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Trade-off Analysis of Nuclear Fuel Cycle

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1. Previous Fuel Cycle Analysis Studies

There have been various studies comparing different alternatives of nuclear fuel cycle system using mass-flow model. Using the unit cost data of each stage of nuclear fuel cycle, the economics of fuel cycle could be derived. Previous studies [1-4] used similar logics to calculate levelized unit electricity cost (LUEC) based on the unit cost data and expected future electricity generation data. The model is mainly used to compare different nuclear fuel cycle options. For Korea's case, majority of models tried to compare once-through cycle (OT) and pyroprocessing-sodium cooled reactor (Pyro-SFR) cycle, which is the most probable option Korea can select. Models were expanded to analyze other criteria for comparing various fuel cycle options. For example, Li et al [4,5] calculated proliferation resistance based on fuzzy logic method which was suggested by TOPS (2000) in their model. Waste management strategy was also analyzed by various studies. The amount of low and intermediate level waste (LILW), spent nuclear fuel (SNF), high level waste (HLW) from reprocessing, was commonly calculated. Some studies calculated the required volume of repository to manage the waste, based on the data of accumulated dose and generated heat. The characteristics of spent fuel were derived from ORIGEN calculations, and the assumed process efficiency (removal efficiency) of pyroprocessing. Uranium utilization factor was also calculated in previous studies to evaluate the energy security criteria.

Some criteria could not be derived based on mass-flow model. For example, the possibility of technology development and public acceptance is hard to be related with the mass-flow data. Previous studies used analytic hierarchy process (AHP) and multi-criteria decision making (MCDM) methods to derive final decision for selecting fuel cycle, since there does not exist a unique solution, nor to give weight for the criteria.

This makes fuel cycle evaluation process more qualitative and decreases objectivity. This is why uncertainty management is important in fuel cycle comparison.

2. Uncertainties of Fuel Cycle Comparison

Previous studies tried to manage uncertainty in various ways. First, the uncertainty of weight derived from MCDM methods were analyzed in systematic ways, such as fuzzy logic. It could assist decision-making process via considering various types of people who has different opinion on selecting fuel cycles. However, there are two major sources of uncertainties, which were originated from the risk of technology development process in the future. The first source of uncertainty is the uncertainty related to the amount of projected electricity generation, the expected time new technology development, installed capacity of new pyroprocessing facility and/or repository, etc. This could be considered using dynamic mass-flow model. There have been several studies tried to optimize the fuel cycle using linear programming, but it could not consider several criteria which is not based on the mass-flow model. The second source of uncertainty is the risk of technology development related to pyroprocessing, sodium-cooled reactor (SFR) and repository. Since the technology is still being developed, characteristics of the process can be changed, which means there exists an uncertainty of cost, safety, proliferation resistance, technology readiness, etc.

This study tries to consider the risk of technology development in fuel cycle analysis. We focused on the second type of uncertainty, which is based on the scenarios of expected challenges in newly developed technologies. Each event affects various criteria, which can change the final decision of fuel cycle option.

2.1 Risk of Technology Development

When comparing OT cycle and Pyro-SFR cycle, the main difference comes from pyroprocessing, SFR and repository. Pyroprocessing technology affects the characteristics of HLW and proliferation resistance. The alternative options of additional process have trade-off with cost and safety. Table I summarizes several technology development options which have considerable effect on evaluating Pyro-SFR cycle against OT cycle.

Table I: Pyroprocessing Technology Development Options

Technology development scenario	Implications
Management strategy of Tc-99 and I-129	SFR fuel characteristics Repository management time Repository cost
Management of Cs/Sr	Repository management time Repository cost
Separation efficiency of U, TRU, RE	SFR fuel characteristics Proliferation resistance Need of additional processes Repository cost
Influence of safeguards equipments	Proliferation resistance Need of additional processes

Tc-99 and I-129 are two significant components in pyroprocessing waste due to high fission yield and long half-life. Their management strategy and removal efficiency will affect SFR fuel characteristics, repository management time and cost, which means the viability of technology criteria will be affected.

Cs and Sr are planned to be treated as gaseous waste form in pyroprocessing. Management strategy and technology development status of them will also affect the characteristics of repository. For example, the additional process to treat Tc, I, Cs and Sr will increase the cost of pyroprocessing, but it can reduce the cost of repository. However, it is hard to quantify the uncertainty of them since the viability of the technology is not known at this moment.

Separation efficiency of U, TRU, RE is the most important variable in pyroprocessing technology development. It affects not only SFR fuel and repository characteristics but also the need of additional processes and proliferation resistance.

The safeguards system affects the operation in direct way. It could increase the proliferation resistance, but the cost and process efficiency will get disadvantages.

In addition to these, public acceptance and safety, which is hard to be measured in quantitative way, would be dependent on the technology development.

These scenarios affect not only the characteristics of pyroprocessing itself, but also SFR and repository. However, the proliferation resistance and public acceptance of whole fuel cycle are less dependent for the risk if technology development, since it does not change the characteristics of spent fuel. It means that the criteria except the total cost mainly depend on the risk of pyroprocessing technology development status. The risk related to SFR and repository could be limited to the cost and time factors. Although SFR and repository also has large uncertainty in its estimated cost, it can be dealt with the cost uncertainty analysis, which has been considered in previous studies.

3. Conclusions

This study analyzed current status of fuel cycle analysis and the need for trade-off analysis, especially related to pyroprocessing technology development. The trade-off of pyroprocessing should be characterized and integrated into the mass-flow model to assess the most appropriate fuel cycle in Korea. To do this, part of the process model should be integrated into mass-flow model to make quantitative trade-off relationship.

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