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Application of Environmental Management Tool to Nuclear Energy Policy related with Environmental Issues

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Abstract

Energy policy is addressing environmental issues and energy conservation has come to be regarded as an important element of environmental policy. According to current situation, concern for environmental preservation has increased the demand for more efficient management and environmentally sound and sustainable development of nuclear energy. Also International Standardization Organization (ISO) has been in the standardization of the detail methodologies of environmental management tool in ISO 14041 – 44 series. In accordance with this movement, Life Cycle Assessment (LCA) has received much attention in industries and decision makers. Therefore, this study explained the international trend of environmental management system and validated the application of LCA to nuclear energy system and radioactive waste management. Also the controversial issues when LCA was directly applied to nuclear industries was pointed out and suggested the new concept to improve the methodologies for the calculation of radiological impact within the LCA framework. Finally, as a preliminary result, LCA of once-through fuel cycle were studied using suggested methodologies. This result could be used as the source materials for the further development of comparative assessment of nuclear and non-nuclear energy as well as decision-making of back-end fuel cycle alternatives.

1. Introduction

1.1 What is LCA?

ISO (International Standardization Organization) and SETAC (Society of Environmental Toxicology and Chemistry) defines LCA(Life Cycle Assessment) as "cradle-to-grave" approach to evaluate and quantify the environmental burdens associated with a product, process, or service at all stages of its life cycle by identifying energy and materials used and wastes released to the environment. Also LCA methodology could include environmental management system, waste reduction schemes and environmental analysis methods. So, This methodology is useful to compare the environmental impacts of different products with the same function or one product with a standard.

The major objectives of LCA are to identify the environmental impact and the environmentally most dominant stage in life cycle of a product, process, or service. LCA consists of general framework of goal and scope, inventory analysis, impact assessment, valuation, and improvement analysis. Step of goal and scope is for the defining the target system and system boundary to be assessed for the calculating the functional unit of system. Inventory analysis means the collection of data related with the input and output materials of system. And impact assessment is subdivided into classification and characterization. It is not, however, distinguished between these two and only talks about classification generally. Classification stage ends up with a list up to ten figures instead of hundreds of specific emissions. It is recommended that the lists of the most common substances be used initially.

In the impact assessment step, environmental impacts of emitted substances (*j)* are classified into about ten environmental impact categories (*i)* then quantitative Environmental Impacts (EI_i) by each environmental category are calculated by multiplying the quantity of emitted substance by the relevant classification factor for that substance as given in equation (1).

$$EI_i = \sum_j Emission_j \times Classification \quad Factor_{i,j} \tag{1}$$

Thus, the environmental impact is characterized by no more than ten values of EI_i instead of hundreds of specific emissions. The list of most common substances and their classification factors in various environmental categories except radionuclides are being developed by foreign organization. Classification factors and references relating to impact categories were summarized in SETAC Final Report (1997) and these factors were generally used in the previous LCA study. The environmental impact categories with non-zero values, their definitions and data sources of classification factors used in this study are shown in Table 1.

Table 1. Environmental Impact Categories, Definitions and Data Sources of Classification Factors

