Collaboration of the Russian Federation and the Kazakhstan Republic for the specialists training in the area of safe and secure nuclear materials management

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Abstract. The paper presents the results obtained in implementing the network form of the specialists training at the level of Masters of Sciences (MS) for nuclear enterprises of the Kazakhstan Republic. The problems related with creating and implementing the MS Graduate Program in safe and secure nuclear materials (NM) management are considered from the standpoint of systematic approach. Especial attention is given to some specific features in implementation of the MS Graduate Program. The paper evaluates reasonability, effectiveness and applicability of the network educational form for the specialists training at the MS level for nuclear enterprises of the Kazakh National Atomic Company “KAZATOMPROM”.

1. Introduction
Global growth of natural uranium mining is provided by three main countries, namely Kazakhstan (39%), Canada (22%) and Australia (9%). An evident advantage of the Kazakhstan Republic, as distinct from other countries – producers of natural uranium, consists in availability of large uranium resources. Kazakhstan takes the second place in the world on natural uranium resources. The identified resources of natural uranium including reasonably assured and inferred resources are evaluated at the level of 1,5 million tons.

Natural uranium is a major mining wealth of the Kazakhstan Republic. Main mineral and raw resources of natural uranium are concentrated in the ore deposits located in South Kazakhstan, Kizil-Orda and Akmolinsk Regions (figure 1) [1].

Amongst various methods of natural uranium mining the in-situ leaching technology is a dominant one because this is the most ecologically clean and economically efficient method of uranium recovery from the earth bowels. Currently in the world, above 50% of natural uranium is mined with application of the in-situ leaching technology.

In the Kazakhstan Republic all the works on natural uranium mining and primary reprocessing are being performed by the National Atomic Company (NAC) “KAZATOMPROM”. The NAC system involves sixteen nuclear enterprises which are engaged in operation of twenty uranium mines on the Kazakhstan territory.
Till 2015 the NAC “KAZATOMPROM” had supplied natural uranium in the form of uranium octa-oxide $\text{U}_3\text{O}_8$. Beginning from 2016, the Company started supplying the higher-quality products, namely uranium powder, fuel pellets and enriched uranium.

![Main regions of natural uranium mining](image)

Figure 1. Main regions of natural uranium mining

Presently, the NAC “KAZATOMPROM” is tightly collaborating with the RF State Corporation “ROSATOM” in natural uranium mining and application of high technologies for manufacturing of high-quality uranium products. In 2017, within the frames of the XIII Forum of Inter-Regional Kazakhstan-Russia Collaboration, the RF State Corporation “ROSATOM” and the NAC “KAZATOMPROM” had signed the Memorandum on mutual understanding and extension of strategic cooperation in the area of nuclear fuel cycle [2].

In order to expand a circle of nuclear specialties and to upgrade quality of the specialists for nuclear industry of the Kazakhstan Republic the NAC “KAZATOMPROM” collaborates actively with the leading Russian higher schools, in particular, with National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), hereinafter – NRNU MEPhI.

Multi-year friendly and business-like links connect NRNU MEPhI and the NAC “KAZATOMPROM” including cooperation in educational efforts. The cooperation in educational area became more fruitful when the network educational form was applied [3]. The network system opened the opportunity to implement a series of the training programs with participation of several universities or some other organizations. The MS Graduate Program “Safe nuclear materials management” (SNMM) may be mentioned here as an example. The SNMM Program is being implemented now with joint efforts undertaken by NRNU MEPhI, Gumilev Europe-Asia National University and the NAC “KAZATOMPROM”.

Both universities (NRNU MEPhI and Gumilev Europe-Asia National University) are partners in the International Regional Network “Education and specialists training in the area of nuclear technologies” (STAR-NET)” [4]. Main missions of the STAR-NET system include conservation of nuclear knowledge and provision of well-skilled human resources in nuclear area. Presently, the STAR-NET system unites thirteen universities–partners from seven countries of East Europe and Central Asia. The STAR-NET system collaborates efficiently with the IAEA by implementing the IAEA initiatives related with the specialists training in nuclear technologies and with attraction of the secondary school-leavers.
The SNMM Program was developed to train the specialists demanded by the enterprises involved in nuclear fuel cycle (NFC) activities. Particular attention was given to initial NFC stages (mining of uranium ore, primary processing of uranium ore, production and affinage of uranium concentrate). Therefore, the SNMM Program became one of the main MS Graduate Programs for nuclear enterprises under the NAC “KAZATOMPROM”. Significance of the SNMM Program is defined, in particular, by large scope of the NAC “KAZATOMPROM” activities. As is known, the Kazakhstan Republic is the largest in the world supplier of natural uranium to the international uranium market.

