Remote detection of raised radioactivity in emission from Beloyarsk nuclear power plant

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Abstract. In the paper, we consider the gas-aerosol radioactive emissions and theoretically justify the possibility of remote detection of increased radioactivity in air emissions from the nuclear reactor BN. The comparative analysis of injected radionuclides into the atmosphere from nuclear power plant with advanced fast neutron reactor is carried out. On example of Beloyarsk nuclear power plant, the problem of remote detection of radioactivity in the atmospheric pollution is examined. Considering the emissions of certain groups, we can conclude: inert gases in the extract tritium in gaseous and liquid emissions, ^{14}C and ^{131}I in the exhaust air, the radioactivity is adsorbed on the particles in the polluted air, and "other" contained in the liquid emissions. Taking into account the total activity of radioactive noble gases and feasibility of remote detection of raised radioactivity in emission from nuclear power plant and radio-chemical plant, we make a conclusion that radiometric system able to detect raised radioactive emission from NPP with fast neutron reactor.

Key Words: NPP, FBR, monitoring,, Gauss model.

1. Introduction

The relevance of this study is the fact that at present all over the world has accumulated a large amount of radioactive waste and as a result exhausted itself stores - more than 270000 tonnes of spent fuel of nuclear power plants (NPP), the storage of which is determined by thousands of years [1]. Time decay of radionuclides and their mobility in the environment allows them to be widely distributed and fall into the natural food chain. Existing solutions to the problem can be divided into: the construction of new nuclear waste storage or re-use of recycled fuel. For example, countries that do not possess the latest nuclear technologies, are planning to build additional storage of radioactive waste, while in Russia, this problem is solved by the design and launch of the NPP with fast neutron reactors (BN-reactor) [2-4].

Zoning contaminated areas in accordance with the Russian legislation: the evacuation zone begins at excess contamination with ^{137}Cs - more than 15 Ci / km² and living area with the right of resettlement begins at 5 Ci / km². As in the case of Fukushima, Rosatom reactors there who work or will work on plutonium. In the MOX fuel runs a multi-purpose reactor in Dimitrovgrad nuclear center (Ulyanovsk region). The intended use of MOX fuel at the 4th block of the Balakovo NPP and power unit BN-800 at Beloyarsk NPP. This means that the cesium contamination will be burdened and more dangerous – plutonium [5].

To carry out the contract “Plutonium Management and Disposition Agreement” between the Government of the United States and the Government of the Russian Federation, in the Russian Federation the fast neutron reactors have used MOX (mixed oxide) fuel are designed and constructed. On the nuclear reactors work with great expectations on fast neutrons, as it would: increase the efficiency of the use of uranium, ^{238}U and ^{232}Th stocks may be involved

in the fuel cycle, which in nature is much greater than ^{235}U - the main fuel for thermal reactors. Including can be used and so-called "depleted uranium" remaining after enrichment of nuclear fuel ^{235}U [6].

It is interesting and relevant to consider the gas-aerosol radioactive emissions and theoretically justify the possibility of remote detection of increased radioactivity in emissions throw out into the atmosphere from the nuclear reactor BN.

2. Estimation of the Inventories of Radioactivity

For the calculation was taken the Beloyarsk Nuclear Power Plant (BNPP) - the only nuclear power plant in Russia with BN-reactor. As place BNPP location: Sverdlovsk region. The distance to the satellite city (Zarechny) - 3 km; to the regional center (Ekaterinburg) - 45 km.

AMB (that stands for "peaceful atom great") - water-graphite channel reactor. The first two power units with water-graphite channel reactors AMB-100 and AMB-200 operated at the Beloyarsk NPP in 1964-1981 and 1967-1989, respectively, and were stopped in connection with the development of the resource [7].

TABLE I: EXISTING POWER UNITS OF BELOYARSK NPP.

