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CITIZEN SCIENCE PROJECT "NUCLEAR E-COLOGY": PHYSICAL RESULTS AND THE EDUCATIONAL IMPACT

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ABSTRACT: We created citizen science project called "nuclear e-cology", and proposed it to high school teachers. Its main purpose was, in particular, to introduce the modern physics and science, in general, to afterhours school activities and eventually to modify high school curricula. We also put a special attention to the teamwork and the general scientific methods. Groups of students initially started the serious scientific work and some of them finished the study in the 2014/15 school year and we found results of their activity of the real physical value. We shortly present some of them here. We discuss here also some educational aspects of the project based on interviews and opinions of teacher involved in the project. We believe that the further work could be fruitful and successful from the point of view of students and teachers.

Key words: Citizen science, physics education, heavy metal contamination, X-ray spectra

INTRODUCTION

The road transportation activity, a primal component of economic development and human welfare, has been highlighted as a significant source of the emission of heavy metals (e.g., cadmium, copper, iron, lead, zinc, or nickel), which impacts the ecological environment on the roadsides and the vicinity of the roads: farmlands, pastures, rivers, residences etc. The heavy metals may enter the food chain as a results of the up-taking of edible plants or may directly contact to people and, with the accessive levels, they can cause serious health risk (Krzyzanowski et al. 2005) and of ecological problems (Bolin et al. 1986). The observation/monitoring the pollution to understand the problems, and to control the effects is discussed extensively in the literature (e.g., Lagerwerff and Specht 1970, Hamilton and Harrison 1991, Degobert 1992). The study about road pollution will be never out-of-date. The demand of the vehicle use throughout the world has never been decreased since 1960 (Dargay et al. 2007). Furthermore, the repetition of the future study conducted at the same road will allow one to monitor the changes of the heavy metal pollution distributing on the roadside.

Many pages were written about the importance of the physical education of the next generation. People trained in physics are essential for the continuing research in particular field, and for maintaining technically sophisticated workforce. Students at the graduate education level in experimental and theoretical physics have opportunity to experience and solve complex problems. Their trainings involve design, build, and test of instrumentations, they learn teamwork, management, and communication skills in addition to gain new technical knowledge and expertise. Their skills are readily applied to a wide range of technological problems of their nations: in medicine, industry, environment, business, management, and government. Future technologies will be steered by these people, but before the undergraduate degree in physics should provide the solid foundations. The undergraduate students should have the opportunity to acquire deep conceptual understanding of fundamental physics and gain important skills also for experimentation in physics. It is known that in the earlier education young students are fascinated by natural phenomena, and it is known that their interest in science starts erosion around the ages of 14 (Murphy and Beggs 2005; Pell and Jarvis 2001; Hadden and Johnsone 1983). Consequently, the students who could potentially follow a science-related career are rejecting this option by the time they reach high school (Smithers and Robinson 1988; Trumper 2006). A way to lead them to educational path in physics is to reinforce them early and maintain their interest – the power of inspiring healthful of curiosity, in the educational process.

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It is hard to find the field interesting, important, 'modern' and possible everywhere. However, we have found the one and we have established the respective citizen science project. We called our project "nuclear e-cology". It is multidisciplinary research project interested eventually on the man-made heavy metal pollution, involving the environmental studies of the surrounding nature based on the atomic structure of the world, and further the structure of the atom and atomic nuclei, using the X-radiation, applying the knowledge of its origin and detection and methods of the X-ray spectroscopy and probably many more detailed subjects which could be touch by the students engaged in the project.

The general question of study the contents of things by the X-ray spectroscopy method is very wide. To make it possible for high school student we narrowed it to the research on the examination of heavy metal pollution in the roadside plants.

The detail description of the project is given elsewhere (Dam-o, 2015, Wibig & Dam-o, 2016, Dam-o et al., 2016). Here we would like to present briefly the idea and results

THE METHOD

The research is focused on the examination of the abundance and their distribution with respect to the distance from the road axis for eight heavy metals: iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), bromine (Br), rubidium (Rb), and strontium (Sr) in the plant species growing on roadside in Poland and Thailand.

