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Curriculum Development for a Nuclear Track in Mechanical Engineering*

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With sponsorship from the US Nuclear Regulatory Commission, Virginia Commonwealth University (VCU) has developed a nuclear engineering track within its undergraduate mechanical engineering program. Eight courses from the mechanical engineering curriculum were replaced with nuclear engineering courses to create the track. For the benefit of other universities which may be contemplating a similar undertaking, the present article presents motivation for the track, justifies and describes the content of the nuclear courses that are included, and explains the courses that were replaced. In contrast to a stand-alone nuclear engineering bachelor's degree or a minor in nuclear engineering combined with a major in mechanical engineering, the VCU nuclear track equips graduates with both the breadth of an accredited mechanical engineering degree and a focused sequence of nuclear courses that is comparable to those taken in typical nuclear engineering degree programs. To achieve the goals of the track, the challenges were to determine which courses to remove from the curriculum while maintaining an accredited mechanical engineering degree, and which courses to add so that the new sequence compares well with typical nuclear engineering degree requirements.

Keywords: nuclear engineering curriculum; nuclear engineering track; undergraduate nuclear engineering education; nuclear engineering at the bachelor's degree level

1. INTRODUCTION

A SIGNIFICANT NUMBER of new fission reactors are now being ordered in the US for the first time in about thirty years. Two issues motivate this renewed interest in nuclear power generation: dependence on foreign oil and global warming. Fission-based power generation can reduce the country's insatiable appetite for fossil fuel, and no carbon dioxide or any other heat-trapping gases are generated as a direct result of nuclear power generation. Along with other pollutants, a coal-fired power plant, in contrast, annually releases 10 billion kg of carbon dioxide into the atmosphere for each 1,000 MW of fully utilized electric capacity—the estimate is based on typical efficiency of coal-fired power plants, carbon content of commonly used coal, and straightforward chemistry analysis. Even hydrogen-fueled or battery-powered automobiles will reduce pollution and dependence on fossil fuel only if nuclear power or other non-fossil, non-polluting fuels are used to produce the hydrogen or to generate the electricity needed to charge the batteries. Furthermore, at the present time and at least into the foreseeable future, the cost of electricity from nuclear power plants is far less than any of the alternative energy technologies now contemplated, such as solar, biomass, and wind. Nuclear power must be part of any future solution to the energy crisis.

The US Bureau of Labor and Statistics has identified nuclear engineering as the second fastest growing engineering discipline, with an expected growth rate of 7% over the next decade [1]. Most job growth will be in research and development and engineering services. With the projected growth in nuclear power will come the need to design new plants and research future nuclear power sources. When the necessity of operating existing nuclear power plants at near full capacity is combined with the expected growth in the number of plants, the need for more nuclear engineers is evident. Nuclear engineers will also be needed to work in defense-related areas, to develop nuclear medical technology, and to improve and enforce waste management and safety standards. About half of the US nuclear industry's workforce will be eligible to retire during the next 10 years [2], further compounding the projected shortage of nuclear engineers. This "perfect storm" of diminishing workforce in an expanding industry has prompted an unprecedented recruitment effort throughout the industry.

To help train the next generation of nuclear engineers, Virginia Commonwealth University (VCU) has initiated a nuclear engineering track within its undergraduate mechanical engineering curriculum. This track was developed with the support of a grant from the US Nuclear Regulatory Commission, and is available to students beginning in the fall 2009 semester. In contrast to a stand-alone nuclear engineering bachelor's degree or a minor in nuclear engineering combined with a major in mechanical engineering, the VCU

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nuclear track equips graduates with both the breadth of an accredited mechanical engineering degree and a focused sequence of nuclear courses that is comparable to those taken in typical nuclear engineering degree programs. For the benefit of other universities which may be contemplating a similar undertaking, the present article presents the motivation for initiating nuclear engineering education at VCU, justifies and describes the content of the nuclear courses that are included in the nuclear engineering track, and explains the courses within the mechanical engineering curriculum that were replaced.

2. MOTIVATION

2.1 Expected growth in the nuclear industry

Due to a renewed interest in nuclear power generation, there is anticipated growth in nuclear engineering education. After several decades of hiatus, nuclear power generation is witnessing a renaissance in the United States. There are 65 nuclear power plants operating 104 reactors in the US [3], but the last new nuclear generation unit came online in 1996. However, during the last few years, some 17 companies and consortia have placed 21 applications with the US Nuclear Regulatory Commission to obtain licenses for 32 new nuclear generating units [4]. In 2007, U.S. manufacturers received tentative orders for seven new nuclear reactors for the US market, and over 65 more for China, Japan, India, Russia, and South Korea. It is projected that construction of new nuclear power plants would have begun as early as 2009. Two issues motivate this renewed interest: growing dependence on foreign oil and global climate change. Nuclear power generation can reduce appetite for fossil fuel in the US and thus serve as one method of reducing harmful greenhouse-gas emissions. Aside from the limited-by-nature hydroelectric power, nuclear energy is the only electricity source that can generate electricity continuously, reliably, efficiently, and with no greenhouse-gas emissions.

