Use of the Underwater Collimated Spectrometric System for Survey of Storage Ponds of Research VVR-2 and OR Reactors – 15118

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ABSTRACT

Spent nuclear fuel removal activities in the National Research Centre “Kurchatov Institute” were resumed in 2004. During the last two years, removal was performed of the spent nuclear fuel from the VVR-2 and OR reactor installations, whose storage facilities are located within the Gas Plant complex. The Gas Plant complex is the experimental base of the Institute of Nuclear Reactors, which is part of the “Kurchatov Institute”. The complex features four storage facilities for spent nuclear fuel, one in a dedicated building for storage of spent nuclear fuel and solid radwaste and three in the reactor building. They are sub-surface vessels filled with water (the volume of water in each is about 6 m^3), closed with top shielding slabs. Some spent fuel assemblies and fuel elements stored are resized, deformed, or have defective claddings. In the course of works on removal from ponds of the spent nuclear fuel, its fragments could get to water. The bottoms of ponds storage are covered with a deposit. The bottom of ponds and water are possible to be pollution by fission products. The survey objective was to find uranium-containing materials (elements of irradiated nuclear fuel) at the bottom of the ponds and evaluation of surface activity of fission products. To solve this problem was used the underwater collimated spectrometric system on the basis of a semiconductor detector CdZnTe (volume of a crystal of 20 mm^3) and a multichannel analyzer InSpector 2000. The detector with the collimator is placed in the waterproof case on which the video camera fastens. The principle of detection of uranium-containing materials is based on the identification of the characteristic peaks in the spectra of uranium radiation measurements in the energy range 95 ÷ 115 keV. The results of the most representative measurements at the bottom of reactor ponds are given. The received results are discussed; comparison of results between in-site pond measurements and gamma spectrometric and radiochemical analysis of the water in the lab is carried out. The received results will be used for scheduling on pond cleaning.

INTRODUCTION

The Gas Plant complex is the experimental base of the Institute of Nuclear Reactors, which is part of the Kurchatov Institute. In 1954, it saw the commissioning of the first Soviet water-cooled water-moderated research reactor VVR-2 on enriched uranium, and until 1983 the complex operated two research water-cooled water-moderated reactors 3 MW (VVR-2) and 300 kW (OR) capacity, which were dismantled in connection with the overall upgrades of the complex. The spent fuel that is currently stored at the complex is the result of reloading of the reactors fuel, as well as discharge of spent fuel performed during the upgrades [1,2]. The reactors used fuel assemblies that contained 16 and 11 fuel rods. The VVR-2 reactor also used assemblies consisting of eight and four fuel rods.

In early 2007, the temporary “wet” storage facilities for spent fuel on the site accommodated 300 spent fuel assemblies (SFAs), 70% of which contained UO_2 MgO fuel enriched to 10% (EK-10), and the remaining 30% UAl fuel enriched to 36% (S-36).

The complex features four storage facilities for spent fuel, one in a dedicated building for storage of spent fuel and solid radwaste and three in the reactor building. They are sub-surface vessels filled with water (the volume of water in each is about 6 m^3), closed with top shielding slabs. The lower part of the vessels features special structures that include absorbers for the assurance of nuclear safety and the cells that accommodate the SFAs.

In 2007-2013 accumulated spent nuclear fuel of research reactor WWR-2 and ER exported for reprocessing at PO "Mayak". During the overload from the cell pond of spent nuclear fuel in special packaging canisters its fragments could fall into the water pools.

The bottoms of pond storage and the pond of the reactor are covered with a slime. The bottom of ponds and water is possible the pollution by fission products.

The survey objective was to find uranium-containing materials (elements of irradiated nuclear fuel) at the bottom of the ponds and evaluation of surface activity of fission products. To solve this problem was used the underwater spectrometric system [3,4].

DESCRIPTION OF THE SPECTROMETRIC SYSTEM

Underwater spectrometer system consists of a measuring unit, a multichannel analyzer InSpector 2000 (Canberra Industries, Inc.) and a computer. Figure 1 shows scheme and photos of the measuring unit.

