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CITIZEN SCIENCE PROJECT NUCLEAR E-COLOGY; SCHOOL STUDENTS' KNOWLEDGE ON X-RAY AND NUCLEAR PHYSICS

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Abstract: We studied the basic knowledge of the nuclear (modern) physics of the high school students participating in our citizen science project "nuclear e-cology". The initial test was conducted before they start any activity. The test was designed for quick answers. It consists of ten multiple choice questions. The test participants can complete it, available also on the internet, with unlimited time. We wish to present here some results. They were analyzed in four categories: all together, by country, by educational level and by gender. Results are based on 223 test answers from Polish, Thai and Russian students. This knowledge have been used for preparations and improvement of the educational materials used in the "nuclear e-cology" project.

Keywords: Citizen science, modern physics education, comparative studies

Introduction

Road transportation activity, a primal component of economic development and human welfare, is increasing around the world as the economies grow. Road traffic has been highlighted as a major source of heavy metal emissions. Consequently, the rise of the road transportation activity causes the higher levels of emitted metals, which impact the ecological environment on the roadside and the surrounding areas such as farmlands, pastures, rivers and residences. Heavy metals enter the food chain as a result of contaminating edible plants or their intake by people and can cause serious health risks.

Proposed research project of the examination of heavy metal pollution on roadside is developed in the citizen science way and for worldwide secondary school students through the internet project entitled "nuclear e-cology". Details are given in (Dam-o, 2015, 2016 and Wibig and Dam-o, 2016). The knowledge which students gain can be a supplement of learning modern physics at schools participating in the project but also a foundation for learning physics on higher educational levels. To accomplish this we should determine the starting point the level of modern (nuclear) physics knowledge of school students and the actual educational possibilities at research centers, scientific labs and universities.

Modern Physics Experiments on Radiation Physics For School Students

Creating the experimental lesson on radiation physics for school students, the present-day curricula at schools and universities as well as physics laboratories available for school students were studied. We focussed on nuclear physics.

Nuclear Physics Curricula at Schools and Universities

Nuclear physics is introduced for curricula in the educational system and people appreciate its advantages and aware of its dangers. Students learn the nuclear physics for the lifetime at the school age only. If ones want to be

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involved in physics career, they could continue education in physics program at university level. Physics curricula at schools are based on national the core curricula. Students in science program are taught nuclear physics at the last years of high school level. The prerequisites are basically the atomic physics. In general, nuclear physics at schools is composed of few subjects: the nuclear structure and properties, isotopes, radioactive decay, nuclear reaction (fusion and fission), mass-energy equivalence, advantage and disadvantage of radioactivity including radiation safety. Additional topics (e.g. nuclear energy, nuclear physics for agriculture, archaeology) and experiments (e.g. rolling dice to simulate radioactive decay, radioactivity counting) can be flexibly added under consideration of the physics teachers.

At the university level, physics curricula are postulated by faculties of physics. Students in Bachelor of Physics study nuclear physics at the third year. The prerequisites are subjects related to quantum mechanics, modern physics and atomic physics. Theoretical part is mostly separated from experimental part. Generally, theoretical part is composted of the topics similar to school level ones with extended details, plus new topics of scattering theory, nuclear models, nuclear resonance, accelerator and nuclear reactor physics. There are cases when the subjects such as semi-empirical mass formula, induced nuclear transformation, kinematics and dynamics of nuclear reactions and general features of atomic and nuclear spectroscopy are introduced additionally. In the experimental part, students perform particle/radiation counting, single and multi-channel energy analysis, absorption coefficient measurements, radioactive decay study, transient equilibrium, nuclear magnetic resonance, interaction of charged particles, δ-rays and neutron interactions with matter, gamma or mass spectroscopy.

Physical Experiments Available For School Students

It is known that physics is a science based on observations and investigations. The experiments are used in schools to motivate students, provide concrete examples of complex concepts, improve understanding of technical apparatus, and verify predictions of theories or models. To teach modern physics there are various resources for experiments available for school students: at school laboratories, science centers, scientific institutes, universities, and e-laboratories (e.g. computer simulations, remote experiments).

