Input values for model validation of dry and wet deposition models based on the environmental measurements after the Ru-106 release in the fall of 2017

Dorottya Jakab, Tamás Pázmándi, Csilla Rudas, Péter Zagyvai*

*Hungarian Academy of Sciences Centre for Energy Research, Budapest, *csilla.rudas@energia.mta.hu*

Introduction

^{106}Ru has been detected in the environment on a nearly continental scale in Europe in the fall of 2017. The isotope of artificial origin was detectable in various environmental media, measurements of the environmental compartments as airborne particulates, deposition and terrestrial indicators were performed both on a national and international basis. The results of these environmental measurements provided input data for the atmospheric transport simulations (e.g. [1]) and validation of the operational dry and wet deposition models.

This work is aimed to provide input data for validation of the operational deposition models and investigate the accuracy of distinct deposition velocities as well as the linear and exponential factors in the scavenging coefficient with the comparison of the measured and simulated deposition values. In this paper, principal considerations regarding the applicability of measured values for modelling of dry and wet deposition and the assumptions for comparing those results with monitoring data are summarized.

Methods

Environmental measurements

Environmental and meteorological measurement results were used as input data provided by the environmental radiological monitoring system of the KFKI Campus (located in Budapest at lat. 47°29'20.89''N and lon. 18°57'13.44''E) [2]:

- **^{106}Ru activity concentration bound to airborne particulates in air**
  - sampled with daily to weekly sampling frequencies,
  - for calculations, total beta activity concentrations (corrected with the representative total beta background to estimate $^{106}Ru/^{106}Rh$ beta activity) in aerosol air filters (*Table 2.*) collected with daily sampling frequency were used.
- **^{106}Ru activity concentration in combined wet and dry deposition**
  - sampled with weekly to monthly sampling frequencies.
- **Precipitation amount**
  - 10 minute-summation with a resolution of 0.1 mm,
  - for calculations, the precipitation intensities were determined based on the hourly summation of 10 minute precipitation amounts,
  - stand-alone records with precipitation intensities within the range of the measurement resolution of 0.1 mm were omitted.

Dry and wet deposition models

Dry deposition model:

$$D(x,y) = C(x,y,z=0) \cdot v_d$$

- $D(x,y)$: activity concentration deposited on the ground surface at point (x,y) due to dry deposition ($Bq \cdot m^{-2}$),
- $C(x,y,z=0)$: time integrated activity concentration in air at ground level at point (x,y) ($Bq \cdot s \cdot m^{-3}$),
- v_d: deposition velocity ($m \cdot s^{-1}$).

Wet deposition model:

$$W(x,y) = \int_0^{PBL} C(x,y,z)dz \cdot (1-\varepsilon_w) \cdot \lambda_w$$

- $W(x,y)$: activity concentration deposited on the ground surface at point (x,y) due to wet deposition ($Bq \cdot m^{-2}$),
- ε_w: wash out fraction (-), subject to continuous rainfall at a constant rate, defined as $\varepsilon_w = 1 - e^{-\lambda_w \cdot \Delta t}$, where Δt is the duration of rainfall (s),
- λ_w: scavenging coefficient (s^{-1}), determined as $\lambda_w = \alpha \cdot I^\beta$, where I is the precipitation intensity ($mm \cdot h^{-1}$), and α is the linear ($h \cdot mm^{-1} \cdot s^{-1}$) whereas β is the exponential factor (-) of the scavenging function.

Calculations

Deposition calculations with the parameterizations used in **SINAC** [3], **IdX** [4] and **NAME** [5] atmospheric dispersion modelling software (see in *Table 1.*) were conducted based on the environmental measurement results to determine the deposited activities due to dry and wet deposition mechanisms.

Table 1: Reference values of dry deposition velocity and factors of the scavenging coefficient for aerosol particles in the examined operational models

Parameter	SINAC	IdX	NAME
$v_{d,aerosol}$ ($m \cdot s^{-1}$)	$1.0 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$
α ($h \cdot mm^{-1} \cdot s^{-1}$)	$1.0 \cdot 10^{-4}$	$5.0 \cdot 10^{-5}$	$8.4 \cdot 10^{-5}$
β (-)	$8.0 \cdot 10^{-1}$	$1.0 \cdot 10^{0}$	$7.9 \cdot 10^{-1}$

Considerations:

- ^{106}Ru activity concentrations were taken to be constant in the hourly time steps over the sampling period. D Pasquill stability category and constant vertical distribution of the time integrated activity concentration was assumed below the planetary boundary layer (PBL) for which default value of 500 m was used.
- v_d dry deposition velocity was taken to be constant over the given sampling intervals.
- λ_w scavenging coefficient and ε_w wash out fraction was calculated for each rainfall event with the associated precipitation intensities.
- Source depletion due to wet deposition was considered for every hour when rainfall was measured. In these instances, the dry deposition was calculated from the residual air activity concentration depleted at ground level based on ε_w wash out fraction. Source depletion due to dry deposition was not taken into account.

Table 2: Input data derived from the measured activity concentrations in ground level air during the presence of ^{106}Ru plume in the Budapest region (from 30.09. until the morning of 04.10.)

