

## Topical Issues of Training of Specialists for Fast Nuclear Power Engineering and the Closed Nuclear Fuel Cycle

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**Abstract.** Questions of staff training for the implementation of innovative projects in the field of nuclear energy are discussed. On the example of the National research nuclear University "MEPhI", having wide experience in the training of personnel for nuclear power, the classification of types of activities and stages of training of experts in the implementation of technologies of fast reactors are presented. The stages of development of the Department "Technology of closed nuclear fuel cycle", created for target training of specialists for the project "Proryv"

**Key Words:** educational technology, multi-disciplinary training, "Proryv"project.

### 1. Introduction

National research nuclear University "MEPhI" (NRNU MEPhI) was founded in 1942 as Moscow mechanical Institute of amunitions, and since 1945 it was known as the Moscow mechanical Institute. Training of specialists for nuclear industry was started after grounding of physical engineering faculty 20 September 1945. There were created departments for the training of engineers and physicists in fields of atomic physics, theoretical physics, nuclear physics, department of applied nuclear physics and precision mechanics. In 1953, divisions of the Institute were founded in closed cities, and the Institute gave the new name the Moscow engineering physics Institute. According to the conception of creators of the Institute, future graduates should have a University level education in physics and mathematics, and have engineering skills. A new stage of development of the University began in 2008 when the NRNU MEPhI became one of the first two national research universities. Today the University is firmly holds the leading position in training of specialists of the highest level, combining the principles of synthesis of education and scientific research laying in the base of its founding.

The "Proryv" project, implemented within the framework of the Federal target program "Nuclear power technologies of new generation for the period 2010-2015 and on prospect till 2020" [1] (task "Development of nuclear reactors on fast neutrons with the closed nuclear fuel cycle") and "Program of innovative development of SC Rosatom" [2], should be the basis of a new technology platform for the Russian nuclear power industry of the XXI century. To implement this task it was necessary to create mechanisms for the transfer of experience and provide training of relevant professionals.

The educational program was supposed to solve the task of grounding of graduates who possess a range of knowledge – from neutron physics to economy of a closed nuclear fuel

cycle, that is, to have an idea about all the processes that occur in a closed nuclear fuel cycle (CNFC) and understand the overall objective and the overall task.

Department "Technology of closed nuclear fuel cycle" was created in 2014 to implement the new multidisciplinary educational program "Nuclear power technologies of new generation", which is clearly tied to specific and ambitious targets related to the training of specialists that will successfully work on one of the most important and essential projects of the State Corporation "Rosatom" and the entire Russian power engineering.

## **2. Educational program "Nuclear power technologies of new generation"**

### **2.1. The structure of the curriculum**

Department "Technology of closed nuclear fuel cycle" of NRNU MEPhI provides training of masters at the basic educational program "Nuclear physics and technologies", profile "Nuclear power technologies of new generation". Training of masters on this program forms specialists of nuclear physics profile of the new generation, capable of creating new technological platform of nuclear energy with the transition to a fundamentally new level of safety, involvement of uranium-238 and products of processing of spent nuclear fuel in the fuel cycle, reduction of storage volumes of highly radioactive nuclear materials. To solve these tasks, masters should, in particular, know the basics of quantum physics and its applications in nuclear energy; possess the modern design codes; to learn the basic radiochemical processes of nuclear power; to know the key technologies and engineering solutions for nuclear power; to have an idea about the economics of nuclear power and its place in the overall structure of power production.

In accordance with these considerations, the structure of the curriculum consists of basic courses of educational standards of NRNU MEPhI and special general courses on technologies of the closed nuclear fuel cycle (CNFC), part of which develops in special courses with advanced study in the directions of CNFC.

Basic courses of educational standard are, for example, "Methodology of scientific knowledge", "Management and marketing", "Special chapters of higher mathematics", "Technical English", "Basics of information security of critical technologies" and some others. These courses are the same throughout the training direction "Nuclear physics and technologies" and implemented in stream form independently on the profile of specific educational program.