The SNMM Program corresponds completely to the RF educational standard 14.04.01 “Nuclear power and thermal physics” [5]. In October 2015 the SNMM Program successfully passed the State accreditation in NRNU MEPhI.

2. Typical features of the MS Graduate Program “Safe nuclear materials management”

2.1. The network form of the MS training for the NAC “KAZATOMPROM”

The network form for implementation of educational programs implies the joint efforts undertaken by universities and nuclear enterprises. These efforts must be aimed at providing the opportunities for the trainees to study the program with application of the network resources. The network SNMM Program is being implemented now as a result of the joint efforts undertaken by the following three collaborators: National Research Nuclear University MEPhI, Gumilev Europe-Asia National University and the National Atomic Company “KAZATOMPROM”.

The higher-school entrants from the NAC “KAZATOMPROM” enterprises are admitted for training under the SNMM Program at NRNU MEPhI which is regarded as a basic educational organization. Gumilev Europe-Asia National University and the NAC “KAZATOMPROM” are responsible for partial implementation of the SNMM Program in the works related with the network educational form as it was foreseen by appropriate agreement. The agreement defines distribution of the responsibilities between NRNU MEPhI, Gumilev University and the NAC “KAZATOMPROM”, sequence of actions on implementation of the SNMM Program, types and scopes of the resources to be used by each organization, the certificates on completion of the SNMM Program and the trainee qualification given to the specialists graduated from the SNMM Program. Joint implementation of the SNMM Program implies that the specialists graduated from the Program will receive the MS degree in the direction 14.04.01 “Nuclear power and thermal physics” with delivery of appropriate certificate by NRNU MEPhI administration. The certificate contains information about the results obtained by the trainees in studying all the training courses and the practical works performed in the network organizations, including the internship works at the NAC “KAZATOMPROM” enterprises.

The following typical features of the network SNMM Program are listed below:

- The “turn-key” form of the specialists training, i.e. the specialists with all required competencies who are completely ready to work at the NAC “KAZATOMPROM” enterprises.
- The network educational form implies periodical visits of the MS students to NRNU MEPhI and Gumilev University for studying some training courses, for passing the tests, home tasks and examinations.
- The students of the SNMM Program can effectively, with proper accounting for their individualities, combine research activity at nuclear enterprises with studies in universities. Such a combination is promoted, up to a certain level, by the distant form chosen to deliver some training disciplines (for example, the training course “Introduction to systems of nuclear materials physical protection, control and accountability”).
- The network SNMM Program is based on a modular principle for creating contents of the training courses and curricula.

2.2. The credit-modular principle for creating the MS Graduate Program “Safe nuclear materials management”
The credit-modular principle is used as a methodological basis for the network form of the Program implementation. The credit-modular system is the educational form that implies a certain combination of modular technology for structure of the training process with quantitative estimation of the contributions given by each training discipline (or training module) to quality of the specialist training that may be described by a circle of the acquired competencies. Important feature of the credit-modular principle is an opportunity to embody easily a systematic educational approach because the credit-modular system is able, with sufficient flexibility, to meet demands for the specialists with different professional competencies.

Development of the modular educational program begins from exact definition of the works type to be performed by future specialist. Then, the required competencies must be defined. The next step includes creating the training modules and elaborating the structure of curriculum with strict accounting for the general requirements listed in the State-level educational standard [5].

The first step in creation of the SNMM Program was analysis of the educational needs, including identification of the works to be performed by future specialist, and formulation of the educational aims. The educational aims can be briefly presented as a set of competencies to be acquired by the specialists graduated from the Program.