2.2 Expected need for nuclear engineers in the US

With the recent renewed interest in nuclear energy, a shortage of trained engineers is now anticipated for the coming decades. The 2008–2009 edition of *The Occupational Outlook Handbook* [1], published by the US Bureau of Labor Statistics, gives the following projections for the period 2006–2016. The total number of engineers in the US is projected to rise from 1,512,000 to 1,671,000 (an 11% increase over the decade). Nuclear engineers are anticipated to increase from 15,000 to 16,000 (a 7% increase). While this percentage increase does not seem to be impressive, two considerations place the number in perspective. First, the number of mechanical engineers is anticipated to increase over the same period from 226,000 to 235,000 (a 4% increase). Second, there is still a need for a new generation of nuclear engineers even if the percentage increase was zero. This is because of an aging workforce in the nuclear power generation industry that needs to be replenished. The median age for workers in the nuclear utility industry is over 48.0 years, as compared to 41.4 years for the entire US workforce. As much as 35% of the present nuclear power industry workers are eligible to retire within the next five years [2]. An additional 11% of that workforce may be lost through attrition over the same period. The challenge of replacing an aging nuclear workforce is made particularly acute because the number of schools graduating nuclear engineers steadily declined over the past few decades.

2.3 Graduation rates and nuclear engineering programs

Beginning in the 1990s (1998–2003), the nation experienced a steady decline in the number of nuclear engineers graduating annually with a bachelor's of science degree, from 222 to 166 students, or a master's of science degree, from 160 to 130 students. Several graduate and undergraduate nuclear engineering academic programs across the US were terminated, including the programs at the University of Virginia and Virginia Tech. Since 2003, enrollment and graduation rates in nuclear engineering have shown a steady increase and in 2006, 346 BS degrees were granted, a 30% increase from 2005. Nevertheless this number is still lower than the average of 400 BS degrees awarded in the early to middle 1990s. There are now only 31 nuclear engineering programs in the US. [5]. However, a number of universities have recognized the increased demand for nuclear engineering graduates and are either resurrecting old programs or initiating new ones.

The decline in nuclear engineering education over the past 20 years is also evident from a review of literature. Using Compendex, the present authors conducted a literature search for scholarly articles using the key words "curriculum" and "nuclear engineering". This includes publications from anywhere in the world, not only the United States. Of the 184 records found, only 82 have been published since the year 2000. The most in any year since then was 23 publications in 2008. Of the 82 papers since 2000, a review shows that only a small number are related to the creation of a minor or concentration [6–9]. The others are primarily focused on new ways of teaching courses in existing programs (e.g. integrating computers into the curriculum [10]), curriculum improvement and course development within those programs [11–13], or the development of technology education [14–20].

2.4 Need for nuclear engineers in the Virginia region

Of the 15,000 nuclear engineers in the United States, Virginia and Washington, D.C., are among the five states that have the highest concentration of nuclear engineers (1,170). Washington, D.C. ($121,180) and Maryland ($114,440) are ranked third and fourth in average salaries, and the *Virginia Beach–Norfolk–Newport News* metropolitan area has the second highest concentration of workers (630) in this occupation [21]. Dominion, AREVA, and Northrop Grumman, three of the leading employers of nuclear engineers in Virginia, are projecting that they will hire several engineers per year over the next ten years to replenish their workforce and meet expansion needs. The nearest undergraduate nuclear engineering degree programs to the Commonwealth of Virginia can be found at North Carolina State University, the University of Maryland, and the University of Tennessee at Knoxville. Based on their graduation rates, these programs do not sufficiently serve the nuclear engineering workforce needs of the Virginia region. Together, the expected increase in the demand for nuclear engineering graduates and the lack of an undergraduate nuclear engineering program in Virginia justifies the need for a nuclear engineering program at the bachelor's level at VCU.

2.5 Engineering at VCU

The School of Engineering at VCU was initiated in 1996 when undergraduate programs in biomedical, chemical, electrical, and mechanical engineering were added to the existing graduate program in biomedical engineering. In 2000, the graduate program was expanded to offer master's and doctoral degrees in engineering, and a new program offering a master's degree in mechanical and nuclear engineering commenced in Fall 2007. The following sections describe the development of a nuclear engineering track within the undergraduate mechanical engineering program at VCU that is available to students starting the fall 2009 semester.

