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Development of the Numerical Guide for Cost-Benefit Analysis of Occupational Radiation Exposure in the Korean Next Generation Reactor

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Abstract

The specific purpose of this study is to develop the numerical guide for the cost-benefit analysis of ORE ($/person-Sv reduction) to meet the criterion of ALARA in the design stage of the KNGR. In deriving the guide, the risk factor which is defined by the risk to unit collective radiation exposure dose (deaths/person-Sv) and the monetary value of human life ($/death) are required. The risk factor has been estimated from various clinical data accumulated for a number of years and continuously modified. And the monetary value of human life is usually quantified using the human capital approach. In this study, the risk to radiation exposure perceived by a group of people is investigated through an extensive poll survey conducted among university students in order to modify the existing risk factor for radiation exposure. And in evaluating the monetary value of human life, the QOL factor is introduced in order to incorporate the degree of public welfare or quality of life. As a result of study, a value within the range of 151,000~172,000 dollars per person-Sv reduction is recommended as the appropriate interim numerical guide for cost-benefit analysis of ORE to meet the criterion of ALARA in the design stage of the KNGR. A poll survey was also conducted in order to see whether the public acceptance cost of nuclear power should be incorporated in developing the guide, and the result of study showed that such a cost does not need to be considered.

1. Introduction

One of the design objectives is to keep levels of occupational radiation exposure (ORE) as low as is reasonably achievable (ALARA) in the Korean Next Generation Reactor (KNGR). The term ALARA means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the occupational health, safety and other societal and socio-economic considerations.

The numerical guide of 1 person-Sv/GWy(e) set out in the utility requirement document[1] of the KNGR provides the numerical guidance on design objectives for the KNGR to meet the requirement that the collective dose equivalent of ORE be kept ALARA. In addition to this guide, ALARA requires to include in the plant all items of reasonably demonstrated technology that, when supplemented to the plant sequentially and in order of diminishing cost-benefit return, can for a favorable cost-benefit ratio effect reductions in collective dose to all the occupational radiation workers of the plant. In reality, however, the numerical guide for cost-benefit analysis should be developed as an interim measure for the KNGR until other appropriate criteria are established. The specific purpose of this study is to develop this numerical guide for cost-benefit analysis of ORE ($/person-Sv reduction) to meet the criterion ALARA in the design stage of the KNGR.

2. Health Detrimental Cost

Use of the linear, no-threshold dose-response model[2] presumes a linear relationship between the radiation dose and the probability of detrimental health effects. Hence, the consequential health effects to a given group of people are considered to be directly proportional to the collective dose (person-Sv) which is defined by the sum of individual doses of the group in this model. Since the health effects can be ultimately represented by a number of human deaths, one can relate the amount of collective dose (person-Sv) with the number of human death.

There have been a great deal of efforts put into work in trying to estimate the monetary value of a human life ($/death) even though it has been considered quite unethical. The process of placing a single value on life is not easy and sometimes considered meaningless since there exist so different views among people in this subject. In case that the monetary value of human life is determined one way another, the health detrimental cost of radiation exposure which is presented by dollars per person-Sv may consist of objective and subjective costs. The objective detrimental cost is based upon the radiation exposure risk factor derived from various sources of available exposure data, which is considered very objective. Meanwhile, the subjective detrimental cost is rather a correction term which could arise as an additional cost caused by the degree of risk aversion to radiation exposure, which is very subjective. It is considered very logical in this study to include the subjective cost which depends on how the risk is perceived by members of the public in the evaluation of health detrimental cost.

In this study, two improvements are made in assessing the unit health detrimental cost. The first improvement is to include the effects of the degree of public welfare or quality of life in evaluating the monetary value of human life. The second improvement is to use a risk aversion factor in order to compensate the risk factor of radiation exposure. In order to evaluate the risk aversion factor by the public, an extensive poll survey is conducted among university students for this study. These two improvements are incorporated in estimating the objective and subjective health detrimental costs, respectively.

2.1. Objective Health Detrimental Cost

The objective health detrimental cost ($/person-Sv), α is composed of three distinct parts, α_1, α_2 and α_3.

$$\alpha = \alpha_1 + \alpha_2 + \alpha_3$$

where, α_1 = detrimental cost due to cancer,
α_2 = detrimental cost due to fatal cancer, and
α_3 = detrimental cost due to severe genetic effects.

The detrimental cost due to cancer, α_1, is defined as the sum of the cancer treatment cost and the cost of productivity loss during treatment.

$$\alpha_1 = P_1 (C_1 T_1 + W T_1) \quad (2)$$

where, P_1 = risk of cancer, Sv^{-1},
T_1 = average period of cancer treatment, yr,
C_1 = average annual cost of cancer treatment, $/person-yr, and
W = annualized monetary value of human life, $/person-yr.