Let us consider some common special courses of the Department. The course "Scientific basis for nuclear power" lasts two semesters and is read by the academician Ponomarev Leonid Ivanovich. In the first semester, the following tasks are solved: acquaintance with the basic concepts and scientific fundamentals of nuclear power, formulating the main problems of modern nuclear power and modern approaches to their solution. In the second semester, the main technical solutions related to the technologies of the closed nuclear fuel cycle are discussed. The individual lectures are delivered by leading experts of industry. For example, the theme "Experience in the use of reactors with lead-bismuth coolant on nuclear submarines and prospects for its use in civilian nuclear power," gives doctor of technical sciences, professor, honored worker of science and technology of the Russian Federation, chief researcher – advisor to the general director of SSC RF-IPPE Georgy Ilyich Toshinsky. Topic "Fast reactors with lead coolant BREST. From concept to prototype" was told in 2016 by a deputy research supervisor of the project BREST, senior researcher of the Joint Stock Company «N.A. Dollezhal Research and Development Institute of Power Engineering» Valery Sergeyevich Smirnov.

The course "Innovation projects management" is given by the head of Department, doctor of technical sciences, professor, deputy general director – director of unit for innovation management of Rosatom Vyacheslav Aleksandrovich Pershukov. The objectives of the course are: familiarization with the strategies of business management, the project location in business management, stages of project life cycle; introduction to intellectual property and management of intellectual rights in holding with state participation on the example of state Corporation "Rosatom".

The purpose of discipline "Economics of closed nuclear fuel cycle", which is read by candidate of technical sciences, head of division NRC "Kurchatov Institute" Subbotin Stanislav Anatolyevich, is the mastering of methods of evaluation of technical and economic indicators and competitiveness of nuclear power. The basic economic principle INPRO is considered as the economic criterion, according to which the proposed solution must be technically feasible and economically affordable.

Among other special common courses of the Department it should be noted:

"Fundamentals of design and engineering calculations for nuclear power plants", which is devoted to thermal hydraulic calculations for nuclear power plants;

"Coolants of nuclear reactors", which introduces students to the areas of application and operating conditions of various coolants;

"Fuel, structural and absorbing materials for fast reactors", which gives students a basic idea about the types of fuel, structural and absorbing materials used in fast neutron reactors;

"Safety, ecology of a closed nuclear fuel cycle", which introduces students to the regulatory and legislative framework to ensure radiation and ecology safety, questions of ecology safety of the individual stages of the nuclear fuel cycle, principles of optimization of expenses on safety, innovative projects and applied approaches to safety.

An example of course, which gets a sequel in the more advanced form, is the course "Theoretical and experimental basis for neutron-nuclear processes: fundamentals of neutron physics". The course is given by doctor of physical and mathematical sciences, professor of the NRNU MEPhI Georgy Valentinovich Tikhomirov. Its task is to prepare students to master special courses related with neutron-physical processes in nuclear reactors. A number of issues that form the basis for analysis and neutron-physical calculation of nuclear reactor plants are studied in this course. Advanced part of the course is called "Neutronics of the active cores of fast reactors and closed nuclear fuel cycle" and is read by the doctor of physics and mathematical sciences, professor, head of department of scientific supervisor PI ITCP "Proryv" Yuri Sergeyevich Homyakov. The course examines: the basic features of neutron physics of fast nuclear reactors, the conceptual provisions on the choice of neutron-physical parameters of reactor on the base of requirements of the closed nuclear fuel cycle, physics of the reproduction of the fuel, transmutation of actinides.

## **2.2.Features of implementation of educational programs in network form**

Evolution of educational standards of higher education is moving steadily towards greater requirements of employers outlined in the professional industry standards. Federal law "On education in Russian Federation" [3] (No. 273 - FZ of December 29, 2012) introduced the possibility of realization of educational programs in network form. When implemented in a network form, the requirements for the educational program are provided by a set of resources given by the organizations involved in its implementation. Such organizations can be

geographically distributed units of the University (intranet mobility), other educational organizations, as well as other (non-educational) organization.

Feasibility of consolidating the resources of different organizations in implementation of the educational program allows to expand the range of educational services and to train personnel in accordance with the programs of development of enterprises and industries, as well as in accordance with the programs of international educational cooperation.