3. COMPARISON TO OTHER PROGRAMS

As stated, there is a growing need for nuclear engineers and the new nuclear track at VCU is designed to help meet that need. The Accreditation Board for Engineering and Technology (ABET) [22] currently lists 21 accredited undergraduate nuclear engineering programs. In addition, a review of mechanical engineering departments at universities in the United States finds approximately ten with nuclear engineering concentrations or tracks that currently exist or will be started soon.

VCU's nuclear program is unique in its scope. The track provides the breadth of an accredited mechanical engineering degree and a focused sequence of eight nuclear courses that is comparable to those taken in typical nuclear engineering degree programs. As shown in Table 1, the eight courses required for VCU's nuclear track are more than those required at other schools with similar concentration programs. This ensures that VCU graduates will leave with the employability of a mechanical engineering degree, but with a significant nuclear engineering skill set.

4. THE NUCLEAR ENGINEERING TRACK

4.1 Overview of the nuclear track

Beginning in the fall 2009 semester, undergraduate students in mechanical engineering can choose between two tracks in the curriculum: the general track, which is equivalent to the original mechanical engineering curriculum, or the nuclear engineering track. The course sequences for the general and nuclear tracks are shown in Figures 1 and 2, respectively. To create the nuclear track, four technical electives, one business course, one math course and two mechanical engineering courses were replaced with six nuclear engineering courses, one nuclear engineering elective and one upper-level physics course. Both tracks require students to complete a minimum of 130 credit hours to earn a bachelor's of science degree in mechanical engineering from VCU. The nuclear track preserves the mechanical engineering courses necessary to maintain ABET accreditation, while including 24 credit hours in nuclear engineering, plus a two-semester nuclear engineering senior design project. Furthermore, students will

Table 1. Number of required nuclear engineering courses in mechanical engineering departments offering a nuclear engineering concentration or track. Number does not include any senior capstone design courses. VCU's requirement of eight nuclear engineering courses exceeds the requirements at other universities

University	Number of required nuclear courses for concentration or track
Virginia Commonwealth University	8
City College of New York	4 [23]
Kansas State University	4 [24]
Lousiana State University	2 [25]
Ohio State University	4–6 [26]
United States Naval Academy	3 [27]
University of Massachusetts-Lowell (nuclear track is in the Chemical Eng. department)	4 [28]
University of Texas of the Permian Basin	6 [29]
Virginia Military Institute	2 [30]
Virginia Tech	4 (certificate) or 6 (minor) [31]

