A Practical Method for Measuring Angular Distribution of Radiation from Multiple Gamma Sources

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ABSTRACT

The multidetector device for measurement of angular distributions of intensity of gamma - radiation is described. Results of tests of experimental model of device are presented and prospects of use of such device are shown.

SUMMARY OF WORK

Radiation survey data are a necessary prerequisite for planning D&D activities at a nuclear facility. For an individual room with a small number of high level radiation sources whose locations are known *a priori*, the survey process, shielding calculations, and work planning process are straightforward. However, when the space is large and complex, or when an accident has left process equipment and the space in disarray, gathering survey data while minimizing dose to the surveyor may require specialized equipment and analytical methods.

The Object Shelter (OS) that encloses the destroyed Unit 4 at the Chornobyl Nuclear Power Plant (ChNPP) contains many intensive radiation sources such as fuel containing material (solidified melted fuel, fragment spent fuel, and fragmented fresh fuel), destroyed/contaminated piping and mechanical equipment, and contaminated dust and debris from accident recovery. These high intensity radiation sources are scattered throughout the facility in unknown configurations, so it is essential to know the angular distribution of gamma radiation in order to plan work and to design shielding.

As previously reported (citation), a prototype tool for measuring angular distribution of gamma radiation was developed, constructed and tested at ChNPP OS [2, 3, 4]. The prototype device, designated ShD-1, consisted primarily of a lead (Pb) sphere containing recessed thermoluminescent detectors (TLDs) [5]. ShD-1 was successfully used to collect radiation survey data for planning the largest construction project yet performed at ChNPP OS, the stabilization project. From this application we gained insight into some limitations of the prototype design and report here advancements in the design.

Some limitations revealed during field use of ShD-1 include:

- Low sensitivity of TLDs relative to the radiation being measured. To measure with satisfactory accuracy it was found that the total dose to the TLDs needed to be at 1 Rad, For radiation conditions in some areas at the OS this required an exposure duration of several days.
- Complexity of preparing ShD-1 for measuring. The device contains 108 TLDs, each of which must be manually inserted into the sphere prior to a measurement and extracted for data collection.
- Complexity of digitization of measured data. Data extraction takes from 3 to 5 hours, after which the data are manually entered into a computer for spatial statistical analysis).
- Impossibility of remote control or remote indication during measurement. The device is set in one location and left undisturbed until removal and data extraction.

To resolve these limitations, a new device designated ShD-3 was developed. The ShD-1 principle of a heavily shielded sphere containing radiation detectors was retained, but the type of detector was improved. In this paper the working model of this device will be described, including photographs (fig. 1) of the instrumentation and preliminary data analysis from actual field application.

A review and analysis of the most commonly used electronic radiation sensors was performed.

Gas discharge detectors. They have low efficiency and don't match due to length. For ensuring of the sufficient attenuation factor on the ShD1 it is necessary to increase the body size. But in this case it will be possible to move the device only with the help of mechanical device. Besides such detector can't be considered as a point detector. So angular distribution of the device will get worse.

Scintillation detectors. The necessity to use light-reflectors in the scintillation detector and light-transformers (photoelectric multiplier or photodiode) renders impossible the creating of acceptable scintillation detectors blocks. Besides light-reflectors and light-transformers will distort gamma field which is detected by thy device.

Ge and Ge(Li) - detectors. The necessity of liquid nitrogen cooling and relatively big size of preamplifiers render impossible to use of such detectors in described multi-detectors device.

CdZnTe detectors. Semi-conductor detectors of ionizing radiation based on crystals of CdTe, CdZnTe, GaAs:

a) small size;

b) not necessary of liquid nitrogen cooling;

c) high efficiency of registration of gamma radiation.

Energy range of detect radiation from 20 to 3000 kiloelectronvolt. Work temperature range from -40 to +50° C. Spectrometers based on CdTe and CdZnTe have energy resolution a few percent. Detector based on CdZnTe keep sensitivity to absorbed dose 80 Mrad. High sensitivity, small size and wide dynamic range of cadmium-zinc-tellurium (CZT) detectors made these sensors the optimum choice for improving the prototype device.

