COMPUTATIONAL ALGORITHMS
IN VEHICLE RADIATION MONITORS

Yu. I. Skorik

The present paper considers the analysis of measurements performed with automatic stationary vehicle radiation monitors, which are intended for discovering radioactive materials being illegally transported in moving automobiles. The instantaneous analysis of measurements — background measurements and measurements performed while monitoring controlled objects — includes the calculation of functionals in successive exposures using rules for making decisions about the results of monitoring. The most widely used and inexpensive portal variant of monitors, which includes two ground-based stands containing \( \gamma \)-ray detectors, is considered. The signals from all detectors are summed. The monitors are equipped with a presence detector, which automatically starts up and stops the monitoring regime.

The objective of this investigation is to develop simple and convenient algorithms that require the minimal computational base and that increase the threshold sensitivity of monitors by taking account of and adequate compensation of the screening of the natural radiation background by moving objects and the dip in the background detected instrumentally. Compensation of such dip by means of logical programs is one of the most often discussed and important problems of portal vehicle monitors, since this physical effect greatly decreases the sensitivity of a monitor [1, 2]. The threshold for adopting a decision is almost always set according to the undisturbed radiation background in the absence of objects, and therefore a large quantity of radioactive materials is required in order to exceed this threshold under conditions when a dip is present in the background as a result of the presence of objects. The decrease in sensitivity is observed by comparing the dip in the background (~ 4–27% [1–3]) and the threshold — the excess due to the additional effect recorded by the monitor, which can reach ~ 4% [4, 5]. The simple method for decreasing the influence of this physical effect — increasing the aperture of the monitor gates — results at the same time in a degradation of sensitivity because of the large distance between the detectors and the radiation source [1, 2, 6].

Existing algorithmic methods for taking account of and compensating for the dip in the background are limited and ineffective because of the large variations of this effect [1, 2, 7, 8]. Even for vehicle monitors with the detectors placed under ground, where the dip in the background is much smaller (on the average ~ 3%) and substantially more stable, only ~ 1% of the effect can be compensated; this is also characteristic for pedestrian portal monitors with a dip ~ 1.5% in the background. There is no concrete information about whether or not this physical effect is compensated in commercially produced vehicle monitors. American standards documents do not stipulate the setting and regulation of the false-alarm level. This could be due to the fact that the dip in the background is taken into account. During operation, only the level can be checked [9]. On the basis of investigations of many variants for overcoming the difficulties discussed, in [2] it is concluded that there are no simple solutions.

Complicated solutions have been obtained for automobile and railroad car monitors for objects which depress the background by up to 30–40% [4, 10]. Here highly sensitive detectors detect a ~ 4% excess above background. Using signals from organized light barriers, which reveal the structure of the objects, statistical filtering is performed with established thresholds adapted to the profile of the dip in the background. The velocity of the objects can be measured with a resolution of ~ 0.8 km/h. The duration of the analysis of each subsequent measurement is less than 0.1 s; all data are stored in a ring memory. Multilevel graphical information is displayed on a monitor and the operator makes decisions about alarms visually. The functional possibilities are implemented using remote central (built-in) grid processors at least of th class PC AT 486 DX 66/2 with 8 MB of RAM. It is obvious that this system of measures for compensating the dip in the background is complicated, expensive, and specific.

The simple known algorithms for making decisions automatically are based on tests of moving sums (or averages) of the detected count over unit subintervals in accordance with the Neiman—Pearson criterion [11, 12]. The count thresholds cor-
responding to a prescribed false-alarm probability $P_{fa}$ (an error of the first kind in adopting a hypothesis that an additional effect is present if it is absent) are established. A digital exponential smoothing filter over several measurements is used [13]. The triggering thresholds in this case are obtained a priori. The measurements are processed in the simplest manner, since a large volume of data in memory is not required. However, such algorithms are more sensitive to fluctuations of the highly variable background. According to the results obtained from natural tests of pedestrian monitors with such algorithms, the efficiency (detection probability $P_d$) with the same value of $P_{fa}$ is approximately equal to the possibilities of the moving sum method.

