NEW INSTRUMENTS AND RADIOACTIVITY MEASUREMENT METHODS APPLIED IN REHABILITATION ACTIVITIES AT RWDS OF RRC KURCHATOV INSTITUTE

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ABSTRACT

The paper presents results of application of a set of new instruments for measurements of characteristics of radwaste during different stages of rehabilitation activity at territory of radwaste disposal site of Kurchatov Institute. These instruments were developed to solve specific problems arising during these works. The description of devices and their parameters are presented also.

INTRODUCTION

The old repositories are characterized by non-uniform RW distribution over the repository volume. The radwaste in the old repositories are mixed with soil, concrete and other materials. A variety of special radiation measurement problems arise in planning and performance of rehabilitation activities at the radwaste disposal site (RWDS) with old, historical repositories, including [1, 2]

- acquisition and refinement of data on composition, location and activity of radwaste in the repositories,
- evaluation of value of radwaste activity to be removed,
- measurement of radioactive contamination of repository structures and soil,
- search for the most active pieces of radwaste in the heaps of repositories.

A number of new instruments and systems were developed to conduct the necessary measurements.

The instruments with collimated scintillation detectors operating both in current and spectrometric modes were used for measurements of the distribution of the radwaste specific activity over layers in the old repositories and in the soil. The measurements are taken in exploratory boreholes that are drilled in the old repositories prior to their opening. The technique of specific activity measurements with collimated detectors was used when examining radioactive contamination of soil in a number of Russian contaminated territories [3,4] and demonstrated a good agreement with results of sampling performed at the same time.

For evaluation of total activity in repositories with free access to radwaste it is possible to use special combined detector radiometers with two sensors.

The operations on withdrawal of middle and high level radwaste from repositories are carried our with remotely controlled robots. For remote search for the most active pieces of radwaste during this work gamma-imaging device was used.

SPECTROMETRIC COLLIMATED DETECTOR

A spectrometric collimated detector (SCD) was developed and fabricated for measurement of depth profiles of specific activity for ^{137}Cs and ^{60}Co radionuclides in the exploratory boreholes.

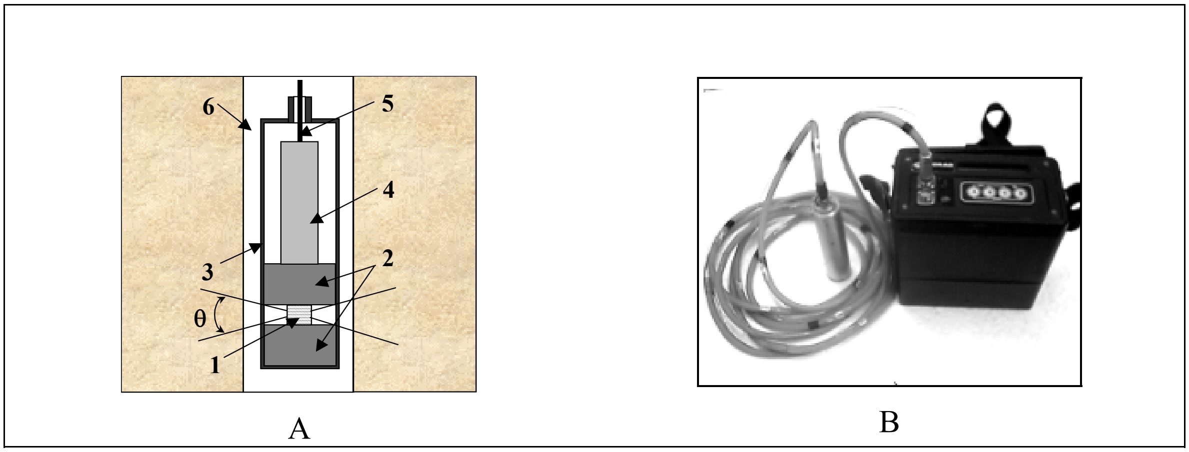

Fig. 1. A) RW activity measurements in a borehole using an SCD.1- scintillator-photodiode sensor, 2 – lead collimator, 3 – detector casing, 4 – signal shaping and amplifier boards, 5 – cable connecting the detector with the portable analyzer, 6 – borehole. B) Appearance detector with the crystal volume of 0.064cm^3 with cable and spectrometric analyzer

The sensor of SCD consists of a CsI(Tl) scintillation crystal optically coupled with a silicon photodiode, and a compact electronic amplifier unit (signal converter – preamplifier and shaper-amplifier). The scintillation crystal is placed between two lead discs producing high spatial resolution of the detector (θ is an angle of collimation). The electronic unit is located in the common housing of the sensor.