As is known, the forms of activity to be performed by future specialists can be defined jointly by universities and stake-holders (or future employer, if available). The forms of activity to be performed by the specialists graduated from the SNMM Program are mainly defined by the works of the NAC “KAZATOMPROM” enterprises, and may be presented as the following three major directions:
- Scientific and research activity;
- Production and technological activity;
- Organizational and managerial activity.

2.3. The competency-based model of the specialists graduated from the Program

The modular educational program is a set and a sequence of the training modules that is aimed at mastering of the competencies needed to acquire the required qualification. Definition of the competency circle for the specialists graduated from the SNMM Program was, in essence, a focal point for implementation of conventional systematic approach to any educational process. Just list of these competencies defines ultimately a circle of the specialists knowledge, i.e. what they must be able to do, what means of research, development and design works they must be able to perform. So, it was very important to evaluate contribution given by each training module (or training course) to the formation of the competencies acquired by the MS students. These contributions show significance of the training module (or training course) for reaching the ultimate goal of the SNMM Program.

List of the competencies acquired by the specialists graduated from the SNMM Program includes, in addition to general cultural and general professional competencies, some specific professional competencies. The following, the most important specific professional competencies (PC) acquired by the MS students are listed below:
- PC-1. The specialists must be able to apply methods for studying NM states and processes with NM at various NFC stages;
- PC-2. The specialists must be able to create theoretical and mathematical models for characterization of the processes related with NM management;
- PC-3. The specialists must be ready to perform research works for updating and upgrading of the processes and devices used at various NFC stages;
- PC-4. The specialists must be able to use contemporary packages of the applied computer codes for solving physical-engineering and safety problems at NFC objects;
- PC-5. The specialists must be able to operate, conduct expertise and repair of the contemporary production equipment used for NM reprocessing.

As it can be seen, the circle of the specific professional competencies has an engineering inclination, and the circle is mainly oriented to the works performed at NFC enterprises.
2.4. Structure and content of the SNMM Program.
The SNMM Program was created in accordance with the credit-modular scheme and, thus, the SNMM Program is very suitable for the network training of future Masters who will be directed to the NAC “KAZATOMPROM” enterprises because different training courses may be studied by the MS students in different places. The training module is a curriculum’s block which consists of several training disciplines. All of them are aimed at one goal, namely the formation of mutually-linked professional competencies. The SNMM Program includes a series of general scientific modules and one general professional module. List of these training modules is presented below.
Module 1: Management of cognitive processes.
Module 2: Foreign language.
Module 3: Management and marketing.
Module 4: General professional module.
Professional part of the SNMM Program consists of the following specialized modules:
Module 5: Nuclear technologies.
Module 6: Current problems of nuclear power engineering.
Module 7: Methods and devices for NM measurements.
Module 8: Nuclear safety and radiation safety. Basic principles of safety regulation.
Module 9: Fundamentals for physical protection, control and accountability of nuclear materials and nuclear facilities.
Module 10: Scientific and research work, practical works.
Module 11: Final state attestation.

One of central places in the SNMM Program is given to studying the contemporary nuclear technologies and experimental methods of NM measurements (the training modules 5 and 7). The spacious training courses “Nuclear technologies” and “Methods and devices for NM measurements” include significant section of the laboratorial practical works. Many other training modules are also accompanied by a series of the laboratorial practical works.

The training module 6 “Current problems of nuclear power engineering” describes contents of the problems (natural resources for nuclear power plants, for instance) to be solved by future specialists graduated from the SNMM Program. If these problems will be successfully resolved, then nuclear power industry will be able to take the leading position in global production of electrical energy.

Despite the most contemporary methods of uranium mining and primary reprocessing are being applied now at the NAC “KAZATOMPROM” enterprises, the problems of safe handling with uranium-containing minerals remain to be extremely significant because of intense ionizing radiation emitted by intermediate products in technological processes for fabrication of pure uranium compounds. Just therefore the SNMM Program includes the training courses “Nuclear safety and radiation safety”, “Basic principles of safety regulation”, “Basic principles of radioactive waste management” and “Radiation effects” which are united in the training module 8.

