The remote methods for radwaste and SNF control

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Abstract. With the examples of developments carried out in the Kurchatov Institute and by the world leaders in the field the presentation considers the devices and methods to obtain remotely information on the distribution of radioactivity in radwaste and SNF. It describes the different types of light portable gamma cameras. The application of scanning spectrometric systems is considers also. The methods of recording UV radiation for detection of alpha contamination with the luminescence of air are presented. We discuss the scope and tasks that can be solved using remote and non-destructive methods.

1. Introduction
Contactless obtaining the distributions of gamma sources in the form of images as a method of research in medicine and astronomy applied to the 50's. Medical devices called gamma camera [1], astronomical – gamma-telescopes. The first portable gamma camera appeared in the nuclear industry as a finder of lost active sources in the hot chambers [2, 4, 5]. For these applications it is necessary to combine the optical image of detected gamma-emitting objects with the location of gamma sources. Accidents at nuclear power plants and the preparation for decommissioning of nuclear facilities stimulated the work on the further development of such tools [3, 6, 7, 10, 11, 22]. From the time of the accident at the Chernobyl nuclear power plant in Russia began to be used the name gammavizor [10-12]. On the world market there are first commercially produced cameras [8,9,24]. The last two decades were time of the research and development to create a lighter and more comfortable in use cameras [13, 14, 19-21, 27-29]. Finally, in recent years, very compact and lightweight cameras [24 -26] weighing about 2-3 kilograms arisen. Progress in these studies is associated with the use of new semiconductor position-sensitive detectors and imaging on the detector by means of coded apertures.

Developers offer a very wide range of applications portable gamma camera: from the search of lost sources, obtaining the distribution of radioactivity in the objects to protect and control leakage of X-ray inspection. Not all the proposals have an implementation in a regular, everyday work with the devices. It may be noted the successful use of gamma cameras in Russia during the inspection of the objects of nuclear legacy [15] and during the work on the decommissioning of research nuclear reactor [16].

Gamma cameras for nuclear industry are based on different imaging principles – pinhole, coded mask, Compton camera. They use different detectors as a spectrometric [6, 9, 23], and without energy resolution [2, 8, 11, 13-14]. Different cameras may be required for different applications. For example, an effective method of scanning space spectrometry detector collimated with subsequent synthesis of images, sometimes also called gamma-ray imaging, and the gamma camera device. It should be noted first implementation of a portable gamma camera based on the principle of the Compton camera [26].
This camera is characterized by the fact that a measurement in a single position determines the distribution of the flow of gamma radiation throughout the solid angle of $4\pi$.

For widespread use of gamma cameras to work at nuclear facilities must be the recognition of the importance of using them solved problems and of course, price reduction, which is now a relatively large due to the high prices of portable position-sensitive detectors.

The following describes the principle of obtaining the gamma images in a variety of portable gamma-cameras, considered the device camera operating parameters, are examples of the gamma images. We consider the scanning system and the system discussed the scope and tasks that can be solved with the new devices.

2. Imaging principles

For the formation of gamma-image on the detector of portable gamma-camera the principle of the camera obscure, or a method of coded apertures is used. Coded aperture (mask) is a set of transparent and opaque to gamma radiation elements arranged in a particular pattern [3]. It comprises a base structure and an extra portion of the mask pattern which defines the basic design of the structure. Family-based mask patterns URA type often used in practical applications due to the advantages set inherent to said coding apertures family.

Scheme of measurements with using a coded mask is shown in Fig 1. Emitting object X gives the detector image M, which displays modulated (coded) aperture A flux of radiation from the source $M = A \ast X$. To determine the source image must hold its restoration using the inverse matrix C of the matrix apertures $C = A^{-1}$. Then $X \sim C \ast M$.

If the measurement is required field of view (in angular coordinates) $\theta \times \theta$ sterradian, with an angular resolution $- \delta \theta$, then the number of elements of the mask (rank masks) will be $N = (\theta / \delta \theta)^2$. If the number of open cells (holes) in the mask n, the transparency mask is $\rho = n / N$.

What are the possible detectors for use in portable systems? There are two types of position-sensitive detectors which are small enough for use in portable systems: Scintillating with different photo registration (PMT or image intensifier + CCD) and semiconductor based detectors of modern semiconductors operating at room temperature - pixel and stripped detectors based on CdTe. First detectors have a large size and complex management and the second in until recently were not very accessible. Recently, the international research consortium develops detector Medipix2[4] made for him power and control through the USB interface, and this detector has become attractive for portable gamma camera. For CdTe detector with a thickness of 2 mm the sensitivity is evaluated using a simple model of image acquisition [6].

![Figure 1. The scheme of gamma-imaging using coded aperture](image_url)

Gamma radiation of the source is modulated by the mask, and a position-sensitive detector detects that shadow picture - shadowgram, encoded image. The signal from the detector is read out in digital form into the computer. The computer produce a restoration of the image - the original distribution of gamma radiation from the source. This image is displayed on the screen, and to identify the sources of gamma-rays the obtained image is necessarily superimposed on an optical image of the scene. As a result, the synthetic image presents distribution of "activity."
Modern compact position-sensitive detectors have good stability, so after spending the necessary calibration, for the obtained images angular distribution of the dose rate of the incident gamma radiation can be derived. This dose gives an estimate of power from individual partial objects at the location of the camera. Well, then, while continuing to analyze the obvious, knowing (from the spectrum, according to preliminary information) emitting nuclides and spending measure the distance to objects can be calculated activity. The partial dose rate is very important information for the dosimetric characterization of premises, staff work areas.