The SCD is moved in increments along a borehole, and spectrum measurements are taken in each point of the profile (Fig. 1). The detector signal is proportional to specific activity of radionuclides uniformly distributed in a layer of contaminated materials falling within the instrument collimation angle θ. The detector is connected to a portable 1024-channel analyzer This instrument has two changeable measuring units with different volumes of scintillation crystal – 0.064 cm^3 and 5.7 cm^3. These sensors differ in sensitivity and are designed for specific activity measurements in repositories with widely differing contamination levels (Table I).

Table I. Characteristics of SCD with Different Volume of Scintillator

Parameter		V_{det}=0.064cm^3	V_{det}=5.7 cm^3
Dimensions of the CsI(Tl) scintillation crystal		4x4x4 mm	∅30x10 mm
Energy resolution for the 662 keV line	no less than	10%	8%
Spatial resolution by depth		5 cm	5 cm
Measuring unit dimensions		∅40x210 mm	∅70x180 mm
The minimum measurable specific activity	with 30% uncertainty at 300 sec exposure	5 x10^3 Bq/kg for ^{137}Cs 2.5x10^3 Bq/kg for ^{60}Co	
The upper limit of the measurable specific activity		5x10^7 Bq/kg for ^{137}Cs, 2.5x10^7 Bq/kg for ^{60}Co	
The minimum measurable specific activity	at 180 sec exposure, 50% uncertainty		50 Bq/kg for ^{137}Cs

CURRENT COLLIMATED DETECTOR

A current collimated detector (CCD) is designed for rapid measurement of a borehole depth profile of ^{137}Cs and ^{60}Co equivalent specific activity A_{Eq} ($A_{Eq} = A_{Cs} + 4A_{Co}$).

The CCD design is similar to that of the SCD. The scintillation sensor operated in current mode. The mean photodiode current is proportional to radiation energy absorbed in the scintillation crystal per unit time and thus to the equivalent specific activity of radionuclides. The detector amplifier signal is transmitted to a voltmeter.

Characteristics of the current collimated detector. Dimensions of the CsI(Tl) scintillation crystal - ∅8x8 mm. Spatial resolution of the collimated detector by depth – 5 cm. The minimum measurable specific activity (sensitivity) is 5x10^3 Bq/kg for ^{60}Co and 10x10^3 Bq/kg for ^{137}Cs. The upper limit of the measurable specific activity is 0.45x10^9 Bq/kg for ^{137}Cs and 0.12x10^9 Bq/kg for ^{60}Co. Overall dimensions - ∅ 40x210 mm.

If it is necessary to determine the activity ratio between ^{137}Cs and ^{60}Co, SCD measurements are taken in several check points almost concurrently with the CCD measurements. This ratio determines the choice of activity to be measured by the CCD. If the activity ratios are determined from the SCD measurements in selected points of the borehole and these values are not of a random nature, results of the CCD measurements for equivalent specific activity can be broken down into ^{137}Cs and ^{60}Co components. This approach reduces the time it takes to examine repositories.

Results of measurements of borehole depth profiles of specific activities with the CCD and SCD devices. It is evident from the Figure 2 that the CCD and SCD data virtually coincide. The data on the depth distribution of activities obtained for a number of boreholes allow not only gaining a pattern of activity distributions over the repository, but also evaluating the total activity of the RW which is of prime importance for planning and optimization of rehabilitation activities, as well as for taking measures to reduce dose burden for the personnel involved.

