http://dx.doi.org/10.5516/NET.06.2013.049

# A STATISTICAL APPROACH FOR DERIVING KEY NFC EVALUATION CRITERIA

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*Received June 12, 2013*
*Accepted for Publication September 11, 2013*

This study suggests 5 evaluation criteria (safety and technology, environmental impact, economic feasibility, social factors, and institutional factors) and 24 evaluation indicators for a NFC (nuclear fuel cycle) derived using factor analysis.

To do so, a survey using 1 on 1 interview was given to nuclear energy experts and local residents who live near nuclear power plants. In addition, by conducting a factor analysis, homogeneous evaluation indicators were grouped with the same evaluation criteria, and unnecessary evaluation criteria and evaluation indicators were dropped out.

As a result of analyzing the weight of evaluation criteria with the sample of nuclear power experts and the general public, both sides recognized safety as the most important evaluation criterion, and the social factors such as public acceptance appeared to be ranked as more important evaluation criteria by the nuclear energy experts than the general public.

KEYWORDS : Nuclear Fuel Cycle, Evaluation Criteria, Evaluation Indicator, Factor Analysis, Screening Factor, Factor Score, Descriptive Statistics, Nuclear Safety

## 1. INTRODUCTION

Recently, due to the influence of the accident at the nuclear power plant in Fukushima Japan, countries have become more divided in their preferences regarding nuclear power.

While the countries that prefer the development of nuclear power technology stress the role of nuclear power, the countries that do not prefer nuclear power claim that the development of nuclear power technology should be reconsidered due to concerns about the safety of nuclear power plants and the problem of spent fuel.

The problem of the treatment and disposal of spent fuel becomes an important factor that determines the sustainability of nuclear power [1]. An advanced nuclear fuel cycle such as pyroprocessing, which can reduce the amount of spent fuel, is recognized as a promising technology [2]. However, to develop such an advanced nuclear fuel cycle, it is necessary to first evaluate the technological and economic validity, and to do so, objective evaluation criteria and evaluation indicators are necessary [3].

The purpose of analyzing diverse nuclear fuel cycles is to select the optimum nuclear fuel cycle suitable for the environment of one's own country, and to maintain nuclear power sustainability [4]. Accordingly, since the nuclear fuel cycle should be evaluated with regard to various factors such as politics, the economy, and society, diverse evaluation criteria and evaluation indicators are necessary [5].

An evaluation of the nuclear fuel cycle is conducted from the selection of various evaluation criteria. Intuitively, safety (technological features), economic feasibility, environmental features, and nuclear non-proliferation can be used as evaluation criteria [6], and such individual evaluation criteria can be explained with various evaluation indicators [7].

However, if too many evaluation indicators are included in one evaluation criterion, the evaluation is not easy, and if too few evaluation indicators are established, the evaluation criteria cannot be explained sufficiently, and thus the evaluation can be distorted [8]. Accordingly, not only should the evaluation indicators be composed of an appropriate number of units, but they should also not overlap. Ambiguous evaluation indicators should be dropped out and necessary evaluation indicators must be included [9].

For example, the securement of land for a high-level radioactive waste (HLW) repository is an important matter that advanced nuclear power nations and the international communities are concerned about. It is difficult for the government to independently determine a reasonable policy, and there is likely to be social conflict because of NIMBYism against nuclear power by the residents of the country. Accordingly, evaluation indicators such as public acceptance should be necessarily considered.

Another example, since pyroprocessing extracts plutonium together with neptunium and curium, is the difficulty in separating only plutonium, and thus proliferation resistance is large. In addition, high level waste (HLW) materials with a long half-life such as plutonium (Pu), neptunium (Np), and curium (Cm) are mostly recycled as the raw material of Sodium-cooled fast reactor (SFR) nuclear fuel, and only the nuclides of short half-life like Cesium (Cs) and strontium (Sr) remain, which can largely reduce the scale of an HLW repository. Accordingly, when evaluating the pyroprocessing nuclear fuel cycle, the proliferation resistance can be an important evaluation indicator [10]. The aim of this study is to suggest the key evaluation criteria and evaluation indicators derived using a factor analysis.

