EVALUATION OF THE PARAMETERS OF RADIOACTIVE CONTAMINATION OF SOILS

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ABSTRACT

After Chornobyl NPP (ChNPP) accident the territory near destroyed Unit 4 (that now with the special confinement has the name the "Shelter" object) is contaminated of fuel fallouts. During liquidation of the accident consequences this territory was covered with pure earth, concrete, etc. As a result a contaminated anthropogenic layer of the soil on the depth up to 10 m was formed. Now the problem of contamination estimation and the soils management arose. For this tasks a gamma logging method was modified conformably to ChNPP conditions. The methods for necessary coefficients receiving and log treatment have been suggested.

INTRODUCTION

Due to uncontrolled disposal, anthropogenic soils layers near the "Shelter" object contain significant amounts of radioactive materials and belong to Type I–III radioactive waste [1]. Optimal engineering solutions for excavations for building foundations, as well as radioactive material removal, are possible if reliable data exist on the amount, spatial distribution, specific activity and other contamination parameters. Gamma logging is one of the methods for evaluation of radioactive material distribution in the soil. Quantitative processing of gamma logging results allows obtaining not just data on exposure dose rate of radioactive layers but the specific activities of radionuclides in them as well. The theory and methods of gamma logging data processing [2, 3] has been developed for uranium deposits. Since cesium is now the major gamma source in the Chornobyl NPP area, modification of the standard method [2] is needed to determine its amount from gamma-logging data. To solve this problem, we have carried out experimental measurements on well models [4] and, basing on these, have developed a method of gamma logging data processing adapted to the conditions of the Shelter's local area.

Contamination of the territory make conditional mainly upon quantity of dispersed fuel, that fall out during accident. There are some ratios between isotopes quantities that were accumulated in active zone of ChNPP Unit 4 [5, 6] that are determined by burn up rate. With some correction, taking delay into account, they are confirmed by soil sample analyze [7]. Among gamma emitters in 15 years after the accident ^{137}Cs have 98-99 %. Therefore they believe that knowing the quantity of cesium gives the possibility through correlation coefficients to determine the bulk activity of soils.

EXPERIMENT AND DATA TREATMENT THEORY

As usual, we assume that the density of radiation sources is uniform within a horizontal layer and changes only with depth (which, as shown in [1], fits the geological profile of the local area). The result of exposure dose rate (EDR) measurement at some depth h_0 in the well may therefore be defined as the integral by depth of contributions from all layers:

$$M(h_0) = \int_{h_{\min}}^{h_{\max}} \varphi(h - h_0) A(h) dh \quad , \qquad \text{(Eq. 1)}$$

where $M(h_0)$ is the measured value of EDR, $A(h)$ is the activity to be determined, $\varphi(h-h_0)$ is the device function of the measuring system. With the assumption of horizontally layered structure of the medium, $\varphi(h-h_0)$ describes the contribution of different layers to the total signal.

To determine experimentally the coefficients linking EDR and activity, models of wells were created. A model well was a sand-filled reservoir, which was close to the real ground composition. A pipe casing, where the sensor of the measurement system was installed, was placed in the center. Thin aluminum tubes, in which a point source of ^{137}Cs could be placed at different altitudes, were placed around the pipe casing. In the case of a point source, the measured EDR M and the source's activity are linked by a simple relationship $M=K \cdot A$, where K is a coefficient that depends on the conditions of the experiment. Measurements of M in a model well with fixed placement of the detector and variable placement of the point source (by height and distance) allowed us to obtain the magnitude and profile of K. This, in turn, allowed obtaining the summary coefficient for an infinitely thin layer with uniform activity. The result of calculations for different layers shows that the contribution of a layer K_h diminishes smoothly with distance between the layer and the center of the detector.

Noting that the measured gamma signal is a sum of signals from sources located within a limited volume around the detector, the movement of the detector along the well may be presented as scanning of an altitude-dependent physical variable by a limited-bandwidth system. In this case, the gamma logging data vs. depth curve may be treated similarly to a spectrum recorded by a system with its own device function. Therefore, the problem of gamma logging data processing is reduced to a standard problem of spectroscopy, i.e. determination of the true spectrum by accounting for the effect of the device function of the measurement system. We attempted to solve Equation (1) by numerical modeling, noting that the experimental values of K_h determine the device function $\varphi(h-h_0)$. The solution is based on Fourier transform. It is known [8] that Equation (1) may be transformed into:

$$M(\omega) = \varphi(\omega) \cdot A(\omega) \quad , \qquad \text{(Eq. 2)}$$

where $M(\omega)$, $\varphi(\omega)$, $A(\omega)$ are Fourier transforms of the respective functions in Equation (1). Thus, knowing M and φ, it is possible to determine the function $A(\omega)$, and find out the function in question $A(h)$ by means of inverse Fourier transform.