Environmental Impact Categories (Unit)	Definition (Data Sources of Classification Factors)
GWP- Global Warming Potential (g CO_2-eq)	An increasing amount of CO_2 in the earth' s atmosphere leads to an increasing absorption of radiation energy and consequently to increase the temperature. Atmospheric emission can be converted to CO_2 emission in g with an equivalent green house effect. (Houghton J, Callander B, Varney S. Climate change 1992: the supplementary report to IPCC scientific assessment. Cambridge: Cambridge University Press, 1992.)
ACP- Acidification Potential (g SO_2-eq)	Acid depletion on soil and into water may lead to changes in the degree of acidity. Atmospheric emissions are converted to SO_2 in g. (Hauschild M, Wenzel H. Acidification as assessment criteria in the EDIP-method. London: Chapman & Hall, 1997.)
ODP- Ozone Depletion Potential (g CFC-eq)	Depletion of the ozone layer leads to an increase in the amount of UV light reaching the earth' s surface. Ozone depletion per unit mass of gas emitted to the atmosphere per year is calculated relative to that of a mass unit of CFC-11 in g (CFCl3 trichlorofluoromethane) (United Nations Environment Programme. International treaties for the protection of the ozone layer, 1997 upgrade handbook. Paris: UNEP, 1998.)
NP- Nutrification Potential (g PO_4-eq)	Addition of nutrients to water or soil will increase production of biomass. This in turn leads to a reduction the oxygen concentration, which affects higher organisms like fish. This is a measure of the capacity to form biomass to an equivalent PO_4 in g. (Lindfors L, Christansen K, Hoffman L, Vitanen Y, Juntilla V, Hanssen O, Ronning A, Ekvall T, Finnvenden G. Nordic life cycle assessment. Copenhagen: Nordic Council of Ministers, 1995.)
ADP- Abiotic Resource Depletion Potential (-)	Abiotic depletion concerns the extraction of non-renewable raw materials such as ores. (Heijungs R, Guinee J, Huppes G, Lankreijer M, Udo de Haes H, Sleeswijk A Environmental life cycle assessment of products. Netherlands: Center of Environmental Science. Leiden University, 1992.)
HCA or HCW Human Toxicity Air/Water (g)	Exposure of man to toxic substances causes health problems. Exposure can take place through air, water or soil especially via the food chain. The unit of this classification factor is g. (Heijungs R, Guinee J, Huppes G, Lankreijer M, Udo de Haes H, Sleeswijk A. Environmental life cycle assessment of products. Netherlands: Center of Environmental Science. Leiden University, 1992.)
ECA- Ecotoxicity Aquatic (m^3)	Exposure to toxic substances causes health problems. Ecotoxicity is defined for water in m^3. (Heijungs R, Guinee J, Huppes G, Lankreijer M, Udo de Haes H, Sleeswijk A. Environmental life cycle assessment of products. Netherlands: Center of Environmental Science. Leiden University, 1992.)

It is very difficult to interpret and compare the environmental impacts from different environmental categories quantitatively. Because the order of magnitude and units of the various environmental impacts differ from each other, normalization and weighting steps are proposed. Normalization Impact (NI_i) is calculated by dividing the EI_i by a normalization reference for a given environmental impact category (*i)* as given in equation (2) and this makes it possible to understand the relative proportion or magnitude for each impact category by reducing the environmental impacts to the dimensionless numbers.

$$NI_i = \frac{EI_i}{Normalization \quad reference_i} \tag{2}$$

Finally, Weighting Impact (WI_i) for an environmental impact category (*i)* is calculated by multiplying the NI_i by a relative significance factor (f_i,) as shown in equation (3). The aim of the weighting step after normalization is to reflect the relative significance of the different types of impacts. WI_i of un-dimensionally weighted value for all environmental categories are added up to single value. Therefore decision-maker could refer to the WI value which represents the quantitative environmental index of a product or service for the final decision of environmental friendliness of product or service.

$$WI_i = NI_i \times f_i \tag{3}$$

1.2 Necessity of LCA

During the late 1980s and early 1990s, the current public regulatory system may not support an optimal degree of regulation for providing the environmental information of product to public. By labeling and advertising products that extolled the environmental qualities of the product, marketers promoted their products. Also public would make an attempt to help the environment and would willing to pay higher prices for these products. So the information on how the product was derived and product was produced through which environmentally benign techniques should be open to public. This technique known as green labeling rapidly became an established part of marketplace. The eco-labeling was developed by ISO and the ISO 14000 series makes it a meaningful tool for efficient environmental stewardship. ISO 14000 is a series of standards and guidance document that falls into two broad categories. The first category is Environmental Management System (EMS). British Standard and the evolving European Communities' Eco-Management have significantly influenced these ISO 14000 EMS standards. And LCA is adopted as the most appropriate EMS tool in ISO 14000 series. The second category is focused in areas of product stewardship. Two standards are under development, one is governing methodology for LCA (ISO 14041 – 44) and the other is governing labeling principles (ISO 14020 – 24). Finally LCA is the term that is currently widely accepted for environmental assessments of products or services on cradle-to-grave basis and LCA can make a significant contribution in providing a scientific basis and would be required essentially for eco-labeling program. And for the following the trend of international environmental regulation, LCA should be studied and participants in LCA should take part in standardization of LCA methodology.

