# An Analysis of Economic Factors for Level 3 PSA

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## 1. Introduction

Since the Fukushima accident, the public's interest in the severe accident risk of the nuclear power plant (NPP) in Korea has increased. In the case that radioactive materials are released from the NPP by a severe accident, it will affect not only on the public's health but also on the social and economic. The level 3 probabilistic safety assessment (L3 PSA) is one of the methods that predicts these effects.

However, in most previous domestic L3 PSAs, the economic factors were not included in the range of assessment or the economic data based on the U.S. were used. The economic factors required for L3 PSA are directly related to the results of the economic risk of the accident. Also, the results of the health risk are indirectly changed by the economic factors because the long-term protective actions are determined with consideration for the costs and benefits. In order to realistically evaluate the risk of the severe accident of domestic NPPs, it is essential to derive the economic factors for L3 PSA reflecting a Korean environment.

In this study, the input value regarding economic factors in MACCS (MELCOR Accident Consequence Code System), which is one of the most popular L3 computational codes, was determined, reflecting the socio-economic situation in Korea. Then, the developed inputs were applied to the level 3 PSA model of the reference plant and the health effects risk and the economic effects risk were evaluated.

## 2. Methods and Results

### *2.1 Economic Factors in MACCS*

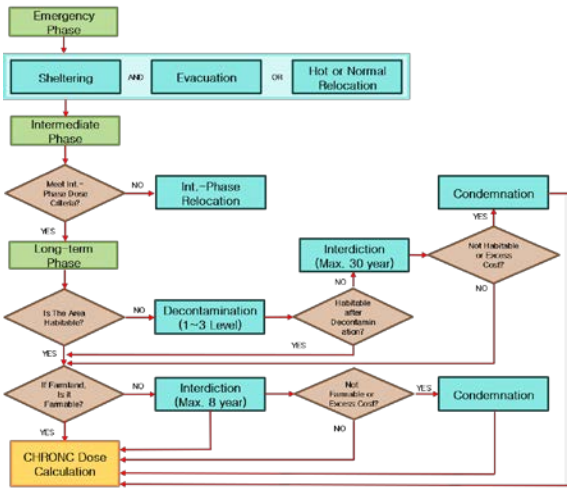


Fig. 1. Flowchart of protective action considered in MACCS

MACCS is a computational code for L3 PSA and widely used around the world. Among the various cost caused by the nuclear accident, only the cost that is taken to implement the protective actions is considered in MACCS. The cost categories covered in MACCS are as follow [1]: Evacuation and temporary relocation cost, crops and milk disposal cost, decontamination cost, interdiction cost, and condemnation cost.

To understand the modeling structure of economic evaluation in MACCS, it is necessary to comprehend the protective actions model first. The flow of the protective actions over time in MACCS is showed in Fig. 1. Sheltering and Evacuation in the emergency phase are aimed at preventing early health effects and implemented immediately regardless of doses or costs. Normal and hotspot relocation is for the non-evacuatee who receive a large dose. In the intermediate phase, only temporary relocation according to dose is considered.

The introduction of protective actions in the long-term phase is decided in stages. After the habitability decision making, the farmability is judged. The introduction of decontamination is considered firstly. If the contamination level after the decontamination in some area is expected to be higher than the criteria, the interdiction will be conducted before the decontamination. And if it is expected not to meet the criteria even though the interdiction with a maximum duration and the whole level decontamination would be carried out or if the cost for them is over than that for the condemnation, condemnation will be performed as soon as the long-term phase begins. Doses of residents in each sector are calculated from the end of these long-term phase protective actions.

In a MACCS model, variables regarding to the economic factors exist in CHRONC module. Related data blocks are as follow: Emergency-Response Cost Data (EVACST, RELCST), Decontamination Plan Data (LVLDEC, TIMEDEC, DSRFCT, CDFRM, CDNFRM, FRFDL, FRNFDL, TFWKF, TFWKNF, DLBCST), Interdiction Plan Cost Data (DPRATE, DSRATE, POPCST), and Regional Characteristics Data (FRCFRM, FRMPRD, DPFRCT, VALWF, VALWNF, FRFIM, FRNFIM). Some variables in the regional characteristics data block can be set differently according to the grid element sector in the site file to reflect the regional differences. Based on the inputs and the results of ATMOS and EARLY module calculation, several kinds of economic cost are estimated by simple mathematical expressions [2].

