Sensitivity study of influence of input parameters variations for removal processes calculations on activity depletion in the radioactive plume and deposition on the ground

P. Pecha   *- Institute of Information Theory and Automation, Prague, Czech Rep.*
          E-mail address: pecha@utia.cas.cz
P. Kuca   *- National Radiation Protection Institute, Prague, Czech Rep.*
E. Pechova   *- ENERGOPROJEKT Prague, Czech Rep.*

Keywords: RADIOACTIVE RELEASES; ATMOSPHERIC DISPERSION; DEPOSITION ON SURFACE; DRY DEPOSITION VELOCITY; LANDUSE DEPENDENCY

Introduction

Radioactive discharges from nuclear facilities to atmosphere are treated for both cases of normal operation and accidental scenarios. Basic initial characteristics are release height, spectrum of airborne radionuclides and their physical-chemical form, weather conditions, duration of the release and its dynamics. Atmospheric dispersion of the plume during its travel over the terrain leads to dilution of activity. Consequently, three basic removal mechanisms contribute to the further depletion of activity from the plume : radioactive decay of radionuclides, their dry deposition (fallout) and wet deposition (washout, rainout).

The effect of radioactive decay is treated simultaneously for the whole group of nuclides in the formulation of radioactive chains when daughter isotopes are borne and will grow in the plume with a decay of the parent products. Unlike the clear physical phenomena of radioactive decay, for dry and wet deposition various speculative expressions underlined by experimental investigations and theoretical deductions are suggested. Dependencies on chemical form of airborne nuclide (elemental form, organic or aerosol bound), surface roughness and actual meteorological situation have to be taken into account.

Calculations of the plume radioactivity depletion and deposition of isotopes on the ground are treated on the polar grid with radial distances up to 80 kilometres from the source of discharges (*Pecha,1999*). Segmented Gaussian plume model for atmospheric dispersion in connection with the diffusion categories according to Pasquill-Gifford notation is used. Alternative formulas for determination of the dispersion coefficients for cases of rural and urban areas can be selected. Code HAVAR can accept a step-wise changes in meteorological situation and dynamics of the release. It is semiempirical in nature and some other phenomena could be more or less successfully taken into account, such as effect of <u>plume rise</u> on the effective height of emission (due to the initial vertical momentum and buoyancy forces), <u>near-standing building</u> wake effect, consideration of real <u>elevation profile</u> of the terrain, <u>reflection</u> of the plume at ground surface and top of the mixing layer (or inversion layer).

The presented paper deals with one particular problem connected with the land use characteristics of the surface and their influence on the plume activity depletion. During the sensitivity calculations a certain simplification is introduced intentionally (flat terrain, no building wake effect, without plume rise and precipitation occurrence) in order to interpret correctly the land use type effect.

Surface coverage categorization

The real spatial distribution of the surface coverage types around the nuclear facility is considered. Wide range of types being considered in the available common databases has to be reduced and finally for our purposes the following five categories of land use types are distinguished according to table 1.

Table 1   Selected land use type categories and characteristic roughness height ξ

layer name	land_use category	char. roughness ξ (m)
water areas	1	0.0001
grassland	2	0.05
agricultural areas	3	0.1
forests	4	1.0
settlements (industrial and urban areas)	5	1.0

Dry deposition of radionuclides results from sedimentation of aerosols or gravitational settling, their impaction and adsorption of vapours and gases on the surface obstacles. It depends firstly on the physical and chemical form of the isotopes released. More, the basic driving variables for the dry deposition (retention coefficients, deposition velocities) depend also on plant type and the stage of plant development, thus introducing here considerable seasonal effect. Special attention is devoted to the forest areas, for which some new knowledge published recently has been adopted here. In general, the dry deposition velocity is assumed about 10 times higher than over agricultural surfaces. Let us assume the values published in (*Gering,1999*) (see table 2), where the particular forest deposition surfaces are taken into account (forest canopy, trunks, understorey, forest soil).

Table 2   Dry deposition velocities v_g (m.s^{-1}) for various surface types according to (*Gering,1999*)

Physical -chemical form	Surface types				
	water	grass	agricultural	forest	urban
noble gases	0	0	0	0	0
aerosols	0.0007	0.0015	0.002	0.0075	0.0005
elemental iodine	0.001	0.015	0.020	0.073	0.005
organically bound iodine	0.0005	0.00015	0.0002	0.00075	0.00005

The values must be treated as maximum $v_{g,max}$ connected to the fully developed vegetation and forest canopy belonging to the summer season.