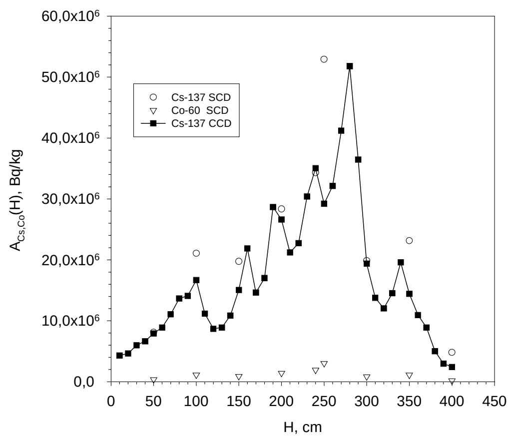

Fig. 2. Distributions of ^{137}Cs and ^{60}Co activities along the borehole depth. The measurements were carried out with the spectrometric collimated detector (SCD) and the current collimated detector (CCD).

EVALUATION OF THE TOTAL ACTIVITY OF RADIONUCLIDES IN A REPOSITORY WITH A COMBINED DETECTOR RADIOMETER

For the purpose of planning of rehabilitation activities, it is necessary to know the estimation of total activity of RW in a specific repository prior to its dismantling. For historical repositories the information on this matter is contradictory very often.

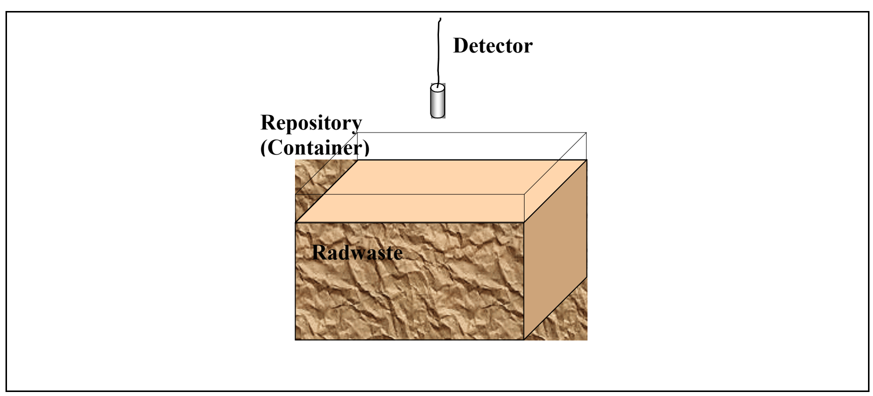

Fig. 3. Geometry of measurements with combined detector radiometer.

A new device radiometer with combined detector was developed for evaluation of the total activity of RW in the repositories. The detector consists of two sensors, one of which is enclosed in lead shielding. Each of the sensors consists of an optically connected $CdWO_4$ scintillator and a Si p-i-n photodiode and operates in the current mode. Both of sensors with electronics are enclosed in a common casing. Signals of the sensors are transmitted to a digital voltmeter. The ratio between ^{137}Cs and ^{60}Co activities is determined from the ratio between signals of these sensors, and activities of these radionuclides are found from the signal of the unshielded sensor.

To estimate RW activity in the repositories, there was developed a mathematical model based on Mote Carlo calculations for the combined detector readings. Parameters that are specified for the model include repository dimensions, radwaste layer thickness, detector position above the filling level (height), and volume fraction or density of the RW (Fig. 3). The calculations take into account processes of multiple interaction of gamma radiation of uniformly distributed radioactive sources in a layer matrix material of known thickness, multiple scattering of gamma quanta in the detector lead shielding and in the sensor's scintillating material. Sensor calibration curves and calibration curves obtained by Monte Carlo calculations are used to estimate the total activity of RW in the repositories.

The combined detector measurement method allows rapid evaluation of the total radionuclide activity. This instrument was used for measurements of total activity in rectangular and cylindrical repositories and other containers completely or partially filled with liquid or solid radwaste (e.g. metal structures) containing ^{137}Cs and ^{60}Co radionuclides.

