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EXPERIENCE IN USING MODELS OF POLLUTANT DISPERSAL IN AN URBAN ENVIRONMENT

S. V. Panchenko,[1] D. A. Pripachkin,[1]
A. I. Kryshev,[2] and M. N. Katkova[2]

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The experience gained in validating calculations of the ground-surface concentration of a pollutant injected into an urban environment from a stationary high-altitude source is presented. A Gaussian model using the average annual emission, the characteristic parameters of the source, and a real annual wind rose, as well as a Lagrangian-type model, in which the input parameters were the average daily emission and hourly meteorological parameters, are examined. The computational results were compared with the measured values of the concentration of ^{131}I. It is shown that when using average annual data the uncertainty of the estimates at a particular point located 4–6 km from the source can reach 4-fold. For emissions which are not protracted (up to one day), even given a full-fledge set of data on the meteorological parameters, the uncertainty of the estimated average daily concentration at the same point can reach one order of magnitude.

For comparative assessments of the population risk from emissions from stationary sources, the dispersal from each individual ventilation pipe is modeled. Then, aided by the dose–effect relation for specified exposure the ground-surface concentration of substances causing adverse health effects in the population is converted into risk [1]. At the next stage of the analysis, the risk from different pollutants at individual points of the urban territory is summed in order to determine the location of the highest values. In this computational scheme the first stage already introduces significant uncertainties – the calculation of the ground-surface concentration from a single source of atmospheric emissions. The difficulties in assessing the ground-surface concentration lie in the fact that the volumetric architecture of an urban settlement can introduce, as many specialists posit, significant local distortions in the computational models. The scale of such distortions can be determined only experimentally, but the setting up of an experiment raises definite difficulties. And it is no accident that the world experience in performing such checks is sparse. The main difficulties arise at the stage of formation of the wind speed and direction fields in the urban space, when it is quite difficult to measure the meteorological parameters at different points. The use of indicating substances to estimate the dispersal of a pollutant emitted into the atmosphere is a natural but rarely used technique. In terms of many properties, radioactive substances are more suitable for experimental checking of dispersion models. Radionuclides as tagged atoms have now been used for more than a hundred years in many fields in the natural sciences and medicine [2]. But the prevailing attitude toward radioactivity deters widespread use of this method in cases where the problem to be solved lies in the field of public safety and control of technogenic risks.

Nevertheless, under favorable circumstances radionuclide markers can sometimes be used to perform an experimental check of model calculations. The present article provides an assessment of the uncertainty of technogenic risks for the general population of Obninsk.

Initial materials and methods. Two enterprises emitting small amounts of radionuclides into the atmosphere, which do not significantly affect the public health, are located in Obninsk: Leipunskii Institute for Physics and Power Engineering (IPPE) and the Karpov Research Institute of Physical Chemistry (NIFKhI) [3, 4]. It is clear from Table 1 that the radionuclide

[1] Nuclear Safety Institute, Russian Academy of Sciences (IBRAE RAS), Moscow, Russia; e-mail: panch@ibrae.ar.ru.
[2] Research and Production Association Typhoon, Obninsk, Russia.

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TABLE 1. Annual Radionuclide Emissions from IPPE and NIFKhI in 2013–2017 [4], Bq

