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Characterizing Parameters Using Expert Judgment and Bayesian Update in the Risk Analysis for Field Radiography

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1. Introduction

Radiological risk assessments can be calculated using crisp estimates of the exposure variables (e.g., source term, exposure time, distance, exposure frequency). However, aggregate and cumulative exposure studies require a better understanding of exposure variables and the uncertainty and variability associated with them[1]. Probabilistic risk assessment (PRA) is a tool for quantitative estimation of risk and associated uncertainties. The prevailing method in PRA is Monte Carlo analysis(MCA), which is a means of quantifying uncertainty or variability in a probabilistic framework using computer simulation.

Risk is expressed as the sum of the product of the frequency and consequence pair over the possible states[2]. The state of a system is a description of its physical condition and its environment. The status of all the barriers, controls defining the system and its environment determine the state. The radiation exposure is given by the summation of the exposure resulted from relevant exposure pathways. The most important factor of risk assessment is characteristic of the input variable. Risk estimation involves propagating the uncertainty distributions through the PRA models.

In this study, the data analysis portion of field radiography PRA is addressed for estimates of the parameters used to determine the frequencies and consequences of the various events modeled. The Delphi survey and the Bayesian update technique are employed in characterizing uncertain variables.

2. Methods and Results

The brief flow chart to estimate radiological risk assessment of field radiography is shown in Figure 1. The input variable collection for risk assessment used the Delphi method based on expert judgment. Bayesian approach used to solve the problem of behavioral approaches for Delphi technique. Batch fit function of Crystalball, which provides optimized distribution of variables using the chi-square testing, is used to set a distribution of input variables[3]. Uncertainties in the resulting risks were analyzed by applying 1D MCA based on the probabilistic inference.

2.1 Delphi survey

Data collections in the process of quantifying uncertain factors employed Delphi method which is based on the expert judgments and opinions. Expert judgment can provide useful information for forecasting, making decisions, and assessing risks. Application areas have been diverse, including nuclear engineering, aerospace, various types of forecasting (economic, technological, meteorological, and snow avalanches), military intelligence, seismic risk, and environmental risk from toxic chemicals[4,5].

A three-stage Delphi survey has been tried out for this study. Twenty expert panel members for this survey comprise of two groups of equal sizes; one from the Korea Institute of Nuclear Safety (KINS) and one from the non-destructive test (NDT) companies. The Delphi questionnaire has been designed as the general questions for ensuring the professionalism of the experts and the detailed questions for perceiving the factors needed for risk assessment. The results of risk estimates using the Delphi panel response for tasks in field radiography are shown in Figure 2. Generally, conservative risk estimates are obtained with the input from experts in the regulatory organization (KINS) compared with those with input from experts in NDT companies.

2.2 Distribution of risk parameters

In order to estimate probabilistic risk distributions of input variables should be set. The input data of 110 were obtained through the three-stage Delphi survey and their distributions were specified using ‘batch fit’ function in the Crystalball. The resulting distributions for the safety factors are summarized in Table I.

Table I: Distribution of safety factors in 3th Delphi survey

Safety factor †	Chi-Square	Distribution	Parameter			
1	1.20	Gamma	0	0.30	0.23	
2	2.00	Beta	0	0.91	0.80	1.28
3	1.60	Exponential	4.26			
4	0.80	Beta	0	0.96	0.38	1.02
5	1.20	Weibull	0	0.08	0.87	
6	4.80	Weibull	0	0.07	0.69	

† 1. Distance , 2. Source connected 3. Personal dosimeter and alarm, 4. Survey performed, 5. Reliability of radiation detector 6. Access

2.3 Bayesian update

A mathematical approach based on the Bayesian inferences was employed for data processing to improve the Delphi results. Application of Bayesian methodology consists of three phases: (i) quantifying prior distribution, (ii) constructing likelihood function and (iii) deriving posterior distribution based on likelihood function incorporated with the prior distribution.

