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Response of Permanent Monitoring Station (PMS) to increased radioactivity level in comparison with thermoluminescent detectors and Gamma Tracer monitor

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Abstract In this work, the response of the Permanent Monitoring Station (PMS) was compared with the readings of environmental thermoluminescent dosimeters (TLD) based on high sensitive MCP-N (LiF:Mg, Cu, P) thermoluminecent detectors and Gamma Tracer, an active device. Thermoluminescent dosimeters were installed close to an automatic warning system of PMS and to a portable Gamma Tracer monitor which is used for long term, continuous measurements in the environment at the INP. For several weeks ^{137}Cs, ^{60}Co, ^{226}Ra and ^{241}Am gamma-ray sources have been placed at distances of a few meters from the dosimeters, in order to modify the radiation environment.

Key words dose rate • environmental radioactivity • thermoluminescent dosimeters

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Introduction

After the Chernobyl reactor accident, radiation monitoring seems to be an important issue for all states in the world. On the basis of the Chernobyl experience, the Polish government decided to set up a radioactive monitoring network. Since 1990 the Central Laboratory for Radiological Protection (CLRP) in Warsaw operates the network of high volume Aerosol Sampling Stations (ASS-500) and also supervises the network of automatic Permanent Monitoring System (PMS) stations which are able to collect and store data from various sensors (dose rate from a G-M tube, gamma spectra from a NaI detector looking around the measurement cabinet, precipitation, outdoor temperature, etc.). The PMS stations are now located in Warsaw, Kraków, Białystok, Gdynia, Szczecin, Lublin, Sanok, Wrocław, Olsztyn, Zielona Góra, Koszalin. The basic principles of environmental monitoring is to complete information of radiological situation, discharges and releases of radionuclides both during normal and emergency situations. The main tasks of such stations are systematic and continuous measurements of radioactivity in the environment. The station producer is Greenwood Engineering. Prolog Development Centre created the PMS system software and ARGOS_NT. Both companies are from Denmark. The PMS system is a part of the Early Warning System in Poland. Our PMS station is one of eleven of such stations, which together form the Polish radioactive monitoring system co-ordinated by the CLRP [6].

In this work, the response of Permanent Monitoring Station (PMS) was compared with the readings of environmental thermoluminescent dosimeters (TLD) based on high sensitive MCP-N (LiF:Mg, Cu, P) and an active device specially designed for environmental radiation surveys

Gamma Tracer. The thermoluminescent dosimeters were installed close to an automatic warning of PMS station, based on a G-M counter, and to a portable Gamma Tracer monitor (Genitron, Germany), which is used for long term, continuous measurements in the environment at the INP. For several weeks ^{137}Cs, ^{60}Co, ^{226}Ra and ^{241}Am gamma-ray sources have been placed at distances of a few meters from the dosimeters, in order to modify the radiation environment.

Material and methods

This work presents the response of different types of instruments to increased artificial radioactivity level, which is a continuation of previously performed experiments [2]. The measurements took place in a sample collection site of the Environmental Radioactivity Laboratory in the INP (Kraków, southern Poland), where the PMS Station is located.

During the experiment three types of detectors were used, namely:

1. A Geiger-Müller (G-M) detector from the PMS – G-M (PMS),
2. Thermoluminescent Dosimeters – TLD,
3. A Gamma-Tracer – GT.

Description of detectors used in the experiment is presented in Table 1.

The PMS system is a surveillance tool for use by the national emergency management agency. It monitors radiation in the environment, especially detects radiological emergency situations (for example nuclear accidents). The basic PMS system consists of measuring Stations (PMS Station) and a Central Monitoring Server (PMS Server) located in the CLRP. The PMS Server handles communications and analysis. It is connected to the PMS Stations by normal telephone lines. At fixed intervals (5–6 times per 24 hours), the PMS server calls each PMS Station and transfers measurement data. The PMS Sever software receives the data and at this point some initial analysis is performed to provide a quick overview and trigger certain alarms. This enables experts to take appropriate action in a radiological emergency situation. Additionally, the measurement data in the database is available for the use of other applications.

