# Dynamical Nuclear Waste Assessment Using the Information Feedback Oriented Algorithm Applicable to the Internet of Things(IoT)

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# 사물 인터넷 (IoT)에 적용할 수 있는 정보 피드백 지향 알고리즘을 사용한 동적 핵폐기물 평가

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**Abstract** Following the advanced fuel cycle initiative (AFCI) promotions in the United States, the analytic proposition for global fuel cycle initiative (GFCI) has been investigated using dynamical simulations. The political and economic aspects are considered simultaneously due to the particular characteristics of the nuclear materials. The spent nuclear fuels (SNFs) are treated as the reprocessing by the nuclear non-proliferation treaty (NPT) exemption nations and the NPT excluded nations. Otherwise, the pyroprocessing and repository can be done without NPT restriction. In addition, the international trade is considered as the economic aspect where the energy production is a key issue of the GFCI. The dynamical simulations have been done until 2050. The result of the International Trade shows the gradually increasing shape. Additionally, the Nuclear Power Plant Operation shows the increasing by stepwise shape.

**Key Words :** Nuclear Energy, Waste, Spent nuclear fuel (SNF), Pyroprocessing

**요 약** 미국의 고급 연료 사이클 이니셔티브 (AFCI) 추진에 이어, 동적 연료 시뮬레이션을 사용하여 글로벌 연료 사이클 이니셔티브 (GFCI)에 대한 분석 제안이 조사되었다. 정치적, 경제적 측면은 핵물질의 특정 특성으로 인해 동시에 고려된다. 미국의 고급 연료 사이클 이니셔티브 (AFCI) 추진에 이어, 동적 연료 시뮬레이션을 사용하여 글로벌 연료 사이클 이니셔티브 (GFCI)에 대한 분석 제안이 조사되었다. 정치적, 경제적 측면은 핵물질의 특정 특성으로 인해 동시에 고려된다. 사용된 핵연료의 미국의 고급 연료 사이클 이니셔티브 (AFCI) 추진에 이어, 동적 연료 시뮬레이션을 사용하여 글로벌 연료 사이클 이니셔티브 (GFCI)에 대한 분석 제안이 조사되었다. 정치적, 경제적 측면은 핵 물질의 특정 특성으로 인해 동시에 고려된다. 사용된 핵연료 (SNF)는 핵 확산 금지 조약 (NPT) 면제 국가와 NPT 제외 국가에 의해 재처리로 처리된다. 그렇지 않으면, 열처리 및 저장소는 NPT 제한 없이 수행 될 수 있다. 또한 국제 무역은 에너지 생산이 GFCI의 주요 이슈인 경제적 측면으로 간주된다. 동적인 시뮬레이션은 2050 년까지 이루어졌다. 국제 무역의 결과는 점차적으로 증가하는 모습을 보여준다. 또한 원자력 발전소 운영은 단계적으로 증가하고 있음을 보여준다.

**주제어 :** 원자력, 폐기물, 폐핵연료 (SNF), 파이로프로세싱

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## 1. Introduction

The dynamical simulations are performed for the global nuclear energy partnership (GNEP) as the peaceful and economically sustainable nuclear energy with the energy promotion policies [1]. The nuclear non-nuclear proliferation treaty (NPT) is a restriction of the new policy in the aspect of the international political matter of which nations are listed in 〈Table 1〉 [2,3]. Pyroprocessing is proposed for avoiding the NPT restriction of the nuclear development by the NPT treated countries.

The pyroprocesing is explained in the basics of the spent technology [4]. There is the electrorefining procedure which has a key to pyrochemical recycling of used spent nuclear fuel (SNF). The process removes the waste fission products from the uranium and other actinides elements in the used fuel. The unfissioned uranium and actinides are then recycled to fast reactors. By electrorefining, the used fuel attached to an anode is suspended in a chemical bath. The electric current then dissolves the used fuel and plates out the uranium and other actinides on the cathode. These extracted elements are then sent to the cathode processor where the residual salt from the refining process is removed. Finally, the remaining actinides and uranium are cast into fresh fuel rods and the salt is recycled back into the electrorefiner.

