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Analysis of Radionuclide Contamination Features in Solid Radioactive Waste of the "Light" Eastern Compartment of Solid Waste Repository of Chornobyl NPP

Keywords:
Chornobyl NPP,
solid radioactive waste,
specific activities,
difficult-to-measure radionuclides,
key nuclides,
correlation factor,
scaling factor.

Chornobyl NPP's operational wastes accumulated before 1986 accident in State Specialized Enterprise "Chornobyl Nuclear Power Plant" solid waste repository (SWR) were studied. Material content of SRW at around 1 m depth in "light" eastern compartment was identified. After a visual examination, the waste materials were split into four streams. Representative samples for laboratory analysis were collected from each waste stream. Specific activities of 24 radionuclides to be certified before the waste is disposed at the Plant for solid radwaste treatment, were investigated. Parameters of correlation between radionuclide activities in specimens were defined. A statistical correlation can be checked for data set without abnormal results and results on values of radionuclide specific activities being less than minimum detectable activity (MDA). The research results demonstrated that the total radioactivity of SRW in the outer layer of eastern compartment storage is, mainly, determined by the content of such radionuclides as ^{137}Cs, ^{60}Co, ^{90}Sr, ^{94}Nb, ^{235}U, ^{238}U, ^{241}Am, ^{3}H and ^{14}C. The data obtained indicate that the scaling factor method can be applied to quantify the specific activity of difficult-to-measure (DTM) radionuclides in the waste. Specific activity of DTM radionuclides such as ^{90}Sr, ^{94}Nb and ^{241}Am can be evaluated with high enough accuracy with using gamma spectrometry of ^{137}Cs and/or ^{60}Co key nuclides (KN). For the rest DTM radionuclides to be certified in the waste, their content according to gamma-ray spectrometry data of KN can be estimated with using Medium Activity Method technique.

Introduction

The management of radioactive waste, especially its safe disposal, is one of the most urgent and complex problems of nuclear energy at the decommissioning stage of nuclear power units [1]. One of the essential activities aimed at decommission of State Specialized Enterprise "Chornobyl Nuclear Power Plant" (SSE ChNPP) is the management of historical solid radioactive wastes (SRW), which have been accumulated over normal work period of its power units. Currently, this type of ChNPP SRW is being stored in the Building No. 85 of Repository for SRW (RSRW) of SSE ChNPP. The filling of RSRW compartments was initiated in 1978 and had been continued before May 2003. Actual SRW nuclide content under their loading was not identified because of lacking at that moment of relevant instrumental and methodical base in the nuclear industry [2]. The rules for SRW management valid in Exclusion Zone [3] require identifying radionuclide content of each package (batch) of wastes coming for its disposal with determining specific and total activity of controllable radionuclides, whose major part refers to difficult-to-measure (DTM) alpha- and beta-emitters.

The experience accumulated during the Ignalina NPP [4, 5] decommissioning demonstrated that it is difficult to predict the nuclide content in very low-level, low- and intermediate-level SRW by purely theoretical methods due to physical and chemical processes involved in waste generation. At the same time, the experimental measurements of nuclide content are the only tool for checking any theoretical predictions. As it turned out, the ChNPP SRW have the same problem. The results of measuring equipment tests of Industrial Complex for SSE ChNPP SRW Management (ICSRWM) showed that calculation algorithms entered into the software of automated system of radiation-technological control (SRTC) do not allow correctly certifying DTM specific and total activity in a waste package [2]. To solve the problem of SRW characterization, application of scaling factor method (SFM) for existing SRTC was recommended by experts of the International Atomic Energy Agency (IAEA) and World Association of Nuclear Operators (WANO) [6, 7].

The SFM is widely used and based on development of a correlation between easy-to-measure (ETM) gamma-emitting nuclides (otherwise, key nuclides – KN) and DTM nuclides, which are contaminated by different materials in nuclear reactor [8–12]. The international standard ISO 21238:2007 [9] provides a general methodology for empirical determination of Scaling Factor's (SF) to evaluate the radioactivity of DTM nuclides in low- and intermediate-level radwaste packages. The activities of DTM nuclides in waste packages are estimated by KN activity measurements and subsequent multiplication of this value by the SF. The SF value is calculated as based on established ratios of radioactive concentrations of DTM nuclides/KN of radionuclide data obtained by sampling and radiochemical analysis methods. In practice, the procedure of empirical determination of SF values includes either sampling of waste and laboratory analysis of radionuclide content, analysis of experimental data and selection of KN based on evidence of correlation, modeling, or in conformity with the proven practice [11]. If a statistical correlation between the DTM's and KN's is not found, so-called "Mean Activity Method" (MAM) can be applied [12]. This technique consists of calculation of arithmetic mean activity of each DTM nuclide in a sample, including the values being below the minimum detectable activity (MDA), and allows assessing the upper bound expected levels of DTM radionuclide activities in a radwaste package and is used in many countries [8].

