NUCLEAR POWER PLANT SYSTEMS AND SECURITY:

A GRADUATE ENGINEERING COURSE

A Thesis Presented to

the Faculty of the Graduate School

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In Partial Fulfillment

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Master of Science

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by

Charles Thomas Poston

Dr. Mark A. Prelas, Thesis Supervisor

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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presented by Charles T. Poston,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Mark Prelas

Professor Tushar Ghosh

Professor Dabir Viswanath

Professor John Bowders

Professor Robert Tompson

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ABSTRACT

With nuclear power poised to begin a significant expansion within the United States, it has become increasingly important to provide engineering students with the knowledge needed to become productive members of the nuclear workforce. Such an education is already provided at the Nuclear Science and Engineering Institute (NSEI) at the University of Missouri-Columbia.

To compliment the courses being taught at the NSEI, a new class was created with the goal of providing students with an understanding of the security and safety systems present at nuclear power plants. A strong emphasis was also placed on providing the supplemental knowledge needed to better grasp the concepts in other nuclear engineering courses.

A secondary goal of the new class was to provide a largely non-technical introduction to safety and security issues at nuclear power plants for students from any academic background.

Chapter 1: Introduction

1.1 Background of Course Creation

In August of 2007 discussions were started with the faculty of the Nuclear Science and Engineering Institute (NSEI) at the University of Missouri – Columbia concerning a grant proposal that was to be submitted to the Nuclear Regulatory Commission (NRC). This proposal, titled, "Development of Educational Infrastructure in the Area of Nuclear Security," provided the initial framework for a new course that would focus on the security issues at nuclear power plants. The outline for the course consisted of four main topics: physical protection, regulations, licensing requirements, and international treaties. The outline is given below in its entirety:

Nuclear plants and security issues, Nuclear Policies and Regulations.
The philosophy of physical protection of a nuclear power plant is well described by the Institute of Nuclear Materials Management (www.inmm.org). The following diagram describes the essential components of physical protection of a plant.

1. *Physical protection*
    - a. *Determination of protection objectives*
    - b. *Facility characterization and assets identification*
    - c. *Threat definition and characterization*
    - d. *Target identification*
    - e. *Protection area design*
        - i. *Exclusion zone*
        - ii. *Protected area*
        - iii. *Vital area*
        - iv. *Material access area*
    - f. *Detection system (interior and exterior)*
    - g. *Delay system design*
    - h. *Response system design (force-on-force, etc)*
2. *Regulation guidance and communication*
3. *Licensing requirements by NRC*
4. *International treaties*