Adoption of the source depletion model for dry deposition removal mechanism

Resulting surface deposition rate R_d^n (Bq.m^{-2}. s^{-1}) of nuclide $\underline{n}$ due to dry deposition is expressed as

$$R_d^n (x,y,z=0) = v_g^n . C^n(x,y,z=0) \qquad (1)$$

v_g^n is dry deposition velocity of radionuclide $\underline{n}$ (for its real physical-chemical form); C^n is activity concentration of nuclide $\underline{n}$ in air at distance x from the source (Gaussian straight-line solution) ; y, z are peripheral and vertical coordinates.

The idea of the source depletion model assumes the C^n to be calculated on the basis of the source strength related to the radial distance x from the source. The rate of change of source strength Q^n of nuclide $\underline{n}$ at distance x from the source is

$$\frac{dQ^n(x)}{dx} = -\int_{-\infty}^{+\infty} v_g^n \cdot C^n(x,y,z=0) \cdot dy \qquad (2)$$

with initial condition Q^n (x=0) = Q_0^n (release rate in Bq/s of nuclide $\underline{n}$ at the point of the source)

Let us consider the values under the plume axis (y=0). After substitution of the Gaussian solution for near-ground concentration C^n we express the ratio $Q^n(x)/Q_0^n = f_F^n$ for the FALLOUT process as

$$f_F^n(x; j) = \exp\left[-\sqrt{\frac{2}{\pi}} \cdot \frac{v_g^n}{u_j^0} \cdot \int_0^x \frac{dx}{\sigma_{z,j} \cdot \exp(h_{ef}^2(j)/2/\sigma_{z,j}^2)} \right] \qquad (3)$$

Here index j denotes the weather category according to Pasquill-Gifford notation. Other parameters of the Gaussian solution are:

u_j^0 … reference wind speed at measurement height 10m

h_{ef} … effective plume axis height

$\sigma_{z,j}$ … vertical diffusion coefficient (Karlsruhe-Jülich exponential set is used here)

The correction factor f_F^n express the total plume depletion due to fallout during its travel from the source to the point x and it is calculated numerically.


Account for the real surface coverage

The solution (3) holds true for a certain spatial averaged dry velocity deposition v_g. For the NPP localities in CR is available rather fine resolution of the surface coverage type. Then, for each subarea of the polar grid used in HAVAR program the prevalent category of the land use type can be determined. The calculated area is divided into total 16 directions of windrose and 35 radial distances from the source (in km):

1, 2, 3, 4, 5,6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100

On figure 1 are drawn several map vector layers around the NPP Temelin. A special attention

Figure 1 A picture of the forest category distribution around NPP Temelin
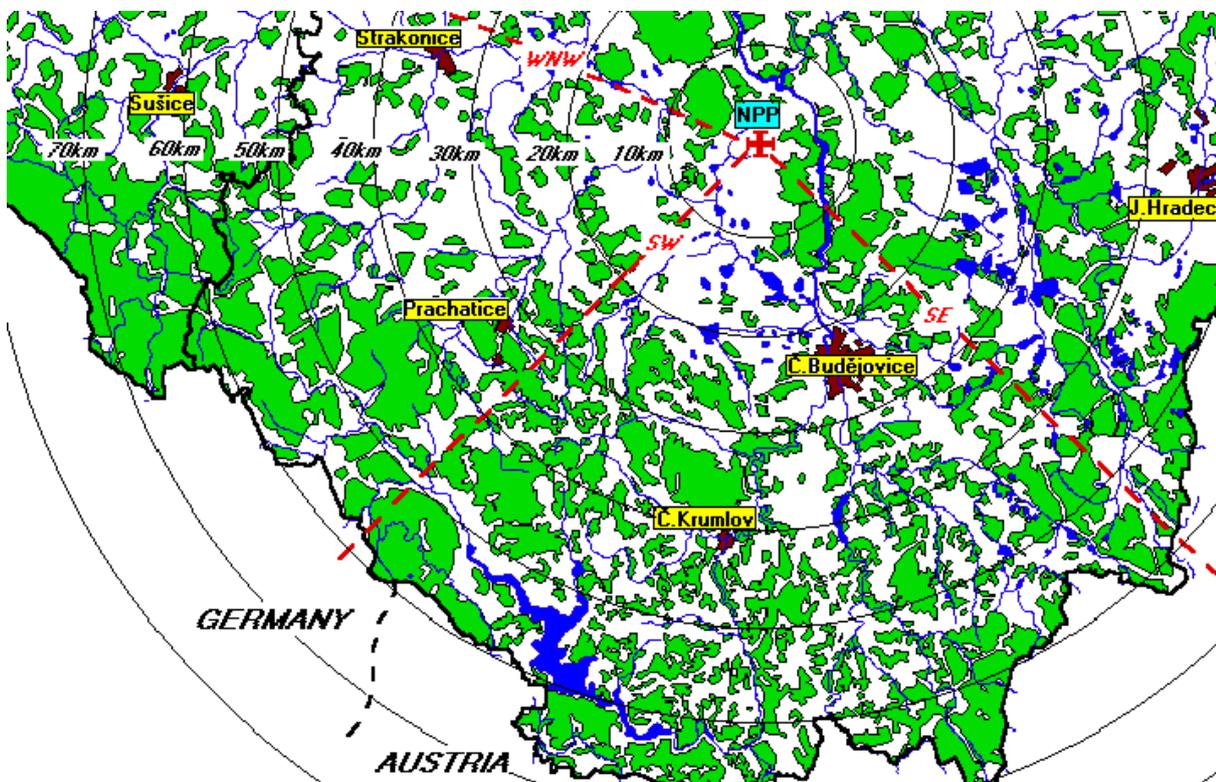
has been devoted to the forests (green areas on figure 1). The intersections of the forest areas with polar calculation grid is done and then the real effect of the local fluctuations in the surface type can be studied. The expression (3) have to be modified, because it is derived under the assumptions of a certain "spatially-averaged" dry deposition velocity v_g^n. It is now distinguished in more detail and then the new notation $v_g^{n,k}$ is introduced. Index k is related to the radial interval $< x_k ; x_{k+1} >$, k=1 ÷ 34 . Thus, the expression (3) have to rewritten for the interval $x \in < x_K ; x_{K+1} >$ into the form

