Considering the Creation of Nuclear Safety Culture through Educational Curriculum in Thailand

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Abstract

This article aims to present nuclear knowledge management prior to the construction of nuclear power plants through a case study of Thailand. Thai governments, especially in the 2010s, have prepared policy packages, regulatory structures, and organizations to facilitate the construction of nuclear power plants. Policy debates regarding nuclear power plants are based on economic benefits, electricity prices, energy security, and concerns of nuclear accidents. To extend the nuclear policy conversation beyond the conventional topics, this article aims to investigate how the idea of nuclear safety culture, as a global concept promoted by the International Atomic Energy Agency, could be added into policy debates. Previous researches have suggested that nuclear curriculum is an important tool to educate people and (re)shape their perceptions and knowledge about nuclear power plants.

Following the useful suggestions of previous studies, this article compares nuclear curricula in both secondary and higher education levels, from Thailand and other countries, to evaluate whether the curricular developers have integrated the idea of nuclear safety culture into the curricula. The research findings indicate that the nuclear curricula from the case studies, including Thailand, have not fully integrated the concept of nuclear safety culture. The article also provides a set of

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alternative topics that integrate the idea of nuclear safety culture for redesigning the nuclear curriculum. The knowledge inherent to nuclear safety culture would increase people's perceptions and understanding of the broader connections between nuclear power and other aspects of society, an ideational condition for identifying the future of nuclear power plants.

Keywords: Nuclear Curricula, Nuclear Safety Culture, Nuclear Energy, Thailand

พิเคราะห์การสร้างวัฒนธรรมความปลอดภัยทางนิวเคลียร์ผ่านหลักสูตรการศึกษาในประเทศไทย

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บทคัดย่อ

บทความชิ้นนี้มีวัตถุประสงค์ที่จะนำเสนอการจัดการความรู้ทางด้านนิวเคลียร์ก่อนการก่อสร้างโรงไฟฟ้านิวเคลียร์ โดยเลือกประเทศไทยเป็นกรณีศึกษา ภายใต้การกลับมาของกระแสความนิยมต่อพลังงานนิวเคลียร์ในทวีปเอเชีย รัฐบาลไทยในช่วงทศวรรษที่ 2550ได้ตระเตรียมชุดนโยบาย โครงสร้างทางกฎหมาย และหน่วยงานต่างๆ เพื่อก่อให้เกิดการก่อสร้างโรงไฟฟ้านิวเคลียร์ ข้อถกเถียงเชิงนโยบายที่เกี่ยวข้องกับโรงไฟฟ้านิวเคลียร์มักวางอยู่บนหลักคิดเรื่องผลประโยชน์ทางเศรษฐกิจ ราคาค่าไฟฟ้า ความมั่นคงทางพลังงาน และความกังวลเรื่องอุบัติภัยจากโรงไฟฟ้านิวเคลียร์ เพื่อที่จะขยายบทสนทนาทางนโยบายนิวเคลียร์ให้ก้าวไปไกลกว่าประเด็นเดิมๆ บทความชิ้นนี้มีเป้าหมายที่จะตรวจสอบว่า ทำอย่างไรที่แนวคิดวัฒนธรรมความปลอดภัยทางนิวเคลียร์ในฐานะที่เป็นแนวคิดระดับโลก ซึ่งได้รับการสนับสนุนจากทบวงการพลังงานปรมาณูระหว่างประเทศ จะถูกผนวกรวมเข้าไปในข้อถกเถียงเชิงนโยบาย งานวิจัยที่ผ่านมาระบุว่า หลักสูตรการเรียนการสอนเกี่ยวกับนิวเคลียร์ถือเป็นเครื่องมือสำคัญที่ให้การศึกษาแก่ประชาชนและปรับเปลี่ยนการรับรู้ และองค์ความรู้ของประชาชนที่มีต่อโรงไฟฟ้านิวเคลียร์

จากข้อแนะนำที่เป็นประโยชน์ของงานวิจัยที่ผ่านมา บทความชิ้นนี้จึงศึกษาเปรียบเทียบหลักสูตรการเรียนการสอนเกี่ยวกับนิวเคลียร์ในระดับมัธยมศึกษาและอุดมศึกษาจากหลายประเทศ รวมถึงประเทศไทย เพื่อที่จะประเมินว่า ผู้พัฒนาหลักสูตรการเรียนการสอนเกี่ยวกับนิวเคลียร์ได้ผสมผสานแนวคิดวัฒนธรรมความปลอดภัยทางนิวเคลียร์เข้าไปในการออกแบบหลักสูตรหรือไม่ ข้อค้นพบจากการวิจัยชี้ให้เห็นว่า หลักสูตรการเรียนการสอนเกี่ยวกับนิวเคลียร์จากประเทศที่เป็นกรณีศึกษารวมทั้งประเทศไทยนั้น ผสมผสานแนวคิดวัฒนธรรมความปลอดภัยทางนิวเคลียร์น้อยมาก