The annualized monetary value of human life is given by

$$W = G \times (1 + f_{QOL}) \times \frac{\sum_{t=1}^{l} \left(\frac{1+E_g}{1+r} \right)^t}{l} \quad (3)$$

where, G = annual GNP per caput, \$/person − yr,

l = life expectancy, yr,

E_g = annual economic growth rate,

r = discount rate, and

f_{QOL} = QOL factor.

The detrimental cost due to fatal cancer, α_2, is defined as the cost of productivity loss due to premature death.

$$\alpha_2 = P_2 W l_{PD} \quad (4)$$

where, P_2 = risk of fatal cancer, Sv^{-1} and

l_{PD} = average premature death due to cancer, yr.

The detrimental cost due to severe genetic effects, α_3, is defined as the cost of productivity loss due to genetic effects. It is assumed that economic activities are impossible during life expectancy due to these effects.

$$\alpha_3 = P_3 W l \quad (5)$$

where, P_3 = risk of severe genetic effects, Sv^{-1}.

2.2. Quality of Life

The most common method for evaluating the monetary value of human life is the human capital approach. This approach takes into account the potential output that is lost to society on the premature death of an individual. The value calculated using this approach becomes the minimum sum that should be spent to avoid a premature death, since it is purely based on economics and contains no allowance for other factors such as the degree of public welfare or quality of life(QOL) in the decision making process.

The concept of QOL is introduced in this study to modify the human capital approach. QOL is defined as the quality of social and physical environment in which people pursue the gratification of their wants and needs. QOL provides the backdrop against which all human activity takes place and provides a flow of valuable services to people which make their pursuit of happiness both possible and easier. [3] Therefore, the higher QOL is, the easier economic activities are possible.

QOL can be represented by a certain factor which is calculated using indicators of public welfare. These indicators are published by the World Bank in the name of Social Indicators of Development (SID)[4] which include clean water supply, life expectancy, education level, etc.

The QOL factor is defined by

$$f_{QOL} = \omega \sum_{i}^{N} \xi_i \frac{(R_{GNP} - R_i)}{R_{GNP}} \quad (6)$$

where, f_{QOL} = QOL factor ($-1 \le f_{QOL} \le 1$),

ω = relation coefficient ($0 \le \omega \le 1$),

ξ_i = weight of the ith SID ($\sum \xi_i = 1$),

R_i = rank of the ith SID,

R_{GNP} = rank of annual GNP per caput, and

N = total number of SIDs considered.

The QOL factor is calculated by considering the rank of annual GNP per caput and that of each SID in Korea. The QOL factor indicates the level of QOL in a nation. The larger the factor is, the higher is the level of QOL than other countries of equivalent economic power. The relation coefficient, ω, implies the degree of relation between the economic productivity and QOL. If ω equals zero, there is no relation between QOL and the economic productivity. Therefore, the resultant value of human life is the same as that calculated by the human capital approach. If ω equals one, there is a strong relationship between the economic productivity and QOL. It is assumed that ω is in the range of zero and one in this study.

2.3. Subjective Health Detrimental Cost

There usually exists a great difference or risk aversion between objective and perceived risks for unknown or catastrophic hazards. The perceived risk plays an important role in determining how people take an action to a risk. The attribute of radiation exposure is one of unknown hazards.

When the general public are asked to evaluate a certain risk, they seldom have concrete statistical backgrounds for its evaluation on hand. In most cases, they must rely on the inferences based on what they remember hearing or observing about the risk in question. This kind of risk is called the perceived risk. Recent psychological researches have identified a number of very general influential rules that people seem to use in this situation. These are called heuristics.[5] The heuristics specifically includes availability and overconfidence. Availability has a special relevance for risk perception. People using this heuristics judge an event as likely or frequently if its instances are easy to imagine or recall. Frequently occurring events are generally easier to imagine and recall than rare events. However, availability is also affected by the factors other than the frequency of occurrence. For example, a disaster of recent occurrence could seriously distort risk judgement even though it is not a likely event. Overconfidence also plays an important role in risk perception. This can keep people from realizing how little they know and how much information is needed about the various problems and risks they face.

The perceived risk is very subjective and can be introduced in decision making process. Let's define β as the subjective health detrimental cost ($/person-Sv).

$$\beta = P_p \{ \eta_1 (W T_1 + C_1 T_1) + \eta_2 W l_{PD} + \eta_3 W l \} \quad (7)$$

where, P_p = subjective risk, Sv^{-1},

η_1, η_1 and η_3 = weights for the radiation effect on cancer treatment cost plus productivity loss during treatment, productivity loss due to premature death, and productivity loss due to severe genetic effects, respectively.

