

**E. K. Garger, V. K. Shynkarenko\*, V. A. Kashpur, G. G. Skorjak, A. K. Kalinovsky**

*Institute for Safety Problems of Nuclear Power Plants, NAS of Ukraine, Kirova str., 36a, Chornobyl, 07270, Ukraine*

## **ASSESSMENT OF AEROSOL RADIATION ENVIRONMENT IN SHORT-RANGE REGION OF ChNPP DURING BUILDING OF THE NEW SAFE CONFINEMENT**

Variability of  $^{137}\text{Cs}$  volume activity in a subsurface layer of the atmosphere of a short-range region of the object "Shelter" (object "Ukryttya") during the works on building of a new safety confinement in 2016 was investigated. Influence of the type and location of works, weather conditions, and sampling points was shown. Excess of medial permissible concentrations of  $^{137}\text{Cs}$  in the air was not fixed during the observations. However, due to the averaging of the measured values of the volume activity for the exposure time of the filter and use of the stationary aerosol samplers, it cannot ensure the absence of excess of the permissible concentrations at the locations of works and on the propagation path of the local emission plumes. In 2016, as well as in 2013 - 2015, high levels of  $^{137}\text{Cs}$  volume activity in the air were preferentially localized near to the machine hall of the 4th block and near to the places of ground works at the industrial site [1]. Concurrently the levels of volume activity essentially grew (practically by the order of magnitude) due to the intense works on the machine hall transformation. The conservative estimation of volume activity of isotopes of the plutonium, executed in the assumption of fuel composition of hot particles, showed the presence of substantial excess of permissible limits even for the average values within, at least, four weeks. Absence of reliable correlation ( $R = -0.09$ ) of  $^{137}\text{Cs}$  volume activity in the air near to the machine hall and near to the aerosol sampler 1,4 km remote from it testifies the localization of pollution within the industrial site.

*Keywords:* object "Shelter" (object "Ukryttya"), building of a new safe confinement, specific activity of air, autoradiography, dissolution kinetics in a pulmonary fluid.

Building of a new safety confinement (NSC) is one of the basic stages of transformation of the 4th power-generating unit of the ChNPP into the ecologically safe system [2]. During the construction and run time of a complex of operations on the industrial site, on the object "Shelter" (preferentially the machine hall of the 4th block) and on the adjoining territory some air-spraying of accumulated radioactive materials and formation of the radioactive aerosols take place. Presence of such anthropogenic sources of radioactive aerosols of variable intensity and duration in the combination with the variability of meteorological conditions can substantially influence the radioaerosol situation near to the object "Shelter".

Inhalation ingress of radionuclides in the organism is one of the main radiation-damaging factors on the personnel working at the site and in the local zone of the object "Shelter". According to the published data of ISP NPP [3 - 5], the average levels of aerosol contamination in the short-range zone of the ChNPP do not exceed the acceptance limits ( $60 \text{ Bk/m}^3$  for  $^{137}\text{Cs}$  [6]), however their peak levels during the run time of some types of operations can get out of these limits [1, 7].

The purpose of this paper is to investigate the impact of different types of building and erecting operations during the building of the NSC and weather conditions during their conducting on the formation and extension of radioactive aerosols in a short-range zone of the object "Shelter".

### **Materials and procedure of operational measurements**

Under the program of radiation pollution control of a surface layer of the atmosphere near to the object "Shelter" in the continuous regime four filter-ventilator units (FVU) have been working: FVU-1 "Wentmeca", located on the east side of SV-1430 approximately in 500 m from the southwest angle of the machine hall; FVU-2 "Typhoon", with 1,4 km removal, near the administrative building (AB) of the object "Shelter"; a FVU-3 "Grad-1.8" located directly near the southern wall of the machine hall and FVU-4 - "Grad-1.0" located on the North side of 4th block (Fig. 1). FVU technical specifications are presented in the Table 1. Material of FVU filters is presented by Petryanov fabric, periodicity of filters change - 7 days.

For the discussion of weather environment there were used data from the minimeteorological station owned by ISP NPP of NAS of Ukraine CR-10 mounted on the roof of an administrative building. The basic meteorological parameters (direction and velocity of wind, temperature, relative air humidity, precipitation) were averaged and saved for 10-minute intervals.

