From M. Skłodowska-Curie to nuclear medicine

Lecture

L8.1

Plutonium-241 in the environment — problems of determination

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Plutonium is an anthropogenic element discovered in the products of nuclear reaction during the bombardment of uranium with deuterons in 1940. Plutonium displayed a high nuclear fission property therefore was largely used for nuclear charges preparation. In this way about 3,600 kg of plutonium isotopes was spread into the atmosphere during a numerous nuclear weapon tests. Moreover, a few nuclear accidents, among others the largest one — Chernobyl disaster in 1986 — caused introducing an additional plutonium load into the environment, especially in Europe. Most of plutonium isotopes present in the environment is the alpha radiation emitters, only Pu-241 emits beta radiation. The alpha radiating plutonium presence in the environment and hazard for human was largely studied and known. On the contrary, beta emitting plutonium was rarely a subject of investigation. However, it is an important isotope, as it was introduced in the environment in ten time larger amount than alpha emitting plutonium. On the other hand, Pu-241 rather quickly decays (half-life 14.4 years) but produces an alpha emitting isotope — Am-241 — of the same radiotoxicity as other plutonium isotopes.

Determination of beta emitters, especially of low energy is particularly complicated: it requires a total dissolution of the sample, separation from other substance of the sample matrix and preparation for radioactivity measurement with proper equipment. Therefore, direct determinations of Pu-241 were hardly performed.

At present, plutonium concentration in various environmental compartments is very low, being not hazardous for human life. However, elaboration of proper radiochemical procedures for determination of Pu-241 is important in the light of a potential risk connected with a construction of a first nuclear power plant in Poland.

Conclusions of our study on the procedures for Pu-241 determination in environmental samples as well as methods of radioactivity measurement with using liquid scintillation spectrometer will be presented. The results of Pu-241 behavior in the environment as concentrations and vertical migration rate in soils will be also shown.

L8.2

Application of the ionizing radiation in the technology, medicine and as a source of the information

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The lecture presents some industrial, medicinal, analytical and environmental applications of the radioisotopes. At present there are up to 200 radioisotopes regularly used in the industry, medicine, agriculture, hydrology or to solve different environmental problems and demand for the compounds labeled with these radioisotopes is increasing rapidly. Nearly all of these radioisotopes are produced artificially. The most common way is by neutron activation in a nuclear reactor. Some radioisotopes are manufactured in a cyclotron in which protons are introduced to the nucleus resulting in a deficiency of neutrons (proton rich).

Radioactive compounds can be used to troubleshoot and optimise several industrial processes. The main advantages of using these technologies are physico-chemical compatibility, high detection sensitivity, in-site detection, and the availability of a number of radiotracers for different phases. The industrial application of the radioisotopes are e.g. the residence time distribution (RTD) measurement, mixing time measurement, flow rate measurement, detection of blockage or leak location in buried pipelines, scanning of the distillation columns (radiometry), and weld defect detection in pipelines (radiography).

Radioactive products which are used in medicine are referred to as radiopharmaceuticals. Tens of millions of nuclear medicine procedures are performed each year. Nuclear medicine uses radiation to provide diagnostic information about the functioning of a person’s specific organs, or to treat them. Diagnostic procedures are now routine. Radiotherapy can be used also to treat some medical conditions, especially cancer, using radiation to weaken or destroy particular targeted cells. Certain nuclear medicine targeted procedures are presented.

Neutron activation analysis is a sensitive multi-element analytical technique used for both qualitative and quantitative analysis of major, minor, trace and rare elements. If NAA is conducted directly on irradiated samples it is termed Instrumental Neutron Activation Analysis (INAA). In some cases irradiated samples are subjected to chemical separation to remove interfering species or to concentrate the radioisotope of interest, this technique is known as Radiochemical Neutron Activation Analysis (RNAA). Some examples of NAA analyses are shown.

All of the aforementioned applications are developed in the Institute of Nuclear Chemistry and Technology.
L8.3

Radiation protection of patients and staff in medicine in the European Union and in the United States of America

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Radiation protection of patients and staff in medical application of ionizing radiation is a real challenge for Medical Physics with respect to different problems in diagnostic imaging with the use of X-rays or radiopharmaceuticals (nuclear medicine) and radiotherapy, such as QA (Quality Assurance) of equipment, dosimetry, treatment planning etc. Examples of current legislation in the EU with its implementation in Poland are presented. These are: Directive 96/23/Euratom laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation (the so-called Basic Safety Standards) - currently under revision - and Directive 97/43/Euratom on the health protection of individuals against the danger of ionizing radiation in relation to medical exposure. These directives were implemented in 2004 by the amendment to the Act of Parliament (Atomic Law) of 2000 and then Regulations issued by the Council of Ministers and those by the Ministry of Health. The regulations in force in the U.S. for the radioprotection of patients and staff in medical applications of ionizing radiation in diagnostics and radiotherapy are shown. In the US, the regulatory system is very complex:

a) for radioactive materials used in medicine the regulatory authority is the U.S. Nuclear Regulatory Commission. However in 37 states the US Nuclear Regulatory Commission has relinquished its authority to the states under signed agreements between the Chairman of the Commission and the governor of the state;

b) for regulating the use of machines that produce radiation, this authority resides in each of the 50 states and varies from state to state. The Conference of Radiation Control Program Directors is responsible for suggesting state regulations to be developed in each state;

c) the U.S. Food and Drug Administration regulates the manufacturers of machines that produce radiation and mammography.

