INTRODUCTION

After the Chernobyl Accidents has happens, the vicinity around the fourth reactor unit, destroyed after explosion, has become the largest outdoor laboratory, where the mankind’s knowledge concerning the radionuclides behaviour in the environment can be essentially tested and improved. An international group of scientists from the Ukraine, USA and the IAEA fellows from Brasil, Kenya, Syria and Iran as participants of Summer School on environmental monitoring, took participation in field exercises to investigate radioecological situation inside 30-km Exclusion Zone at three different sites: two fields and one forest with different levels of contamination.

The present radioecological situation inside the 30-km Exclusion Zone is mainly determined by the $^{137}$Cs + $^{134}$Cs, $^{90}$Sr and transuranic elements as well [1]. The international group divided into teams and performed gamma and beta surveys, in-situ gamma-spectrometry and vegetation and soil sampling in contaminated field and forest locations.

The aim of this work was to investigate the peculiarities of measurement at different sites and to develop recommendations on group-made environmental monitoring.
EXPERIMENTAL

Sites description

Three sites were established for a training on environmental monitoring. Site 1 was a part of field used before an accident has happened to grow agricultural cultures. This field site was large, open, flat and grassy terrain of clay soils. Site 2 represents a forest ecosystem and was situated in 50 meters from an edge of pine forest. Site was quite flat with typical vegetation for a given locality. Site 3 was situated 100m in southern direction from Site 2. But when all measurements have been conducted and activities calculated, it was found, that the $^{137}$Cs activity distribution was uniform. It means the deep cultivation took place after radioactivity fallout. That is why the results, concerning Site 3 were omitted from the next consideration.

Fig. 1 shows the locations of sites relatively to Exclusion Zone.

Measurement technique

**Gamma - survey**

Within selected areas (Fig.2) dose rates and gamma flux were measured at two different heights (0.05m and 1m) (Fig 3, 3A). Ten measurements for dose rate and for gamma flux were done at each of the points and ten measurements only for dose rate were done around the centre of the selected area. The measurements were performed by a GM tube dose rate meter which an acceptable main error limit (95% confidence interval) of $\pm(30 + 1.0 \times \text{Unit}/R\%)$, ($R$-dose rate in units of the corresponding subrange -mR/h or R/h) and a scintillation detector with a range from 0 to 10000 s$^{-1}$ for dose rate and gamma flux respectively.

**Beta - survey**

To determine the beta - surface contamination in the selected area, beta - radiometer with thin-walled cylindrical type GM-tube have been used. Two measurements (one - with bare detector, second one - with detector, severed by stainless filter thick enough to stop electrons) have been conducted. The difference of readings of both measurements was interpreted as an electron contribution. The frequency histograms are given in Fig.4 for both sites.

**In-situ gamma spectrometry**

As well known to determine the inventory of $^{137}$Cs (activity per unity area) through a combination between in-situ measurements and soil sampling, for undisturbed after fallout land a square area at least of 10x10m far away from roads is needed.

In practice, the characterisation of contamination of a site may involve in situ gamma spectra measurements in conjunction with soil sampling. It also reduces the number of samples to be collected and gives a representative average activity value for a large area of ground. In-situ gamma measurements were done in the area at points in a height of 1m using the Silena Nuclear Processor - SNIP 201N/W and NaI(Tl) detector. The gamma spectra obtained had a post-treatment using the Silena Simcas (Computer-based Nuclear Analysis System) in order to grant a better result. Figure 5 presented an example of the in-situ gamma spectra obtained.

**Soil sampling**

For soil sampling a top soil cutter having 6cm diameter and 20cm height has been used. 10 cores were taken to make a single sample. Then 20cm layer was divided into 5 subsamples, representing 0-2cm, 2-5cm, 5-10cm, 10-15cm and 15-20cm layers. The subsamples collected for each measurement point were sealed in double-walls plastic bags. A sheet of paper, containing all the information about sample (identification, geographical position, etc.) was located between plastic bag walls.
Fig. 1. Sites location within the Exclusion Zone.
Fig 2. Measurement net for investigated site 2.

![Measurement net for investigated site 2.](image)

Fig. 3. Statistical treatment of dose rate results.

- **average 1m**: 33.26
- **weighted error**: 3.05
- **standard deviation**: 2.36
- **Total error**: 3.86

- **average 0.05m**: 40.94
- **weighted error**: 2.19
- **standard deviation**: 4.05
- **Total error**: 4.60

**FIG. 3.** Statistical treatment of dose rate results.
**FIG. 3A.** Statistical treatment of gamma flux results.

- **average 1m**: 30.82
- **weighted error**: 1.15
- **standard deviation**: 1.76
- **Total error**: 2.11

- **average 0.05m**: 33.54
- **weighted error**: 0.94
- **standard deviation**: 2.33
- **Total error**: 2.51

**FIG. 4.** Statistical treatment of beta surface results of 30 points.

- **Average**: 132.83
- **Standard deviation**: 69.79

**FIG. 3A.** Statistical treatment of gamma flux results.

**FIG. 4.** Statistical treatment of beta surface results of 30 points.
Grass and mat sampling

For a site 1 according to [3] grass were collected 1cm above the mat region (2cm above the surface). Only part of grass was collected, which was separated from the underlying mat since radionuclide concentration in the mat were expected to be far greater than that in the grass. For a site 2 a mat was collected from the area 0.25 m² and care was taken to avoid collecting the underlying soil material.