Measurements of  $^{137}\text{Cs}$  gamma-ray activity of the exposed air filters were made by the means of a semiconductor spectrometer of corporation ORTEC.

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\* Corresponding author. E-mail address: [shynkarenko.viktor@gmail.com](mailto:shynkarenko.viktor@gmail.com)

Kinetics of dissolution of the hot aerosol particles in the Gamble simulator of human lung fluid was investigated using the procedure presented in [1, 7, 8], Gamble simulator composition is presented in the same papers.

Table 1. The basic technical specifications of FVU

FVU performances	FVU-1 "Wentmeca"	FVU-2 "Typhoon"	FVU-3 "Grad-1.8"	FVU-4 "Grad-1.0"
Sampling altitude, m	1,0	2,5	1,8	1,0
Productivity, m <sup>3</sup> /h	300	4500	450	450
Filter area, m <sup>2</sup>	0,36	0,78	0,56	0,56

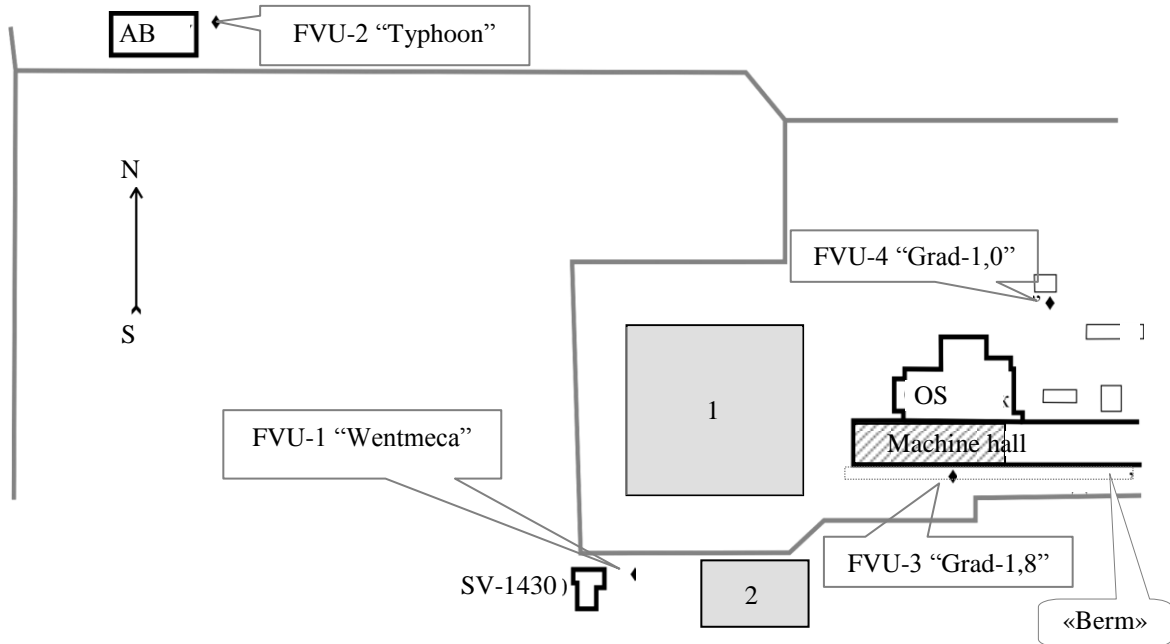


Fig. 1. The FVU location map in a short-range region of the object "Shelter":

- basic (1) and auxiliary (2) industrial sites;
- zone of dismantling of the roof of machine hall.

## Results and discussion

Dynamics of air volume activity in the subsurface layer of the atmosphere near to the object "Shelter" is shown on Fig. 2. It is possible to clearly separate a few periods with heightened volume activity of <sup>137</sup>Cs in the air on this figure. It is necessary to note a substantial (almost by the order) increase of the specific activity in comparison with registered in 2013 - 2015 [1]. The basic sources of the aerosol ejections (operations on dismantle of the roof and equipment, open surface of the machine hall, excavation works that reveal surface soils strongly polluted during the crash) are in most cases concentrated in the 10 - 50 m area from FVU-3.