Number power	**Reactor type**	**Installed capacity, MW**	**Launch date**
3	BN-600	600	08.04.1980
4	BN-800	880	10.12.2015
The total installed capacity of 1480 MW			

Average values for emissions 1985-1989 yy. NPP with fast neutron reactor in normal operation are presented in the table 2. The amount of radioactivity and radionuclide composition of emissions depend on the type of reactor [8]. Considering the emissions of certain groups, we can conclude: inert gases in the extract tritium in gaseous and liquid emissions, ^{14}C and ^{131}I in the exhaust air, the radioactivity is adsorbed on the particles in the polluted air, and "other" contained in the liquid emissions. RBG (radioactive noble gases) occur through nuclear fission and radioactive decay of the fission products in the fuel. Furthermore, noble gases can be resulted by neutron activation. Thus, ^{41}Ar may also be produced in the air around the reactor vessel, within the FBR in the reactor container of argon buffer gas to sodium or cooled gas from the cooling gas of argon impurities.

The main elements contained in the emissions from the BN are ^{24}Na (33%), ^{137}Cs (33%), ^{134}Cs (16%). Some radionuclides with a small half-time and secondary (lower, lower) share, some not included in the list.

TABLE II: THE AVERAGE VALUE OF RADIONUCLIDE EMISSIONS (1985-1989) OF THE NUCLEAR REACTOR ON FAST NEUTRONS [10].

Emissions of radionuclides, TBq $GW^{-1}y^{-1}$		
Radioactive Nobel Gases		150
air	3H	96
liquid	3H	2.9
air	14C	0.12
	131I	0.0009
air	particles	0.0002
liquid	others	0.028

According to [10] atmospheric emissions:

TABLE III: EMISSION OF RADIONUCLIDES OF DIFFERENT TYPE OF REACTOR.

Emissions of radionuclides, TBq $GW^{-1}y^{-1}$	
PWR / VVER	81
BWR / nuclear reactor of boiling type	290
GCR / gas-cooled reactor	2100
HWR / heavy-water nuclear reactor	190
LWGR / water-graphite nuclear reactor	2000

The tables [2] and [3] show that the atmospheric emissions of radionuclides from the NPP with fast neutron reactor is comparable with emission of radionuclides of PWR, BWR and HWR. Paper [11] shows the estimation of annual emissions in the atmosphere from two reactors with electric capacity 1000 W of BWR and PWR reactors. Below we compare emission of radionuclide for three type of reactors.

TABLE IV: THE ESTIMATION OF ANNUAL EMISSIONS IN THE ATMOSPHERE FROM THREE REACTORS WITH ELECTRIC CAPACITY 1000 W.

Radionuclide	**BWR, Bq·y^{-1}**	**PWR, Bq·y^{-1}**	**FBR, Bq·y^{-1}**
^{41}Ar	9.25·1011	9.25·10^{11}	—
^{83m}Kr	< 3.7·1010	3.7·10^{10}	—
^{85m}Kr	5.55·1012	5.2·1011	—
^{85}Kr	1.073·1013	1.739·1013	—
^{87}Kr	7.4·1012	1.11·1011	—
^{88}Kr	8.88·1012	8.51·1011	—
^{131m}Xe	6.66·1011	3.034·1012	—
^{133m}Xe	< 3.7·1010	4.44·1012	—
^{133}Xe	1.184·1014	4.44·1014	—
^{135m}Xe	2.738·1013	< 3.7·1010	—
^{135}Xe	4.07·1013	3.182·1012	—
^{138}Xe	5.18·1013	< 3.7·1010	—
^{131}I	1.11·10^{10}	9.25·10^{8}	9·10^{2}
^{133}I	9.07·1010	8.51·108	—
^{14}C	3.515·1011	2.96·1011	1.2·10^{5}
^{3}H	1.591·1012	4.07·1013	9.7·10^{7}
Total activity	2.7·10^{14}	5.2·10^{14}	1.5·10^{8}

Symbol "—" does not mean that above radionuclides are not throw out from NPP with FBR. It means that we have not any information about radionuclide composition. Taking into account total activity of RBG and feasibility to detect raised concentration of radioactive impurity in NPP and RCP emissions [12] we could conclude that radiometer system able to detect radioactive emission from nuclear power plant with fast neutron reactor.

