Preparing Non-nuclear Engineers for the Nuclear Field

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Abstract – Global warming and energy crises are demanding sustainable engineering. Academia needs to respond with enhanced curricula to better prepare students for the changing world. Only a limited number of American programs have nuclear-related components, and new engineering departments or even concentrations may not be achievable due to student population or institutional funds. At a minimum, a single introductory course would benefit the modern education of all engineering majors as well as provide a hiring pool for industry. Promoting technical appreciation rather than apprehension of nuclear technology, nuclear power generation will be employed as the model application of interdisciplinary systems engineering. This technical elective can also provide multi-disciplinary team experiences which may be lacking due to ever-decreasing degree hour requirements. As an example, the innovative initiation of nuclear technical education at the University of Mississippi is detailed.

Keywords: Nuclear, Industry, Systems, Elective

INTRODUCTION

Environmental, energy, and economic concerns are leading to exploration of sustainable alternative energy as never before. As the greatest user of world energy resources, the United States of America should certainly contribute to energy technological education and development. An understanding of power generation is important for all modern-day engineers, and nuclear energy serves as a good example of a technically viable option that is oft overlooked due to non-technical fears. While global perspectives are shifting, only a limited number of American programs have nuclear-related components. Twenty-four universities have nuclear-related programs, including Nuclear or Radiological Engineering, Nuclear Science, or Nuclear Physics; some are strictly graduate programs related to industrial research and development. Another nineteen programs exist regarding Health Physics [2].

Neither the United States nor the European Union has a comprehensive system for nuclear engineering education. Russia's higher education system may be considered a model of how industry and education can progress together. As the nuclear industry required quality specialists, the education system responded accordingly. Russian universities have served as a direct supply to fulfill nuclear needs. In fact, a "Training Methodological Commission" for each nuclear-related emphasis ensures that industrial needs are met [5]. However, this system is more equivalent to technical certification training in the U.S. system.

Minimally meeting this educational need, a nuclear-related introductory course complies with common university goals by enhancing engineering curricula, providing more qualified non-nuclear engineers for the nuclear industry, and improving faculty teaching competencies. The only required cost is faculty time, which has been covered at the University of Mississippi by a Nuclear Regulatory Commission Educational Grant. Usually enough interest exists so that at least one instructor will be interested. The resulting nuclear training is an educational benefit for both students and the faculty at large. The appropriate lecturer needs little experience with nuclear systems in particular but does need a broad-based view of complex engineered systems. In fact, the examination of a new technical field may have

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the added benefit of research stimulation. The development of nuclear engineering education will also improve student recruitment and industrial collaboration. However, participation from the nuclear industry may be a challenge due to confidentiality and security. If possible, industrial plant site tours can contribute to the educational experience by allowing students to see full-scale systems in a practical application.

As an example, the initiation of nuclear technical education at the University of Mississippi is discussed. Nuclear power generation will be employed as the model application of interdisciplinary systems engineering. Promoting technical appreciation rather than apprehension of nuclear technology, the proposed course relates nuclear systems engineering, safe reactor design, infrastructure sustainability, and environmental management. Although this module will not be offered until the fall semester of 2009, course development and assessment plans are discussed from the viewpoint of a professor with nuclear industrial experience.

The ultimate effect is the promotion of technical understanding rather than general apprehension of nuclear technology. While mass media tends to feed public fears, risk perception can be reduced through education [8]. For the most part, the more people understand the risks and benefits, the more comfortable they become with nuclear power. However, a thin line divides education and persuasion. Proponents of nuclear energy must be careful not to present bias versus facts, such as selecting statistics. Sung and Vaganov explore both sides of this argument with conflicting findings. Technical education alleviates fears of technically-minded people, but overall public opinions are strongly formed against nuclear power expansion. The inertia of this opinion is an enormous and often irrational risk perception [11].

MOTIVATION

Public attitudes are changing with increased rolling blackouts and energy costs. More and more countries have turned to nuclear plants to ease their power grids. Misperceptions have existed even in the technical community, contributing to a shortage of qualified graduates in the nuclear-related industries, especially as that workforce ages. Due to the nominal number of nuclear engineering programs, more non-nuclear engineers are hired than nuclear engineers, making proper training even more vital.