ShD-1 TLDs were replaced by CZT-detectors and electronic instrumentation for data acquisition, storage and processing. Crystal size was 6x6x3 mm. An aluminum capsule with a CZT detector was placed into each aperture of the lead sphere to construct ShD-3.

Principal scheme of preprocessing and data storage is shown on fig. 2.

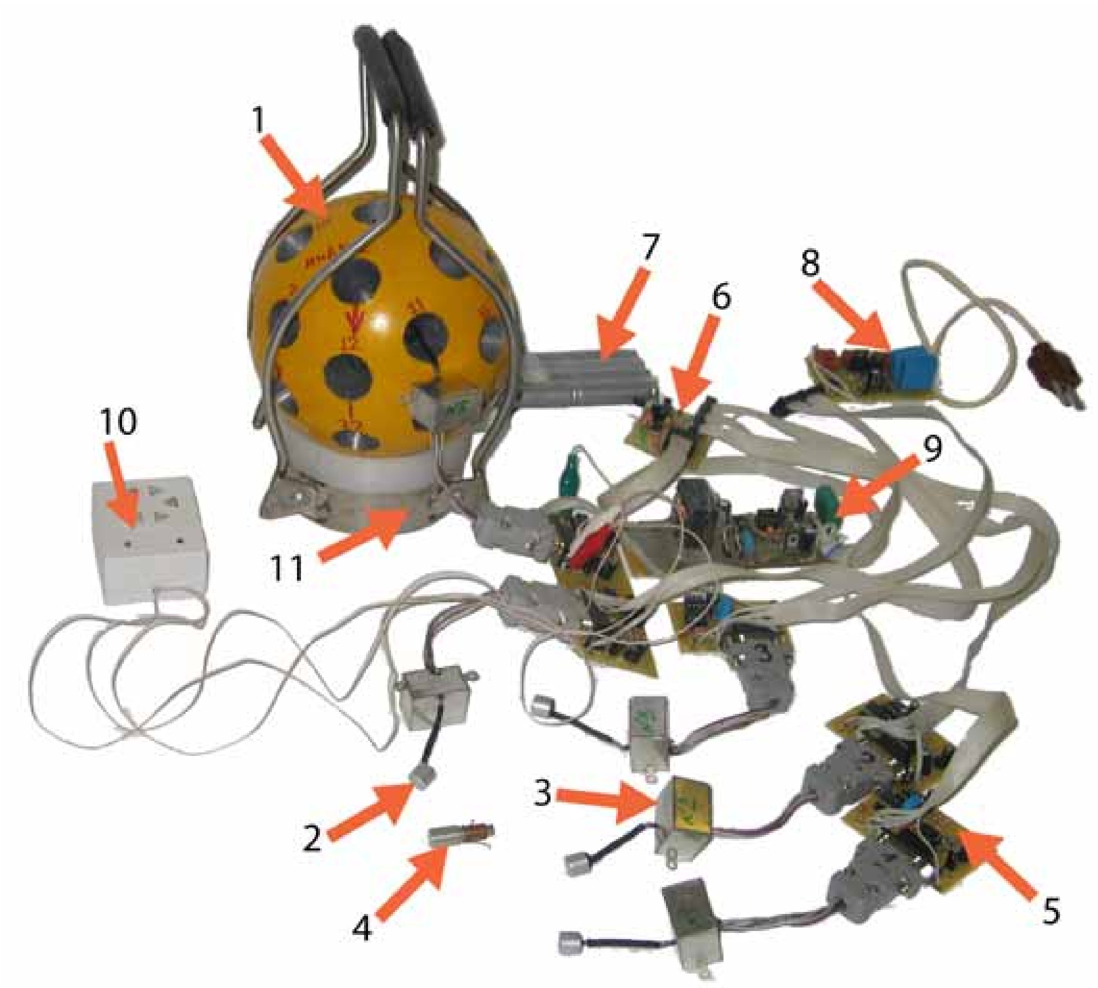

Fig. 1. Experimental model of ShD-3 device.
1 – leaden body with collimating apertures, *2* – capsules with detecrors, *3* – preamplifier, *4* – capsules with TLD (ShD-1), *5* – preparation card, 6 – control card, 7 – power source 10V, 8 – charger, 9 – voltage changer, 10 – beep annunciator, 11 – leg

Major data acquisition components include preamplifier, comparator-discriminator, counter, and memory.

