Isotopic Methods in Environmental Studies and Environmental Protection

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Abstract *- The specialization called "Isotopic Method" was appointed in the Faculty of Mathematics and Physics, Silesian University of Technology in year 2009. The graduates of this specialization will be prepared to undertake the professional work in the field of physical experimental methods in research and protection of natural as well as working environment, including strongly transformed industrial environment. The mainly emphasized experimental education is the application of advanced methods and measurement techniques in radioisotope and luminescence investigations in the environment. The measurements of luminescence of rocks and minerals, and radioactivity and concentration of natural and anthropogenic radioisotopes, as well as stable isotopes of light elements in lithosphere, atmosphere, biosphere and hydrosphere, enable the reconstruction and monitoring of environmental change in recent time as well as in more distant past. The main emphasis of professional education is given to application of advanced methods and measurement techniques enable to reconstruct and monitor the environmental change and construction of absolute time scales for the events in Earth history as well as for human civilization development. There is a strong need for interdisciplinary education in physics, natural and historical sciences in order to cooperate profitably in frame of future research projects.*

Index Terms *– Archaeology, Environmental physics, Environmental protection, Geology, Isotopic studies*

EDUCATIONAL ACTIVITIES

Full time studies

The GADAM Centre of Excellence (Gliwice Absolute DAting Methods Centre) concentrates its activities on basic research into radioisotope methods; radiometric and luminescence methods of absolute dating; and stable isotopes and their applications. These disciplines are of the great importance for the development of other sciences, namely geology and other earth sciences, environmental sciences, and archaeology. The Centre focuses its work on methods that provide different climate proxies and climate related data; carbon and oxygen stable isotope ratios are used as palaeothermometers; information about global carbon cycle; data regarding changes in solar activity and Earth's magnetic field; information about contemporary and past soil erosion and sedimentation processes in different environments; chronological framework for geological and environmental processes and for archaeological cultures in different time scale. The staff of the Centre is involved in education activities of the Faculty of Mathematics and Physics, Silesian University if Technology. In order to make use of the scientific potential of the Centre's scientists, two specialisations were created. They evolved from the specialisation called 'Environmental physics' that was started in the first half of nineties of the last century in that faculty. These two new specialisations are 'Physics in environmental protection' and 'Physics in earth sciences and archaeology'.

The graduates of 'Physics in environmental protection' will be prepared to undertake professional work in the field of physical experimental methods in research and protection of the natural environment as well as working environment, including strongly transformed industrial environment.

A separate thematic block comprises subjects of basic physical acoustics, physics of noise, vibroacoustics, and various acoustic hazards of natural and working environment. Specialists in this field may find employment in a range of institutions connected with the monitoring of the environment, ecological institutes, and medical institutes.

The syllabus posits large independence of study by incorporation of seminars aimed at training in current professional literature. Most of the fundamental and professional subjects include not only lectures, but also a significant amount of laboratory training.

The program of study includes several blocks of subjects of fundamental education, comprising of:

- fundamentals of experimental physics,
- mathematical subjects,
- fundamentals of computer sciences and computerized measurement systems,

- fundamentals of electrical and electronic measurements.

The essential specialised education of 'Physics in environmental protection' comprises following thematic blocks:

- geophysics and physics of atmosphere,
- measurements and dosimetry of nuclear radiation,
- radiation protection,
- isotopic control of food and fuels,
- acoustic measurements and noise protection,
- technologies in environmental protection,
- biology, ecology, and soil protection.

The main emphasis of professional education in "Physics in earth sciences and archaeology" is given to application of advanced methods and measurement techniques in radioisotope and luminescence investigations; these techniques enable the reconstruction and monitoring of environmental change and the construction of absolute time scales for events in Earth history as well as for human civilization development. There is a strong need for interdisciplinary education in physics, natural and historical sciences in order to cooperate profitably in the framework of future research projects. The diversity of natural education and the possibility to undertake pedagogical courses enable the graduates to become teachers as well. The syllabus comprises several blocks of subjects of fundamental education, like the "Physics in environmental protection" specialisation, and a following block of professional subjects:

- measurements of nuclear radiation,
- mass spectrometry,
- geosphere and matter circulation,
- palaeoclimatic changes and methods of their reconstruction,
- dating of rocks, minerals and archaeological objects by means of isotope methods,
- history and archaeological dating of cultures.