Amongst many aspects of the principal conception “Safe NM management”, conservation and provision of trustworthy information about nuclear materials continue playing significant role because it is a basis for successful resolving the problems related with effective and safe NM management. The training module 9 “Fundamentals for physical protection, control and accountability of nuclear materials and nuclear facilities” is devoted to studying the problems related with safe NM management. The training module 9 includes the following training courses: “Computerized systems for NM control and accountability”, “Introduction to systems for NM physical protection, control and accountability”, “Technical tools for physical protection of nuclear sites”.

2.4.1. Distribution of the training load in the SNMM Program.
The training load in the SNMM Program is regulated with application of the credit system. A credit is a unit for quantitative evaluation of the training load to the MS students. The credits made it possible to evaluate contribution of each training discipline to total labor expenses of the MS students. When evaluating the training load, we used the following presumption: one credit is approximately equivalent
to 36 (thirty-six) academic hours (one academic hour equals 45 (forty-five) minutes). The RF State standard [5] established full training load for the MS Graduate Programs at the level of 120 credits. Besides, the training load must be uniformly distributed over full duration of the educational process. Distribution of the training load on the training modules of the SNMM Program is shown in the following Table 1.

**Table 1.** The training load on the modules of the SNMM Program.

| Module No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|------------|---|---|---|---|---|---|---|---|---|----|----|
| Training load, credits | 4 | 4 | 3 | 15 | 10 | 4 | 7 | 7 | 8 | 50 | 8 |

According to the training load of the MS students, two major parts of the SNMM Program should be noted. The first professional part of the Program includes the specialized training modules No. 5÷9. These training modules (36 credits, in total) must give the MS students the knowledge and skills needed for successful NM management. The second part (50 credits, in total) consists of the training research works and the internship works of the MS students. When performing these works, the MS students will acquire the skills needed for practical usage of the acquired knowledge. The training load distributed by such a way answers the main mission of the network educational system, namely to train the specialists in the areas of uranium mining and fabrication of high-quality uranium products at the NAC “KAZATOMPROM” enterprises.

### 2.4.2. Evaluation of completeness in the circle of competencies within the frames of the SNMM Program

In many cases one individual training module is able to form a desirable competency only partially. So, the SNMM Program considers the following four levels of the competency formation:
- The level “0” means absence of the desirable competency.
- The level “1” means an initial step in the competency formation, i.e. general awareness and understanding of the competency essence..
- The level “2” means that the trainee understands the competency in practical applications, i.e. the MS student is able to demonstrate the competency and use it partially.
- The level “3” means the extended (advanced) quality of the competency, when the MS student acquired full scope of knowledge and is able to use the competency with the higher efficiency.

The competency levels PC1 ÷ PC5 acquired by the MS students after studying the general scientific, general professional and specialized training modules of the SNMM Program are presented in table 2. These data allowed us to evaluate significance of individual training modules for acquirement of specific competencies by the specialists graduated from the SNMM Program. In this respect it seems reasonable to consider the training modules No. 4, 10 and 11. Significance of the general professional training module No. 4 is defined by its predestination as an engineering basis for further career growth of future specialists. As is seen, in the competency sense, main mission of the general professional training module is to form (or upgrade) the competency from the zero level up to the first level. Certainly, role of the training module No. 4 depends mainly on the previous training courses studied by the MS students. In the SNMM Program the training module No. 4 consists of the following disciplines:
- Selected chapters of general physics.
- Special chapters of higher mathematics.
- Nuclear physics.
- Radiation effects.
- Nuclear knowledge management.
- Computerized technologies.
- Applied mathematical statistics.
Contents of the training modules No. 10 and 11 include various forms of research activity, practical and internship works, and preparation of the MS theses as a final stage of the SNMM Program. Just during these steps the MS students begin the active phase in practical applications of the acquired knowledge. These works define significance of the training modules No. 10 and 11 in the competency structure of the SNMM Program.