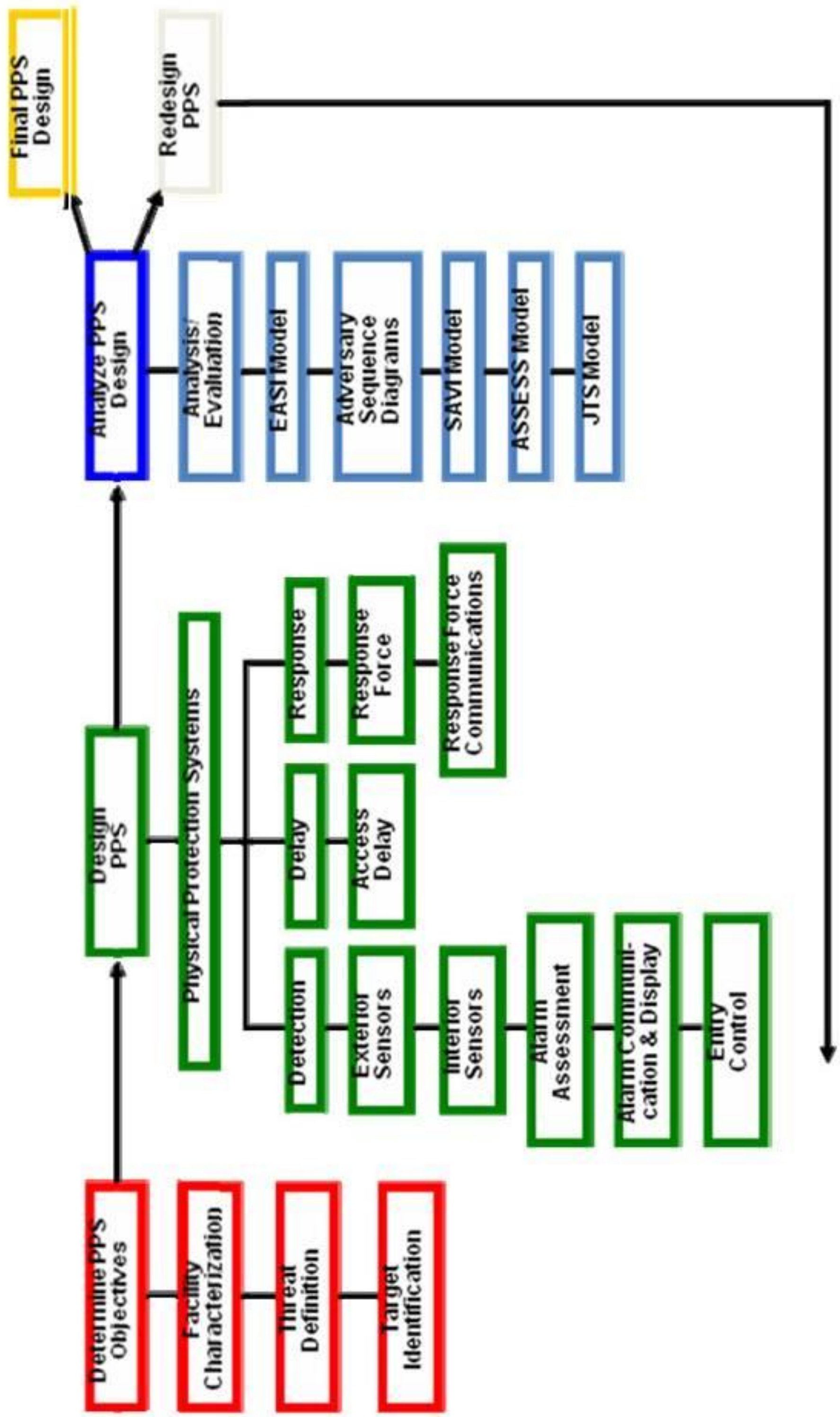

Figure 1. Physical protection philosophy
Image Source: www.inmm.org

That initial outline would act as the foundation for all lessons concerning physical security theory and implementation. Almost all changes to the course took the form of additions to this initial plan.

Outlines for two other courses were also presented within the proposal, but after considering the interests and backgrounds of the students willing to pursue the development of those courses, the author of this work was best suited to researching and creating a course based primarily on security issues.

1.2 Background of Author

The author's background included a four year involvement with the Department of Homeland Security's Scholarship and Fellowship Program. While an undergraduate scholar and later as a graduate fellow, he was exposed to, and developed a great interest in, nuclear security in the United States. Yearly conferences in Washington D.C. allowed the author to remain current with shifting political concerns and objectives relating to securing the homeland. Time spent working at the Nevada Test Site, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory on projects funded by the Department of Homeland Security, helped to provide him with the background knowledge needed to understand the importance of teaching security principles to students that would be entering the nuclear industry.

While a student in the NSEI, the author was able to experience what he believed was a typical experience within the department. This included enrollment in some of the most common courses taken by all nuclear engineering students. Knowing what was and was not taught in these courses allowed for him to make informed decisions about what needed to be presented in the class that he would eventually teach.

Chapter 2: Methodology

2.1 Initial Work to Create Curriculum

Crafting the curriculum for a new course was initially a difficult task. The basic outline of topics to cover was presented in the original NRC grant proposal, but after discussions with faculty it was decided that there would be a degree of flexibility in the information that would ultimately be presented.

The greatest decision that was faced was what topics other than security needed to be covered. Ideas were discussed within the department and the basic framework for the course was formed. Dr. Mark Prelas, the advisor for the project, provided much of the early help. Eventually, outside input was sought as well.

2.2 Theory Behind the Choice of Curriculum

A great deal of time was spent in developing a theory that would underlay the topics that would be chosen to be presented. Security would remain a major focus, but other less sensitive, and possibly more useful information would have to be added to the course.

An early outline created by the author and Dr. Prelas consisted of four main parts: physical security, nuclear power plant systems and fuels, NRC regulations, and international treaties. After looking at the courses already being offered by the NSEI, several major changes were made to avoid duplicating material that was already being taught or being developed concurrently.

Most of the lessons on nuclear fuel and fuel cycles were dropped when it became known that another graduate student was researching materials for a course based solely on that topic. The section on international treaties was removed to avoid any possible overlap with a course entitled "Nonproliferation Issues for Weapons of Mass Destruction." In that course, the functions of the International Atomic Energy Agency and the U.S. State Department related to nuclear materials are already covered.

Material added to the lesson plan included a series of presentations on the history of major nuclear accidents, their causes, effects, and changes made in the industry as a result of those specific events. To give students a greater appreciation for the measures currently taken to ensure safety, it was thought necessary to discuss where nuclear power had gone wrong in the past.

The study of NRC regulations was too broad a topic, so in the interest of time and practicality, only a limited selection of regulations would be presented. It was decided to cover those regulations that dealt with the physical security of nuclear materials and nuclear power plants. In that way, some introduction to the format of the regulations could be given while focusing on another of the course's main objectives.