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บทความชิ้นนี้จึงเสนอชุดของหัวข้อที่เป็นทางเลือก ซึ่งบรรจุแนวคิดวัฒนธรรมความปลอดภัยทางนิวเคลียร์ในฐานะข้อเสนอแนะเพื่อปรับปรุงการออกแบบหลักสูตรการเรียนการสอนเกี่ยวกับนิวเคลียร์ องค์ความรู้ที่เกี่ยวข้องกับวัฒนธรรมความปลอดภัยทางนิวเคลียร์จะช่วยเพิ่มการรับรู้ของประชาชนเพื่อจะเข้าใจความเชื่อมโยงที่กว้างขวางขึ้นระหว่างนิวเคลียร์และประเด็นทางสังคมอื่นๆ ซึ่งจะเป็นเงื่อนไขทางความคิดสำหรับการกำหนดอนาคตของโรงไฟฟ้านิวเคลียร์

คำสำคัญ: หลักสูตรการเรียนการสอนเกี่ยวกับนิวเคลียร์ วัฒนธรรมความปลอดภัยทางนิวเคลียร์ พลังงานนิวเคลียร์ ประเทศไทย

Introduction: The Second Nuclear Renaissance in Asia and its Significance

The positive perception of nuclear power plants has been challenged by the various cases of nuclear disasters, such as the 1979 Three Miles Island disaster, the 1986 Chernobyl disaster, and the 2011 Fukushima Daiichi disaster. The negative impacts of such nuclear disasters have created public concern regarding the safety of nuclear power. However, the number of nuclear power plants is continuously increasing. The rise of nuclear power plant construction seems to be in contrast with the negative images of the nuclear power plant accidents. Annual reports by the International Atomic Energy Agency (IAEA) (2019) pointed out that the numbers of worldwide nuclear reactors had grown approximately 2.7% (see Exhibit 1). Upon considering the number of nuclear reactors in each region, Exhibit 1 illustrates that the number of nuclear power plants in the Asia Pacific region had increased dramatically. The amount of nuclear energy consumption also supports this argument, as presented in Exhibit 2 which demonstrates the increasing rate of nuclear energy consumption in the Asia Pacific and ranks it as number two in the world. Based on the statistical data, it is important to pay attention to the Asia Pacific region in order to better understand the second wave of nuclear renaissance.

The literature review of the two journals that publish high quality articles from worldwide energy policy analysts, the *Energy Policy Journal* and *Journal of Energy Research & Social Science*, it was found that Japan, China, and South Korea were frequently chosen as the case studies. The energy policy researchers used these countries to understand the patterns of public opinion, perception, and behavior regarding nuclear power plants (Wang et al, 2019; Roh and Lee, 2018; Arikawa, 2014). The other groups of energy policy researchers adopted cost-benefit analysis to compare the policy costs between nuclear, renewable energy, and natural gas in South Korea (Hong and Brook, 2018), and to calculate the costs of nuclear power plant construction and related accidents in Japan (Matsuo and Nei, 2019; Behling et al, 2019). These previous studies were typically concentrated on countries where nuclear power plants were already installed and proposed

suggestions for (re)designing their nuclear energy policy. The core effort of the previous studies, then, was to establish a base of knowledge regarding citizens' behavior and socio-economic costs following the installation of nuclear utilities.

The current study looks at Thailand as a case study because although a nuclear plant is not installed yet, the Thai government has prepared a concrete plan to build nuclear utilities (Energy Policy and Planning Office, 2015). In this sense, Thailand serves as an ideal case to examine nuclear knowledge management *before* the construction of nuclear power plants. The management of nuclear knowledge before the construction of nuclear plants can be a significant tool to shape citizens' behavior, attitude, and perception toward the nuclear power plants and to design a way of thinking that calculates the costs of nuclear energy policy. In other words, nuclear knowledge management plays a crucial role in influencing the acceptance or rejection of nuclear power plants. The next section will address the following two questions: *what is the background of Thailand's nuclear energy policy? And how can the management of nuclear knowledge be further investigated?*

The Effort to Construct Nuclear Power Plants in Thailand

Since 1961, with the enactment of the Atomic Energy for Peace Act, the Thai government has prepared policy packages, regulatory structures, and organizations to support the construction of the nuclear power plants and the further promotion of nuclear energy consumption. The government's efforts to construct the nuclear power plants are reflected in the development of nuclear policy packages and regulations (see Exhibit 3).