Radionuclide	2013	2014	2015	2016	2017
IPPE					
^{57}Co	$1.62\cdot10^{8}$	$4.10\cdot10^{7}$	$9.07\cdot10^{6}$	$8.10\cdot10^{6}$	$6.60\cdot10^{6}$
^{65}Zn	$1.70\cdot10^{5}$	Not detected	$2.30\cdot10^{6}$	$5.00\cdot10^{5}$	$3.90\cdot10^{5}$
^{90}Sr	$4.60\cdot10^{6}$	$2.80\cdot10^{6}$	$4.20\cdot10^{6}$	$7.40\cdot10^{5}$	$5.70\cdot10^{5}$
^{137}Cs	$2.77\cdot10^{6}$	$2.62\cdot10^{6}$	$1.71\cdot10^{6}$	$6.28\cdot10^{7}$	$7.57\cdot10^{6}$
^{109}Cd	$2.10\cdot10^{7}$	$1.10\cdot10^{7}$	$4.30\cdot10^{6}$	$4.50\cdot10^{6}$	$5.80\cdot10^{6}$
^{241}Am	Not detected				$1.10\cdot10^{6}$
^{68}Ge	$4.60\cdot10^{6}$	$2.80\cdot10^{6}$	Not detected		
^{68}Ge + ^{68}Ga	Not detected		$4.20\cdot10^{6}$	$5.20\cdot10^{6}$	$6.00\cdot10^{6}$
NIFKhI					
^{41}Ar	$2.5\cdot10^{13}$	$4.5\cdot10^{13}$	$7.8\cdot10^{13}$	$1.7\cdot10^{14}$	$9.3\cdot10^{13}$
^{85m}Kr	$5.2\cdot10^{12}$	$2.7\cdot10^{12}$	$2.2\cdot10^{13}$	$1.4\cdot10^{13}$	$1.3\cdot10^{13}$
^{131}I	$1.2\cdot10^{11}$	$1.6\cdot10^{11}$	$8.5\cdot10^{11}$	$1.4\cdot10^{12}$	$1.6\cdot10^{12}$
^{132}I	$3.6\cdot10^{10}$	$9.1\cdot10^{10}$	$1.6\cdot10^{12}$	$1.0\cdot10^{12}$	$1.9\cdot10^{12}$
^{133}I	$1.1\cdot10^{10}$	$2.1\cdot10^{10}$	$4.4\cdot10^{11}$	$8.8\cdot10^{11}$	$1.0\cdot10^{12}$
^{135}I	$6.3\cdot10^{7}$	$2.7\cdot10^{8}$	$4.6\cdot10^{10}$	$4.6\cdot10^{10}$	$7.1\cdot10^{10}$
^{133}Xe	$9.1\cdot10^{13}$	$2.4\cdot10^{13}$	2.5·1014	$1.6\cdot10^{14}$	$8.8\cdot10^{13}$
^{135}Xe	$5.0\cdot10^{13}$	$1.9\cdot10^{13}$	2.0·1014	$1.7\cdot10^{14}$	$1.1\cdot10^{14}$
^{135m}Xe	Not detected				$1.8\cdot10^{13}$

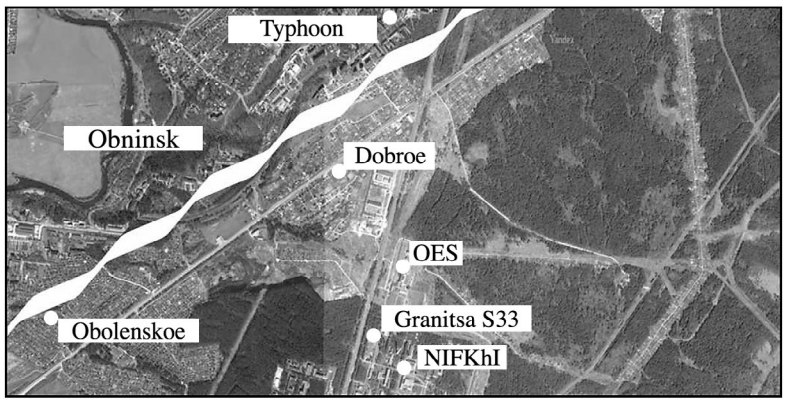

Fig. 1. Location of control points for the volumetric activity of ^{131}I from NIFKhI in ground-surface air.

composition of the emissions from the NIFKhI consists of relatively short-lived radionuclides, whereas mainly long-lived nuclides predominate in the IPPE emissions. Moreover, the injected activity for NIFKhI is many orders of magnitude higher. This makes it possible to choose NIFKhI as a source of radioactive emissions using ^{131}I as a reference nuclide to check the dispersal model. This choice is determined by the system operating at NIFKhI for monitoring the content of this particular radionuclide in the ground-surface air (Fig. 1, Table 2) [4, 5]. Moreover, in Obninsk the meteorological parameters – air temperature and humidity, wind speed and direction, pressure, turbulence characteristics at different heights above the ground

TABLE 2. Volumetric Activity of ^{131}I in Air in Obninsk, on the Boundaries of the Observation Zone and the Sanitary-Protection Zone at NIFKhI [4, 5], Bq/m^3

Control point	Distance from source, km	2013	2014	2015	2016	2017
NIFKhI:						
sanitary-protection zone	0.4	$6.64\cdot10^{-3}$	$5.28\cdot10^{-4}$	$1.33\cdot10^{-3}$	$6.70\cdot10^{-3}$	$4.88\cdot10^{-3}$
observation zone	0.8	$7.64\cdot10^{-3}$	$7.97\cdot10^{-3}$	$1.27\cdot10^{-3}$	Not detected	$1.13\cdot10^{-2}$
Obninsk	4.6	$7.3\cdot10^{-5}$	$2.5\cdot10^{-5}$	$4.82\cdot10^{-4}$	$3.12\cdot10^{-4}$	$4.12\cdot10^{-4}$