Synchronous recording of some peaks of volume activity by various FVU can be found on the Fig. 2. It can be explained with use of the directions and forces of winds acting during the exposure time. Comparison of data on volume activity at the points of FVU location, meteorological data, types and locations of conducted operations allows to correlated the observed peaks with the specified factors. So, peaks 4-5 are caused by the active operations on the territory which borders on the southern wall of the machine hall - platform "Berm". The refinement of the dismantled fragments of the machine hall construction, their loading on transport and export were performed during that period of time. There were also conducted the preliminary operations for the foundation lying under the eastern face in the eastern section of the machine hall. Peak 6 corresponds to the formation of "eastern" opening in the eastern section of the machine hall, essential for the construction of the face wall of NSC. Active operations on a extraction, cutting and export of a considerable quantity of constructions fragments were conducted on this territory.

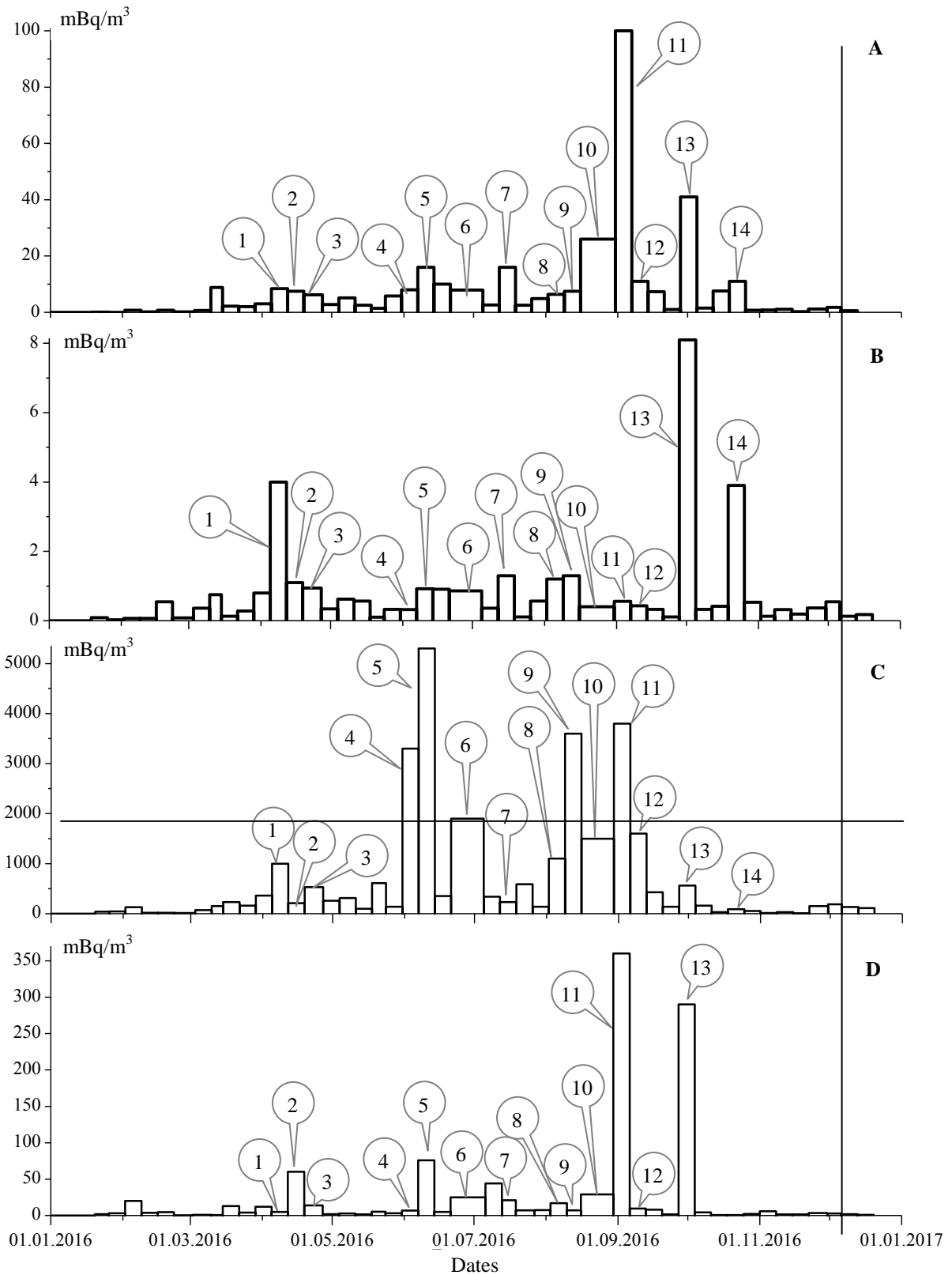


Fig. 2. Dynamics of  $^{137}\text{Cs}$  volume activity in the shallow layer of the atmosphere near to the object "Shelter".  
 A - FVU-1 "Wentmeca"; B - FVU-2 "Typhoon";  
 C - FVU-3 "Grad-1.8"; D - FVU-4 "Grad-1.0".  
 The vertical line corresponds to an expiry date of movement of the object "Arch", horizontal - maximum concentration limits for plutonium [1]

Strong gusts of S-SW wind (8 ÷ 15 m/s) and dust whirlwinds were observed here with the open roof of the machine hall. Peaks 9 - 11 were registered during the building of the east face wall and works on removal of

fragments of constructions. Wind is western and northwestern; peak 10 corresponds to western wind gusting to 15 m/s, whirlwinds on the platform "Berm".

Table 2 presents the coefficients of correlations between specific activities of  $^{137}\text{Cs}$  in the air near the stationary aerosol samplers and some meteorological parameters. Negative values of the correlation coefficients between the volume activity at the sampling points and relative humidity of air testifies the substantial role of this meteorological parameter in the inhibition of radioactive aerosols formation. Table 2 shows also the presence of reliable correlations between the volume activities of  $^{137}\text{Cs}$  in the air near various FVU. These correlations can be caused by the presence of matching links, i.e. they