2.3 Outside Input on Course Content

An evening of discussion with a current NRC inspector led to several important conclusions and changes to the curriculum. His advice was to be very sensitive to security issues. The current political and security climate in the United States could make any detailed discussion of nuclear power plant security subject to unwanted attention from the government or even from those who might have ill-intent towards our nation. After a realization that the initial plan envisioned for the course might garner such attention, it was decided to generalize the information presented and to abandon an initial design project with a fictional nuclear power plant. It was that meeting that prompted a serious change in direction for the course. Much more attention would need to be given to other topics to make up for the lack of detailed information surrounding nuclear power plant security that could be presented.

Following the talk with the NRC inspector, a visit to the Callaway Nuclear Plant was arranged to meet with emergency planners and security personnel. During that day of interviews, a new focus became clear. Safety at nuclear power plants was something that not only captured the public's attention, but was of great concern to the industry as well. By shifting away from a class dealing almost purely with security, it would be possible to introduce another key part of the nuclear industry. It was hoped that this emphasis on safety would take the form of both the study of safety systems and of the procedures that involve preventing and managing accidents.

More time seeking outside opinions was spent at the 2007 American Nuclear Society National Conference in Washington D.C. Representatives of the nuclear industry were sought out to gather their opinions on what topics they believed needed to be covered in a class such as was being proposed. They were also questioned as to what qualities their new employees typically lacked or were deficient in. Almost invariably the answer was that they did not have an understanding how systems interacted within a power plant. Recent college graduates were perceived as having good technical skills, but were initially poor at foreseeing the possible consequences of the work they performed. This reaction helped to emphasize the need to spend time teaching the "big picture" in a classroom setting.

2.4 Development and Evolution of Course Topics

It quickly became apparent that a great deal of preparation would be required before it would be possible to write and speak on the issues to be taught with any degree of authority. Since the author had the same basic background as any potential student, pressure was felt to gain as much understanding of the chosen course topics as possible in the short time that was available.

The schedule planned for the development of course materials was designed such that the course could be taught during the spring semester of 2008 if there was sufficient interest from students. When such interest was found, regular meeting times were set up and the final phase of the course development began.

Prior to the beginning of the semester and the start of the class, there was no way of knowing what the makeup of the enrolled students would be. Being offered as a graduate course, it was assumed that the students would be more knowledgeable than a typical undergraduate, but could still have vastly different levels of experience in the field of nuclear engineering. It was through good fortune that the students who chose to sign up came from different backgrounds. A large concern was that if only upper level nuclear engineering students signed up, there would be some resistance or indifference to material that might be below their level or that would only serve as a review.

2.5 Changes to Syllabus

It became evident that as the course progressed, that the outline presented on the syllabus would not be followed precisely. With this flexibility, the course could be tailored to the needs of the students. For example, after a brief mention of the thermodynamic properties of a nuclear power plant, it was discovered that a majority of the class had never studied thermodynamics in depth. As a response, a lecture was created to briefly cover the aspects of thermodynamics that governed the heat cycles present at a power plant. It was understood that the lesson could in no way serve as a substitute for a semester long course in thermodynamics, but it was able to convey a basic understanding of the purposes of the heat management systems that exist at a power reactor. Later in the course a similar revelation was made concerning the effects of ionizing radiation on biological systems. A lesson was added to help students understand the concerns about radiation exposure during an accident. Without knowledge of the effects of varying levels of radiation dose, the information surrounding reactor accidents could lose its impact.

2.6 Final Course Content

When the final course curriculum was created, it consisted of three parts: systems, security, and supplemental knowledge. Those parts of the curriculum and their component parts are detailed in Figure 2.