The processes of collecting and preparing samples, analyzing X-ray spectra was carried out by the groups of the school students (at the age from 11 to 18), under supervision of the scientists of the "nuclear e-cology" project, in an remote laboratory fashion.

In principle, each group was expected to collect 18 biological samples on a roadside with distances from the road axis of "0", 25, and 50 meters (within the ±2 meter `accuracy' depending on availability of the plants and features of the research site). For each sample leaves of selected plant species should be collected evenly from the plants over the area of about one square meter around. The process of sample preparation consist of:

- cleaning – remove unwanted parts from plant and thoroughly rinse with distilled water;
- drying – dry the plant samples in free dust and ventilated room for 20 days or dry with drying oven at 60° C for 7 days;
- grinding – grind the dried plants into fine powder (non-fibrous) with ceramic mortar;
- packing – pack 5 g of a powder sample in a clean polyethylene bag, seal it and label the bag.

All listed items are to be done by school students. When completed, they have to send the samples to the "nuclear e-cology" central lab in Łódź (in person or via conventional mail). At the laboratory, we were responsible to further prepare the targets for the measurement and perform the measurement in the Laboratory of X-ray Methods of Jan Kochanowski University in Kielce.

In the present study, to determine the concentration of elements in the samples, the TXRF method (Klockenkämper, 1997) was used. This method is a modification of the X-ray fluorescence method (XRF) (Van Grieken R., Markowicz A. (eds), 1993) with special experimental geometry. The main idea of the XRF technique is excitation in analyzed sample, irradiated by X-rays generated in the X-ray tube, the characteristic X-rays. Emitted by sample X-rays are registered as a X-ray spectrum on which the lines of the characteristic X-rays are observed. The position of the line maximum identifies the energy of X-ray, and consequently, the element from which the characteristic X-rays were emitted. The intensity of the line is proportional to the element concentration. The total reflection X-ray measurements were performed with the S2 Picofox Bruker spectrometer (User Manual S2 PICOFOX, 2012). Typical TXRF analysis needs the sample in the liquid form. The plant ample was prepared by adding to about 0,1 g of sample 4 ml of HNO_3, 2 ml of H_2O_2 and 0,2 ml of Ga (100 μg/g) as an internal standard. Plant solution was placed in a microwave oven for the 20 s (10 s two times). Next, about 5-10 μl of solution was deposited on silicon sample carrier and dried in temperature of 40°C. This dried residuum was analyzed in TXRF spectrometer for 1000 s.

PICOFOX S2 spectrometer measures and calculates the elements concentration automatically. In presented project, we would like, however, to make this elaborated measurement process educational (more `human') to show the physic behind it. We took the raw spectrum data from the PICOFOX S2 spectrometer and used them as an input for special fitting program made by us just for purposes of our "nuclear e-cology" project.

The skill of fitting data is one of the more important abilities of the experimentalists. The mathematical models of the minimization of errors or computer programs which `fit' the data with presupposed curves do not give the students the feeing of the real power of the measurement and the uncertainty of the obtained, fitted result. If the

student can move lines with the computer mouse and see what is the effect of the change of the line width or the peak position, his/her general physics education increases substantially. The fitting procedure is not easy, anyway. We found that the very important and hard problem is to understand what the background is and how to take it into account. We have prepared the test which each student has to pass before he can start to work with the real data. He/she have to show, that he/she can adjust the Gaussian curves to the three special cases which we selected as a problems for testing.
When students were able to reasonably work with data, the files with their raw spectrum data obtained from all samples they delivered were added to the available database of the project and students can downloaded them to the Java applet available at the project web page and start the real work. They were asked to make the best estimation of the profile line parameters and to get areas under each peaks in the spectrum from each sample. There are about 150 (18 times 8) relative abundancies each described by three free parameters. This shows the scale of the project! Students were asked to put all the numbers to specially prepared Excel spreadsheet which draw the respective graphs showing the results of the measurement is a clear and consistent way. The experimental group spreadsheets were sent to us and stands for the base of the project 'global report'.