Nine years after the enactment of the 1961 Atomic Energy for Peace Act, the government approved a project proposed by the Electricity Generating Authority of Thailand (EGAT) to construct a nuclear plant in the Ao Pai area of Chonburi province. However, the government decided to suspend the project in 1976 when a natural gas field was discovered in the Gulf of Thailand and the public expressed concern regarding radioactive leakage (Wongkomtan, 2011: 33-34). The formulation of policy to promote the construction of nuclear plants was then suspended for

36 years. However, in 2006 the government enacted the Royal Decree on Thailand Institute of Nuclear Technology to establish a nuclear academic institute for the purpose of researching nuclear technology and training staff to improve nuclear energy production in the future (Royal Decree on Thailand Institute of Nuclear Technology, 2006). After the academic organization was established, the 2010 government implemented the Thailand Power Development Plan, which approved the construction of the five nuclear power plants between 2021 and 2030 that would provide 5,000 megawatts of energy (Thailand Power Development Plan, 2010).

The 2011 nuclear crisis in Fukushima Daiichi, Japan affected Thailand's planned construction of nuclear power plants. Pictures of the nuclear disaster in the media influenced the public to question the safety of nuclear energy. In response, the Thai authorities decided in 2015 to adjust the Thailand Power Development Plan, reducing the number of nuclear plants from five to two, and lowering the generating capacity to 2,000 megawatts (Thailand Power Development Plan, 2015). The timeline of construction was also delayed to 2036. Progress in the creation of the nuclear energy policy package occurred again in 2017 when the government approved the Policy and Strategic Plan for Development of Nuclear Energy (10-year plan) and the Action Plan on Policy and Strategic Plan for Development of Nuclear Energy (5-year plan). The core content of both plans was focused on setting a timeframe for beginning the construction of the nuclear power plants. In the 5-year plan, the Thai authorities noted that "in the next 6-10 years, Thailand would be ready to produce electricity from the nuclear power plants" (Committee on Nuclear Energy for Peace, 2017: 5-6).

The government's efforts to promote the construction of the nuclear power plants were met with both support and criticism. Supporters cited economic benefit, environmental protection, and energy security as the benefits of nuclear power. For example, when compared with other energy sources, such as coal, natural gas, or renewable energy, the nuclear power plants generate electricity at the lowest price (Prachachat, July 17, 2012). This form of energy could also reduce the emissions that lead to air pollution, a key factor in global warming (Thairat,

December 11, 2009). Moreover, the nuclear power plants would help to diversify the country's energy portfolio, which could strengthen its energy security (Thairat, October 6, 2009). On the other hand, the critics frequently raised the issues of safety and potential negative impacts of nuclear power. Civil society groups and environmentalists, for example, pointed to the disasters that resulted in radioactive leaks, which have severely impacted human and animal lives. The most common references are to the cases of Chernobyl and Fukushima Daiichi in an effort to remind supporters of the hazards of nuclear power plants (Thairat, January 21, 2011).

Both advocacy and criticism provide useful material to educate people and stimulate public participation in setting the nuclear agenda. However, neither supporters nor critics seem to pay much attention to nuclear safety culture, which is a global concept promoted by the IAEA in the discussion of nuclear energy policy. The concept of nuclear safety culture includes safety guidelines, standards, and ideational frameworks to address nuclear technical management, including how nuclear technology is managed during the installation, operation, and maintenance period, as well as the creation of nuclear safety culture and how to facilitate social learning that can improve policy discussions. Nuclear safety culture would also help to further reframe the conventional nuclear debates to better address the issue of safety, which is the most pressing concern of nuclear power plants. The OECD Nuclear Energy Agency (2016: 13) suggested that nuclear safety culture should be integrated as a sub-national culture through the national education system. Moray (2001: 50) elaborated that the education system plays a crucial role in training people and providing the public with an analytical lens through which to view nuclear power.

In order to offer recommendations to further advance the concept of nuclear safety culture within public opinion and stakeholder policy debates, this study aims to examine Thai nuclear curricula through the following questions:

1) What are the key characteristics of nuclear educational programs in other countries and in Thailand?

