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Design, Development and Implementation of a Master of Science Program for Chemical and Nuclear Engineering: Integration of CAPE (Modelling, Simulation and Control) Skills

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The paper deals with the definition of guidelines to integrate the topics Computer-Aided Process Engineering (CAPE), specifically modeling, simulation and control, with the nuclear engineering field. This novel educational program arises from specific market analyses that show the increasing and relevant request of different countries (i.e. Russian Federation) for specialists skilled in chemical engineering as well as in nuclear physics and chemistry of radioactive elements. Competences in CAPE typical of chemical engineering such as the model predictive control, the dynamic optimization and the phenomenological modeling are going to be extended to the nuclear field. Conversely, complex physico-chemical phenomena of nuclear engineering are going to enlarge modeling viewpoint of the chemical engineering field

1. Introduction

Nuclear engineering formation and applications are focused on complex physico-chemical processes and their mandatory connection to the so-called Technology of High Responsibility (THR). THR is based on the simultaneous targets of maximum efficiency in nuclear fuel consumption and maximum operational security. These targets are attained at all the steps from scientific research and development to the design and operation of nuclear reactors and to the management of the nuclear fuel cycle as well. Specifically, the activities related to the management of the nuclear fuel cycle is strongly related to the typical operations of chemical engineering (e.g., purification and separation) and the topics and skills related to it, with obvious special requirements for radiation and nuclear safety. This strongly motivates the need for an integrated educational program to form a new kind of specialist in chemical engineering with skills on nuclear physics and chemistry of radioactive elements. Current trend in global economy imposes to handle cost reduction by preserving the maximum safety target and the achievement seems not possible, or at least quite cumbersome, without taking into account the modern Computer-Aided Process Engineering (CAPE) techniques based on the nonlinear model predictive control, dynamic real-time optimization, and robust data interpretation.
Recently, Latif and co-workers (Latif et al., 2013) showed the increasing request of specialists and training tools for the chemical and nuclear engineering. Worldwide past and ongoing experiences have shown the effectiveness of academic collaborations to set up integrated educational programs (Chawla et al., 2010). From this perspective, this paper aims at defining a high specialist Master of Science Program in Chemical and Nuclear Engineering, basing on the existing collaborations and institutional agreements between Tomsk Polytechnic University (TPU), Russian Federation, Department of Electronics and Automation of Nuclear

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Plants (TPU, 2014) and Politecnico di Milano (POLIMI), Italy, Department di Chimica, Materiali e Ingegneria Chimica "Giulio Natta" (POLIMI, 2014).

2. Methodology for Master of Science Program in Chemical and Nuclear Engineering

The urgent need in competent engineers in automated nuclear equipment, reactors and technological processes of nuclear fuel production led to the establishment of the Department of Electronics and Automation of Nuclear Plants in Tomsk in 1954 (TPU, 2014) and after 60 years from its foundation, the department is very active in all the branches of automation and process control and has graduated 1444 engineers.. Pioneer activities were related to the development of instruments, devices, and techniques for state diagnostic for the industrial-scale graphite-uranium reactor, together with the diagnostic of process conditions in radiochemical production. The Department of Electronics and Automation of Nuclear Plants developed specific process monitoring devices to assess online the nuclear flux dispersion and the energy holdups in the active volume of nuclear reactors, and self-adapt systems for nuclear flux dispersion.

Hot research topics are the development of automation system efficiency upgrading, integration of state-of-the-art IT solutions in automatic process control system (APCS) design, the APCS development of nuclear fuel cycle (NFC) for governmental Rosatom corporation (Goryunov et al., 2012).

