# DEVELOPMENT OF NUCLEAR EDUCATION STANDARDS

Sergij V. BEGUN, Vasilij V. BEGUN

**Abstract:** If we analyze the causes of severe accidents in the world nuclear industry, we find in most cases common root causes: project deficiency, human error. The fundamental remedy of these root causes is only possible through improvement of nuclear education. Development of the nuclear education standards for the nuclear industry staff and the certification system for teaching staff are proposed. Recommendations with mandatory for the nuclear industry staff disciplines, appropriate knowledge and skills were developed. Propositions for the principles and structure of the certification system for teaching staff are formulated. The risk of emergency situations and accidents in nuclear industry will be significantly reduced.

**Keywords:** Nuclear Education. Education Standard. Training, Certification.

## 1 INTRODUCTION

Nuclear power can provide the essential part of humanity energy needs for thousands of years as pointed out in [1].

But if one more accident of the scale like Three-Mile Island (1979), Chernobyl (1986) or Fukushima (2011) will occur, the consequences may lead to the rejection of nuclear energy in many countries and even in the whole world. This assumption is confirmed by the decisions of some countries to provide the moratorium on the development or complete phase out of nuclear energy, especially after the Chernobyl accident in 1986, and after the accident at the Fukushima Daiichi Nuclear Power Plant in 2011.

Therefore, taken in account the global consequences of severe accidents on all nuclear energy in the world, there is a time to develop the international standards in the field of nuclear energy, which should be mandatory for all the countries with nuclear energy.

If we analyze the causes of above mentioned severe accidents, we find common root causes: project deficiency, human error. These confirmed by the results of post accident analysis of Three Mile Island accident [2, 3], of Chernobyl accident [4, 5], as well as in the case of Fukushima accident [6, 7, 8]. The fundamental remedy of these root causes is only possible through improvement of nuclear education. The corresponding qualification enhancement of designers will lead to the elimination of design deficiencies at the design stage or during the operation of the existing nuclear facilities. The personnel qualification enhancement will lead to the identification of design deficiencies, which were missed at the design phase and to the reduction of errors during the operation of nuclear facilities.

The analysis of nuclear education curricula at various universities shows a significant difference in training in the same specialty. Often, this situation is related to the actual circumstances at the universities for different reasons. Sometimes this is due to the direction of scientific activity of the teaching staff at the departments. This creates a precedent of different education level of professionals in the industry.

There are a lot of good practice (mainly in old universities), where the teaching staff are the best industry experts with great experience of work in the industry. But, there are some negative effects associated with the lack of qualified teaching staff in the field of special education at some universities. The later described situation is particularly due to the much lower teacher salaries compared to industry experts. This phenomenon is especially evident in the teaching of special subjects. In such cases, it is often not taught what is needed, but what they can teach. As a result, trained specialists have significant gaps in knowledge, and with this incomplete knowledge they come to the nuclear industry.

Therefore, at this paper we propose to define a set of mandatory fundamental disciplines for the study, which correspond to the set of knowledge and skills of nuclear energy specialists, covering all the main stages of the nuclear fuel cycle.

Obviously, this point of view, first of all, should be implemented to the teaching of special disciplines related to nuclear and radiation safety. Unfortunately, there is a reality, when these disciplines are taught by assistants, who do not have any experience in the industry. Such teachers have only theoretical knowledge about equipment and processes. In our opinion, such situation can cause a lack of training both for Bachelor`s degree students and for Master`s degree students. Therefore, from our point of view, the special requirements to higher education teachers in the field of nuclear energy should be developed similar to the current requirements in the industry: periodical certification, the requirements for initial education and work experience in the industry. In this connection it is necessary to develop the system of certification of special disciplines teachers. The universities, that do not have own teachers with proper skills, will need to provide teaching by inviting certified professionals, until they train local specialists.