2) Comparing the characteristics of nuclear educational programs in other countries with those in Thailand, what are the main differences and similarities?

3) Is the concept of nuclear safety culture integrated into the nuclear curricula of the countries' education system? If so, how?

The research guided by these three questions seeks to reveal the creation of a nuclear educational system. Focusing specifically on the case of Thailand, the creation of a nuclear curriculum could reflect the process of managing nuclear knowledge *before* the installation of nuclear power plants. Data collection for this study relied on the documentary-based sources, including academic articles and government reports on nuclear curricula. The document survey was utilized to gather details of nuclear curricula and the data was clustered according to related nuclear subjects for further analysis of the curriculum design. The current study starts with a review of the existing concept of nuclear safety culture in order to establish the analytical framework. The article then reviews the nuclear education programs from other countries to provide a global context for comparison to the Thai case. The next section focuses specifically on the design of Thailand's nuclear curriculum. Finally, the last section of this article offers the tentative topics that integrate the concept of nuclear safety culture to further improve the nuclear curriculum design, public perception, and nuclear policy debates.

Nuclear Safety Culture: A Sub-Concept of Organizational Safety Culture

Nuclear safety culture was developed within the ideational framework of safety science. The core idea of safety science concentrates on how to prevent, control, and handle accidents or hazardous incidents in organizations. Safety science developed into its third phase in the 1940s, the so-called socio-technical phase, in which scholars in the field believed that the accidents or incidents were created by the interactions of technical and individual, social, managerial, or organizational factors. The idea of safety culture then emerged, centering its focus on socio-technical systems to improve the safety performance of organizations (Wilpert, 2001: pp.8-9).

The concept of nuclear safety culture was developed in the 1980s, following the 1986 Chernobyl nuclear accident (Cooper, 2002). The International Nuclear Safety Advisory Group of the IAEA was the first nuclear organization that articulated the term 'nuclear safety culture' in its report on the Chernobyl disaster. Nuclear safety culture was originally defined as the safety regime that should prevail at any nuclear power plant. The term 'regime' in the report referred to the proper regulatory systems implemented to ensure nuclear safety (International Nuclear Safety Advisory Group, 1992: p. 21). The first definition of nuclear safety culture emphasized the significant role of regulations, which have the authority to enforce responsibility and nuclear safety measures. However, the definition was shifted in 1998 when the IAEA reframed the concept of nuclear safety culture by prioritizing the personal behavior of nuclear plant staffs and the relevant regulatory bodies. The concept was described as follows:

"Nuclear safety culture was the assembly of characteristics and attitudes in organizations and individuals which established that nuclear plant safety issues received the top attention warranted by their significance. Safety Culture was also an amalgamation of values, standards, morals, and norms of acceptable behavior. These are aimed at maintaining a self-disciplined approach to the enhancement of safety beyond legislative and regulatory requirements." (International Atomic Energy Agency, 1998:3)

The second definition expanded the core discipline of nuclear safety culture to shape people's awareness of the nuclear power plants. The most recent update to the concept of nuclear safety culture occurred in 2005. The IAEA linked the concept to policymaking by stating that the policy that concerns with complex beliefs, values, and behavior must be formulated to sustain nuclear power plants, as well as to enforce safety controls within operating plants. The IAEA noted that:

"Safety culture is the complexity of beliefs, shared values and behavior reflected in making decisions and performing work. The presence of a strong safety culture in maintenance contributes significant value to the safe operation of a plant. With respect to plant maintenance, safety culture means keeping the maintenance

process on track and in control at every stage of plant performance." (International Atomic Energy Agency, 2005: 2)

Through the historical development of this concept, nuclear safety culture essentially refers to the creation of nuclear safety standards through the three components: 1) implementation of nuclear regulations to strengthen personal responsibility and nuclear plant performance; 2) increased self-awareness regarding nuclear safety; and 3) designing appropriate policies and maintenance systems to safeguard the nuclear plants from operational accidents.

The previous definitions, as described above, also provided the basic elements or principles needed to establish nuclear safety culture. The principles included the four components: key actors' roles, education or training systems, systematic safety procedures, and social incentives (see Exhibit 4). The details of each component are summarized below (International Atomic Energy Agency, 1991; International Atomic Energy Agency, 2005; OECD Nuclear Energy Agency, 2016):

1) Key actors' roles

The first component points to the crucial roles of key actors who have the authority to make decisions regarding the management of nuclear power plants, including the plant leaders, senior managers, safety auditors or safety reviewers, and high-ranking officers in the regulatory bodies. These key actors should commit to following and promoting nuclear safety procedures. Moreover, these high-ranking staffs should exhibit the appropriate behavior and demonstrate a safety-minded attitude in order to serve as a role model for other members of staff. Furthermore, the behavior of ordinary staffs is also important to the promotion of nuclear safety standards, including the ability to openly communicate with their supervisors when safety standards are violated.

