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Preliminary Assessment of the Total Activity of Disposed Radioactive Waste in Module A-1 of the Radioactive Waste Disposal Site "Pidlisnyi"

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radioactive waste disposal site "Pidlisnyi",
radioactive waste.

Preliminary assessment of the total activity of localized radioactive waste in module A-1 of the radioactive waste disposal site (RWDS) "Pidlisnyi" was carried out, based on the survey, calculation and the main research works conducted on the RWDS "Pidlisnyi". The survey determined the dose rate on the surface of the storage module. 16 wells were made, up to the depth of the "body" of radioactive waste over the entire plane of module A-1. The analysis of the cores showed that the thickness of radioactive waste, concrete and gravel-sand backfill fluctuate throughout the plane of module A-1, that was taken into account in the simulation and calculation. The assessment was carried out using the program code MicroShield. The results of the calculations showed that the ambient dose rate of gamma radiation at the selected point on the storage surface for this model is $7.6 \cdot 10^{-4}$ μSv/h. At the same time, the results of field tests of module A-1 of RWDS "Pidlisnyi" showed that the dose rate of gamma radiation at this point is 7.8 μSv/h. Therefore, the dose rate of gamma radiation on the surface of the module is formed by radiation from the gravel-sand backfill. As part of this work, the inverse problem of determining the activity by known dose rate values was solved to assess the total waste activity. The results of the preliminary assessment showed that the total waste activity in module A-1 is approximately $1.5 \cdot 10^{15}$ Bq.

Introduction

The radioactive waste disposal site (RWDS) "Pidlisnyi" was constructed in the area of the former settlement Pidlisnyi. The object was commissioned in December 1986 for the localization of solid radioactive waste (RAW) in bulk with a dose rate of gamma radiation from 5 to 250 R/h.

The RWDS "Pidlisnyi" is a modular type surface repository for the localization of RAW, developed under the project of the Open Joint Stock Company "All-Union Research and Design Institute of Power Engineering" (OJSC "VDPPET") in 1986 in an emergency response [1].

The initial design included 8 concrete modules. The first stage in operation is two concrete modules A-1 and B-1, which were used for localization of RAW. Module A-1 (Fig. 1) was designed to localize waste in bulk and B-1 — to dispose containers containing waste. The rest of six modules were empty. The module A-1 was filled mostly with loose and construction RAW in bulk. Module B-1 was filled with RAW in containers and bulk over containers. The radioactive waste in both modules was filled with concrete and covered with a layer of sand-gravel mixture.

The total volume of waste in module A-1 is estimated at 2650 m^3 [1], waste density is 1995 kg/m^3. Physical composition of RAW consists of graphite, build-

ing debris of Chornobyl nuclear power plant (ChNPP) Unit 4, construction waste of ChNPP industrial zone. After the RAW was loaded in the module, the waste was filled with liquid concrete [1]. The total volume of concrete was 2296 m^3 (thickness of the layer is 1.5 m) and 2457 m^3 (thickness of the layer 1.6 m) for modules A-1 and B-1, respectively.

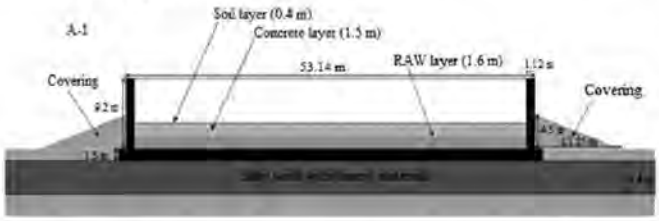

Fig. 1. Scheme of RWDS "Pidlisnyi", module A-1

Modules consist of concrete walls formed from prefabricated concrete blocks located on a common concrete slab with a thickness of 1.5 m. The plates are located on a thick layer of clay thickness of about 4.4 m. The size of the base plate of each module is about 52 m×32 m. Walls of the module A-1 have a thickness of 1.12 m. Around the walls of the module, covering with height 4.5 m was constructed.

The designer of OJSC "VDPPET" guaranteed the reliability of the structures of the RWDS "Pidlisnyi" modules to 20 years [2]. According to the normative documents of Ukraine, all high-level and long-lived RAW should be buried in geological storage facilities. Thus, the state of RWDS and RAW requires continuous monitoring, in order to increase knowledge about the characteristics of radioactive waste, as well as to clarify the measures for the safety of their storage at the subsequent stages of the design of geological repositories and the preparation of technologies for reburial in the future.