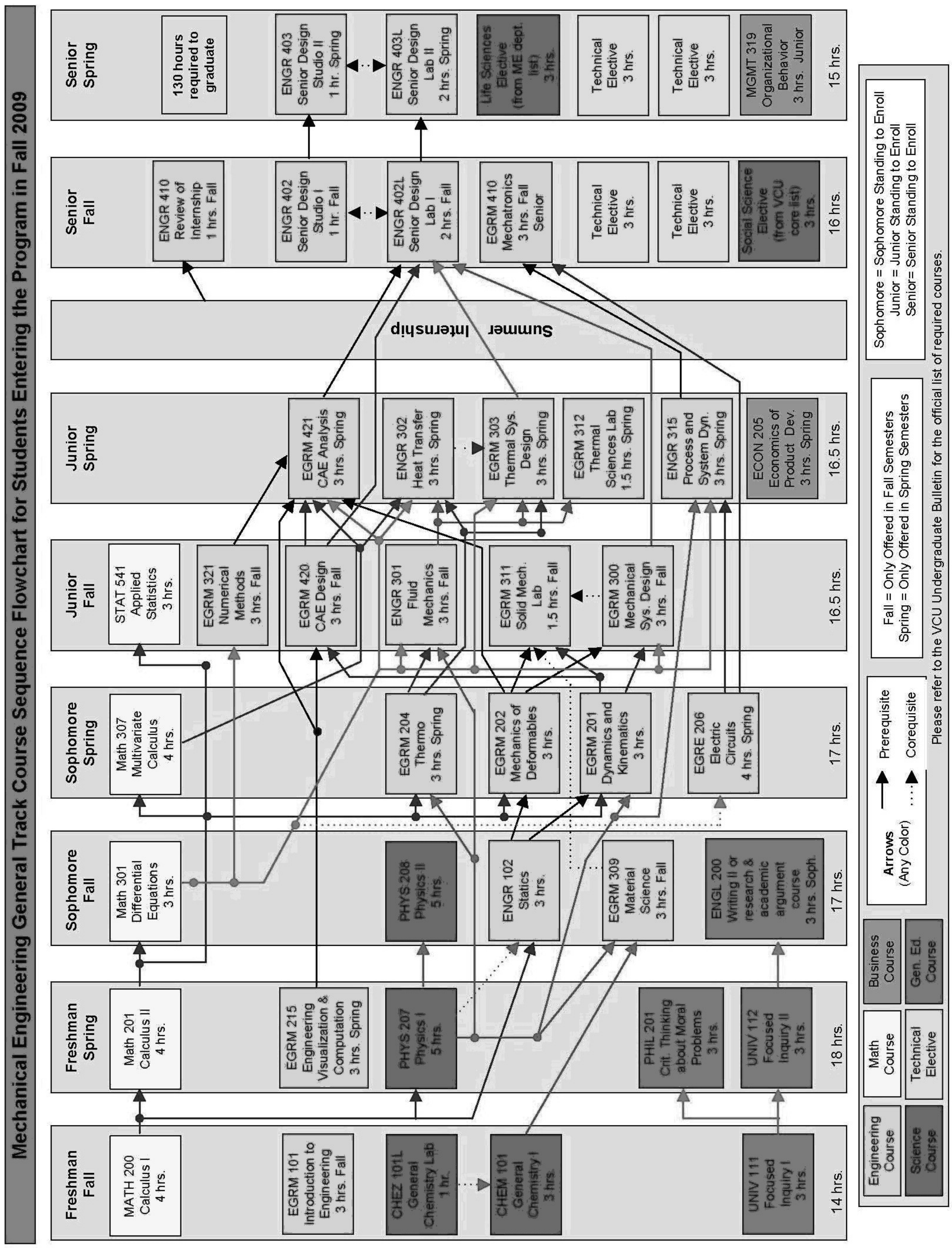

Fig. 1. Mechanical engineering general track curriculum.