Extramural post-diploma internet studies

The GADAM Centre also launched extramural, non-resident, post-MSc studies assisted by Internet "Methods of absolute dating and applications". The aim of this course is the integration of different disciplines at the university level and supplementary interdisciplinary education for natural science graduates, earth science graduates, and archaeology graduates. Upon completion of the Course and defending a thesis the student will receive a diploma certifying the completion of post-MSc studies. The language of the studies is English.

The objectives of the Post-MSc course "Methods of absolute dating and applications" are:

- encouraging young researchers specialised in archaeology, earth sciences, and environmental sciences to apply absolute dating methods in solving problems relevant to their research work,
- acquainting young researchers with isotope and radiometric methods used in investigations of natural and human transformed environment,
- dissemination of information about dating methods and isotope methods among natural and earth scientists, and archaeologists,
- education of students in physical basis of dating methods and isotope methods with respect to palaeoenvironmental aspects of possible applications of these methods,
- preparing young researchers for work in interdisciplinary research teams.

Detailed information about both MSc graduate and post-graduate studies can be found on the web-site **www.carbon14.pl/education.html.**

MAIN TOPICS OF SCIENTIFIC BACKGROUND

Isotopes in contemporary environment

All elements occurring in nature have up to several varieties that are called isotopes. Some of these isotopes are stable (e.g. hydrogen isotopes ^{1}H, ^{2}H, carbon isotopes ^{12}C, ^{13}C, oxygen isotopes ^{16}O, ^{18}O), others are unstable (e.g. hydrogen isotope ^{3}H or carbon isotope ^{14}C). The unstable ones undergo radioactive decay. In this process ionising alpha, beta, and gamma radiation is produced.

The isotopic composition of various elements (e.g. carbon, oxygen, hydrogen) can give us information about the human impact on the environment, as well as it enables us to observe various processes in the natural environment.

To start with let us consider carbon isotopes. The two stable isotopes occurring in nature are ^{12}C and ^{13}C whose natural abundance is about 99% and 1%, respectively. Another isotope occurring in nature is ^{14}C – an unstable isotope of a half-life equal to 5730 years, which is cosmogenic, i.e. it is constantly being produced in the upper part of the atmosphere so that its concentration in atmospheric carbon fluctuates only slightly. ^{14}C is used for dating of mainly organic material – a living organism absorbs carbon from the environment during its life in the form of food (animals or humans) or air (plants). After its death the accumulated ^{14}C decays. Measuring ^{14}C concentration in an investigated object it is possible to determine how long the organism had been dead.

During various chemical and physical processes (for example assimilation of carbon) there is a phenomenon called isotopic fractionation – a different rate of reacting due to differences in weight. E.g. the concentration of ^{13}C in plants will differ form that in the surrounding atmosphere [1]. The difference also depends on the type of metabolism occurring in a given plant. Hence, in the natural environment there are natural fluctuations of isotopic composition of different elements. Similar considerations are valid for other elements, like oxygen or hydrogen.

The measurement of the fluctuations of isotope composition can give us information about natural processes or human impact on the environment. A good example is the use of carbon isotopes for estimating the influence of fossil fuel burning on the environment. Fossil carbon is ^{14}C dead (i.e. it does not contain any ^{14}C because all the ^{14}C decayed during its burial); it also has a different ^{13}C concentration than the current atmospheric carbon. Therefore burning f large quantities of fossil carbon will change the concentration of ^{13}C and ^{14}C in respect to that one that would have been observed without it [2]. This phenomenon is nicely recorded in annual growth tree rings [3, 4]. The isotopic composition of the carbon extracted from tree rings is a reflection of the isotopic composition of carbon in the atmosphere.