The involvement of international (e.g. WHO, IAEA, ICRP, ICRU) and regional organizations (e.g. EFOMP, AAPM) in ensuring the safety of patients and staff in medical applications of ionizing radiation is discussed. The European Energy Commission in August 2010 issued a Communication document on the medical use of ionizing radiation aiming at ensuring clarity of Community actions in this field and at defining an approach to a common EC policy and strategy.

L8.4

Radiopharmaceuticals — nuclear probes for molecular imaging and therapy

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First applications of natural radioactive isotopes in the twenties of XX century in investigation of mechanisms in chemical reactions initiated further development of methods utilizing radioactive tracers and later wide application of radioisotopes in various scientific investigations. The test utilizing iodine-131 (131I) for investigation of iodine uptake by thyroid tissue was introduced in 1937–1939, other radioisotopes successfully used for patient treatment at the same time were 32P and 89Sr. The potential of radionuclides in the treatment of patients led to the development of Nuclear Medicine, the branch of medicine which both in diagnosis and therapy utilizes open radiation sources – radiopharmaceuticals.

Nowadays the radiopharmaceuticals are recognized as pharmaceutical products and are approved for marketing in the same way as all other drugs. The diagnostic and therapeutic procedures of Nuclear Medicine are well established and utilized in healthcare in many disciplines, in oncology, cardiology, neurology etc., supported by the developments in the radiation imaging equipment. In recent years the rapid expansion in the use of radioisotopes in nuclear medicine has been observed involving various biologically active molecules as carriers due to the better knowledge of the potential targets which are present in the human body in sufficient quantities. Somatostatin receptors have been shown as the target which could be effectively utilized for diagnostics with 99mTc or 68Ga labeled analogs or for therapy with beta-emiters such as carrier-free 90Y and carrier-added 177Lu. Several other potential targets, which are either expressed on the cell membrane (extracellular) such as transporters, neurotransmitter receptors, hormone receptors, neuropeptide receptors, growth factor receptors and tumour-associated antibody epitopes or intracellular like metabolic pathways, DNA/RNA or other organelles are currently under investigation. The availability of radionuclides and potential targets allows to construct tailor-made radiopharmaceuticals for radionuclide diagnostics and therapy choosing from a variety of half-lives, energies and applicable chemistry. Radionuclides such as 131I, 99mTc, 186/188Re, 166Ho and 153Sm have found applications in clinical procedures and have been used for cancer therapy, bone pain palliation, radiosynovectomy, intravascular radiation therapy and other disorders. Other radionuclides including 177Lu, 161Tb, 67Cu, 47Sc with promising physical and chemical properties still need to be explored. Approaches using alpha therapies may allow better targeting of residual disease in specific therapeutic frameworks. New developments in PET radiopharmaceuticals radiolabelled with 18F, 68Ga or 89Zr and the combination of PET for dosimetric applications involving the therapeutic matched radionuclide pairs such as 64Cu or 44/47Sc allow promising improvements in calculation of absorbed doses for an individual patient. Various techniques have been developed in order to improve and personalize the therapeutic effect of internal radiotherapy. Regulatory aspects: approval of clinical trial, Marketing Authorisation, GMP and Good Radiopharmacy Practice are additional challenge.
Chlorophylls interactions in vitro with metal ions can lead to the formations of new metalloderivatives of potential biomedical applications (e.g. photodynamic therapy and diagnosis). In vivo they can cause considerable problems for the operation and efficiency of photosynthetic apparatus. Therefore clarification of the mechanisms of chlorophylls metalation and transmetalation processes is important for bioinorganic chemistry, biochemistry and medical sciences. Detailed spectroscopic and kinetic studies have been carried out on the reactions of pheophytin $a$ and chlorophyll $a$ with many metal ions in organic solvents. They show variety in reaction pathways, that lead either to complex formation or degradation of the tetrapyrrolic ring. Besides redox properties of metal ion, some other factors, such as the solvent and counter ion have revealed considerable impact on the reaction course. Two different pathways of chlorophylls oxidation were distinguished on the basis of UV-vis spectroscopic investigations. Both can be accessible for chlorophyll $a$ and pheophytin $a$ with the same copper (II) salts, as well as the typical porphyrins-like metal incorporation mechanism, depending on reaction conditions. These conditions were described using spectroscopic and electrochemical techniques. Kinetic studies were performed in order to obtain the detailed description of multistep mechanisms of chlorophylls oxidation. They indicated, that one-electron oxidation is usually a reversible process whereas the reactions involving more electrons are responsible for macrocycle opening and thus damage of the tetrapyrrolic system.