can testify the overlap of the areas of several aerosol samplers by the cloud of radioactive aerosol, or by the cooperative effect of meteorological factors. In order to distinguish these effects there were estimated the coefficients of pair partial correlations between specific activities in the areas of aerosol samplers location, the values of these coefficients are presented in the Table 3.

*Table 2. Correlation relationships between the specific activities of  $^{137}\text{Cs}$  in the air near the stationary aerosol samplers and some meteorological parameters*

	FVU-1	FVU-2	FVU-3	FVU-4	Humidity	Rainfall
FVU-1	1,0	<b>0,32*</b>	<b>0,51</b>	<b>0,91</b>	-0,29	-0,24
FVU-2	<b>0,32</b>	1,0	0,06	<b>0,49</b>	-0,24	-0,21
FVU-3	<b>0,51</b>	0,06	1,0	<b>0,42</b>	<b>-0,48</b>	-0,27
FVU-4	<b>0,91</b>	<b>0,49</b>	<b>0,42</b>	1,0	-0,16	-0,19
Humidity	-0,29	-0,24	<b>-0,48</b>	-0,16	1,0	<b>0,52</b>
Rainfall	-0,24	-0,21	-0,27	-0,19	<b>0,52</b>	1,0

\*The Bold type is used for the coefficients of correlation with confidence probability  $p > 0.95$ .

*Table 3. Coefficients of partial correlations between the specific activities of  $^{137}\text{Cs}$  in the air near the stationary aerosol samplers*

	FVU-1	FVU-2	FVU-3	FVU-4
FVU-1	1,00	0,26	<b>0,40*</b>	<b>0,90</b>
FVU-2	0,26	1,00	-0,09	<b>0,47</b>
FVU-3	<b>0,40</b>	-0,09	1,00	<b>0,35</b>
FVU-4	<b>0,90</b>	<b>0,47</b>	<b>0,35</b>	1,00

The reliable levels of partial correlations presented in the Table 2, testify the close relationship between the levels of volume activity near the closely-spaced FVU 1, 3 and 4 that in some cases testifies the overlap of territory of location of these three FVU by the aerosol clouds generated near the FVU-3. At the same time the absence of reliable correlation between specific activities near the FVU-3 and FVU-2 (located 1,4 km away) testifies that radioactive aerosol clouds remained localized within a short-range region of building. Small distances of transport are caused, apparently, by the fact that this radioactive aerosol contains a considerable quantity of relatively large fuel particles with aerodynamic diameters of tens and the first hundreds of microns which are responsible for the significant amount of specific activity. As it is known [9, 10], particles of such sizes quickly fall out on an underlying surface. Fig. 3 presents autoradiographs of the air filters for the period 30.08. – 9.06.2016 (peak 11). They illustrate substantial decrease of number of large "hot" particles on the filters FVU-1 and FVU-4 in comparison with FVU-3.

