Progress in NUCLEAR SCIENCE and TECHNOLOGY, Vol. 1, p.468-470 (2011)

ARTICLE

A Probabilistic Cost Assessment of a Nuclear Reactor Accident Focused on Evacuation and Radiological Health Effects

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The economic cost of a severe accident at a nuclear power plant was evaluated with the probabilistic approach. A 1 GWe PWR plant at Uljin in Korea was selected as the model plant and the accident scenario giving the highest radiological consequence, after calculations with MACSS code, was used as the conditions for input variables. The assessment covers only the cost that would incurred due to the evacuation of affected population and the radiological health effects. The two dimensional Monte Carlo Analysis method was applied to cope with the variability and uncertainty in the variables determining the cost. In addition, sensitivity analyses were performed to indentify the important variables in assessment of economic costs. The resulting cost of around 100 billion Korean Won (approximately 100 million US dollars) seems somewhat lower than the speculated, which can be attributed to the fact that the model plant is located at a remote site from the highly populated areas.

KEYWORDS: nuclear power plant, severe accidents, economic cost, radiological health effects, two-dimensional Monte Carlo analysis

I. Introduction

As one perspective of risk associated with reactor accidents, the economic damage to the society is an important topic. Assessment of economic risk however is not a simple task due to wide spectrum of hazard caused by a nuclear reactor accident and multiple factors involved in quantification of the consequences. Indeed, OECD/NEA emphasized strongly that there is no single value for "cost of an accident" in nuclear power plant.[1,2)]

In this respect, the probabilistic estimation becomes an attractive tool for this task. In the probabilistic analysis, the one-dimensional Monte Carlo analysis (1D MCA) has been used to characterize variability in each input. An advanced technique called the two-dimensional Monte Carlo analysis (2D MCA) is getting attraction because it gives better insights by providing both uncertainty (U-type) and variability (V-type) in one or more input variables.[3,4)]

Many types of hazards can be transformed into economic loss. In addition to the direct costs, which include the capital loss of the plant under accident, cost incurred by emergency response and cost of banning local products, indirect costs such as impact to the public health and cost caused by sensitive reaction of the public can follow. Since quantification of all the costs is extensively complicated, the economic impact related to only evacuation and radiological health effects are considered in this paper.

As a model nuclear power plant, a PWR of 1 GWe at Uljin, on the east coast of Korea, was selected. The 2D MCA method was applied in the process of quantifying uncertain factors. For the purpose of this study, it is assumed that the radioactive plume is directed the residential area.

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II. Materials and Method

The radiological consequences of a severe accident at the nuclear power plant were calculated by use of the MACSS code system.[5)] The basic information needed for estimation of the economic impact, e.g. expected range of affected area, dose levels depending on the distance from the reactor and numbers of exposed person, is obtained from the calculations.

1. Model for Cost evaluation

1.1. Evacuation Cost

The total evacuation cost consists of three components: transport, accommodation and loss of income.[6,7)]

Transport cost includes the direct expenditures due to the movement of people away from and back to the relocation area. Two kinds of transports can be used for the evacuation of persons (i.e. private transport and planned transport by emergency operation team). Based on the result of a questionnaire survey, it is assumed that 99% of the population use private transport. The average distance between the evacuation area and the destination is 50km.[8)] For private transport, the average number of people per vehicle is set to 3.8.

Accommodation cost includes that incurred when people cannot use their own dwellings or houses during the period of evacuation. The total accommodation cost is obtained by multiplying the number of people evacuated by a unit cost of accommodation per capita per day and by the duration of evacuation, which reflects the experiences of natural disaster. Loss of income cost means that of benefit loss due to stop of production facilities in the evacuated area. The total loss of income is then obtained by multiplying the number of people evacuated by a loss of income per capita per day (unit cost) and by the duration of evacuation. The unit cost is derived

from the national Gross Domestic product (GDP) data for the potentially affected region.

1.2. Early Health Effect Cost

The evaluation of the total early health effect cost is evaluated by using the human capital approach which assumes that two cost categories contribute to health effect costs: (i) the cost for medical treatment for early health effects, and (ii) the losses of an individual contribution to the economy.