School Laboratories

Generally, in experimental class, students have to work into groups consisting of 3 – 4 people. The teacher plays a role of the lab supervisor who helps students to efficiently conduct the experiment by clearly explaining the significance of each activity, providing specific and clear instruction, encouraging experimenters to search for the answer and pointing out potential problems. However, all depend on availability of apparatus. The lack of the equipment is a usual situation, and physics teacher has to use the lab demonstrations or lecture demonstration instead.

For the nuclear physics, there are two experiments suggested in high school physics textbooks; the first is rolling dice to simulate radioactive decay and radioactivity counting (Jona and Vondracek 2011; Murray and Hart 2012) and the experiment on radioactivity counting. We searched at a few online shops (e.g. Amazon, Anythingradioactive), and we found that they offer the Geiger-Müller counter for prices starting from ~100$ and radioactive sources (also pieces of minerals) from 10$, and a special storage box (for radioactive source) made of lead at 15–30$. The rolling dice experiment are much cheaper, but their attractiveness is much smaller, and it is in fact is a toy model of real modern physics experiment.

Out of School Laboratories

The visiting out of the school places of learning may enhance students' motivation in science (Schmidt, Fuccia and Ralle, 2011). Students can see, or even participate in, experiments that are relevant to current scientific issues, in an authentic environment. Many schools have annual programs for visiting extracurricular places of learning, e.g. science centers/museums, university laboratories, scientific institutions. Few examples are:
at science centers/museums:

the Ontario science center in Canada, participants will have the chance to test different combinations of materials to see how effective they may be at blocking intense radiation,
the national science and technology center (Questacon) in Canberra, Australia, on special event such as Grey Day, participants will have chance to learn about radiation and how it is absorbed,

at universities: the Center of Scientific and Technological Equipments of Walailak University in Nakhon Si Thammarat, Thailand, offers schools the scientists and laboratory facilities where school students can experimentally study radioactivity using the Geiger-Müller counter,
the nuclear engineering program of Texas A&M University in US, prospective students are invited to visit nuclear reactors and research laboratories all year long,
at scientific institutions:

the school labs of the Helmholtz Center in Hamburg, Germany, offer the Day Activity of experiment in nuclear physics (topics of shielding, magnetic field, scattering, half-life, and distance law) for students of grade 9th and 10th, the education programs guided tours, at the summer school at CERN in Geneva, Switzerland, participants will learn about particle physics, accelerators, and CERN experiments, the Institute of Nuclear Physics PAN in Kraków, Poland, provides sightseeing of selected laboratories of the Institute and participants can also choose the workshops which they would like to attend for learning nuclear physics. In addition, to visit out of school laboratories, prior date arrangement and sometimes the entrance cost might be required from participants.
e-laboratories

The e-laboratories refer to computer simulation and remote laboratories (for real experiments) which allow users to access through the on-line or off-line computers. This type of laboratories is flexible, no time and place restrictions, but does not provide students with hand on experience and lab supervisors. Examples are:
the computer simulations:

the website of PhET Interactive Simulations, University of Colorado Boulder, provides interactive simulations of alpha decay, beta decay, nuclear fission and radioactive dating game,
the remote laboratories:
the iSES e-laboratory in Czech Republic offers the remote control experiment for learning protection against ionizing radiation by distance and shielding;
the remote laboratory center for Australian is devoted to science and math education for high school students: FAR (Freely-Accessible Remote) Labs is a project led by the department of physics at La Trobe University. It provides Australian students with the exploration of different radioactive sources/barriers and inverse-square law;
the iLab Network of the Massachustts Institute of Technology and Northwestern University, gives school students access to the remote radioactivity laboratory for learning Inverse-square law.

