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New day of radiochemistry

In 2015, Russian scientific community celebrated the birthday anniversary of Full Member of the Russian Academy of Sciences Boris F.Myasoedov — the leading Russian radiochemist, Head of the Scientific council on radiochemistry of the Presidium of the RAS and the State Corporation 'Rosatom', whose more than 65-year scientific carrier has been devoted to the development of basic radiochemistry and radiochemical and radiation technologies. This anniversary provided occasion for publishing a special issue of Russian Chemical Reviews that is devoted to the modern trends in radiochemistry and its achievements in which the impact of Russian radiochemists is obvious.

As a branch of modern science, radiochemistry is a relatively young field of research and development dating back to 1896. However, this discovery largely determined the further routes of human civilization development. Before 1949, the development of nuclear sciences, among which radiochemistry is one of the most important, represented fundamental research of various types of ionizing radiations, their interactions with matter and study of the chemical properties of radioactive atoms. However, since the end of 1940s, research and development in the field of practical application of nuclear radiation, mainly for military purposes, has become explosive. The nuclear projects implemented in the USSR and the USA served as the stimulus and driving force for achievements in various fields of science and technology and determined the human development in the 20th century. In the Soviet Union, nuclear project stimulated the peaceful nuclear power industry, rocketry for space exploration, development of nuclear power installations for marine vessels and satellites, applications of radiation technologies in industry, development of the modern methods of nuclear medicine, *etc*. Currently, radioactive nuclides in substances and devices and mechanisms that use them are widely employed in scientific research and in various fields of industry, medicine and biology, in particular, for diagnosis and treatment of socially significant diseases. The nuclear industry is successfully developed in a number of technologically advanced countries.

The leading scientists who participated in the Soviet nuclear project formed the basic scientific framework in the country. For example, in 1956, the Joint Institute for Nuclear Research (JINR) was founded in Dubna to study the fundamental properties of the matter. In the same years, a project aimed at the synthesis of new transuranium elements of the Mendeleev Periodic Table was launched under the supervision of G.N.Flerov. Future Academician, B.F.Myasoedov, who was then a junior researcher at the Vernadsky Institute of Geochemistry and Analytical Chemistry, participated in this research. Nowadays the Flerov Laboratory of Nuclear Reactions is a top scientific institution engaged in the synthesis and physicochemical studies of new superheavy elements. The Factory of Superheavy Elements, the first large-scale project aimed to conduct research in the field of synthesis and studies of new elements, is currently implemented on the basis of this Laboratory. Seventeen new elements with atomic numbers from 102 to 118 have been synthesized during the last 60 years, and nine of them, were synthesized at the JINR, including five new superheavy elements in the last 10 years. In 2012, the IUPAC approved the names Flerovium (Fl) and Livermorium (Lv) for new superheavy elements with atomic numbers 114 and 116 ('the first birds from the stability island') in the recognition of the laboratories that participated in their synthesis.[1] In December 2015, the IUPAC published a press release[2] on the discovery of new chemical elements with atomic numbers 113, 115, 117 and 118. The discoverers proposed the names Nihonium (Nh), Moscovium (Mc), Tennessine (Ts) and Oganesson (Og) for the 113rd, 115th, 117th and 118th elements, respectively.[3] The elements with z of 115, 117 and 118 were synthesized at the JINR in the nuclear reactions of Ca-48 ions with americium-243, berkelium-249 and californium-249 targets and the priority in their discovery was given to the Flerov Laboratory of Nuclear Reactions of the JINR, the Livermore National Laboratory and the Oak Ridge National Laboratory.

It is difficult to overestimate the role of radiochemistry in the research of new elements — actually, a new research field, 'single atom chemistry of superheavy elements', has been established at the JINR. It includes the chemical identification of superheavy elements, study of their chemical properties and contributions of relativistic effects as well as more specific elucidation of the nuclear physical properties of superheavy elements.

The main challenges of applied radiochemistry nowadays are related to improvement of the nuclear fuel cycle technologies, environmental protection and development of nuclear medicine.