The main purpose of this paper is to define the problem of *common* mandatory basis of knowledge and competence determination, which should be obligatory for the operational personnel, technical experts of the operating organization and the regulatory body, decision makers in the industry. As a result, in our opinion, the people with a certain defined set of competences should be at all levels in the industry. The existence of a common basis of knowledge and competences provides the following benefits:

1. Increase in the efficiency and speed of information exchange at all levels in the industry while reducing the probability of incorrect perception of information through a common language and a common understanding of processes.
2. Consistent knowledge of what to do in standard situations.
3. Clear consistent understanding at all levels of the industry of possible ways to solve arising safety problems due to sufficient knowledge of the basic processes and opportunities to influence on the sequence of events.
4. Increasing of the probability of timely decision-making as a result of clear understanding of the time limits for each type of decision-making by all specialists and managers.
5. Improving consistency in the divisions of industry, including consistency in emergency situations.

The most important processes should be identified to determine the list and content of mandatory for study disciplines. Such processes are:

a) most strongly influence to the production data of industry,
b) have the greatest impact on safety.

Improvement of knowledge about the first type (a) of processes would lead to more efficient use of facilities and their stable work. Improvement of knowledge about the second type (b) of processes will reduce the probability of accidents and lead to more effective emergency response.

## 2 DESCRIPTION OF EXISTING EDUCATIONAL AND TRAINING SYSTEM

At present the structure of education and training of industry specialists in all countries has approximately the same form shown schematically in Fig. 1.

After graduation from universities and the professional selection, young specialists are trained at the Training Center (TC). Every nuclear power plant (NPP) usually has its own TC as a subdivision of NPP. The retraining for the new position is also performed at TC.

The training at NPPs has a systematic and planned nature. This training is based on the developed teaching and methodological materials in accordance with the standard training programs for certain positions of NPP operational personnel and technical managers. The Full-Scale Training Simulators of NPP (FSTS of NPP), Local and Analytical Simulators are designed and built for these purposes in TCs.