School Students' Knowledge On X-Ray And Modern Physics

Before preparation of our "nuclear e-cology" lesson, the initial test was conducted among school students of secondary and high schools levels of Poland, Thailand and Russia, where the lesson was announced in the year 2013. This test was aimed to survey background knowledge of school students about modern physics and X-ray in particular. Results from the test were used in the planning activities and creating the materials for school students. The test was designed for quick answers. It consists of 10 multiple choice questions. The participants can complete the test, also on the Internet. The results were analyzed into four categories;
general (in total) – 223 school students;

by country – 114 Polish, 20 Thai and 90 Russian school students;
by educational level – 124 secondary school and 100 high school students;
by gender – 123 girls and 86 boys.
Questions from 1 to 6 were on theoretical part of atomic and nuclear physics. The first two questions were about constitution of atoms which is basic knowledge that the students have to know before learning about subatomic structure and property.
The general results of question 1 were shown in Fig. 1.

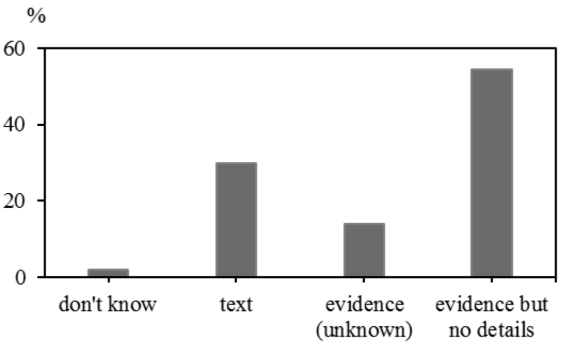

Figure 1. The results for the general category of the question 1: *how do you know that matter is made up of atoms?*

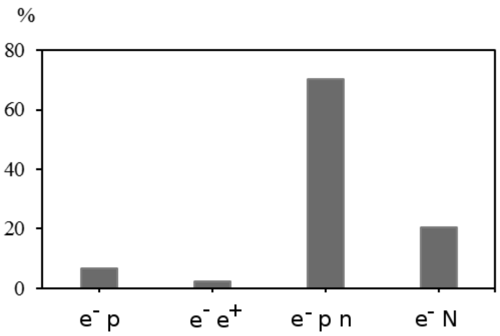

Figure 2. The results for the general category of the question 2: *what are atoms made of?*

Most of the test participants, at 98.0% of all, knew that atoms are constituents of matter. About 1/3 of them believes what they have been told, 2/3 believes that there are some (physical) evidences.

Question 2 goes deeper: what is inside atoms, and the general results show in Fig. 2. All categories shown the same results as shown in Fig. 2. Distribution of answers among possible choices for different categories (country, educational level and gender) has again no any significant difference. Over 90% of the test participants knew of what atoms make up. This number confirms that some school students, mostly of secondary level do not know anything about constitution of the atom.

Question 3 and 4 were about nuclei instability. In question 3, the test were asked to specify unstable nucleus. Results are shown in Fig. 3.

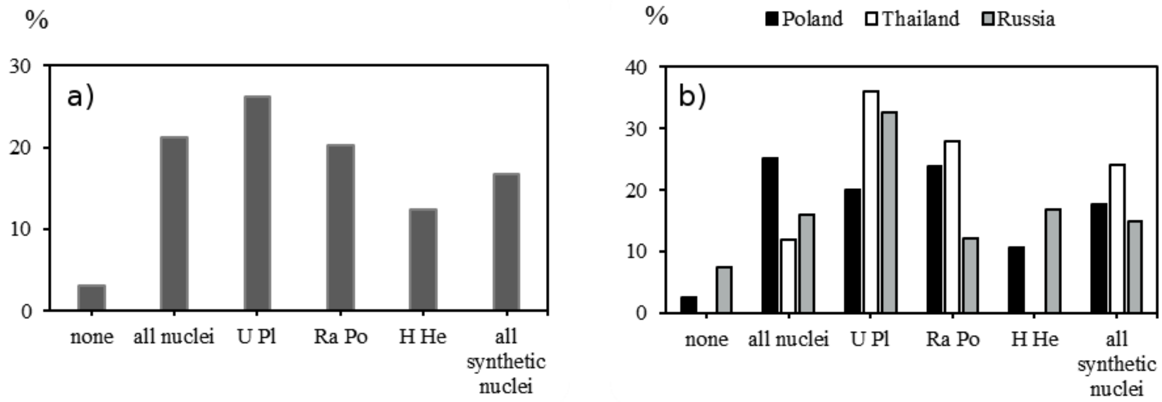

Figure 3. The results for the general category (a) and country category (b) of the question 3: *which nucleus is unstable?*

