New Postgraduate Programs in Nuclear Engineering to Meet the Needs of the Canadian Nuclear Industry

George BEREZNAI[1] and William GARLAND[2]

[1]*University of Ontario Institute of Technology*

2000 Simcoe Street North, Oshawa, Ontario, Canada, L1H 7K4

Tel. 905-721-3142, Fax. 905-721-3169, E-mail george.bereznai@uoit.ca

[2]*University Network of Excellence in Nuclear Engineering*

1280 Main Street West, Hamilton, Ontario, Canada, L8S 4L8

Tel. 905-525-9140 x24925, Fax. 905-528-4339, E-mail: garlandw@mcmaster.ca

The paper reviews the current state of nuclear engineering postgraduate education in Canada, with emphasis on the new courses and programs that have been introduced since PBNC2006. The importance of these developments is presented against a background of the aging of the reactor fleet that came into operation in the 1970s, 1980s and early 1990s, along with the changing training needs and demographics of the nuclear industry. The demand for nuclear engineers continues to grow in order to operate, maintain, upgrade and refurbish the existing units, as well as to design, construct, commission and operate the new reactors that are being proposed in Canada and abroad. Responding to this demand, a consortium of key Canadian nuclear companies, and universities that conduct research and offer postgraduate courses in nuclear engineering, have formed UNENE (University Network of Excellence in Nuclear Engineering). In addition to funding research chairs at seven universities in Ontario, UNENE offers a course-based master of nuclear engineering program. In this way, industry funding has effectively revitalized existing, and initiated new, nuclear programs at established universities. In addition, one of the UNENE partners, the newly established University of Ontario Institute of Technology (UOIT), is offering both research and course-based master of nuclear engineering programs as of September 2008. Based on the experiences of UNENE and UOIT the paper explores the gap between the mandates of universities and the nuclear industry, collectively and individually. It is shown that by recognizing the differences and capitalizing on their respective strengths, the graduate and postgraduate educational programs conducted by universities can be effective to complement the training and experience that only the industry can offer.

Keywords: *nuclear power, CANDU, education, training, research, aging of workforce*

1. Introduction

In Canada's most industrialized province, Ontario, nuclear power plants have been providing a significant portion of electrical generation since the early 1970s. For the last two decades, approximately 50% of the electrical energy has been generated from nuclear units, all of the CANDU (CANada Deuterium Uranium) type. There are currently 16 units in operation, ranging from the Pickering"A" units (2x515 MWe net capacity, placed in-service 1971-73) to the Darlington units (4x881 MWe net capacity, placed in-service 1990-90), and two Bruce "A" units (each 769 MWe, with in-service dates in 1977 and 1978) under refurbishment [1]. The two Pickering "A" and the other two Bruce "A" units have already been refurbished, and studies are currently under way to determine the cost-benefit of refurbishing the four Pickering "B" units (each 516 MWe) and the four Bruce "B" units (each 860 MWe). On-going utilization of nuclear-electric generation in Ontario is also planned to include new units to be built, with the selection of site and technology expected around the end of 2008.

The demographics of the work force is aging just as much as the generating stations. Virtually everyone involved with the design, construction and commissioning of the first set of commercial units at Pickering has already retired, and a large fraction of the current nuclear engineers is expected to retire in the next 5 years.

Currently approximately 100 newly graduated engineers and another 100 experienced engineers are hired annually by the nuclear industry to make up for the people retiring, and to handle the on-going maintenance and operational needs. About 20% of the newly hired engineers have education and/or experience in the industry, the rest need on-the-job training and post-graduate education to achieve the desired level of expertise.

2. Undergraduate nuclear engineering education

There is a wide range of engineering education programs in Canada, as well as a strong level of immigrants with engineering degrees. The majority of the engineers in the nuclear industry graduate from one of the traditional chemical, electrical, and mechanical engineering programs, and there are only a few universities that offer engineering programs specific to the nuclear field. In Ontario, McMaster University offers a nuclear option in engineering physics, while the University of Ontario Institute of Technology (UOIT) is the only Canadian university with an accredited undergraduate nuclear engineering program [2].