The usability of the program developed for numerical modeling was determined on test functions. Using the fact that the calculation method is based on Fourier transform, the random noise [which is a major concern in solving inverse problems of the type presented by Equation (1)] was removed by a Butterworth-type filter that removed high frequencies. As a result of this

procedure, a restored function was obtained which fitted the original function satisfactorily. The results of modeling and calculations are presented in Fig.1.

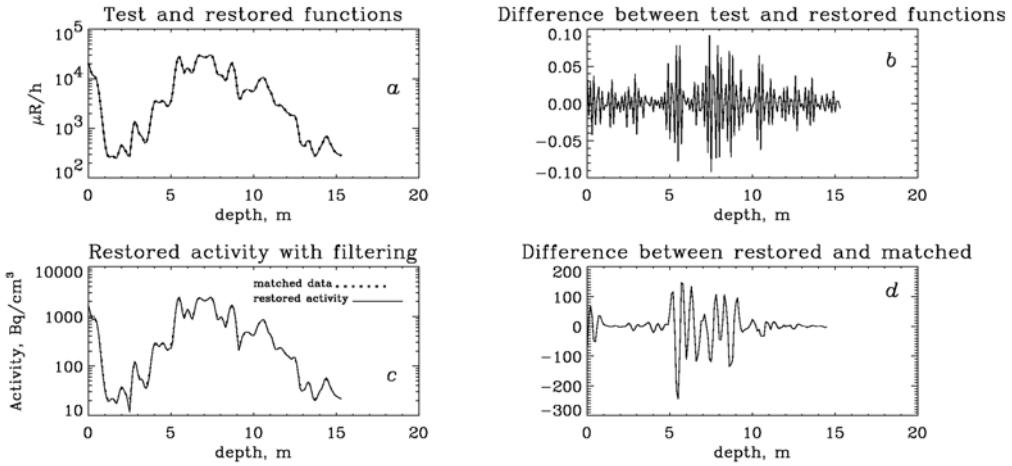

Fig. 1. Results of Modeling and Calculations

Fig. 1a shows the experimental depth profile of EDR obtained by gamma-logging. It was used as a test curve for method demonstration. One may see that the peak in the 5–10 m depth interval is so big that changes of the profile in the remainder of the depth range are not visible on the chart scale. Therefore results are presented in logarithmic scale. The dotted line on Fig. 1a shows the results of test calculations, namely, the same function and the result of its restoration after convolution with the device function. Fig. 1b, where the difference between the test and restored functions is shown, indicates that the method produces practically unique restoration of the original function. The software tested in this way was used to recover the true values of activity from EDR measurements obtained by gamma logging. The solid curve in Fig. 1c shows the result of the *A(h)* function restoration from the experimental data (Fig. 1a).

The developed method of calculations also allows rough express evaluation of activity amount from the EDR measurement data. As seen in Fig. 1a, functions *M* and *A* have sufficiently matching shapes, so that one of them may be obtained from the other by simply multiplying by a constant factor *k* instead of solving the inverse problem [Equations (1), (2)]. It is only necessary to evaluate quantitatively the resulting error.

If we are interested in the total activity amount of ^{137}Cs, which is determined by the area under the curve, the factor *k* should be selected so as to minimize the difference in areas under the curves of EDR and activity. The smallest (practically zero) difference occurs at $k_{min} \approx 0.033$. This value was used for EDR evaluation plotted in Fig. 1c (dotted line). The difference between restored and estimated (by multiplication) values does not exceed 10%, as shown in Fig. 1d.

A direct test of the developed method was performed in a special experiment. A model well was created with a pipe casing in the center, in which the detector could be moved. At a certain depth, a layer of sand with a given specific activity of ^{137}Cs was formed. The specific activity of ^{137}Cs, calculated using the proposed method, was in satisfactory agreement with the true value.

CONCLUSIONS

The method for determination of ^{137} Cs specific activity, and using correlation an activity of others radionuclides too in soils of local zone of "Shelter" object and industrial site of ChNPP have been developed. The method is based on treatment of wells γ-logging data and takes into account the conditions of the Shelter's local area. The necessary for direct solving of Equation (1) coefficients were received from experimental measurements on the wells models.

The developed method gives the possibility to estimate a nuclear fuel quantity, that have fallen on the surrounding of emergency unit territory and were disposal in anthropogenic soils.

The method can be used also for control of ^{137} Cs contamination around radioactive wastes disposals and repositories.

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