In order to obtain the cost for medical treatment, the unit cost of each effect is multiplied by the rounded value of the number of effects expected, which is given by MACSS calculations. The cost of loss to economy due to illness is calculated by multiplying the number of expected cases of each category of effect by the unit cost of one year lost and by the discounted number of years of life lost per type of effect.

1.3. Late Health Effect Cost

Similarly, the total late health effect is assumed to have the two costs, that is, the cost of medical treatment for late health effects and that of losses of an individual contribution to the economy. The late health effects include all the types of radiation induced cancers and the heritable diseases. The unit cost for the medical treatment corresponds to the weighted average value of cancer treatment (86%) and hereditary effect treatment (14%).[9] The total cost for medical treatment is obtained by multiplying the expected number per year by the unit cost for medical treatment, the later being discounted using a discount factor calculated for each year on the bases of a discount rate of 5%.

2. Sensitivity Analysis

For the purpose of sensitivity analysis, variables estimated from sub-model involving observed data and surrogate or assumed data should be segregated within the probabilistic analysis models. Thus, a probability function is developed for such variables based on observed data without the effect of surrogate or assumed data. The segregation has the benefit of improving the characterization of the input variables and the identification of significant contributors in model outputs[3]. In this work, to obtain reliable output, significant correlations among input variables were taken into account in the Monte Carlo simulation. Spearman's rank correlation coefficients (RHOs) are calculated for input variables to determine if significant correlation exists.

3. Two-dimensional Monte Carlo Analysis

The 2D MCA was used with an uncertainty analysis that requires variability to be distinguished from other types of uncertainty.[10] All probability density functions (PDFs) used to describe the variability in the model have some certain degree of uncertainties. For example, variability in the period of evacuation can be presented by using a normal PDF with a mean and a standard deviation, but this model is subject to uncertainty.

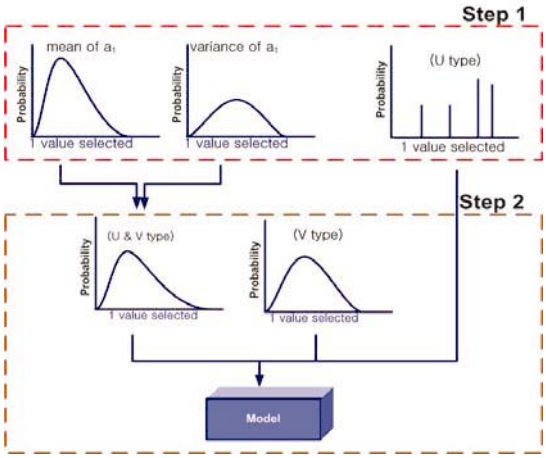

Fig. 1 Illustration of the 2D Monte Carlo simulation process.

The process of 2D MCA is illustrated in **Fig. 1.** The number of runs used was 100,000 and 250 for the inner and outer loop, respectively. Thus, a total of 250 cumulative distribution functions (CDFs) were generated.

III. Results and Discussion

This study aims at estimating the economic risks like the quantitative damages based on the methodology for ECONOM Module of RODOS. Plausible data sets reflecting the culture, society, economy and health indices in Korea were investigated and then the probabilistic distributions of the variables were derived. The probabilistic analysis reflecting these distributions were performed by cost variable using the CrystalBall 7.2.1 program.[11] The results were presented as the cost distributions and the representative percentiles by cost.

The 250 CDFs generated through 2D MCA are used to plot the 90% confidence interval for the median as shown in **Fig. 2**, where 1D MCA results are compared.

Confidence limits for the 2.5th, 5th, 10th, 25th, 50th, 75th, 90th, 95th and the 97.5th percentiles of early economic cost are given in **Fig. 3**. As can be seen from **Fig. 3** and **Table 1**,

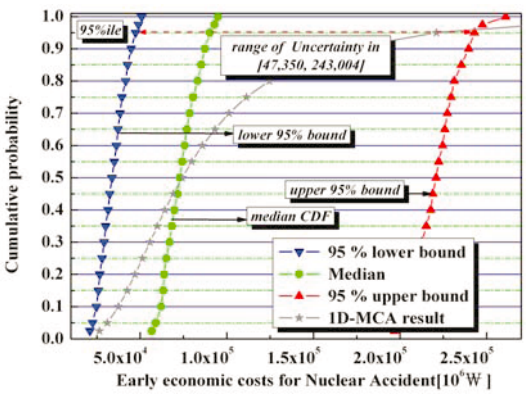

Fig. 2 90% confidence intervals of economic costs for a hypothetical severe accident at Uljin unit 3or 4.