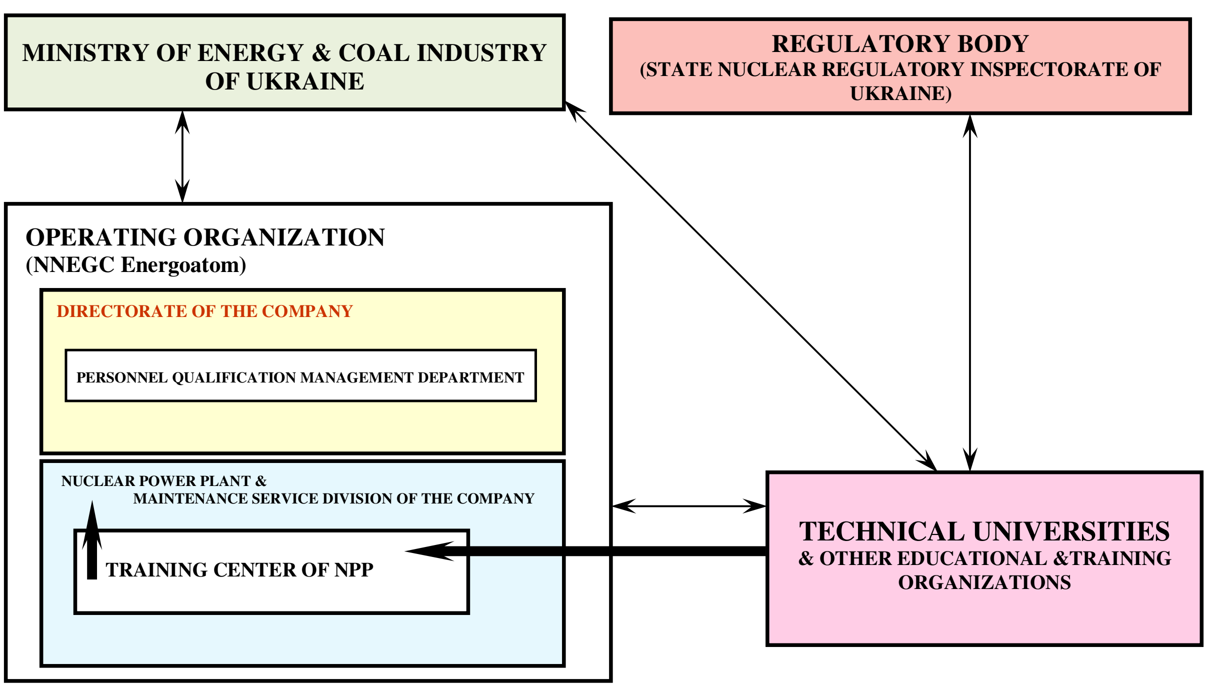


**Fig. 1** Scheme of personnel education and training for the nuclear industry of Ukraine

The powerful computer systems are used in these simulators, which allow to perform the real-time simulation of processes in nuclear power reactor, turbines, other equipment of NPP and the NPP as a whole with actuation of protection and blocking systems. Thus, for all trained specialists of all categories and levels there is the opportunity of gradual improvement of knowledge and skills concerning all technological operations at the NPP under the guidance of experienced instructors.

The tough psychophysiological selection is mandatory before subsequent training for the ones, who will work on the operational positions (licensed personnel). The subsequent education and training is long enough, you can see some related information for the selected positions in Table 1.

**Table 1** Education and training of license personnel at NNEGC Energoatom.

| Position | Time of education under interruption of work (months) | Time of training at the FSTS of NPP (hours) | Total work experience after retraining (months) |
|---|---|---|---|
| Principal Engineer of Reactor Control | 9-11 | 220 | 33-35 |
| Shift Supervisor of Reactor Department | 5-6 | 220 | 49-53 |
| Principal Engineer of NPP Unit Control | 11-12 | 116 | 50-58 |
| Shift Supervisor of NPP Unit / Shift supervisor of NPP Units | Reactor Department - 14-16;<br>Turbine Department - 21-24;<br>Electricity Department / Department of Heat Automatics and Measurements - 24-27. | 255 | 55-69 |

Let us note that the "Safety culture" discipline is an integral mandatory part of education and training programs for all the categories of license personnel, and includes the following topics:
- Fundamentals and characteristics of safety culture.
- The role of the human factor in ensuring the safety culture.
- The role of the trainee specialist in ensuring the safety.
- Self-assessment of the personnel.
- Quality assurance.

As a result, the operational personnel and the technical management of the NPP unit become the well trained professionals, what is confirmed by international missions. But in this scheme, shown in Fig. 1 and Table 1, there are significant drawbacks:

1. Different basic level of education after graduation from technical universities.
2. Fairly high cost of license personnel training.

Indeed, education under interruption of work is being performed during 1-2 years. It is clear that this condition is strongly correlated with the first one, which is the subject of our paper. Today technical university graduate need to finish learning at the TC of NPP or even to learn again. Let us note that the described above educational and training system exists for training mainly of operational personnel for nuclear industry. Directorate and management of NPP, operating organization staff, technical experts have, at best, the following simplified scheme of education and training, see Fig. 2.

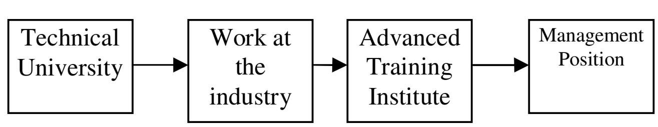


**Fig. 2** Scheme of non-operational staff education and training

As we can see from Fig. 1 and Table 1, that in the case of operational personnel training and education, the gaps in knowledge and skills after technical university could be corrected with high probability during the process of education and training at the TC of NPP (1-2 years). But in the case of non-operational staff training and education (Fig. 2), the chance to correct the gaps in knowledge and skills after technical university is minimal - these gaps in basic knowledge and skills can not be corrected during the short-term retraining courses at the Advanced Training Institute. Therefore, the education at the technical universities should be standardized to make impossible the gaps in critical knowledge and skills, which are most strongly influence to the production data of industry and have the greatest impact on safety.