The PMS station continuously measures gamma radiation dose rate (Geiger-Müller counter), collects gamma radiation spectra (NaI detector) and acquires basic meteorological parameters i.e. precipitation, temperature (outdoor and of the NaI crystal). In the sensor part, there are three small vials containing a small amount of thorium ore (monazite sand) located near the NaI detector (see Fig. 1). Their task is to strengthen the natural stabilization peak (^{208}Tl) used for energy calibration. Thorium slightly increases the dose rate measured by the G-M tube, but its influence is negligible and, moreover, the aim of the system is to detect alarm situations. The G-M data consist of a single floating-point value ambient dose equivalent rate $H^*(10)$ in microsiverts per hour. The G-M data was collected each minute. These measurements are collected and written to data-files on disc. PMS is connected directly to the CLRP by a computer network [6].

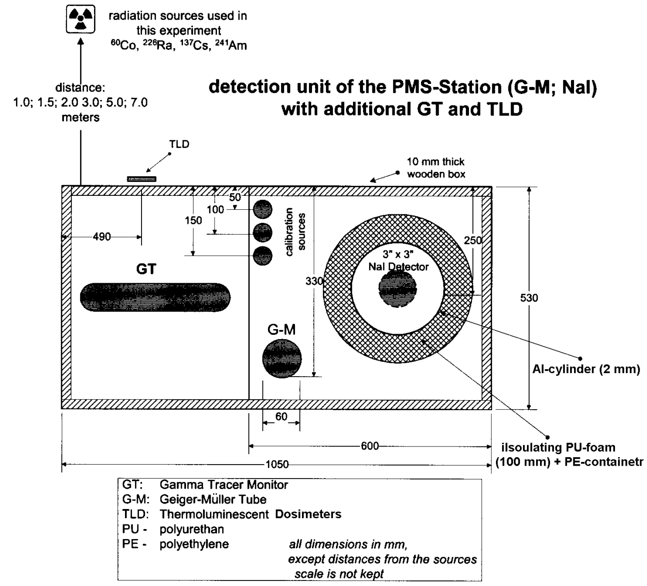

Fig. 1. Scheme of the detection unit – PMS-Station with additional GT and TLD.

About 40 stations of PMS type are used in Europe in the Baltic Sea Region (Denmark, Estonia, Latvia, Lithuania, Poland and Russia). The detailed description of the PMS detectors (NaI and G-M tube detectors) is given in user's manual (PMS-RIS∅, Denmark). To present results of the measurements obtained with PMS, we had to develop a software to convert the output file from the PMS into an ASCI file. The layout of the data file from the PMS station software is presented in Fig. 2. This computer program (PMS2TXT) also changes the file names from WINDOWS NT 3.51-Workstation to the ordinary DOS system. The output file of this program gives values of a start and end time of the measurement, temperature inside the electronic box – T_{in}, outdoor temperature – T_{out}, rain intensity – Rain, and dose rate – G-M, as separate columns (see Fig. 3). This

Table 1. Description of detectors used in the experiment.

Detector	TLD	PMS	GT
Type	LiF:Mg,Cu,P; 3 pieces in card	Geiger-Müller tube	2 × Geiger-Müller
Sensitivity	0.04 μGy/imp	no data	100 nGy/h
Measurement range	1 μGy – 0.1 Gy	no data	20 nGy/h – 10 mGy/h
Error (1σ)	±7%	no data	±3%
Error of calibrations	±5%	no data	±5%
Energy characteristics	±20%	no data	±30% (45-1300 keV)
Measurement cycling	24 h	10 min	1–120 min
Dimension	45 × 35 mm	ϕ 60 mm × 550 mm	ϕ 60 mm × 690 mm
Cover	4 mm polyethylene	1 mm aluminium	1 mm aluminium
Temperature range	–40°C ÷ +50°C	–20°C ÷ +70°C	–40°C ÷ +70°C