At present, the department is saved of dominant position in APCS development of NFC, included the APCS development of uranium hexafluoride. From 2014 TPU's group joined the "Proriv" project funded by Rosatom corporation, where new generation codes have to be developed for the modelling of key and ancillary parts related to the NFC, such as the nuclear waste recovery and purification, the nuclear waste neutralization, and the nuclear fuel synthesis and predisposition for power generation. TPU's staff is also very active in collaboration with the international community (e.g., the world's leading forum for scientific and technical cooperation in the peaceful uses of nuclear technology - International Atomic Energy Agency (IAEA)). A key project is the energy generation at the industrial scale from the controlled thermonuclear fusion under development at the Kazakstan National nuclear center for the development of measuring devices and automation hardware/software - TOKAMAK – KTM (Gryaznevich et al., 2009).Within this picture, the development of optimal and predictive control methodologies for systems subject to complex dynamics is a novel branch of research at the Department of Electronics and Automation of Nuclear Plants. The very foundations of this activity have their roots in the use of dynamic mathematical models to foresee in advance the future behavior of the plants and, therefore, to act properly in the due time not only to preserve the safety and effectiveness of operating conditions, but also to continuously re-optimize them (Manenti, 2011, Rossi et al., 2014). Such an activity is jointly carried out by TPU and Politecnico di Milano (POLIMI, 2014).

The origins of the Department of Chemistry, Materials and Chemical Engineering "Giulio Natta" of the Politecnico di Milano date back to 1883, when a laboratory for Technological Chemistry was established in the former "Regio Istituto Tecnico Superiore" (founded in 1863). In 1963, Giulio Natta, ex-aequo with Karl Ziegler, was awarded the Nobel Prize for Chemistry for their discovery of stereospecific polymerization in 1954 and the modern department is named in his honor. The CMIC department activities can be classified in three areas: Chemistry, Applied Physical Chemistry, Industrial Chemistry and Chemical Engineering. Especially the chemical engineering competences are required in this novel Master of Science Program with topics related to process modeling and optimization aimed at reducing the environmental impact, improving the raw material utilization, reducing the energy consumption and waste production, and to optimize the performance yield within the food-energy-water nexus.

The research groups have developed a well-established database for kinetics and unit operations, which could be exploited to properly characterize industrial systems at different scales (kinetic microscale, reactor mesoscale, process macroscale) and predict their performances with high reliability. Also, dedicated numerical libraries have been associated to properly and promptly solve the resulting multi-scale systems and making them useful for practical offline and online uses. The possibility to merge different scales each other and to effectively solve the resulting models offers the great opportunity to redefine the layout of the existing processes by exploiting the peculiarities of their intrinsic physical-chemical-biological behavior and, therefore, to exploit at best all the mechanisms behind the chemical and physical transformations that occur in the process itself. Such an approach is nowadays spread and adopted not only in different countries but also in several areas and scientific communities. In addition, several priority patents and high-impact-factor journal publications corroborate the technological and scientific relevance of such a multi-scale methodology. As an example, the Sustainable Process Engineering Research (SuPER) team published about 300 papers since 2009 on journals with impact factor up to 15, attracting national and international funding and visitors.

Being mainly based on mathematical modeling and optimization algorithm, the research activity developed at Politecnico di Milano matches the experimental activity performed at Tomsk Polytechnic University. To exploit at best the potential synergy, the "Computer-Aided Nuclear Engineering" Master of Science Programme is set.

Nuclear engineering topics can be classified in Nuclear Reactor Engineering and Chemical Engineering in the Nuclear Area as qualitatively sketched in Figure 1.

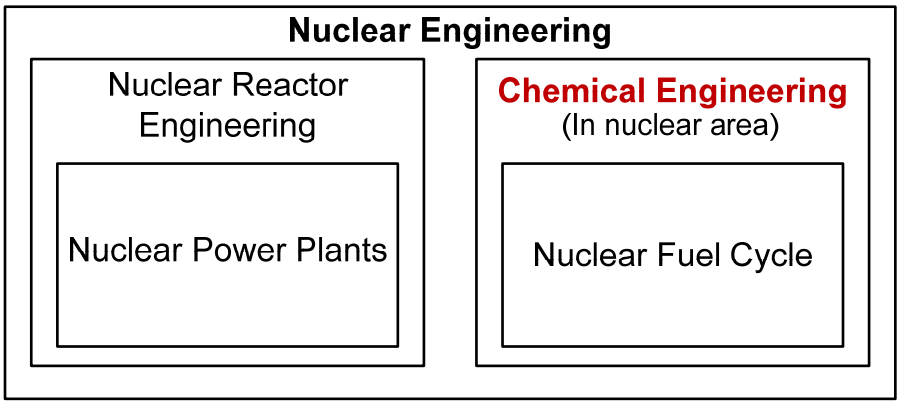

Figure 1: Simplified structure of Nuclear Engineering

The educational programme includes:

- The development of numerical methods and software/hardware systems for advanced process control (APC) of high-tech and knowledge-intensive production in the nuclear industry and energy. The development is related to the selection of proper research methods, the improvement of existing techniques, and the definition of novel performing and practical solutions;
- Practical projects for the aforementioned tasks;
- Industrial and technological activities dealing with the validation and process operations of existing and new technologies;
- The process modeling, simulation and experimental research in the field of automation by means of the latest scientific and technical achievements;
- The development of new methods and techniques to manage technical processes and the production of nuclear industry and energy (development of instruments for nuclear industry and energy);
- Engineering and scientific problems solutions under uncertainty; development of techniques based on robust approaches for specific production problems associated to the use of advanced technologies in the field of automation;
- Design, setup and operation of APC systems and facilities for equipment testing;
- Design of specialized electronic devices for nuclear power plants and industry;
- Design, setup and operation of autonomous systems, automated control systems of operation lines and processes.

The competences and skills expected from the graduate students of the “Computer-Aided Nuclear Enigneering” are:

- The ability to apply knowledge about the processes and apparatuses of production of nuclear industry and energy for the understanding of APC systems targets and objectives;
- -The ability to apply knowledge of APC systems theory and practice, including mathematical, information, numerical methods and technical support for the appropriate operation of such systems;
- Understanding of the overall production management structure of nuclear industry and energy, in order to understand their personal role there;
- Readiness for organizational and managerial work with task forces;
- Validated knowledge of industrial safety in nuclear industry and energy;
- The ability to apply knowledge of APCS theory and practice, including mathematical, information, numerical methods and technical support for systems design as consistent with specified requirements and conditions;
- -The ability to apply knowledge in electronics and automation fields for new facilities design of automated control systems;
- The ability to apply knowledge about technical processes and apparatuses of the nuclear industry and energy to develop their mathematical description towards to APC system research and design;
- To have scientific investigation skills, to be able to plan and analyze results;
- The ability to summarize and main results detachment;

- The ability to synthesize ideas and recommendations based on results analysis;
- The ability to organize and conduct academic studies;
- The ability to explain educational material;
- The ability to hold a quality presentation;
- The ability to make a quality job completed presentation.

University competences in master's program realization:
TPU will base its effort in the training in the Nuclear Engineering field, including nuclear physics, chemistry of radioactive elements, radiation and nuclear safety, but will provide also a number of professional competences in the field of electric engineering, electronics, control theory, digital control systems, control systems of nuclear power plants and processes.
POLIMI will handle the training in the Chemical Engineering field, including the development of detailed kinetic models, thermodynamic models, steady-state and dynamic process simulations, online robust data reconciliation, process optimization techniques and optimal control, and supply-chain management.

3. Request investigation on graduate students with major in Computer Aided Process System Engineering (Nuclear Engineering)

Graduate students of Department of Electronics and Automation of Nuclear Plants had taken by the example of "Computer Aided Nuclear Engineering" request. Every year Department of Electronics and Automation of Nuclear Plants is receiving specific requests from more than 30 private and public societies, and market request are continuously increasing. Information about graduate employability over the last 6 years is reported in Table 1. Figure 2 shows the request of graduates (G) on the outgrowing supply (P) per year.
It should be noted the department provides stage periods and external practical experiences for students at the facilities of the involved organizations. The students have the opportunity to visit three different organizations during their studies and to select one of them for their stage/external period.