3. Modelling of General Hydrogen Atom in the Emission Plume.

Location of the Beloyarsk Nuclear Power Plant is sufficiently near to Ekaterinburg city about 45 km. In the case of accidental release, the regional center may contaminated by hypothetic radioactive plume from the nuclear power plant. Below we try to consider that using existing methods. Despite the location of Ekaterinburg is right, taking wind diagram presented on fig.1, it is imported to note in summertime wind direction is changed.

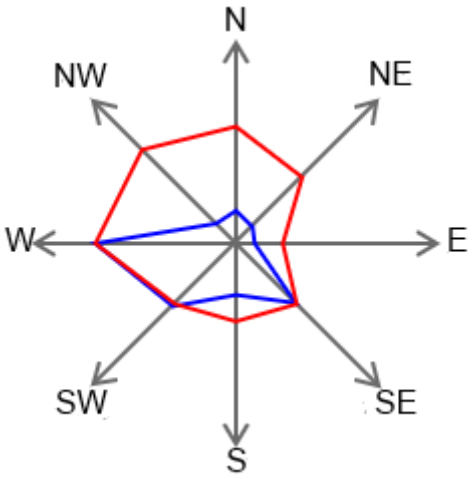

FIG. 1. Wind diagram in Ekaterinburg city: (red line – July, blue one - January).[13]

For estimation of a spatial distribution of radionuclides in the area of the emission plume the Pasquill-Gifford computational model which content enunciated in [14] was used. It is based on: the Pasquill classification of weather conditions according to which it is used six classes of the stability; Gaussian model of distribution of the radioactive admixture in the cloud of emission. The model is applicable for distances up to 10 - 12 km downwind from a source, on longer distances it produce the understated estimates. According to [14] general formula for calculation of average particles concentration in air is written:

$$q_A(x,y,z) = \frac{Q}{2\pi \cdot \sigma_y(x) \cdot \sigma_z(x) \cdot U_{sr}} \cdot \exp\left[-\frac{y^2}{2\sigma_y^2(x)}\right] \cdot \left[\exp\left[-\frac{\left(z-h_{eff}\right)^2}{2\sigma_z^2(x)}\right] + \exp\left[-\frac{\left(z+h_{eff}\right)^2}{2\sigma_z^2(x)}\right]\right] \quad Bq/cm^3,$$

where Q is the particles concentration, Bq·s^{-1}; x is the coordinate count off from a source in a direction of a medial wind, m; y is the coordinate normal to x direction, m; z is the vertical coordinate, m; U_{sr} is the wind speed averaged by mixing layer, m·s^{-1}; h_{eff} is the effective release height, m; $\sigma_y \sigma_z$ are the dispersion coefficients (standard deviation) in corresponding directions.

The effective height of release is defined by formula: $h_{eff} = h + \Delta h$, where h is the additional hoisting height of plume due to the thermal and dynamic factors:

$$\Delta h = A_1 \cdot \left(2,61\frac{\sqrt{Q_h}}{u_h} + 0,029\frac{\upsilon_s D_0}{u_h}\right)$$

Q_h is a heat power of source, kW; u_h is a wind speed on release height, m/s; u_s is output of air (gases) speed from a mouth of source, m/s; D_0 is a diameter of source mouth, m; A_1 is dimensionless parameter is defined by the class of atmospheric stability (table 5).

The industrial air is thrown out in the atmosphere by exhaust ventilation through the vent tube, which altitude not less than 100 meters. Vent tube is sole source of all gaseous atmospheric emissions. Radioactive gases were observed even after their deactivation in the vent tube. An air velocity in a vent tube end is more than 10 m·s-1 and more than a wind velocity at the same altitude in 1.5 - 2 times. Diameter of the air duct can be rather significant

up to 1.5 meters [15, 16]. The calculation of generated atomic hydrogen density was carried out under stationary formation of atomic hydrogen in the atmosphere and for conditions presented in table V:

TABLE V: THE INITIAL DATA FOR CALCULATION.