$$ f_F^n(x\ ;j)\ =\ \exp\left[-\sqrt{\frac{2}{\pi}}\ \cdot\frac{1}{u_j^0}\cdot\sum_{k=1}^{k=K}\ \int_{xk}^{xk+1}\frac{v_g^{n,k}}{\sigma_{z,j}\cdot\exp(h_{ef}^2(j)/2/\sigma_{z,j}^2)}\cdot dx\right] \tag{4} $$

Comment to the source depletion model: The dry deposition occurs only in the lowest layer near the ground. But the source depletion model assumes "well-mixing" of the admixtures within the whole plume and then the total deposition between source and receptor is overestimated. At the same time the radioactive discharges remaining airborne are underpredicted.

Sensitivity calculations and results

During the sensitivity study the input coefficients for dry and wet deposition are varied and responses of the main resulted values are demonstrated. The fluctuations of the input parameters are selected in accordance with: a) uncertainties stated by particular authors of semi-empirical expressions, b) mutual magnitudes of deposition velocities between particular land use types, c) seasonal changes of deposition capability for scenarios of average year surface characteristics and those for fully developed plant canopy (case of maximum leaf area index). In conclusion of this paper some particular results related to estimation of the fully developed forest canopy with maximum dry deposition velocities are presented.

Figure 2
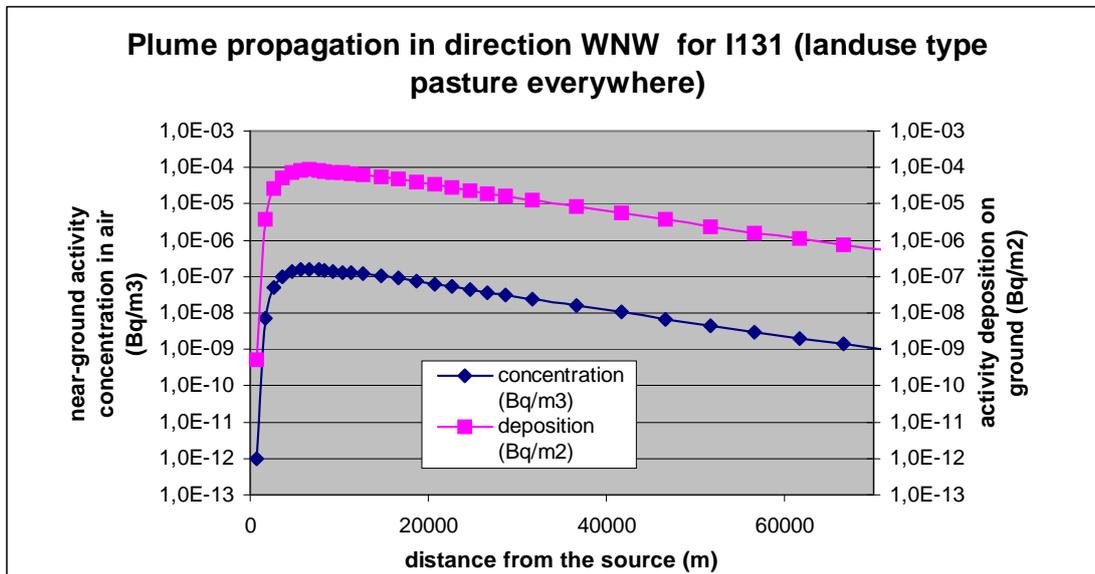
Three characteristic windrose directions can be found from the point of view of forest areas distribution from figure 1 and idealised to the following :