During our observations in all air sampling points there was not observed any exceeding of the permissible  $^{137}\text{Cs}$  concentrations for the air of working area of the A class personnel - 60 Bq/m<sup>3</sup> [6]. However, as it has already been presented in the paper [7], the conducted measurements cannot guarantee the absence of exceeding directly near to the place of operations or along the propagation path of the torch of emission. Besides that, the long time of averaging during the samples taking (5 - 7 days) substantially smoothed separate transient local emissions of radioactive aerosols during the works in a short-range regions. Considering all this circumstances, it is necessary to recognize that there is a probability of transient

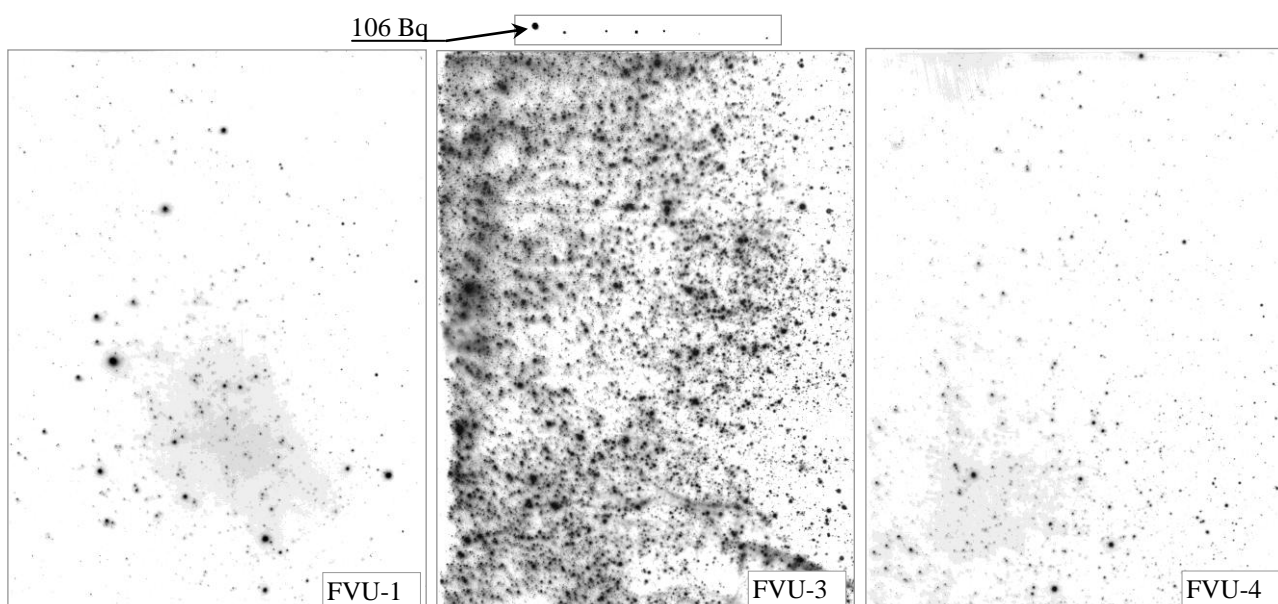


Fig. 3. Autoradiogramms of air filters for the period 30.08. – 9.06.2016 (peak 11).

Above - an autoradiogram of the bar of hot particles with known activity, the biggest spot corresponds to a fuel particle with  $\beta$ -activity of 106 Bq.

exceeding of permitted  $^{137}\text{Cs}$  concentrations in the air directly near to the work location in the short-range region of the object "Shelter".