The comparison of results obtained with the professional software of the PICOFOX S2 spectrometer of Kielce lab and our project software using the method of fitting `by eye' is presented in Fig. 1. As we can see the agreement is quite good.

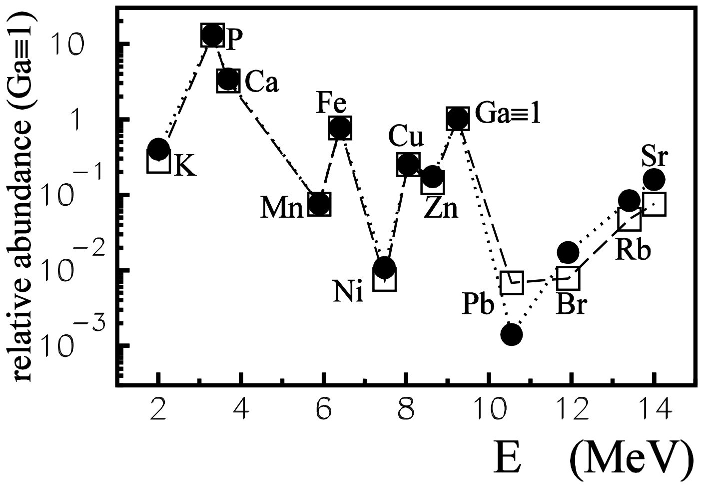

Figure 1: Net area (with respect to gallium) of analyzed element peaks analyzed using our software (solid circles) compared with the Kielce PICOFOX S2 spectrometer program (empty squares).

Results obtained from all students group were sent do our laboratory in form of individual reports. Each group finalize its experimental activity at the final web conference, where they presented findings discussed results and proposed eventual conclusions and remarks. The data from all groups were available to all the participant and some 'global analysis' are , in principle allowed. To conclude first run of the project we combined the students results and, surprisingly, we have found that they have some scientific, not only educational, value.

RESULTS

Physical results

Physical results of the "nuclear e-cology" project consists of two important findings. The first is the confirmation and even more, the quantitatively estimated character of the dependence of the heavy metal pollution as a function of the distance from the road axis. Below we present our results compared with other measurements.
The other experiments shown in Fig. 2 are based on different techniques and sometimes used different samplings, and different species, of course. Alov et al. (2007) presented results of heavy metal pollution in soil samples collected from ground surface. The results shed by Usman and Gaya (2013) are the relative concentration of iron with respect to the copper at distances very close to road edge obtained the plant species *Hyptis suaveolens* (L.). They measured trace metal concentration using atomic absorption spectroscopy. The same technique was used by Lagerwerff and Specht (1970) to measure the pollution in roadside soil and grass in US. The experiment by Zhao et al. (2010) shows the distribution of heavy metal in plants (e.g. *Gramineae*, *Cymbopogon caesius*, *Oryza stiva* L., etc.) along the sloping roadside on Mangshi–Ruili and Dali–Baoshan highways in mountaineous areas of Yunnan province, China.

Lead, considered as the most toxic among heavy metals emitted from automobiles, was studied by many research groups. In the comparison shown in Fig. 2d we compared our result to the results of Lagerwerff and Specht (1997) , Zhao et al. (2010), and also Viard at el. (2004) who the samples of atmospheric deposits were studied and Othman et al. (1997) who measure average lead levels in eggplant and parseley from agricultural lands on vicinity of two roads in Damacus city, Syria with the anodic stripping voltametric method.