The answers in Fig. 3 (a) are scattered among the choices both right and wrong. This can indicated that there is a fraction of test participants who has a knowledge on nuclei stability. Among three countries (Fig. 3b), percentage of Thai participants who selected the right answers is higher than Polish and Russian participants. This would be an effect of different physics curricula. It should be noticed also that in case of Polish participants the selection of polonium and radium was preferred. It is obvious because these elements were discovered by the famous Polish scientist – Marie Curie (Curie-Skłodowska, or Skłodowska-Curie in Poland).

Question 4 again test deeper the participant knowledge about the unstable nuclide. Results are shown in Fig. 4.

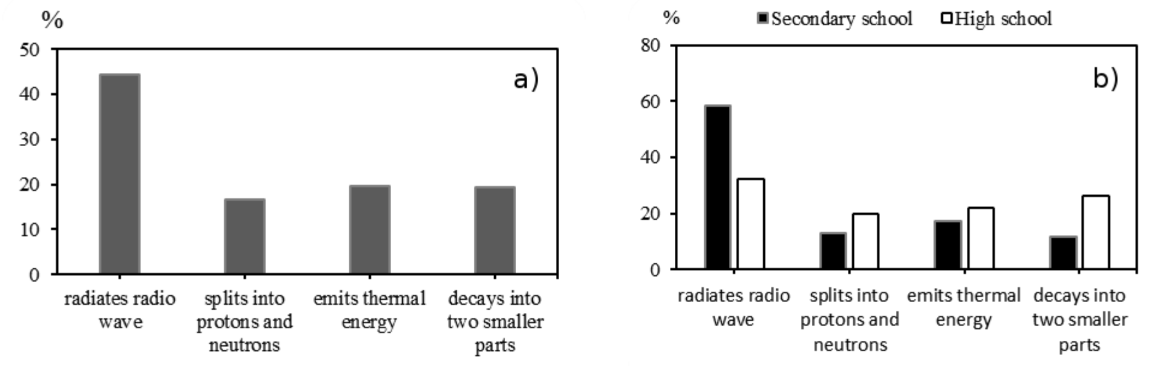

Figure 4. The results for the general category (a) and the educational level category (b) of the question 4: *what might happen to an unstable nucleus (radioactive)?*

The most popular answer was the first choice: "radiates radio wave", 44% of all answers. The other three answers were chosen roughly the same rate lower than the half the first one choice (Fig. 4a). The significant effect of school education is seen when compare the percentage of the right answer for secondary and high school students. This result confirm that the big number of the test participants had not taught about radioactivity at schools yet.

Question 5 was about particle accelerators, what our test participants knew about the basic principle of particle acceleration. Results are shown in Fig. 5.

