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Feasibility Study on Application of New Concept of Environmental Assessment to Nuclear Energy

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Abstract

The existing environmental assessments of nuclear energy are focused on the two kinds of issues such as prevention of green house gas emission and radiological impact assessment. So, the comparative assessment of the other resources such as fossil fuels has been the main part and this result has been the side of nuclear power as the clean energy resource. However, now is when to develop the methodology that approaches to environmental assessment of energy in terms of the various environmental categories. Life Cycle Assessment (LCA) would be the effective environmental assessment tool, which is able to meet the necessity mentioned above. Also 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, this study suggests the new concept of environmental assessment. Also current status of development for the classification factor of radiological impact is introduced and investigates the feasibility of application of it to nuclear power generation system.

1. Introduction

Necessity of Application

Today's nuclear power plants in Korea are primarily used to supply base-load electricity due to the insufficiency of energy resources and rapid increase of electricity demand. In compliance with the government policy, Korea Electric Power Corporation (KEPCO) established an ambitious nuclear power plant construction program and total 25 units will be connected to the grid in Korea by 2010 (Kori 1 will be decommissioned in 2009). According to the expansion of the nuclear power program, it is necessary to analyse the environmental impact of nuclear fuel cycle. And in recent years attention to environmental problems has been increased for more efficient management of Environmentally Sound and Sustainable Development (ESSD) of nuclear energy. Therefore it is necessary to apply LCA methodology covering the whole nuclear fuel cycle from the point of view of the improvement of environmental friendliness of nuclear power generation.

Background of New Concept

LCA is “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 are to identify the environmental impact and the environmentally most dominant stage in life cycle of nuclear power generation system and to suggest the new methodology to solve the problem when LCA is applied to facility releasing the radioactive wastes. 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 and for the calculating the functional unit of system mass balance. 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 initially the lists of the most common substances be used. The list of most common substances and their classification factors on various environmental themes used in this study are data prepared by Center of Environmental Science (CML) in Leiden University and the list of United Nations Environment Programme(UNEP)[1]. The environmental impact categories for which data are available and non-zero are followings;

- Abiotic Resources Depletion Potential (ADP)
- Global Warming Potential (GWP)
- Ozone Depletion Potential (ODP)
- Acidification Potential (ACP)
- Human Toxicity Potential through Air, Water and Solid (HCT)
- Ecotoxicity through Aquatic and Terrestrial (ECT)
- Nutrification Potential (NP)

Classification factors related with these impact categories could be calculated as followings;

(1) ADP

The quantity if a resource used (m_i) is linked to the recoverable resources (M_i) of that resources.

$$abioticdepletion = \sum_i \frac{m_i}{M_i}$$

(2) GWP

The GWP of a substance is the ratio between the contribution to the heat radiation absorption resulting from the instantaneous release of 1 kg of a greenhouse gas and an equal emission of CO_2 integrated over time (longer time horizons 100 – 500 years)

$$GWP_i = \frac{\int_0^t a_i c_i(t)\,dt}{\int_0^t a_{co2} c_{co2}(t)\,dt}$$

a is the heat radiation absorption per unit concentration increase of greenhouse gas, c is the concentration of the greenhouse gas.

(3) ODP

The ODP is defined as the ratio between ozone breakdown in the equilibrium state due to annual emissions of a quantity of a substance released into the atmosphere and the breakdown of ozone in the equilibrium state due to an equal quantity of CHC-11.

$$ODP_i = \frac{d\,[O_3]_i}{d\,[O_3]_{CFC-11}}$$

δ represents the change in the ozone column.

(4) HCT
These effect factors are calculated by using the ADI (acceptable daily intake) values defined by the WHO and the TDI (tolerable daily intake) values similarly defined.

(5) ECT
For the time being the exposure factor for the classification of ecotoxic substances will be assumed to be 1. Hence the classification factor will depend solely on the effect factor. "MTC_{EPA}" (maximum tolerable concentration) is expressed in mg/m^3 water or soil. The ecotoxicological classification factor for aquatic ecosystem (ECA) and terrestrial ecosystem (ECT) is

$$ECA\ or\ ECT = \frac{1}{MTC_{EPA}}$$

(6) AP
AP is defined as the ratio between the number of potential H+ equivalents (n_i) per mass unit substance (M_i) and the number of potential H+ equivalents per mass unit of a reference substance SO_2 is proposed as the reference.

$$AP_i = \frac{n_i / M_i}{n_{SO2} / M_{SO2}}$$

(7) Nutrification
NP is defined as the ratio between the potential biomass in N equivalents per emitter quantity of substance (M_i) and the potential biomass in N equivalents per emitter quantity of a reference substance such as PO_4^{3-}

$$NP_i = \frac{n_i / M_i}{n_{PO4} / M_{PO4}}$$

2. Suggestion of Methodology

Problem of Existing Method

However, direct introduction of LCA to the nuclear power generation system is difficult due to the absence of the methodology for the radiological impact assessment within the LCA framework i.e. classification factors of radiological impact are not supplied. Because 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, it is necessary to develop the classification factor of radiological impact.