1.3. Necessity of Application of LCA to Electricity, especially to Nuclear

In accordance with progress in the standardization of methodologies in the ISO-14040s, LCA has received much attention in industries. Most industrial processes consume electricity. It is often found that electricity consumed during use of electrical appliances predominates in the total primary energy consumption and emissions of these products' life cycles. Thus, the results of inventories analyses of industrial products are usually sensitive to data on electricity. So, it is quite important for LCA practitioners to develop reliable life cycle inventories for electricity. However, only a few figures concerning emissions related to electricity have been reported.

Especially for nuclear energy, it is the major source of electricity generation in Korea due to the lack of domestic energy resources. In recent years, concern for environmental preservation has increased the demand for more efficient management and environmentally sound and sustainable development of nuclear energy. As the Korean government has not determined yet the preferred nuclear fuel cycle option, it is necessary to develop and apply an appropriate environmental management tool to environmental impacts of available options.

Existing environmental impact assessments of the nuclear power generation system have been focused on two issues. One is the comparative assessment relative to other energy of the economic and environmental aspects of CO_2 emissions, and the other is radiological risk assessment. However, it is necessary to take a broader view and apply a LCA methodology in the context of the environmental management of the nuclear power generation system.

2. State of the Art

2.1 International Standardization

The first study to look at life cycle aspects of products and data from the late sixties and early seventies, focused on issues such as energy efficiency, the consumption of raw materials and to extent, waste disposal. In 1969, for example, the CoCa Cola Company funded a study to compare resource consumption and environmental releases associated with beverage container. In the seventies and eighties many LCAs were made, mainly by and for companies in the USA and some in Sweden and Switzerland.

In the eighties two types of activity developed. The first is primarily social with an emphasis on procedures and terminology. The other type of activity is primarily scientific to work out the methodology of LCA in more detail. The former activities are mainly collective and procedural and related to the influence. The latter activities consist of individual or small group scientific activities.

In the nineties, all types of developments in LCA had accelerated with SETAC. One year later, ISO started the framework and methods. Under this situation, Technical Committee 207 (TC207) under the control of ISO has been formulated the environmental management standards and has acted as an incentive for self-organizing and self-regulating approaches to environmental protection as shown in Table 2.

Table 2. ISO 14000 Series' Category

Environmental Management System		Product Stewardship	
14000	Guidance on How To Set Up and Improve EMS	14040 14041 14042 14043 14044	Principles & Framework of LCA Goal & Scope Definition Life Cycle Inventory Analysis Life Cycle Impact Assessment Interpretation
14001	EMS Specification Standard for Registration Purposes	14020 - 14024	Environmental Labeling
14010- 14012	Auditing Principles and Procedures for Internal/External Auditors		
14031	Guidance on Measuring Environmental Performance		

2.2 in Korea

From the middle of the 1990s, LCA was introduced to Korean industries and academy. In the beginning, most studies were the follow-up of the foreign study on application of LCA to product, and after that government tried to construct dataset for environmental inventory in Korea and students in universities have been interested in standardization of methodology. More detail trends are as follows in Table 3.