It is necessary to note that the basic radiological hazard for territory near to the object "Shelter" is presented by the total impact of the main remaining radionuclides -  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ ,  $^{239-240}\text{Pu}$ . Some estimations of the  $^{239-240}\text{Pu}$  volume activity in our samples can be made using the level of  $^{137}\text{Cs}$ . As it was presented in papers [11, 12], there are observed substantial differences in the isotope composition and properties of large and small "hot" particles.  $^{137}\text{Cs}/^{239-240}\text{Pu}$  ratio for large particles fluctuates near the mean value for the irradiated fuel and has magnitude of the order 60. At the same time, small "hot" particles can be intensively enriched with  $^{137}\text{Cs}$ . For example  $^{137}\text{Cs}/^{239-240}\text{Pu}$  ratio presented in [11] for such particles exceeds the average value for fuel more than 20 times. Unlike the particles with fuel composition,  $^{137}\text{Cs}$  from low-active cesium particles can be quickly dissolved in the simulants of human lung fluid [8, 11, 12].

In order to study the kinetics of  $^{137}\text{Cs}$  dissolution in the stimulant of the lung fluid there were selected the fragments of the filters exposed on installation FVU-3 prior to the beginning (a fragment 1) and during the active operations on the machine hall transformation (fragments 2 and 3). Exposure dates of the filters, registered  $^{137}\text{Cs}$  volume activity in the air and part of instant  $^{137}\text{Cs}$  are presented in the Table 4.

Table 4 shows that the part of instant  $^{137}\text{Cs}$  during an active phase of building does not exceed 10 % that allows to accept the relationship  $^{137}\text{Cs}/\text{Pu} \approx 60$ , that corresponds medial fuel composition, as a conservative estimation for the observed radioactive aerosols. So far as level of  $^{239-240}\text{Pu}$  permissible concentrations for the air of working area for the personnel of A class is  $0,03 \text{ Bq/m}^3$  [6], it is necessary to accept the level of  $^{137}\text{Cs}$  activity near to object "Shelter" equal to  $\approx 1,8 \div 2 \text{ Bq/m}^3$  as the critically allowed. This level is marked by horizontal line on the Fig. 2. It can be seen that during the time of building works there was observed substantial exceeding of the allowed level for the plutonium isotopes, even for average values of a specific activity, at least during four weeks from this figure.

Table 4. The part of instant  $^{137}\text{Cs}$  in the fragments of air filters

No of fragment	No of peak	Exposure time		$^{137}\text{Cs}$ Volume activity in the air, $\text{mBq/m}^3$	$^{137}\text{Cs}$ Activity of fragment, Bq	Fraction of instant $^{137}\text{Cs}$ , %
		Start	Finish			
1	No	22.03.2016	29.03.2016	160	27,9	18,7
2	1	05.04.2016	12.04.2016	1000	147	9,8
3	6	21.06.2016	05.07.2016	1900	771	6,8

## Conclusions

The measurements of  $^{137}\text{Cs}$  volume activity in the air of the short-range region of the object "Shelter" made throughout 2016 testify that:

$^{137}\text{Cs}$  volume activity in the air correlates with an type, intensity and a location of works, and meteorological conditions during their performance;

the largest intensity of radioactive aerosols generation was observed during the operations on transformation of the 4th block machine hall and earth-excavation with opening of the polluted buried stratum. The formed radioactive aerosol clouds remained localized within the short-range region of building zone;

the exceeding of  $^{137}\text{Cs}$  permissible concentrations in the air was not registered during all time of observations. However, it does not guarantee the absence of such exceeding at works location and along the plume of local emission, because big time of averaging (5 - 7 days) intensively smoothes the separate transient local emissions of radioactive aerosols;

the conservative estimation of plutonium isotopes volume activity, conducted on the assumption of the fuel composition of hot particles, displayed presence of the substantial exceeding of permissible levels even for the averaged values, at least, within four weeks;

after the end of mounting of object "Arch" there was observed a substantial reduction of  $^{137}\text{Cs}$  volume activity in the air of a short-range region.

