

MOBILE SPECTROMETRIC SYSTEM BASED ON LaBr₃(Ce) DETECTORS

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1. Introduction

Decommissioning of objects that pose a radiation hazard or a threat of nuclear contamination, such as nuclear research reactors or storage sites for spent nuclear fuel and radioactive wastes, requires the ecological rehabilitation of the utilized buildings and territories and their free release [1]. If radioactively polluted areas are discovered, decontamination measures to remove the radioactive wastes and recultivation of the contaminated territory are required. The ecological rehabilitation of the territories demands a thorough knowledge of the radionuclide composition of the contaminants, their activity and their distribution inside the boundaries of the territories to be rehabilitated. The same information is required for the ecological monitoring of contaminated territories and radioactively polluted areas such as Chernobyl, Fukushima, etc. [2,3].

Usually the radiation monitoring of industrial and natural territories is done with portable spectrometric equipment using appropriate measurement methods [4-6]. Such measurements provide rather sufficient information on the radionuclide composition of the contaminants, and their distribution by area and depth. However, such measurements are labor-intensive enough, and require essential labor inputs of highly qualified specialists and their time.

Remote aerial mapping of gamma radiation could be of great assistance for the solution of such tasks, but while it allows the measurement of vast spaces, it does not supply sufficiently detailed information, and thus does not correspond to the requirements for the preparation works in ecological rehabilitation and release [7]. Moreover, the remote aerial mapping is sometimes complicated by industrial buildings and low detection efficiency due to the long distance between detector and the object.

The present work shows the results of the development of a mobile spectrometric system based on a LaBr₃(Ce) spectrometer intended for measuring the energy distribution of gamma radiation and the identification of gamma radionuclides, as well as for defining the specific and surface activity of gamma radionuclides in natural occurrence, distributed over large areas, locally, in urban housing and industrial zones, as well as on open natural territories. The application of such a mobile radiation system is invaluable for their ecological rehabilitation and control release.

2. Mobile Device

An upgraded and refitted electric car was used as the mobile vehicle for our system. Wide wheels with a large diameter (52 cm) were fitted to the car to increase the ground clearance up to 26 cm and improve its cross-country capability. A powerful battery provides a working time of over 6-8 hours in standard measurement mode for the mobile spectrometric system. A reduced gear system has been developed and installed in the electric car to provide a motion rate from 0,5 to 5 km/h during the measurements (slow mode). To implement an homogeneous gamma-mapping while the electric car is in motion, an additional cruise control module has been installed. With this module, the electric car is able to move with a speed of 5 – 25 km/h (fast mode).



Fig. 1. Mobile spectrometric system

A configurable mount was designed to deploy the detectors to the chassis of the electric car in vertical or horizontal positions as needed (Fig.1). The detectors point downward for *in situ* measurements and sideways to evaluate the activity and dose rate in hazardous objects (containers, barriers etc.). The design of the mount allows changing the distance between the detector axes from 500 to 1200 mm and between the surface of the detector casing and the ground from 250 to 600 mm.

A *Leica* navigation system with a screen for route programming has been chosen as a positioning-geolocation system. The antenna of the positioning system is located between the detection units on longitudinal axis of electric car. The accuracy of navigation system's geolocation is better than 0.5 m and is secured by RTK (real time kinematics) - correction technology.

3. Spectrometer

The spectrometer consists of two scintillation detectors based on $\text{LaBr}_3(\text{Ce})$ crystals dimensions $\text{Ø}51 \times 51 \text{ mm}$ (Saint-Gobain) and R62331 photomultipliers (Hamamatsu). Shaped signals of the detectors are analyzed by a two section multichannel analyzer. The gain adjustment of the spectrometric sections is automated mode in software. As two reference spectra sectors we have used inseparable peaks in the energy region of 32-37 keV and 1436 keV from the impurity ^{138}La , which is permanently present in the background spectrum for the present crystal type. Relative energy resolution of the spectrometer for the gamma-radiation line of the radionuclide ^{137}Cs with energy 661.7 keV was $\leq 3.1\%$; the integral nonlinearity over the range of gamma-radiation energies from 40 to 3000 keV was $\leq \pm 0.4\%$.