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$HB
PMS_STATION_9                               {station code}
$RB
TEMP-NAI
1998:03:31:23:00-1998:04:01:00:00           {start and end time of the measurement} yy:mm:dd:hh:mm]
1.66e+001                                   {temperature of NaI crystal detector Celsius degree, T NaI}
$RE
$RB
TEMP-ENCL
1998:03:31:23:00-1998:04:01:00:00
1.80e+001                                   {temperature in the inside of electronic box, Tin}
$RE
$RB
TEMP-OUT
1998:03:31:23:00-1998:04:01:00:00
4.67e+000                                   {outdoor temperature, Tout}
$RE
$RB
RAIN
1998:03:31:23:00-1998:04:01:00:00
 0.00                                       {rain intensity [mm/h], Rain}
$RE
$RB
GM
1998:03:31:23:00-1998:04:01:00:00
1.10e-001                                   {dose rate G-M – [mikroSv/h], G-M}
$RE
$RB
NAI
1998:03:31:23:00-1998:04:01:00:00
0,0,0,0,0,2035,12001,13686,...... (itd)     {number of counts in the gamma spectra from NaI}
.....................................................................
$RE
$RB
NAI-PARAM
1998:03:31:23:00-1998:04:01:00:00
450.22,3533.00,3540.00,2219.17,960.00,   {working parameters of NaI and G-M tube}
$RE
ALARM
OK
EOF            {end of file}
................
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Fig. 2. The layout of the data file from the PMS station software.

makes the data easy to use in presentation and statistical calculation.

The Gamma Tracer portable device was designed especially for measurements of radiation background in the environment. It allows measuring dose rates as kerma rate in air at the level from ca. 50 nGy/h up to 1 mGy/h for time periods ranging from 1 min up to 1 h. GT is equipped with two independent counter channels, which, complemented with the Geiger-Müller counter tube GT, was calibrated using a ^{137}Cs source, by their manufacturer [4]. A tube-shaped metal casing reliably protects the electronic components of the Gamma Tracer probe from harmful environmental influences. The tube disposeses of a wall thickness of 1 mm and thus has a minimal capability to absorb intruding radiation. The transfer of data is effected by binary codes for wireless data transmission to the PC computer.

Thermoluminescent dosimeters, produced by Health Physics Laboratory (INP), are being widely used for dosimetry of radiation in the environment. In this work, high sensitive LiF: Mg, Cu, P detectors (trade name MCP-N) were used. The properties of MCP-N detectors and their use in practical measurements of doses in the environment are described in [1, 3]. The TLD consist of three MCP-N detectors, closed in a 2 mm thick PCV container, packed in a light-tight Al foil and a waterproof polyethylene bag. TLD and GT were calibrated at the INP calibration site in terms of air kerma free-in air by applying a 0.5 mGy gamma dose ray dose from a ^{137}Cs source, while for the PMS in tens of ambient dose rate equivalent – $H^*(10)$, calibrated by the manufacturer.

Table 2. Description of radioactive sources used in the experiment.

Source	Decay $T_{1/2}$ [year]	Energy Eγ	Activity [MBq]
^{137}Cs	30	661.6	41.97
^{226}Ra	1.6×10^3	Multilines	34.6
^{241}Am	432.2	59.5	Unknown
^{60}Co	5.3	1173.2 1332.5	4.32

	T NaI	T_{in}	T_{out}	Rain	G-M
1998:03:23:23:50-1998:03:24:00:00	8.33	16.30	-3.17	0.00	0.11
1998:03:24:00:00-1998:03:24:00:10	8.34	16.20	-3.06	0.00	0.11
1998:03:24:00:10-1998:03:24:00:20	8.36	16.10	-3.01	0.00	0.10
1998:03:24:00:20-1998:03:24:00:30	8.31	16.00	-3.01	0.00	0.10
1998:03:24:00:30-1998:03:24:00:40	8.30	16.00	-3.05	0.00	0.11
1998:03:24:00:40-1998:03:24:00:50	8.21	15.90	-2.97	0.00	0.11

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Fig. 3. The layout of the data file from the PMS_2_TXT software.