The risk aversion factor to radiation exposure is introduced in order to assess the subjective risk. The risk aversion factor is defined as the difference between objective and perceived risks. A poll survey was conducted to evaluate the risk aversion factor. The risk aversion factor is drawn from the survey responses, which specifically represents the degree of risk perception by the respondents to radiation exposure cancer rate. η_1, η_2 and η_3 are computed using the data given in ICRP-60.[6]

3. Results of Study

3.1. α

The data used for quantifying α value are summarized in Table 1. For present value evaluation, it is assumed that the discount rate (r) and the annual economic growth rate (Eg) are 5% and 5.5%, respectively.

In evaluating the QOL factor, the weights are considered the same for all SIDs. The result of evaluation shows that the QOL factor lies between 0 and −0.118 depending on the value of ω. The negative value of the QOL factor implies that the level of public welfare in Korea is lower than the average level of the countries with economic strength equivalent to Korea.

Thus, the resultant α value is in the range of 140,000～160,000($/person-Sv) depending on the value of relation coefficient.

3.2. β

There were 152 responses of university students in the survey. The results of survey show that the respondents express a typical risk aversion to radiation exposure as given in Figure 1. To estimate the risk aversion factor, a linear approximation and geometric mean are used. It is assumed that each weight of radiation exposure effect, that is fatal cancer, nonfatal cancer, and severe genetic effects, is proportionate to the data given in ICRP-60.

The results of survey and data used for quantifying β are presented in Table 2.

The resultant β value is in the range of 10,500～

Table 1. Data Used for Quantifying α

Symbol	Definition	Value	Unit	Reference
P_1	total cancer risk due to radiation exposure	6.0×10^{-1}	Sv^{-1}	[6]
P_2	fatal cancer risk due to radiation exposure	5.0×10^{-2}	Sv^{-1}	[6]
P_3	genetic risk due to radiation exposure	1.3×10^{-2}	Sv^{-1}	[6]
T_1	mean period for treatment	2	yr	[7]
C_1	medical expenditure on treatment per year	50,000	$/person-yr	[7]
V	annual GNP per caput	10,000	$/person-yr	
E_g	annual economic growth rate	5.5	%	[7]
r	discounting rate per year	5	%	[7]
l	life expectancy	71	yr	[4]
l_{PD}	life expectancy - age at premature death(56)	15	yr	[4],[7]
R_{GNP}	rank of annual GNP per person	35th		[4]
R_1	rank of life expectancy	61st	(71 yr)	[4]
R_2	rank of population growth rate	37th	(0.9%)	[4]
R_3	rank of energy consumption per person	46th	(1,898kg,Oil)	[4]
R_4	rank of medical service	65th		[4]
R_5	rank of clean water supply	20th	(93%)	[4]
R_6	rank of education	22nd	(88%)	[4]
R_7	rank of subscription rate(newspaper)	33rd	(146/1,000)	[4]

Table 2. Data Used for Quantifying β

Parameter	Definition	Value
P_p	additional perceived risk for radiation exposure	0.52×10^{-2}/Sv
η_1	weighting factor for cancer	1
η_2	weighting factor for fatal cancer	0.83
η_3	weighting factor for severe genetic effects	0.22

12,000 ($/person-Sv). This value is calculated based upon the annual earning of radiational workers five times higher than that of the general public and the risk aversion by radiation workers is assumed to be the same as that by the survey respondents, i. e., university students.

According to previous studies, however, the degree of risk aversion by radiation workers is lower than that by the general public.[9] Therefore, the actual β value may be lower than the calculated value in this study if we conduct the same survey among workers rather than university students.

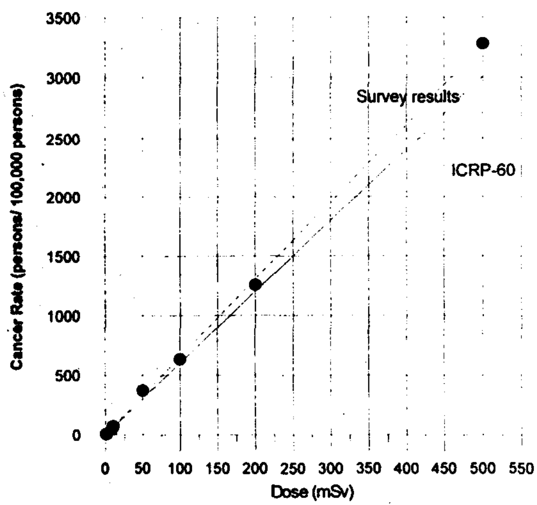

Fig. 1. Perceived Risk (Survey Results)

3.3. Public Acceptance Cost for Nuclear Power

The public acceptance cost for nuclear power is defined as the cost of compensation to acquire higher social acceptability for nuclear power. This cost has nothing to do with the direct operation cost of nuclear plant. This cost may include the costs of advertisement, public hearing, publication of pamphlets, and compensation for plant siting.