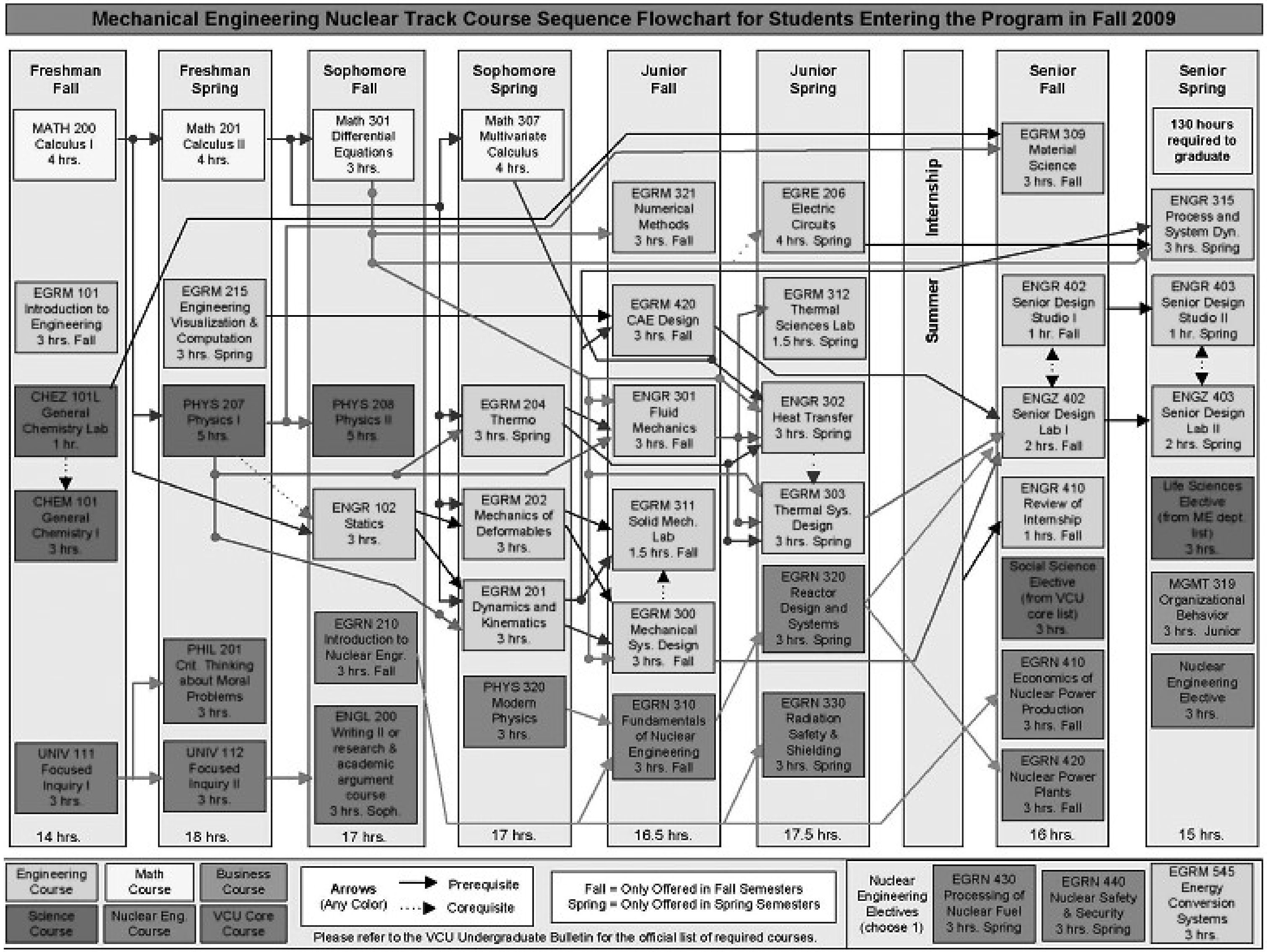

Fig. 2. Mechanical engineering nuclear track curriculum.

complete a required summer internship or co-op at companies such as Dominion , AREVA, Northrop Grumman, and GE-Hitachi Nuclear Energy, all of which have representatives on our Nuclear Engineering Industrial Advisory Board, or at other companies and government regulatory agencies that employ nuclear engineers.

4.2 Objectives of the nuclear engineering track

Our nuclear engineering track is aimed at assisting industries and government in Virginia and elsewhere in the nation in their efforts to utilize safe nuclear power to better our economy and environment. The program has the following objectives for undergraduate education:

- Provide the students with an in-depth knowledge of mathematics, mechanical, and nuclear engineering needed to solve problems of our nuclear power industry;
- Provide students with the knowledge of component design, system and process analysis, and safety in the nuclear power generation;
- Prepare students to understand the social, economic, environmental, and ethical issues when dealing with real world problems;
- Provide the students with inter-disciplinary problem solving and communication skills.

VCU nuclear engineering track will prepare our mechanical engineering graduates to become expert professionals in the nuclear power generation industry.

4.3 Course selection for the nuclear track

The nuclear engineering curricula at several prominent universities were examined to identify the essential courses to include in our nuclear track. The two nuclear engineering programs most comparable to our track are North Carolina State University (NC State) and Rensselaer Polytechnic Institute (RPI). The nuclear engineering courses from these programs are listed in Table 2 along with the courses in our nuclear track and the courses from our previous mechanical engineering curriculum—now designated the general track—that were replaced to create the nuclear track. For a bachelor's of science degree in nuclear engineering, both NC State and RPI require eleven nuclear engineering courses, including nuclear engineering electives and senior design. Students graduating from our nuclear track will receive a bachelor's of science degree in mechanical engineering, which

Table 2. Courses in the VCU nuclear engineering and general tracks in mechanical engineering and in the nuclear engineering programs at NC State and RPI

#	VCU Nuclear Engineering Track Courses	VCU General Track Courses (replaced to create nuclear track)	NC State Nuclear Engineering Courses	RPI Nuclear Engineering Courses
Required Courses				
1	EGRN 210 Introduction to Nuclear Engineering	Technical Elective	Introduction to Nuclear Engineering	Introduction to Nuclear Engineering
2	PHYS 320 Modern Physics	Technical Elective	Nuclear Reactor Energy Conversion	Nuclear Phenomena for Engineering Applications
3	EGRN 310 Fundamentals of Nuclear Engineering	Technical Elective	Fundamentals of Nuclear Engineering	Fundamentals of Nuclear Engineering
4	EGRN 330 Radiation Safety and Shielding	STAT 541 Applied Statistics	Radiation Sources, Interaction & Detection Radiation Safety and Shielding	Nuclear Engineering & Engineering Physics Lab Radiological Engineering
5	EGRN 320 Reactor Design and Systems	EGRM 421 CAE Analysis	Reactor Analysis and Design	Physics of Nuclear Reactors
6	EGRN 420 Nuclear Power Plants	EGRM 410 Mechatronics	Reactor Engineering Reactor Systems	Nuclear Power Systems Engineering
7	EGRN 410 Economics of Nuclear Power Production	ECON 205 Economics of Product Development and Markets		
Nuclear Engineering Electives				
8	Nuclear Engineering Elective	Technical Elective	Nuclear Engineering Elective	Nuclear Engineering Elective I Nuclear Engineering Elective II
Senior Design				
9	ENGR/ENGZ 402 Senior Design Studio and Lab I	ENGR/ENGZ 402 Senior Design Studio and Lab I	Nuclear Engineering Senior Design Preparation	Senior Design Project I
10	ENGR/ENGZ 403 Senior Design Studio and Lab II	ENGR/ENGZ 403 Senior Design Studio and Lab II	Nuclear Engineering Design Project	Senior Design Project II