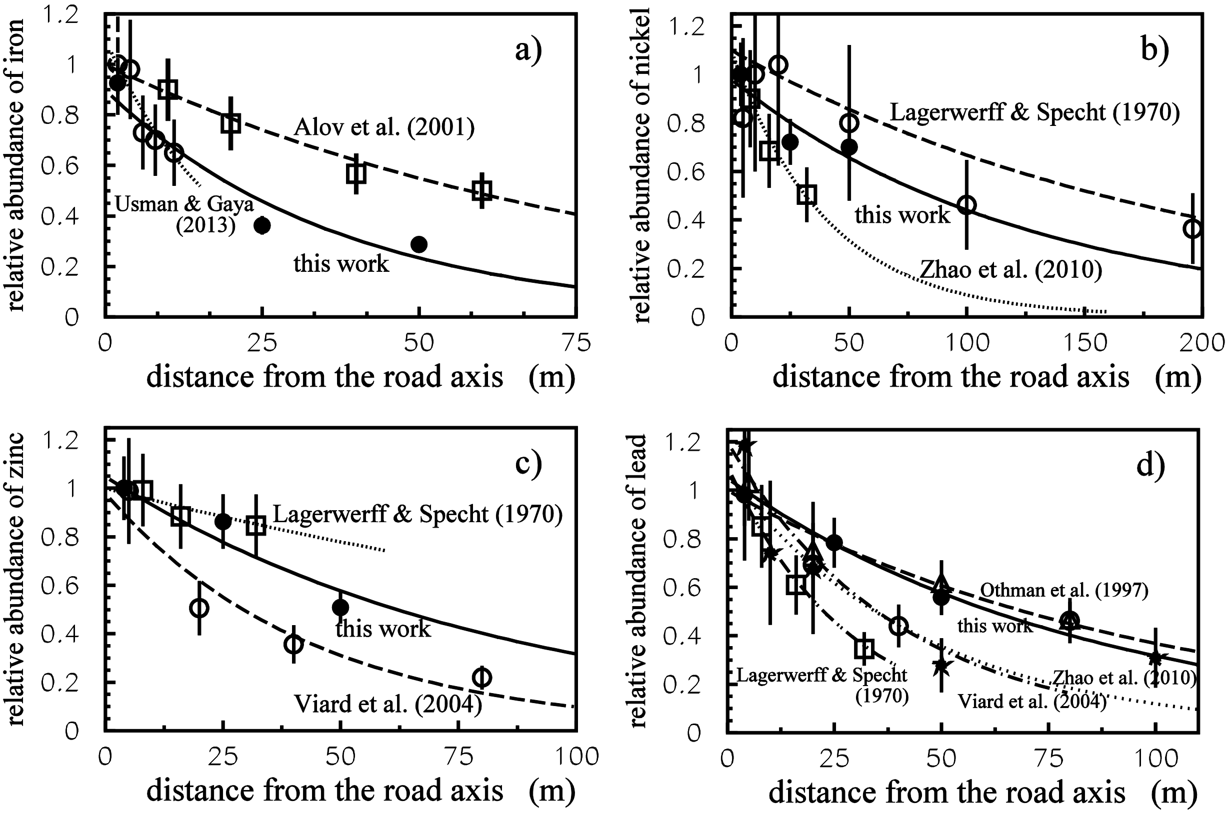

Figure 2: Relative abundances from our study (black circles) compared with other experiment results for four elements: iron (a) (Alov et al, 2001) - squares, (Usman & Gaya, 2013) – empty circles, nickel (b) (Lagerwerff and Specht, 1970) - empty circles, (Zhao et al. 2010), zinc (c) (Lagerwerff and Specht, 1970) – squares, (Viard et al., 2004) - empty circles and lead (d) (Lagerwerff and Specht, 1970) - squares, (Othman et al.,1997) – empty circles, (Viard et al., 2004) – triangles and (Zhao et al., 2010) stars. The lines shows exponential decreases adjusted to each data set. According to small statistics they should be taken with care.

No experimental results concerning the distribution of the bromine aside the road no experimental results have been published yet. Our measurement shows that the characteristic decrease length of relative abundance of bromine is of order of 50 m. It is well within the range of decrease rates of other heavy metals shown in Fig.3.