2) Education and training system

The second component suggests that to maintain nuclear safety knowledge and practices, educational or training systems related to nuclear safety should be provided to all staff members and to the general public. In addition, the organizations

and government agencies should assess the understanding gained from such systems in order to improve their practices.

3) Systematic safety procedures

The third component recommends that the nuclear power plants and government agencies should provide both staff and the public with guidelines that describe and demonstrate systematic procedures to address the nuclear accidents.

4) Social incentive

The final component mentions social incentives, such as rewards for good practices and sanctions for dangerous practices. The social incentives function to encourage staff members and other people to maintain nuclear safety standards. On the other hand, the sanctions could come from social norms that monitor and control behaviors or actions that violate the nuclear safety principles.

The analytical framework used to analyze nuclear safety culture provides the helpful guidelines to examine the nuclear curricula of various countries, including Thailand, in order to address the third research question.

Nuclear Themes in Curricula around the World

This study selected nuclear curricula from foreign countries as the cases with which to compare Thailand's nuclear curriculum. Data was collected using Google Scholar, a journal article search engine, and articles that reported on nuclear curricula in various countries was analyzed. Eight cases were found using Google Scholar, including Japan, South Korea, Indonesia, the Philippines, Sri Lanka, Brazil, Kenya, and Slovakia. The nuclear curricula of secondary and higher education levels were the target area of this study for two reasons. First, young generations who are studying in high schools and universities will soon become the adults who have decision-making power regarding the future of nuclear energy policy. Nuclear curricula in high schools and universities are, then, a powerful tool to encourage the discussion and negotiation of nuclear energy policy (Korea Atomic Energy Research Institute, 2003: 3). Second, the nuclear curricula at the high school and

university levels provide fundamental knowledge for those who are interested in working with the nuclear organizations such as the nuclear plants, nuclear regulatory bodies, and nuclear government agencies. In this sense, high school and university curricula are core mechanisms in the education of future nuclear experts through the provision of basic knowledge and preparatory skills (International Atomic Energy Agency, 2011: 4).

Reviewing international nuclear curricula, the findings indicate that its design is composed of three main subjects: 1) Radiation or Radioactivity, 2) Nuclear Power Plants, Nuclear Engineering, and Nuclear Physics, and 3) Applied Subjects (see Exhibit 5). It is important to note that the subjects here are included in the national textbooks and course structures of public schools and universities of the selected countries, meaning that a majority of their children have access to this knowledge. The details of nuclear subjects from the selected countries are summarized below (Karsono, 2005; Slugen, 2005; Hewamanna, 2007; Bernido, 2007; Barabas and Sabundjian, 2013; Choi, Kim and Han, 2017; Mwangi and Gatari, 2018; Kim and Goto, 2019).

1) Radiation and Radioactivity is a core subject that is included in the nuclear curricula of each country. The content of this subject at the secondary level is composed of the basic knowledge necessary for understanding what radiation or radioactivity is, how to use radiation or radioactivity in daily life, and how to protect yourselves from the effects of radiation. Some example topics in this subject are: the history of nuclear and radiation; misunderstandings about radiation; types of radiation; uses of radiation in food, medical treatment, and industry; radiation incidents and contamination; and environmental disasters caused by radioactive leaks. In higher education, the Radiation or Radioactivity subject provides advanced understanding regarding how it interacts with other sciences, how to cope with the side effects of radiation or radioactivity, and how to analyze or evaluate the risk of radiation or radioactivity. Some example topics include: radiation in chemistry, physics, environment, and medical science; radiation interactions; radiation detection; radiation protection; and probability risk analysis.

2) Nuclear Power Plants, Nuclear Engineering, and Nuclear Physics is another basic subject that all selected nuclear curricula share (see Exhibit 5). The core focus of this subject in secondary education normally concentrates on the basic principles of nuclear power, such as the atomic and the nuclear structure, their constituents, and their interactions. Some example topics include nuclear physics; nuclear fusion and fission; nuclear power generation; and the use of nuclear power and its issues. The content of this subject at the higher education level relates to nuclear application and technology for utilization. The topics include nuclear physics; nuclear power plants; nuclear reactors; nuclear power plant equipment; materials for nuclear power plants; and decommissioning nuclear power plants.