The preamplifier increases the magnitude of detector impulses. The preamplifier output impulse has a negative direction and 10 microsecond duration. Impulse form is near to Gauss distribution.

The comparator-discriminator, counter micro-controller, nonvolatile memory and voltage stabilizer are located on a separate card.

The comparator-discriminator transforms the preamplifier output into a logic level impulse. Discrimination level is adjusted for every detector channel separately and is set to a level corresponding to ^{241}Am (59.6 keV).

A micro-controller, 12C508A, operating under a proprietary program, performs limited on-board signal processing and control functions. Now as a micro-scheme of nonvolatile memory is used 24C16 (Atmel). Memory – 2 kB. This limits possibilities to increase number of stored impulses (measuring cycles).

A small amount, 2 Kb, of on-board nonvolatile memory is available. Stored data is transmitted by double-wire interface I^2C at 50 kbps speed to a remote computer for spatial statistical analysis.

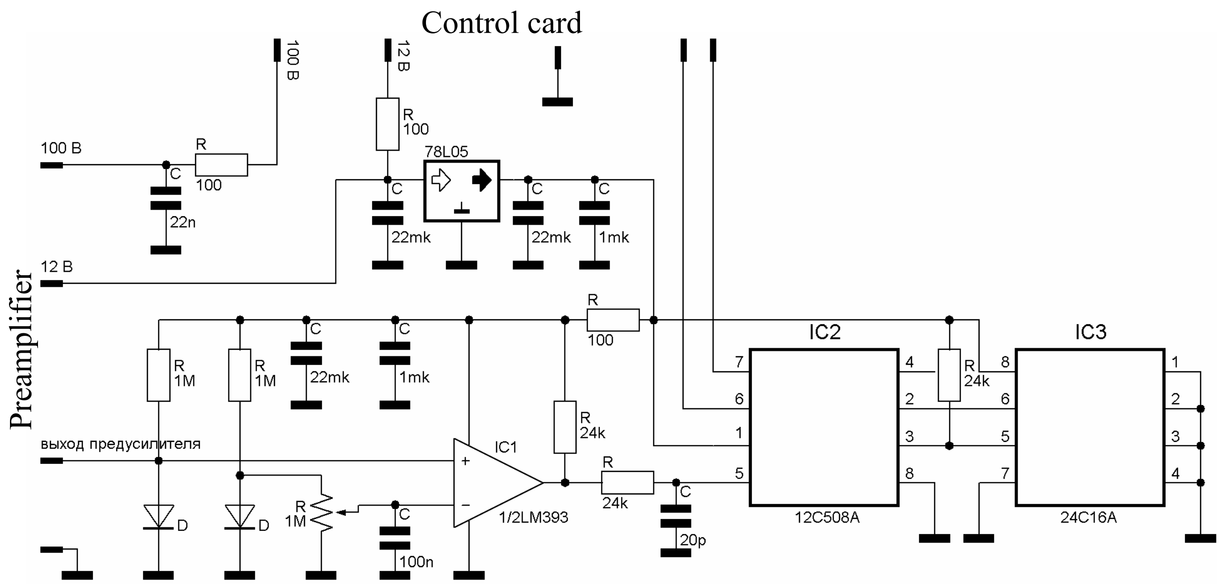

Fig. 2. Principal scheme of preprocessing and data storage

Response time for external control commands (for example, adjusting sample time interval) is relatively fast, no more then 10 µs.

Measuring data are stored into programmable memory (NVRAM). Then these data transported to a computer with the help of the programmer. The computer makes the final data processing for ShD-3.

Intermediate data registration is carried out for such reasons:

a) For increasing of reliability and measuring accuracy,

b) For having control under possible strays during field works near different accidental sources,

c) For checking hypothesis about normal distribution,

d) For study of dynamics of registration efficiency under different periodical external forces (in this model every 8 sec).

Memory chip limits time of one measuring cycle by 2.5 hour.