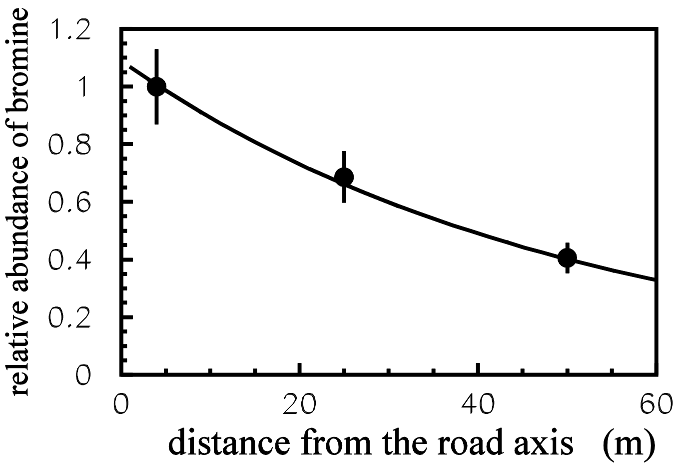

Figure 3. Comparison of decreasing relative abundances of bromine of combined data of the four research sites from our study to the studies.

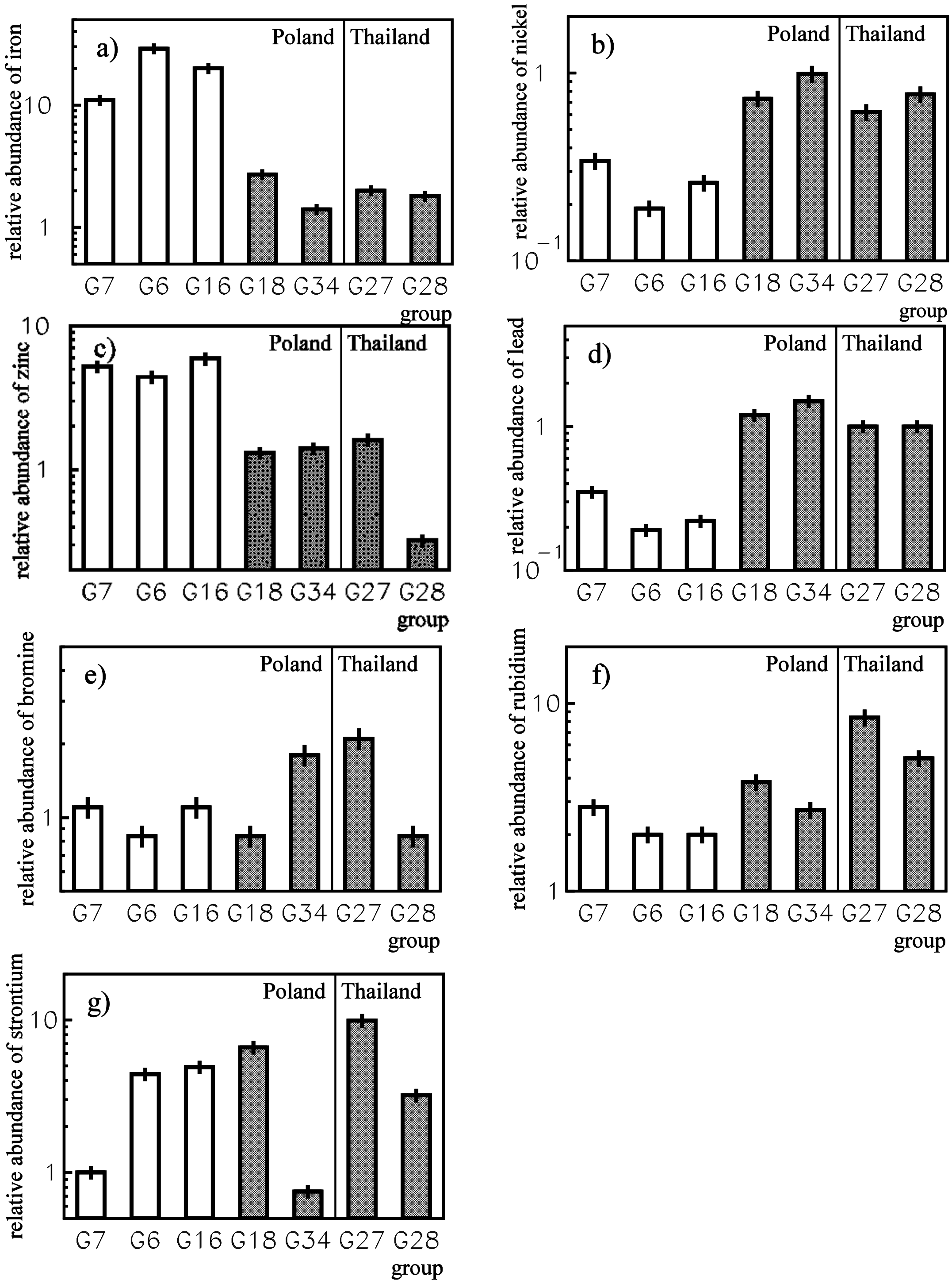

Figure 4. The average relative abundance of iron (a) and nickel (b), zinc (c), lead (d), bromine (e), rubidium (f) and strontium (g) in roadside plants of different research sites in Poland and in Thailand.

Detailed studies made by us gives the accuracy or all measured points is of order of 10%. This part of the work could not be performed by students of one group because of two reasons: first is that it needs rather deep understanding of the uncertainty theory, and the second, it used data collected by all group to estimate the spread of individual measurements.

Another finding, quite unexpected, also needs the comparison of results obtained by different groups. To conclude the first stage of the project measurements we made the comparison of the average abundancies measured by all groups and we noticed intriguing systematic discrepancy. It is shown in Fig. 4. Results of first three group (G7 - Wartkowice, G6 and G16 – Rawa Mazowiecka I and II) are systematically higher than the rest four (G18 – Łowicz, G34 – Łódź, G27 and G28 – Nakhon Si Thammarat I and II) for the iron (Fig. 4a) and lower for the nickel (Fig. 4b) relative abundances. For other elements in Fig.4: the lead behaves similar to nickel while zinc to the iron. For the bromine, strontium and rubidium the evidences of the existence of the effect are weak and rather inconclusive. Trying to understand this we ask students for additional information about their research site which could be helpful and eventually we have found that the first three groups studied sites which were effected by the roads which were build relatively not long time ago, while the other four were in the vicinity of the old roads. We set the boundary at 10 years: the first roads are younger than 10 years while the next are older. This effect was observed for the first time, and we have to say that students participating in the "nuclear e-cology" project could be proud of this discovery. They experienced, in a sense, the excitement of being the trailblazer – a kind of strong stimulus for further scientific activity.