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**Е. К. Гаргер, В. К. Шинкаренко, В. О. Кашпур, Г. Г. Скоряк, О. К. Калиновський**

*Інститут проблем безпеки АЕС НАН України, вул. Кірова, 36а, Чорнобиль, 07270, Україна*

### **ОЦІНКА АЕРОЗОЛЬНОЇ РАДІАЦІЙНОЇ ОБСТАНОВКИ У БЛИЖНІЙ ЗОНІ ЧАЕС ПІД ЧАС БУДІВНИЦТВА НОВОГО БЕЗПЕЧНОГО КОНФАЙНМЕНТА**

Досліджено мінливість об'ємної активності  $^{137}\text{Cs}$  у приземному шарі атмосфери ближньої зони об'єкта «Укриття» під час проведення робіт зі спорудження нового безпечного конфайнмента у 2016 р. Продемонстровано вплив виду та місця проведення робіт, метеорологічних умов, а також місця відбору проб. За час спостережень не зафіксовано перевищення середніх допустимих концентрацій  $^{137}\text{Cs}$  в повітрі. Однак унаслідок усереднення вимірних значень об'ємної активності за часом експозиції фільтра та використання стаціонарних пробовідбірників даний факт не може гарантувати відсутність перевищень у місцях проведення робіт і по шляху поширення факелів локальних викидів. У 2016 р., як і в 2013 - 2015 рр., високі рівні об'ємної активності  $^{137}\text{Cs}$  в повітрі були переважно локалізовані поблизу машинного залу 4-го блока та біля місць проведення земляних робіт на промисловому майданчику [1]. При цьому самі рівні об'ємної активності істотно зросли (практично на порядок) у зв'язку з інтенсивними роботами по трансформації машинного залу. Консервативна оцінка об'ємної активності ізотопів плутонію, виконана у припущенні паливного складу гарячих частинок, показала наявність істотних перевищень допустимих рівнів навіть для усереднених величин, у крайньому випадку, протягом чотирьох тижнів. Відсутність достовірної кореляції об'ємної активності  $^{137}\text{Cs}$  в повітрі поблизу машинного залу та біля віддаленого від нього на 1,4 км пробовідбірника ( $R = -0,09$ ) свідчить про локалізацію забруднень у межах промислового майданчика.

*Ключові слова:* об'єкт «Укриття», будівництво нового безпечного конфайнмента, об'ємна активність повітря, авторадіографія, кінетика розчинення в легеневій рідині.

**Е. К. Гаргер, В. К. Шинкаренко, В. А. Кашпур, Г. Г. Скоряк, А. К. Калиновский**

*Інститут проблем безопасности АЭС НАН Украины, ул. Кирова, 36а, Чернобыль, 07270, Украина*

### **ОЦЕНКА АЭРОЗОЛЬНОЙ РАДИАЦИОННОЙ ОБСТАНОВКИ В БЛИЖНЕЙ ЗОНЕ ЧАЭС ВО ВРЕМЯ СТРОИТЕЛЬСТВА НОВОГО БЕЗОПАСНОГО КОНФАЙНМЕНТА**

Исследована изменчивость объемной активности  $^{137}\text{Cs}$  в приземном слое атмосферы ближней зоны объекта «Укрытие» во время проведения работ по сооружению нового безопасного конфайнмента в 2016 г. Продемонстрировано влияние вида и места проведения работ, метеорологических условий, а также места отбора проб. За время наблюдений не зафиксированы превышения средних допустимых концентраций  $^{137}\text{Cs}$  в воздухе. Однако вследствие усреднения измеренных значений объемной активности по времени экспозиции фильтра и использования стационарных пробоотборников данный факт не может гарантировать отсутствие превышений в местах проведения работ и по пути распространения факелов локальных выбросов. В 2016 г., как и в 2013 – 2015 гг., высокие уровни объемной активности  $^{137}\text{Cs}$  в воздухе были преимущественно локализованы вблизи машинного зала 4-го блока и около мест проведения земляных работ на промышленной площадке [1]. При этом сами уровни объемной активности существенно выросли (практически на порядок) в связи с интенсивными работами по преобразованию машинного зала. Консервативная оценка объемной активности изотопов плутония, выполненная в предположении топливного состава горячих частиц, показала наличие существенных превышений допустимых уровней даже для усредненных величин, по крайней мере, в течение четырех недель. Отсутствие достоверной корреляции объемной активности  $^{137}\text{Cs}$  в воздухе возле машинного зала и возле удаленного от него на 1,4 км пробоотборника ( $R = -0,09$ ) свидетельствует о локализации загрязнений в пределах промышленной площадки.

*Ключевые слова:* объект «Укрытие», строительство нового безопасного конфайнмента, объемная активность воздуха, авторадіографія, кінетика розтворення в легочній жидкості.

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