The methodology of calculating the classification factor, which has been used until now generally, is based on the "Critical Volume Approach". Classification factor calculated from the critical volume approach can be expressed as

$$m_l = L_{subs,comp} \times m_{subs,comp}$$

m_l : emission of a reference substance

$L_{subs,comp}$: classification factor of substance initially emitted to compartment

$m_{susb,comp}$: emission of a substance to a compartment

This approach is that an emission of a toxic substance is divided by its tolerable limit. This approach, however, does not consider the fate behaviour of pollutant and is clearly not valid, since routes of exposure can vary widely. So, it is necessary to introduce the other approach related to the realistic concept such as the risk model.

Calculation of Classification Factor

Since the mid-1980s United States Environmental Protection Agency (EPA) has issued a series of the Federal guidance documents for providing the technical information to assist their implementation of radiation protection programs. The EPA provides the risk coefficients for cancer attributable to exposure to any of approximately 100 important radionuclides through internal and external exposure route.

The risk coefficient is expressed as the probability of radiogenic cancer mortality or morbidity per unit activity inhaled or ingested for internal exposure or per unit time-integrated activity concentration in air or soil for external exposure. And the risk coefficient could be interpreted as average risk per unit exposure for persons exposed throughout life to a constant activity concentration of radionuclide in an environmental medium[2]. In the risk coefficients age and gender specific information are included, therefore, this interpretation could be translated to the numerical equations for internal and external exposure respectively.

$$\overline{r_a} = \frac{\int_0^\infty u(x) r_a(x) S(x) dx}{\int_0^\infty u(x) S(x) dx}$$

$$\overline{r_e} = \frac{\int_0^\infty r_e(x) S(x) dx}{\int_0^\infty S(x) dx}$$

where *u(x)* is usage rate of environmental media
s(x) is survival function
r(x) is risk coefficients

Since the external exposure is not considered to be age dependent and the usage rate, *u(x)*, is unnecessary, lifetime risk for external exposure is reduced simply to the function of risk coefficient and survival function.

Risk coefficients for inhalation of radionuclide in air means the probability of cancer mortality or morbidity per unit intake (Bq^{-1}). The intake rate for a radionuclide in air is assumed to depend on age and gender, so intake is averaged over all ages and both genders. Risk coefficient for ingestion is expressed as that for the inhalation. For the assessment of the intake of a radionuclide in food, its activity concentration in food and an average usage rate are necessary. The risk coefficient for external exposure is expressed as the probability of cancer mortality or morbidity per unit time integrated activity concentration in air, on the ground surface, or in soil.

For a given exposure scenario, the computation of lifetime cancer risk, R, associated with intake I, or external exposure X involves $R = r \times I$ for intake by inhalation or ingestion and $R = r \times X$ for external exposure. However, to calculate the classification factor for radioactive substance from the radiological impact assessment method directly, some problems should be solved.

Firstly, some kinds of manipulation steps are added to calculate the classification factor from the source term. Generally, only amounts with the unit of Bq^{-1} of radioactive substances released from the nuclear fuel cycle are used in the life cycle inventory. Table 1 shows radionuclides released from the nuclear fuel cycle[3]. It must be possible to calculate the effect score of radiological impact by multiplying the source term by classification factor. Therefore following information is considered. For the external exposure, estimation of the time-integrated activity concentration *X* requires information on the concentration of the radionuclide in the medium and the length of the exposure period. For the internal exposure scenario, estimation of the per capita activity intake *I* of the radionuclide requires the same information, plus an estimate of the average usage rate of the medium by members of the population during the exposure period. The calculation scheme of classification factor is given in Fig. 1.

Table 1. Radionuclides released from Nuclear Fuel Cycle

Mining and Milling	
Gas	Ra-222, U-234, -235, -238
Liq.	U-234, -235, -238
Conversion, Enrichment, Fuel fabrication	
Gas	U-234, -235, -238
Liq.	U-234, -235, -238
Reactor Normal Operation	
Gas	H-3, C-14, Co-58, -60, Kr-85, I-131, -133, Xe-133, Cs-134, -137
Liq.	H-3, Mn-54, Co-58, Co-60, Ag-110m, Sb-124, I-131, Cs-134, -137
Reprocessing	
Gas	H-3, C-14, Kr-85, I-129, -131, -133, Pu-238, -239
Liq.	H-3, C-14, Co-60, Sr-90, Ru-106, I-129, Am-241, Sb-125, Cs-134, -137, U-238238, Pu-238, -239,
Low Level Waste Disposal	
Sol.	H-3, C-14, Co-60, Ni-59, -63, Sr-90, Zr-93, Nb-94, Mo-93, Tv-99, Pd-107, I-129, Cs-135, -137, U-234, -238, Pu-239, -241, Am-241, Np-237