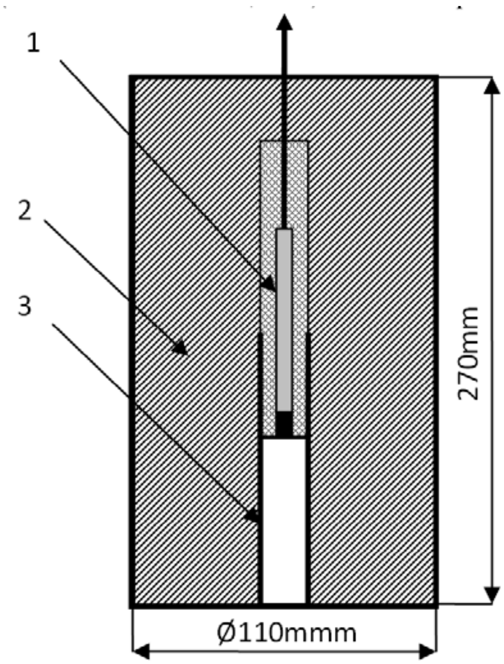


Fig. 1. The scheme and photo of the measuring unit.:

1 - the CZD detector, 2 – the shielding, 3- the protective layer of cadmium.

The measuring unit consists of a semiconductor detector CdZnTe (CZT) crystal with a volume of 20 mm^3 [5,6] placed in a lead shield with a collimator. The housing of the measuring unit is waterproof, made of steel. For visual inspection of conditions of measurements and more information about the object of the measurement unit is equipped underwater video camera. The shielding has a cylindrical shape. Its thickness is 40 mm and the diameter collimator - 20 mm. The inner surface of the collimator has a protective layer of cadmium of thickness 2 mm. This protective layer absorbs the characteristic radiation of lead that occurs under the influence of external radiation from radionuclides. Crystal detector situated on the axis of symmetry of protection and is removed at 120 mm from the bottom surface of the detector unit. Full angle of view of the collimator is 12^0. The total weight of the spectrometer measuring unit is 25 kg. Immersion in water of the device is performed using the hoist, to which it is suspended on a steel cable. Control the orientation of the measuring unit relative to the bottom pond and reactor designs made in the image with an underwater video camera.

SPECTROMETRIC INVESTIGATION OF THE POND STORAGES OF GAS PLANT COMPLEX

The are three storages of spent nuclear fuel in reactor hall of Gas Plant complex. The storage №15, №16, and №26 are ponds with detentions 1,5x1,5x2,5 meters. The storage pond №16 and №26 are divided in 9 cells each by massive bafflers inside for nuclear safety. The cells are closed by protective covers. In some protective covers there are technological hole for overload spent nuclear fuel. Each technological hole is closed by protective covers. Instead the storage pond №15 has not divided by massive baffler into the cell. Figure 2 shows a photo of the storage №16 (top view).

Fig.2 Photo of the storage №16 (top view).

Investigation by video camera of storages, after removing spent nuclear fuel, shows a layer of slime and different constrictive elements (fig.3).

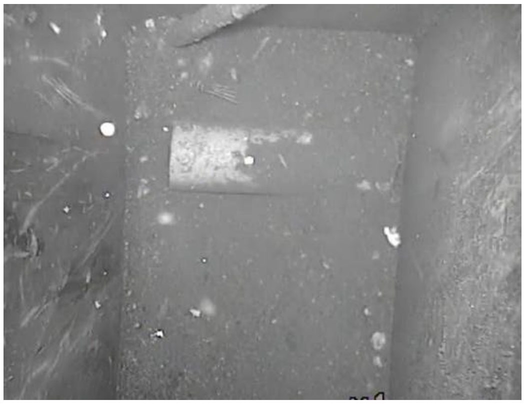
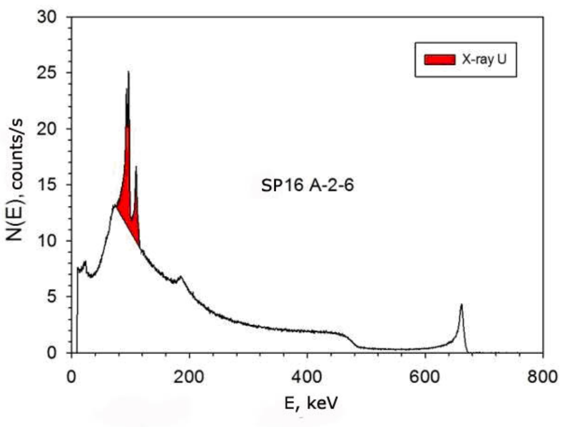
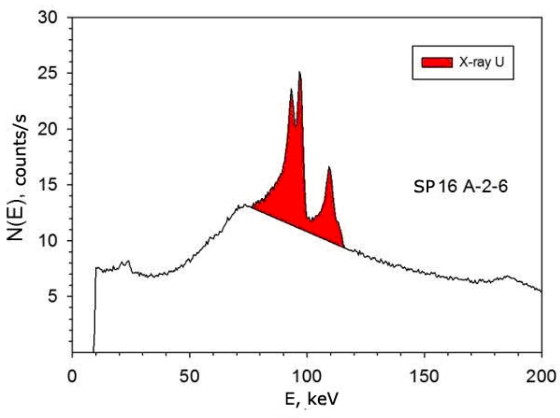