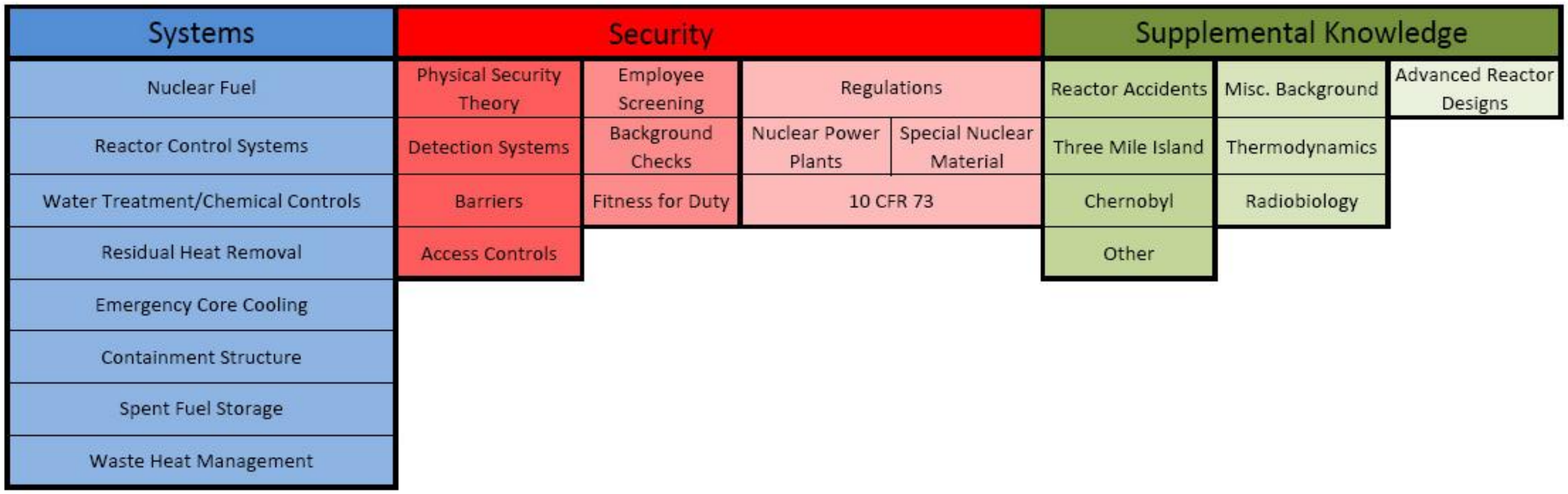

Figure 2. Breakdown of the Three Main Course Topics

The first part of the course to be covered included a series of lectures comparing the major mechanical systems at boiling water reactors and pressurized water reactors. These two basic designs make up the U.S. commercial reactor fleet. The systems examined during the lessons were covered in enough detail so that student would have an understanding of how reactors are controlled beyond the simple diagrams most often presented in other classes.

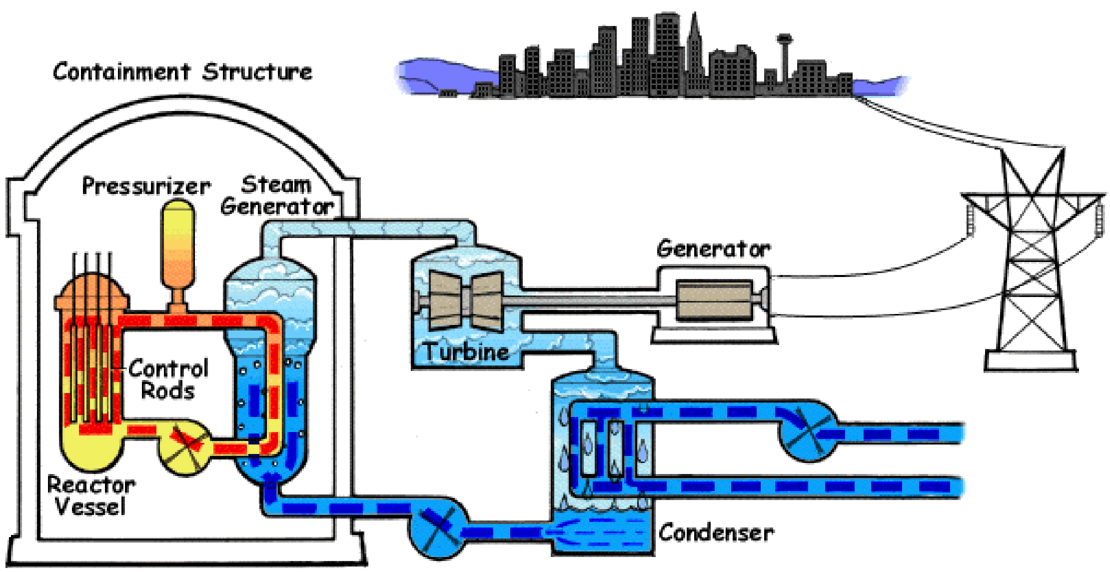

Figure 3. Oversimplified Diagram of Pressurized Water Reactor
Image Source: Nuclear Regulatory Commission

The discussion of physical security issues at nuclear power plants was accomplished with two different approaches. First, a series of lessons covered the theory and basic parts of a physical security plan. Those lessons were entirely generic and could be applied to any high value facility. Next, the Code of Federal Regulations was consulted to provide the specific regulations that apply to nuclear power plants. In an effort to be sensitive to security concerns, no site specific information or examples were discussed. Finally, a lesson was taught that covered the process that must be undertaken to be granted access to a nuclear plant. Background checks and fitness for duty programs were reviewed.

The rest of the course fell into the category called "supplemental knowledge." This covered any information that was presented that would enhance the effectiveness of other lessons in the course or other courses within the NSEI. The review of past reactor accidents, and lectures covering thermodynamics and radiobiology were included in this category. The semester ended with a series of lectures on advanced reactor designs. As new nuclear power plants are to be built in the United States, it was felt necessary to discuss some of the designs now available to utilities.