The industrial application of nuclear power started in 1954 when the first nuclear power plant with electric power of 5 MW was lauched in the USSR. According to the IAEA statistics, in 2013, 434 nuclear units located in 30 countries were responsible for production of 371.7 GW of electric power.[4] In the last three decades, Belarus became one more country that launched the project of construction of its first nuclear power plant. The number of reactors at the construction stage in 2013 was as large as 72, which was the record high number since 1989. Among these reactors, 48 are located in Asia, as well as 42 out of the 52 newly built reactors connected to electric power grids since 2000. According to the IAEA forecast, the growth in the field of nuclear power production is estimated to be from 17% (pessimistic scenario) to 94% (optimistic scenario). In Russia, 33 nuclear units were in operation at ten nuclear power plants by the end of 2014 with total electric power of 23.6 GW, which is approximately 13% of the bulk energy production in Russia.

One of the factors that have adverse effect on the further development of nuclear power engineering is the problem of management of accumulated spent nuclear fuel (SNF) and radioactive wastes (RW). New effective extraction processes using highly selective reagents for SNF reprocessing and RW fractionation have to be developed to solve this issue. The research into the synthesis and applications of new extractants is actively conducted in many countries. Various types of compounds that could be applied to solve specific tasks of radiochemical technology have been proposed, *e.g.*, Tc-99 separation upon SNF reprocessing or separation of rare earth elements and minor actinides (for example, amercicium and curium), which have very similar chemical properties. The optimal strategy to solve these complex problems is to elucidate the basic relationships between a recognizing molecular structure and its target property. Afterwards, such a molecular structure is synthesized and its properties are studied experimentally. As a result, the molecular structure could be modified to improve some properties (*e.g.*, selectivity towards particular elements, solubility in various diluents, *etc.*). The application of quantum chemical methods to forecast the properties of various molecular structures can markedly simplify the research and reduce its cost, as there is no need to synthesize large series of compounds. Furthermore, supercomputer modelling helps to reveal the mechanisms of chemical transformations that cannot be studied experimentally.

Due to the high radiation hazard and chemical toxicity, high-level wastes after fractionation need to be immobilized into a safer state for further storage or disposal. The choice of the matrix material for immobilization of RW depends on the chemical and radionuclide composition of these wastes. A variety of materials are suitable for these purposes including cements, glasses and mineral-like matrices. One should consider their chemical and radiation stability as well as the maximum amount of RW that can be immobilized into the matrix.

At the end of the 20th century, as was predicted by V.I.Vernadsky, the human civilization entered the phase of global impact on the environment. The extensive development of nuclear industry brought about the beginning of the third stage of nuclear science development. During this stage, the environmental protection problems come to the fore. This is associated with the development of new effective methods of RW management and environmental protection from radioactive contamination. The main global sources of man-made radionuclides in the environment are atmospheric and ground nuclear weapon tests and large-scale accidents like in Chernobyl and Fukushima. The main potential sources of man-made radionuclides in the environment are radiochemical enterprises for SNF reprocessing. The research tasks of the radiochemistry are not only to determine the bulk concentrations of radionuclides in the samples collected in the environment but also to study the physicochemical species of radionuclides, which dictate their migration behaviour.

In the new century, nuclear medicine is a rapily developing and promising line of research in radiochemistry. The modern diagnostic and therapeutic approaches for numerous socially significant diseases (cancer, cardiological and neurological diseases) are related to the delivery of radionuclides to the target cells using various molecular vectors like peptides, monoclonal antibodies, module nanotransporters, nanoparticles, *etc*. The role of radiochemistry is to develop methods for production and purification of radionuclides for nuclear medicine and to study properties of radiopharmaceuticals and routes of their target delivery.

Therefore, modern radiochemistry is an interdisciplinary science the findings and outcomes of which are utilized in quite a few other branches of science including physics, biology, chemistry, chemical engineering, geology and geochemistry and even social sciences (for example radionuclide dating).

The authors of the reviews published in this journal issue are leading scientists, colleagues and followers of Academician B.F.Myasoedov.

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