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실용적인 원전공학 교육을 위한 시스템즈 엔지니어 프로그램

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Systems Engineer Program for Practical Nuclear Power Plant Engineering Education

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Abstract : KEPCO International Nuclear Graduate School (KINGS) is dedicated to nurturing leadership-level professionals in nuclear power plant (NPP) engineering. KINGS have designed curriculum based on two philosophies. First, we balance aspects of discipline engineering, specialty engineering, and management engineering in the framework of systems engineering. Second, KINGS have designed the curriculum so that students can learn and experience the know-what, know-how and know-why level knowledge of NPP engineering and management. The specialization programs are opened during the 2nd year for 3 trimesters and those are a process of learning through practical project courses. The objectives of the specialization programs are to help students to learn the NPP life cycle technologies in highly structured and systematic ways. The systems engineer program (SEP) is one of the specialization programs. A practical case of the SEP which was applied to the project course for the NPP electric power system design education will be elaborated in this paper.

Key Words : Specialization program, Systems engineer program, Nuclear power plant, Project course, Subject unit

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1. Introduction

KINGS has been established in 2011 to train and educate leadership-level practical professionals for international nuclear power installation. In addition, cultivating quality-approaches in engineering education with advanced master degree programs is another goal of KINGS. To achieve these goals, KINGS adopted trans-disciplinary approach in handling NPP life cycle activities and applied systems engineering to nuclear power plant technology and administration. In addition, the 2nd year courses are operated with project base team teaching and team learning method based on the fundamental knowledge acquired during first year.

The SEP is an unique education program of KINGS integrated all above strategies [1].

2. Nurturing Practical Engineers

"Infrastructure and regulation are the keys to a successful and safe nuclear installation program. Strong knowledge base and human capital infrastructure is also necessary for the long-term sustainability of a nuclear program. Safety and security are essential parts of any nuclear program. All capabilities on own resources is not realistic in time and cost. Therefore, different knowledge and skills for different project stages are required. Nuclear safety is not confirmed through theoretical knowledge. Practical on-time application to real situations is important. Enhancement of problem solving capability based upon strong scientific knowledge and decision making capability based upon the Conceive-Design-Implement-Operate (CDIO) framework are necessary [2]."

In terms of above mentioned requirements and conditions, the professionals for nuclear installation program should be practical. The practical engineer can be defined as a professional in-between engineers and project decision makers. "The practical engineer has extensive and up to date knowledge in the fields of engineering and technology. The job of the practical engineer is to see the implementation of the processes and products developed by the academic engineers. The practical engineer is responsible for managing projects and overseeing work procedures at various levels [3]." Therefore, the practical engineer education program integrates theoretical study with practical training in technology and management.

For the nurturing of the leadership level practical engineers, KINGS adopted systems engineering as a backbone of the curriculum. The first step of systems engineering process is to identify and analyze the requirements. In the view point of educational organization, nuclear industry becomes a customer. Therefore, customer requirements can be defined as listed in the section '2.1 industrial needs'. And, functional requirements and performance requirements requested for educational organization are as summarized in the section 2.2 to 2.3 [2].

2.1 Industrial Needs

- Practical engineers who have experiential knowledge
- Leadership level engineers who have management capability
- Specific work capabilities in nuclear power

plant engineering, manufacturing & construction, operation & maintenance area
- Conform to global and international standard

2.2 Educational Needs

- Combining education and research
- Synthesizing theoretical and experiential knowledge
- Harmonizing technology and management expertise
- Integrating and optimizing lifecycle concerns
- Operating classes with multinational composite teams
- Integrate theoretical study with practical training in technology and management
- Specifically focus to nuclear power plant engineering and management.
- Systems engineering approach with reverse engineering techniques

2.3 Capability of Practical Engineers

- Integrate total engineering efforts to meet cost, schedule and technical performance objectives
- Define needs, design system, control design process, and analyze & evaluate design product.

3. Framework of specialization program

The specialization program is a project based team teaching and team learning program running in KINGS for second year course. It aims at master the joint application design (JAD) which promotes project oriented integrated product and process team (IPP) activities. Students are expected to improve their analysis, design, and management practices while working on the specialization program [4, 5].