TABLE 3. Computed and Measured Average Annual Concentration of ^{131}I in Obninsk

Parameter	2014	2015	2016
^{131}I emission, Bq/sec	$5.07\cdot10^3$	$2.70\cdot10^4$	$4.44\cdot10^4$
Recurrence of wind direction R	0.13	0.14	0.13
^{131}I concentration, Bq/m^3:			
computed	$1.0\cdot10^{-4}$	$5.5\cdot10^{-4}$	$8.6\cdot10^{-4}$
measured	$2.5\cdot10^{-5}$	$4.8\cdot10^{-4}$	$3.1\cdot10^{-4}$
Ratio of computed to measured values	4.1	1.1	2.7

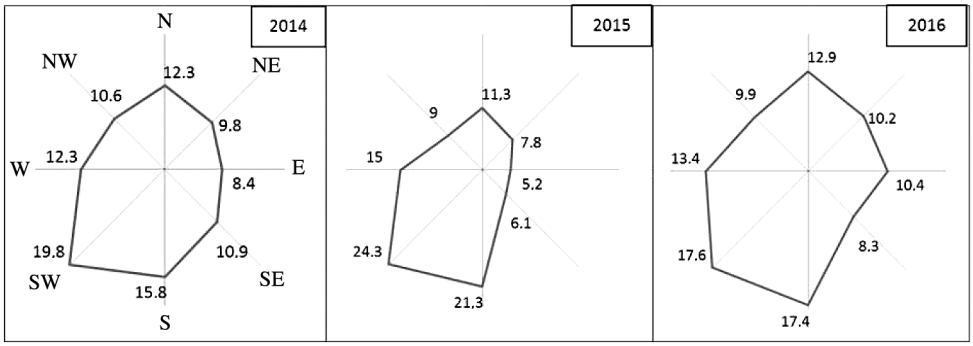

Fig. 2. Average annual wind rose in Obninsk in 2014–2016.

– are continuously measured with the aid of instruments placed on a meteorological mast (VMM-310). Aside from detailed data, widely used annual data are presented for separate parameters. A typical example is the average annual wind rose in Obninsk in 2015 (Fig. 2).

Another circumstance favorable for checking the quality of dispersal models is associated with observations performed at the Research and Production Association Typhoon of the radioactive air aerosols, including ^{131}I in molecular and aerosol form.

Methodological approaches to pollutant dispersal assessment. The average annual concentration C of a radionuclide in air can be determined from the annual emission Q, the characteristic wind rose R, and the dispersion coefficient σ, taken, for example, from the handbook [6], according to the relation $C = Q\sigma R$.

So, the following parameters can be used for the Typhoon site: average annual rate of emission of ^{131}I in 2014–2016, $\sigma = 1.5\cdot10^{-7}$ sec/m^3 for emission altitude 30 m, which corresponds to the arrangement of the ventilation pipes on the roof of building VVR-ts, located on the grounds of the NIFKhI, with roughness coefficient z_o = 100 cm and primary weather categories C and D, and distance x = 4.6 km of the control point from the pipe. The initial data and the computational results are presented in Table 3.

TABLE 4. Data on the Meteorological Conditions in May 21 and 22, 2015, in Obninsk, According to Typhoon Data

Time, h	Wind speed, wind direction, and temperature at height 8 m			Temperature at height 121 m, °C	Temperature gradient, °C/100 m
	m/sec	deg	°C		
May 21, 2015					
0	0.1	118	11.3	20.7	8.32
1	0.3	69	10.8	20.9	8.94
2	0.1	109	10.3	20.3	8.85
3	0.2	66	9.7	20.5	9.56
4	0.1	89	9.2	19.8	9.38
5	0.1	118	9.1	18.7	8.50
6	0.1	224	11.6	18.7	6.28
7	0.1	74	14.4	18.9	3.98
8	0.4	153	19	18.4	–0.53
9	1.2	192	22.2	20.5	–1.50
10	1.5	159	23.9	22	–1.68
11	2.2	205	24	22.6	–1.24
12	2.1	167	25.3	23.4	–1.68
13	1.8	140	26.4	24.4	–1.77
14	2.6	185	27.1	25.1	–1.77
15	2.1	193	27.6	25.7	–1.68
16	2.1	196	27.9	26	–1.68
17	1.9	189	27.6	26.3	–1.15
18	2.1	181	27.6	26.6	–0.88
19	0.7	190	26.7	26.2	–0.44
20	0.6	136	24.4	25.5	0.97
21	0.4	108	19.5	24.8	4.69
22	0.2	133	19.4	23.9	3.98
23	0.6	183	18.4	23.2	4.25
24	0.2	113	16	22.5	5.75
May 22, 2015					
1	0.4	120	15.1	21.9	6.02
2	0.4	160	14.9	21.7	6.02
3	1.1	276	18.3	20.4	1.86
4	0.8	189	16.2	20.4	3.72
5	1.4	203	18	20.2	1.95
6	1.3	206	19	19.8	0.71
7	2.1	201	20.4	20	–0.35
8	1.1	203	20.4	19.8	–0.53
9	0.8	225	22.1	20.7	–1.24