Sampling start	Sampling end	Sampling duration (h)	Activity concentration ($mBq \cdot m^{-3}$)	Time integrated activity concentration ($Bq \cdot s \cdot m^{-3}$)	Constant time integrated activity concentration in hourly time step ($Bq \cdot s \cdot m^{-3}$)
30.09. 06:50	01.10. 06:44	23.9	7.8 ± 0.4	$6.7 \cdot 10^{2}$	$2.8 \cdot 10^{1}$
01.10. 06:44	02.10. 09:22	26.6	33.5 ± 1.9	$3.2 \cdot 10^{3}$	$1.2 \cdot 10^{2}$
02.10. 09:22	03.10. 09:25	24.0	15.5 ± 0.9	$1.3 \cdot 10^{3}$	$5.6 \cdot 10^{1}$
03.10. 09:25	04.10. 09:13	23.8	7.6 ± 0.4	$6.5 \cdot 10^{2}$	$2.7 \cdot 10^{1}$

Results & Discussion

Table 3: Calculated values for dry deposition (D) over the sampling intervals, for wet deposition (W) values for each rainfall event, and the summation of calculated dry and wet deposition activity concentrations (D+W) compared with measured (combined sampling of dry and wet deposition with a one-week long sampling frequency) deposition values. Summation of precipitation intensities (I) and deposited activities for the time period of 30.09-02.10. and 02.10-04.10. is highlighted in bold font. Dashed lines show the filter change of the daily air sampling.

Time period	I ($mm \cdot h^{-1}$)	SINAC D ($Bq \cdot m^{-2}$)	SINAC W ($Bq \cdot m^{-2}$)	SINAC D+W ($Bq \cdot m^{-2}$)	IdX D ($Bq \cdot m^{-2}$)	IdX W ($Bq \cdot m^{-2}$)	IdX D+W ($Bq \cdot m^{-2}$)	NAME D ($Bq \cdot m^{-2}$)	NAME W ($Bq \cdot m^{-2}$)	NAME D+W ($Bq \cdot m^{-2}$)	Measured D+W ($Bq \cdot m^{-2}$)
30.09. 06:50-01.10. 06:44		0.67			1.3			0.67			
01.10. 06:44-20:00		1.6			3.2			1.6			
01.10. 20:00-21:00	0.2[a]	0.10	1.5		0.22	0.58		0.10	1.3		
01.10. 21:00-22:00		0.12			0.24			0.12			
01.10. 22:00-23:00	0.3[a]	0.092	2.0		0.22	0.86		0.096	1.7		
01.10. 23:00-02.10. 09:22		1.2			2.5			1.2			
30.09. 06:50-02.10. 09:22	**0.5**	3.8	3.5	**7.3**	7.7	1.4	**9.1**	3.8	3.0	**6.8**	**<2.1**
02.10. 09:22-13:00		0.20			0.41			0.20			
02.10. 13:00-14:00	0.3[a]	0.043	0.93		0.10	0.40		0.044	0.81		
02.10. 14:00-03.10. 09:25		1.1			2.2			1.1			
03.10. 09:25-15:00		0.15			0.31			0.15			
03.10. 15:00-16:00	0.6	0.017	0.72		0.044	0.37		0.018	0.63		
03.10. 16:00-17:00	2.2	0.0071	1.3		0.025	1.0		0.0089	1.2		
03.10. 17:00-18:00	0.8	0.015	0.85		0.041	0.47		0.016	0.75		
03.10. 18:00-19:00	0.5	0.018	0.64		0.046	0.31		0.019	0.56		
03.10. 19:00-20:00	0.8	0.015	0.85		0.041	0.47		0.016	0.7		
03.10. 20:00-04.10. 08:00		0.33			0.65			0.33			
04.10. 08:00-09:00	2.5[a]	0.0061	1.3		0.022	1.1		0.0079	1.3		
04.10. 09:00-10:00	2.9[a,b]	0.0051	1.4		0.019	1.2		0.0067	1.3		
02.10. 09:22-04.10. 10:00	**10.6**	1.9	8.0	**9.9**	3.9	5.3	**9.2**	1.9	7.3	**9.2**	**11.3 ± 2.2**

[a] Presumably locally prevailing precipitation intensities, which deviate significantly from the daily summations of rainfall published in the daily reports of the Hungarian Meteorological Service (OMSZ).
[b] On 4 October the air sampling lasted until 9:13 but the rainfall happened prior to the filter change.

- Since dry deposition is a linear function of dry deposition velocity, the significant overestimation of the dry deposition during the first sampling period (30.09-02.10.) indicates that the true value of dry deposition velocity was smaller than the default values used by SINAC and NAME (i.e. $<1.0 \cdot 10^{-3}$ $m \cdot s^{-1}$). Because of the functional particle size dependency of the dry deposition velocity, it thereby implies the deposition of aerosol particles with small aerodynamic diameter (≤ 1 µm).
- The deposition activity concentrations calculated for the second sampling period (02.10-04.10.), when wet deposition dominated, agree within the margin of error (±19.5%) with the measured values (with disregarding the dependence of raindrop-size distribution and the form of the precipitation on the scavenging coefficient).
- Perturbation of the exponential variable of the scavenging coefficient to determine its optimal value showed that the usage of distinct parameter values would have been accurate for light rainfalls in the first sampling interval and heavier rain events in the second sampling period.
- Through the example model validation calculations various limitations appearing in field measurements, such as the crude temporal resolution of environmental measurements and the reliability and spatial variability of meteorological observations were showed.

References

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