1. direction WNW – only sparse occurrence of forests
2. direction SW   – sparse occurr. of forests up to 24. km, from 24. km continuous forest
3. direction SE   – sparse occurrence of forests from 22 to 40 km, otherwise continuous forest

A particular results for case 1 in comparison with case 2 are presented on figures 2 and 3. In both cases is assumed elemental form of I131, the weather category F, u_{10} = 1 m/s, normalised release

rate of 1Bq/s for each nuclide (duration of release is 10 hours), release height = 100m, zero thermal power and vertical momentum of release, for forest areas the values from tab. 2 are use. For simplification for other "no-forest" categories the only values for grassland (pasture) is used. Comparing the results, the degree of the activity depletion from the plume travelling over the extensive forest border areas of the Czech Republic can be estimated.

Figure 3
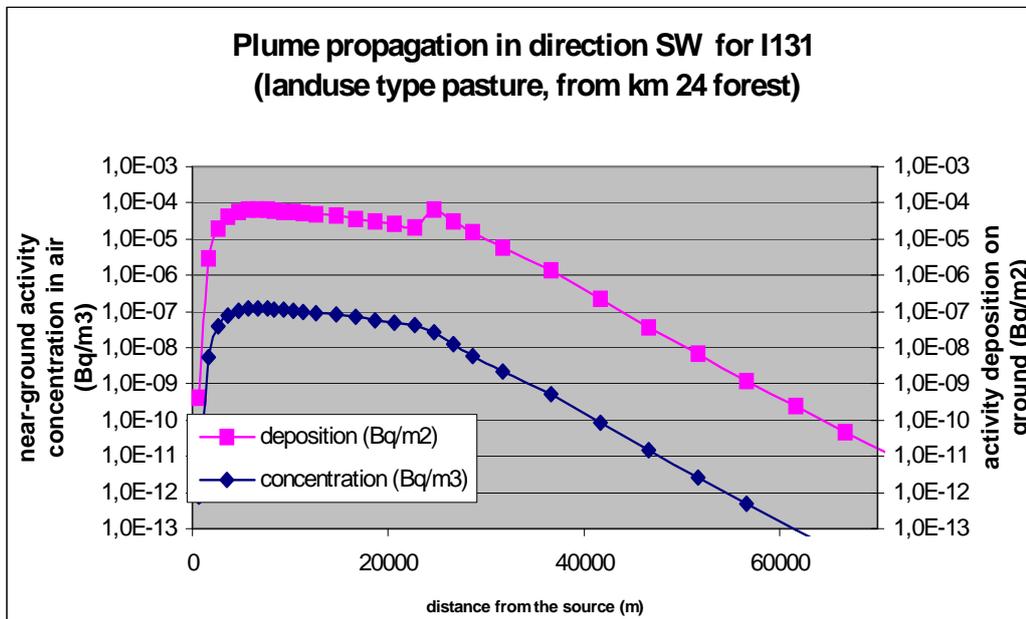
More results for different weather categories, nuclides (and its physical chemical forms), source term parameters and windrose directions are generated. Combinations with occurrence of precipitation revealed prevalent effect of the washout removal mechanism for rain intensity > 5 mm/hour. The new knowledge (*Bunzl,1997*) related to the migration of the Cs initially deposited on ground is adopted for case of the long-term deposition calculation.

Besides the results of the sensitivity calculations some additional tasks having character of the "worst case" studies are analysed, especially for cases of cumulation of the most adverse meteorological conditions from dispersion point of view. Finally, the main results of calculations represented by spatial distribution of near-ground activity concentration in air [Bq.m^{-3}] for each nuclide and its deposition on the ground [Bq.m^{-2}] are assumed to be submitted for the further process of Environmental Impact Assessment.

References

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