TABLE 5. Measured Volumetric Activity of ^{131}I in the Ground-Surface Air in Obninsk in May 2015 (Typhoon site), μBq/m^3

Date	Molecular form	Aerosol form
08–12	183	<1
12–13	148	90
13–14	490	<1
14–15	103	530
15–18	10	<1
18–19	100	155
21–22	5100	580
22–25	220	430
26–27	100	42
27–28	340	700
28–29	108	68

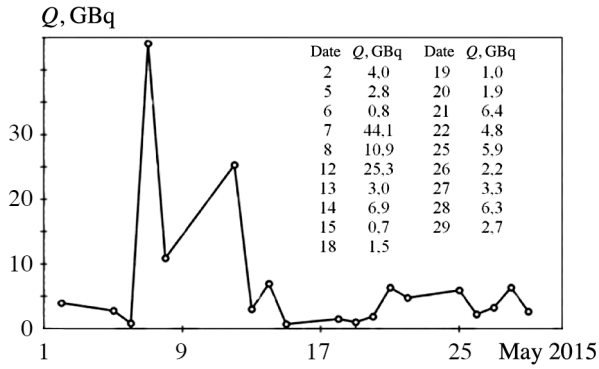

Fig. 3. Sample of daily emissions of ^{131}I entering the atmosphere from NIFKhI in May 2015 (information provided by NIFKhI).

Comparing the computed and measured concentrations shows satisfactory agreement from the standpoint of radiation safety. The maximum difference was about a factor of four. The parameters of the model of [7] were picked on the basis of the averaged experimental data [8]. This empirical model is the working model for IAEA and is used in many practical applications, as a rule, for distances up to 10–15 km from the source.

At the same time, specialists presuppose that the model can give a significant uncertainty in particular situations. The problem studied in the present article included, in particular, an evaluation of the uncertainty when using pollutant emissions averaged over a time interval that is significantly shorter but still quite long enough relative to the changes in the meteorological conditions. It would be more accurate to use meteorological data in a software module of the Lagrangian type. To this end the daily emission of ^{131}I during May 2015 was examined. As Table 4 shows, even during a single month the uncertainty of ^{131}I emission is equal to almost a factor of 100. To a significant extent this attests the need to also examine shorter time intervals in order to verify a model. It follows from physical considerations that the length of such intervals must be comparable with the duration of a stable wind direction, i.e., for the conditions in Obninsk they range from one hour to several hours (Fig. 3).

A check of the quality of the dispersal models was initiated for the data obtained at Typhoon in May 2015 on the concentration of ^{131}I, in aerosol and molecular form, in the ground-surface air on-site (Table 5). The output capacity of the air filtering setup was equal to 800–1300 m^3/h. The relative error of the measurement of ^{131}I was in the range of 10–30%. The exposure of the filters, for example, during May 21–22, 2015, when a heightened ^{131}I concentration in ground-surface air was observed, was equal to 48 h. The exposure of the filters in the sanitary-protection zone and the observation zone at NIFKhI