2.7 Lesson Presentation Style

Classroom presentations were made primarily with Microsoft PowerPoint®. It was observed by the author that such presentations were acceptable, but not ideal for a small class size. Lessons that did not feature graphical or multimedia aspects tended to be less interesting to the audience. An early effort to provide very clean and easy to read presentations led instead to a bland format. The format used throughout the course lent itself well to printing, but left much to be desired when projected on a screen.

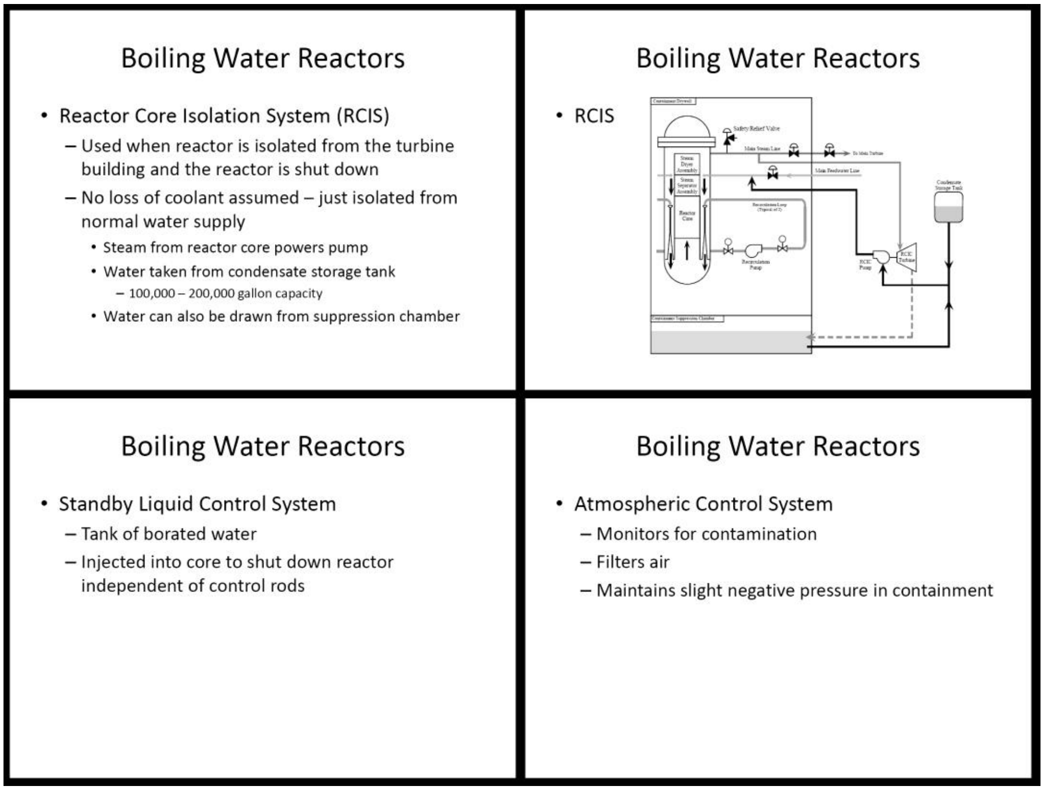

Figure 4. Typical Style of PowerPoint® Slides Used in Lectures

At various times throughout the semester the students were informally questioned as a group concerning the way the course was being taught. Input was sought on ways to make the class more interesting or easier to follow. No substantive suggestions were made, and so the instructional style remained unchanged.

2.8 Use of the Internet to Support Coursework

Throughout the semester each lesson and accompanying lecture notes were posted online for the benefit the students. Being a small course and lacking other resources, the author used his “Bengal Space” provided to all University students. It was not an ideal way to post materials online, but it was sufficient. Future efforts should seek to improve the online course content.