This article is aimed at analyzing radionuclide content of RSRW "light" eastern compartment in order to establish radionuclide contamination features, which were a basis for SRW characterization with using the SFM.

Objects and methods

As investigation objects, the material referred to SRW and stockpiled in "light" eastern compartment of SSE ChNPP RSRW were used. This cubicle is located in Building No. 85 of ICSRWM and filled by the SRW produced of operational wastes originated during the ChNPP unit work from 1978 before 1986. The wastes were delivered in this repository in special containers with using motor transport. The SRW was unloaded in compartments in bulk method through the hatches located at the RSRW roof. Low-level operational wastes were stockpiled in two "light" compartments. Total volume of operational SRW is evaluated at 1,069 m^3, and their summary activity (under mean filling density making $1.5 \cdot 10^3$ kg/m^3) is evaluated at $1.1 \cdot 10^{11}$ Bq. Compartment mothballing was realized prior to Unit 4 accident. Total amount of the wastes received for storage before compartment mothballing made 668 m^3, under mean density being $1.5 \cdot 10^3$ kg/m^3. Average specific activity of SRW equals to 70 kBq/g and gives ground to refer the object under investigation to the low-level RAW. Calculated total activity of SRW in compartment volume is evaluated at $7 \cdot 10^{10}$ Bq.

Within the framework of preparation of measures to characterize the SRW accumulated in RSRW and their next burial at the Plant for solid radwaste treatment (PTSRW), unsealing of "light" eastern compartment and sampling of specimens and laboratory analysis of specific activity of radionuclides contained in the SRW were realized on November 16, 2016. After a visual examination, the waste materials were split into four streams (Tab. 1). Representative samples for laboratory analysis were selected from each stream. Tab. 2 shows a list of methods and devices that were used to determine the content of each radionuclide to be certified in the SRW according to [3]. Sampling procedure, methods and instrumentation used in the work, are described in details in [2].

To provide statistical plausibility of evaluated parameters of regression dependencies of data sub-selection corresponding to the same DTM-KN pairs, they were merged into one. The data on values of radionuclide specific activities being less than MDA were excluded from the analysis.

At the next data analysis stage it was taken into account that selected measurement results being analyzed can in-

Table 1. General characterization of waste materials split into four streams

Stream No.	Waste materials
1	Metal waste produced as result of recovery and repair work
2	Rubber products, elastron, cable products and heat insulation unsuitable to reuse
3	Reconstruction waste (sand, concrete, plaster, wood) producible as result of recovery and repair work
4	Rags, worn special clothing, spent individual protection gear (IPG), paper

clude potential outliers, which are extremely large or small relatively to the rest measurement data and, therefore, they are suspected in misrepresenting the population from which they were collected. The nature of these derived data can be diverse one. The potential outliers may occur from transcription errors, data-coding errors, or measurement system problems. Based on assumption that these lab measurements (specific activity of DTM and ETM in SRW samples) belong to normal (Gaussian) distribution, analyzed selection were checked for abnormality of measurement outliers according to Grubbs criterion [13]. The hypothesis that we are testing in every case is that all observations in the sample come from the same normal population. To determine in data selection x1 ≤ x2 ≤ x3 < … ≤ Xn (in growing magnitude order) of outliers that occur on the high (Xn) or low (x1) side, to evaluate the test criterion (Tn or T_1), universal calculation formula (1) shall be always used. Critical values for the case of 5 percent levels of significance (0.05) are given in the Tab. 3 ("one-sided" significance levels).

$$T_i = \left| \frac{(\bar{x} - x_i)}{s} \right|, \quad (1)$$

Table 2. Methods and instrumentation used in the work

Radionuclides	Measurement method	Devices
^{60}Co, ^{94}Nb, ^{137}Cs, ^{241}Am	Gamma-ray spectrometry	HPGe gamma-ray spectrometer SEG-002 ("Atom Komplex Prylad", Ukraine)
^{3}H, ^{14}C, ^{63}Ni, ^{90}Sr, ^{241}Pu	Liquid scintillation counting	Liquid scintillation counter Hidex 300SL
^{237}Np, ^{238}Pu, $^{241,243}Am$	Alpha-particles spectrometry	Alpha-particles spectrometer SEA-01 ("Atom Komplex Prylad", Ukraine)
^{10}Be, $^{59,63}Ni$, ^{93}Zr, ^{94}Nb, ^{99}Tc, ^{129}I, ^{135}Cs, ^{237}Np, ^{243}Am, $^{235,236,238}U$, $^{239,240,241,242}Pu$,	ICP mass-spectrometry	Mass-spectrometry systemAgilent 7500 Series ICP-MS