To change natural gamma background radiation, four different types of commercial radioactive sources were used (see Table 2). They were placed 1 meter above the ground at different distances from the detectors. The data about the distances and the detectors are presented in Table 4. To change the gamma spectrum, different sealed sources have been chosen. A ^{241}Am source represented the low energy photons – 59.5 keV, ^{137}Cs (661.6 keV) the middle ones and ^{60}Co (1173.2, 1332.5 keV) the high-energy region. A ^{226}Ra source was used to simulate radioactive contamination of the environment in the wide energy range of gamma-rays.

Table 3 shows a comparison between TLD and GT relative to a PTW-UNIDOS Farmer 30 cm^3 ionisation chamber (PTW 2236). The details of calculation of the dose are given in work [1]. A comparative measurement shows the difference between TLD, GT and PTW and the change of the readings depending on the gamma rays characteristics. For the ^{226}Ra reading, TLD and GT were by 1.7% and 9% higher than that of PTW. For energy 1250 keV, the kerma rates obtained with GT are by 18% higher than those measured with PTW. Construction of the PMS station did not allow putting the TLDs and GT detectors at exactly the same distance from the radiation sources. This was the reason of possible errors in the calculated values of gamma dose rates.

The results of air kerma rate obtained during the measurements are presented in Table 4 together with exemplary background and theoretical gamma-ray dose calculation. The dose rate was calculated using formula (1) [5]:

$$\dot{D} = \Gamma \cdot \frac{A}{r^2} \text{ [cGy/h]} \qquad (1)$$

where: A – source activity [GBq], r – detector-source distance [m], Γ – specific γ-ray constant,

and: $\Gamma_{Cs\text{-}137} = 8.0 \cdot 10^{-3}$ [cGy·m^2·(h·GBq)$^{-1}$],
$\Gamma_{Ra\text{-}226} = 21.4 \cdot 10^{-3}$ [cGy·m^2·(h·GBq)$^{-1}$],
$\Gamma_{Co\text{-}60} = 30.8 \cdot 10^{-3}$ [cGy·m^2·(h·GBq)$^{-1}$].

Results

The results obtained for the ^{241}Am source from the G-M in comparison with the ones obtained by the TLDs were almost equal (4% difference). During the experiment read-

Table 3. Relative dose rate obtained with TLD and GT in comparison with PTW ionisation chamber.

Source	TLD/PTW	GT/PTW
^{226}Ra	1.02 ± 0.02	1.09 ± 0.04
^{60}Co	0.99 ± 0.02	1.14 ± 0.05

	$\dot{K}_{air}$	$\dot{D}_{air}$	$\dot{K}_{air}$	$\dot{K}_{air}$
	measured			calculated
Source/(distance)	TLD [nGy/h] (±1σ)	PMS [nSv/h] (±1σ)	GT [nGy/h] (±1σ)	[nGy/h]
Background	70 ± 4	106 ± 5	no data	–
^{226}Ra / (7.0 m)	249 ± 15	239 ± 5	no data	150
^{137}Cs / (3.0 m)	353 ± 27	381 ± 5	410 ± 14	370
^{137}Cs / (4.0 m)	214 ± 18	250 ± 6	275 ± 11	210
^{137}Cs / (5.0 m)	no data	201 ± 3	206 ± 10	130
^{137}Cs / (7.0 m)	122 ± 10	146 ± 5	141 ± 9	70
^{60}Co / (1.5 m)	535 ± 42	561 ± 10	701 ± 18	590
^{60}Co / (3.0 m)	185 ± 14	230 ± 6	231 ± 11	150
^{60}Co / (5.0 m)	117 ± 9	151 ± 6	143 ± 8	55
^{241}Am / (1.0 m)	268 ± 23	278 ± 6	222 ± 40	no data

Table 4. The measured and calculated dose rates for different sources, detectors and distances.

ings from the GT, compared with those of TLDs were by 17% lower. Previous experiments showed that the GT readings for energy 60 keV were higher by 2% in comparison with the reference value obtained by an ionization chamber [1].