To provide the operation of the spectrometric system over the temperature range -40 to $+60^\circ\text{C}$, the detection units were placed in a specially designed, thermostabilised housing with built-in heat exchangers and thermal sensors, which provided protection level IP54 against climatic

conditions. The end face of the housing has carbon windows to reduce the minimum possible detectable energy for gamma radiation to 40 keV. The registration efficiency of the detection unit (in its thermos-stabilized housing) in gamma radiation from the full absorption peak of the radionuclide ^{137}Cs with energy 661,7 keV emitted from a point source 5cm from the detector window was $\geq 0,6\%$. To measure local pollution areas, the detection units could be supplied with tungsten (or lead) collimators, which are fixed directly on detector housing. The geometry obtained there provides a measurement area of approximately 0.25 m^2 .

A protected, shockproof notebook computer (GETAC) was used as the control panel for the spectrometric part of the system, and it was placed in a special rotary holder above the panel of the electric car to the right of the driver's seat. The holder stabilizes the computer during the motion while making it easy to remove after the operation. The spectrometric system control structure is based on the minimization of wire connections at the operator location and the application of wireless technologies for all system component connection (notebook, navigation device and router with spectrometer cable connected).

4. Software

The software package TRIO-MAP, which is a modified version of the basic software GMAP [8], was developed for the spectrometric system. The software was developed in cooperation with the Emergency Technical Centre (S-Petersburg, Russian Federation) and has been tested in real-life environments at various contaminated territories. The TRIO-MAP software provides the following basic functions:

- control of the spectrometer (measurement start and stop, spectrum reading);
- spectrometer adjustment (amplification adjustment, spectrometric section parameters);
- data acquisition from the navigation device (time, local and global coordinates, velocity, course, etc.);
- spectrum acquisition visualization and processing functions (peak search, peak area calculation, radionuclide identification, etc.);
- calculation of values and their uncertainties (activity (specific and surface), compliance factor, ambient dose rate equivalent);
- sound alarm at dose rate above threshold;
- fast display of measurement results in tables and on the map, as well as color coding to compare levels of each radionuclide;
- recording results in a file and data base;
- reporting and transferring data transfer to external programs (Excel etc.).

The TRIO-MAP software calculates the specific activity in (Bq/g); the surface activity (Bq/cm^2); the minimal detection activity (MDA), the ambient dose rate equivalent ($\mu\text{Sv}/\text{h}$); the compliance factor, which shows the level of permissible free release from the monitoring territory. Additionally, it displays the local (ETRS89) and global (WGS84) coordinates and electric car speed.

The obtained results are plotted on the map as so-called layers. Also, the association of actions with the table and the map provides, for example switching between layers, selection of the marker of a measured point. The location maps themselves could be loaded in automated mode from the corresponding Google data base through an internet connection. Alternatively, the maps could be loaded in advance with the free software SAS Planet (see. Fig.2) [9].



Fig.2. Software interface with plotted measurement points on the common display and Google maps.

TRIO-MAP allows measurements in two adjustable modes, dynamic (operative estimation of the situation during movement) and static (careful measurement on a point without movement). One of the advantages of the TRIO-MAP software is its ability to interface with various spectrometric devices thanks to the separation between the operation and spectrometer modules (data exchange and individual settings) from the module that provides the calculations, visualization and display on the map.

5. System Calibration

Calibration of the mobile spectrometric system was performed using the certified software MCC-MT [10,11], which provides calculation of the standard radionuclide spectra and values of the registration efficiencies by the Monte Carlo method, using a geometric model of the device. (see Fig.3). The obtained standard spectra are applied to compile a sensitivity matrix (calibration file), which is the basis on which the software calculates the activities using standard methods (matrix method). Also, there is ability to calculate the radionuclide activities by analyzing separate peaks, applying efficiency curves.