In 2002, OJSC "VDPPET" developed "Report on production, economic and scientific-practical activity of 2002", which presents data on inventory of radionuclide composition and activity of radioactive waste in storage for the period of 1987 and recalculation to 2016. According to this report, the total RAW activity in 1987 was $1.74 \cdot 10^{18}$ Bq and from the recalculation for 2016–$2.32 \cdot 10^{17}$ Bq. Tab. 1 shows the radionuclides and their activity according to the results of the inventory conducted by OJSC "VDPPET". However, the activity data are not one-digit, as in the inventory of RAW storage facilities as of 01.01.1990 the total activity of radionuclides was 3 orders of magnitude lower than according to the data of OJSC "VDPPET".

Conducting field studies to determine the characteristics of the A-1 module RWDS "Pidlisnyi"

In the framework of the Agreement on Scientific and Technical Cooperation no. 101/18 dated June 21, 2018 between the State Specialized Enterprise "Centralized Enterprise for the Management of Radioactive Waste" (SSE "CEMRW"), the State Specialized Enterprise "Chornobyl NPP", the State Specialized Enterprise "Ecocenter" and the Institute for Safety Problems of the Nuclear Power Plants of the NAS of Ukraine (ISP NPP) research work on the survey of the RWDS Pidlisnyi was conducted.

As a result of studies, the dose rate on the surface of the storage module was determined, followed by the drilling of 16 wells, to the depth of the "body" of RAW, which are located throughout the plane of module A-1 (Fig. 2). Analysis of the obtained cores showed that the thickness, rad, concrete and gravel-sand backfill fluctuated throughout the plane of module A-1 (Tab. 2).

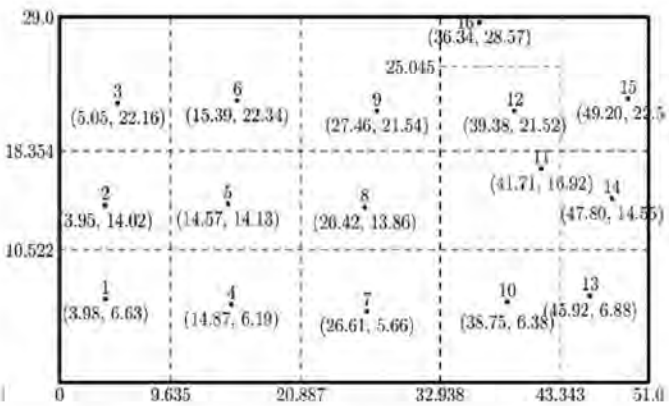

Fig. 2. Scheme of wells location in module A-1 of RWDS "Pidlisnyi"

Also, measurements of gamma-logging of wells were carried out throughout the depth in increments of 10 cm, resulting in the data of gamma radiation power at the height of the wells. The activity distribution in the radioactive layer is substantially uneven. Thus, in well 8, the dose rate reaches 130 mSv/h, significant levels of dose rate are also found in wells 1, 3, 4, 10 and 16. At the same time, in wells 13, 14 and 15 dose rate is relatively small, indicating the absence of highly active radiation sources in the area. The data obtained was used to compare with the data obtained from the preliminary assessment of the total activity of localized RAW in module A-1.

However, the main task under the Agreement is to evaluate the total RAW activity in Module A-1 of the RWDS "Pidlisnyi" using the Monte Carlo method (using

Table 1. Radionuclide composition and activity of RAW in module A-1 of the RWDS "Pidlisnyi" (According to the results of the inventory conducted by OJSC "VDPPET")