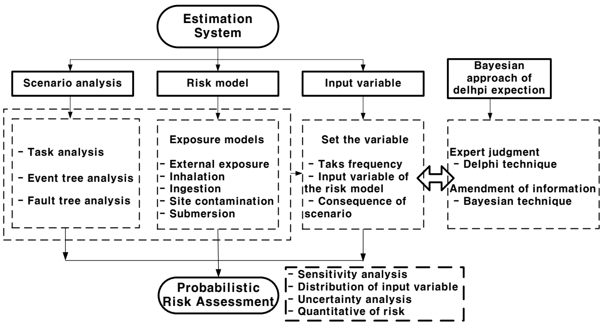
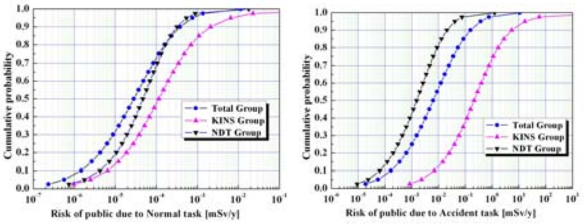
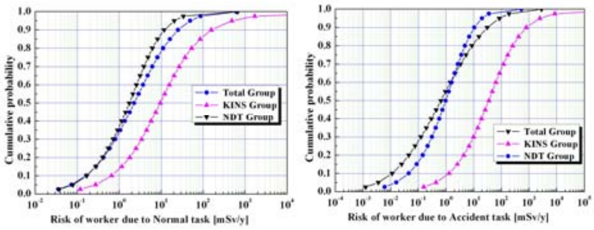


FIG. 1. The brief flow chart to estimate radiological risk assessment of field radiography.

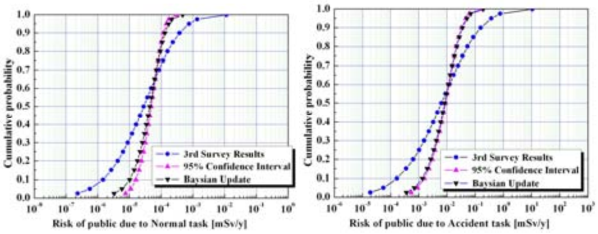


(a) public

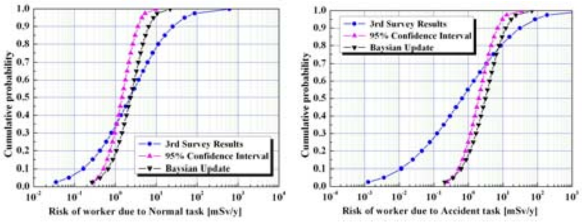


(b) worker

FIG. 2. Risks from assessment using Delphi panel response in field radiography; (a) Public (b) Worker due to normal task and accident.



(a) public



(b) worker

FIG. 3. Risk distributions from different characterizing methods of input variable; (a) Public (b) Worker due to normal task and accident.

WinBUGS statistic package based on the Markov Chain Monte Carlo method was used for deriving the posterior distribution[6].

The risk results by the input characteristic are depicted as the cumulative density functions (CDF) in Figure 3. The overall risks based on the Bayesian updating of the inputs are compared with both those without updating(3rd survey) and those resulted from the estimation employing data within the 95% confidence interval at the third-stage Delphi survey. The CDFs from without updating provides unrealistic exposures in the lower and upper bounds. On the other hand, the risks from the Bayesian updating well agree with the risks reflecting 95% confidence interval. The latter, however, suffers arbitrary rejection of some collected data.

3. Conclusions

The expert role provides valuable information through his or her decision within the framework of the availability of the data which are uncertain and restrictive, but certainly needed for risk analysis. In this study, the Delphi survey was tried out for obtaining the expert decisions, and the risks of the public and the workers were evaluated by the input characteristics. The approach characterizing input parameters using the Bayesian inference provided improved risk estimates without intentional rejection of part of the data, which demonstrated utility of Bayesian updating of distributions of uncertain input parameters in probabilistic risk analysis.

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