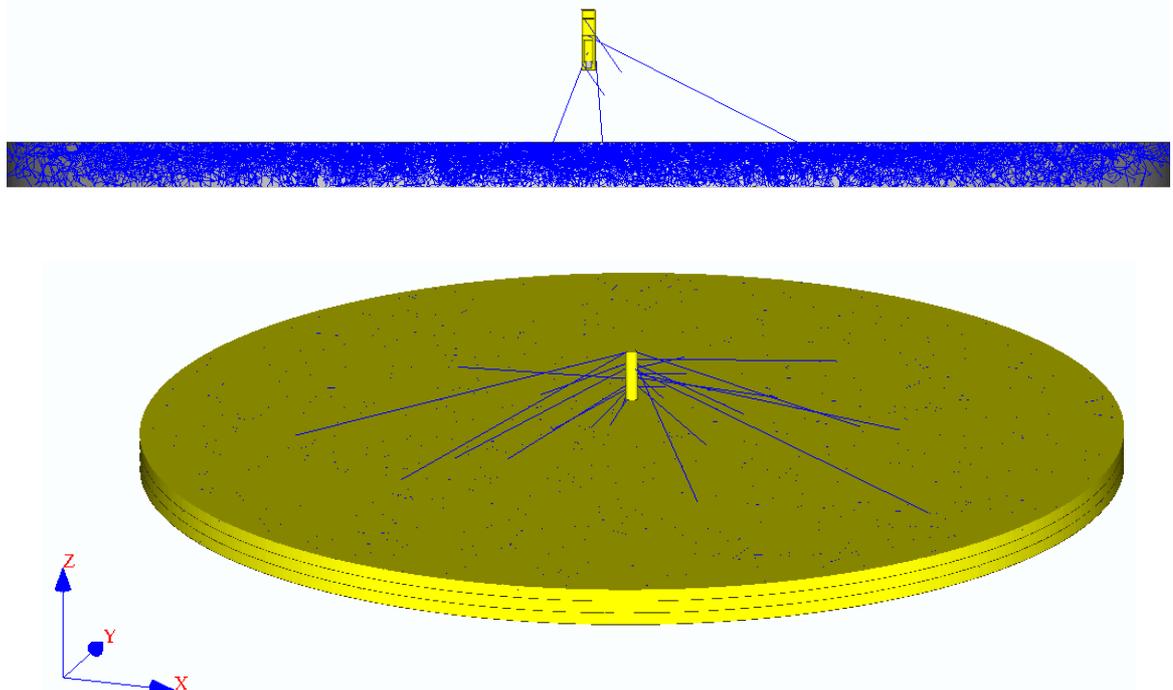


Fig.3. Measurement geometry model, made in the software MCC-MT

The standard calibration of the mobile spectrometric system contains the data for the calculation of the surface activity of anthropogenic radionuclides Cs-137, Cs-134, and Co-60 in fresh and old fallouts; specific activity of natural radionuclides Ra-226, Th-232, and K-40. The extended uncertainty in the surface activity measurement results does not exceed 30% ($k=2$) [12].

Tables 1 and 2 show measurement ranges of the surface and specific activities of the main radionuclides. The limit of the acceptable main relative error of the activity measurement does not exceed 50% ($P=0,95$). The measurement time for one point is 300 s. The detectors are positioned perpendicular to the ground surface.

Table 1. Measurement range of radionuclides surface activity

Measurement geometry (Distance between detector and ground surface, cm)	Measured radionuclide	Activity measurement range, Bq/cm ²
25	¹³⁷ Cs	0,035 – 1300
	⁶⁰ Co	0,021 – 650
	¹³⁴ Cs	0,024 – 500
40	¹³⁷ Cs	0,04 – 1400
	⁶⁰ Co	0,023 – 720
	¹³⁴ Cs	0,025 – 560
60	¹³⁷ Cs	0,046 – 1600
	⁶⁰ Co	0,028 – 820
	¹³⁴ Cs	0,028 – 620

Table 2. Measurement range of radionuclides specific activity

Measurement geometry (Distance between detector and ground surface, cm)	Measured radionuclide	Activity measurement range, Bq/cm ²
25	¹³⁷ Cs	from 0,0074 to 125
	⁶⁰ Co	0,0034 – 50
	¹³⁴ Cs	0,005 – 50
	⁴⁰ K	0,19 – 930
	²²⁶ Ra	0,01 – 50
	²³² Th	0,013 – 40
40	¹³⁷ Cs	0,0086 – 130
	⁶⁰ Co	0,0038 – 55
	¹³⁴ Cs	0,0054 – 55
	⁴⁰ K	0,20 – 1000
	²²⁶ Ra	0,01 – 50
	²³² Th	0,014 – 45
60	¹³⁷ Cs	0,0090 – 1300
	⁶⁰ Co	0,0040 – 650
	¹³⁴ Cs	0,0055 – 500
	⁴⁰ K	0,21 – 500
	²²⁶ Ra	0,01 – 50
	²³² Th	0,015 – 50

6. Conclusions

The results of the present work demonstrate that rapid developments in information technologies, the appearance of portable computers, modern navigation equipment, measurement and data transfer devices today make possible the development of mobile measurement systems that are able to execute the required radiation measurement as well as preliminary analysis, visualization, mapping and data transfer in real time. Thanks to high energy resolution and high registration efficiency of gamma radiation, LaBr₃(Ce) detectors are perfect for the development of such devices.

7. References

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