Radionuclide	1987 Bq	1987 Bq/g	Type of radiation	Half-life, years	2016 Bq/g	2016 Bq
^{90}Sr	1,53E+17	1,93E+07	β	29,12	9,70E+06	7,66E+16
^{99}Tc	2,98E+14	3,77E+04	β	213000,0	3,77E+04	2,98E+14
^{106}Ru	3,03E+17	3,84E+07	β	1,01	–	–
^{125}Sb	1,09E+16	1,38E+06	β	2,77	9,73E+02	7,68E+12
^{134}Cs	1,49E+17	1,89E+07	β	2,06	1,10E+03	8,72E+12
^{137}Cs	2,00E+17	2,53E+07	βγ	30,0	1,30E+07	1,02E+17
^{144}Ce	3,46E+17	4,38E+07	β	0,78	–	–
^{147}Pm	2,05E+17	2,60E+07	β	2,62	1,22E+04	9,67E+13
^{151}Sm	3,11E+14	3,93E+04	β	90,00	3,15E+04	2,49E+14
^{154}Eu	1,45E+16	1,83E+06	β	8,80	1,87E+05	1,47E+15
^{155}Eu	8,95E+15	1,13E+06	β	4,86	1,81E+04	1,43E+14
^{243}Am	1,86E+13	2,36E+03	α	7380,0	2,35E+03	1,86E+13
^{239}Pu	5,22E+14	6,60E+04	α	24065,0	6,60E+04	5,21E+14
^{244}Cm	6,22E+14	7,87E+04	α	18,11	2,59E+04	2,05E+14
^{240}Pu	1,22E+15	1,55E+05	α	6537,00	1,55E+05	1,22E+15
^{238}Pu	2,01E+15	2,54E+05	α	87,74	2,02E+05	1,59E+15
^{238}U	9,77E+11	1,24E+02	α	4468000000	1,24E+02	9,77E+11
^{242}Pu	3,34E+12	4,23E+02	α	376300	4,23E+02	3,34E+12
^{241}Am	2,80E+14	3,54E+04	α	432,20	3,38E+04	2,67E+14
^{241}Pu	1,88E+17	2,37E+07	β	14,40	5,88E+06	4,65E+16
^{90}Y	1,53E+17	1,93E+07	β	0,01	–	–
^{91}Y	2,41E+14	3,05E+04	β	0,16	–	–
^{93}Zr	4,03E+12	5,11E+02	βγ	1530000,0	5,10E+02	4,03E+12
^{95}Zr	7,88E+14	9,98E+04	βγ	0,18	–	–
^{239}Np	1,86E+13	2,36E+03	α	0,01	–	–
^{235}U	3,24E+10	4,10E+00	α	704000000,0	4,10E+00	3,24E+10
^{242}Cm	1,41E+15	1,79E+05	α	0,45	–	–
Total		1,74E+18				2,32E+17

Table 2. RAW, concrete and gravel-sand thicknesses

№ region	Thickness of RAW, m	Thickness of concrete, m	Thickness of gravel-sand, m
1	1,46	1,00	1,29
2	1,20	0,80	1,6
3	1,26	0,60	1,79
4	1,33	1,30	0,94
5	1,29	1,60	0,74
6	0,42	2,30	0,72
7	1,92	0,80	0,88
8	2,04	1,10	0,21
9	1,75	1,10	0,33
10	1,18	1,50	0,12
11	1,17	0,90	0,57
12	1,24	1,10	0,45
13	0,96	0,90	0,24
14	0,67	0,70	0,48
15	1,35	0,02	0,86
16	1,27	0,70	1,22

MCNP code software). MicroShield software code was used for preliminary asssessment of the total activity of prohibited RAW in module A-1 of the RWDS "Pidlisnyi" and for preliminary assessment.

Modeling and analysis

To determine the contribution of RAW activity to the gamma radiation dose rate on the surface of module A-1, using the MicroShield code, a simplified model of the module was constructed, which includes a layer of RAW, concrete and gravel-sand backfill. The thickness of the layers was defined as the average value of the thicknesses obtained during the field tests of Module A-1 by specialists of the SSE "CEMRW" and the ISP NPP. The geometric characteristics that were used to construct the model are shown in Tab. 3.

The radionuclide composition and activity of the elements were adopted in accordance with Tab. 1, where the total RAW activity in module A-1 is 2.32×10^{17} Bq (as of 2016). The energy spectrum for the calculation was determined according to the radionuclides specified in Tab. 1 The position of the detection point was chosen

Table 3. The radionuclide composition and activity of the elements were taken in accordance with

Layer	Height, cm	Width, cm	Length, cm
RAW	128	2500	5200
Concrete	103	2500	5200
Gravel-sand covering	76	2500	5200

in such a way that the thicknesses of the average geometric dimensions at its location coincide with the actually measured thicknesses of RAW, concrete and gravel-sand backfill and corresponds to the well no. 5 in Fig. 2. The model image is shown in Fig. 3.