Non-physical results

The involvement of nonprofessional scientists in "real" scientific research (known as "crowd science", "citizen science", or "network science") has become increasingly important in conservation science (conservation biology, environmental science). The open collaborative fashion in citizen science helps scientists with the large collection of data which would be impossible to examine extensively by traditional field research models because of limitations of time and resources. In the field of physics almost all citizen science projects are related to astronomy. Generally, participants are involved in inspection and classification of images of galaxies and stars (Tulloch et al. 2013a and 2013b; Franzoni and Sauermann 2014). So far, there is no project where the participants play the important role in physical experiments and which is designed to conform to physics the curricula at school level as we are going to do.

Teachers

The teachers share with us their opinions and comments about the experimental lesson. They were not only enthusiastic but gave us also important suggestions for further improvement of the project.

The positive attitude of the school teachers, who participated the project, towards the experimental lesson on X-ray spectroscopy was expressed through their suggestion to the new students to take part in the lesson. There is a case of a school, Princess Chulabhorn's College Nakhon Si Thammarat, in Thailand, where the teacher, who participated the project, is a teacher of physics teaching high school students. He has been teaching in the topic of atomic physics and nuclear physics for years. After activities in the project in the year 2013/2014, the teacher suggested students of the next academic year in atomic and nuclear physics class to take part in the experimental lesson of the "nuclear e-cology" project, as the lesson can fulfil student's knowledge of X-rays and the application of spectroscopy. In Poland the most of participants and teachers of the year 2013-14 were in secondary school level. The atomic and nuclear physics are not taught intensively at this level, so, the experimental lesson of the project was suggested as the general science activity which not rely on atomic physics and nuclear physics class.