In both cases the size of the area sampled and heights of grass were recorded. All samples were packed into plastic bags.
Sample preparation

At the laboratory soil samples were allowed to dry at room temperature for couple days. Then low-temperature (50 °C) drying continued for about 16 hours. Then dry mass of the whole sample material was recorded. Afterwards samples were crushed, ground with special mill, homogenised and sieved using mesh size 1mm. About half of all samples prepared were tested for homogeneity: each sample was divided into 8 or 10 subsamples and gross-beta counting was measured. The differences never exceed 10-15%.

A prepared sample (120cm³) was packed into a plastic container and consolidated by shaking. Typical masses were about 140-160 grams.

Gamma-spectrometry measurement

Gamma-emitting radionuclides were determined for all samples by gamma-spectrometer, consisting of 12% Ge(Li) detector, passive steel-lead shielding (mass 4000kg), associated electronics, PC with own-created software for gamma spectra processing [4].

The detector was calibrated with appropriate standard sources. The QC/QA program included every week efficiency and FWHM measurements for point sources 137Cs and 60Co. Also the IAEA references samples [5] were used to control procedures of activity determinations.

RESULTS AND DISCUSSION

Dose rate measurements are presented in Fig. 3, gamma flux measurements in Fig. 3A, beta surface contamination in Fig. 4, for both sites. Keeping in the mind results on frequency distribution of above mentioned characteristic it is easy to prove the trueness that the distribution of activity at site 1 is quite uniform from the point of view of dose rate and gamma flux measurements. The only exclusion was observed in point 2, where a hot spot test value [6] gave a value 1.52.

Having calculated uncertainties of Hot Spot Test it should be mentioned, that majority of results is not distinguished, for instance, points 2,3,6,7,8 have approximately the same results. But, at the same time, three different kinds of measurement proved the presence of Hot spot edge at site 1. Concerning the beta measurements at this site, we can see bigger deviations from point to point, but Hot Spot area was detected certainly. The same results were observed for a site 2: big deviations in beta-contamination, but hot spot area was not detected. Also we strove to make fitting of frequency histograms in order to obtain parameters of log-normal or normal distribution. But due to lack of results it was impossible to prove usage of one of different kinds of distribution.

Distribution in the soil profile is presented in Fig. 5 and Table II for site 2.

<table>
<thead>
<tr>
<th>Table I. Total Surface Contamination Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>N°</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>15</td>
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<tr>
<td>16</td>
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<tr>
<td>21</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>23</td>
</tr>
<tr>
<td>average</td>
</tr>
<tr>
<td>weighted error</td>
</tr>
<tr>
<td>standard deviation</td>
</tr>
<tr>
<td>Total error</td>
</tr>
</tbody>
</table>
Table II. Activity of soil profiles.

<table>
<thead>
<tr>
<th>layer</th>
<th>mat</th>
<th>0 2</th>
<th>2 5</th>
<th>5 10</th>
<th>10 15</th>
<th>15 20</th>
<th>total</th>
<th>error</th>
</tr>
</thead>
<tbody>
<tr>
<td>point</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.895</td>
<td>1.814</td>
<td>0.070</td>
<td>0.047</td>
<td>0.022</td>
<td>0.007</td>
<td>2.855</td>
<td>0.137</td>
</tr>
<tr>
<td>9</td>
<td>2.336</td>
<td>4.765</td>
<td>0.677</td>
<td>0.461</td>
<td>0.448</td>
<td>0.108</td>
<td>8.705</td>
<td>0.369</td>
</tr>
<tr>
<td>10</td>
<td>1.534</td>
<td>1.469</td>
<td>0.195</td>
<td>0.165</td>
<td>0.356</td>
<td>0.137</td>
<td>3.856</td>
<td>0.125</td>
</tr>
<tr>
<td>14</td>
<td>0.974</td>
<td>1.644</td>
<td>1.241</td>
<td>0.023</td>
<td>0.043</td>
<td>0.036</td>
<td>3.961</td>
<td>0.157</td>
</tr>
<tr>
<td>15</td>
<td>2.048</td>
<td>2.285</td>
<td>0.265</td>
<td>0.373</td>
<td>0.087</td>
<td>0.040</td>
<td>5.097</td>
<td>0.180</td>
</tr>
<tr>
<td>16</td>
<td>1.184</td>
<td>1.979</td>
<td>0.218</td>
<td>0.336</td>
<td>0.132</td>
<td>0.051</td>
<td>3.900</td>
<td>0.155</td>
</tr>
<tr>
<td>21</td>
<td>1.035</td>
<td>1.391</td>
<td>0.481</td>
<td>0.294</td>
<td>0.069</td>
<td>0.020</td>
<td>3.291</td>
<td>0.121</td>
</tr>
<tr>
<td>22</td>
<td>0.744</td>
<td>0.838</td>
<td>0.115</td>
<td>0.099</td>
<td>0.042</td>
<td>0.054</td>
<td>1.893</td>
<td>0.069</td>
</tr>
<tr>
<td>23</td>
<td>1.523</td>
<td>4.776</td>
<td>0.571</td>
<td>0.259</td>
<td>0.098</td>
<td>0.078</td>
<td>7.305</td>
<td>0.347</td>
</tr>
</tbody>
</table>