Many students prefer to study for the traditional degrees at the undergraduate level, as this gives them wider options for employment. If they join the nuclear industry, most of the engineers will receive training specific to their work assignments, while some will decide to specialize and elect to enter a graduate nuclear engineering program.

It requires a significant level of nuclear industrial activity for a country or region to have the demand for nuclear engineering graduates to be able to attract a sufficient number of students in order to mount a sustainable nuclear engineering undergraduate program. At the same time, most universities do not see it as their mandate to offer undergraduate programs that focus on meeting a particular industry's needs for employees with specialized knowledge. Instead the academic interests typically are biased towards research and graduate programs of broader applicability.

UOIT has been in a unique position in terms of being located close to the six Pickering and four Darlington operating units, most of which are expected to be refurbished, as well as some of the new units likely to be located at Darlington. In addition, Ontario Power Generation has relocated its engineering support staff into the Pickering area, and there are also several consulting companies with offices within easy driving distance of UOIT. The creation of UOIT by the Government of Ontario included the mandate to offer programs that produced graduates in demand by industry, and nuclear engineering was identified as one such program. About 100 students were admitted when the program was first offered in 2003, and the first graduates are already in the workforce. At the current level of interest approximately 50 graduates are expected from the nuclear engineering program each year, although once the site and timing of the new build and the schedule for refurbishments are announced, there could be a doubling of the number of students selecting nuclear engineering, with a corresponding increase in the number of graduates.

Canadian universities that offer graduate programs in the nuclear field will usually have at least one or two courses that undergraduate students can take as electives. Such opportunities broaden the base of graduates with improved understanding of the issues specific to a career in the nuclear industry, and they also improve the employability of such graduates.

3. Graduate programs in nuclear engineering

In the Province of Ontario several universities offer graduate level courses and conduct research in nuclear engineering, including McMaster, Queen's, Toronto, Waterloo, Western Ontario, UOIT, Guelph and the Royal Military College (RMC), but only McMaster, UOIT and RMC offer graduate degrees in nuclear engineering. Quebec's Ecole Polytechnique in Montreal is the only Canadian university outside Ontario that offers graduate programs in nuclear engineering. In the Province of New Brunswick where a single CANDU unit is in operation, the University of New Brunswick (UNB) offers graduate programs that include a significant level of nuclear engineering courses.

In order to enhance the research capability and access to graduate level degrees in nuclear engineering, leading members of Canada's nuclear industry, including Ontario Power Generation, Bruce Power and Atomic Energy of Canada Limited, decided to make a long term financial commitment to support the nuclear programs at the above universities, forming UNENE (University Network of Excellence in Nuclear Engineering) in 2002 [3]. Through Federal Government grants that match the industry's contribution to research and in-kind contributions from universities, over $20 million CAD has been contributed to UNENE with commitments for a second similar phase of funding. To date nine research chairs have been established, and a course-based Master of Nuclear Engineering (M.Eng.) program offered. Some of the unique aspects of the M.Eng. program are that students can enroll (and have the degree awarded) at any of the participating universities while taking courses offered at any of these universities, and the courses are offered typically on weekends and condensed into six to eight week sessions.

The courses that have been offered under the UNENE M.Eng. program are shown in Table 1. To gain the degree, participants need to complete either ten courses, or eight courses and an industrial research project. The four courses shown in bold must be included in the courses completed. A total of 72 students have enrolled in the program, of which 24 have already graduated 39 are currently active in the program. Feedback from graduates and their employers have been positive, it has recognized the specialist knowledge gained by the participants, often resulting in accelerated career progressions.