Table 3. LCA Activities in Korea

Organization	Work Scope	Year
Industrial Advanced Administration	International Environmental Standardization Case Study of Industrial Sectors for Advanced Environmental Management Technologies	1993 1994
Ministry of Commerce, Industry and Energy	A Pilot Scale for the Development of Energy LCI Methodology	1997
Ministry of Environment	Development of LCA Methodology and Application to Korean Industries	1997
Univ. of Seoul	A Study on Methodology and Application of LCA (Ph.D)	1994
KAIST (Chemical Eng. and Civil Eng.)	Application of LCA on Polyethylene, Polypropylene, PET Beverage Containers Preliminary Comparison of Ecology-Economy Balance for Steel and Concrete Bridges Using LCA Technique Economy-Ecology Balance of Taejon City Municipal Solid Waste Management by LCA and WRAP Development and Application of LCA Methodology for Chemical Processes	1995 1996 1997 1998
KAIST (Nuclear Eng.)	Development of Classification Factor of Radionuclides and Application of LCA to Electricity	2000
Others	Aju Univ., KunKuk Univ., Korean Society of LCA and Eco-Consulting Companies	

3. Application Field of Nuclear

3.1 Environmental Management

Currently in Korea, spent fuels and radioactive wastes are stored at the interim storage pool. Korean government and utility have selected the nuclear energy as the major source of the electricity generation and expanded the nuclear power program. However, they have faced the significant problems arising from the spent fuel management, which results from the absence of the fixed back-end fuel cycle policy. Through the series of efforts such as fuel burn-up increase, storage rack expansion and dry storage construction, Korea delayed the decision so far. Nevertheless, the amount of spent fuel arising from nuclear power plants in Korea is a tremendous problem. In order to accommodate its needs, Korea must take the necessary initiative to solve its problem for the management of its spent fuel considering the environmental impact. Korean utility has used the existing pools for the interim storage of spent fuel and the site selection of repository has been delayed by a series of demonstration of local residents in several candidate sites since 1989.

Therefore, reprocessing and DUPIC options are necessary to be considered together with the once-through option. As long as the non-proliferation can be assured, the permanent solution for the storage problem will be the recycling of spent fuel. A recycling is related with the environment aspect. If the reprocessing facility is to be constructed, there is the definite advantage to ease the spent fuel discharging problem and to reduce the uranium resources utilization. However wastes arising through the reprocessing process such as PUREX or DUPIC will be increased due to the additional necessary process comparing with the once-through cycle. Therefore, these wastes from additional processes will cause the environmental impact while saving of raw materials through reprocessing will take a role as the environmental benefits. LCA is useful to assess and compare the environmental impact and benefits.

Also, LCA is applicable to the remediation of contaminated sites such as disposal site of radioactive wastes or nuclear facility. Decontamination and decommissioning (D&D) process could be analyzed by LCA. For example, decision tool could be developed by integrating many options of D&D techniques. Through this application, life cycle inventory for several techniques used in remedial actions are constructed and comparisons are allowed among many scenarios. Also this work suggests a new methodology for environmental assessment and makes it possible to establish the extensive infra-database related with the nuclear power generation system.

3.2 Energy Policy

Very explicitly now, energy policy is addressing environmental issues and energy conservation has come to be regarded as an important element of environmental policy. According to current situation, concern for environmental preservation has increased the demand for more efficient management and environmentally sound and sustainable development of nuclear energy. The Korean government has selected the nuclear energy as the major source of electricity generation in Korea due to the lack of domestic energy resources, however, it has not determined yet the nuclear energy policy relating to recycling or direct disposal of spent nuclear fuels. So it is necessary to develop and apply an appropriate environmental management tool to environmental impact assessment of available options prior to a decision of policy. Existing environmental impact assessments of the nuclear energy have been focused on two issues. One is the comparative assessment with other energies of the economic and environmental aspects, and the other is only radiological risk assessment. However, it is necessary to take a broader view and apply a LCA methodology in the context of the environmental management for the decision - making of nuclear energy policy.