activity precipitation		0 $mm \cdot h^{-1}$
heat power of source		1 kW
ventiduct	height	100 m
	diameter	1 m
average wind speeds in a direction of impurity transfer	at height of 1 m at height of windvane at height of 10 m at height of emission	5 $m \cdot s^{-1}$
output of air (gases) speed from a mouth of source		10 $m \cdot s^{-1}$
type of a radioactive impurity	the partial impurity (atomic)	

The above-wrote formulas there are an averaging of emission 1 hour and x at meters. The results of calculations with the atmospheric stability classes also are presented below:

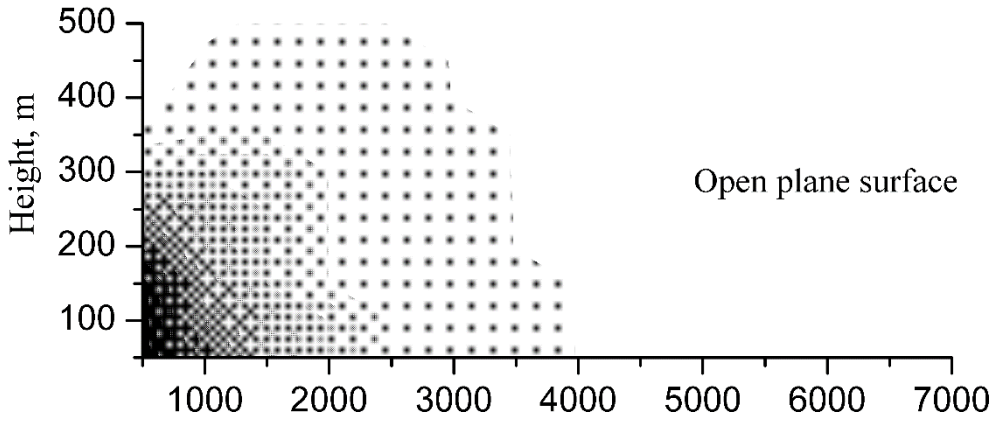

FIG. 2. Distribution of stationary concentration of atomic hydrogen in the atmosphere at NPP emissions under stable atmospheric condition.

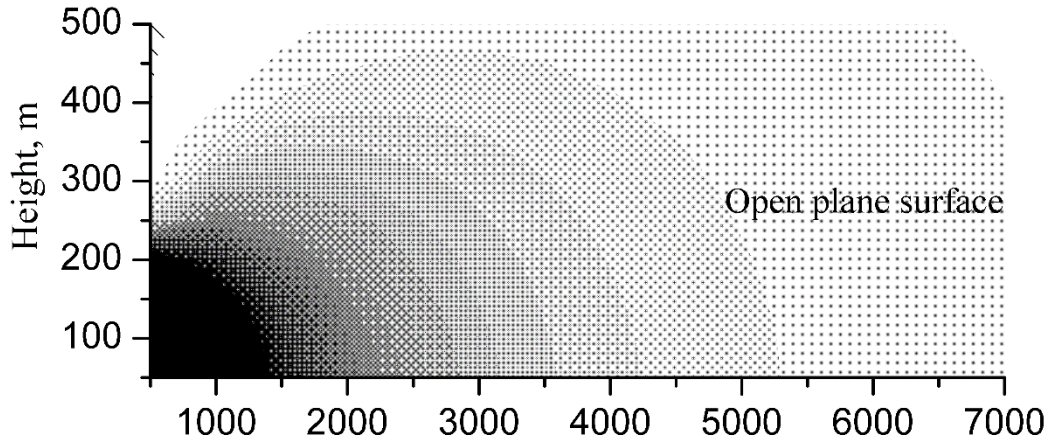

FIG. 3. Distribution of stationary concentration of atomic hydrogen in the atmosphere at NPP emissions under slightly unstable atmospheric condition.