## 3 LIST OF OBLIGATORY KNOWLEDGE AND SKILLS

Nuclear energy - the largest source of low carbon electricity after hydropower in the world [9], but nuclear power plants are complex technological objects and dangerous objects. Severe accidents at nuclear facilities can have global consequences outside the national boundaries of separate country. Therefore, the safe operation of nuclear facilities is associated with high demands on staff and managers at all levels.

Let us consider a common basis of knowledge, which should be mandatory for the *industry staff*: the operational personnel, technical experts of the operating organization and the regulatory body, decision makers in the industry. It is known that the solution of that problem starts with the requirements analysis to the volume of knowledge on the position (profession). Based on the requirements to the professions of the nuclear industry and personal experience, we consider it necessary the regulation (standardization) of a minimum amount of industry staff knowledge, including general educational disciplines. At the next part of paper, we note, first of all, on the validity of proposed requirements by the reasons of their application to industry specialists.

*1. Mathematics.* Mathematical knowledge needed to understand the laws of physics and chemistry that are associated with the processes of the nuclear fuel cycle and with the emergency processes. Knowledge in this case should be divided into the list of general mandatory knowledge for all of the categories of persons and the list of additional knowledge for executives. Therefore, from our point of view, nuclear industry staff`s general mandatory knowledge in mathematics should be in accordance with relevant generally recognized curricula of technical universities, including mathematical modeling.

Additional knowledge for executives (technical experts of the operating organization and the regulatory body, decision makers in the industry) should include elements of the theory of management, including control algorithms for stochastic processes (risk management), the mathematical basis of modern computer codes for the nuclear industry and other specific knowledge. This list of additional knowledge may be included both in the curricula for Master's degree and in the retraining curricula for the nuclear industry specialists.

*2. Programming.* Every modern control and management systems of complex objects, which are the nuclear facilities, include computer codes. Basic knowledge of programming is required to use these computer codes. It is much more difficult (impossible) without programming to create designs of nuclear facilities, to offer new solutions and perform the technical evaluation of such projects and solutions. Therefore, nuclear industry staff`s general mandatory knowledge in programming should be in accordance with relevant generally recognized curricula of technical universities.

The technical experts of the operating organization and the regulatory body should have additional knowledge of relevant computer codes algorithms and skills of their use for the evaluation of new projects and solutions.

*3. Descriptive Geometry.* Knowledge of descriptive geometry is necessary to all of the above categories: the operational personnel, technical experts of the operating organization and the regulatory body, decision makers in the industry - all of them should be able to read drawings, schemes and diagrams, which are the parts of technical documentation. There is impossible to understand the text (and formulas) of technical documentation without a proper understanding of the graphical part of the technical documentation.

*4. Probability Theory.* Knowledge of probability theory and basics of probabilistic safety analysis are required for operating personnel to understand the fundamentals of modern safety concept and assess their contribution to the enhancing of the general level of safety culture at a particular facility and at the industry as a whole. These knowledge define operating personnel`s ability to evaluate their contribution to reducing the risk of accidents. Knowledge of probability theory is required for technical experts of the operating organization and the regulatory body, the decision makers in the industry for the ability to calculate risks using methods of probabilistic safety analysis. International practice has shown that the implementation of risk-based approach is one of the most effective ways to reduce the probability of accidents in all types of dangerous objects.