includes ten nuclear engineering courses, including nuclear engineering electives and senior design. Thus, our graduates will have completed a comparable number of nuclear engineering courses to those students receiving degrees in nuclear engineering at other institutions. Detailed descriptions of each our nuclear courses are provided in the next section.

4.4 Comparison between the general and nuclear engineering tracks in mechanical engineering

Nuclear engineering is a focused discipline that lies within the broad discipline of mechanical engineering; at many universities, undergraduate programs in nuclear engineering and mechanical engineering are taught within the same department. The VCU undergraduate program in mechanical engineering was fully accredited by ABET in 2000 and 2006. The goal for our track program is to provide students in both tracks with an accredited degree in mechanical engineering, but enable students interested in nuclear engineering to formally focus in that area. Students in the nuclear track will take more focused courses and fewer electives. The specific differences between the tracks are listed in Table 2.

The distinction between the tracks will involve between four and eight courses, depending on which technical electives are selected by students in the general track. Students in the general track will choose four technical elective courses, while students in the nuclear track will take three required nuclear engineering courses and choose one technical elective focused on a topic relevant to nuclear engineering.

To maintain accreditation in mechanical engineering, four courses in the mechanical track were replaced by equivalent, or similar, courses in the nuclear track. Students in the general track will learn statistics in STAT 541, Applied Statistics for Scientists and Engineers, while students in the nuclear track will learn and apply the statistical concepts necessary for radiation detection in EGRN 330, Radiation Safety and Shielding. Students in the general track will learn computer aided engineering analysis by taking EGRM 421, CAE Analysis, while students in the nuclear track will learn to analyze and design reactor systems in EGRN 320, Reactor Design and Systems. In the general track, students will integrate their knowledge of mechanical and electrical systems in EGRM 410, Mechatronics, while students in the nuclear track will integrate their knowledge of mechanical and nuclear reactor systems in EGRN 410, Nuclear Power Plants. Finally, students in both tracks will learn economics; with students in the general track taking ECON 205, Economics of Product Development and Markets and students in the nuclear track taking the more focused course ENGR 410, Economics of Nuclear Power Production. Existing mechanical engineering courses that will be essential to the nuclear engineering degree include Thermodynamics, Fluid Mechanics, Heat Transfer, Thermal Systems Design, Materials Science, Thermal Sciences Lab, Summer Internship, and Senior Design, the last with projects directly related to nuclear engineering.

4.5 Nuclear reactor experience

Since VCU—an urban university located in downtown Richmond, Virginia—has no immediate or future plans to construct a nuclear reactor, our undergraduate program will train future nuclear engineers in reactor technology using other venues. Our options include using one of the reactor simulators located at Dominion, distance-learning using a research reactor at another university, such as the University of Wisconsin—Madison, or hands-on learning using our home-built see-through reactor simulator. This device has all the transport and control processes of a real reactor except the nuclear reaction that is replaced by an electric heating element. It can be used for realistic training of future nuclear engineers in all aspects of safety and accident scenarios. During the academic year 2008–2009, three teams of undergraduate students from the departments of mechanical engineering and electrical & computer engineering designed and fabricated this see-through reactor as part of their capstone senior design projects, and Dominion funded the cost of materials and supplies. Initial testing of the simulator is in progress. Future design teams will continually improve the design and operation of our home-built reactor simulator.

5. NUCLEAR ENGINEERING COURSE DESCRIPTIONS

Six required nuclear engineering courses, one upper-level physics course, and one nuclear engineering elective are required for the nuclear engineering track. The course descriptions are listed in the order they will be completed by students in the track.

EGRN 210 Introduction to Nuclear Engineering: An introductory course to familiarize students with the concepts, systems, and application of nuclear energy. Topics include radioactivity, fission, fusion, reactor concepts, biological effects of radiation, nuclear propulsion and radioactive waste disposal. Designed to provide students with a broad perspective of nuclear engineering.

