed by equation $d(\Delta a^d)/dt = S^p - \lambda^d \cdot \Delta a^d$ with initial condition $\Delta a^d(t_{k-1}) = 0$. Source term S^p represents contribution from parent decay which is assumed constant within $< t_{k-1}, t_k>$ according to $S^p = [\, a^p(t_{k-1}) + a^p(t_k)\,]/2 \cdot \lambda^d \cdot \beta^{p\to d}$. It is determined and stored in the previous independent calculations for parent nuclide. The considerations result in solution $\Delta a^d(t') = S^p/\lambda^d \cdot [1-\exp(-\lambda^d t')]$ on interval $t' \in < 0 , t_k - t_{k-1}>$. We shall restrict to average value $\Delta a^d(t'_{av})$ related to $t'_{av} = (t_k - t_{k-1})/2$. Generally, the SGPM model calculates radiological values gradually in each successive elementary shift $< t_{k-1}, t_k>$, k=1, … , K. In the first step of the next interval, standalone daughter nuclide is assumed and the corresponding new quantities are calculated. In the second step, averaged values of parent activity contribution in the new elementary interval are recalculated and added to the

quantities. Analogous considerations are introduced into the numerical process for contribution of parent nuclide to daughter activity deposition (more detailed in [4]).

TESTS FOR KR88 → RB88 PAIR

The numerical algorithm described in the previous paragraph, which is congruent with the basic SGPM scheme, is more general. It covers not only the chains such as illustrated in Fig. 1 but also parent-daughter pairs having different physical-chemical forms in the release. Important example is noble gas KR88 that decays to daughter RB88 which is assumed to be formed as aerosol and then deposits. Even though RB88 is short-lived nuclide ($T_{1/2}$= 17.8 min), its parent KR88 ($T_{1/2}$= 2.84 h) can disseminate the daughter up to many tens of kilometers from the source. Then, the contribution of KR88→RB88 pair to irradiation burden in early stage of accident have to be examined.

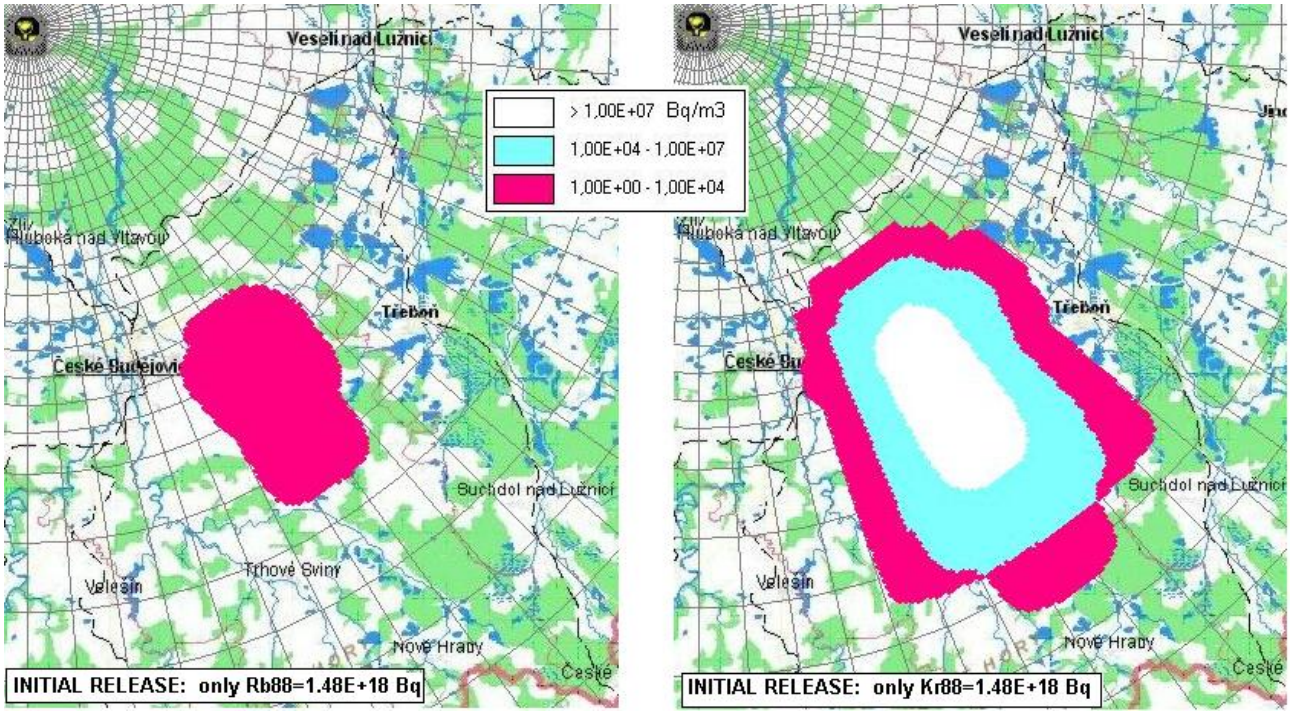


Figure 3. Dissemination of Rb88 to longer distances (values of near-ground activity concentrations just 5 hours after release). Initial release lasts 1 hour, meteo from Case 2 [2]

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