where $\bar{x}$ — arithmetic mean of all n values, x_i — values from x_1 (lowest) to x_n (highest) value, respectively, s — estimate of population standard deviation calculated with n — 1 degrees. A condition to delete measurement result (x_i) from data array as an abnormal one was the excess of T_i evaluated on formula (1) of T critical value, is as follows:

$$T_i > T, \quad (2)$$

where T — critical values from Tab. 3 according to data amount, which are equal to n.

After the result, which has not passed the check (2), was deleted, calculation on formula (1) was again carried

Table 3. Critical values for T (one-sided test) and 5 % significant level [13]

Data amount, n	T	Data amount, n	T	Data amount, n	T	Data amount, n	T
3	1.15	12	2.29	21	2.58	35	2.82
4	1.46	13	2.33	22	2.60	38	2.85*
5	1.67	14	2.37	23	2.62	40	2.87
6	1.82	15	2.41	24	2.64	45	2.92*
7	1.94	16	2.44	25	2.66	50	2.96
8	2.03	17	2.47	30	2.75	55	2.99*
9	2.11	18	2.50	31	2.76*	60	3.03
10	2.18	19	2.53	32	2.78*	65	3.06*
11	2.23	20	2.56	33	2.79*	70	3.09

*Values are approximated.

out for reduced data population. The test was repeated as long as the data remained after drop-out satisfied the Grubbs criterion (Tab. 3). These tests shall be used to identify data points that require their further investigation only. In accordance with [8, 9], regression dependence between specific activities of ETM and DTM radionuclides, or their logarithms in SRW being analyzed, was conducted in assumption of available dependence of type (3) or (4).

$$A_{DTM} = a \cdot A_{KN}^{b}, \quad (3)$$

where A_{DTM} and A_{KN} — relevant specific activities of DTM (Y) and KN (X) in sample; *a* and *b* — regressions parameters (constants) for given DTM–KN pair.

$$Ln(A_{DTM}) = Ln(a) + b \cdot Ln(A_{KN}). \quad (4)$$

In line with [14, 15], for each radionuclide X–Y pair within the limits of selection (sub-selection) of resulted specific activities, the hypothesis was checked about availability/absence of correlation ($b \neq 0$ or $b = 0$) in the simple linear regression model for 5 percent level significance. Under available correlation ($b \neq 0$), a measure of significance of pair correlation coefficient was evaluated on the law of normal distribution of random variables. For each regression equation, confidence intervals for *a, LN(a)* and *b* parameters were determined. Reliability rate of correlation coefficient was defined from inequality (5) on the results of comparison with a value multiple of its mean error calculated with the formula (6).

$$r_{(X,Y)} > 3\sigma_{|r(X,Y)|}. \quad (5)$$

$$\sigma_{|r(X,Y)|} = \pm \frac{1 - r^2_{(X,Y)}}{\sqrt{n}}, \quad (6)$$

where $r_{(X,Y)}$ — correlation between radionuclide activities, *n* — number of results with specific activity > MDA. In case, when inequality condition (5) was satisfied, correlation coefficient was recognized as a reliable one and which reflects the desired relationship expressed by established regression equation (4).

Results and Discussion

The results of laboratory studies have stated that the radioactivity of upper layer of operational SRW materials being stored in the ChNPP RSRW is determined, mainly, by such radionuclides as: ^{137}Cs, ^{60}Co, ^{90}Sr, ^{94}Nb, ^{235}U, ^{238}U, ^{241}Am, ^{3}H and ^{14}C. Since the measured activities cover several orders of magnitude, the logarithmic scale has been used (see Fig. 1–4). The linear scale of data representation was used for such pairs of radionuclides as ^{235}U — ^{238}U and ^{3}H — ^{14}C (see Fig. 5–6). Data relating to different waste streams is plotted on the graph with various shape dots. Specific activity of the other radionuclides is below of corresponding MDA of the equipment used for measurements (see Tab. 2). Such results within the framework of current report have not represented any special interest and were excluded from further statistical data analysis.