5. *Physics.* All of listed above categories - industry staff - should, as a minimum, have knowledge of the following topics:

1. General Physics;
2. Mechanics;
3. Properties of Materials;
4. Thermodynamics;
5. Thermal Hydraulics;
6. Electricity and Magnetism;
7. Atomic Physics;
8. The Fundamentals of Quantum Mechanics;
9. Nuclear and Neutron Physics;
10. Dosimetry;
11. Fundamentals of radiometry and spectrometry.

It is impossible to understand fully the processes that occur in nuclear facilities, to evaluate the project and the technical solutions, to organize proper planning of nuclear facilities operation without this knowledge and competences in physics.

*6. Chemistry.* Knowledge of chemistry basics should be mandatory for all of listed above categories (both Bachelor`s degree, Master`s degree). Knowledge of chemistry is necessary for the ability to organize in a proper manner the nuclear facility chemistry both in normal operation and under the emergency conditions. Knowledge of chemical processes is an important element in reducing the probability of accidents at nuclear facilities. Knowledge of chemical processes in emergency situations can have a decisive impact on the prevention of accidents by making timely decisions. The technical experts of the operating organization and the regulatory body, decision makers in the industry (Master`s degree) must have the deep knowledge of chemical processes at the nuclear facilities both in normal operation and under the emergency conditions.

*7. The Special Knowledge and Competences* in the nuclear industry should include, first of all, the issues of the nuclear reactors theory, the descriptions of nuclear facilities designs, descriptions of primary and secondary equipment of nuclear facilities, operation issues, safety culture, safety analysis. All of listed above categories - industry staff (both Bachelor`s degree, Master`s degree) should have knowledge of:

1. Types of Nuclear Facilities;
2. Nuclear and Heat Power Plants;
3. Heat and Mechanical Equipment of Nuclear Facilities;
4. Nuclear Power Reactors;
5. Theory of Nuclear Reactors;
6. Non-stationary Processes in Nuclear Facilities;
7. Pumps;
8. Steam Generators;
9. Turbines and Electricity Generators;
10. Operation of Nuclear Facilities;
11. Emergency Processes at Nuclear Facilities;
12. Construction, Decommissioning and Decontamination of Nuclear Power Plants.

The technical experts of the operating organization and the regulatory body, decision makers in the industry (Master`s degree) as a result of studying of the listed above special knowledge should be able to carry out the engineering design calculations for nuclear facilities with the specified parameters using advanced computer codes. Operating personnel (Bachelor`s degree) must be able to carry out similar calculations on a simplified level.

Listed above special skills and knowledge will give to the one the ability to identify the design deficiencies under the operation of nuclear facility, which have been missed in the design phase of the nuclear facility project. It also improves the speed and the probability of making the right decisions in unusual (non-standard) situations.

*8. The Law.* Knowledge of law basics should be mandatory for all of listed above categories (both Bachelor`s degree, Master`s degree). At the laws and regulatory documents the rules, procedures and instructions both for normal operation and for emergency situations usually are established. The regulatory documents include the safety limits that should not be exceeded. The knowledge of law is necessary to understand the level of responsibility for the abnormal operation of nuclear facility and for the emergency situations and accidents. The technical experts of the operating organization and the regulatory body, decision makers in the industry (Master`s degree) should have the deep knowledge of law.

*9. Safety Culture.* Safety culture should be studied as a generalization, systematization discipline at the end of the course.

All of listed above categories - industry staff - should have knowledge of:

1. The structure of the nuclear industry and the general information on nuclear facilities;
2. Safety management techniques based on risk assessments;
3. The basic concepts of socionics and sociometry;
4. Procedures for the analysis of violations at nuclear power plants (nuclear facilities);
5. Methods of human factor impact assessment on safety;
6. Psychology of security;
7. Best practices in the management of the nuclear energy industry;
8. Components of safety culture at various levels;
9. The documentary basis of the safety culture;
10. Methods of safety culture level assessment.