The participation of school teachers in the project is beneficial to the project. They observe students' activities and thus they gain more information about the experiment and the project as a whole. The teachers are further able to provide their students, prospective participants, with the extended information related to the experimental lesson. It helps the prospective participants to understand what they are going to experience when they take part in the "nuclear e-cology" project. Finally the placing of the experimental lesson as an suggestive activity to school students, year after year, helps the project in maintaining momentum of the research.

Students, participants of the project

The scientific research associated with the application X-ray spectroscopy to environmental science with the experimental lesson entitled "examination of some heavy metals in roadside plants" meets interest of a number of school students both in secondary and high school level. The school students taking part in the lesson had ability to carry out the research via the prepared lesson, with the assistance of the laboratory scientists. According to the number of participants of the continuing edition in the year 2014-15, some of them were told for the lesson by their school teachers and some were told by their friends who formerly participated in the project. This implies that the lesson can fulfil teaching and learning physics at schools. However, the lesson may be not appropriate for every school students. There is the number of participants who quitted the project before the completion of all assignments. The reasons why they have quite the project given by those participants are mainly:

- some school students were not really interested in the lesson (scientific activity). This situation happened in one case of 7 groups registered from the same school. They did not find the scientific activity of interest by themselves, except for their teacher. They completed activities on field work and preparing samples but they did not have intention to learn physics and to analyze spectra,
- some school students were not longer interested in the lesson. This happened to 6 groups of students who all were studying at the first year of secondary school (12–13 years old). It seemed that at the beginning

they were eager to participate, however after they have got a few assignments from the laboratory (e.g., study experimental instruction, survey roadsides, practicing the fit software), they declined their interest.

This information indicates that the activities of the experimental lesson of X-ray spectroscopy should be introduced to school students mainly for the groups of gifted students and students who are interested in science. Students of these groups are potentially able to learn some new and advance subjects in physics and they have self-motivation to carry out the scientific research and to find the results.

Importance of the meetings and e-mail/teleconference sessions

Activities in the experimental lesson were arranged in the way similar to the experimental class at schools that the school students were assigned to work into groups and have a laboratory scientist (instead of a teacher at schools) play the role of lab supervisor. The communication between the experimenters and the lab supervisor aided by the Internet application, especially via video conference (e.g. Google Hangout), is very useful here, because:

– it allows the lab supervisor to help the participants to efficiently conduct the experiment by giving clear instruction, explaining the significance of the activities, encouraging the participants to find out the answer and pointing out potential problems,
– it allows the participants to meet, ask and discuss any problem related to their work with the laboratory scientists that they could perceive the real existence of the laboratory and believe in the real collaboration, not just learning from materials presenting on the web pages,
– it allows the participants to meet other students to exchange data in real time,
– it is flexible as the meeting participants can join video conference from for example laboratories, schools, homes, etc. and it is obviously cheaper and faster than in-person meetings.

For e-mailing, it allows us in regular correspondence for such as updating news, sending information of learning materials, arranging appointments including questioning/answering miscellaneous topics. The idea of communicating approach via teleconference is one of the strongest point of the project offered to the participants, which other distant laboratories could not offer for education purposes. We found by personal observations and from remarks of school teachers using computer simulations and remote experiments on the web, that when a student questions arise, in most cases there are no one who gives the answer or advice. After such experiences, students interest of study on the internet fades out. In order to retain the learners' attention on such distant learning the activity of teleconference (as well as e-mailing) is necessary.

We also arranged a number of meetings at some schools in the area of Lodz Province. It was not regular activates in the general plan for every participants' groups. As the project was newly found, we would like to meet the participants and school teachers in-person and establish long-term relationship. Certainly, the in-person meeting is more efficient than teleconferences. However, the in-person meeting is not as flexible as the teleconference is and it requires some expense for travel.