A correlation analysis of measured specific activity of above mentioned radionuclides in operational solid waste of ChNPP was performed. As the Figures show, except for Stream 2, the number of results with radionuclide specific activity being above the MDA for the samples referring to different streams, turned out to be low ones. To obtain more reliable evaluation of features of possible trends, the

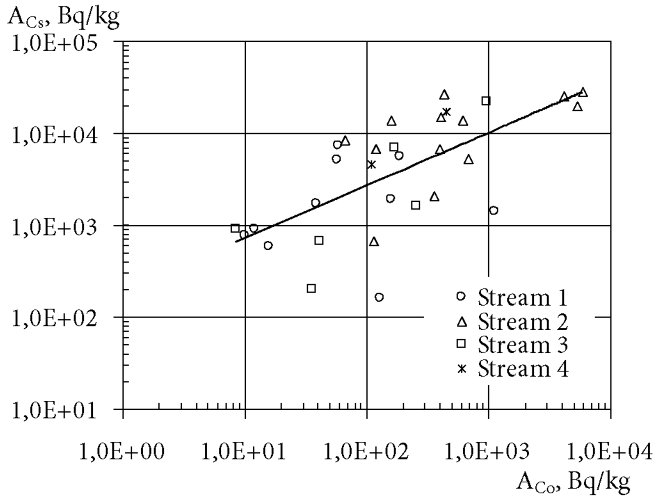

Fig. 1. Correlation of ^{137}Cs and ^{60}Co specific activities in SRW of ChNPP

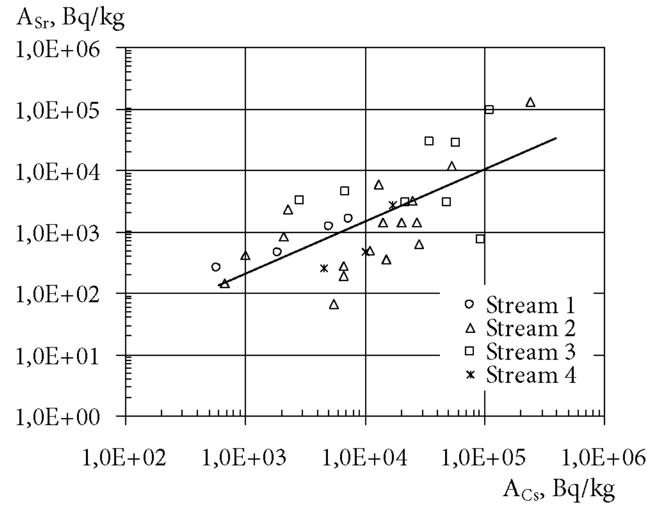

Fig. 2. Correlation of ^{90}Sr and ^{137}Cs specific activities in ChNPP's solid radioactive waste

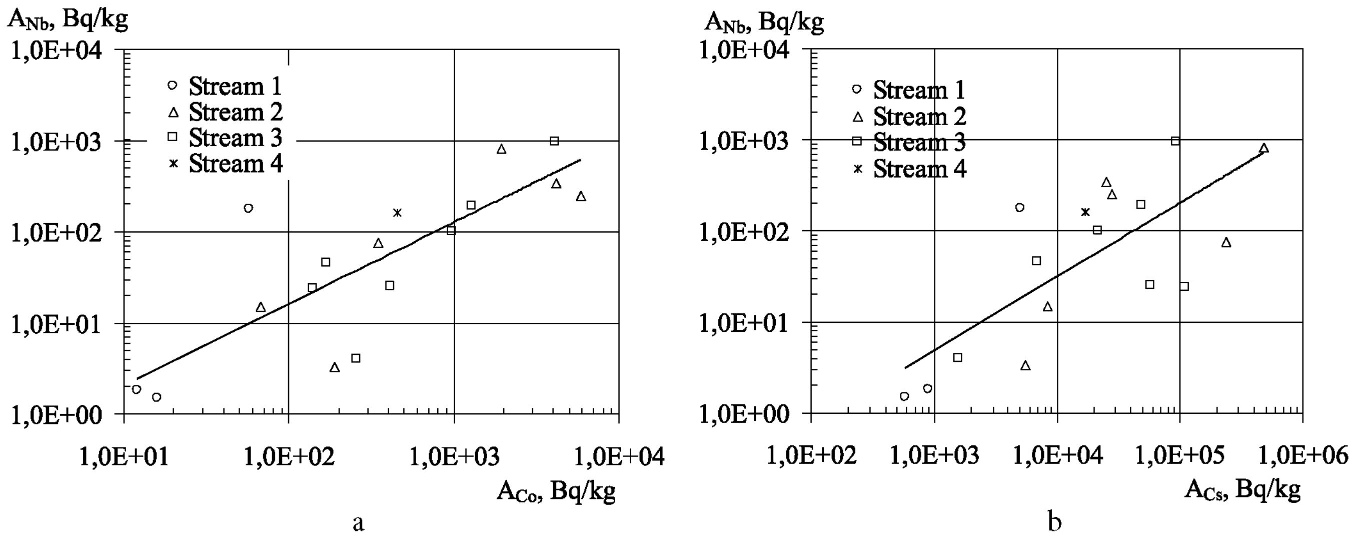

Fig. 3. Correlation of ^{94}Nb specific activities with specific activities of KN ^{60}Co (a) and ^{137}Cs (b) in SRW of ChNPP