PHYS 320 Modern Physics: Foundations of modern physics including special relativity, thermal radiation and quantization, wave-particle duality of radiation and matter, Schrödinger equation, atomic, nuclear and particle physics, and molecular structure and spectra.

EGRN 310 Fundamentals of Nuclear Engineering: Emphasizes the fundamentals of nuclear engineering. Topics include the interaction of neutrons with matter, fission, neutron diffusion and moderation, reactor kinetics and dynamics, and radiation detection and measurement.

EGRN 330 Radiation Safety and Shielding: Fundamentals of radiation safety and shielding with focus on sources of radioactivity, interaction of radiation with matter, biological effects of radiation, dosimetry, attenuation of gamma rays and neutrons and effectiveness of shielding methods.

EGRN 320 Reactor Design and Systems: Engineering principles of nuclear reactors, emphasizing power reactors. Specific topics include power plant thermodynamics, reactor heat generation and removal (single-phase as well as two-phase coolant flow and heat transfer), and structural mechanics. The course also covers engineering considerations in reactor design.

EGRN 410 Economics of Nuclear Power Production: Fundamentals of engineering economic analysis are applied to energy supply, demand, prices, and production with specific emphasis on nuclear energy, the capital cost of nuclear power plants, the nuclear fuel cycle and associated energy technologies.

EGRN 420 Nuclear Power Plants: Design and analysis of nuclear power plants. Review of thermodynamic cycles and reactor types; analysis of the coupling of the reactor and the power plant; thermal and mechanical design of steam turbines; turbogenerators; auxiliary systems; design synthesis and heat balance calculations; operation of nuclear reactors.

5.1 Electives for the nuclear engineering track

Students in the nuclear engineering track will choose one of the following courses as their nuclear elective. This list is expected to expand significantly as enrollment in the nuclear engineering track grows. Furthermore, appropriate courses from the graduate program may also be used as the nuclear elective.

EGRN 430 Processing of Nuclear Fuel: A study of processing techniques involved in the nuclear fuel cycle. Topics include front-end stages of nuclear cycle (sources and exploration of nuclear fuel, mining, milling, fuel conversion, fuel enrichment, and fabrication), how processing influences in-core fuel performance and study of back-end stages (spent fuel re-processing, waste disposal and management).

EGRN 440 Nuclear Safety and Security: A study of technological risks and security issues related to nuclear power. Analysis of nuclear reactor system components and operational features that are relevant to safety; reactor containment; safety analysis of nuclear power plants using deterministic and probabilistic models; methods for human, environmental and ecological risk assessment; NRC regulations and procedures; safeguarding against natural (earthquake, tornadoes) and human (domestic and international) threats; classification and consequences of accidents including historical case studies.

EGRM 545 Energy Conversion Systems: Quantitative and qualitative study of traditional and alternative systems used to generate electricity. Topics include combustion, coal-fired boilers, nuclear reactors, steam turbine blading, gas turbine combustors, turbo-generator design, internal combustion engines, solar thermal systems, photovoltaic devices, wind energy, geothermal energy, and fuel cells. Additional topics of interest to the students may be discussed.

6. ASSESSMENT

Assessing the outcomes of the new nuclear engineering track curriculum will be a critical part of the implementation program. This is necessary not only for continuous improvement of the program, but also to ensure that the program obtains and maintains accreditation from ABET (Accreditation Board for Engineering and Technology).

Our assessment plan is based on the highly successful system already used to evaluate our existing Mechanical Engineering Curriculum and reflects two guiding principles:

1. Assessment will occur at every level of the program as a routine part of program management—We will assess student performance nearly continuously throughout the lessons in every course in the curriculum. We will assess again in a more comprehensive manner as each block of instruction ends, as each academic term ends, and as a given group of students successfully completes the program. Alumni will be assessed post-graduation at regular intervals.
2. All constituencies will participate in the assessment process—Assessment encompasses far more than grading of currently enrolled students. Alumni, employers, industrial partners, the Industrial Advisory Board, and the Mechanical and Nuclear Engineering faculty will all participate in the assessment process. An Assessment Committee will be appointed by the department chair to develop several assessment instruments (alumni survey, employer survey, etc.) and to collect and collate the data associated with those instruments.

The existing Mechanical Engineering assessment plan includes many assessment methods as outlined below. The new Nuclear Engineering Track will be assessed using similar methods:

1. Course Grades: The grades in each course will provide information on student mastery of the material covered in that course. Grades on individual assignments (homework, quizzes, tests, projects, final exams) will provide a measure of how well students understand particular topics. Students will be required to pass all engineering courses with a ‘C’ or better and

all students must present their work at the Senior Design Showcase.