All of these categories - industry staff - must have the skills in:

1. Estimations of equipment reliability based on operation results and risk assessments;
2. The organization of sociological surveys in the team;
3. The analysis of violations;
4. Assessments human factor impact on safety;
5. Analysis of the psychological causes of violations;
6. Self-assessment of safety culture level;
7. Assessment of safety culture level at the department.

The inclusion "safety culture" discipline in the Bachelor`s degree curriculum for the nuclear industry specialists allows creation competences:

- the ability to detect hidden failures and unresolved safety issues,
- the ability to identify the significance of events, problems in safety ensuring and adequately respond to these problems,
- the ability to learn from experience and solve problems in safety.

Safety culture is a modern concept of safety ensuring at dangerous objects and, as already mentioned, is also studied in retraining courses at the TC of NPP. The inclusion of this discipline in the Bachelor`s degree curriculum, in our opinion, is necessary for special (safe) behavior motives formation of future professionals from the student`s bench.

*10. Probabilistic safety analysis.* From safety analysis disciplines we consider it necessary to study the probabilistic safety analysis (PSA) with the implementation of this method at the computer code SAPHIRE. This course, in our opinion, should be included only to Master`s degree curriculum. The study of PSA with SAPHIRE code course is useful not only for the formation of NPP systems analysis skills and safety of the NPP unit, but also develops logical thinking, helps to understand the cause-effect relationship of operation and failures of the equipment.

## 4 DEVELOPMENT OF STANDARDS. TRAINING AND CERTIFICATION OF SPECIALISTS

### 4.1 Teaching staff certification

As shown above, the specific requirements for the teaching staff are necessary at the technical universities that provide nuclear knowledge. The scope of their competence must meet the above requirements and the state of knowledge in the industry. The appropriate procedures for admission to work and certification should be ensured. As a result, certified teachers should be not only in TC of NPP, but also in technical universities - all of them are the teachers of the nuclear industry. Both, the teachers at technical universities and the TC of NPP teachers should have a salary at the level of directorate of NPP and have the same responsibility for the training results. The education at the industry under such conditions will have a structure of continuous process, which will facilitate the progress in safety enhancement.

### 4.2 International standards development

The coordination center of the international standards of education development, in our opinion, should be the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO). This activity will be most effective under conditions of mandatory implementation of the developed standards by all the operators of nuclear facilities in the world. The first steps towards this direction are described in [10] and in [11]. For the training and certification of technical experts and teachers, from our point of view, as a first step, the working group should be created. In addition to IAEA and WANO experts and divisions, it is possible and necessary to use The World Nuclear University (WNU), Asian Network for Education in Nuclear Technology (ANENT) and leading technical universities of the world.

## 5 POSSIBILITIES OF PROLIFERATION SENSITIVE KNOWLEDGE RESTRICTION

In establishing restrictions to the distribution of knowledge in the industry, we should remember that only through openness of nuclear knowledge, which are necessary for the development of peaceful nuclear energy uses, is possible to achieve a significant increase in the global level of safety in the world.

There are great difficulties in the direction of distribution control of proliferation sensitive knowledge, due to objective reasons.

The main difficulty in this case is that one does not need very much to know for primitive small capacity nuclear bombs and for "dirty" bombs creation, which can cause no less harmful consequences than advanced high capacity nuclear bombs. All these knowledge are the part of basics mandatory knowledge necessary for peaceful nuclear energy.

Moreover, one of the reasons is the presence of part or all of corresponding knowledge in the open type scientific publications on the nuclear and related topics, as well as existence of all or a substantial part of the relevant information at the Internet.

It is impossible to carry out the development of science with the global exchange of information and thus hope that this information will not fall into the wrong hands - on the contrary - this information will be in the wrong hands shortly after the appearance in any form, as the potential nuclear or radiological terrorists are focused their search on such information using all available methods and tools.