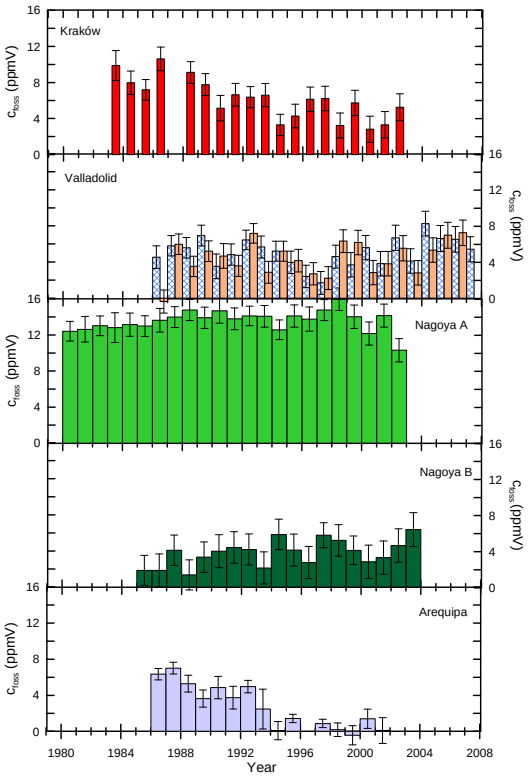

Figure 1. Changes of fossil fuel component (c_{foss}) of CO_2 concentration calculated from radiocarbon concentration in annual tree rings.

Other examples are ^{137}Cs and ^{134}Cs – isotopes that do not occur in the natural environment. They were produced in large quantities in the atmospheric nuclear tests in the 50s and 60s and in much smaller quantities during the Chernobyl accident. ^{134}Cs has a much shorter half-life than ^{137}Cs and it decays relatively fast after release. But ^{137}Cs has a sufficient half-life to be applied as a valuable sediment tracer in environmental studies, in particular for the estimation of soil erosion rates or lacustrine sedimentation rate [5]. Caesium is rapidly and strongly absorbed by soil particles, especially by clay minerals. Caesium reaches the soil in several ways, e.g. by direct deposition from the atmosphere, wash-off from vegetation, deposition from water etc. Figure 2 presents an example of vertical distribution of ^{137}Cs in soil profiles.

Yet another application of isotope research of the environment is the use of lead isotope ^{210}Pb to date lake sediments [6]. There are two sources of ^{210}Pb isotope occurring in the water-basin sediments. It is the decay of ^{214}Po, an element of the ^{238}U series in the deposit (so called autigenic lead), and the decay of ^{214}Po occurring outside the lake and introduced into the lake by water flowing into it and from the atmosphere (so called allochthonous lead). The half-life of ^{210}Pb is 22.6 years. The presence of allochthonous lead in the sediment may be used to determine its age in the range of up to a few half-lives. See Figure 2, for an example of an age profile in lake sediment.

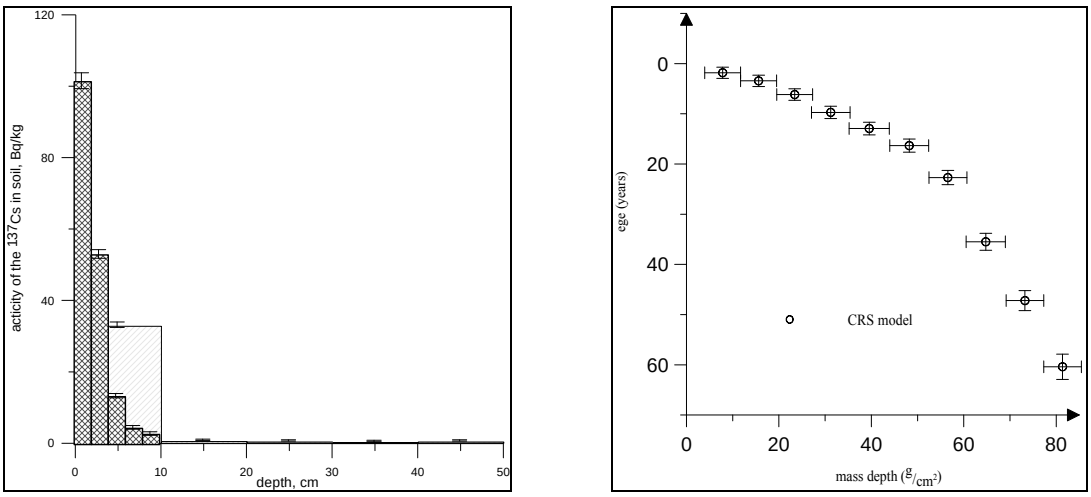

Figure 2. The left plot shows the vertical distribution of ^{137}Cs at a soil profile at site in southern Poland [6]. The right – ^{210}Pb age of lake sediments from a site in Upper Silesia, Southern Poland [7]

Isotopes in palaeoenvironmental research

For the determination of the age of rocks, minerals, and archaeological artefacts there are two groups of methods connected with radioactive decay being used. These groups are taking advantage of 1) the radioactive decay; and 2) accumulation of radiation damage by some minerals.