Fig.3 Photo of the storage bottom.

The dosimetric measurements of the storage pond №16 of Gas Plant complex shows a significant increase of exposure dose rate in bottom area in 2 cells (A-2-6 and V-3-2). The radiochemical analysis of water samples from storage №16 shows presence of uranium and plutonium radionuclides. This suggests that components of fuel matrix could be on the bottom of the storage. For determination of exact location and nuclide composition of radioactive sources was made the investigation of the bottom of these cells by underwater spectrometric system. The obtained spectra in measurement of the bottom of cells A-2-6 and B-3-2 are shown in fig. 4 and 5. The red areas marked the peaks of the characteristic radiation of uranium.

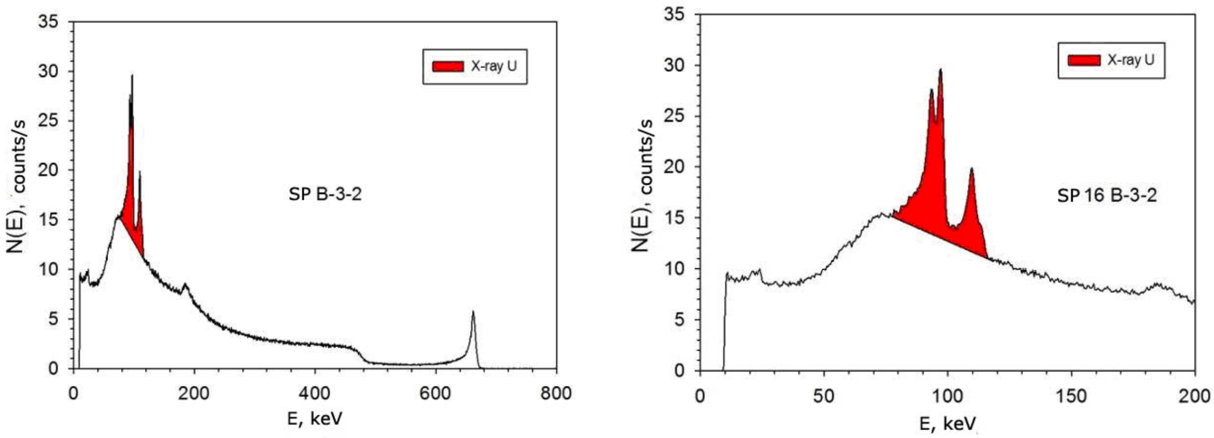


a)



b)

Fig 4. The apparatus spectra from the bottom of cell A-2-6 from storage pond SP№ 16 (a), the low energy region fragment of the same spectrum (b).



a) b)

Fig 5. The apparatus spectra from the bottom of cell B-3-2 from storage SP№ 16 (a), the low energy region fragment of the same spectrum (b).