In order to determine whether there is a need to consider this kind of cost in the decision making process, the social acceptability of nuclear power needs to be measured. This acceptability is measured using a poll survey in this study. The acceptability measuring process is composed of three steps. First, the social average perceived risk (P_{pm}) is measured. In the survey the respondents express the perceived risk in the score from 0 to 100 for each of 14 hazards. The mean value of the perceived risks of 14 hazards in daily life may be used for this risk. Second, the perceived risk of nuclear power (P_{pN}) is measured. Third, the comparison is performed as follows : if P_{pm} is larger than P_{pN}, the public acceptance cost needs not be considered in decision making process, and if P_{pm} is smaller than P_{pN}, the public acceptance cost should be considered in decision making process.

The results are summarized in Figure 2.

According to Figure 2, the perceived risk of nuclear power is ranked the 10th. This value is lower than the mean value of social average perceived risk. This implies that the social acceptability of nuclear power is affirmative in Korea. Therefore, the public acceptance cost for nuclear power needs not be considered in decision making process.

In aggregating the terms described above, the results of study show that the numerical guide for cost-benefit analysis of ORE should be in the range of 151,000~172,000 ($/person-Sv) as summarized in Table 3.

4. Conclusions and Recommendations

This study suggests a numerical guide for cost-benefit analysis of occupational radiation exposure in the design stage of the KNGR. Based on the results of study, the following conclusions and recommendations apply :

1) The correction factor of QOL is introduced as an index of social welfare in assessing the value of life.

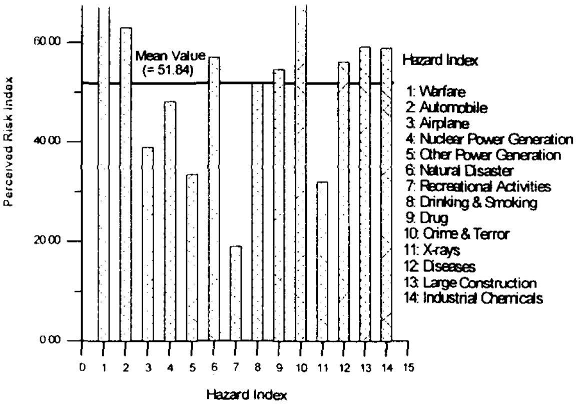

Fig. 2. The Perceived Risks Ranks

Table 3. Summary of Results

Source	Value ($/person-Sv)	Remarks	Reference
USNRC	100,000 (75)	effluents control at LWR	[8]
NRPB	10,000 (89)	based on human capital	[7]
CEPN	1,800 ~ 5,400	based on human capital and present value evaluation	[7]
IAEA	3,000 (85)	minimum value for transboundary exposure	[7]
Nakashima	5,000 (86)	human capital and non-fatal loss	[10]
KAERI	13,000 (94)	human capital and non-fatal loss	[7]
Present Study	151,000 – 172,000 (95)	human capital with QOL and perceived risk	

2) The perceived risk for radiation exposure and the public acceptance of nuclear power are evaluated using a technique of poll survey among university students, which is considered a good way of incorporating the public opinion in the decision making process.
3) The proposed numerical guide will provide a good interim guideline in designing the facilities of radiation protection to comply with ALARA.
4) For future work, three additional studies are recommended : conductance of a comprehensive poll survey which properly reflects the public opinion, construction of an appropriate medical database of radiation exposure in Korea, and performance of a further study on the relation between social factors and associated monetary values.

Acknowledgement

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References

1. Research & Development on Next Generation Reactor (Phase I) : Design of Radiation Protection, KEPRI (1994)
2. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection. ICRP Publication 26, Pergamon Press (1977)
3. Thomas M. Power, The Economic Value of the Quality of Life, Westview Press/Boulder, Colorado (1980)
4. World Bank, Social Indicators of Development (1993)
5. Paul Slovic et al., Facts and Fears : Understanding Perceived Risk, in R. Schwing and W.A. Albers, Jr. (eds.) Societal Risk Assessment : How Safe Is Safe Enough? (1980)
6. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Pergamon Press (1991)
7. A Study on the Radiation and Environmental Safety : Development of Radiation Protection and Measurement Technology, KAERI/RR-1328/93 (1994)
8. Commission of the European Communities, Radiation Protection : ALARA from Theory towards Practice, EUR 13796EN, Luxembourg (1991)
9. Mika Kivim ki and Raija Kalimo, Risk Perception Among Nuclear Power Plant Personnel : A Survey, Risk Analysis, Vol 13, No 4 (1993)
10. Y. Nakashima, M. Doi, Study of the System of Dose Limitation : Long Term Variation of the α_0 Value in Japan, IAEA-SM-285/06, In Proceedings of a Symposium, Vienna, 10-14 March 1986 jointly organized by IAEA and OECD/NEA, IAEA, Vienna (1986)