Academia needs to respond by at least providing future engineers the opportunity to choose careers in the nuclear industry. The students must be informed of facts, not fiction, regarding nuclear so that they can make well-informed decisions. As the Bureau of Labor Statistics reports, the number of employees in the nuclear industry fell from 72,000 in 1990 to 56,000 in 2001. As of 2002 employee numbers began increasing, leveling out to 62,000 in 2006. These numbers of employees may be sufficient to support the current state of nuclear power generation but not a nuclear resurgence. Just 0.61% of engineers work in this growing industry. While demand is skyrocketing, employee compensation is also quite high. Engineers in the nuclear industry command the third highest salaries of all engineers. The average engineer earns $66,190 while the average nuclear engineer earns 39% more, or $92,040. In fact, the top 10% of the industry's engineers earn at least $124,510 [10].

The use of nuclear power plants as an example of a complex engineered system directly trains students for introductory positions at the 32 U.S. nuclear operating companies and 4 manufacturing companies. Positions in the nuclear industry occur in numerous states including Idaho, South Carolina, Washington, Virginia, Colorado, Nevada, Maryland, Georgia, Illinois, Ohio, Nevada, Alabama, Tennessee, and the District of Columbia. Potential jobs vary from plant design and operation to environmental effect research. Engineering students are actively being recruited by nuclear companies, such as Entergy and Southern Nuclear Operating Company at the University of Mississippi. Students are drawn to this industry by interesting, environmentally-conscious work in addition to the excellent compensation.

Engineering curricula can benefit from a nuclear-based technical elective. This course option can channel graduates into virtually any industry by improving their ability to consolidate major topics in different engineering specialties. A nuclear systems technical elective will contribute to nearly all program outcomes of the Accreditation Board of Engineering and Technology (ABET). Specifically satisfying Criterion 3's Outcomes (a), (c), and (k), the systems engineering approach will require students to assimilate information from various courses and apply their knowledge to process engineering. The topic of nuclear energy will introduce contemporary issues and critical thinking into engineering problems [Outcomes (e), (i), (j)]. The format of the course can incorporate multidisciplinary teamwork and improve communication skills [Outcomes (d), (g)]. This course will require students to participate in interdisciplinary teams which are extremely rare since most engineering seniors work on capstone design projects entirely within a single specialty or even one subspecialty. This interaction in a unique field may serve to engage students, especially when degree hour reduction is the norm. The result will be a deep comprehension of complex systems in a "global, economic, environmental, and societal context," as noted in Outcome (h). While political issues are not the focus of this technical course, professional and ethical issues must be discussed within the context of safe design [Outcome (f)] [1].

Further discipline-specific criteria can also be satisfied by a nuclear-related technical elective. Civil engineering, for example, additionally prescribes to the Body of Knowledge as published by the American Society of Civil Engineers. This document imparts the 24 ideal qualities of the engineer of year 2025. Technical goals that can be addressed through this course include problem recognition and solving; design; sustainability; contemporary issues and historical perspectives; and risk and uncertainty. One final aspiration is breadth in civil engineering areas: most civil engineers do not even consider the nuclear industry as a potential employer. Professional goals to be addressed include communication, public policy, globalization, leadership, teamwork, and ethics. The coursework may also improve upon an engineer's attitude toward complex issues, thus contributing to lifelong learning [3].

School and departmental objectives may also be augmented by a nuclear-related technical elective. The development of new educational areas and improved research diversity are especially beneficial at the school or college level, facilitating partnerships and collaborations with industry and government. As a clean fuel option, demand exists among most areas of engineering and several applied sciences. At the University of Mississippi, organizational support has been obtained from the School of Engineering as well as the departments of civil, chemical, mechanical, geological, electrical, and general engineering. This course will meet the School of Engineering’s objective of preparing students with a broad-based education for entering the engineering profession, for advanced studies, and for careers in research. Since each has a limited number of technical electives in its respective curriculum, department chairs need to encouraging their students to enroll, thus strengthening discipline interaction. This endeavor is most strongly supported by the Department of Civil Engineering as the course fulfills its vision for a state-of-the-art undergraduate curriculum and also supports its program objective of productive alumni in the workplace. Offering seminar presentations and informational sessions in multiple arenas can boost course enrollment. The dual-listing of the course as both an undergraduate elective and a first-year graduate course should ensure sufficient student interest even in universities with smaller technical populations, as at the University of Mississippi.

As beneficial byproducts, collaborative research efforts can be enhanced through such a course. The new expertise will encourage cooperation between colleagues in similar or even dissimilar fields. International universities have already begun developing connections to improve nuclear education. For example, a 2008 cooperative effort among three universities in Japan and Indonesia have resulted in student and faculty exchange and joint curriculum development. An additional upshot has been research coordination in the related fields, including radioactive waste processing, fuel system development, and next generation reactors [9].

