DOSIMETRIC CONTROL SYSTEM FOR A NUCLEAR ELECTRONICS TRAINING LABORATORY

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Analyzing the specific nature of working with radioactive sources in the Nuclear Electronics training laboratory we have formulated the precise requirements for the Dosimetric equipment. It has been proven that the stipulated requirements could be met by a dosimeter, functioning by the spectrum weight function method, using a NaI(Tl) scintillation detector. The provided simulation and experimental data confirms the aforementioned conclusions.

Keywords: dosimetry, SWFM, NaI(Tl) scintillation detector

1. INTRODUCTION

1.1. Prior Research

The dosimetric measurements are an essential branch of the ionizing radiation metrology, directly linked to the human safety and the quality of the environmental 0,0. In the Nuclear Electronics Laboratory of the FETT, at the TU – Sofia, we show specific interest in that matter. All measurements that have been carried out so far were aiming at the calculation of the absorbed dose from logarithmic spectral data 00, temperature stability of scintillation detectors with NaI(Tl) crystals 0, methods for mobile detection of low-activity radioactive sources (with levels close to the natural background radiation) 00.

In the course of the experiments, intended to define the dosimetric parameters from logarithmic spectres, the conditions made it possible to conduct also some measurements by the spectral weight function method (SWFM) 0. Main advantage of the second method is the express gaining of results, as well as much simpler schematic solutions.

1.2. Motivation and Goals

At this moment, in the Nuclear Electronics Laboratory for dosimetric control are used dosimeters and intensionmeters, built up from Geiger-Mueller detectors. The extremely low activity of the used isotopes, necessitate the use of highly sensitive dosimetric equipment, which could be used as a means of dosimetric control in the training laboratory.

The goal is to build up an equipment that will be used in the Nuclear Electronics training laboratory for systematic dosimetric control and test its metrological characteristics.

2. PROBLEM STATEMENT

2.1. Evaluation of the Specific Conditions

In the construction of the dosimetric control system in the Nuclear Electronics training laboratory have been taken into consideration the specific prerequisites for work with radioactive sources (RS), which reflect on the equipment requirements. The latter can be summarized to:

1. The laboratory work should be conveyed only with "closed" RSs. There is no need of measuring α-sources, including Radon, as well as of surface β-contaminations. No roentgen and neutron sources should be used. This leads to some limitations regarding the technical requirements for the dosimetric equipment – it is only necessary that it can measure γ-rays.

2. All RSs used should have extremely low activity. The dose capacities they generate are very low and comparable to the natural background radiation. This particularity lays down some requirements for the sensitivity of the equipment and implies the use of highly effective detector systems.

3. All measurements should be conducted in laboratory environment – i.e. within a small temperature range. Thus all problems caused by the detector systems' temperature dependency.

4. Distinctive feature is the episodic character of the work – a student will need to work 5, or 6 times with a RS during the course of a school year. The extremely low activity and the character of the used sources make unnecessary the use of individual dosimetric monitors. The optimal solution in this case is the continuous measurement of the dose rate during work and of the natural gamma- background when it is over.

2.2. Dosimetric Equipment Requirements Layout

The specific conditions under which the classes are carried out in the laboratory allow for the particular dosimetric equipment requirements to be defined. They are the following:

1. Continuous registration and archiving of the dose rate values, thus allowing for later retrospective analysis of the occurring events. The organization of the data massive should exclude any possible manipulation.

2. Automatic registration and storage into a long-term archive of the equipment power-on and –off time-stamp.

3. Presence of an alarm channel – audio and light – that will turn on when a preset level of the temporary value of the dose rate is exceeded.

4. The applied measurement method should have high precision and sensitivity, as well as guarantee the fast retrieval of the measurement results – within several seconds to a minute.

5. The system should have an embedded procedure for precise energy calibration of the detector system.

2.3. Evaluation of the possible applications of the existing dosimetric methods

Despite their vast variety, the dosimetric methods and equipment could be divided into two groups – *radiometric* and *spectrometric* 0.

With the *radiometric methods* the dose is calculated based on the radiation flow, and the dose rate – from the measurement of the density of the flow. The dosimeters 0, are assembled by a radiation detector and a single-channel registration device (analog or digital) with its corresponding controls. As radiation detectors for this type of measurements are used mainly ionizing chambers, Geiger-Moeller counters and scintillation detectors. Their major disadvantage is the low sensitivity and the insufficient precision.

The absorbed dose can be estimated noticeably more precisely with the *spectrometric method*, due to the fact that taking down the amplitude spectre of the signals from the detector we have data for the number of registered γ -quanta and their energy distribution.