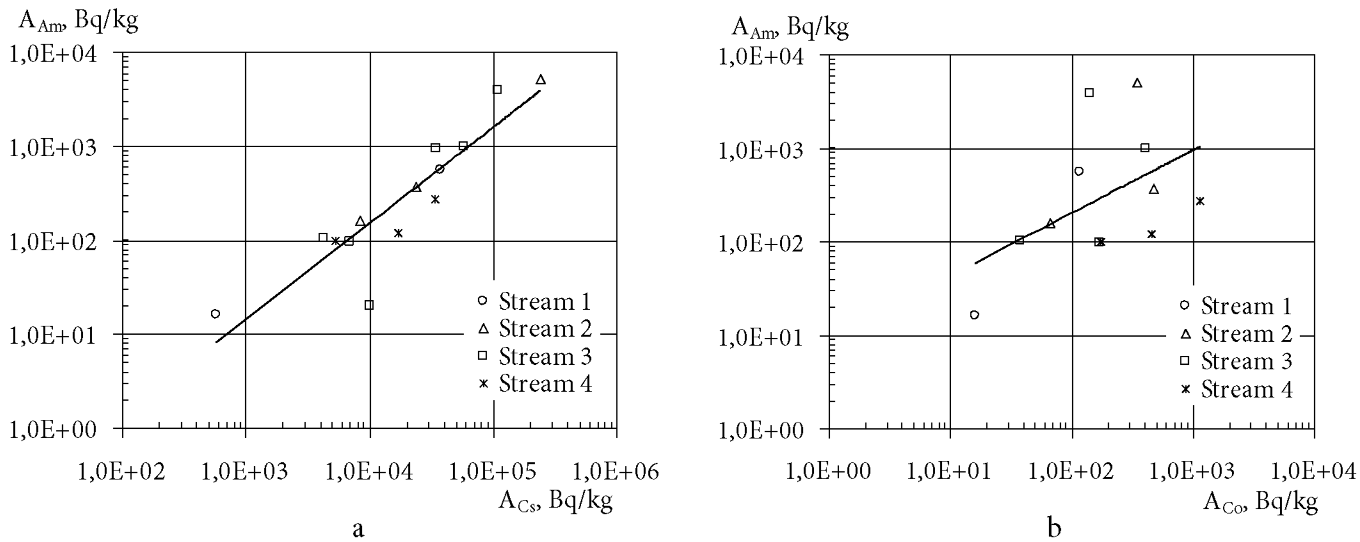

Fig. 4. Correlation of ^{241}Am specific activities with the KN ^{137}Cs (a) and ^{60}Co (b) specific activities in SRW of ChNPP

data collected for diverse waste streams were united in one data retrieval.

To summarize the data, the results of correlation analysis and parameters of established regression dependencies with values of confidence intervals are presented in the Table 4. For the vast majority of radionuclide pairs, analysis results confirm the reasonableness of such data combination. These radionuclides include also the DTM–KN pairs, which are recommended to be used for DTM's characterization in SRW packages on the results of gamma-ray spectrometry [8]. The parameters of obtained dependencies for alternative DTM–KN (^{137}Cs and/or ^{60}Co) options were compared. As the Table 4 shows, there are some pairs among the radionuclides, which have a close correlation between their specific activities in measured range. The pairs are as follows: ^{137}Cs — ^{60}Co, ^{90}Sr — ^{137}Cs, ^{94}Nb — ^{60}Co, ^{94}Nb — ^{60}Cs, ^{241}Am — ^{137}Cs and ^{235}U — ^{238}U. That's certainly understandable, since these radionuclides are related to the same groups having a common source of origin. The reactor core is the main contaminant due to generation of radionuclides during neutron capture, or nuclear fission and activation of reactor core components. These radionuclides can be released to the technological media of NPP due to fuel cladding defects and corrosion of metal structures of reactor core components and contamination of the main circulation circuit (MCC) coolant due to direct contact. Each step of radionuclide transition from one medium to another (fuel matrix to clad gap, MCC coolant surface to structural materials) results in some change of activity concentrations of isotopes of