Contact with current nuclear-related programs is vital for faculty self-education and course development. One extremely helpful resource is the Department of Nuclear, Plasma, and Radiological Engineering at the University of Illinois at Urbana-Champaign [7]. In order to design a course that meets workforce demands, industrial partnerships are also recommended. Both Entergy and Southern Nuclear Operating Company are contributing to the creation of the nuclear-related course at the University of Mississippi.

DEVELOPMENT

The modern generation of engineers faces new energy challenges. Avoiding social discussions, the course instructor must provide a factual overview of major power system principles. He/she will need to effectively use nuclear systems engineering as an example of a multidisciplinary system design. Developing students’ capacities for integrative approaches to complex systems is fundamental to success, responsibility, and engagement in global society [4].

An introductory nuclear engineering course for non-nuclear engineers should employ several instructional approaches in order to convey systems engineering through the technical issues of nuclear power. The lectures must be carefully designed in order to serve the widest audience. To this end, minimal pre-requisite courses should be required, but basic thermodynamics and chemistry are suggested. Course lectures will be the most beneficial when creative methods are used. With its ability to display photographs and animations, Microsoft PowerPoint is an efficient means of material presentation. However, PowerPoint slides alone are usually received negatively by students in the classroom [6]. Therefore, enhanced learning will result from the combination of group discussion and projects. Group interactions as interdisciplinary teams can be coordinated for these assignments. Relating nuclear power to individual student interests, projects will also allow students to delve into a discipline-related topic and teach it to others.

While incorporating the nuclear power industry's specific needs is possible, an entire field cannot be covered in just one course. Introductory courses in nuclear engineering departments are quite similar to introductory courses in any engineering department: obtainable learning objectives in limited areas. In this course, upperclassmen with technical majors can delve further into complex engineered systems. However, under no condition can a professor explain every aspect of each system. The prevention of over-reaching instructor expectations will create an awkward balance between industrial needs and time constraints. Successful course materials must limit the daily scope to digestible nuggets. Similar to that to be used at the University of Mississippi, a suggested course outline is included below, along with estimated percentages for coverage of each major topic.

I. History of nuclear industry (10%)

The discovery of natural radiation phenomena will be briefly introduced. Varying from water to weapon, the development of radiological engineering uses will be discussed. Public policy issues will also be introduced to aid students in selecting research paper topics that relate to their own interests. As media examples, the Three Mile Island and Chernobyl incidents will be examined for public opinion; their value for instruction on human error will also be probed. Including environmental and health risks, direct statistical comparisons will be made between the nuclear industry and other means of power generation.

II. Fission processes (10%)

A discussion of nuclear fission processes must begin with atomic chemistry. The properties of different radioactive isotopes will be discussed as each relates to practical applications, such as corrosion inhibition or medical tracing. The fission energy cycle will be described through nuclear chain reactions beginning with fuel pellets or rods. The uranium enrichment process will be addressed as a self-sustaining fuel source.

III. Design principles (20%)

Major factors to be discussed involve operation, mechanics, and safety. The economics of nuclear power are important to the resurgence of nuclear. Reactor design criteria will be analyzed through selection of reactor components for primary and secondary systems. The operation and design of the reactor will be described through systems instruction including the core and steam systems. Components to be incorporated are turbines, condensers, pumps, compressors, distillers, boilers, and generators. The engineering design controls for power generation and distribution components will be stressed as will thermodynamic cycles such as the Rankine steam turbine cycle, Brayton gas turbine cycle, and Carnot efficiency.

The safety components involved in the reactor design are numerous, and the risk analysis extends into several fields. Human factors are interwoven with emergency operating procedures, so criticality and accident scenarios will be discussed. The combination of design, equipment, and personnel reliability will be related to industrial incidents. Security efforts will also be discussed: fears of weapons proliferation and terrorist attacks have restrained the nuclear industry worldwide. Radiation containment via metal cladding, reactor vessel, and concrete shielding will be related to aging plants. The water chemistry affects corrosion properties so it influences reactor design selection.

IV. Reactor systems and components (20%)

Several reactor types and their mechanical layouts will be presented. The advantages and disadvantages of each will be discussed. For instance, the economic benefits of pressurized water reactors will be weighed against the higher pressure requirements. Sizing and design specifications will include fuel rod assembly, reactor vessel construction, power loop requirements, and steam generator types. A similar analysis of boiling water reactors is required to understand the potential dangers as those at Chernobyl. Additional reactor designs may include light water reactors, heavy water reactors, high temperature gas cooled reactors, very high temperature reactors, and liquid metal fast reactors. The reprocessing reactor and fast breeder reactor will be offered as sustainable power options. Smaller and potentially safer reactor options will also be presented.