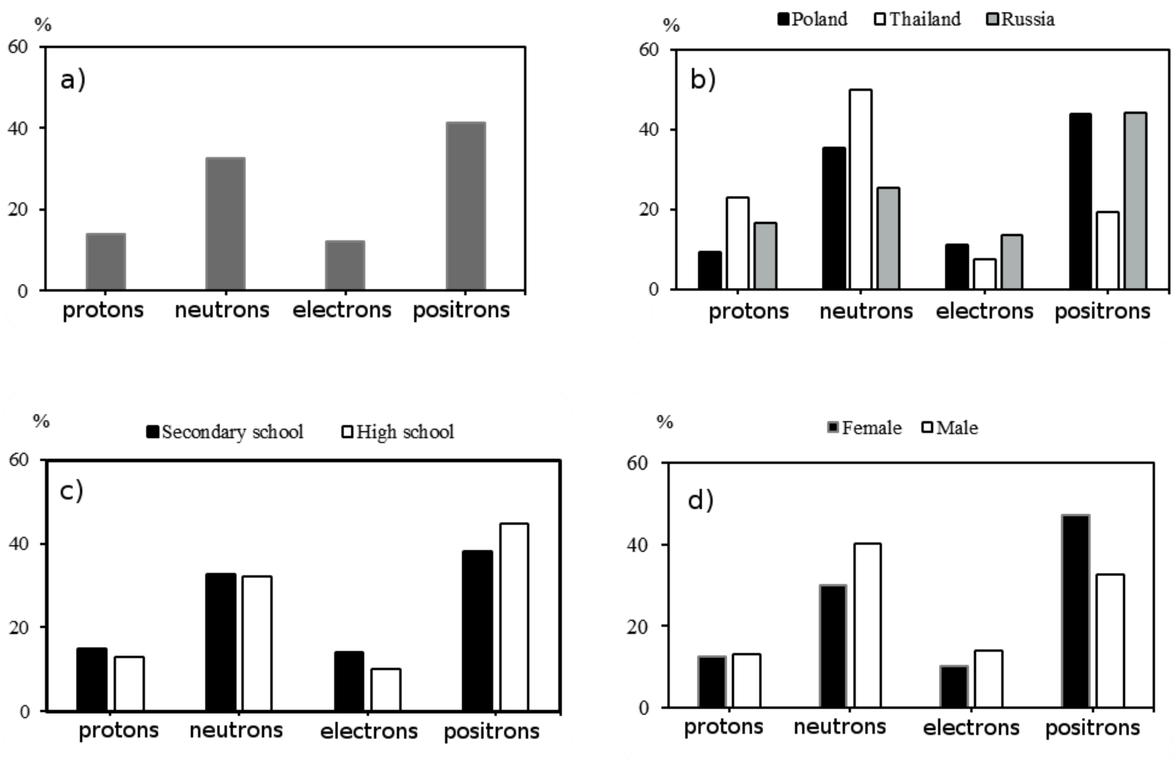

Figure 5. The results for the general category (a), the country category (b), the educational level category (c) and the gender category (d) of the question 5: *what particles <u>cannot</u> be accelerated in accelerators (cyclotrons)*?

The results of all categories in Fig. 5 show rather randomly distributed answers with the slight preference of the best known particles: protons and electrons. It might imply that school students did not know much (at even nothing) about acceleration principles, and school education does not help here as we can see in the Fig. 5c. However, some differences can be found comparing different countries analysed (Fig. 5b). In Thailand the knowledge on particle physics seems to be higher what corresponds with results for question 3. It is interesting that the differences are noticed also for the gender category (Fig. 5d).

Question 6 was about the contents in living matters. The results are shown in Fig. 6.

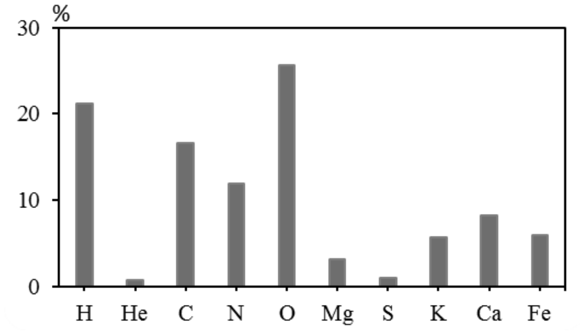

Figure 6. The results for the general category of the question 6: *select the first three chemical elements, which are the highest content in living matter (plants, animals).*

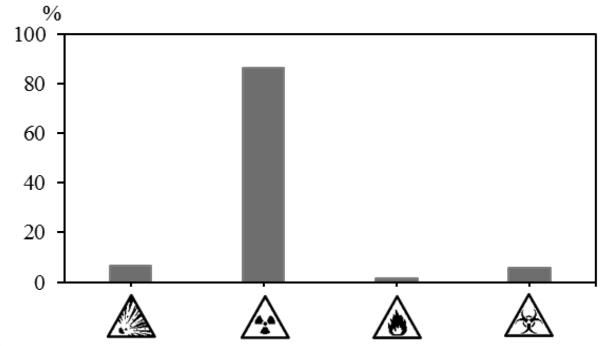

Figure 7. The results for the general category of the question 7: *which sign is the radiation warning sign?*

The answers shows that in school students knew the basic elements in living matters. We consider that this knowledge however did not originated on physics lessons but rather chemistry or biology.