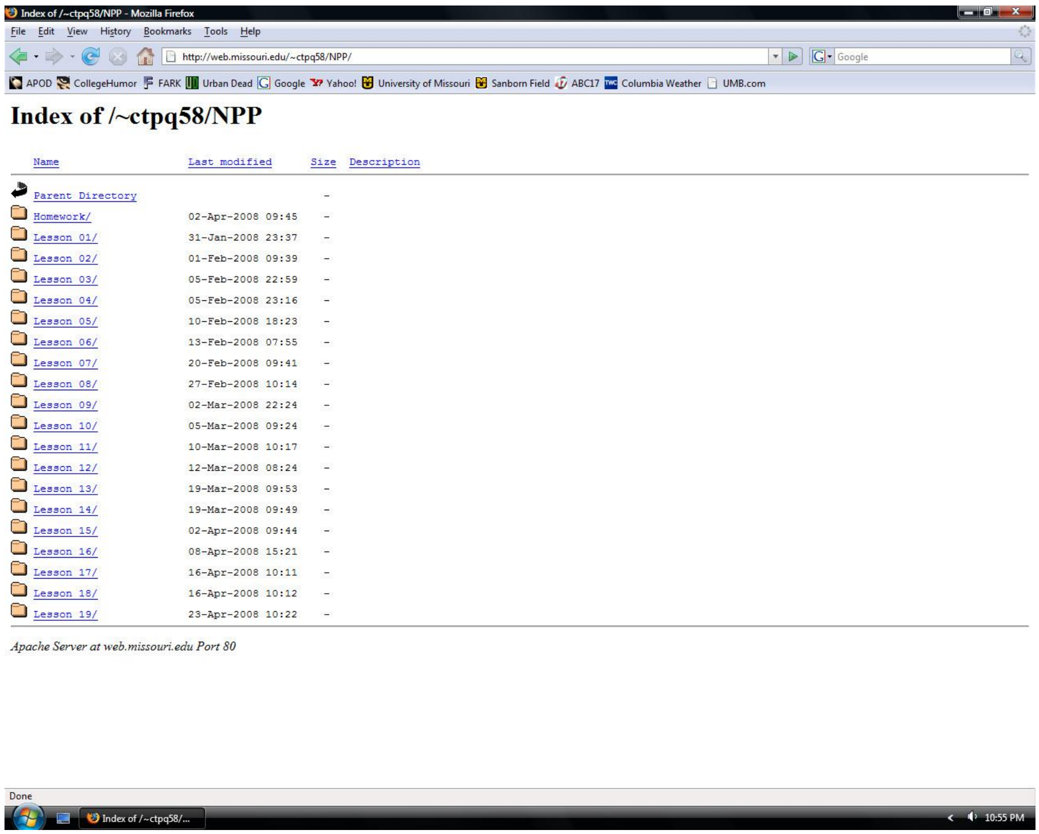

Figure 5. Format of Online Course Materials

2.9 Course Assignments

The assignments handed out during the course consisted of a series of four to five page research papers on topics related to the material covered in class. These assignments were designed in such a way as to be accessible to students from any background. No significant mathematical calculations were required during the course. The final project, given in place of a final exam, took the form of a longer research project of approximately fifteen pages coupled with an in-class presentation of around twenty minutes. In practice, the final presentations took the form of directed group discussions. Each student talked for nearly forty minutes and provided an excellent opportunity for the author to evaluate their knowledge of the chosen subject. The author found these presentations to be one of the highlights of the course.

One of the early goals of the class was to provide a substantial design project during the part of the course dealing with security. Unfortunately, this project was never created. As such, an ideal way to reinforce the lessons dealing with the theory of physical security was lost.

2.10 Organized Presentation of "Supplemental" Material

The creation of a source of supplemental knowledge in nuclear power plants and nuclear power plant security was a driving force behind the final curriculum. The revised course's primary goal was to introduce students to the ideas and events that would be needed to understand the fields of nuclear power plant security and safety. For example, describing something as "a potential Chernobyl" has no real meaning if one does not know what went on at that ill-fated Soviet power plant.

To understand what is critical to safety and security at a nuclear power plant, one must first have a basic understanding of the systems and equipment that are present at a typical power reactor. Once an understanding of the basic systems of the plant was achieved, more advanced topics that built on that understanding could be introduced. This would be done in both the new course and in other classes offered by the NSEI.

In the experience of the author, engineering courses can sometimes lack focus on "the big picture," or an overall understanding of how systems interact with each other. Great detail is rightly given to first principles and basic physics, but to be more effective it should be coupled with an effort to explain how such principles are used in practice.

2.11 Importance of Examples in Lessons

Whenever possible, an effort was made to use the experiences of the author to illustrate what was being discussed in class with examples. Time spent at national laboratories gave some insight into security procedures and the expectations that exist at facilities that deal with nuclear technology. It was the author's belief that sharing such experiences helped to increase retention of material. Rather than memorizing a list of facts, the students had real-life examples of what was being taught. Relevant stories from an instructor allow a topic to be shown in application with a person that the students know. Instead of an abstract concept, the lesson becomes "real."

2.12 Appeal of Course Outside the NSEI

Although designed to primarily serve nuclear engineering students, there could be some demand for the course among other majors as well. No advanced technical background was needed for the majority of coursework, so any motivated student at the University could have taken the class and received benefit, regardless of major. This opens up the possibility of using the course as a recruitment or informational tool to inform others about the great lengths that are taken to assure that nuclear power plants are kept safe and secure.