Table I: Estimated Value of Economic Variables

| Variable | Description [3] | Methods | Value |
|---|---|---|---|
| EVACST | Emergency Phase Cost of Evacuation/Relocation | Transport + Lodging and Food + Loss-of-income | 95 ($/man-day) |
| RELCST | Relocation Cost per Person-Day | | 95 ($/man-day) |
| DPRATE | Property Depreciation Rate | Depreciation Rate at Normal ∗ 5 | 0.167 (per year) |
| DSRATE | Societal Discount Rate for Property | Interest Rate + Property Tax | 0.02 (per year) |
| POPCST | Per Capita Cost of Long-Term Relocation | Annual Added Value / Population | 24,000 ($/man) |
| FRCFRM | Fraction of Area Used for Farming | (Dry Paddy + Rice Paddy + Orchard + Pasture) / Total Area | 0.201 |
| FRMPRD | Average Annual Farm Production | (Per Capita Agriculture, Forestry, and Fisheries GRDP ∗ Farm Population) / (Agriculture, Forestry, and Fisheries Population ∗ Farmland Area) | 12,915.6 ($/hectare) |
| DPFRCT | Farm Production Dairy Fraction | Livestock Products Revenue / Gross Agriculture Revenue | 0.086 |
| VALWF | Value of Farm Wealth | (Farm Household Fixed Asset ∗ Number of Farmhouse) / Farmland Area | 167,967.5 ($/hectare) |
| VALWNF | Value of Nonfarm Wealth | (Real Asset by House ∗ Number of House – Total Farm Wealth) / Population | 101,410.8 ($/hectare) |
| FRFIM | Farm Wealth Improvements Fraction | Appraisement of Buildings, Structures, and Equipment in Farm Household / Farm Household Fixed Asset | 0.2435 |
| FRNFIM | Nonfarm Wealth Improvements Fraction | 1 - (Land Asset ∗ Land Price Fluctuation + Farm Household Land Asset ∗ Number of Farmhouse) / Nonfarm Real Asset | 0.2925 |

*2.2 Korean-specific Value of Economic Variables*

A Korea-specific value was estimated based on the methodologies and descriptions stated in various studies and reports such as WASH-1400, NUREG-1150, and MACCS manual [1, 4, 5]. Statistics, enforcement ordinances, and research results from domestic authorities such as Statistics Korea, bank of Korea, Korea Appraisal, and etc. were utilized as base data sources. And the necessity of inflation adjustment was reduced by using as the latest data as far as possible. The exchange rate was assumed as 1$=1,069 Won.

However, variables in the decontamination plan data block were excluded in the range of this study. Among the variables about decontamination efficiency, duration, and cost, it is unreasonable to alter the value of one variable only because there is some correlation between them. In other words, they will be varied according to the implementation sequence. Also, the data of massive decontamination at the nuclear plant accident in a Korea environment are intensely insufficient. The process of deriving value used in NUREG-1150 and US SOARCA studies are too unclearly explained to adjust them for Korea environment [6]. Due to these reasons, the decontamination plan data block was decided to be excluded.

The estimation method and value of each variables considered in this study are tabulated in Table I. The variables in the regional characteristics data except the wealth improvements fraction can be replaced with corresponding variables in the site file. And various values can be assigned to each grid element according to the region index in the site file. Therefore, for these variables, the value by province was estimated. Values in Table I are the national average. In addition, the function to figure out an administrative district of each sector and to assign region index were added in the MSPAR-SITE code, a preprocessor of MACCS [7]. Fig. 2 is the MSPAR-SITE screen running this function.