Last three questions were about radiation in people's live. Answers to the simple question 7 was about caution sign (Fig. 7) show that most of the test participants knew the radiation warning sign. The results might reflect young people's (and the general also) awareness of radiation safety.

Question 8 was about application of X-rays. The results are shown in Fig. 8.

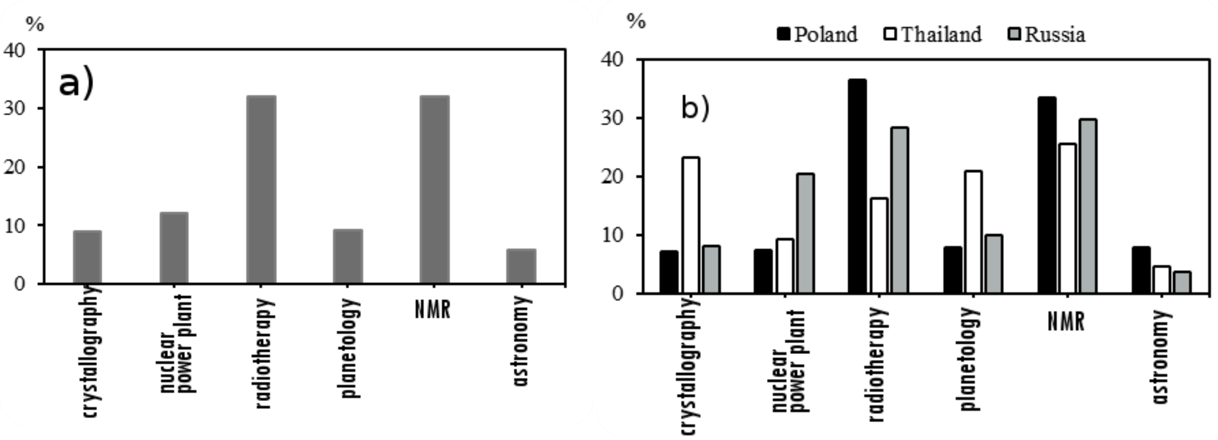

Figure 8. The results for the general category (a) and the country category (b) of the question 8: *select field which uses electromagnetic wave in the range of X-rays.*

The results of all categories in Fig. 8 showed that application of X-ray in radiotherapy was rather well-known among the participants. It was noticed that the nuclear magnetic resonance imaging which is an application of the quantum mechanical properties of nuclear spin (not X-rays) was selected very often. Again 1/3 of test participant appears to know very little about the modern physics and its applications. The interesting difference is also seen for the Thai children' answers when compare to Polish and Russian students. It corresponds to results on questions 3 and 5.Question 9 was about exposure to X-ray radiation of people in different circumstances and the last question was about the children opinion about the environmental effects of different kind of electric power plants. Results were shown in Figs. 9 and 10. According to the opinion of more than 90% test participants three professions: radiologists, nuclear physicists and airport security staffs had contact to X-rays. It shows that the opinion of the profession nuclear physicist is rather far from the real situation. It could be one on many reasons not taken yet into account for the lack of willing to study physics in general.

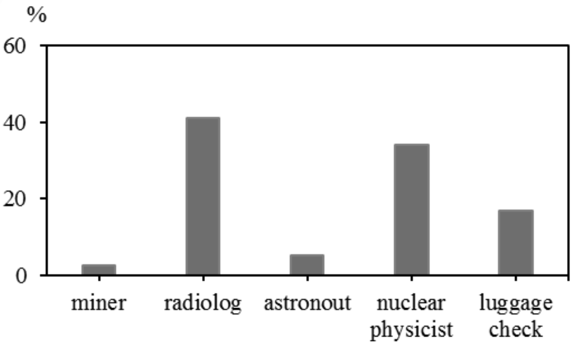

Figure 9. The results for the general category of the question 9: *what profession has contact to X-rays?*