As a charger we use eight of NiCd accumulators. Voltage 10 V, capacity 1 A*h. It is enough for off-line operation during 10 hours. A special charger for these accumulators has been made.

Changer from 10 V to 100 V (for detectors power supply) provides stabilized output voltage at the decreasing of input voltage to 8 V. Output current – up to 10 mA.

Control chip was made in the form of cross-chip. The detectors and power source are connected to it. On this chip are situated:

- Micro-controller 12C508A. It produces control impulses for countable micro-controllers.
- Voltage monitors 10 V and 100 V with leds indication.
- Interference protection

For usability of debugging and control under measuring process a little indicated block with sound and leds indication of impulses availability has been created.

Measuring data are stored into programmable memory (NVRAM). Then these data transported to a computer with the help of the programmer. The computer makes the final data processing for ShD-3.

Programmer PonyProg with program application (http://www.LancOS.com) is used for reading from nonvolatile memory and for preparing it for the next measuring cycle.

For data preprocessing a special computational program *detector.xls* (Visual Basic) has been developed. The use of notebook gives possibility to read information and to control measuring results on-line, not only in a laboratory but in field condition.

The calibration measuring of sensitivity to static and variable electric and magnetic fields, to temperature has been carried out in certified laboratory:

- electric field strength changed from 0 to 6000 V/m;
- magnetic-field strength changed from 0 to 400 A/m;
- temperature changed from -20 to +60° C.

During all measuring seances the malfunction of the device haven't happened. Significant changes in electric and magnetic fields haven't caused changes in device characteristics.

Insignificant reduction of registration efficiency (up to 20 %) has been observed when the temperature decreases below 10° C. However, this effect is equal for all examined detectors and we can expect that it will not have effect to angular distribution measuring. Nevertheless, we are going to set up a heat-sensing device and to fix one more additional parameter for each measuring.

Intermediate results (in 8 sec) allow to do a statistic analysis and to control the dynamics of doze rate changing. Fig. 4 shows time-dependence of report number for one of detectors. During measuring we fixed doze rate in a place where detector was situated.

IMPORTANCE OF WORK Field testing has demonstrated that ShD-3 is an innovative device capable of providing angular distribution of gamma sources under difficult conditions that may be encountered in D&D of nuclear facilities. The device may also have homeland security applications.

