ENHANCING NUCLEAR SECURITY CONCEPTS AND PRINCIPLES ON ADVANCED NUCLEAR REACTOR COURSES

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ABSTRACT

Increasing demand of energy worldwide, diminishing conventional energy resources as well as increasing global risk on conventional energy resources utilization forces the development of alternative energy resources utilization. Nuclear energy becomes attractive alternative due to its capability to produce output energy in massive and continue manner. The recent nuclear energy technology poses two main unresolved problems, i.e. nuclear fuel resources (U-235) and long live radioactive waste (spent fuel). To solve these problems, the advanced nuclear reactor designs must have breeding capability to utilize the far more plentiful fertile fuel resources (U-238 and Th-232) and capability to transmute trans-uranium nuclides or minor actinides. Learning on accidents occurred in some previous nuclear reactor, increasing safety aspect is needed for the next nuclear reactor design. The breeding and transmuting capability means the advanced reactor operation need advanced nuclear fuel cycle and fuel management. The advanced nuclear fuel cycle and fuel management will include production of artificial fissile materials and processing them. In nuclear security point of view, production and processing of fissile materials pose additional threat. The Advanced Nuclear Reactor Course is an elective course in Nuclear Study Program in Engineering Physics Department, Faculty of Engineering, Universitas Gadjah Mada. This Course give broad but general knowledge to student related to history of nuclear engineering, roles, design improvements and the two main unresolved problems which are to be solved by advanced nuclear reactor design. In term of nuclear security, this course gives the student challenges to identify possible threats related to designs, operations, fuel cycles and fuel management (including waste treatment). This course then gives possible concepts or approaches for solving these threats.

Keywords: Nuclear Security Concept, Advanced Nuclear Reactor Course

A. INTRODUCTION

Nuclear reactor technology has become a prove technology for supplying energy demand continuously in vast amount. The role of nuclear energy technology in the future is predicted to be more important to replace the role of conventional energy technology. The role of conventional energy technology will be reduced due to the diminishing of the proven conventional energy resources and its environment impact, i.e. global warming.

The recent nuclear energy technology has been proven in term of economic aspect and safety aspect. However the recent nuclear energy technology poses two major problems, those are the sustainability of the known proven nuclear fuel resources and the problem related to very long term radioactive waste (spent fuel) handling.

The recent nuclear power reactors practically can only utilize U-235 as fuel to generate output energy. Meanwhile, the U-235 exists only 0.7 % mass of natural uranium. This means that the recent nuclear power reactor can only utilize maximally 0.7 % of uranium resources. The average specific fuel consumption of the recent nuclear reactors (LWRs) is 20 ton of enriched
uranium (i.e. 5% of U-235) per GWey. To provide this amount, 180 ton per GWey must be mined. For the recent nuclear power generation capacity, the known proven worldwide uranium resources are expected to be available only for the next 50 years [1]. The more abundant nuclear fuel resources, i.e. thorium still can not be utilized by the recent nuclear reactors.

The recent nuclear reactors averagely produce 20 ton per GWey of spent fuel. The 5% of the spent fuel is fission products which have average half life of several tens years. The rest is transuranium. The rest of U-235 and U-238 dominate the transuranium (i.e. roughly 92% of spent fuel mass). The U-235 and U-238 are considered not harmful to environment due to their very-very long half life (i.e. million years; this means very low specific activity). However, approximately 3% of the spent fuel are plutonium isotopes and minor actinides which has radioactivity level thousand times then U-235 or U-238 and very long half life (i.e. several ten thousand years). The existence of the minor actinides give the problem of the very long term radioactive waste handling related to spent fuel.

In order to both of preserve nuclear fuel resources and avoiding the problem of handling very long term radioactive material, the next generation of nuclear reactor tend to be developed as breeder reactors. The breeder reactors have capability to utilize both of fissile and fertile nuclides of nuclear fuel resources (i.e. uranium and thorium) [2]. The breeder reactors can also be used to utilize the leftover of U-235 and U-238 and also plutonium isotopes in the spent fuel of the recent reactors. Some of the next generation reactors are designed to have capability to transmute minor actinide to become fissile nuclides or nuclides that has shorter half life. Thus the next generation reactor will be designed to solve the main problems of the recent nuclear reactor technology, those are the sustainability of nuclear fuel resources and the handling of very long term radioactive wastes.