Additionally because construction planning of new power plants is dependent on the market price and competitive pricing among the electrical resources may cause the unbalance of electricity supply planning, electricity security should be reviewed by the estimation of future cost for electricity generation and energy mix strategy. In order to support decision-making of this problem, integrated environmental and economic analysis model need to be developed. To achieve this aim, LCA for the environmental analysis and economic analysis on unit price for 1GWh electricity generation would be coupled explicitly.

4. Complementary Work of LCA in Nuclear Energy System

4.1 Problem of Existing LCA Study

Classification of the radiological impact and calculation of the environmental impact from the radioactive substances are indispensable as long as the nuclear energy is considered in the application of LCA for the utilization of energy in the industry. However, direct introduction of LCA to the nuclear energy is difficult more or less due to the absence of the methodology for the radiological impact assessment within the LCA framework. Therefore, complementary study is necessary for development of classification factor of radionuclides.

Classification factors for impacts on human health and the environment in the framework of LCA have typically been calculated using the Critical Volume (CV) approach. The CV approach for radionuclides was suggested by R. Heijungs in 1992 to characterize the environmental impact through a procedure in which the emission of a radionuclide is divided by its intake standard, such as its Annual Limit on Intake (ALI). However, CV approach is in adequate and inappropriate. First, the intake standard value applies only to impacts due to inhalation and ingestion so external exposure is excluded from the consideration. Second, this approach does not take into account both of exposure and effect of radionuclides for the different radiological exposure pathways and assumes that all substances have the same fate properties. This approach just divides an emission by a reference concentration. Therefore the CV approach is clearly not suitable for nuclear fuel cycle analysis.

In order to apply the LCA directly to nuclear fuel cycle and calculate the classification factor of radionuclides within the framework of LCA, other methodologies such as CST 95 and Eco-indicator 98 are worth while to be reviewed.

Critical Surface Time (CST) 95 method was developed by O. Jolliet. In this method fate factors of pollutants meaning that an emission flow generates a concentration increase (kg/m^3 per kg/m2-yr = m^2-yr/m^3) are determined empirically and effect factor is assumed to be equal to the inverse of the Predicted No Effect Concentration (kg/m^3).

Improvement in this method that fate and exposure factor cannot be assumed to be 1 any more in the determination of classification factor and consideration of inter-media transport of pollutant are valuable results compared to the previous LCA. However, unsolved problems are remained in this method as follows. In CST 95, many values (such as the average residues of pesticides in food) are extrapolated on the basis of only a single study. Better estimation of residence time of pollutant is required and different human condition (sex, age, cancer probability and so on) should be introduced. So far, reference substance of each category has been chosen arbitrary. Thus new criteria should be fixed to select the adequate reference substance. Dilution volume is not appropriate for pollutants with short mean life because they do not have enough time to be diluted in the environmental volume.

Eco-indicator 98 method developed by Pré consultant is available for the calculation of toxicity. This method is to develop the single scores for designers. Important improvements comparing to CV approach are the use of fate analysis and the much better definition of the damage categories concerned with the human health and ecosystem health. However, this method is especially for Europe so that this would restrict the applicability to other regions. And this methodology consists of natural science for calculating changes in the environment and weighting procedure for establishing the seriousness of these changes, i.e., damage using social science. Damage calculation uses three different indicators such as energy for damage to resources, Potentially Affected Fraction (PAF) for damage to ecosystem, and Disability Adjusted Life Years (DALY) for damage to human as shown in Figure 1. Eco-indicator 98 method introduces many new concepts and important innovations in LCA methodology development such as consistent use of cultural perspectives to manage subjectivity, however, there is a constant need for updating.