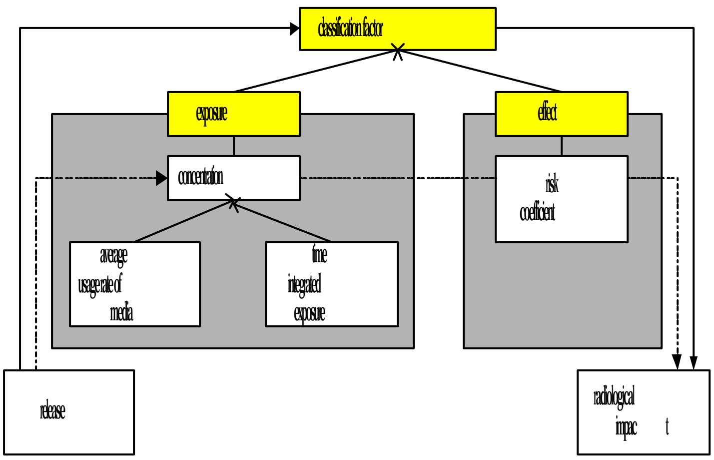

Fig. 1. Calculation scheme of classification factor

Secondly, it is necessary to take into account the exposure pathway. It is proper to recognize that risk coefficients are classified according to the different environmental media rather than the exposure route. Therefore the assessment of for each pathway must be done for each radionuclide. Exposure pathway to be considered is shown in Fig. 2. The exposure pathway is divided as followings.

- inhalation of a radionuclide in air
- ingestion of a radionuclide in water and food

- external exposure to radiation from a radionuclide in air, on the ground surface and in soil

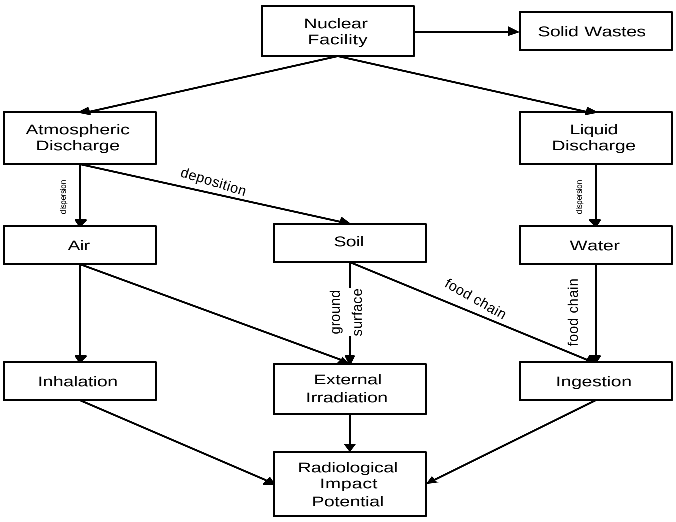

Fig. 2. Exposure pathway

Finally, they have the different form of the inhaled material according to the rate of absorption from the lungs to blood classified by ICRP Publication 66. Type F stands for the fast rate, Type M for medium rate and Type S for slow rate. So, the various values divided by the exposure pathway and deposition type need to be integrated and converted to the single value representing the radiological impact for each radionuclide.

The classification factor for external exposure, however, does not consider the effect of half-life of radioactive nuclides when the time-integrated concentration of radioactive substance is calculated. Therefore, it could be recommended that the radioactivity concentration be calculated by the computer simulation code for radiation dose released from the nuclear facility for more accurate calculation of radiological risk from the external exposure. Also some nuclides in list of risk coefficient are not available for calculation of the classification factor because they are not calculated, which are the problems to be solved.

3. 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. Current study related to the development for the classification factor of radiological impact and to the endeavour at application of new environmental assessment tool to nuclear energy have been pursuing. Of course this work is necessary to be supplemented steadily and continuously according to the calculating method as mentioned above. Then, single valuation representing the radiological impact and considering both exposure and effect of each radionuclide can be possible from the only information of radionuclide release to the classification factor through calculating the concentration.

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 power generation system and it is possible to improve the scientific basis of LCA with the emphasis on the nuclear power generation system.

4. Reference

[1] R. Heijungs, "Environmental Life Cycle Assessment of Products- Guide and Backgrounds", CML,1992

[2] Keith F.Eckerman, "Health Risk from Low-Level Environmental Exposure to Radionuclide", EPA, 1998

[3] CEPN, "Externality of Energy, Vol. 5: Nuclear", EC, 1995