Average | 1.36 | 2.32 | 0.42 | 0.22 | 0.14 | 0.049 | 4.54 |
Weighted error | 0.20 |
Stdev | 0.51 | 1.35 | 0.34 | 0.14 | 0.14 | 0.037 | 2.05 |
Total error | 2.25 |

From these tables and figures we can see, that approximately 90-95% of total caesium activity are concentrated in 0-5cm upper layer of soil for a site 1. This result is in a good agreement with other researchers [7].

For a site 2 we found, that approximately 30% of total activity contain in mat and this value twice less than in [8]. But, at the same time, mat and 0-5cm soil layer contain 90-95% of total activity, that is in a good accordance with the same reference.

IN-SITU

In Situ measurements for field and forest sites.

It is wellknown [9], that the fundamental quantities used for in situ spectrometry include full absorption peak count rate $N$, and source activity $A$. In practice we would like to deal with single factor to convert from the registered full energy absorption peak count rate in the pulse height distribution of a field measurement to the activity concentration (or exposure rate) of gamma-emitting radionuclides surrounded the detector at the investigated site.

The converted formula can generally be written as:

$$A=k_k A N_F$$

(1)

where

- $A$ - soil radioactivity concentration (Ci/km$^2$);
- $N_F$ - count rate in a representative full energy peak originated from the gamma-emitting nuclide of interest in a field measurements;
- $k$ - In situ calibration factor.

Should be noted that the In Situ calibration factor value depends on the in-depth activity distribution profile and absorption properties of the investigated surface (soil for field and soil and forest mat for forest, in our case). Briefly speaking, natural radionuclides are usually uniformly distributed whereas fresh fallout radionuclides cause a surface distribution. In field measurements an unshielded detector simultaneously measures gamma-fields from radionuclides of all types of distribution. But the field area from which principal photons contribute is considerably larger for plane distribution than for uniform distributions. For example that in field measurement of superficially distributed $^{137}\text{Cs}$ at 662 keV 90% of the primary gamma flux originates from distance within 60m (corresponding to a surface area of 11300 m$^2$). This distance decreases to 8m (corresponding to an area of 200m$^2$ if the activity is
uniformly distributed in the soil. Also, must be noted for distributions that are close to a uniform one, over 90% of the total flux comes from the first 10 cm of soil. The situation is even more extreme in case of a shallow distribution. For example, in case of soil density equal cm$^2$/g, more than 75% of the total flux comes from the first 1 mm of soil. It is particularly important to consider this effect when calibration procedures for in situ measurements are carried out.

Due to differences in radionuclides migration processes and site conditions for fields and forests we compared the results of the In Situ measurements from the calibration factors obtaining points of view.

In Table III the results of In situ and gamma-spectrometric measurements are presented both for field and forest sites.

<table>
<thead>
<tr>
<th></th>
<th>A, Ci/km$^2$</th>
<th>Error</th>
<th>Count rate, s$^{-1}$</th>
<th>Error</th>
<th>k</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field</td>
<td>9.29</td>
<td>40%</td>
<td>572</td>
<td>0.5%</td>
<td>16.2</td>
<td>42%</td>
</tr>
<tr>
<td>Forest</td>
<td>4.54</td>
<td>35%</td>
<td>358</td>
<td>0.9%</td>
<td>12.6</td>
<td>37%</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The main results of this article is a group made measurements on environmental monitoring. We can conclude, that:

a). The non-uniformity of caesium activity has to be discussed as the main source of uncertainty, affecting the final results of field exercises. This conclusion is very important for a strategy of survey.

b). To retrieve the true situation of activity distribution as many results as possible should be taken into account.

c). Keeping in the mind about the teaching character of Summer School and presence of team, it should be mentioned, that there is no certain procedure to make measurements in point surrounded by people occasionally. That can be a reason of big standard deviation for dose rate and gamma flux measurement. In the case of beta flux measurement big standard deviation can be explained by different composition of upper layer (soil + mat), overscattering of beta particles, natural transfer (wind, rain, etc.).

d). To obtain statistically meaningful results it is very important to adopt the sampling methodology to real situation of spot - profile radioactive contamination (sampling site, representativity, etc.).

REFERENCES


[2] POYARKOV, V., HORDYNSKY, D., NAZAROV, A., COSTA RAMOS, A., ENYENZE, K., Radiological Evaluation of an agricultural field in Chernobyl accident area, see pages