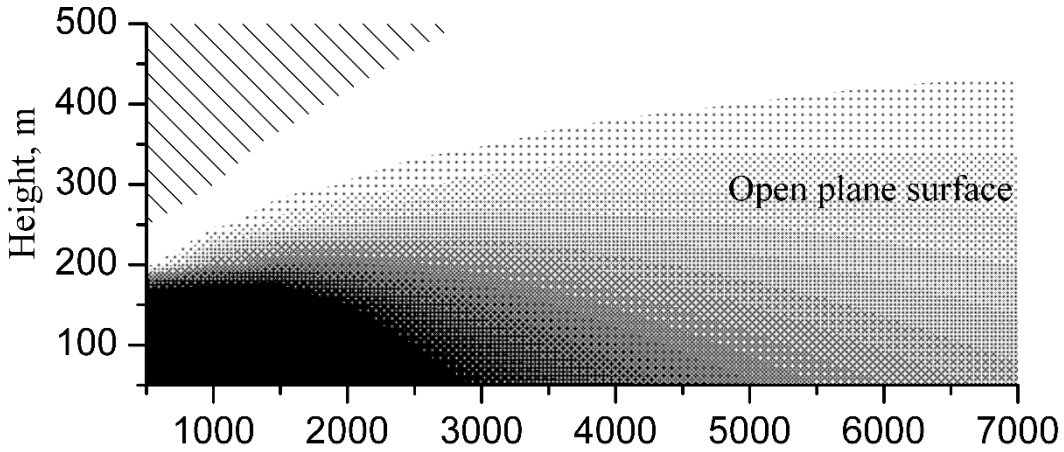

FIG. 4. Distribution of stationary concentration of atomic hydrogen in the atmosphere at NPP emissions under unstable atmospheric condition.

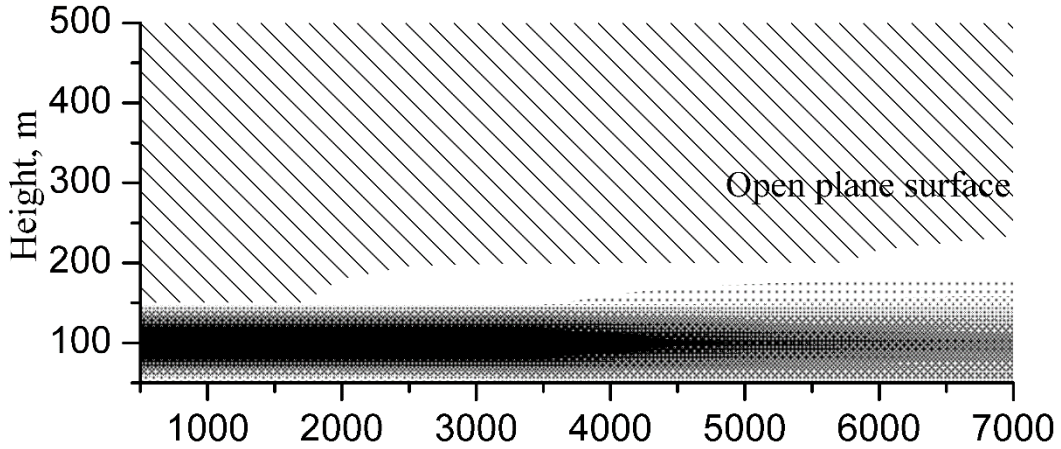

FIG. 5. Distribution of stationary concentration of atomic hydrogen in the atmosphere at NPP emissions under neutral atmospheric condition.

4. Conclusion.

The analysis of figures shows, that under the stable of the atmosphere the radiation is distributed to the plume uniformly for the open plane surface with small roughness. The obtained results show that the stratification of the atmosphere and the underlying surface locate areas of emission with increased concentration of the radionuclides. In consequence of which the intensity of radiation at 1420 MHz from these areas will be increased. Thus, measuring intensity of radiation at 1420 MHz with consideration for parameters of the atmosphere it is possible to forecast the level of radiation on hypothetic contaminated area, on example of Beloyarsk NPP. The results can be used for the solution of the inverse problem by estimation of emission activity on radiation intensity of markers.

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