One of the main blocks of the educational program "Nuclear power technologies of new generation" is the block of disciplines that can be called "Radiochemistry and the nuclear fuel cycle". For the effective implementation of this block, it was needed to use not only human but also material resources of partner organizations. For this purpose, relevant contract on the network implementation of the educational program were made.

Implementation of the block of disciplines (FIG. 1) lasts for three semesters with the increase of amount. The course «Radiochemistry» is given in MEPhI by lecturers of D. Mendeleev University of Chemical Technology of Russia (MUCTR). The discipline «Radiochemistry» is dedicated to acquaint students with the peculiarities of behaviour of radioactive isotopes in ultra small concentrations in solution, gas and solid phase, their distribution between the phases in the co-precipitation process, adsorption, ion and isotope exchange, electrochemistry, which is associated with the processing technology of spent nuclear fuel, radioactive waste and analysis of the quality of coolant in nuclear power plants. The discipline is levelling the incoming students, the account of the course is a two hour lecture per week.

The knowledge gained by students in the study of the course «Radiochemistry» is in demand later for the course «Radiochemistry (special chapters)», which is delivered on the basis of MUCTR in the amount of five classroom hours per week, including laboratory work. Obtained in the performance labs the ability and skills of radioactive drugs, the safety basis for work with open sources of radiation are the basic and necessary in the future to prevent a variety of emergency situations involving possible radioactive contamination of the atmosphere laboratory, clothing, skin, equipment at work at nuclear facilities. Complex laboratory works included in the curriculum will allow students to practice to get acquainted with the specifics of work in the radiochemical laboratory, learn radioactive drugs and radiometric equipment to determine the entire spectrum of radiation, and experimental reinforce the knowledge gained in lectures, in qualitative and quantitative radiochemical analysis, and use of radioactive tracers to solve various analytical problems. The purpose of discipline «Radiochemistry (special chapters)» is the study of behavior radioactive isotopes in the technologies of the nuclear fuel cycle, the methods of analysis, concentration and separation.

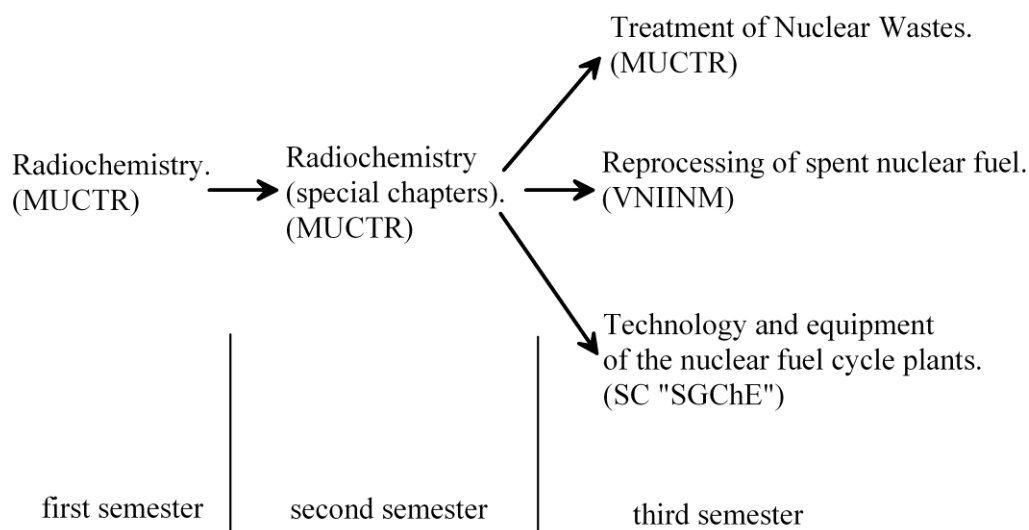


FIG. 1. The structure of the block of disciplines «Radiochemistry and nuclear fuel cycle».