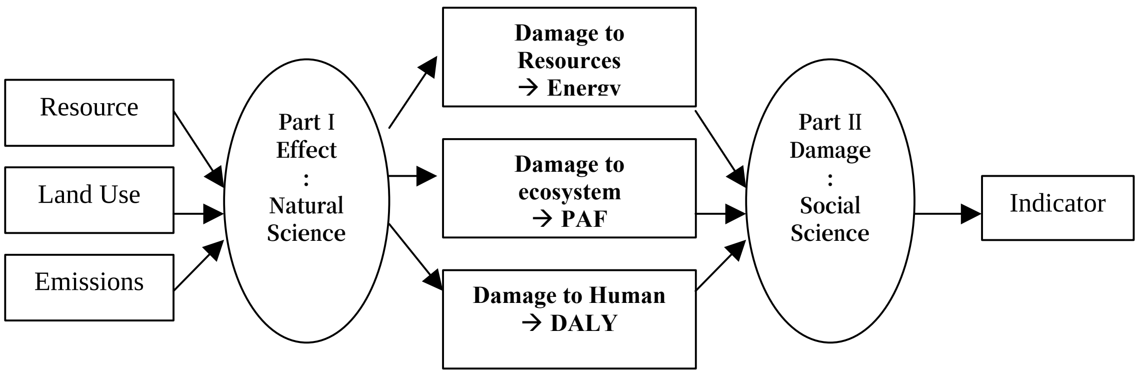

Figure 1. Eco-Indicator 98 Method

These methodologies could give some guides for the calculation of classification factors for radionuclides, however, they have some limitations for this aim and should be modified properly. Therefore this study intend to suggest the new concept of the direct application of LCA to nuclear energy system.

4.2 Preliminary Study Result

Scheme of calculating classification factors for radionuclides is explained in this section. The classification factor takes into account both of the exposure and health effects of radionuclides, which makes supplement to existing CV approach. Calculation of exposure is based on the provisional method of Heijungs and others (1992) in which it is assumed that a substance will disperse uniformly in this medium throughout the world. Exposure is typically related with the concentrations of radionuclides in medium, which can be determined by the quantity of radioactivity, and the length of exposure period. This calculation procedure makes it possible to consider the overall impact of each radionuclide overall the pathways considered. The calculation of exposure requires data about the size of the parts of the environmental media, the route in which emitted substances are distributed, the daily intake from each media and the number of people who are potentially exposed. The larger the part of the medium in which an emitted substance is dispersed the more it will be diluted and the lower exposure will be. However, Heijungs and others did not consider different routes in which emitted substances are distributed and merely distinguished the environmental medias of air, water and soil. So various exposure pathways are suggested and adopted.

Generally the pathways based on Drecier and others (1995) are adopted in the radiological impact. Because they describe the simple pathways including atmospheric and liquid discharge into the environment and their dispersion in different media, minor pathways have been neglected. However, waste disposal in the ground is added in this study. Exposure pathways including inhalation of a radionuclide in air, ingestion of a radionuclide in water and food, and external exposure to radiation from a radionuclide in air, on the ground surface and in soil are taken into account in Figure 2. The emissions from each facility fall into the three major categories of atmospheric discharge into the environment, liquid discharge into the water and waste disposal in the ground.