For the ^{137}Cs and ^{60}Co sources the G-M readings showed 15% (^{137}Cs) and 19% (^{60}Co) higher values than those of TLDs, while the same ratio for GT and TLDs showed about 20% and 26% higher values, respectively. Those results could be determined with higher uncertainties, because the TLD's were placed outside the PMS wooden box, while the two other detectors were put inside the box. This caused differences in the distance between the sources and detectors. It was impossible to keep exactly the same conditions as those during the calibration of GT and TLD in the calibration site.

For ^{226}Ra the G-M showed a 4% higher dose rate than that of TLD's. For this irradiation GT was not available. The ratio of the G-M and GT response to the one given by the TLD is presented in a graphic form in Fig. 4. In Fig. 6 the response is shown of the NaI detector from the PMS station for an increased radioactivity level caused by the used sources. Comparison of the dose rates measured with the G-M detector from the PMS station, the GT detector and TLD's for different distances and sources are presented in Fig. 7.

Discussion

The differences between the measured and calculated values are caused by the natural background, not included in the theoretical assumptions. The difference is about 70 nGy/h – which responds well to the natural level of background in the measurement site. The dose rate measurements show that all the three environmental radioactivity detectors (GT, G-M, TLD) used in the INP, reacted correctly (within the same order of magnitude) to the simulated increase of dose rate in the environment in the wide range – from 50% up to 6 times higher.

The observed differences could be explained by the different conditions of the measurements for each detector, for example, for different distance and other geometrical factors (shielding). The GT results are about 15% higher than those obtained with the PMS station, which is caused by the energetic characteristics of the GT.

In comparison with the TLD's, the GM tube from the PMS station gives results that are about 45% higher for measurement of only natural background. This could be caused by the energy characteristics for high energies photons from the three small vials containing the small amount of thorium ore (monazite sand). These sources are located near the NaI and G-M detectors (see Fig. 1). Their task is to strengthen the natural stabilization peak (^{208}Tl) used for energy calibration.

The described systems for environmental measurements of ionising radiation available at the INP reacted properly to the simulated increase of dose rate. The results obtained are comparable in the wide energy range (from 60 keV up to 1.4 MeV), although there are some differences (see Table 4, Figs. 4 and 5). The simulated energy spectrum is

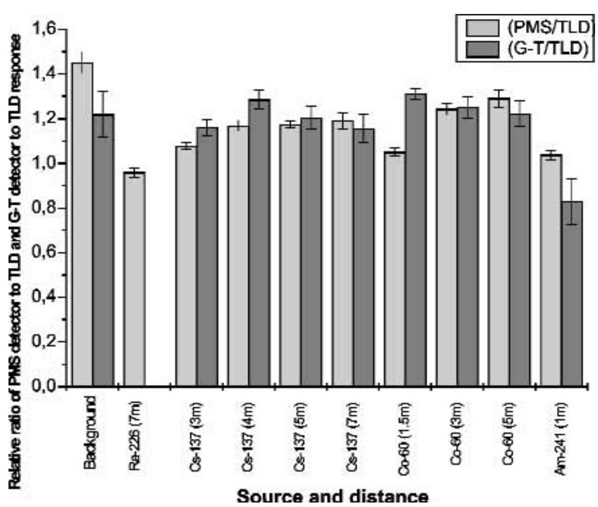

Fig. 4. Response of PMS detector relative to TLD and GT detector to TLD.

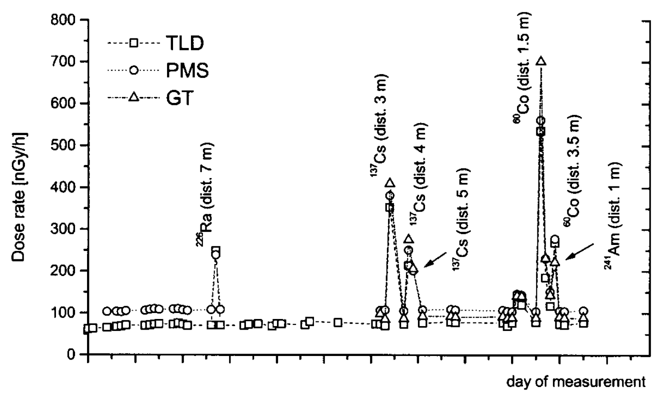

Fig. 5. The measured dose rates for different detectors, sources and distances.