Three disciplines are already given in the block «Radiochemistry and nuclear fuel cycle» during the third semester. The course «Treatment of Nuclear Wastes» is lectured on the basis of MUCTR in the amount of five classroom hours per week. The purpose of the discipline is to introduce students to technologies of management with radioactive waste, formed as a result of working with radio-nuclides. At present the possibility of practical training in the framework of the course on the basis of VNIKhT is under consideration.

The course «Reprocessing of spent nuclear fuel» is given by leading experts of VNIINM on the basis of this organization in the amount of four classroom hours per week. The purpose of the discipline is to prepare students for the engineering and chemical-technological problems related to development of reprocessing technologies of spent nuclear fuel and equipment for their implementation.

The skills, obtained in the first two semesters, are developed during mastering the course «Technology and equipment of enterprises of nuclear fuel cycle». At present the course is developed as follows. Students leave for Seversk (Seversk Technological Institute of MEPHI) where they undergo theoretical training for the first week six hours per day. The second week is devoted to a familiarization practice at Stock Company «Siberian Group of Chemical Enterprises» (SC «SGChE») with a visit to the radiochemical plant, sublimation plant, isotope separation plant, industrial reactor and chemical-metallurgical plant. Construction of a pilot demonstrational power complex is being carried out just at the site of SC «SGChE». The complex consists of a fast reactor installation «BREST-OD-300» with in-situ closed nuclear fuel cycle, including the production of uranium-plutonium nitride fuel (fuel fabrication), as well as the processing of irradiated nuclear fuel to produce a secondary uranium-plutonium nitride fuel (re-fabrication of fuel). Students can get acquainted with the construction process and, at the moment, with the technology of fuel production and the fuel assemblies from nitride fuel. It is planned to move the course to a remote platform CLP4NET in the amount of four hours per week with a weekly full-time practice at the SC «SGChE».

### 2.3. Practice and research work of students

Essential in the educational process is allocated for research work and study practices. Besides the above described practices at JSC "SGChE", in the first semester students visit the Museum of uranium ores (JSC VNIHT) and the world's First NPP (SSC RF IPPE). The possibility of organizing a weekly practice in Dimitrovgrad SRI of nuclear reactors is considered with the purpose of acquaintance with the multipurpose fast research reactor.

To prepare good specialists it is indispensable combination of theory and practice. This balance was met in the development of the master curriculum. During the first semester, one day in the schedule was completely free of other items for the research work, during the second semester – two days, during the third semester – three days.

The first graduation of masters was in 2016. Five students of the ten have completed the qualification work in JSC VNIINM, three students in JSC VNIHT, and one student in PI ITCP "Proryv" and JSC SSC RF IPPE. All the topics were related to actual problems of technologies of the closed nuclear fuel cycle to be solved in the centers of responsibility of PI ITCP "Proryv". Among the topics of master's theses there were: "Justification of parameters of purification system of sodium coolant in relation to fast reactors of the new generation", "Method of increasing the share of open porosity of tablets of mixed nitride uranium-plutonium fuel", "Study of the process of treatment of metal fission products produced in pyroelectrochemical process stage of processing of spent nuclear fuel." From students admitted in 2015, five students perform scientific research work in JSC VNIINM, two students in PI ITCP "Proryv", one student in the ISDNP RAS and one student in NRC "Kurchatov Institute". Among the topics: "Comparative evaluation of radiation doses of population from emissions of the modules of EDPC during normal operation and emergency situations", "Creation of stand of liquid chromatography for purification of the extract in the recycling process of spent nuclear fuel", "Analysis of the possibility of penetration of steam in the active core of lead reactor when leakage of steam generator". The numerical distribution of students at enterprises shows that most of them bind the subjects of their studies with physical chemical processes of manufacture and processing of nuclear fuel.

### 3. Conclusions

The implementation of the basic educational program of the Department "Technology of closed nuclear fuel cycle" is aimed at training for the responsibility centers of the "Proryv" project that has required involvement of leading experts of the enterprises of Rosatom to the educational process. The part of education is realized in network form. Joint actions of the NRNU MEPhI, Mendeleyev's RChTU, JSC VNIINM, SC SGChE allowed to form a unique block of disciplines aimed at a comprehensive training of graduates, which would be impossible to implement using one organization

### 4. References

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