3) Applied Subjects integrates social science knowledge into the curricula to provide further social, economic, and political contexts. The example topics taught in South Korea, Kenya, and Thailand include the history of nuclear energy, nuclear regulations, history of nuclear accidents, and nuclear proliferation.

This section briefly summarized the key characteristics of the nuclear curricula from the other countries. The findings serve as the initial dataset to compare the nuclear curricula of Thailand with that of the other selected countries.

Nuclear Subjects in Thailand's Curriculum

This section analyzes the characteristics of Thailand's nuclear curriculum through the consideration of subjects from the national teaching guideline, national textbooks, and nuclear undergraduate programs at Chulalongkorn University. The Institute for the Promotion of Teaching Science and Technology, a government agency under the Ministry of Education, published the secondary level (high school) national nuclear teaching guideline (Institute for the Promotion of Teaching Science and Technology, 2010) and the nuclear textbooks (Institute for the Promotion of Teaching Science and Technology, 2012). In this sense, the subjects included in the teaching guideline and textbooks should reflect the core nuclear knowledge of Thai society. The nuclear undergraduate programs offered at Chulalongkorn University (Faculty of Engineering, Chulalongkorn University, 2018) were selected because

Chulalongkorn University is the only institution in Thailand that offers a complete nuclear course at both undergraduate and graduate levels. The nuclear educational programs at Chulalongkorn University, then, reflect a more comprehensive base of nuclear knowledge that could influence the public perception.

The nuclear curriculum in Thailand also shares the same content with international curricula, which, as outlined above, are based on 1) Radiation or Radioactivity, 2) Nuclear Power Plants, Nuclear Engineering, and Nuclear Physics, and 3) Applied Subjects.

The group of Radiation or Radioactivity subjects at the secondary level in Thailand is quite similar to that of the Korean curriculum. Thai high school students study the fundamental knowledge of radiation, advantages and effects of radiation, and protection from radiation. The topics included in the secondary curriculum include the history of radioactivity discovery; types of radiation; advantages of radioactivity in agriculture, medical treatment, industry, and archeology; and radiation protection. The Radiation or Radioactivity subjects in the undergraduate program include advanced concepts to explore in-depth about nuclear knowledge, including radiation sources, nuclear radiation properties, and the interaction of radiation with matter. The topics include nuclear radiation detection and measurement, radiation protection, and uses of radiation in industry.

The core content of Nuclear Power Plants, Nuclear Engineering, and Nuclear Physics at the secondary level explains the components of a nucleus, nuclear reactions, the concepts of fission and fusion, and the advantages of electricity production from nuclear power plants. These basic concepts are developed into more complex topics in the undergraduate program, aiming to understand advanced nuclear technology; the linkages between nuclear technology and the environment, medicine, and social activities; advantages of nuclear technology in medicine and manufacturing; and the use of technology to prevent and manage the nuclear accidents and their effects. The list of example topics includes nuclear engineering, nuclear materials, nuclear power plant technology, nuclear reactor analysis, environmental aspects, nuclear reactor safety, nuclear weapons, and nuclear accidents.

The Faculty of Engineering at Chulalongkorn University has interestingly designed and added Applied Subjects to its nuclear curriculum. It integrates, to some extent, the ideas of social science and nuclear safety to create two subjects: 1) Nuclear Safety, Security, and Safeguards; and 2) Social Science for Nuclear Engineering. From the course descriptions, both subjects link together the ideas of economics, policy analysis, law, public communication, sociology, and education in order to create an interdisciplinary perspective that acknowledges the wider connections between nuclear science and social issues.

Enhancement of Nuclear Safety Culture in the Curriculum Design

Based on the research findings, the international nuclear curricula concentrate on the two main groups of content: 1) Radiation or Radioactivity, and 2) Nuclear Power Plants, Nuclear Engineering, and Nuclear Physics. Some cases, such as South Korea and Kenya, try to offer an alternative content by integrating the ideas of social science, including history and law, in the analysis of nuclear power. Thailand's nuclear curriculum design also shares similarities in its content, as it is based heavily on the subjects of Radiation or Radioactivity and Nuclear Power Plants, Nuclear Engineering, and Nuclear Physics. Jho et al. (2014) investigated South Korean high school students' understanding of knowledge, attitude, and decision-making as it relates to nuclear energy policy. The results prominently indicated that science-based knowledge, such as radiation, radioactivity, nuclear engineering, and nuclear physics, does not have a significant impact on Korean students' decision whether or not to support nuclear power plants. This reveals that social science knowledge should be more integrated into nuclear curricula to provide a wider contextual analysis of the positive and negative connections between nuclear power and society.