Report of the group

In general, the school students have some experience on writing lab report (a simple one) in science class since the first year of their secondary school level. Besides dealing with many data sets, the experimental report which they had to write in the "nuclear e-cology" research is nothing extraordinary. It consists of the part of results (with table of data and graphs) which requires data from spectra analysis. The participants were able to complete this part correctly in most cases. This demonstrates that they have learnt about deconvolution of X-ray spectra and the method of spectrum analysis. It can be supposed that if these students would be involved in the work related of spectrum analysis, they will understand what the spectrum is, how to get data from that raw spectrum and how the spectrum analysis programs works. The second part of the report is the part of discussion and conclusions. Students describe there all the findings emerged from the group studies with possible or supposed explanations. Generally, the participants were able to give some explanation with logical, clear manner and straightforward form. However, some weak point appeared quite often and need to be explained and clarified. The main problem is the measurement uncertainty. Students usually wrote what they directly had seen in the graphs. If one point is below the neighboring points the usual claim is that the particular element abundance decreases at particular distance. The little deeper analysis sometimes shows that this is an effect of one, single sample, one contaminated spectrum, or even one wrong net area estimation or mistake in the record file. The scientific criticism seems to be not established yet. The usual childish scrutiny are far too less for our purposes. The "nuclear e-cology" project is the possibility to introduce the scientific methodology also in this aspect. The analysis of the uncertainty is crucial, but it can be applied only in a qualitative way. It can be assumed that students in general do not know what the uncertainty is and how to take it into account in the analysis. The one way is that the laboratory scientists should introduce to the students the way to roughly estimate the uncertainty and show them how to use it. When succeeded, it will be an important step for the students experimentation skills.

Reports of students' groups were reviewed by us, laboratory scientists in a iterative way: participants' group submits the report, the lab scientists check it and give them, if necessary, the feedback comments, which were used by the students to improve the report and submit it again. The procedure continues until the final report is created. Information in participants' report about feature and environment of the research sites, traffic rate data, road category, road age, etc. was found very useful in the understanding of the 'global' general results.
From the environmental science point of view, the students addressed their concerns about environment through the discussions and questions of possible causes, sources and impacts of heavy metal pollution, solution of reducing and removing heavy metals accumulating in roadside soil and also ways to prevent emission of the heavy metals from road transportation.

It should be mentioned that all data from the study are recorded in the research database available on the website of the project where anyone can access.

CONCLUSION

Summarizing the physical side of the "nuclear e-cology" project we examined the relative abundances of iron, nickel, zinc, lead, bromine, rubidium and strontium in roadside plants along different studied sites in Poland and Thailand with the X-ray fluorescence spectrometry method. Two general findings are reported:

1. It was found that some heavy metal pollution observed in the analyzed samples depends on the age of the road.
2. It was found that the relative abundances of iron, nickel, zinc, lead and bromine decreased with the increase of the distance from the road.

In more details:

1a. The level of pollution in the plant samples in the vicinity of the roads built earlier than 10 years ago are by no means different than for the new roads.
1b. The difference depends strongly on the particular element.

2a. The distance dependence confirms the effect of the road transportation as a source of these element pollution.
2b. The average characteristic decrease length of the relative abundances of iron, nickel, zinc and lead was estimated to be in the range of 40 – 80 m.
2c. For the first time the decrease pattern was observed for the relative abundance of the bromine. The average characteristic decrease length for bromine pollution is about 50 m.
2d. It was established that the relative abundances of rubidium and strontium did not exhibit a regular gradient as a function of distance from the road. These two heavy elements are probably not derived, mainly, from the road traffic.

From the educational point of view the summary could be made in one sentence: we have created the citizen science project "nuclear e-cology" which involved school students to do research on the important region on the edge of physics, ecology, biology, environmental and nature monitoring/conservation science and, what is more important, we have shown that it works in practice.

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