From the existing spectrometric detectors – proportional gas counters, scintillation and semiconductor detectors, the most appropriate for dosimetric measurements are the scintillation detectors, although they have the lowest energy resolution. The reasons for his are:

- The proportional counters are relatively slow and have short life;
- The semiconductor detectors are very expensive and require special operational conditions – low temperature, liquid nitrogen maintenance;
- For dosimetric measurements is not needed very high energy resolution.

Those factors determine the choice of the NaI(Tl) crystal scintillation detectors as optimal solution for dosimetric purposes. They are fairly common and are not too expensive. There are no particular requirements for their exploitation and have good energy resolution – 8-10%.

In order to define the dose rate from the energy spectre there is needed a single-channel spectral analyzer, which is an expensive and precise piece of equipment. Statistically significant results can be obtained only through continuous (several minutes) spectre accumulation. This makes impossible the definition of the dose from spectrometric data for the current application.

2.4. Spectrum Weight Function Method

The Spectrum Weight Function Method (SWFM) has been developed in the Japanese Atomic Energy Research Institute *(JAERI)* in 1965 0. The weight function *G(E)* has been introduced, relating the absorbed dose *D* to the impulse spectre by the equation:

$$D = \int_{E\min}^{E\max} F(E).G(E)dE$$

where *F(E)* is the spectral distribution in the energy range from $E_{\min}$ to $E_{\max}$.

If the weight function *G(E)* is replaced by *G(t)*, the method can be realized with relatively simple hardware. The dose rate is measured throughout a defined time

interval T, in which the level of discrimination of the integral amplitude discriminator is changing from a defined minimal value to a certain maximum value, corresponding to *G(t)*. The total number of impulses N_{tot}, accumulated in the registration unit in the meantime will be:

$$N_{tot} = \sum_{t_1}^{t_2} N(t).G(t)\,,$$

where *N(t)* is the sequence of input impulses (with various amplitude!), incoming during the measurement time $T=t_2-t_1$. The physical meaning is that in this way the impulses with higher amplitude (corresponding to γ-quanta with higher energy) are measured longer and have bigger contribution in the total number of impulses N_{tot}. In this case for the dose rate is valid:

$$P_D = k_S \frac{N_{tot}.E_{\max}}{T},$$

where: k_S is a coefficient, reflecting the mass of the detector

$E_{\max}$ is the maximum radiation energy, corresponding to the highest temporary value of *G(t)*.

With the form of the weight function *G(t)* is compensated the effectiveness of the detector system for emissions with different energies. For the calculation of the мощността на дозата, absorbed in the volume of the detector, is used the linear change of the integral discriminator's discrimination level 0. For the determination of the air kerma K_a, or the ambient dose *H**(10), the discrimination level change function is more complex, reflecting the different correlations due to the photo-effect and the Compton effect on the air and the scintillation material and etc 00.

3. RESULTS

3.1. SWFM Simulation, based on the spectrometric data

A calculation procedure has been applied on spectrometric data, gathered with a logarithmic spectral analyzer, that simulates the data registration, corresponding to the spectrum weight function method. The detector system has been calibrated against the spectral lines of the radioactive isotopes of ^{241}Am (59,6 kEV) and ^{60}Co (1,17 и 1,34 MEV). A criterion for the accuracy of the binding is the resulting position of ^{137}Cs. On Fig.1 is shown the differential spectre of the natural radioactive gamma-background and the reduced data distributed by channels, based on the spectrum weight function. A linear correlation has been used for the modulation weight function and the resulting data corresponds to the absorbed dose in the detector volume (scintillator). The correlation between the

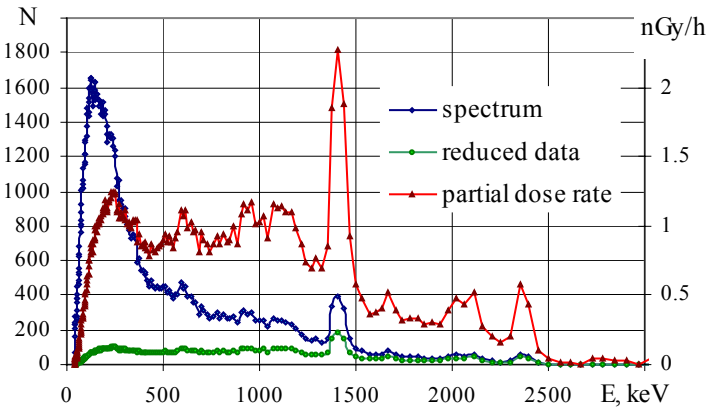

Fig.1

partial dose rate and the energy of the registered radiation is also shown. The value of the dose rate, derived from this data using the spectrometric method is 142,66 nGy/h, and using the spectrum weight function method – 141,28 nGy/h. The advantage of the spectrum weight function method is in the fact that the total number of registered impulses is proportional to the dose rate. This gives the opportunity to get to the final result through a much more simple calculation procedure.