Modern algorithms are based on a systematic analysis of the Wald likelihood ratios (see, for example, [14]). The sum of functionals of measurements, taking account of $P_d$ and $P_{fa}$, is calculated at each unit time interval and compared with two previously determined thresholds for accepting the hypothesis of the background or of the background together with the additional effect. If a decision is not made, then the next observation is considered. In contrast to other types of algorithms, in which the total duration of the tests is fixed, here the duration of the tests is variable and on the average shorter than with the same value of $P_{fa}$. Here lies the important advantage of this approach in application to pedestrian monitors in the examination of a stationary object [15] as well as for monitor stations (examination of a stationary automobile), for which this group of algorithms was developed. In the last application, the efficiency of the algorithm is approximately equivalent to that of the single-interval method [7]. For monitoring moving automobiles, this algorithm is no worse than other algorithms [15]; for pedestrian monitors it is approximately equivalent to using a moving sum [7, 13], which has also been confirmed by experience gained over 10 years of using this method [6]. Compared with other types of algorithms, systematic analysis requires more complicated analysis of the results. Functionals of the measurements contain quadratic forms. The use of linear functions, based on Poisson’s statistics, in some cases should probably degrade the efficiency of the algorithms, since experience in operating pedestrian monitors has shown that the probability distribution can differ from the Poisson law and even from the Gaussian law [15, 16]. The calculation of thresholds is more complicated. For a fixed duration of the measurements, forced solutions are required, if the presence or absence of a radiation source has not been fixed. If a decision concerning the background is adopted too early, the tests must be performed again with a penalty for possible lost false alarms [17]. A large volume of data must be stored in the working memory [8]. It is also necessary to overcome difficulties due to the enhanced sensitivity of algorithms to short-scale electronic noise, which is averaged better in other algorithms [17]. Successful practical implementation of algorithms of this type in monitors requires the use of a microprocessor [8, 18]. A controller with such a processor was developed in the USA for automobile stations, in which the advantages of a systematic analysis are greater. The unified version of this computer has been used in portal pedestrian and automobile monitors, including with neutron sensors, as well as in other types of systems [3, 14].

It follows on this basis that it is possible to develop simple and convenient algorithms for automatic operation of portal automobile monitors, in general, on the basis of all the algorithms considered, the efficiency of the latter algorithms being comparable and each can serve as a sample for comparison.

Evidently, the algorithms must be developed and optimized in accordance with information about the profiles (along the objects) of the dip in the background, encompassing the most complete set of types of objects. Profiles from more than 10 different objects were measured for the development of the American automobile monitors. Even for pedestrian monitors, in which compensation of the dip is less important, about 10 different objects were investigated earlier [13], and in addition an algorithm of a new type, taking account of the average characteristics of each potential pedestrian, is under development [6].

The investigations performed depend on information about a small number of real and model objects, differing in length and depth of the dip in the background. The experimental profiles of instrumental distributions of the effect from several different compositions of radioactive materials on the whole agree with existing information [1, 2]. Sometimes the characteristic features on the wings of the distributions differ, which can probably be explained by subtleties in the structure of specific types of automobiles.

The following processes and parameters were modeled and taken into account in the development, optimization, and assessment of the efficiency of the algorithms:

- the instrumental profiles of the counting rate for both the background together with its dip and the distribution of additional effects combined with the background with the velocity of the objects in the range 7–15 km/h;
- variants of the relative arrangement, along the objects, of profiles of the background and the effect and different levels of effects while maintaining the shape of the temporal distribution;
- repeated ensembles of random realizations (over each pass) of the instrumental count in single temporal subintervals as a function of the indicated profiles of the mathematical expectation of the counting rate;
- moving sum of the random count (for modeling the operation of the standard algorithm).