2.13 Use of Field Trips Within the Course

During the spring of 2008 it was planned to take several tours of nearby facilities that would enhance the understanding of the systems present at a nuclear power plant. Classroom instruction could only provide a limited view of the complexity and size of the inner workings of a nuclear reactor. By visiting an operating facility, students would be able to see firsthand what was previously presented only on paper.

2.14 Visit to the Campus Power Plant

The first trip taken was to the coal-fired power plant on the campus of the University of Missouri – Columbia. The convenience of having this power plant within walking distance of the classroom provided the opportunity for students to see systems that were close analogs to those discussed in class. Generators, steam turbines, cooling towers, condensers, and heat exchangers were all present at the campus power plant and were performing the same functions they would at a nuclear power plant. There was a substantial difference in the physical size of the equipment, but it was hoped that when a trip to an actual nuclear plant was scheduled, that a greater understanding and appreciation could be had for the size and complexity of the systems there. The tour of the coal plant also provided an opportunity to compare and contrast the advantages and disadvantages of each type of facility. It was important to have the students exposed to some of the alternatives to nuclear power. Constant praise of the nuclear industry without a critical eye towards potential problems was avoided.

2.15 Aborted Trip to the Callaway Nuclear Power Plant

A visit to the Callaway nuclear power plant was initially planned for the course, but due to scheduling conflicts and a lack of time, such a trip never occurred. The NSEI has close ties to the Callaway plant and its proximity to the University made it an ideal facility for a visit. Future teachings of the course should make an effort to coordinate a tour.

2.16 Visit to the Duane Arnold Energy Center

Since a trip to the Callaway power plant never materialized, arrangements were made to take the class to the Duane Arnold Energy Center (DAEC) outside of Cedar Rapids, Iowa. A thorough tour of the facility was given by a veteran employee. Additionally, a meeting was set up with one of the plant's systems engineers. That engineer made a presentation to the class about the type of work that he was responsible for on a daily basis. The presentation was focused on the methodology and procedures that went into identifying and solving a problem within the site's cooling towers. For those students that were interested in entering the nuclear industry it was a great opportunity to question a current employee about the pros and cons of working at a nuclear power plant.

The tour included visits to many of the systems that were discussed during the initial lectures presented in the course. This reference back to earlier lessons was ideal for reinforcing information taught in previous months. For example, many of the security features that were observed around the site were obviously due to the implementation of the NRC regulations that were reviewed in class. Such small details could have been missed if not for the supplemental knowledge provided.

Without the lectures at the beginning of the semester, the tour would not have been nearly as effective. If possible, any future tours organized for this course should be scheduled to take place late in the semester.

It was suggested by the students who participated in the trip to the DAEC that a similar trip to Callaway would have provided many of the same benefits and would not have required an overnight stay out of state.

2.17 Influence of Current NSEI Courses

It was not a coincidence that this course drew upon some of the work that had already been done within the Nuclear Science and Engineering Institute. The NSEI offers a course entitled, “The Science and Technology of Terrorism and Counterterrorism” which has appeal outside of the department. It is taught in such a way as to provide enough information to its students so that current news and world events can be better understood. Personal experience in that class showed that there was a cross-discipline interest in the issues that were covered. It was hoped that this new course would provide a similar benefit to the understanding of the issues surrounding the safety and security of nuclear power.

As the United States moves toward the construction of new power reactors, it is vital for the industry to promote itself as a clean and safe source of electrical power. One way to further that mission is to educate as many people as possible about the facts concerning nuclear power plant security and safety. With better education, the public will be able to evaluate issues facing them and make decisions based on facts rather than irrational fears.

Chapter 3: Conclusions

3.1 Effectiveness of Course Materials

During the teaching of the course the author observed that students maintained a fairly high level of interest in the lessons presented. The material on nuclear power plant systems was already familiar to most of the students and so it was easy for them to follow along while picking up new information. Less well received were the lessons that provided an overview of the regulations concerning the physical protection of nuclear power plants. By their nature, federal regulations do not excite students. The author's opinion is that significant improvements could be made in the teaching of the regulations either through the use of guest speakers, better presentations, or use of properly designed assignments.

3.2 Feedback from Students

A survey was given to students at the end of the course to gather their opinions of the topics that were taught and the methods that were used to teach them. Most of the comments were positive, but several suggestions were made that could help improve the course.

Almost unanimously, the tours of the power plants were rated as the highlights of the course. The ability to be in the presence of the machinery described in class was highly effective in generating interest in the course material. Several students expressed regret that more tours were not taken during the semester.

Nuclear power plant systems and the history of nuclear reactor accidents were listed by most as the most enjoyable in-class lessons. However, even those lessons were critiqued by the students. Chief among their complaints was a lack of sufficient multimedia to accompany the presentations. Additional material could be added to the course to make up for this deficiency, but care would need to be taken to limit the amount of time consumed by additional videos and animations.