Table 1 Courses offered towards the UNENE M.Eng. in Nuclear Engineering

Course Title	Universities offering the course
Nuclear Plant Systems and Operations	**McMaster, UOIT**
Reactor Physics	**McMaster, UOIT**
Nuclear Reactor Safety Design	**McMaster, UOIT**
Reactor Thermalhydraulics	**McMaster, UOIT**
Control, Instrumentation and Electrical Systems in CANDU Plants	Western, UOIT
Nuclear Fuel Waste Management	Western, UOIT
Project Management for Nuclear Engineers	Western, UOIT
Engineering Risk and Reliability	Waterloo, UOIT
Power Plant Thermodynamics	UNB, UOIT
Radiation Health Risks and Benefits	McMaster, UOIT
Nuclear Materials	Queen's, UOIT
Fuel Management	RMC, UOIT
Reactor Chemistry and Corrosion	UNB, UOIT
Industrial Research Project	All

As can be seen from Table 1, only UOIT offers the full range of courses required for the M.Eng. degree. This ability is a direct consequence of the undergraduate program that UOIT offers, and the expectation that significant numbers of present and future employees in the nuclear industry will take graduate courses from UOIT. By its location, UOIT has a potential market in its vicinity of over 1,000 engineers and scientists working in the nuclear field, allowing the University to build up a core faculty of 10 professors. Furthermore, again due to UOIT's proximity to the nuclear plants and their engineering support organizations, it has been relatively easy to find adjunct and part time professors to teach courses at both the undergraduate and the graduate levels.

At most Ontario universities that offer graduate programs in engineering, students seeking a degree at the Master's level can usually select to enroll either in a Master of Applied Science (MASc) or a Master of Engineering (MEng) program. The former is typically regarded as "research based" and requires completion of four to six courses plus a thesis based on the student's research, and which the student must defend in front of an examination committee. Most students enrolled in an MASc program are studying full time, although there is increasing demand for part time studies. The MEng program, such as the one described above as offered by UNENE, is labeled as "course-based", requiring either in the order of ten courses, or seven to eight courses plus a project that based either on a university-based research conducted by the student, or an industrial project that makes use of research and development performed by the student at work.

Table 2 shows the titles of the courses offered at UOIT towards MASc and MEng in nuclear engineering, organized into areas of specialty and delivery units. The listing of the courses by specialty is only to aid a potential student in selecting courses relevant to his or her area of desired study, the degree requirements allow choosing courses from any of the specialties. Other restrictions exist, such as students may take no more than one-third of their courses from the undergraduate courses, and they must take at least half of their graduate courses from the ones offered by the Faculty of Energy Systems and Nuclear Science (FESNS). In all cases the choice of courses selected to meet the requirements of the specific degree will require the approval of the FESNS Graduate Program Director; taking into consideration the student's undergraduate program, research interests, and the recommendation of the student's thesis or project supervisor. (http://gradstudies.uoit.ca)

One of the major obstacles to people wanting to gain a graduate degree while working full time has been the traditional approach of Ontario universities to offer courses only a classroom setting delivered Monday to Friday between the hours of 9 am and 5 pm. The solution implemented by UNENE, and significantly contributing to the success of their MEng program, has been to offer the courses on weekends and in a more intensive deliver format (eight hour days and a semester duration of six to eight weeks). Support via e-mail to the students has also been a significant help to overcome the reduced contact time between the course instructor and the participants.

Recognizing that people in industry who want to access graduate programs face problems posed by the distance between the university and the work place, as well as between the traditional lecture and working hours, UOIT is making all the courses available for the graduate degrees accessible via the Internet. Furthermore, because of the large number of potential students within commuting distance of UOIT, all the classes are scheduled as single three hour blocks once a week, and the majority of them will be offered after 4 pm Monday to Friday. The possibility of weekend classes is subject to consensus between the professor and students in any given class.

A WebCT course website has a significant role in the delivery of resources for all courses: syllabus, schedule, assignments, solutions to homework assignments and tests, and past exams, handouts, and supplementary notes are included for every course. While all UOIT classrooms and labs are equipped with VCR, DVD, data projectors, and wired and wireless Internet access, the ones for nuclear graduate courses will also have digital video recording, made available to students both in real time and as play-back via the Internet [4].