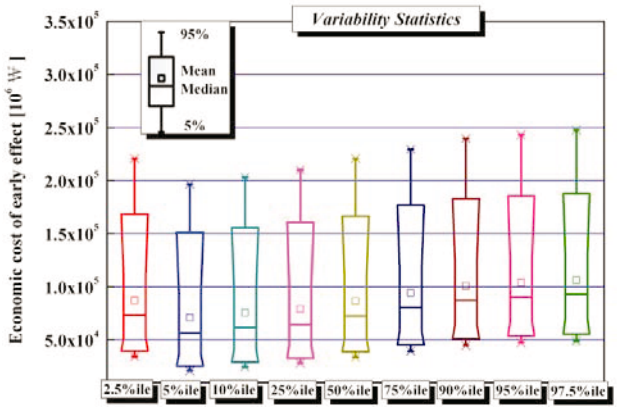

Fig. 3 Statistical summary for variability of economic cost from the 2D MCA. The presented are 90% confidence intervals for each percentile indicated.

Table 1 Summary of economic costs

Method	Percentile	Range of total early economic cost [million won]			
		5%	Median	Mean	95%
2D MCA	2.5%ile	21,000	56,659	79,100	151,389
	50%ile	33,654	72,955	93,197	220,895
	97.5%ile	49,036	92,985	110,533	247,631
1D MCA		31,061	74,241	94,031	221,044

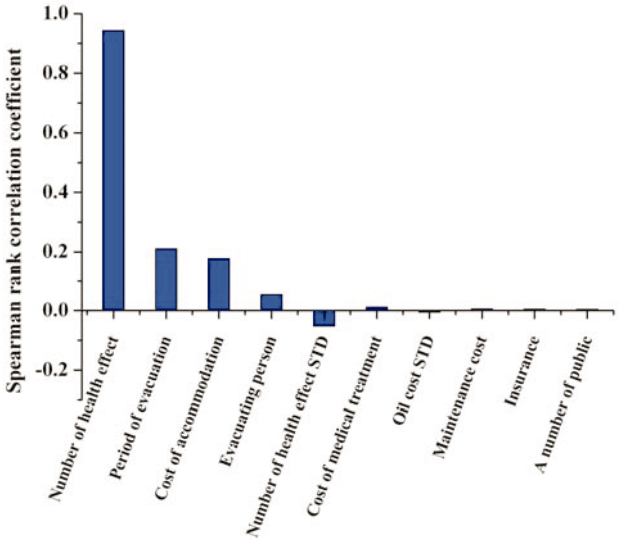

Fig. 4 Sensitivity of input variables in the economic cost models.

the simulation suggests there is the median that the 97.5th percentile economic cost is below 93 billion won.

Additionally, the sensitivity analysis was performed on each of effect of the input variables to determine the factors having high effect on the economic costs. RHOs were to be 0.94, 0.21, 0.18 and 0.05 for number of health effect, period of evacuation, cost of accommodation and evacuating persons, respectively as shown in **Fig.4**, which is the order of the sensitivities to economic costs.

IV. Conclusion

The economic risk of a nuclear accident is one of major concerns in a country with operating nuclear power plants. This study attempted to assess economic damages from a hypothetical accident at a nuclear power plant in Korea although it is not exhaustive by focusing on the cost of evacuation and radiological health effects. A probabilistic approach using 2D MCA was employed to cope with the variabilities and uncertainties in the variables. Since the model plant is located in remote region of Korea, the estimated economic damage remains in the order of 100 billion Korean Wons (roughly 100 million US dollars). Considering that the economic risk assessment is still at an early stage of development, the methodology in this study should be refined and expanded further to be used in the overall economic risk of a sever accident in a nuclear power reactor.

Acknowledgments

This work was supported by Korean Ministry of Knowledge Economy (2008-P-EP-HM-E-06-0000), Ministry of Education, Science and Technology of Korea, and Sunkwang Atomic Energy Safety Co., Ltd..

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