3.1 Principles for Specialization Program

The operation principle of specialization program is team-based teaching and learning. Moreover, the 'project-based' class operation should provide opportunities for:

- Balanced development of the technology production, technology management and project management capabilities;
- Balanced development of the discipline engineering, specialty engineering and management engineering capabilities;
- Acquisition of field-oriented, hands-on experience base knowledge;
- Cultivating team-based cooperative spirit.

3.2 Requirements for Specialization Program

All the teaching courses should be connected and interfaced with practical work field. The course schedule is planned according to the field schedule of the on-going project in areas of design, manufacturing, construction, commissioning and operation. Education management should set the educational purpose fully fitted to the requisite conditions of countries or institution where the students will be sent to, and educational program based on the users' requirements in the certain period to achieve the purpose.

Specialization program should be composed of synthesis subject module, which combines the core academic knowledge with the experienced knowledge to enable students to fully play the role of a NPP industry engineer with leadership.

Plant design engineering, which is classified as the field of science and engineering, requires the academic base to perform the various design works including the function, performance, and control of the system, components, and structure of the plant. In addition, specialty engineering aspects also should be included in the specialization program. Specialty engineering is the engineering field, which systemizes the experienced knowledge, which cannot be gained from the normal academic program.

A NPP project is the comprehensive and great scale of project which features the long-term technology development period, thorough quality management, complex technology connection and interferences, and massive investment size and financial structure. Accordingly, a project course is composed of multiple modules and a module can be sub divided into subject units. Each subject unit will contain the elements and attributes of design engineering, specialty engineering, and management engineering to let students approach to the practical problems that are likely to happen in the field in a comprehensive way. Each subject unit should be operated using standardized template. Three subject units are executed per trimester.

3.3 Technology Expert Program (TEP)

The objective of the TEP is to foster leadership level technology experts who are capable of identifying and resolving problems in NPP systems and overall engineering processes.

The TEP focuses on obtaining integral capability in holistic areas of design, construction, operation, and maintenance of NPP systems and discipline engineering interfaces using reverse engineering and re-engineering methods. The composition of TEP is approximately discipline engineering 60%, specialty engineering 30%, and management engineering is 10%.

3.4 Systems Engineer Program (SEP)

The objective of the SEP is to cultivate leadership level engineering managers who are capable of systematically integrating, controlling and managing complex and diverse NPP technologies and technical trends.

The SEP focuses on the technology trend analysis, systems engineering management and efficiency enhancement of design, manufacture, construction and O&M of NPP systems and components. The composition of SEP is approximately discipline engineering 40%, specialty engineering 20%, and management engineering is 40%.

3.5 Project Engineers Program (PEP)

The objective of the PEP is fostering leadership level project managers who are capable of systematically and efficiently manage NPP projects occurring in the holistic NPP life cycle of design, manufacture, construction, O&M, and etc.

The PEP focuses on the management engineering based on the project management to develop nuclear policy, develop project plan, and integrate the NPP project. The composition of PEP is approximately discipline engineering 10%, specialty engineering 30%, and management engineering is 60%.

4. A case study of the SEP

Among the above three specialization programs, the SEP is chosen in this study. In order to introduce the SEP, we selected Emergency

Power Systems (EPSs) in nuclear power plants as a topic of the case study. The EPSs are integral parts of the safety systems and serve as support features for safety systems for the purpose of supplying and distributing power to those systems and to other designated items important to safety [6].

4.1 Course Description

This course deals with discipline (electrical) engineering, engineering management, engineering control, quality management, and specialty engineering in regard to the design of EPSs.

Engineering management has the same objects as project management; high quality, within scope, on schedule, and within budget. Project quality is affected by balancing project scope, time and cost. High quality projects deliver the required product, service or result within scope, on time, and within budget. The relationship among these factors is such that if any one of the three factors changes, at least one other factor is likely to be affected. Therefore, successful engineering management requires actively managing these factors. Engineering management also overlaps with procurement management and construction management. So, in the view point of project management, these three management areas have to be properly coordinated [7].

The engineering control system consists of four different control elements; engineering budget, engineering schedule, engineering progress, and engineering performance measurement. Each control function is in an integrated fashion with others. The functions can be applied to planning and analyzing engineering works for the engineering control to ensure the projects are managed within the budget and on the schedule [8].