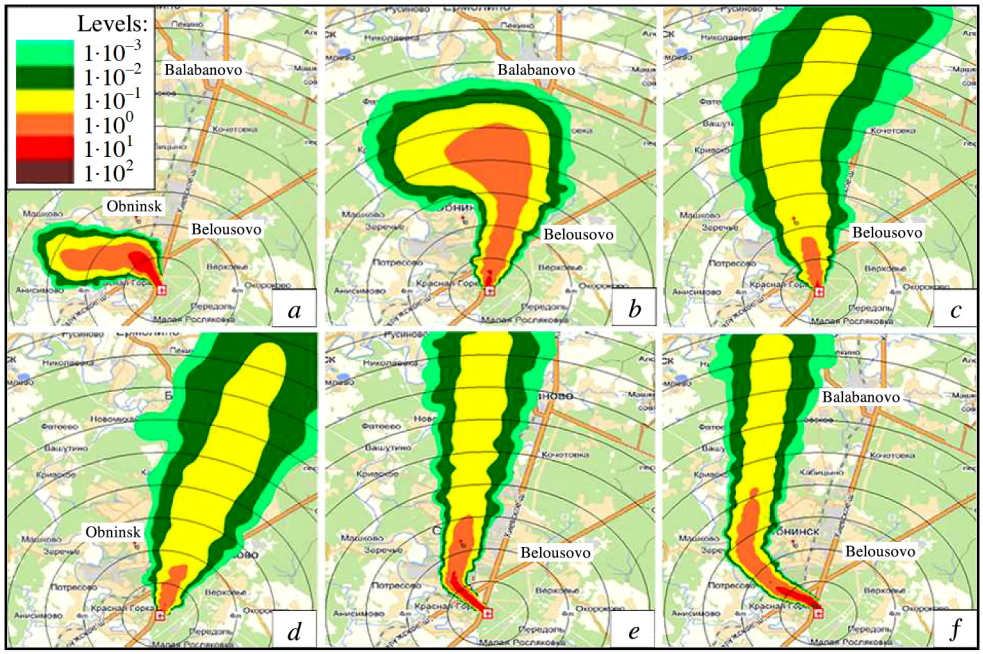

Fig. 4. Volumetric activity of ^{131}I-containing aerosols in atmospheric air on May 21, 2015 at 9 (*a*), 10 (*b*), 13 (*c*), 17 (*d*), 21 (*e*), and 23 h (*f*).

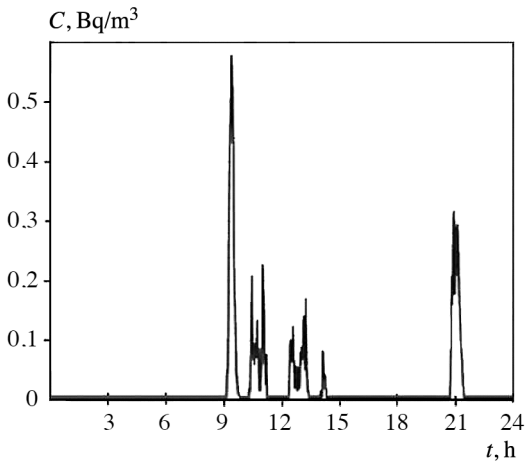

Fig. 5. Computed dynamics of the volumetric activity of ^{131}I on May 21 and 22, 2015 at the location of the air filtering setup.

was equal to two weeks. In the period from May13–29, 2015 the average concentration was equal to 8920 μBq/m^3 at the boundary of the sanitary-protection zone and 1700 μBq/m^3 at the boundary of the observation zone.

Modeling the dispersal of ^{131}I was performed with the aid of the Rostekhnadzor-attested Nostradamus software, in which an advection diffusion Lagrangian model is used [9]. The dispersal of ^{131}I-containing radioactive aerosols during technological emissions occurring from NIFKhI on 21 May is shown in Fig. 4. In the modeling it was assumed that during the considered period ^{131}I entered the atmosphere uniformly. The point at which an air sample was obtained lies predominantly north-northwest of the NIFKhI grounds, so that radioactive iodine can enter the sample, obtained on the filter, only during north-westward and northward transport.

The modeling showed that a cloud with the radioactive iodine passed through the detection point several times over two days. Three characteristic intervals can be identified: from 9 to 14 h and approximately at 21 h on May 21 and from 0 to 4 h on May 22 (Fig. 5). Thus the modeling performed with the use of the real meteorological parameters and the Lagrangian

type models make it possible to refine the kinetics of pollutant passage at a specific point and reveal the local maxima of the ground-surface concentration. The integral of the concentration of ^{131}I over two days according to the computational data was equal to 1.0 ± 0.3 Bq·h/m^3. The measured value of the integral of the concentration of ^{131}I on the Typhoon site was equal to 0.14 ± 0.04 Bq·h/m^3, i.e., less by approximately a factor of 7. The conservatism of the assessments for salvo-like accidental emissions and for scheduled emissions with a known field of meteorological parameters currently is approximately an order of magnitude.

Discussion and conclusions. The verification of the model of the dispersal of harmful pollutants emitted from stationary sources in residential zones remains a problematic task requiring both accumulation of experimental information as well as the deepest possible development of the models themselves.

The average annual data can be used for comparative assessment of the risk to a healthy population from pollutants of different nature which are emitted into the atmosphere by industrial enterprises. The error of such assessments can be overstated by several-fold. However, for determining the relative effect of pollutants the uncertainty of the assessments will be appreciably lower.

For quantitative assessment of the concentration of a pollutant in ground-surface aire for comparatively short-time emissions (from several hours to days), the uncertainty in a particular point can reach an order of magnitude even if high-quality meteorological parameters are available.

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