3.2. Structure of the dosimetric system

In order to provide environment for the conveying of a more precise detector energy calibration, the dosimetric system is realized following a structural scheme,

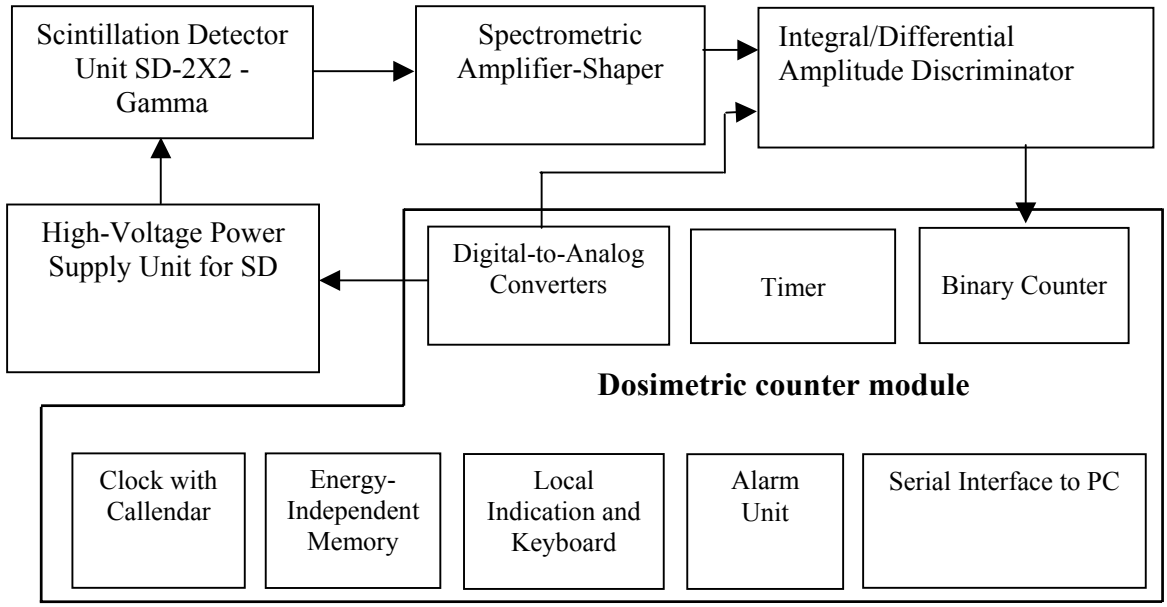

Fig. 2

diverging form the already know solutions. The differences are in the use of a differential amplitude discriminator that can be switched to work into controlled integral discriminator regime. Its differential regime is used during energy calibration, and it goes into the general measurement mode while in integral regime. This structure guarantees much more precise binding of the scale against the gamma-quanta energy and thus – higher measurement accuracy.

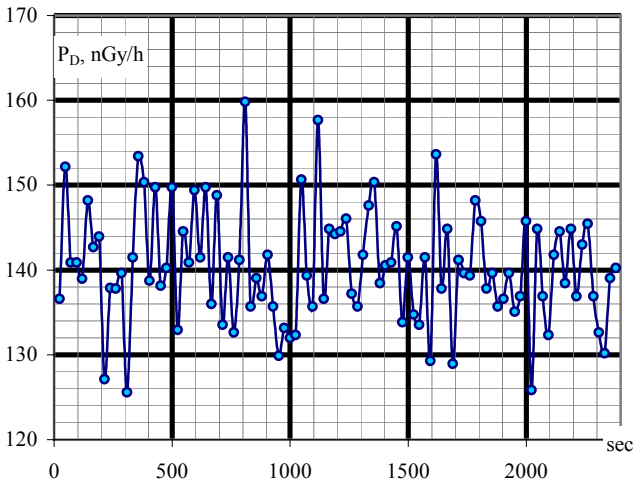

Fig.3

4. CONCLUSIONS

The results from γ-background measurement in laboratory environment, following the described method, after energy callibration are presented on Fig.3. The calculated mean value 140,35 nGy/h at mean deviation 6,64 nGy/h. This result is well correlated with the data, gathered after the processing of the

logarythmic γ-spectres. The control measurement of calibration sources ^{241}Am, ^{137}Cs и ^{60}Co gives us the following corresponding values 523,51 nGy/h against 522,12 nGy/h. Those results make ground for a statement that the use of the Spectrum Weight Function Method provides high precision and sensitivity, comparable to the one delivered by the spectrometric data with a relatively much more simple hardware, shorter measurement time and allowing higher impulse rate. A disadvantage of this method is the slightly higher mean deviation.

5. ACKNOWLEDGEMENTS

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