The nuclear undergraduate program at the university level, as seen in the case of Thailand, seems to integrate social science-based knowledge into its nuclear curriculum more so than the other cases. Focusing mainly on the concept of nuclear safety, which has been included in Chulalongkorn University's nuclear curriculum, it is important to consider how this concept could be applied to the *design* of nuclear curriculum. Furthermore, it should be observed whether the

subjects of nuclear safety also include the core principle of nuclear safety culture. To address these concerns, this study adopts the analytical framework of nuclear safety culture to analyze the subjects.

According to the research findings, it can be said that nuclear safety culture is often overlooked by secondary teachers and university professors in the design of nuclear curricula. Only the case of nuclear curriculum from Chulalongkorn University in Thailand reflects the integration of nuclear safety ideas. However, the course description of the Nuclear Safety, Security, and Safeguards subject focuses mainly on the two aspects: 1) nuclear technological safety, which is concentrated on how to correctly employ nuclear equipment, control errors, and prevent accidents, and 2) nuclear related policies and regulations, both domestic and international, to maintain nuclear technological safety. The key concepts of nuclear safety culture, actors' roles, education system, safety procedures, and social incentives, are not included in the course description. The question, then, is how the idea of nuclear safety culture can be better integrated into the nuclear curricula. The current study suggests that the developers of nuclear curricula should integrate the concept of nuclear safety culture by either adding it to the existing subjects or creating new separate subjects.

Suggestions of topics that could be added into the nuclear curricula are as follows:

- Nuclear Safety Institutions

This topic should detail domestic and international institutions that have the authority to monitor, safeguard, and investigate nuclear accidents. Moreover, it should describe the collaboration that occurs between related institutions when a nuclear accident occurs. This topic can help people to identify which institutions they should contact for assistance if a nuclear accident happens.

- Plans and Procedures for Safeguarding People from Nuclear Disasters

This topic should provide the international standards or procedures to safeguard people from the nuclear disasters. It would further discuss the governments'

plans or systematic procedures that people should follow to protect themselves from the nuclear accidents. Moreover, the plans and procedures for coping with the nuclear accidents from other countries could be selected as case studies to advance peoples' understanding.

- Practices for Living with Nuclear Accidents

This topic should be added as a practical subject, including training by simulation of the nuclear accidents. The safeguarding plans and procedures, as provided in previous subjects, should be practiced to ensure that people are prepared.

- Communication to Establish Awareness about Nuclear Safety

The content of this topic should discuss methods and tools for communication about nuclear safety. A handbook or leaflet is an example of a more traditional tool for communication about nuclear safety. Social media presents an advantageous opportunity to communicate to the public about nuclear safety on various platforms. The new formats of communication on the online platform may also provide more incentive for younger generations to show their interest in nuclear safety.

Conclusion

Facing the wave of the nuclear renaissance in Asia, this study selected the nuclear curriculum from Thailand to understand the strategy of managing nuclear knowledge before the construction of nuclear power plants. The study recognizes that nuclear curriculum is a powerful tool for knowledge management that can shape the public's perception of nuclear power plants. The design of nuclear curriculum is, then, a fundamental aspect of shaping the public's attitude and influencing decisions regarding nuclear power plant policy. The study found that the developers of nuclear curricula often overlook the integration of nuclear safety culture because they mainly focus on nuclear scientific knowledge such as radiation, radioactivity, nuclear engineering, and nuclear physics.

Addressing the above problem, the study suggests a number of alternative topics for nuclear curriculum developers to (re)design the curricula. The topics include Nuclear Safety Institutions, Plans and Procedures for Safeguarding People from Nuclear Disaster, Practices for Living with Nuclear Accidents, and Communication to Establish Awareness about Nuclear Safety. The proposed topics seek to enhance people's understanding of the broader connections between nuclear power and other aspects of society, promoting ideational conditions for establishing the future of nuclear power plants.

Due to the limitations of data sources, the current study was unable to access documents that report on nuclear curricula in some leading nuclear countries such as China, Russia, France, and the United States of America. Therefore, the study could not identify how leading nuclear countries develop their nuclear curricula for the management of nuclear knowledge, which is used to further sustain domestic nuclear power plants and to export nuclear power abroad. This research gap should be examined in the future. For example, a comparative study of nuclear curricula between the countries involved with the first wave and the second wave of nuclear renaissance should be conducted to illustrate the nuclear knowledge transformation. Moreover, researchers who are interested in this topic should look deeper into the way the nuclear courses are taught and the experiments are performed in order to comprehensively understand how the concept of nuclear safety culture is integrated into the class activities.