V. Radiological management (10%)

The detection of radiation will be discussed. The significance of human exposure to various quantities of millirems will be discussed. Comparisons will be made between common sources of exposure (air travel, natural foods, medical use, etc.) and living near or working in a nuclear power plant. The absorbed radiation in the human body depends upon several factors including spatial distance, oxygen concentration, energy transfer rate, and bioresponse. Radiation overdose can create respiratory, gastrointestinal, neurological, vision, skin, and birth abnormalities.
Radioactive waste management will be addressed in detail. Significantly less than other power generation industries, relatively small amounts of waste are generated due to the high efficiency of nuclear power plants. However, this waste does retain radioactive properties and must be properly handled. High radioactivity wastes can be recycled or reprocessed through lower level processes, such as medical radiation uses, to obtain waste with low levels of radioactivity. However, the half-life of even these materials can be millions of years, so safe storage is a necessity. Like garbage in general, burial is the most common storage form, but the locations of such facilities is extremely controversial. Currently, U.S. laws require safe storage for 10,000 years: a brief discussion of U.S. laws will take place. Environmental remediation will also be addressed through treatment options often called "dilute and disperse, delay and decay, concentrate and confine."

VI. Advanced topics (15%)

Numerous issues involving the nuclear industry are well-suited for technical student projects. A research paper and/or presentation should be required of each student enrollee. The research subjects will span the possible variety of student backgrounds from biology to electrical engineering. The project objective is to relate nuclear power to student interests while improving their communication skills. Ensuring relevancy, contemporary topics should be used for student projects, and subject areas can include social and environmental aspects. Example topics include Non-Destructive Testing: Flaw Detection Using Iridium and Selenium; Electronics Using Radioactive Materials as Semiconductors; Biomedical Radiation: Diagnostic Imaging and Cancer Therapy; Nuclear Propulsion of Naval Vessels; The Use of Nuclear Distillation for Desalination; Space Power: Rocket Propulsion and Cosmic Radiation; Global Warming: How the Nuclear Industry Can Change Emissions; The Mining and Enriching of Uranium; Gamma Radiation Sterilization as Insect Control; Food Preservation through Irradiation; Yucca Mountain: Storage Technology, Strategy, and Difficulties; Bioremediation through Flora and Fauna; and NIMBY: Not In My BackYard!

ASSESSMENT

Evaluation plans must include both course assessment of the students and student assessment of the course. Students are not expected to become experts on nuclear energy: as this course will survey the field, students should develop an integrated concept of industrial systems. While the instructional value of examinations is arguable, select practice should be included to measure students' technical comprehension and relate directly to the industrial requirements of new employees. Student presentation skills can be evaluated by the professor as well as other students based upon their own understanding of each topic. Indirectly assessed through confidential surveys, enrollees will be asked to rate technical level, material presentation, and course format. Questions should be formulated to gauge the success of course objectives, and comments should be utilized to improve future course offerings.

One item that has yet to be decided is if a non-engineering track will be offered. There is a potential, as well as desire, for the enrollment of several undergraduate majors, including (but not limited to) chemistry, biology, public policy, and environmental science/studies. Non-technical or less-technical majors must also be evaluated on a non-engineering basis. The project and paper appear to be the best means of student assessment for all students, and any non-engineer enrollees may be orally examined by the instructor to determine their comprehension level. A one-on-one oral session may also be a good idea to assess all students (if possible) as well as obtain direct feedback even though anonymity is not preserved.

Once the academic expertise is developed, this course is sustainable for future offerings. No equipment or supplies are required but may be useful. Supplemental technical support is recommended for website development. Continually expanding, a digital online library aids in distance learning as well as the development of other nuclear-related courses both in-house and worldwide. If available, a nuclear power plant site visit is suggested to aid in student visualization of schematic diagrams as connected to actual plants. As part of the course, enrolled students can heavily document the plant visit, and journals can be compiled and published for internet publication. Institutional interest may also lead to larger contributions to the technical community, such as a nuclear engineering sequence or professional engineering workshop.

CONCLUSION

Even the minimal development of nuclear engineering at an institution of higher learning can aid in student recruitment while developing relationships with industry. The use of nuclear energy as a "grabber" can encourage student comprehension of complex systems engineering. The new pool of more qualified graduates will draw recruiters from multiple industries to the university. New hires will already possess general knowledge of industrial systems, reducing on-the-job training at company expense. Since the students will understand nuclear principles prior to employment, greater worker retention rate also is expected. By expanding both engineering curricula and faculty competencies, this single multidisciplinary course can pay both educational and research dividends. The author intends to publish lessons learned subsequent to the course offering in the Journal of Engineering Education.

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