The most crude assumption of the method is the notion that the radionuclide activity is rather uniformly distributed over the repository volume. This assumption is responsible for the basic methodological error of the measurement method that may be as high as 200-300%. For estimation of total activity in old repository it suffices to know at least the true order of magnitude for this value. Therefore, the error of 200-300% is acceptable in such cases. Main parameters of radiometer are presented in Table II.

Table II. Main Parameters of Radiometer with Combined Detector

Sensors	$CdWO_4$ scintillator + Si p-i-n photodiode
Operations mode	current registration
Operating exposure dose range	0.01 – 5 R/h
Measured nuclides	^{137}Cs and ^{60}Co

The developed instrument was used to measure the total activity of RW in the set old repositories at the RWDS that allowed planning various protective measures during the rehabilitation activities. These acquired values of radwaste total activity in the repositories agree well with results of subsequent activity measurements for the radwaste withdrawn from the repository (Table III).

Table III. Results of Measurements of Total Activity by Different Methods

Method of measurements	Total activity of ^{137}Cs
SCD and CCD	(6.5 ± 1.0) Ci
Radiometer with combined detector	(5.8 ± 0.7) Ci

THE APPLICATION OF GAMMA-IMAGING DEVICE AT EXTRACTION OF THE RADIOACTIVE WASTE FROM TEMPORAL REPOSITORY

The gamma imaging devices are applied for assessment of nuclear contamination of the equipment and premises at a stage of preparation of this nuclear installations and equipment to disassembly. Some prototypes of such instruments were developed in resent years [5-7].

Industrial prototype of portable gamma imaging device for nuclear environment was developed in Kurchatov Institute and applied for search of hot spots and mapping of radioactivity distributions during work at RWDS [8]. The principle of the device’s operation consists in the following. First, two cone collimator forms the gamma - image of object on plate of scintillating crystal. The light image arising in a crystal is transferred via the fiber optic taper to an input window of the MCP image intensifier. The intensified image is detected by a digital video camera and is transferred in the computer. The gamma image is presented on display as distribution of gamma-ray intensity, falling into collimator from different directions. The gamma image may be presented in pseudocolors and imposed on a video image of the objects for identification of the most active elements of radwaste. The video image is transmitted with an additional video camera.

The most useful application the gamma-imaging device have found as instrument for operative control on medium level RW withdrawal from temporary repository. This repository represents a concrete-brick trench in the ground, which was filled with solid RW. The free volume between RW elements was filled with concrete. Before beginning of RW withdrawal additional protective shelter was constructed around the repository from concrete blocks walls with overlapping by concrete plates to decrease the dose rates at RWDS. Destruction of repository was carried out from above, and for this some of overlapping plates were removed (Fig. 4). The RW were withdrawn into metal containers (low level RW), or into concrete containers (medium level RW) with remote controlled robots.

The gamma-imaging device was established on a support behind a concrete wall of the additional protective construction for control on withdrawal of the radioactive waste from temporal repository and identification the most active radwaste elements. Since the device worked in a strong background radiation field it was placed into additional leaden shielding with thickness of 5 cm. The device worked in a continuous mode of the gamma image acquisition. The exposure time of one gamma image was from 20 sec to 5 minutes. The radwaste were loaded into special containers by remotely controlled robots.