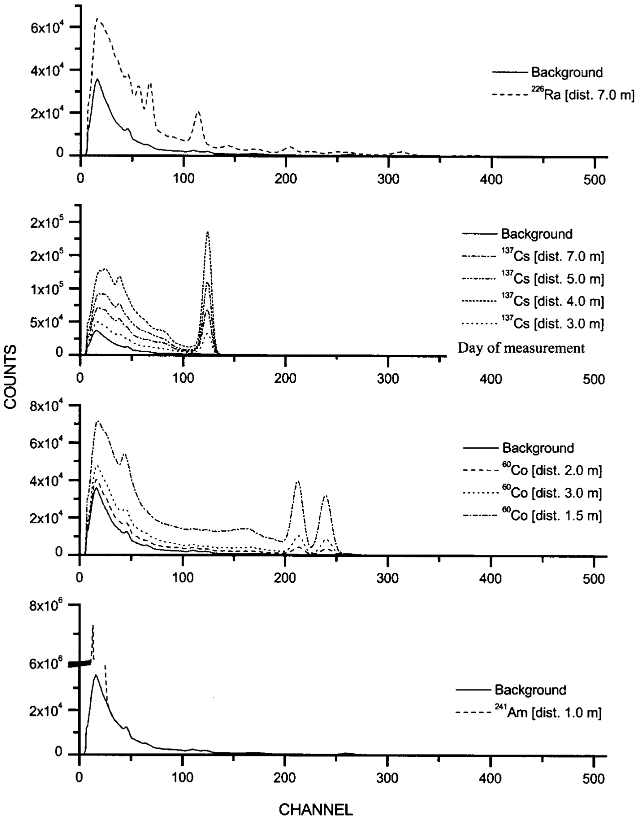

Fig. 6. Gamma spectra of ^{241}Am, ^{60}Co, ^{137}Cs, ^{226}Ra obtained by NaI PMS detector.

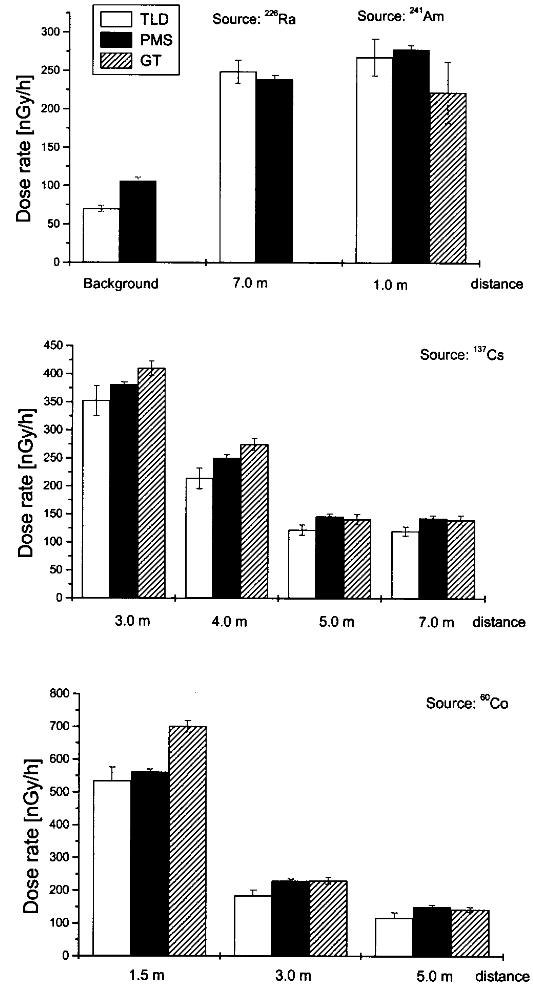

Fig. 7. A comparison of dose rates from different sources, distances and detectors.

representative for typical artificial radioactive contamination of the environment during nuclear accidents, which confirms usefulness of the PMS station, GT and TL dosimeters in radiation emergency situations.

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