Project quality management consists of all activities of the overall management function that determine the quality policy, objectives, & responsibilities and implements them by means such as quality planning, quality assurance, quality control, and quality improvement, within the quality system [9].

Specialty engineering may include reliability, maintainability, human factors, materials and processes, engineering standards, life cycle cost analysts, Electromagnetic interference/ electromagnetic compatibility (EMI/EMC), etc. [10].

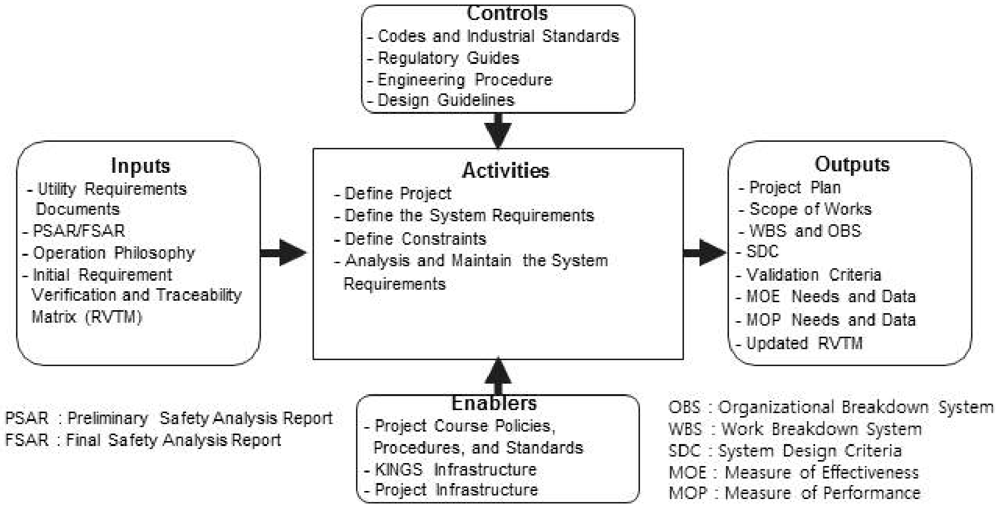
Discipline engineering aspects of this course are development of operation philosophy, allocation of functions, determination of technical specifications, design of drawings, and simulation of EPSs.

4.2 Scope of Works of the SEP

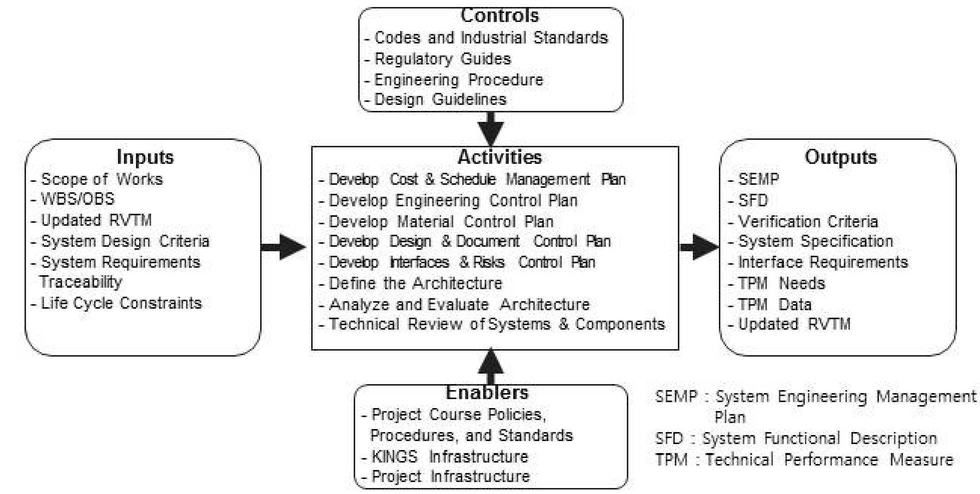
The SEP titled with "Emergency Power Systems for Nuclear Power Plants" composed of three (3) subject units. Those are "Project Planning and Requirements Review", "Design Management and Architecture Design", and "Design Synthesis and Verification". And, the context diagrams are as shown in Fig. 1 to 3.