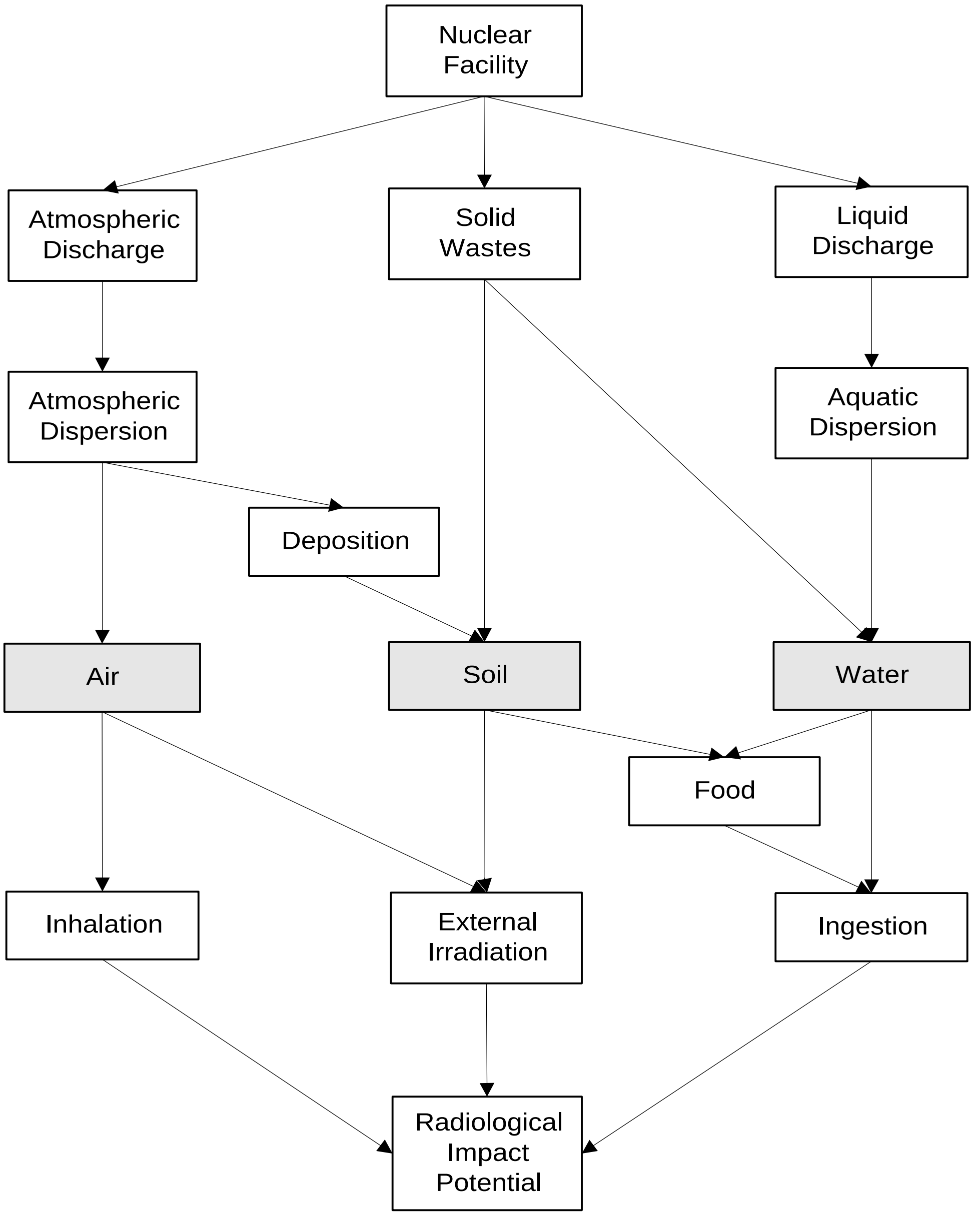

Figure 2. Exposure Pathway

For each the exposure pathway, several steps are involved in calculating the classification factor. For external exposure, estimation of the time-integrated activity concentration requires information on the concentration of the radionuclide in the medium and the length of the exposure period. For internal exposure, an estimate of the per capita activity intake of the radionuclide requires the same information plus an estimate of the average usage rate of the medium by the members of the population during the exposure period. Health effects of radionuclides are represented by risk coefficients provided by the EPA, which are defined as the probability of radiogenic cancer mortality or morbidity per unit of internal or external exposure. Risk coefficients have advantages that these are adequate for non-uniform distribution and derived as age and gender specific values. This is important because general effective dose estimation by International Commission on Radiological Protection (ICRP) is based on an idealized population receiving a uniform equivalent dose over the whole body. A nominal fatality probability coefficient of 0.05 Sv^{-1} is given in ICRP 60 (1991) for all cancer types combined. This value is referred to as nominal because of the uncertainties inherent in radiation risk estimates. If the dose is non-uniform, this nominal coefficient will be less accurate. In contrast to risk estimates based on the product of a nominal probability coefficient and effective dose, the risk coefficients take into account the age and gender dependence in usage of contaminated environmental media, which is generally not considered in risk estimates based on the simple product of a nominal probability coefficient and effective dose.