In many practical problems enough information about the location of the source or nature of the distribution of radioactivity in large objects without quantitative assessments.

2.1. The results of applications
The portable gamma-ray imager was used for solving of different tasks during activity on dismantling of research reactors, remediation of sites, radwaste storage. These tasks include: Location of primary source terms; shielding design and optimization; finding discrete radioactive particles; locating of gamma-ray sources in shipping containers; locating and tracking crud in pipes and valves; tracking sources through time; identifying fuel failures; clean-up verification; determining spatial extent of contamination; filling in blank areas of traditional survey maps; emergency response; decommissioning and decontamination control; differentiating scatter and contamination; after operation contamination control.

In the fig. the results of gamma-ray imaging of packages with HLRW are presented. Main gamma emitter in these images is Co-60.
3. Scanning spectrometric systems
The scanning collimated spectrometric system is presented in fig. 5.

![Figure 5](image)

**Figure 5.** Scanning collimated spectrometric system. Main parts: 1-collimated detector, 2-video camera, 3-control unit, 4-rotator

Maps of activity distribution measured with scanning collimated spectrometric system are presented in fig 6 and 7.

![Maps of activity distribution](image)

Total activity of $^{60}$Co: $2.12 \times 10^9$ Bq

Total activity of $^{137}$Cs: $5.9 \times 10^9$ Bq

**Figure 6.** Results of gamma-ray scanning in a room with contaminated facility. Main gamma emitters are Co-60 and Cs-137.
Total activity of \( ^{60} \text{Co} \): \( 3.67 \times 10^8 \) Bq

Total activity of \( ^{137} \text{Cs} \): \( 2.59 \times 10^8 \) Bq

Figure 7. New distribution of gamma-activity in a room with contaminated facility if main sources are removed in dismantling works. Results of modelling.

4. Remote monitoring of alpha-ray contamination

Remote monitoring of alpha-ray contamination is very important problem for activities connected with decommission of installation of nuclear fuel processing. There are [34-37] some approaches for optical detection of alpha contamination based on measurements of fluorescence of atmospheric air in near ultraviolet (wavelength – 240 – 390 nm) region. Relative intensities of luminescence lines of air for excitation by Cm-244 can be seen in fig.8. CEA group at Marcoule is developing imaging systems based on this method [35, 36]. Large problem in this approach is solar (or other sources) UV background. New UV cameras are suitable for imaging of \( \alpha \)-contamination by fluorescence of atmospheric air the as they are so called solar blind (SB) – they are sensitive to UV this wavelength less 290 nm only and are non-sensitive to solar UV.

Figure 8. Luminescence spectra of air for excitation by Cm-244 source with activity 100 mCi. Numbers under spectral lines are their corresponding luminescence \( \times 10^5 \).

4.1. Application of DayCor SBUV camera

DayCor SuperB UV camera (fig. 9) has sensitivity \( 3 \times 10^{-18} \) W/cm\(^2\) enables detection and displaying corona emission as weak as 1.5 pC at distance 8 m, and capture moving targets without smearing the output image. As discharge energies are relatively high this camera work in TV frame rate mode and have integration up to \( \sim 1 \) sec only. Our estimations [37] show that, that such sensitivity is enough for visualization of strong enough alpha sources without additional updating of industrial SBUV cameras. Thus for a point source of alpha radiation (typical energy of \( E_a = 5 \) MeV) located on distance 3 m
activity for which it can be found out is equal \(10^5\) Bq. Homogeneous surface contamination, which can be detected is 300 Bq/cm\(^2\).

![Image of camera DayCor SuperB and dependence of relative sensitivity of its UV detector on wavelength][38]

**Figure 9.** Photo of camera DayCor SuperB and dependence of relative sensitivity of its UV detector on wavelength [38]

![Images of 3 alpha sources of \(~ 50\) kBq each. Exposure - 10000 sec.]

**Figure 10.** Images of 3 alpha sources of \(~ 50\) kBq each. Exposure - 10000 sec.

5. Conclusions

In result of the study we conclude that technology of industrial Solar blind UV cameras may be used for remote mapping of alpha contamination with reasonable surface activity. First UV images of alpha sources at day light conditions were obtained.

Industrial SBUV cameras CoroCam and DayCor family are suitable for alpha contamination detection and mapping. For a point source of alpha radiation (typical energy of rays \(E_a = 5\) MeV) located on distance 3 m activity for which it can detected is \(\approx 10^5\) Bq. Homogeneous surface contamination, which can be revealed for 300 Bq/cm\(^2\).

At measurements with accumulation of a signal, for exposition 600 sec it is possible to expect, that for a point source of alpha radiation \((E_a = 5\text{ MeV})\) with activity \(3.10^4\) Bq located on distance 3 m the activity will be detected. Homogeneously contaminated surface can be revealed for surface activity 100 Bq/cm\(^2\).

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