Almost all nuclear decay processes of naturally occurring isotopes can be used in geochronological research [7]. Only a few methods find a wider application, but for the research of the Quaternary the ^{14}C decay method, called radiocarbon dating, is the leading one. In recent years, radiocarbon dating is supported by the uranium-thorium dating method. It is based on the disturbance of the radioactive equilibrium in the natural uranium decay series. In the research of anthropogenic processes and geoformation processes, the ^{137}Cs and ^{210}Pb methods find their application relatively frequently.

The second group, so called dosimetric methods is based on the measurements of absorbed radiation dose. There is a smaller number of methods than in the first group. They are in general more difficult in application and are less precise. In the investigations of Quaternary sediments the dominating methods are OSL (Optically Stimulated Luminescence) and TL (thermoluminescence) [8].

Two main methods implemented in the Gliwice laboratory are radiocarbon dating and luminescence dating (in particular optically stimulated luminescence dating). The former method is used for dating of organic material (as mentioned in the previous point). The age span is up to ca 50,000 years and the suitable samples are plant and animal remains, speleothems, calcareous tufas, molluscs, calcareous lake gyttja. The age span of luminescence methods is typically up to 250,000 years and it is suitable for dating sediments containing quartz and feldspars.

The concentration of various isotopes can be used to gain knowledge about the environment on Earth in the past. Combining the data about isotopes with the results of dating, it is possible to reconstruct the temporal isotopic composition changes in the past. For example, the concentration of ^{18}O is a temperature marker. Therefore, by the measurements of the concentration of this isotope in the past (preferably in long, undisturbed sedimentation profiles, e.g. lake sediments or ice cores) and combining it with dating results it is possible to reconstruct climate changes in a given area. Figure 3 presents an example of the temperature changes in Poland and India during the last 13,000 years obtained by combining ^{18}O measurements with radiocarbon dating [9].

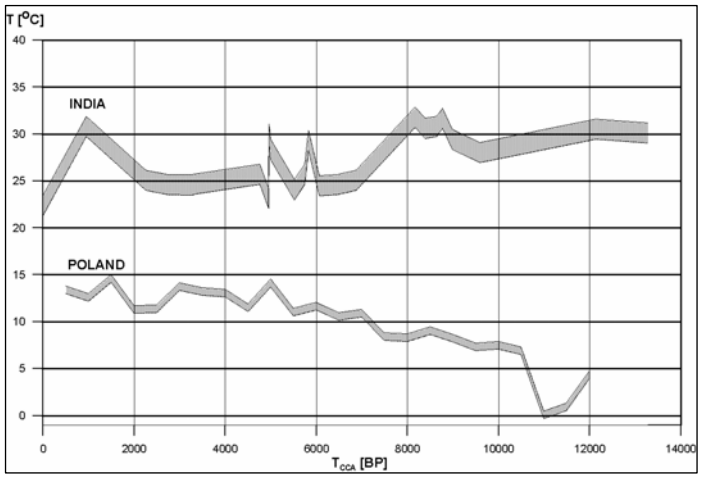

Figure 3. Changes of average annual temperature for Poland and spring temperature for India in the period of last 13,000 years reconstructed in thew basis of 14C (time scale) and 18O (temperature indicator) [10].

Human history on the environmental background

Large sets of dates obtained for one type of sediment with well-defined sedimentation conditions, are particularly useful for the reconstruction of environmental changes in the past. To such sediments belong speleothems or peat that can be dated with the radiocarbon method and loesses which are dated by luminescence. The climatic and environmental requirements for sedimentation result in that in periods of favourable conditions the density of dates is large. By creating sets of dates for a certain type of sediment and geographical region and their statistical analysis [10, 11] it is possible to define periods of warmer, colder, wetter, or drier periods. Based on such analysis and through the accumulation of objects indicating human activity in these periods, it is possible to demonstrate settlement periods of various archaeological cultures [12]. Figure 4 shows an example of statistical analysis for Mesolithic and Neolithic sites in Poland during the last 15,000 calendar years. The plots show cumulative probability distributions based on calibrated ^{14}C dates. The grey areas show time intervals in which the climatic conditions were conducive to increased human settling. All dates were obtained in the ^{14}C laboratory of the GADAM Centre.