Of course the next generation nuclear reactors must be more safe, more reliably and more economic than the recent nuclear reactor. The another important issue is the diversity of output energy. While the recent nuclear reactors are basically utilized for large scale electric generation, the next generation reactors are utilized for various energy used with larger power spectrum. The next generation reactors are developed for small power output (modular reactor) as well as for large power output. The next generation reactors are designed to produce electricity as well as thermal power for various cogeneration process such as desalination [3], space heating, hydrogen production [4] and various endothermic chemical reactions.

The development of breeder reactors means that more fissile material will be produces from fertile material resources such as natural uranium and natural thorium [2]. As the consequence, several type of fissile material processing systems will be developed [5]. These will give several problems related to nuclear safety, safeguard and security in term of the fissile material handling and processing [6,7]

The “Advanced Reactor Technology” course will be delivered as an optional undergraduate level course in Nuclear Engineering Study Program, Universitas Gadjah Mada. The “Advanced Reactor Technology” course will describe several types of advanced nuclear reactor design concepts and several next generation technology and related nuclear fuel cycles. The advanced nuclear safety, safeguard and security concept [6,7] will also be described in this course.

This course will delivered as descriptive explanation and classical or group discussion. The difficulties related to mathematical formulation of theoretical concepts, mathematical solution, mathematical inference, etc. will be avoided in this course. The students who interest to
study more detail about some specifics aspects related to nuclear reactor technology are pursued to take the more specific related course.

**B. COURSE CONTENTS**

**General Objective**

The general objective of this course is to construct general, broad, not very detail but comprehensive knowledge to student about advanced reactor technology concepts and the several aspects related to the advanced reactor technology.

**Objectives**

To construct general, broad but comprehensive knowledge, this course will give the students the hystorical background and problems related to the recent nuclear reactor technology and the rasional and strategic goal to develop advanced reactor. For the purpose, the objectives or this course is is to give the student the basics understanding of :
- Historical background of nuclear reactor technology
- Reason for urgently developing advanced nuclear reactor technology
- General requirements for advanced nuclear reactor design
- Advanced nuclear reactor design types
- Safety aspects of advanced nuclear reactor
- Safeguard aspects
- Security aspects related to advanced reactor technology (fuel, waste and radioactive material processing)

**Outcomes**

The learning outcomes are strongly related to the objectives. Thus After taking this course, the students gain the abilities to :

a. Explain the historical background of nuclear reactor technology and the achievements.

b. Explain the reasoning of how urgent to develop advanced nuclear reactor technology

c. Explain the general required design criteria of advanced nuclear reactor technology, in the aspects of fuel resources sustainability, waste reduction, increasing safety, safeguard, security, reliability and economy

d. Explain the general characteristic of several proposed advanced nuclear reactor designs (advanced research reactors, advanced power reactors of NTD generation and 4th generation)

e. Explain the safety requirements of advanced nuclear reactor and how several proposed advanced nuclear reactor designs fulfill these requirements

f. Explain the requirements of advanced nuclear reactor in term of safeguard and how several proposed advanced nuclear reactor designs fulfill these requirements

g. Explain the security problems related to advanced nuclear reactor technology and concepts to solve these problems