Exhibit 1: Numbers of Nuclear Reactor from 2004 to 2018 by Each Region

Region	Numbers of Nuclear Reactors (Unit)		Percentage of Increase (+) or Decrease (-)
	2004	2018	
North America	121	117	(-) 3.30
Latin America	6	7	(+) 16.66
Asia Pacific	98	137	(+) 39.79
Europe	207	183	(-) 11.59
Africa	2	2	0
Total	434	446	(+) 2.76

Source: International Atomic Energy Agency. (2004-2019). *Nuclear Power Reactors in the World*. Vienna: International Atomic Energy Agency.

Exhibit 2: Nuclear Energy Consumption in the World from 2000 to 2018

Region	Numbers of Nuclear Energy Consumption (Million tones oil equivalent)		Percentage of Increase (+) or Decrease (-)
	2000	2018	
North America	197.8	217.9	(+) 10.16
Latin America	2.8	5.1	(+) 82.14
Asia Pacific	113.3	125.3	(+) 10.59
Europe	267.4	258.8	(-) 3.21
Africa	3.1	2.5	(-) 19.35
Total	584.4	609.6	(+)

Source: BP p.l.c. (2019). *BP Statistical Review of World Energy 2019*. London: BP.

Exhibit 3: Timeline of the Nuclear Policy Packages and the Regulations of Thailand

Years	Policy/ Regulation
1961	Atomic Energy for Peace Act
1970	The Announcement of Revolutionary Council in Setting up Nuclear Power Plant
2006	Royal Decree on Thailand Institute of Nuclear Technology
2010	Power Development Plan, 2010
2015	Power Development Plan, 2015
2016	Nuclear Energy for Peace Act
2017	- Policy and Strategic Plan for Development of Nuclear Energy (10 years) - Action Plan on Policy and Strategic Plan for Development of Nuclear Energy (5 years)
2018	Royal Decree on Thailand Institute of Nuclear Technology (2nd Amendment)
2019	Nuclear Energy for Peace Act (2nd Amendment)

Source: Summarized by the author

Exhibit 4: Comparison of the nuclear safety culture criteria by the IAEA and the OECD Nuclear Energy Agency

IAEA (1991)	IAEA (2005)	OECD (2016)
Individual awareness of the importance of safety	Willingness of plant management to apply, and thus demonstrate, the principles of a strong safety culture, as well as their consistent handling of conflicts concerning safety culture issues	Leadership for safety is to be demonstrated at all levels in the regulatory body
Knowledge and competence, conferred by training and instruction of personnel and by theirself-education	Everyday efforts and good practices of maintenance staff, including the application of a learning process	All staff of the regulatory body has individual responsibility and accountability for exhibiting behaviours that set the standard for safety

Exhibit 4: Comparison of the nuclear safety culture criteria by the IAEA and the OECD Nuclear Energy Agency (cont)

IAEA (1991)	IAEA (2005)	OECD (2016)
Commitment, requiring demonstration at senior management level of the high priority of safety and adoption by individuals of the common goal of safety	Special education and training of personnel	The culture of the regulatory body promotes safety and facilitates cooperation and open communication
Motivation, through leadership, the setting of objectives and systems of rewards and sanctions, and through individuals 'self-generated attitudes	Procedures focused on mission goals that are rooted in the safety culture	Implementing a holistic approach to safety is ensured by working in a systematic manner
Supervision, including audit and review practices, with readiness to respond to individuals 'questioning attitudes		Continuous improvement, learning and self-assessment are encouraged at all levels in the organization
Responsibility, through formal assignment and description of duties and their understanding by individuals		

Source: Summarized by the author

Exhibit 5: The List of Nuclear Subjects in Each Country's Curricula

Subjects / Countries	Radiation/ Radioactivity	Nuclear Power Plant/ Nuclear Engineering/ Nuclear Physics	Applied Subject
Secondary Education			
Brazil	√	√	×
Japan	√	√	×
Sri Lanka	√	√	×
South Korea	√	√	√
Thailand	√	√	×
Higher Education			
Indonesia	√	√	×
Kenya	√	√	√
Slovakia	√	√	×
Sri Lanka	√	√	×
The Philippines	√	√	×
Thailand	√	√	√

Source: Summarized by the author

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