Table 2 Courses offered at UOIT towards MASc and MEng in nuclear engineering, organized into areas of specialty and delivery units

Fuel Cycle	**Nuclear Power Plant Systems**	**Math and Science Fundamentals**	**Health Physics**	**Radiological Applications**	**Management and Professional**
Graduate courses delivered by Faculty of Energy Systems and Nuclear Science					
Fuel Management in Nuclear Reactors; Advanced Topics in Radioactive Waste Management; Advanced Topics in Environmental Degradation of Materials	Reactor Physics; Advanced Reactor Physics; Advanced Reactor Engineering; Advanced Nuclear Thermalhydraulics; Heat Transfer in Nuclear Reactor Applications; Power Plant Thermodynamics; Reactor Containment Systems; Control, Instrumentation and Electrical Systems for CANDU plants; Advanced Reactor Control; Advances in Nuclear Power Plant Systems	Mathematical Methods in Nuclear Applications; Transport Theory; Monte Carlo Methods; Applied Risk Analysis; Nuclear Concepts for Engineers and Scientists; Environmental Modelling;	Occupational Health and Safety; Advanced Radiation Science; Advanced Dosimetry; Advanced Radiation Biophysics and Microdosi-metry	Physics of Radiation Therapy; Aerosol Mechanics; Non-destructive Analysis; Industrial Radiography; Nuclear Forensic Analysis	Project Management for Nuclear Engineers; Software Quality Management; *MASc Thesis;* *Seminar;* *Industrial Research Project;* *Graduate Research Project*
Graduate courses delivered by Faculty of Engineering and Applied Science or Faculty of Science					
	Advanced Turbo Machinery; Computational Fluid Dynamics; Embedded Real-Time Control Systems; Analysis and Control of Nonlinear Systems; Adaptive Control; Intelligent Control Systems; Power System Operations, Analysis and Planning	Mathematical Modelling; High-Performance Computing; Numerical Methods for Ordinary DEs; Numerical Methods for Partial Ordinary DEs; Advanced Optimization; User Interface Design			
Undergraduate courses available for graduate credit delivered by Faculty of Energy Systems &Nuclear Science					
Corrosion for Engineers; Radioactive Waste Management Design; Nuclear Fuel Cycles	Nuclear Plant Chemistry; Nuclear Plant Safety Design; Nuclear Plant Operations; Reactor Control; Nuclear Reactor Design; Nuclear Plant Design and Simulation	Risk Analysis Methods; Nuclear Materials; Principles of Fusion Energy	Radiation Biophysics and Dosimetry; Radiation Detection and Measurement; Shielding Design	Industrial Applications of Radiation Techniques; Radioisotopes and Radiation Machines	
6 courses	23 courses	15 courses	7 courses	7 courses	2 courses

4. Conclusion

The success of the nuclear renaissance will depend to a significant degree on the availability of the engineers and scientists educated and trained in the many specialties that make up the industry. Three significant obstacles that have to be overcome in achieving the required quality and quantity of specialists are the ones posed by demographics, geography and institutional differences between universities and industry. To a large degree, the approaches implemented in Ontario are designed to overcome these obstacles.

UNENE brings together industry members and universities with nuclear needs and capabilities to manage the knowledge transition from the experienced workers as they approach retirement, and provide a vehicle for archiving the knowledge and transferring it to the newly hired graduates and to people with only a few years of nuclear industry experience. The creation of research chairs results in centers of expertise and attracts students to areas of research previously under funded. Complementing their research, the chair professors offer courses to the graduate students to help them meet the program course requirements, as well as offering elective courses at the undergraduate level that attract more students to the nuclear field.

The availability of the UNENE courses on weekends, and the offering of the UOIT courses in the evenings and via the Internet are helping to overcome the difficulties due to distance between the work place and the university. UNENE and the market-oriented mandate of UOIT both are significant factors in overcoming the institutional gap: the funding provided by the industry partners, the sharing of management responsibilities on how UNENE funds are spent on research and on the type of courses offered, the proximity and partnerships between UOIT and some of the large nuclear industry partners are all designed to bring industry and university into a closer working relationship.

5. References

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