h. Explain several possible application of advanced nuclear reactor technology

**Schedule**

The “Advanced Nuclear Reactor” course will be delivered for 2 credits in one semester. This course is delivered using the methods of tutorial, group assignment and discussion. The complete schedule of this course is as follow :
<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Substance</th>
</tr>
</thead>
</table>
| 1    | Nuclear reactor as alternative energy | a. Increasing energy demand  
b. Limitation of proven conventional energy resources  
c. Environmental impact related to conventional energy utilization |
| 2    | Nuclear reactor Technology, role, problems and developments | a. Brief history of nuclear reactor technology  
b. Role of nuclear reactor technology  
c. Problems related to nuclear reactor technology:  - limitation of U-235 content in currently known proven nuclear fuel resources  - accumulation of nuclear fuel wastes  - evaluation of safety aspects  - security problem related to nuclear material processing |
| 3    | Advanced Nuclear reactor principles | a. Low fuel consumption (high burn up, breeding)  
b. Low radioactive waste production  
c. Increasing safety (inherent safe, enhance passive safety system)  
d. Economics (design simplification, short construction, reliability increasing)  
e. Secure (non proliferation resistant)  
f. Increasing Utilization flexibility |
| 4    | Role of advanced nuclear reactor | a. Efficient electricity production  
b. Process heat application - low temperature (desalination, space heating, thermal refrigeration, drying) - medium temperature (enhanced oil recovery, oil refinery, others) - high temperature (coal gasification, hydrogen production, others)  
c. Valuable radionuclide production |
| 5    | Advanced Nuclear Reactor Type and Characteristics | a. Power Reactor (Near Term Deployment (NTD) Reactor)  
b. Power Reactor (Gen IV Reactors: SCWR, AHWR, VHTR, GCFR, LMFR, MSR) |
| 6    | Mid Semester Examination |  |
| 9    | Advanced Nuclear Fuel Cycle | 1. Utilization of LWR spent fuel in Fast Breeder Fuel Cycle to utilize totally natural uranium resources (SCWR, GCFR, LMFR and their variants)  
2. Thermal breeder fuel cycle to utilize totally natural thorium resources (SCWR, AHWR, MSR and their variants) |
| 10   | Advanced Nuclear Fuel Cycle and management | 1. Long life core design (CANDLE breeder Concept)  
2. On site fuel reprocessing concept for breeder reactor  
3. OTTO breeder concept for reactor types those can be fueled on line (AHWR, pebble bed HTR)  
4. On power fuel processing concept for liquid fuel reactor (MSR) |
| 11   | Innovation of safety | 1. Reviewing safety philosophy (DBA, beyond DBA, severe accident, accident management, risk acceptance)  
2. Enhanced inherent safe (low excess reactivity, negative power feedback)  
3. Total passive safety system against DBA and beyond DBA to avoid severe accident (passive shutdown system, passive post shutdown cooling system, passive cooling system for all radioactive material handling components at normal operation and accidents)  
4. Enhanced multiple barrier plus utilization of environmentally available heat sink  
5. Severe accident management facility |
| 12   | Security aspect related to the development of advanced reactor technology | 1. Threat identification related to material (high purity fissile and radioactive materials)  
2. Threat identification related to process (uranium enrichment, spent fuel reprocessing, radioactive waste processing, valuable radioactive processing)  
3. Security problem solving approach (engineering approach, legal / regulation approach, culture approach) |
| 13   | Engineering approach for solving security problem | a. Enhance on site process for fuel and radioactive waste processing (avoiding transportation of nuclear fuel and radioactive material)  - Long life or high burn up fuel design (CANDLE or OTTO concept)  - On site fuel reprocessing and waste process  - On power fuel processing and waste process for liquid fuel reactor  
b. Encapsuled nuclear fuel and radioactive material for transportation with special container that protected by legal rules or codes |
| 14   | Application of safety and security principles in the examples of advanced nuclear reactor design | PCMSR design |
| 15   | Other reactor design |  |
| 16   | Final Semester Examination or Assignment |  |
Assessment and Grading

The assessment and grading is as follow:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Discussion</td>
<td>30</td>
</tr>
<tr>
<td>Mid semester examination</td>
<td>30</td>
</tr>
<tr>
<td>Final examination</td>
<td>40</td>
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<table>
<thead>
<tr>
<th>Score</th>
<th>Grade</th>
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<tbody>
<tr>
<td>80 – 100</td>
<td>A</td>
</tr>
<tr>
<td>70 – 79,9</td>
<td>B+</td>
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<tr>
<td>60 – 69,9</td>
<td>B</td>
</tr>
<tr>
<td>50 – 59,9</td>
<td>C+</td>
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<tr>
<td>40 – 49,9</td>
<td>C</td>
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<tr>
<td>30 – 39,9</td>
<td>D</td>
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<tr>
<td>&lt; 30</td>
<td>E</td>
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Recommended Text Book

The recommended Text Book, Reading Materials and Lecture Notes related to this course are listed below:

8. IAEA Nuclear Security Series No 8, Preventive and Protective Measures Against Insider Threats
9. IAEA Nuclear Security Series No 11, Security of Radioactive Sources
11. IAEA Safety Standards, Safety of Nuclear Power Plant : Design, Specific Safety Requirements No. SSR-2/1
C. COURSE DESCRIPTION AND EVALUATION

Course description

The first deliberation of the Advanced Nuclear Reactor, enhanced with nuclear security concept, is as an even semester course at the year of 2015. The course started at January 2015 and finished at June 2015. This also acts as the first trial of this course. The results of this first trial is subjected to evaluation to improve this course for the next deliberation.