〈Table 1〉 Classification of nuclear waste [2,3]

| Year | Content |
|---|---|
| Reporcessing | Belgium, China, Germany, France, UK, Italy, India, Japan, Pakistan, Russia, USA |
| Pyroprocessing | Global nuclear energy partnership (GNEP) based as Australia, Bulgaria, China, France, Ghana, Hungary, Japan, Jordan, Kazakhstan, Lithuania, Poland, Romania, Russia, Slovenia, Ukraine, United States, and additional 9 nations as Armenia, Canada, Estonia, Italy, Republic of Korea (South Korea), Morocco, Oman, Senegal, United Kingdom |

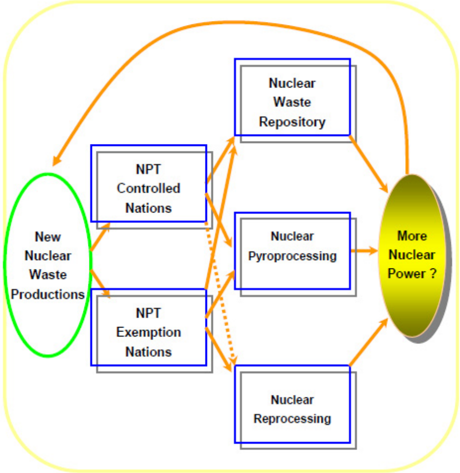
Otherwise, the nuclear reprocessing can treat the SNF for the fast reactor fuel. Used nuclear fuel has long been reprocessed to extract fissile materials for recycling and to reduce the volume of high-level wastes [5]. New reprocessing technologies are being developed to be deployed in conjunction with fast neutron reactors which will burn all long-lived actinides. Currently, all commercial reprocessing plants use the well-proven hydrometallurgical PUREX (plutonium uranium extraction) process where the work involves dissolving the fuel elements in concentrated nitric acid. Chemical separation of uranium and plutonium is then undertaken by solvent extraction steps. The Pu and U can be returned to the input side of the fuel cycle – the uranium to the conversion plant prior to re-enrichment and the plutonium straight to mixed oxide (MOX) fuel fabrication.

The eternal option for SNF is to treat by the nuclear repository. This geological processing has been done in many nations. At present, there is clear and unequivocal understanding that each country is ethically and legally responsible for its own wastes. Therefore, the default position is that all nuclear wastes will be disposed in each of the 40 or so countries concerned [6].The main ingredients of high-level nuclear wastes are created in the nuclear reactors which make the electricity in 31 countries. There is thus no moral obligation on uranium suppliers in respect to the wastes, other than that involved in safeguards procedures.

The nuclear energy consumptions are related to the national economic growth [7]. This article attempts to test the causal relationship between nuclear energy consumption and real GDP for nine developed countries during the period 1971-2005 by including capital and labor as additional variables. Using a modified version of the Granger causality test developed by Toda and Yamamoto [8], they found a unidirectional causality running from nuclear energy consumption to economic growth in Japan, Netherlands and Switzerland; the opposite unidirectional causality running from economic growth to nuclear energy consumption in Canada and Sweden; and a bi-directional causality running between economic growth and nuclear energy consumption in France, Spain, the United Kingdom and the United States.

The main modeling of this paper is to make dynamical simulations in the interested matter. The economic and political issues of the SNF are focused in the study. The re-use of the nuclear waste can increase the energy production capability due to the characteristics of the nuclear stuff. However, the nuclear energy could produce the nuclear bomb. So, the control of the nuclear material is to make the international consents by the proliferation preventions. This work shows the economic consideration is mainly examined with the SNF treatment in the international trade where the nuclear bomb possibility should be reduced.