The measured spectra indicated presence of spent nuclear fuel in these cells of storage №16. Use the spectra from cells A-2-6 and B-3-2 we estimate surface density of uranium in located slime. Evaluation was carried out on the activity of ^{137}Cs (a product of uranium fission) through the calibration factor, which estimate the connection between the value of count rate at the peak of the total absorption of apparatus spectra and the activity of the radionuclide ^{137}Cs. The results are presented in table 1.

Table 1. Evaluation of the surface density of uranium in located slime.

№ of cell	Surface density of uranium, g/cm^2
A-2-6	4,9x10^{-2}
B-3-2	3,4x10^{-2}

RADIOCHEMICAL AND SPECTROMETRIC ANALYSIS OF SAMPLES OF WATER AND SLIME

The samples of water and bottom slime was taken from storage №16 for complex spectrometric and radiochemical analysis. The slime on the bottom of storage pond is a suspension-like of fine particles. The gamma spectroscopy system ISOCS/LABSOCS with semi-conductor detector HPG mod GC1518 and InSpector-200 multichannel analyzer was used for estimate water and bottom slime samples specific activity. The method of radiochemical separation of uranium and plutonium radionuclides for determination its activity was describes in [7,8]. α-spectrum of the prepared target was analyzed with the vacuum Alpha Analyst Integrated Alpha Spectrometer of Canberra company with a semi-conductor passivated implanted planar silicon detector. The concentrations of ^{241}Pu in samples were measured by the highly sensitive spectrometric complex SKS-07P-B11 with liquid scintillator ULTIMA GOLD AB and calculated by the “Liquid Master” software. Spectrometric analysis showed presence in water ^{137}Cs

($1.26x10^6$ Bq/l) и ^{60}Co ($4.12x10^2$ Bq/l) isotopes. The result of γ- spectrometric analysis of bottom slime sample represented in Tab.2.

Table 2. The specific activity of radionuclides in bottom slime in the storage №16.

Isotope	^{241}Am	^{137}Cs	^{60}Co	^{152}Eu	^{154}Eu	^{155}Eu
A, Bk/l	$1.1x10^4$	$1.8x10^6$	$2.4x10^3$	$6.8x10^2$	$3.4x10^3$	$1.5x10^2$

The results of the α- spectrometric analysis of water and bottom slime sample presented in Tab. 3.

Table 3. The specific activity of α-radionuclides in water and bottom slime in the storage №16.

Isotop	^{234}U	^{235}U	^{236}U	^{238}U	$^{239+240}$Pu	^{238}Pu	^{241}Pu
Water A, Bq/l	59	2.1	3.5	2.2	10.3	4.2	9
Bottom slime Bq/g	460	14	31	20.4	10000	4200	42512

There was partly destroyed fuel element in the storage №16 and the fuel particles could present in the water.

After filtration of 1 liter water with slime from bottom of storage pond we could get ~ 10 g dried slime. Using this estimation activity of ^{238}U in wet slime is about 200 Bq/l. Therefore in 1 liter of wet slime there are 16 mg of ^{238}U. The mass of other uranium and plutonium isotopes can be neglected. Thickness of slime layer on the bottom of storage pond is ~ 5 cm.

When we carried out measurements with underwater spectrometric system in its the field of view may be located above 35 cm^3 of this slime. This volume of slime contains 500 µg of ^{238}U.

But in our measurements with underwater spectrometric system surface density of uranium at the pond bottom in cell A-2-6 was $4,9x10^{-2}$ g/cm^2, and in cell B-3-2 - $3,4x10^{-2}$ g/cm^2. The detector field of view was about 7 cm^2 of pond bottom surface during measurements. Thus in this points of measurements we determine 0,35 g and 0,26 g ^{238}U. Therefore except uranium in slime and in water there is presence of fuel particles from destroyed fuel elements on the bottom of the storage pond №16.

CONCLUSION

Radiation investigation of storage pond in Gas Plant complex using underwater spectrometric system was carried out. We determine the location and estimate the surface activity of radionuclide during these measurements. Radiochemical analysis of samples of water and slime showed the presence of the fuel matrix. Comparison of the measurement data obtained using underwater spectrometric system with the results of the radiochemical analysis showed that the particles of fuel from defective fuel elements presence on the bottom of the storage pond №16. The obtained data will be used further in works on the inspected objects.

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