3.3 Use of Guest Speakers

Under the initial plan for the course, several guest speakers were to be contacted to give presentations. Current or former nuclear power plant employees would have been able to give personal accounts of their experiences in the nuclear industry and could have provided advice to those who may enter the field in the future. Part of the appeal of using guest speakers tied back into the desire to use examples or personal stories to illustrate important points.

Due to scheduling conflicts and a need to cover the material already created, no guest speakers made presentations for the class. A better balancing of the course material would easily allow sufficient time for guest speakers in the future.

3.4 Rebalancing of Course

The course materials were divided into the three main topics of systems, security, and supplemental knowledge. The balance of those topics was of concern to the author and ultimately did not meet his expectations.   Too much time was spent discussing material that was interesting and relevant, but not vital to the goals of the course. Any future attempt at teaching the material should make a concerted attempt to more equally balance the main topics. Equal time for the sake of equal time is not necessary, but experience has shown, that it is a reasonable way to divide the course.

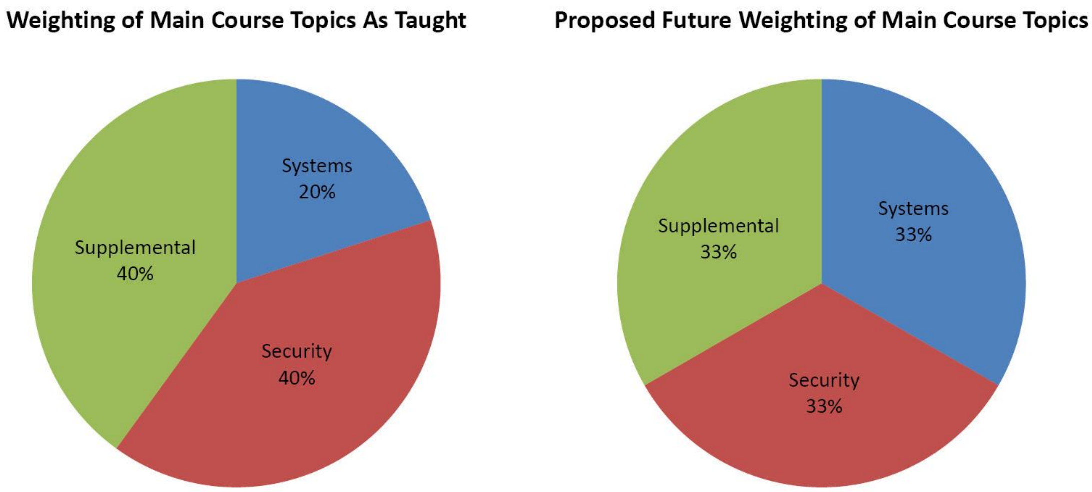

Figure 6. Weighting of Time Given to Main Course Topics

3.5 Lessons to Remove

There was no individual lesson presented that seemed entirely without merit, but some lectures could be either shortened or removed from the curriculum without causing problems for the remaining material.

Class time was spent after each field trip to discuss what was seen and to try and connect any new information with what had already been taught. In principle and practice this worked well, but too much time was spent in class reviewing what had already been discussed. The time reserved for such review could be shortened without causing problems. It is suggested that such reviews could take place in the form of informal discussions during the travel to and from the tour locations.

The lessons covering Three Mile Island and Chernobyl provided some of the more interesting lectures during the course, but in hindsight, were out of proportion with their overall importance. With such a large amount of information available about each event, too much effort was placed on trying to convey a moment-by-moment breakdown of each accident. The most important information could have been presented more quickly, freeing up time for other topics.

3.6 Lessons to Add

Two of the most important topics that were not covered in any great detail were emergency preparedness and emergency response. A great deal of time was spent discussing security response in case of an emergency, but time did not allow for a series of lessons detailing the interaction between the power plant and local, state, and federal authorities in case of an accident. The author considers this to be the largest single omission from the course. The initial plan was to focus on security and safety. Safety was only studied from a systems perspective. While safety systems are vital to the continuing operation of a nuclear power plant, the communication and collaboration with the public deserves equal attention.

3.7 Place of New Course Within the NSEI

As the course evolved, it became obvious that while some upper level nuclear engineering graduate students would no doubt benefit from the material, it would be far better suited to those just entering the field. Providing relevant background material is far more effective at the beginning of an education than at the end. In an ideal case, this information would be imparted early so that other coursework would be more effective as it was being taught. However, in some cases it could serve as a way to clarify ideas and concepts to those who have already been through some nuclear training.

In its final form, this course was best suited to those just starting a nuclear engineering education. That would include either first year graduate students or undergraduate seniors who are looking to enter the nuclear field.

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