In the Subject Unit 1, project define, work breakdown, system requirements define, and project scheduling are performed. Among them, project planning corresponds to management engineering and requirement analysis corresponds to discipline engineering work. The outputs of Subject Unit 1 (Fig. 1) are used as inputs for the Subject Unit 2 (Fig. 2).

In the Subject Unit 2, participants make plan

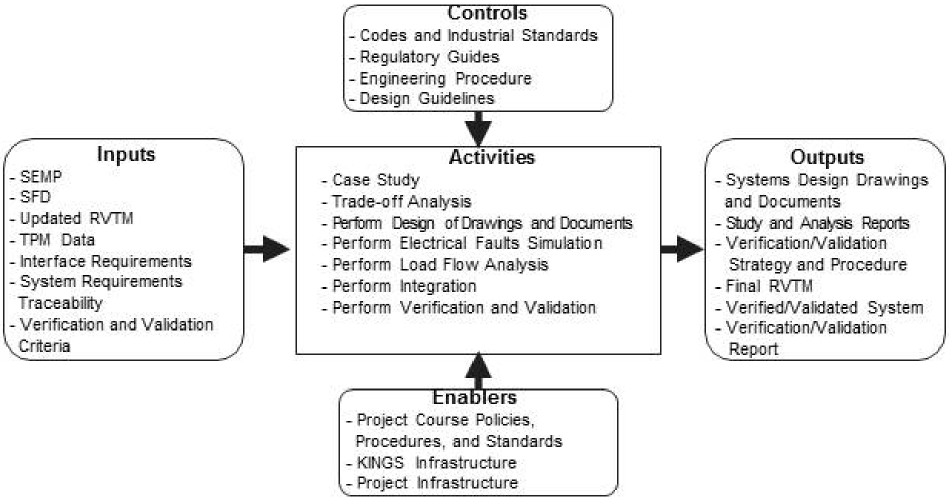


[Figure 1] Context Diagram for Project Planning and Requirements Review



[Figure 2] Context Diagram for Design Management and Architecture Design

for the cost and schedule management, engineering control, material control, design and document control, and interfaces and risks control. Then, the systems engineering management plan (SEMP) is developed based on the plans. After that, functional analysis and allocation are performed to develop system functional description (SFD). In the Subject Unit 2, technical specifications for the major equipment of the emergency power system such as emergency diesel generators, distribution panels, batteries, and chargers are determined. Among the works performing in the Subject Unit 2, the cost and schedule, engineering, material, design, risk, and interface control works correspond to management engineering. And, discipline engineering and specialty engineering works are also required for functional analysis and allocation. For example, the analysis of environmental impact of batteries and EMC of control and protection system are typical specialty engineering works.

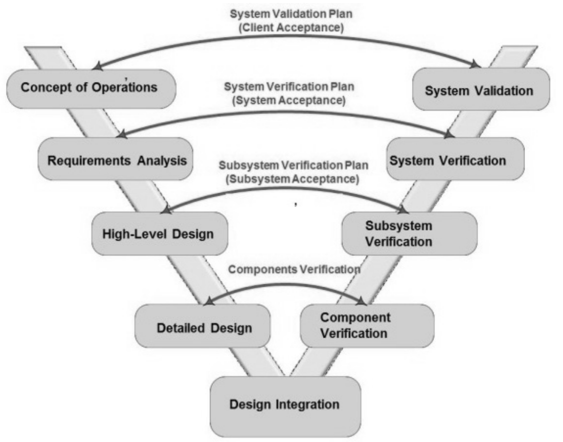


[Figure 3] Context Diagram for Design Synthesis and Verification

For the optimization of the emergency power systems, in the Subject Unit 3 (Fig. 3), the study of specialty engineering aspects is performed. Through the trade-off analysis the best suitable type of equipment is selected. To design the most secure system, analyze the reliability of emergency system. After that development of design drawings is followed. In the last, by using electrical transient analysis program (ETAP) verify the stability of the emergency power system. The short circuit fault simulation, load follow analysis, and motor starting simulations are those verification studies. In the last, validate the system according to the validation criteria prepared during Subject Unit 1.