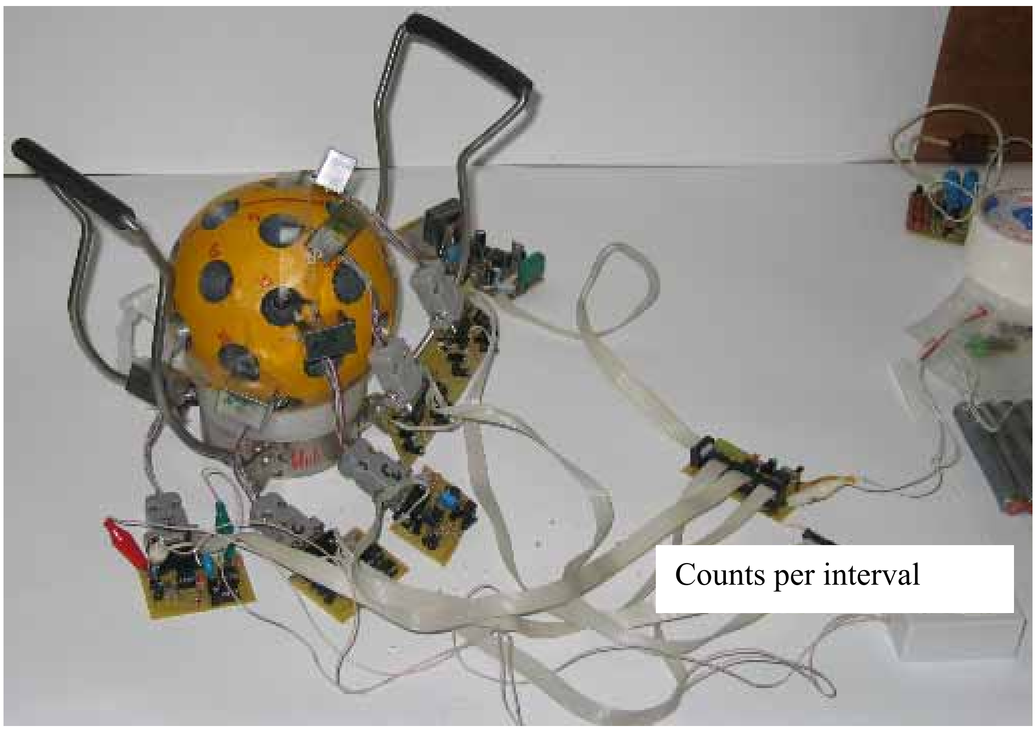

Fig. 3. Ready experimental model on the base of 5 CdZnTe detectors

Test measuring of experimental sample of ShD-3 showed that CdZnTe detectors are perspective for creating mobile autonomy multi-detector device for measuring of angular distribution of gamma radiation.

The device characteristics don't change under variable electric and magnetic fields impact. It was observed little decreasing of efficiency of gamma radiation registration under environment temperature decreasing. This effect could be easily taken into account by adding a heat-sensing device or by considering the temperature data.

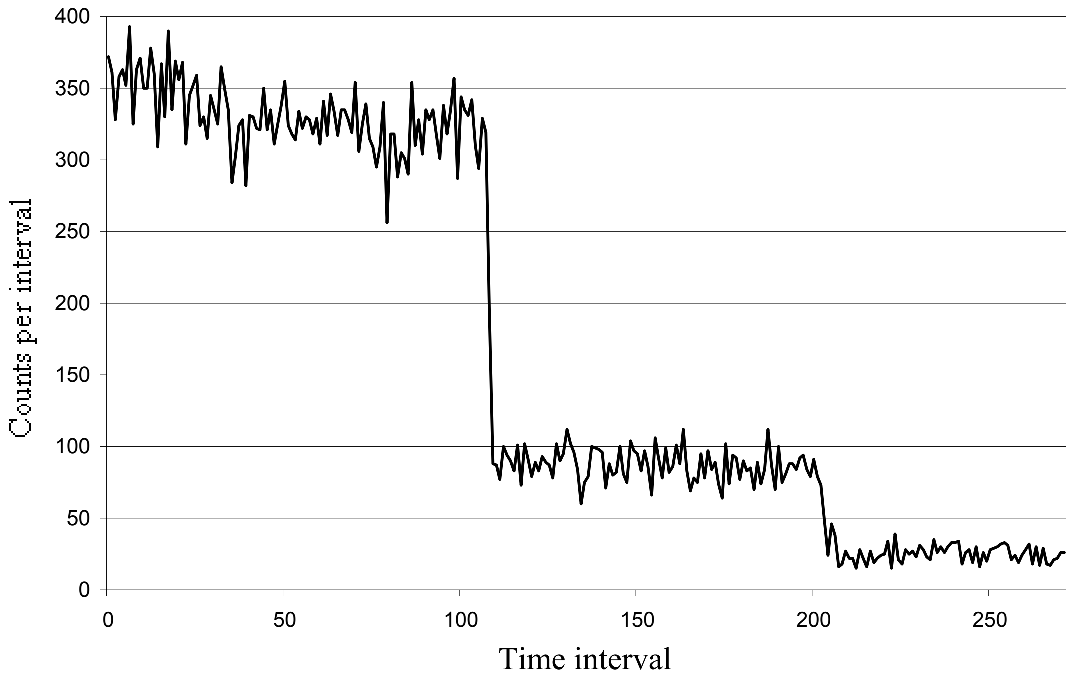

Fig. 4. – Detection efficiency vs time

The measuring results show that this system can be taken as a base system for pre-production model l. But it is necessary to make some improvements for cycloinverter efficiency factor increasing (in this model it is a main source of power consumption), simplification of the procedure of data transition to computer (now each channel has its own memory), reduce scheme size. Particularly it is rationally to use up-to-date SMD microcontroller combining in self function of signal comparator, counting scheme, nonvolatile memory and PC interface.

Investigations showed that ShD-3 device is perspective for solving different problems, which are connected with measuring of radiation environment in difficult conditions, for finding of gamma radiation sources, for controlling under source moving.

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