**Table 2.** Formation of the professional competencies PC1 ÷ PC5 through studying the training modules of the SNMM Program.

| Professional competencies | PC-1 | PC-2 | PC-3 | PC-4 | PC-5 |
|---------------------------|------|------|------|------|------|
| Initial level in the competency forming | 0    | 0    | 0    | 0    | 0    |
| Module 4                  | 0 → 1 | 0 → 1 | 0 → 1 | 0 → 1 | 0 → 1 |
| Module 5                  | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 |
| Module 6                  | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 |
| Module 7                  | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 |
| Module 8                  | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 |
| Module 9                  | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 | 1 → 2 |
| Module 10                 | 2 → 3 | 2 → 3 | 2 → 3 | 2 → 3 | 2 → 3 |
| Module 11                 | 2 → 3 | 2 → 3 | 2 → 3 | 2 → 3 | 2 → 3 |
| Final level in the competency forming | 3    | 3    | 3    | 3    | 3    |

3. Some statistical data about collaboration between NRNU MEPhI, Gumilev University and the NAC “KAZATOMPROM” with the frames of the SNMM Program

Beginning from autumn 2015, NRNU MEPhI is implementing the network educational form of the SNMM Program for the specialists from the NAC “KAZATOMPROM”. The first generation (six trainees) successfully defended their MS theses in June 2017.

Presently, the second-year MS students (the second generation) completed the educational process while the first-year MS students (the third generation) successfully completed curriculum for the first year of the educational process.

Defense of the MS theses by the second-generation MS students was held on June 27, 2018. The MS students who successfully graduated from the SNMM Program in 2018 together with instructors of the Program are shown in figure 2.

As is expected, defense of the MS theses by the third-generation of the MS students (twelve trainees) will be held in June 2019. So, a tendency may be seen towards steady growth of the trainee quantity. This tendency is a good indicator on successful implementation of the SNMM Program.

It is noteworthy here that topics of the MS theses defended by the MS students of the SNMM Program have a strictly purposeful applied nature and answer the problem to be solved by nuclear industry of the Kazakhstan Republic. The following topics of the MS theses defended by the MS students of the SNMM Program in 2018 are presented below as typical examples:

- Control of nuclear materials in raw uranium at uranium ore mining and primary reprocessing;
- Reduction of uranium enrichment in the research pulsed uranium-graphite reactor at the National Nuclear Center (Kurchatov, Kazakhstan) in order to provide global nuclear and physical safety;
- Methodology for NM physical inventory taking and NM balance summing up at facilities for production of natural uranium concentrate and natural uranium octa-oxide;
- Methodology for checking-up of uranium control and accounting system at enterprises for natural uranium ore mining and primary reprocessing;
- Planning of actions on NM management during decommissioning of nuclear facility;
- Risk assessment at physical protection of nuclear materials containing natural uranium;
- Analysis of conditions for safe NM management during operation of light-water reactors.

Figure 2. Members of the State Examining Board and the MS students of the SNMM Program (the student group No. M16-182) in June 2018.

4. Conclusion
The paper presents some results from analysis of the methodological principles used in development of the network educational form for the MS Graduate Program “Safe nuclear materials management”. The following main conclusions can be derived from the analysis:
- The network educational form for the specialists training at the Master of Sciences level may be estimated as a reasonable and effective option under conditions when real employers of future specialists are available;
- Joint (employer – university) elaboration of the educational tasks makes it possible to train the specialists in the “turn-key” format, i.e. the specialists graduated from the SNMM Program must be completely ready to work at the employer’s enterprise;
- System of the professional competencies acquired by the specialists graduated from the SNMM Program significantly simplifies concordance of the training plans between future employers and universities;
Modular structure of the SNMM Program makes the process of the competencies forming more flexible and visual. At the same time, modular structure is a very convenient form for correct and timely distribution of functions and missions between participants of the network educational process;

Application of the credit system to constructing the curricula for the SNMM Program allowed us to make the training load of the MS students more uniform and more compliant with requirements of RF State standard 14.04.01 “Nuclear power and thermal physics”;

On the whole, implementation of the network training program “Safe nuclear materials management” during the last several years demonstrated its necessity for the NAC “KAZATOMPROM” and possibilities of its further development and advancement for strengthening of scientific and technological contacts between the RF State Corporation “ROSATOM” and the National Atomic Company “KAZATOMPROM”.

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