2. End-of-Course Evaluations: The student-completed end-of-course evaluations will provide subjective and anecdotal information on how well the students believe they are learning the material provided in an individual course. These evaluations will be reviewed at the end of each semester by the course instructor and the department chair.
3. Exit Interviews: As a requirement for graduation, each senior will be required to complete a survey and meet with the department chair for an exit interview. The survey will be designed in part to directly assess the students' perception of how well they feel they have mastered the program objectives and outcomes.
4. Faculty Observations: As experts in Mechanical and Nuclear Engineering as well as in Engineering Education, the faculty often have an immediate and intuitive feel for how well the students being prepared to meet the program objectives before more formal assessment takes place. Qualitative faculty input into changes needed in the curriculum, program outcomes and program objectives will be gathered through roundtable discussions and faculty meetings.
5. Employer Internship Surveys: Every VCU Nuclear Engineering student will be required to complete an internship prior to graduation. The industrial supervisors of these students will be surveyed to determine student technical skills and personal attributes.
6. Student Internship Survey: The mandatory internship will provide the students with a taste of the requirements of the engineering workplace. They will return with ideas about how the curriculum should be changed in order to better prepare them for employment. After completion of the internship, each intern will complete a self-evaluation survey of his/her technical skills and personal attributes.
7. Two and Five Year Alumni Survey: As the students graduate, they will be surveyed when they reach their two and five year anniversaries. The survey will be designed to directly assess the alumni's perception of how well they have mastered the program objectives and outcomes.
8. Two- and Five-Year Employer Survey: Managers and supervisors at the companies which employ our alumni will be surveyed to determine the graduate's preparedness for the workplace. The questions will ask the employers to evaluate both the importance as well as the alumni mastery of the program objectives and outcomes.
9. Industrial Advisory Board Review of Student Work: The Nuclear Engineering Industrial Advisory Board is composed of experts from industry, academia, and government. At semi-annual meetings, they will meet with the chair and selected faculty to review the progress of the program and help set objectives. They will also be invited to participate in the annual Senior Design Showcase and provide feedback on the quality of the student work.
10. Percent Participation in Professional Societies: An important component of Life-long Learning and Professionalism is becoming active in professional engineering societies. The number of students in American Nuclear Society (ANS) at the time of graduation will be assessed.
11. Teamwork Evaluations by Students: Students will work together on the Senior Capstone Design Course and will evaluate the participation of each team member.
12. Number of Students taking/passing the FE Exam: The Fundamentals of Engineering (FE) exam covers subject matter taught in a typical EAC/ABET-accredited baccalaureate engineering program. As such, it provides an independent, quantitative measure of student understanding. It is also the first step towards a PE license, an important milestone in some industries. During exit interviews and alumni surveys, students will be questioned as to whether they have taken and passed the FE exam. In addition, anonymous records of VCU Nuclear Engineering student performance on the exam are available from the NCEES and will be reviewed.
13. Patents, Papers, Presentations: Undergraduate students will work in research labs on a variety of projects and these projects often result in patents, journal and conference papers, and in conference presentations.
14. Student-on-student mentoring: More advanced students (juniors and seniors) will provide mentoring for underclassmen and high school students. This develops life-long learning and leadership skills. It will also provide underclassmen with a different perspective from that provided by the faculty.

7. CONCLUSIONS

Virginia Commonwealth University has developed a nuclear engineering track within its undergraduate mechanical engineering curriculum. In contrast to a stand-alone nuclear engineering bachelor's degree or a minor in nuclear engineering combined with a major in mechanical engineering, the VCU nuclear track equips graduates with both the breadth of an accredited mechanical engineering degree and a focused sequence of eight nuclear courses that is comparable to those taken in typical nuclear engineering degree programs. To achieve the goals of the track, the challenges were to determine which courses to remove from the curriculum while maintaining an accredited mechanical engineering degree, and which courses to add so that the new sequence compares well with typical nuclear engineering degree requirements. This had to be done without changing the total number of credits needed to graduate. We are confident that the challenge has been met with a program that earned the approval of four levels of university curriculum committees. The particular strategy that we implemented to achieve a track in nuclear engineering while maintaining an accredited degree in mechanical engineering may be useful to other universities contemplating a similar goal. Our next step is to consider the addition of a bachelor's degree in nuclear engineering, a more elaborate step as compared to the design of a track, which additionally requires the approval of the State Council of Higher Education for Virginia (SCHEV), and ultimately accreditation by the Accreditation Board for Engineering and Technology (ABET).

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