The previous investigations for the dynamical simulation have been done for the importance of the economic aspect [9-12]. The major focusing point of the study is the economic factor which is related to the electricity generations using the nuclear fuels. The dynamical simulations were quantified by the type of the nuclear fuels [9]. Hence, the higher efficient fuel can change the transient situations of the values. The new kind of fuel type, pyroprocessing, is significantly changed from the reprocessing in the nuclear power plants (NPPs). The high-level nuclear fuel waste decision tree in the United States is modified for this study which is in the [Fig. 1] [9]. There are no regulations for any policy of the waste beyond 63,000 MT in the nation. The repository is dominated by the long-term heat (Pu and Am) and possibly by long-term dose (Np, Pu, Am, and others) [9].




[Fig. 1] Modeling of nuclear fuel dynamics

The system dynamics (SD) simulations are constructed for the dynamical quantification of the nuclear fuel cycle. Especially, the high-level nuclear waste (HLW) material is focused. SD was created by Dr. J. Forrester in Massachusetts Institute of Technology (MIT) for the quantifications of the systematic situations, in which related algorithms has been used for the non-linear characteristics of the social and economic system. There are SD tests and models of the complex features in the dynamical scenarios of the interested matters. There are several SD applications for the organizations by the transitions of the time [13-14]. Additionally, there are some decision-making related papers [15-17]. The dynamic simulation method is introduced using the SD where some computer packages as the Vensim [18], PowerSim [19], and ITHINK [20] have been applied for the quantifications. In this study, the Vensim PLE for window version is used for the simulations. SD is considered an appropriate approach for predicting the dynamic results of the interactions and analyzing the implications of different policies given such complexities, as proposed by Forrester [21]. The construction of causal loop diagrams and stock and flow diagrams is necessary to form an SD context for applications.

There are some papers in the nuclear material matters. Thomas studied the J-value method enabled health and safety schemes aimed at preserving or extending life to be assessed on a common, objective basis for the first time, irrespective of industrial sector [22]. Jones worked that the improvements in nuclear safety were often achieved through introducing a new safety measure that reduced the frequency of a hazardous accident rather than its consequences [23]. In addition, the Yucca mountain paper was published by Malone [24] where a number of important and unresolved issues had arisen with respect to the geologic and hydrologic suitability of Yucca Mountain for isolating nuclear wastes. Albrecht showed the biosphere dose conversion factors were computed for the French high-level geological waste disposal concept and illustrated for the combined probabilistic and deterministic approach [25].

## 2. Background

The SD is a computer-aided approach to policy analysis and design [26]. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems. That is, this is literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality.

This field had been developed initially by the work of Jay W. Forrester. The seminal book as Industrial Dynamics [13] is still a significant statement of philosophy and methodology in the field [26]. The ranges of applications expanded from corporate and industrial problems to include the management of research and development, urban stagnation and decay, commodity cycles, and the dynamics of growth in a finite world during ten years of its publication. Subsequently, it has applied to economics, public policy, defense, social science, environmental studies and other areas, as well as its home field, management. The name industrial dynamics no longer does justify to the breadth of the field, so it has become generalized to SD. The modern name suggests links to other systems methodologies, but the links are weak and misleading. SD emerges out of servomechanisms engineering, not general systems theory or cybernetics [27].

There are several approaches by SD as follows [26];

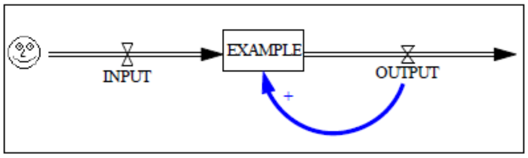
- ◆ Dynamical defining problems in terms of graphs over time
- ◆ Striving for an endogenous, behavioral view of the significant dynamics of a system, a focus inward on the characteristics of a system
- ◆ Thinking of all concepts in the real system as continuous quantities by loops of feedback causality
- ◆ Identifying independent stocks or accumulations in the system with flows
- ◆ Dynamical formulating a behavioral model
- ◆ The computer simulation model in nonlinear equations with a diagram capturing the stock-and-flow/causal feedback structure of the system
- ◆ Model derived understandings and applicable policy insights

◆ Model based understandings and insights applicable to the internet of things (IoT)