Using classification factors preliminary calculated, LCA of the once-through fuel cycle of nuclear energy system were described. First this study constructed the environmental data set associated with the emissions and radionuclides to different environmental media and evaluated their environmental impacts using the LCA methodology. This is coincided with the current worldwide situation of the close relation between the environmental issues and energy policy. As a result, once-through fuel cycle turned out to cause the environmental impact of 4.32E-3 based on the un-dimensionally weighted value. Also, the important environmental impacts in un-dimensionally weighted impact that could be associated with once-through fuel cycle currently implemented in Korea turned out to be ADP (4.12E-3), HCA (9.19E-5), ECA (4.8E-5), NP (3.43E-5) and HCW (1.29E-5). RP (1.06E-7) was less significant than other categories, even though a high relative significance factor was assigned. The significant environmental category was ADP caused by the utilization of uranium resources that was the major contributor of 95.4% to total environmental impacts, and the environmentally dominant stage was found to be mining/milling stage. Also 99% of RP turned to be caused by mining/milling stage and power plant operation, and the most radiologically significant pathway was internal exposure, especially due to the inhalation of air.

Table 4. Results of EI, NI, and WI of Nuclear Energy System

	ADP	GWP	ODP	HCA	HCW
EI	7.33+1*	2.80+1	6.14-4	4.08+1	5.50+0
NI	2.49-2	4.95-6	7.43-6	6.12-4	8.59-5
WI	4.12-3	8.26-7	1.24-6	9.19-5	1.29-5
	ECA	**ACP**	**NP**	**RP**	**Total**
EI	1.41+1	4.63+0	7.01+0	1.36-6	-
NI	3.39-4	8.21-5	2.48-4	5.00-7	-
WI	4.80-5	9.41-6	3.43-5	1.06-7	4.32E-3

* : 7.33+1 means 7.33E+1.

Table 5. Environmentally Dominant Stages for Once-Through Fuel Cycle

Impact Category	**ADP** [95.39%]	**GWP** [0.02%]	**ODP** [0.03%]	**HCA** [2.13%]	**HCW** [0.3%]
Stage	Mining/Milling (96%)	Fabrication (94%)	Fabrication (99%)	Conversion (77%)	Mining/Milling (78%)
Impact Category	**ECA** [1.11%]	**ACP** [0.22%]	**NP** [0.798%]	**RP** [0.002%]	
Stage	Mining/Milling (98%)	NPP (99%)	NPP (99%)	Mining/Milling (67%)	

Of course this study is preliminarily carried out. It is necessary to be supplemented steadily and continuously in term of the collection of environmental data and the calculating method as mentioned above. However, it might be necessary to provide objectively the environmental predominance of nuclear energy over other energy sources in respect of environmental management in near future. Therefore, this result is very useful as the source materials for the further development of comparative assessment of nuclear and non-nuclear energy as well as decision-making of nuclear fuel cycle alternatives.

5. Conclusion

This study suggests new methodology for environmental assessment and makes it possible to establish the extensive infra-database related with nuclear power generation system. In detail, this study explained the international trend of environmental management system and validated the application of LCA to nuclear energy system and radioactive waste management. Also the controversial issues when LCA was directly applied to nuclear industries were pointed out and suggested the new concept to improve the methodologies for the calculation of radiological impact within the LCA framework. Using this improved concept, LCA of once-through fuel cycle was accomplished preliminarily. This result could be used as the source materials for the further development of comparative assessment of nuclear and non-nuclear energy as well as decision-making of back-end fuel cycle alternatives. Of course this work is necessary to be supplemented steadily and continuously according to the calculating method as mentioned above. Even though some unresolved issues remain such as the extension of health end-points addressed, this study has made important advances in the environmental impact assessment of nuclear energy system and it is possible to improve the scientific basis of LCA with the emphasis on the nuclear energy system.

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