4.3 Work Process of the SEP

The systems engineering approach is adopted for the performing of the SEP. "The function of systems engineering is to guide the engineering of complex systems. To guide is defined as "to lead, manage, or direct, usually based on the superior experience in pursuing a given course" and "to show the way." This



[Figure 4] Systems Engineering V-model for SEP

characterization emphasizes the process of selecting the path for others to follow from among many possible courses. [11]"

The systems engineering method can be thought of as the systematic application of the scientific method to the engineering of a complex system. This process is depicted in Fig. 4 [12] and contains the following activities: requirements analysis process, high level design (architectural design) process, detail design (implementation) process, integration process, verification process and validation process [13]. In terms of project life cycle, the SEP is performed in accordance with the system life cycle processes recommended by ISO/IEC 15288:2008.

4.3.1 Requirement Analysis

The purpose of requirements analysis is to elicit and analyze stakeholder needs, transform those needs into top-tier product requirements, flow down applicable requirements and constraints to all product tiers, and re-iterate these activities until the entirety of the product's life cycle functions and requirements are identified, captured, defined, and analyzed [14]. For example, in the Subject Unit 1, all of the requirements for emergency power systems specified in the codes, standards, and regulatory guides are reviewed. And, the requirements review results are defined as design criteria.

4.3.2 High Level Design

The purpose of this systems engineering process activity is to transform the functional, performance, interface and other requirements that were identified through requirements analysis into a coherent description of system functions that can be used to guide the detail design activity that follows. The designer will need to know what the system must do, how well, and what constraints will limit design flexibility.

In this step a system design is created based on the system requirements that define the overall framework for the system. Sub-systems of the system are identified and decomposed further into components. Requirements are allocated to the system components, and interfaces are specified in detail. Detailed specifications are created for the hardware and software components to be developed, and final product selections are made for off-the-shelf components. Major outputs of the Subject Unit 2 are produced in this process.

4.3.3 Detailed Design and Integration

In the detailed design process complete description of the end items constituting the total system are produced. For complex systems, a massive engineering effort is required to produce all the necessary plans, specifications, drawings, and other documentation necessary to justify the decision to begin fabrication and/or installation.

Design integration is a creative activity that develops a physical architecture (a set of product, system, and/or software elements) capable of performing the required functions within the limits of the performance parameters prescribed.

In the SEP for EPSs, the major work of this step is drawing design which is the main activity of the Subject Unit 3.

4.3.4 Verification and Validation

For each step of the system engineering process, the output will be compared to the requirements. This part of the process is called the verification loop. Each requirement at each step of development must be verifiable. Baseline documentation developed during the systems engineering process must establish the method of verification for each requirement. Appropriate methods of verification include examination, demonstration, analysis (including modeling and simulation), and testing. Formal test and evaluation (both developmental and operational) are important contributors to the verification of systems [14].

Validation is the process of determining the manner and degree to which a result is accurate representation of the real world from the perspective of the intended uses of the system, and of establishing the level of confidence that should be placed on this assessment [15]. In the development of a complex system, even though the preceding steps of the design outputs may have been carried out apparently in full compliance with requirements, there still needs to be an explicit validation of the design before the next phase is undertaken [16].

In the SEP, verification and validation process is required for all of three subject units. When elicit the requirements for each process, verification methods also should be established. Electrical simulation and analysis works which will be performed in the Subject Unit 3 are typical verification and validation activities.

5. Conclusion

The SEP has been developed to achieve KINGS's establishment goals. The SEP is one of the three specialization programs prepared for 2nd year students of KINGS. The KINGS specialization program adopted trans-disciplinary approach by project based team teaching method in handling NPP life cycle activities and applied systems engineering to nuclear power plant technology and administration. All students of KINGS learn systems engineering as a compulsory course during three trimesters of the 1st year. Then utilize systems engineering knowledge in the 2nd year specialization program.

In other words, the goal of the SEP has been to provide a set of capabilities that can be used in combinations that integrate, control and manage complex and diverse NPP technologies and technical trends. As elaborated in this paper, the students who take the SEP titled with "Emergency Power Systems for NPP" can acquire the knowledge and skills required to be a systems engineer who has capabilities of engineering control and management, technology trend analysis, trade-off analysis, risk management, and verification and validation for the design of optimized emergency power systems.

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