In addition, history has proved ineffectiveness of so-called "secret" developments, the reason for that is the presence of global competition and struggle for spheres of influence. Therefore, all those, who wanted or wants to learn this information - received the necessary knowledge sources sooner or later. And for the realization of their plans, they will need only nuclear materials, because everything else they can get legally. They can train the appropriate specialists, paying for their education at the leading universities of the world, this is not a problem. Therefore, getting of proliferation sensitive knowledge in the wrong hands and the development by them of missing links of knowledge - it is only a matter of time - how long after the appearance they will own a complete set of knowledge and technology. As a conclusion, while investigating nuclear technology, developers should understand that most or all of this knowledge will be available to the potential nuclear or radiological terrorists after a time more or less in each case.

A significant problem in this area is that the nuclear reactors on thermal neutrons with an open nuclear fuel cycle have limits on the amount of fuel at the relatively low price range as shown in [12] and [1]. Known fact is that the average content of U-235 in natural uranium is 0.72% [13]. There is a need to create an additional neutron source in the case of thorium for energy production use to activate the fissile nuclei U-233 from the stable nuclei of Th-232. Therefore, both in the case of thorium and uranium the most efficient use of natural resources will be implementation of nuclear reactors on fast neutrons with a closed nuclear fuel cycle as shown by [14, 15] and in the IAEA reports [16, 17].

Transition to the use of fast neutron reactors with reprocessing of spent nuclear fuel to extract fissile material from it, which should be realized in the case of a closed fuel cycle, will significantly increase of proliferation risks.

From our point of view, most likely, it will be impossible to restrict the distribution of proliferation sensitive technologies as the depletion of oil and gas resources in the world and concentration of remaining resources of oil and gas in limited number of countries (potential monopolists). Such processes will start, in our opinion, from developing countries with poor natural resources. Therefore, when making decisions about the future of nuclear energy development and distribution of relevant knowledge, it is necessary to compare the risks of proliferation in the variant of centralized enrichment and reprocessing with transportation on long distances with proliferation risks in the variant of construction of licensed controlled enrichment and reprocessing plants in the expanded list of countries, that have operational nuclear reactors and closed nuclear fuel cycle, with transportation inside of these countries on short distances.

The enhancement of the global development of nuclear power in the world is mainly tied with the global need to reconsider the attitude towards nuclear materials as to a source of peaceful power, but not as to the nuclear weapons. The tough control over the movement and use of nuclear materials should be implemented. To all violators of the nuclear nonproliferation regime the use of economic sanctions should be mandatory.

## 6 CONCLUSIONS

The international regulation and standardization of the set of mandatory educational disciplines for the study, a list of relevant knowledge and skills of nuclear energy specialists, covering all the main stages of the nuclear fuel cycle is proposed to perform. The obligatory certification of technical universities teachers at the international level is offered.

The IAEA and WANO should be the coordination centers of the international standards of education development. In addition to IAEA and WANO experts and divisions, it is possible and necessary to use WNU, ANENT and leading technical universities of the world.

The combined efforts to create mandatory standards for nuclear education will lead to significant reduction of risk or even to the impossibility of severe accidents. This is an opportunity and need for further development of nuclear energy.

All of these efforts will be useless without transparency of nuclear knowledge necessary for the development of peaceful nuclear energy. Obviously, non-proliferation of nuclear weapons, technology and corresponding knowledge should be taken into account.

For the successful implementation of such standards the joint efforts of countries using nuclear energy with appropriate mechanisms of influence on the countries, that do not want to implement these standards, will be needed. For these purposes the role and the authorities of the IAEA and WANO should be reconsidered and fixed in the form of international treaties.

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Sergij V. BEGUN, Ph.D.
National Institute for Strategic Studies
Pyrogova str. 7-a
010 30 Kyiv
Ukraine
E-mail: shell3@ukr.net

Vasilij V. BEGUN., Ph.D.
Institute of Mathematical Machines &
Systems Problems
Academician Glushkova Avenue 42
036 80 Kyiv
Ukraine
E-mail: begunw@ukr.net