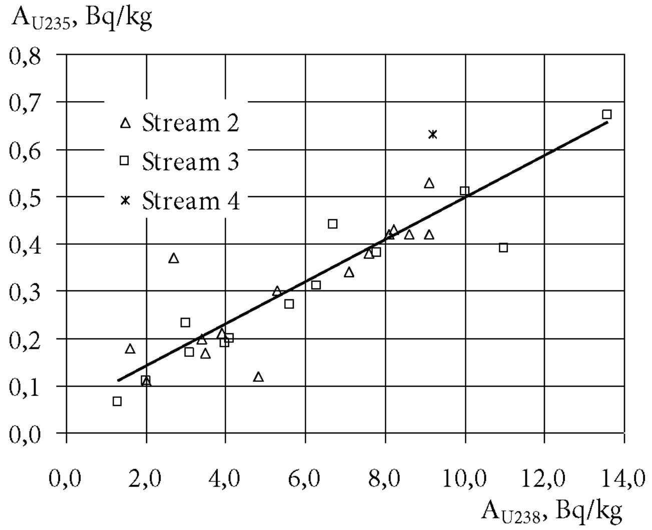

Fig. 5. Correlation of ^{235}U and ^{238}U specific activities in SRW of ChNPP

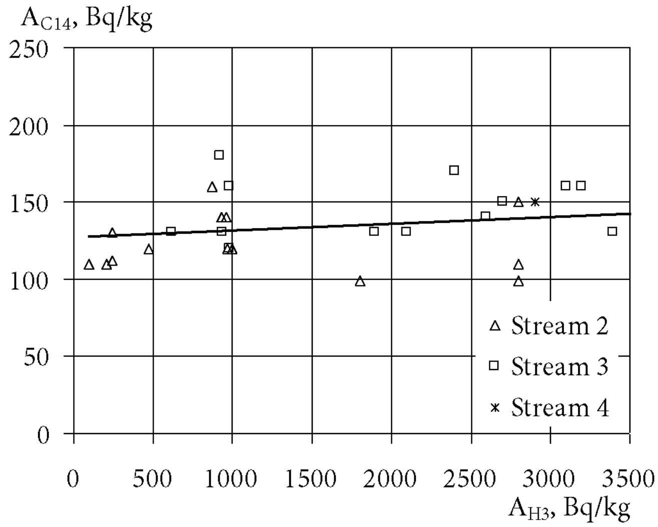

Fig. 6. The lack of correlation between the specific activities of radionuclides in SRW of ChNPP

different chemical elements due to different physical and chemical properties. As result, the ratios of isotope activities, in general, will be different in nuclear fuel, reactor core components, and final radioactive waste. This implies that isotopes of elements with some common chemical properties (solubility in water, chemical activity) can be expected to behave similarly during their transport through technological media of NPP.

The comparison with criterion (5) has demonstrated that evaluated correlation coefficients were reliable for above radionuclide pairs, and, hence, for established regression dependencies. For ^{241}Am — ^{60}Co and ^{14}C — ^{3}H pairs, correlation was very low. It is clear, since the radionuclides belong to different groups depending on their origin nature. The exceptions were for ^{94}Nb — ^{137}Cs pair only, for which a close correlation dependence was revealed between their specific activities. The detected feature is, probably, a typical one for operational SRW of ChNPP within investigated layer of waste materials.

For the rest radionuclide pairs, even after the removal of abnormal results, no correlation between the data is observed. Therefore, the results of conducted correlation and regression analysis were also not inserted in the Table 4. A special mention should be made for the result obtained by us for the pair of radionuclides (^{3}H — ^{14}C), which is shown in Fig. 6. A similar result is not so surprising one, too. For instance, a reliable correlation between ^{3}H and ^{14}C nuclides may not be detected in many cases for waste streams [8].

In practical aspects, found features of formation of radioactive contamination of various materials and stable ratios of radionuclide activities in their mixtures allow conducting reliable calculation of activity levels of DTM radionuclides in the waste packages (certification)

Table 4. The results of established correlation between radionuclides (Y–X) activity in SRW