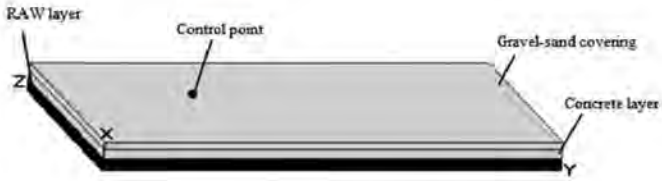

Fig. 3. Estimated model of module A-1 of RWDS "Pidlisnyi"

The results of the calculations showed that the level of the ambient dose of gamma radiation at the selected point on the surface of the repository for this model is 7.6×10^{-4} μSv/h. At the same time, the results of field inspections of the module A-1 RWDS "Pidlisnyi" showed that the dose rate of the gamma radiation at this point is 7.8 μSv/h. Analyzing the obtained results, it can be concluded that the contribution to the dose rate of gamma radiation on the surface of the module A-1 from localized RAW is negligible.

The next step was to determine the proportion of contribution to gamma radiation dose from gravel-sand backfill.

In order to determine the contribution of gravel-sand backfill activity to the dose rate of gamma radiation on the surface of the module A-1, using the MicroShield software code, a simplified model of the fill layer was constructed. The average thickness of the layer of gravel-sand backfill was 76 cm. The radionuclide composition and activity of the elements were taken in accordance with the table 4 in [4].

According to the table 4 [4], the main contribution to the filling activity is made by ^{137}Cs with an average specific activity of 90 kBq/kg. The average specific activity of ^{241}Am is 3 Bq/kg, and ^{90}Sr is 30 Bq/kg. Bulk density of gravel-sand backfill was taken 1.43 g/cm^3.

The results of the modelling and calculations show that the dose rate of gamma radiation on the surface of the

module A-1 is 6.6 μSv/h. The obtained result correlates well with the gamma radiation dose rate measured in the course of field survey –7.8 μSv/h. Thus, we can conclude that the dose rate of gamma radiation on the surface of the module A-1 of the RWDS "Pidlisnyi" is formed mainly due to radiation from gravel-sand backfill.

A simplified model of RAW layer was constructed using the MicroShield software code to determine the total activity of RAW that are localized in the module A-1 of RWDS "Pidlisnyi". The average thickness of the RAW layer is 128 cm. The radionuclide composition and activity of the elements were taken according to the data shown in table 1 [4]. The MicroShield software code does not allow the inverse scattering of radiation from the concrete layer, which is above the RAW layer. The relevant error in determining the dose rate can be estimated at 10–20% of the end result. In order to obtain a more accurate result, further research will use Monte Carlo modelling using the MCNP code.

The results of simulation and calculations show that when using the value of total radionuclide activity in accordance with the table 1 [4], the dose rate of gamma radiation on the RAW surface is $1.39 \cdot 10^6$ μSv/h. In this case, the dose rate of gamma radiation measured during surveys (according to logging) is three orders of magnitude smaller and is $8.9 \cdot 10^3$ μSv/h.

In order to explain this discrepancy, it should be held in mind that, according to [1], inventories of RAW of module A-1 are ambiguous. Thus, according to [3], as of 2016, the total activity of radionuclides in the module is three orders of magnitude lower than that of OJSC "VDPPET". In the framework of this work for the assessment of the total activity of waste the inverse problem was solved with the determination of activity by known levels of dose rate. According to the results of preliminary assessments, it can be concluded that the total activity of RAW located in the module A-1 of RWDS "Pidlisnyi" is approximately $1{,}5 \cdot 10^{15}$ Bq.

The data obtained during the modelling and preliminary assessments will be used in the future for more accurate estimation of the total activity of RAW in the module A-1 of RWDS "Pidlisnyi" using the MCNP code.

Conclusions

1. The total activity of RAW, localized in the module A-1 of RWDS "Pidlisnyi", is two orders of magnitude lower than the data of VDPPET (according to 2016) and is an order of magnitude higher than the data of the results of inventory of the RWDS, and is approximately $1{,}5 \cdot 10^{15}$Bq.