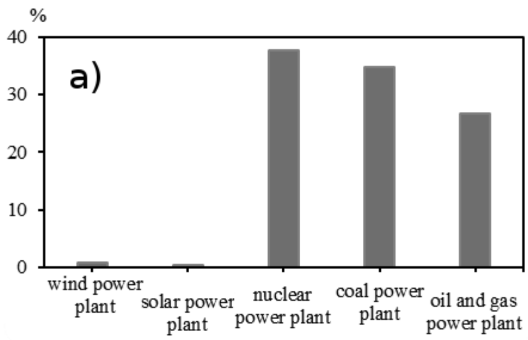

Figure 10a. The results for the general category (a) of the question 10: *select large-scale energy-producing technology which is the most harmful to environment.*

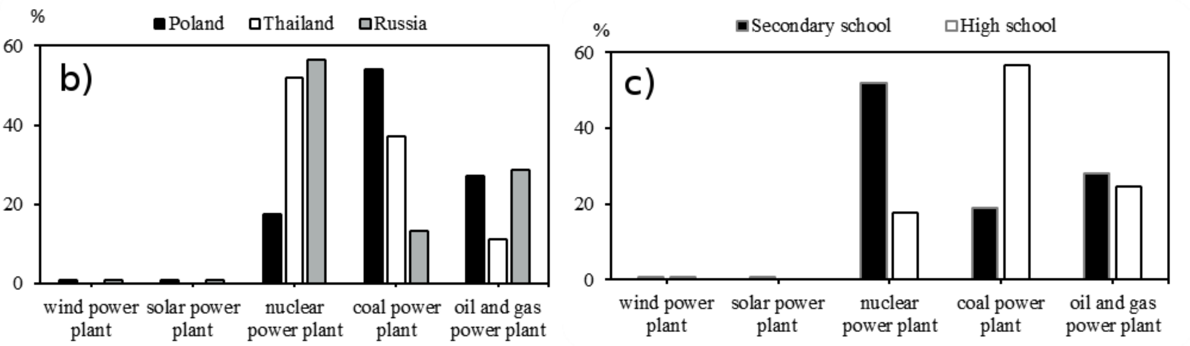

Figure 10b,c. The results for the country category (b) and the educational level category (c) of the question 10*: select large-scale energy-producing technology which is the most harmful to environment.*

Concerning the environment effect of power plants it is obvious that almost no one chose the wind and solar power plants as the worst solution for the future, but there is surprisingly clear country difference, seen in Fig. 10b. The majority of school students in Poland, the country where the electricity is generated using coal power plant technology, considered technology of coal burning the most harmful to the environment. The majority of students in Russia, the country producing electricity using also nuclear technology, considered technology of nuclear power plants the most harmful. The Chernobyl disaster effect is also probably important here. Students in Thailand, the country producing electricity mostly from fossil fuels (oil and gas, mainly) with no nuclear power plants, considered technologies of nuclear power plants and coal burning comparably harmful to environment. Interesting is also the abnormal change of preference between the secondary and high school levels.

Conclusion

The information emerging from results of our test allows us to conclude that school students at secondary and high school levels have a foundation necessary for start activities in our “nuclear e-cology” project. The experimental lesson on X-ray spectroscopy could be based, partially, on the knowledge possessed by school students and it is possible to introduce proposed experimental lesson to school. Summarising the questions about particle accelerators, uses of the radiation, and the exposure to the radiation, show that knowledge on X-rays and the modern physics of school students is limited by simple contents suggested in school curricula in physics. School students who are interested in physics, generally are expected to know more than that simple knowledge written in a school textbook. The experimental lesson associated with an up-to-date technology of X-rays would advantage such school students who are interested in physics for learning physics at the higher level. However, since some parts of the lesson (e.g. identification of elemental emission lines, X-ray spectrum analysis) are new and may be difficult for school students to understand just from the textbook on the Internet page, the variety of types of learning material, such as tutorials and demonstration video clips, examples of research papers, etc., have to be prepared for them. The actual state of the knowledge of the prospective participants of “nuclear e-cology” project has to take into account for the creation of appropriate and effective educational materials

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