Table 1: Information about graduate employability (in Russia)

Years	Graduate students	Graduate students requests	Involved organizations
2014	24	101	27
2013	34	103	30
2012	21	103	29
2011	25	66	17
2010	36	83	24
2009	39	138	26

The nuclear industry of European Union have the same problem with a shortage of engineers like in Russia. In Britain (Atkins, 2014) engineering stuff is searched at related industries. A shortage of engineers in Nuclear Industry is topical more than ever. In UK new 10 plant units is planned to build, and for with reason service companies try to solve with problem by organizing special training and retraining programs, e.g. Atkins launched its own training program.
The nuclear industry has demographic problems. Many specialists retire on a pension when program of nuclear plants construction starts. For example, until 2020 the UK will need for 830,000 scientists, technologists and engineers. However, only 23,000 engineers are finished British Universities annually.
In the USA, the education problem in nuclear field is priority. The problem of the shortage of skilled scientists attached great importance at the federal level. In the United States, as in many other countries, do not spare the money shots. In 2005, Minenergo of Russia approved educational grant program developed by Nuclear Regulatory Commission (NRC). The program aims to support various educational program. At the result, it needs experts in all stages of the NFC. Program budget is calculated for the each financial year. It equaled 4,7 million US dollars in 2013 financial year. Accredited higher state or private foundations can send an application in program.

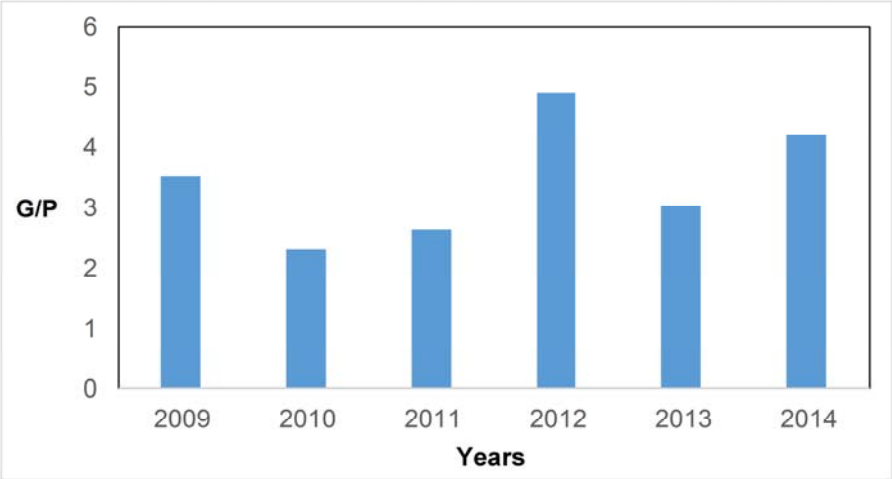

Figure 2: Information about graduate students request over the last 5 year (in Russia)

Nuclear scientists preparation in France takes place in the framework of the European Nuclear Education Network (ENEN), which was founded in 2003 and included over 30 of the most prestigious nuclear universities in Europe now. The main objective of ENEN is to save and develop of nuclear knowledge.
Eight Japan institutions is the largest suppliers of educational programs for future workers in the industry. There are Tokyo Institute of Technology, University of Kyoto, Osaka, Tohoku, Nagoya, Hokkaido and Kyushu. The most prestigious university is Tokyo Institute of Technology (TIT). Now there has about 10,000. Students, nearly half - for undergraduate, another 3.5 thousand. - On Master 1,500 - Doctoral and about a hundred - the so-called scholars, mostly foreigners.
Thus, the actuality of the engineers training for the nuclear industry is very high, and the development of the industry requires continuous graduate skills improvement, it needs to correct of existing programs and develop new ones for with reason.

4. Conclusions

Chapter 2 Nuclear Engineering needs specialists training in the chemical engineering field with nuclear physics, chemistry of radioactive elements and other skills. Knowledge in process modeling, process control, process optimization, advanced process control and robust data reconciliation is the key-element for this novel specialist, which market request is strongly increasing in different countries. A program allows to prepare specialists in Nuclear Engineering field with Computer Aided Process abilities for Nuclear Reactor Engineering *и* Chemical Enginering. It is unique and requested program (4-5 requests on one graduate students). It is shown a high quality of specialist training in economy sector. Graduate students can work in design organizations, where they will effectively solve optimization and math modeling tasks. On the other hand, they can make commissioning and show themselves like as specialists in on-line tuning of Control system field. Based on strong theoretic training, in academic's organizations graduates can rage on, develop a new control technology and follow further area such as process modeling, process control, process optimization, advanced process control and robust data reconciliation. Thus, the program implementation will provide a significant economic effect and safety in Nuclear Engineering field.

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