2. The contribution of gamma-radiation dose to the surface of the module A-1 from RAW is insignificant and is formed due to radiation from gravel-sand backfill.

3. On the basis of the specified data of the radionuclide composition and activity of the nuclides, a more precise asssessment of the total activity of the localized RAW in the module A-1 of RWDS "Pidlisnyi" by the Monte-Carlo method using the MCNP code will be carried out.

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Попередня оцінка сумарної активності локалізованих радіоактивних відходів у модулі А-1 пункту захоронення радіоактивних відходів «Підлісний»

Проведено попередню оцінку сумарної активності локалізованих радіоактивних відходів у модулі А-1 пункту захоронення радіоактивних відходів (ПЗРВ) «Підлісний» на основі проведених дослідницьких робіт з обстеження ПЗРВ «Підлісний» та проведених розрахунків. У результаті обстеження було визначено потужність дози на поверхні модуля сховища. Було зроблено 16 свердловин до глибини залягання «тіла» радіоактивних відходів (РАВ) по всій площині модуля А-1 по всій глибині з кроком 10 см, у результаті чого отримано дані потужності гамма-випромінювання по висоті свердловин. Аналіз отриманих керн показав, що товщини РАВ, бетону та гравійно-піщаної за-

сипки по всій площині модуля А-1 коливаються, що враховувалося під час моделювання та проведення розрахунків. Оцінка проводилася з використанням програмного коду MicroShield. Результати розрахунків показали, що потужність амбієнтної дози гамма-випромінювання в обраній точці на поверхні сховища для цієї моделі становить $7{,}6 \cdot 10^{-4}$ мкЗв/год. При цьому результати натурних обстежень модуля А-1 ПЗРВ «Підлісний» показали, що потужність дози гамма-випромінювання в цій точці становить 7,8 мкЗв/год. Отже, потужність дози гамма-випромінювання на поверхні модуля формується за рахунок випромінювання від гравійно-піщаної засипки. У рамках роботи для оцінки сумарної активності відходів було розв'язано зворотну задачу з визначення активності відомими значеннями потужності дози. Результати попередньої оцінки також показали, що сумарна активність відходів у модулі А-1 становить приблизно $1{,}5 \cdot 10^{15}$ Бк.

Ключові слова: пункт захоронення радіоактивних відходів «Підлісний», радіоактивні відходи.

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Предварительная оценка суммарной активности локализованных радиоактивных отходов в модуле А-1 пункта захоронения радиоактивных отходов «Подлесный»

Проведена предварительная оценка суммарной активности локализованных радиоактивных отходов в модуле А-1 пункта захоронения радиоактивных отходов (ПЗРО) «Подлесный» на основании проведенных исследовательских работ по обследованию ПЗРО «Подлесный» и проведенных расчетов. В результате обследования была определена мощность дозы на поверхности модуля хранилища. Было сделано 16 скважин до глубины залегания «тела» радиоактивных отходов (РАО) по всей плоскости модуля А-1. Анализ полученных керн показал, что толщины РАО, бетона и гравийно-песчаной засыпки по всей плоскости модуля А-1 колеблются, что учитывалось при моделировании и проведении расчетов. Оценка проводилась с использованием программного кода MicroShield. Результаты расчетов показали, что мощность амбиентной дозы гамма-излучения в выбранной точке на поверхности хранилища для данной модели составляет $7{,}6 \cdot 10^{-4}$ мкЗв/ч. При этом результаты натурных обследований модуля А-1 ПЗРО «Подлесный» показали, что мощность дозы гамма-излучения в этой точке составляет 7,8 мкЗв/ч. Итак, мощность дозы гамма-излучения на поверхности модуля формируется за счет излучения от гравийно-песчаной засыпки. В рамках данной работы для оценки суммарной активности отходов была решена обратная задача по определению активности известными значениями мощности дозы. Также результаты предварительной оценки показали, что суммарная активность отходов в модуле А-1 составляет примерно $1{,}5 \cdot 10^{15}$ Бк.

Ключевые слова: пункт захоронения радиоактивных отходов «Подлесный», радиоактивные отходы.

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