## 2. SURVEY OF PRECEDING STUDIES

Since the 1990s, countries with advanced nuclear energy programs have derived various evaluation criteria and evaluation indicators to analyze diverse nuclear fuel cycles, such as public acceptance, eco-friendliness, and safety. Recently, nuclear energy research institutions have been developing screening methods and factor analysis, which is a statistical method to derive reasonable evaluation criteria. For instance, in 2012, ANL (Argonne National Laboratory) hosted a seminar, and derived 9 high-level evaluation criteria (① nuclear waste management, ② nuclear proliferation risk, ③ nuclear material security risk, ④ safety, ⑤ financial risk and economics, ⑥ environmental impact, ⑦ resource utilization, ⑧ development and deployment risk, and ⑨ institutional issues) [11].

In addition, in 2012, OECD/NEA collected the opinions of experts from countries with advanced nuclear power programs, and derived 2 general upper level evaluation criteria (① government and public acceptance, ② technological features and economic feasibility) and detailed evaluation criteria. The detailed evaluation criteria of the government and public acceptance criterion include the security of energy supplies, non-proliferation, public acceptance, environmental effects, waste management, transport, and legal and regulatory aspects. The technical and economic evaluation criteria include the development of fast reactors and fuel cycles, technological challenges and industrial acceptability for different systems, retrievability of waste, safety aspects, costs, and economic development [12].

In addition, INPRO (International Project on Innovative Nuclear Reactors and Fuel Cycles) chose a total of 7 evaluation criteria (① economic feasibility, ② infrastructure, ③ waste management, ④ proliferation resistance, ⑤ physical protection, ⑥ safety, ⑦ environment) to evaluate the sustainability of nuclear energy. In 1999, the IAEA derived the evaluation criteria of sociality, economic feasibility, and the environment, and GEN IV chose the evaluation criteria of sustainability, safety and reliability, and economic feasibility [2].

After reviewing the evaluation criteria of foreign countries, it appears that they mostly chose similar evaluation criteria.

The evaluation criteria chosen in common were determined to be safety, sociality, economic feasibility, and environmental impact. Such evaluation criteria have been recognized as important items to be considered when evaluating the alternatives to the nuclear fuel cycle since the latter half of the 1990s.

## 3. DEFINITION AND PROPERTIES OF EVALUATION INDICATORS

Evaluation indicators can be largely classified into three categories: ad hoc indicators, indicators based on data, and composite indicators. Ad hoc indicators are indicators temporarily made when the government needs to justify a policy. Indicators based on data are indicators developed through factor analysis, and composite indicators are indicators that mix various items. The indicators that evaluators are greatly interested in are indicators based on data [13].

The factors that influence the choice of evaluation indicators are the level and the feasibility of the measurement. The feasibility is the possibility of collecting data required for analysis.

In other words, the measurement level is the problem of choosing the yardstick for the measurement indicators. The yardstick which corresponds to the characteristics of the concerned indicator should be a nominal scale, ordinal scale, interval scale, or ratio scale [14].

In addition, the basic elements of the evaluation indicators are the definition of the indicator, the weight, and the rating interval. The weight means the evaluation weight of each indicator when putting the scores together, and the rating interval means the expression of the rating to the extent of the evaluation [15].

## 4. THE METHOD OF SCREENING EVALUATION CRITERIA

The evaluation criteria list is generally first made by using the usual procedure, as shown in Fig. 1, and reasonable evaluation criteria and evaluation indicators are chosen through a factor analysis with this list [16].

The methods used to derive evaluation indicators are largely of three kinds: a literature investigation to find indicators which have already been developed, a top-down method in which expert opinion is used to construct the list, and a bottom-up method using the list of evaluation indicators derived in preceding studies.

In this paper, the third method was used, and factor analysis was used to group evaluation indicators which have homogeneous characteristics with the same evaluation criteria [17].