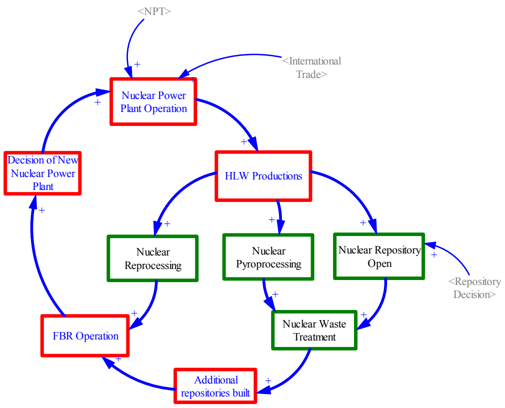
Generally, several characteristics of the SD are shown [28] as Nonlinearity, Stock-flow, feedback, and time path where EXAMPLE for accumulation and INPUT/PUTPUT for flows are in [Fig. 2] with feedback.

## 3. Methods

The modeling for GFCI is shown in the [Fig. 3]. The Nuclear Power Plant Operation is the start point for the simulations. This dynamical modeling is done from 2012 to 2050. The main loop flows to 3 cases in HLW Productions to Nuclear Reprocessing, Nuclear Pyroprocessing, and Nuclear Repository Open. Since the Nuclear Reprocessing is done to NPT exemptions nations and some permitted or politically restricted countries. Otherwise, the other two cases are open to all nations.



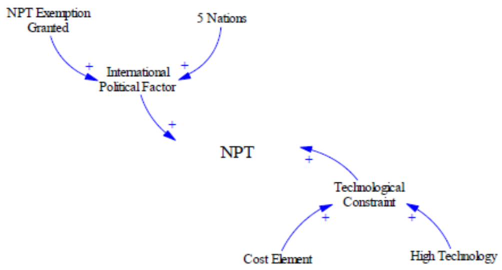

[Fig. 2] Stock-flow and Feedback



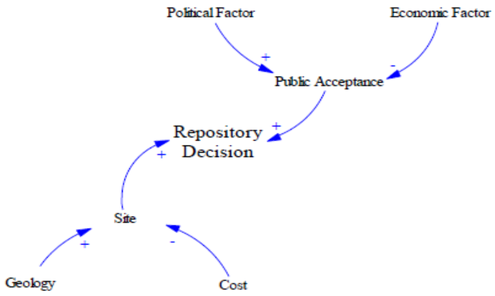

[Fig. 3] Dynamic simulator for GFCI

[Fig. 4] is the NPT modeling where the NPT is analyzed by International Political Factor and Technological Constraint. The NPT exempted 5 nations are the USA, Russia, China, France, and UK. The NPT Exemption Granted means the Belgium, Italy, India, Japan, and Pakistan are categorized by reprocessing nations by the political circumstances.

[Fig. 5] shows the Repository Decision where the social-economic factors are concerned. Especially, the site selection is extremely difficult task. The HLW repository should guarantee several hundreds of thousands of years. ⟨Table 2⟩ is the values of the HLW productions. In the Nuclear Reprocessing, the weighting is 0.1.




[Fig. 4] Modeling for NPT

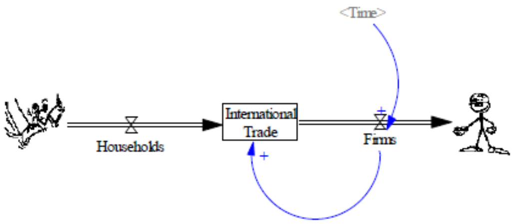



[Fig. 5] Modeling for Repository Decision

⟨Table 2⟩ Values of HLW productions

| Classification | Content |
| --- | --- |
| Nuclear Reprocessing | HLW Productions*0.1 |
| Nuclear Pyroprocessing | HLW Productions |
| Nuclear Repository Open | HLW Productions*Repository Decision |

[Fig. 6] is the modeling of International Trade where the Firm and Households are modified by circular flow in an open economy [29], in which the flow describes originally the flow of goods and services/expenditures and receipts in an open economy with three sectors – households, firms and the international sector. Each economic transaction that involves an exchange of goods or services must be matched by a corresponding flow of expenditures and receipt of payment. The modification of the modeling shows the adaptations to the nuclear energy market. This modeling is the relationship between the domestic and global economic factors. The quantification values are shown in 〈Table 3〉. In the case of time 2020, if the generated random number is lower than 0.3, the value is 0. Otherwise it is 1. The other cases are obtained in similar ways.