Fig. No.	Radionuclides		Data amount, n	Regression parameters		Correlation coefficient
	Y	X		*Ln(a)*	b	
1	^{137}Cs	^{60}Co	29	5,17 ± 1,53	0,59 ± 0,30	0,67 ± 0,08
2	^{90}Sr	^{137}Cs	32	−0,45 ± 3,19	0,84 ± 0,34	0,68 ± 0,06
3a	^{94}Nb	^{60}Co	17	−1,35 ± 2,23	0,89 ± 0,36	0,80 ± 0,06
3b	^{94}Nb	^{137}Cs	17	−4,05 ± 3,95	0,81 ± 0,40	0,75 ± 0,07
4a	^{241}Am	^{137}Cs	14	−4,42 ± 2,92	1,02 ± 0,30	0,90 ± 0,03
5	^{235}U	^{238}U	29	−2,61 ± 0,31	0,81 ± 0,18	0,87 ± 0,03

Note. 95 % confidence intervals of estimated parameters.

according to gamma-ray spectrometry of KN content. As it was highlighted above, the SFM was recommended by the IAEA and WANO experts for practical implementation in Chornobyl radwaste [6, 7] characterization. Regression analysis of logarithms is used in such countries as Germany, Hungary, Lithuania, Mexico and Slovakia [8]. It is a simple enough technique for definition of SF value, which corresponds (see Tab. 4) to the coefficient *b* in the formula (4). For such forms of results distribution, which are shown in the Figs. 1–4, it is recommended to use a second technique to estimate the SF's value which is based on the hypothesis that the underlying distribution of SFs is often log-normal [8, 12]. If SF are log-normally distributed, the geometric mean SF is a robust central tendency estimator. When the data points are spread over several orders of magnitude (as in our case, see Figs. 1–5), a statistical analysis of activity ratio logarithms makes it possible to more accurately estimate the median of results distribution and to obtain a more realistic value of the SF. This way to determine the SF was used in our work [2].

Finally, if a statistical correlation between the DTM's and KN's is not found, that the MAM can be applied. This technique consists of calculation of arithmetic mean activity of each DTM nuclide in a sample, including the values being below the MDA [12]. The MAM also allows assessing the expected levels of DTM radionuclide activities and is used to characterize the radwaste in many countries, but it brings to more conservative estimate of total activity (upper bound values) in a package, as compared to above described method [2, 8].

The results of correlation analysis presented in this work indicate that for characterization of operational wastes generated at the Chornobyl nuclear power plant and those, which had been stored in the storage before 1986 accident, the SFM can also be used. At the same time, the SRW of ChNPP has characteristics and features of radionuclide contamination similar to those characteristics of operational SRW of other NPPs, including the Ignalina NPP with RBMK-1500 reactors.

Conclusions

The laboratory analysis of experimental data enabled evaluating some typical features of contaminated solid waste of ChNPP, which were formed during the normal operation of power units (before 1986 accident), and which are subject to final disposal in the near future. The analysis results demonstrate that the data on logarithmic scales can be approximated by a linear dependence of DTM radionuclide activities to the KN with rather narrow ranges of confidence intervals for established correlation parameters. The calculated correlation is enough to predict with sufficiently high accuracy the DTM radionuclide activities of such as ^{90}Sr, ^{94}Nb and ^{241}Am, with using the KN (^{137}Cs and/or ^{60}Co).

In order to certify radionuclide content and specific as well as total activity in the waste packages, the availability of a good correlation between ^{137}Cs and ^{60}Co allows, in some cases, using the data of ^{60}Co gamma spectrometry instead of ^{137}Cs data.

The data on specific activity of other radionuclides do not permit estimating the parameters of DTM/KN activity ratio with good accuracy. However, in accordance with the world practices, they can be used for conservative or upper limit of SF values with using MAM, which, in case of its application, would allow certifying DTM radionuclide contents in the SRW packages.

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Аналіз закономірностей радіонуклідного забруднення твердих радіоактивних відходів «легкого» східного відсіку сховища Чорнобильської АЕС

Відповідно до критеріїв прийняття на захоронення, діючих у зоні відчуження Чорнобильської АЕС, кожна упаковка твердих радіоактивних відходів (ТРВ), що надходить від ДСП «Чорнобильська АЕС», повинна пройти характеризацію за даними визначення питомої та сумарної активності (паспортизацію) більше 20 радіонуклідів. Серед них переважна частина належить до радіонуклідів, що важко вимірюються (РВВ). За результатами випробувань промислового комплексу з поводження з ТРВ було встановлено, що автоматизована система радіаційно-технологічного контролю не дозволяє коректно визначити активність РВВ в упаковці. Для вирішення цієї проблеми було прийнято рішення впровадити в технологію поводження з РАВ методологію радіонуклідних векторів (коефіцієнти масштабування).

