ARTICLE IN PRESS

Nuclear Engineering and Technology xxx (2016) 1–17

Available online at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

An Integrated Multicriteria Decision-making Approach for Evaluating Nuclear Fuel Cycle Systems for Long-term Sustainability on the Basis of an Equilibrium Model: Technique for Order of Preference by Similarity to Ideal Solution, Preference Ranking Organization Method for Enrichment Evaluation, and Multiattribute Utility Theory Combined with Analytic Hierarchy Process

Saerom Yoon [a,*], *Sungyeol Choi* [b], *and Wonil Ko* [c]

[a] *Department of Quantum Energy Chemical Engineering, Korea University of Science and Technology (KUST), Gajungro 217, Yuseong-Gu, Daejeon 305-350, Republic of Korea*

[b] *Ulsan National Institute of Science and Technology, UNIST-Gil 50, Eonyang-eup, Ulju-Gun 689-798, Republic of Korea*

[c] *Nonproliferation System Development Division, Korea Atomic Energy Research Institute (KAERI), Daedeok-Daero 989-111, Yuseong-Gu, Daejeon 305-353, Republic of Korea*

A R T I C L E I N F O

Article history:
Received 29 July 2015
Received in revised form
7 July 2016
Accepted 8 July 2016
Available online xxx

Keywords:
Equilibrium Model
Multicriteria Decision Making
Nuclear Fuel Cycle

A B S T R A C T

The focus on the issues surrounding spent nuclear fuel and lifetime extension of old nuclear power plants continues to grow nowadays. A transparent decision-making process to identify the best suitable nuclear fuel cycle (NFC) is considered to be the key task in the current situation. Through this study, an attempt is made to develop an equilibrium model for the NFC to calculate the material flows based on 1 TWh of electricity production, and to perform integrated multicriteria decision-making method analyses via the analytic hierarchy process technique for order of preference by similarity to ideal solution, preference ranking organization method for enrichment evaluation, and multiattribute utility theory methods. This comparative study is aimed at screening and ranking the three selected NFC options against five aspects: sustainability, environmental friendliness, economics, proliferation resistance, and technical feasibility. The selected fuel cycle options include pressurized water reactor (PWR) once-through cycle, PWR mixed oxide cycle, or pyroprocessing sodium-cooled fast reactor cycle. A sensitivity analysis was performed to prove the

* *Corresponding author.*
E-mail address: saerom88@kaeri.re.kr (S. Yoon).
http://dx.doi.org/10.1016/j.net.2016.07.009

Pressurized Water Reactor Pyro-processing Sodium-Cooled Fast Reactor
Sustainability

robustness of the results and explore the influence of criteria on the obtained ranking. As a result of the comparative analysis, the pyroprocessing sodium-cooled fast reactor cycle is determined to be the most competitive option among the NFC scenarios.

1. Introduction

Although nuclear power is considered to be a stable source of electricity with low carbon emissions, the public continually raises several critical questions about the sustainability of nuclear power. These serious contentions include multiple interconnected issues on efficiently using uranium resources, securing an environmentally friendly way to handle waste, ensuring peaceful use of nuclear energy, maintaining economic competitiveness compared with other electricity sources, and assessing the technical feasibility of advanced nuclear energy systems. Prior to developing a national policy regarding future fuel cycles, many countries are seeking plausible answers to these controversial issues as they are subjected to public scrutiny.

In a number of different fields, many scholars have developed multicriteria decision-making (MCDM) methods to explicitly evaluate several alternatives and make more informed and better decisions [1]. The MCDM methods include the analytic hierarchy process (AHP) [2,3], preference ranking organization method for enrichment evaluation (PROMETHEE) [4–6], technique for order of preference by similarity to ideal solution (TOPSIS) [7], and multiattribute utility theory (MAUT) [8]. Among these, MAUT has been applied to the widest range of decision-making problems in nuclear energy programs such as disposal site selection of nuclear wastes [9–11], nuclear emergency management [12,13], disposal of weapon-grade Pu [14,15], and decommissioning of nuclear reactors [16].

However, there are many shortcomings caused by the use of a single particular MCDM method. The results of a single method do not provide sufficient evidence to support policy decision making. The current research trend of MCDM is thus to combine two or more methods as part of an effort to compensate for the weakness caused by biased method usage. As a comparative study combining various MCDM methods with respect to nuclear fuel cycle (NFC) analysis has rarely been reported, such a study is expected to offer meaningful results converging to the optimal future fuel cycle.

This study selected three NFC options and evaluated them against five different criteria, which were broken down into 10 subcriteria: sustainability (natural uranium requirements), environmental friendliness [spent fuels, minor actinides, high-level waste (HLW) to be disposed of, and underground excavation volume], proliferation resistance (material composition of spent nuclear fuel and Pu inventory), economics (electricity generation costs), and technical feasibility (technology readiness level and licensing difficulty level) [17]. The fuel cycle options include the once-through cycle using a pressurized water reactor (PWR), the PWR mixed oxide (PWR-MOX) cycle, and the sodium-cooled fast reactor and pyroprocessing (PWR Pyro-SFR) cycle. This study has attempted to analyze three fuel cycle options using TOPSIS, PROMETHEE, and MAUT combined with AHP [18]. Although data uncertainties are still involved, this analysis allows us to produce a systematic evaluation of the options with multiple criteria.

2. Materials and methods

2.1. *Reference fuel cycle model and data: three scenarios*

We selected three fuel cycle options that would likely be adopted by the Korean government considering the current situation of nuclear power generation: the once-through cycle, the PWR-MOX cycle, and the PWR Pyro-SFR cycle. These options are differentiated in terms of treatment of spent nuclear fuels from PWRs as either dirty wastes or useful resources. Fig. 1 shows the simplified material flow between reactors and key fuel cycle facilities in the backend fuel cycle.

The same sets of data were used across these fuel cycle options. In the three fuel cycle options, there are two different types of reactors—PWR and SFR. Table 1 includes technical parameters of the two reactors required to analyze material flow. The data were adopted from commercial plants for PWR and prototype designs for SFR. As all fuel cycle options begin with the same steps, most processes in the frontend fuel cycle (i.e., mining, milling, conversion, and enrichment) are commonly applicable to all options. By contrast, each option has its own processes in the backend fuel cycle. Table 2 contains the performance data of the fuel cycle processes in the three fuel cycle options. In addition, the actinide compositions of spent nuclear fuels for each reactor are summarized in Table 3.

PWR spent fuels are directly transported to a repository in the once-through cycle. In the PWR-MOX cycle, U and Pu from PWR spent UO_2 fuels are recovered and then reused in MOX PWRs. In the PWR Pyro-SFR cycle, molten-salt pyroprocessing facilities fabricate fast reactor fuels from recovered U and transuranic elements (TRUs) from PWR spent fuels. For a fair comparison, all these options are assumed to produce the same amount of electricity, a total of 1 TWh, at the equilibrium state.

2.2. *Equilibrium fuel cycle model*

This study mainly concentrates on using the equilibrium model to calculate the material flows based on 1 TWh of electricity from the current status to the advanced system in the long term.

Please cite this article in press as: S. Yoon et al., An Integrated Multicriteria Decision-making Approach for Evaluating Nuclear Fuel Cycle Systems for Long-term Sustainability on the Basis of an Equilibrium Model: Technique for..., Nuclear Engineering and Technology (2016), http://dx.doi.org/10.1016/j.net.2016.07.009