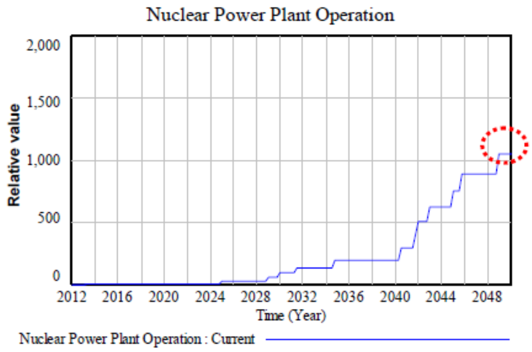

[Fig. 6] Modeling of International Trade

〈Table 3〉 Degree of the Firms in International Trade

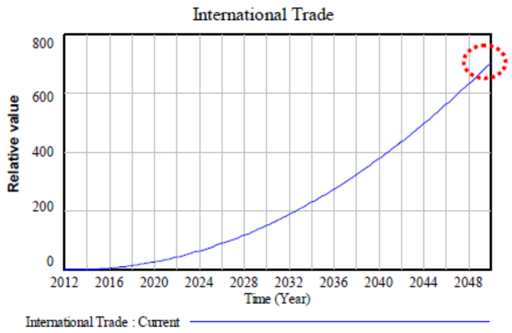
| Time | Content |
|---|---|
| ~ 2020 | if random number < 0.3, then 0, else 1 |
| ~ 2030 | if random number < 0.5, then 0, else 1 |
| ~ 2050 | if random number < 0.8, then 0, else 1 |

## 4. Results

[Fig. 7] means the relative values are increasing gradually. The values of *Y*-axis are the relative value with no dimension. So, the importance of the factor can be estimated by the comparative values. The lowest value is 1.0 in 2012 and the highest value is 705.004 in 2050. There is the Simulation of Nuclear Power Plant Operation in [Fig. 8]. The graphs show the stepwise increasing where the lowest value is 0.0 until 2013 and the highest value is 1,050.46 in 2050. That is to say, the value increases about 1,050 times higher than the initial value. This means the successful GFCI would be accomplished as the 1,050 times possibilities. So, this value is different from the probability values which are usually use for the exceptions of the social-economic matters. This quantity is compared easily with other possible conditioned simulations. Finally, Nuclear Power Plant in [Fig. 8] is 1.48 times higher than that of International Trade in [Fig. 7].




[Fig. 7] Simulation of International Trade




[Fig. 8] Simulation of Nuclear Power Plant Operation

## 5. Conclusions

The dynamical modeling has been performed for the SNF treatment. The economic factor as well as the political factor is important due to the characteristics of the nuclear materials. NPT is a key issue to develop the SNF. There are 3 kinds of the processes where the reprocessing, pyroprecessing and geological disposal of the SNF. The inferential trade is a critical factor energy production of nuclear energy. There are some points of the significances of the study.

- Economic and political matters are considered for SNF treatment simultaneously.
- The global scope modeling is simulated.
- Dynamical study shows the variation changeable results.
- The simulation of the study is done until 2050.
- Fast reactor is proposed for the final reactor type.

For the future work, it is necessary to social matters like the public acceptances (PA). This is very critical matter in the selections of the nuclear repository. The PA is increasing the significance in constructing the national scale facility, which is deeply related to general social safety [30]. Especially, the nuclear waste repository selection provokes the national concerns. The research of the PA should be done in the aspect of the governmental level. After, the R&D of PA, the generalized research is accomplished by the economic, political, and social applications.

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