У рамках підготовки заходів щодо характеризації ТРВ і подальшого захоронення їх на заводі з переробки радіоактивних відходів було проведено розкриття «легкого» східного відсіку сховища ТРВ (СТРВ). У п'яти точках відсіку з глибини до 1 м було відібрано репрезентативні проби матеріалів, які після візуального огляду були розділені на чотири потоки відходів. У лабораторних умовах зразки відходів було досліджено на вміст 24 радіонуклідів, що підлягають обов'язковій паспортизації. Для визначення питомої активності радіонуклідів використовували методи альфа-, бета- і гамма-спектрометрії, рідинної сцинтиляції та ICPM-спектрометрії. Результати вимірювань було проаналізовано за допомогою кореляційно-регресійного аналізу з використанням статистичних методів відсіву анормальних результатів вимірювань (критерій Граббса). Результати вимірювань у вигляді «<МДА» (менше значення мінімально детектованої активності обладнання, що використовувалось) із вибірок даних виключались.

За результатами проведеного дослідження встановлено, що радіонуклідний склад верхнього шару експлуатаційних ТРВ ДСП «Чорнобильська АЕС», накопичених і законсервованих ще до аварії 1986 р. в «легкому» східному відсіку СТРВ, визначається вмістом таких радіонуклідів, як ^{137}Cs, ^{60}Co, ^{90}Sr, ^{94}Nb, ^{235}U, ^{238}U, ^{241}Am, ^{3}H та ^{14}C. Питома активність інших радіонуклідів не перевищує значень МДА. Отримані дані свідчать про те, що метод коефіцієнтів масштабування може бути використаний для розрахунку прогнозного значення питомої активності РВВ у відходах. Зважаючи на високі показники кореляційної залежності, питома активність таких РВВ, як ^{90}Sr, ^{94}Nb і ^{241}Am, може бути оцінена з досить високою точністю за даними гамма-спектрометрії реперних радіонуклідів ^{137}Cs і/або ^{60}Co. Питома активність інших РВВ, що підлягають паспортизації у складі упаковок відходів, може бути розрахована з високим ступенем консервативності із застосуванням так званого методу середньої активності, що рекомендується застосовувати за відсутності кореляції або за наявності результатів вимірювань у вигляді «<МДА».

Ключові слова: Чорнобильська АЕС, тверді радіоактивні відходи, питома активність, радіонукліди, що важко вимірюються, реперні радіонукліди, коефіцієнт кореляції, коефіцієнти масштабування.

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Анализ закономерностей радионуклидного загрязнения твердых радиоактивных отходов «легкого» восточного отсека хранилища твердых отходов Чернобыльской АЭС

Изучен состав эксплуатационных твердых радиоактивных отходов (ТРО), накопленных и законсервированных до аварии 1986 г. в «легком» восточном отсеке хранилища твердых отходов (ХТО) ГСП «Чернобыльская АЭС». Материалы, образцы которых были извлечены из глубины до 1 м, после визуального осмотра были разделены на четыре потока отходов в соответствии с рекомендуемой классификацией. От каждого потока были отобраны репрезентативные образцы отходов для последующего лабораторного анализа. В соответствии с критериями принятия ТРО на захоронение, действующими для завода по переработке ТРО, отобранные пробы были исследованы на содержание в их составе 24 альфа-, бета- и гамма-излучающих радионуклидов, подлежащих паспортизации. По данным измерений оценены коэффициенты корреляции и параметры регрессионных зависимостей для радионуклидов, уровни удельной активности которых оказались выше минимально детектируемой активности (МДА). Выборки данных анализировались после удаления значений в виде «<МДА» и анормальных результатов, не удовлетворяющих критерию Граббса. Установлено, что радиоактивность ТРО в верхнем слое материалов, хранящихся в «легком» восточном отсеке ХТО, определяется в основном содержанием таких радионуклидов, как ^{137}Cs, ^{60}Co, ^{90}Sr, ^{94}Nb, ^{235}U, ^{238}U, ^{241}Am, ^{3}H и ^{14}C. Полученные данные свидетельствуют о том, что метод коэффициентов масштабирования может быть использован для количественного определения удельной активности трудноизмеряемых радионуклидов (ТИР) в отходах. Удельная активность таких ТИР, как ^{90}Sr, ^{94}Nb и ^{241}Am, может быть оценена с достаточно высокой точностью по данным гамма-спектрометрии реперных радионуклидов ^{137}Cs и/или ^{60}Co. Удельная и суммарная активность остальных ТИР, подлежащих паспортизации в составе упаковок отходов, может быть рассчитана с применением так называемого метода средней активности.

Ключевые слова: Чернобыльская АЭС, твердые радиоактивные отходы, удельная активность, трудноизмеряемые радионуклиды, реперные радионуклиды, коэффициент корреляции, коэффициент масштабирования.

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