The deliberation method of this course is tutorial but the students are pursued to ask questions or give their opinion during tutorial. In the case of the questions, the lecturer will give answer directly to the questions or allows the other students to give the answers. The lecturer can give chance for the other students, may be to give another answers to support the first answers or may be to counter the first answers. Similarly in the case of student opinions. The students are allowed to give different opinion of what the lecturer explain. Another students are allowed to give their opinion. Thus the discussion atmosphere in the class will be created. Finally the lecturer gives conclusion of the discussion.

The first three topics give awareness of the students about the global problem of energy worldwide and gives rational understanding of nuclear energy role to solve the worldwide energy problem. However the critical thinking is also built for the students, that is the recent nuclear energy technology poses several serious problems those must be solved. The students understanding of requirements or criteria for the next generation of nuclear reactor technology are then built based on the solutions to solve these problems.

The next topics give description of the proposed designs of next generation of nuclear reactors. Due to so many proposed designs of such reactors and the limiting allocated time to deliver these topics, the explanations of these topics are not detail. However, some types of advanced nuclear reactors are described more detail as examples. Some aspects related to the safety, security and safeguard of the example advanced reactor designs are identified. The lecture will allow the students to discuss these aspect.

The advanced reactors tend to be developed as breeder reactor to solve the problems of fuel resources sustainability and long term radioactive wastes. As the consequences, several fuel reprocessing methods and new fuel cycle concepts will be developed. This course give general description of several fuel reprocessing methods and new fuel cycle concepts adopted for several advanced reactor designs. The students are then pursued to discuss the safety, security and safeguard aspects related to these fuel processing methods and fuel cycle concepts.

The principles of safety, security and safeguard, based on IAEA safety and security series are delivered to the students at week 11, 12 and 13 of this course. The last topics of this course discusses how these principles can be applied to a special type of advanced reactors.

The mid semester examination is an essay examination. The students pursue to answer some examination questions. The final examination is a paper writing assignment. The lecture pursues the student to choose a certain type of advanced reactor. The student then must give general description this reactor related to general features such as reactor system, energy conversion system etc. The student must identify the aspects of safety, security and safeguard of this chosen reactor design and how far the chosen reactor design apply the principles of safety, security and safeguard.

The group examinations have been given to the students. The students are divided into several groups. The students are allowed to choose the membership of the groups, i.e. each student are allowed to choose the group that they become the member of these groups. Each
group is allowed to become as a company that has activity related to advanced reactor technology such as reactor owner or operator, supplier of reactor components, fuel fabrication, waste treatment etc. Then they must identify the aspect related to safety, security and safeguard; discuss the hazard potential related to safety and the threat potential related to security. Then the must discuss how to design the appropriate safety and security system. Finally they must give presentation related to the result of their discussion.

Course Results
The result of mid semester examination shows that the students able to understand the important concepts of advanced reactor technology as mentioned at the first seven weeks courses. The students able to explain the reasons in developing the advanced reactors, requirements of advanced reactor in term of safety, safeguard, security and the role of advanced reactor in future energy system. The students able to explain the example of the advanced reactor design.

At the date that this paper is written, the course is still in progress, thus the result of the final examination is not yet available. The group discussions are still in progress. However the ongoing discussions show that the students able to understand the aspects of safety and security.

Course evaluation
Based on this first trial, the main problem of the deliberation of the course is the limiting time compare to the broad scope of this course. However, as stated in the general objective of this course; i.e. to construct general, broad, not very detail but comprehensive knowledge to student about advanced reactor technology concepts and the several aspects related to the advanced reactor technology; the scope of the course must not be narrowed.

The problem must be solved by optimizing topics, i.e. gives the students the most important subtopics to build broad and comprehensive understanding. After that this course must able to build the students awareness to study more details about certain more interested subtopics to them.

Variation of teaching methods and teaching tools also must be developed to improve this course.

D. SUMMARY
The Advanced Nuclear Reactor Course enhanced with Nuclear Security has been developed. This course is planned to be an optional undergraduate level course in Nuclear Engineering Study Program, Universitas Gadjah Mada. The first deliberation of the Advanced Nuclear Reactor, enhanced with nuclear security concept, is as an even semester course at the year of 2015. The main problem of the deliberation of the course is the limiting time compare to the broad scope of this course. The problem must be solved by optimizing topics, i.e. gives the students the most important subtopics to build broad and comprehensive understanding.

REFERENCES