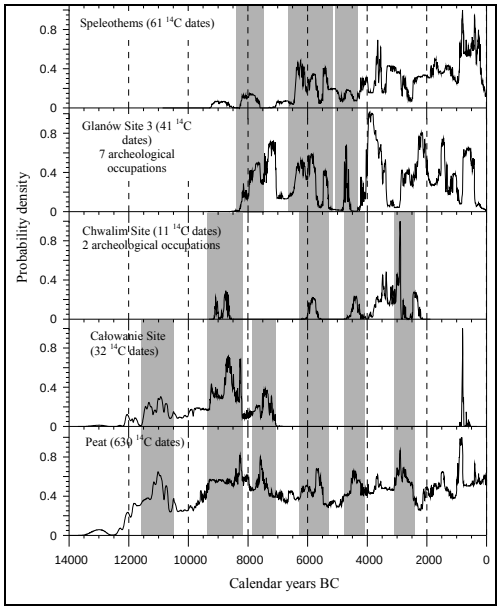

Figure 4. Periods (grey areas) of more intense human activity at Mesolithic and Neolithic sites in Poland reconstructed on the basis of cumulative probability distribution of dates [13].

HIGH LEVEL EDUCATION

The GADAM Centre organised six international workshops "Presentation and understanding of dating results" (2003), "Towards improved absolute chronology of Late Pleistocene and Holocene" (2004), "Isotope methods in environmental studies" (2005), "Isotopes in karst sediments and environmental studies" (2007), "Trees and forests as an archive of last millennium climate" (2008), "Climate change and human activity recorded in lake and fluvial environment" (2009). The workshops were aimed at doctoral students and young scientists. They were organised within the project Centre of Excellence GADAM. At these workshops lectures were delivered by invited scientists from abroad, Poland, and by scientists of the Centre. The Centre has also been organising a triennial international conference "Methods of Absolute Chronology". The participants are Polish and foreign scientists as well as PhD students. In 2010, took place the 10^{th} edition of the conference. Information about the workshops and conferences can be found under http://www.carbon14.pl/conference

SUMMARY

The emphasized experimental education is the application of advanced methods and measurement techniques in radioisotope and luminescence investigations of the environment. The measurements of luminescence of rocks and minerals, and radioactivity and concentration of natural and anthropogenic radioisotopes (^{235}U, ^{232}Th, ^{40}K, ^{137}Cs, ^{210}Pb, ^{14}C, ^{13}C, ^{3}H), as well as stable isotopes of light elements (^{2}H, ^{13}C, ^{15}N, ^{18}O, ^{34}S) in the lithosphere, atmosphere, biosphere, and hydrosphere, enable the reconstruction and monitoring of the environmental changes in recent times as well as in the more distant past.

The other important domain of education is the dosimetry of nuclear radiation in contemporary environment, natural and changed due to the anthropogenic impact. The block of subjects in this field enables gaining knowledge about radiological protection. The graduates are employed in various institutions engaged in monitoring of the environment, ecological institutes, and medical institutes who apply radiotherapy.

Both thematic blocks of professional training are strongly related to the scientific activities of the Department of Radioisotopes, Institute of Physics. The investigations are undertaken in the laboratories 'Gliwice Radiocarbon Laboratory' and 'Luminescence Dating Laboratory' as well as in the laboratories for measurements and spectrometry of nuclear radiation, mass spectrometry laboratory, and dendrochronological laboratory. As a result of a contest announced by the European Commission, the Department of Radioisotopes achieved the status of Centre of Excellence 'GADAM Centre' (Gliwice Absolute DAting Method Centre).

Thank to the wide scientific activities in the fields presented above, scientists working at the GADAM Centre are very well suited to teach students the subjects listed above ensuring a very high level of student training.

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