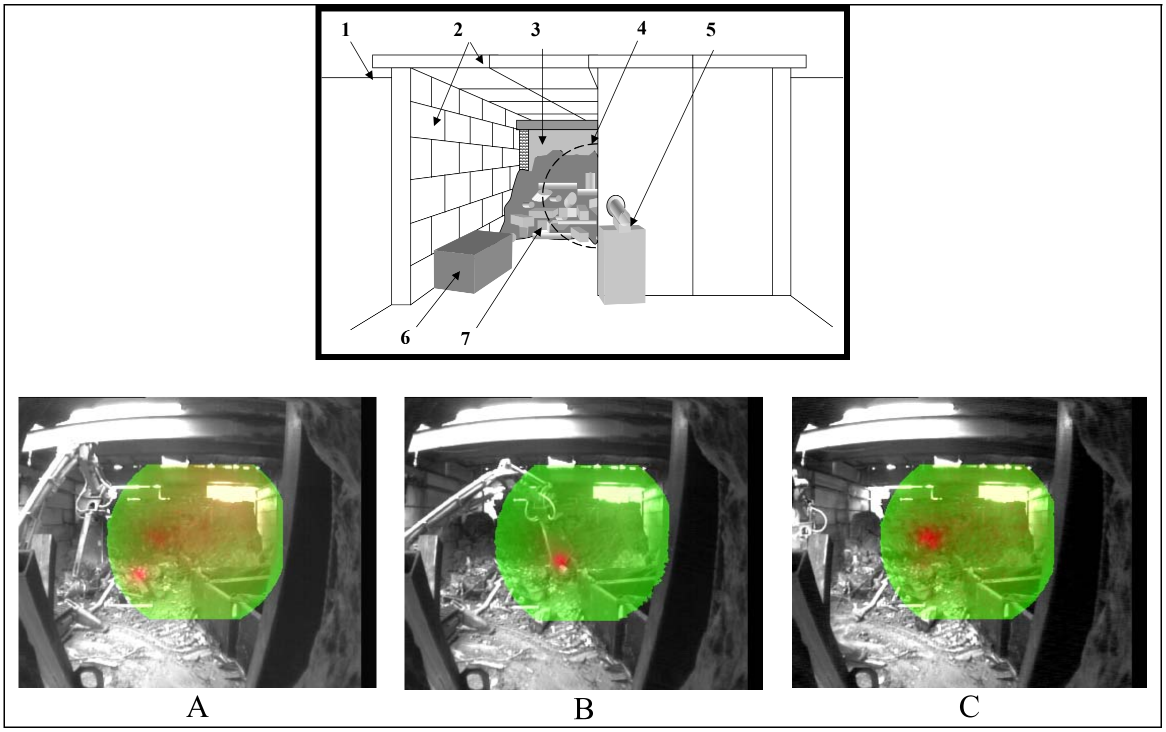

Fig. 4. Layout of gamma-ray imaging during radwaste withdrawal from old repository and consecutive acquired gamma- images . 1 - ground level, 2 – walls and roof of a shelter, 3 – radwaste repository, 4 – field of view of the device, 5 – gamma imaging device, 6 –container, 7 – solid RW.

Figure 4 shows also the consecutive gamma-images (imposed on the video images) received during works on radwaste withdrawal from the repository and loading into containers for transportation. Intensities in every gamma image are normalized to the most intensive source in field of view. In image A someone can see that the most active source is contaminated pipe. The process of carry the pipe into the container by the robot is shown in an image B. Here the pipe is closer to gamma-imager and the intensity of its radiation became higher in comparison with other sources. After removal of this pipe from the device's field of view a cumulate of other pipes and cases in ruins of repository became the most active source in the stage (image C).

The search via visualization and removal of the most active sources reduce the exposure dose inside an additional protective construction in 2-5 times. After that it was possible to remove the weak radioactive wastes with excavator through the opening on the roof of a protective construction.

For the first time gamma-imaging device operating in a continuous mode was used directly during works with the radioactive waste for visualization the most active sources. The visualization of gamma-sources allows the control of works on extraction of the radioactive wastes from temporal repositories.

CONCLUSION

Results of application of new instruments and diagnostic means at RWDS of RRC Kurchatov Institute have demonstrated high efficiency of their use in the rehabilitation activities.

The instruments were used during the entire cycle of the works, from the initial survey of the repository condition and to disassembly of the repository structures upon extraction of the radwaste. The measurements performed allowed evaluating the composition, location and activity of the RW found in the old repositories; monitoring radiation situation for safe transfer of the RW from the old repositories to containers. The obtained values of the total activity of the radwaste in the old repositories prior to its opening agree well with the activity measurements for the radwaste loaded in the containers.

The visualization of the most active gamma-sources with gamma imaging device is very convenient method for control of works on radioactive wastes withdrawal from temporal repositories at high dose rate conditions.

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