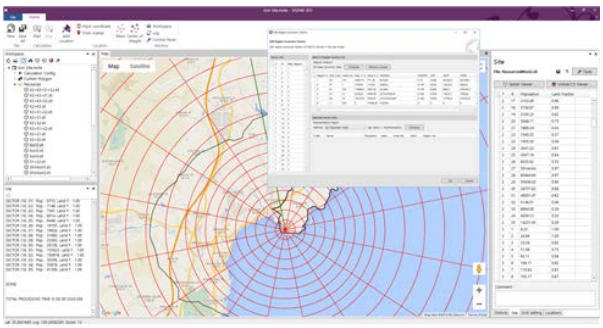

Fig. 2. Region index assignment in MSPAR-SITE code

### *2.2 Preliminary Level 3 PSA*

A preliminary level 3 PSA was conducted, applying the Korea-specific value of economic variables to the MACCS model. A value of the variables in the decontamination plan data were referred from US SOARCA (State-Of-the-Art Reactor Consequence Analyses) study [3]. The OPR1000 type reactor in Kori site was selected as a reference plant. The MACCS model used in the preliminary evaluation is based on an existing model developed for regulatory objectives [8]. Several parts such as the core inventory, food-chain model, evacuation velocity were improved from it. The frequency of each source term category (STC) is from the results of the level 1 and 2 PSA. STC 5 and 9 were excluded in this evaluation due to their zero frequency.

The health effects risk of the reference plant model with Korea-specific economic factors were analyzed. It is notable that the cost-benefit approach is not considered in the introduction of early phase emergency responses. So, the economic factors have an effect only on the latent health risk such as cancer, not on the early health risk.

In the domestic regulatory framework, the radius for health effects risk evaluation is not clearly defined yet. Therefore, the radii were set with the consideration of the US NRC criteria or the boundary of domestic PAZ (Precautionary Action Zone) and UPZ (Urgent Protective Action Planning Zone). Also, the domestic QHO (Quantitative Health Objectives) is not explicitly established yet. The OHQ suggestion, $5E^{-7}$/year for early health risk and $1E^{-6}$/year for latent health risk, proposed by the regulatory body were adopted as a benchmark for comparison with the results [9].

Table II shows risk margins, the QHO divided by the estimated risk results. It is confirmed that the preliminary evaluation results are significantly lower than the QHO in terms of the early health risk. Although the margin of the latent health risk, 79 to 101, is lower than that of the early health risk, it is enough to meet QHO suggestion.

Table II: Health Effects Risk Margin

| Radius | Early Health Risk Margin | Latent Health Risk Margin |
|---|---|---|
| US NRC (2 / 16 km) | 49,408 | 101 |
| PAZ & UPZ (5 / 26 km) | 209,278 | 79 |

The economic effects results are also analyzed. The long-term protective actions following the severe accident such as decontamination and their economic effects can occur in the area far from the plant so that 80km was selected as the radius of the evaluation. The risk measure to compare with the economic effects results are not well established yet. So, in this paper, the economic effects results are expressed as the relative magnitude of each STC and the risk contribution of each cost category.

Table III: Relative Total Economic Costs of STCs

| STC No. | Failure Mode | Total Economic Costs Ratio |
|---|---|---|
| 1 | NO CF, MELTSTOP | 7.23 |
| 2 | NO CF, RV FAIL | 7.23 |
| 3 | ECF, LEAK | 20.14 |
| 4 | ECF, RUPTURE | 37.00 |
| 6 | LCF, LEAK | 12.78 |
| 7 | LCF, LEAK | 13.98 |
| 8 | LCF, LEAK | 14.92 |
| 10 | LCF, RUPTURE | 15.12 |
| 11 | LCF, RUPTURE | 14.72 |
| 12 | LCF, RUPTURE | 16.53 |
| 13 | BMT | 12.58 |
| 14 | CFBRB | 396.07 |
| 15 | NOT ISO CHR, CSR | 8.70 |
| 16 | NOT ISO, FAIL | 32.85 |
| 17 | ISLOCA | 702.49 |
| 18 | SGTR | 287.69 |

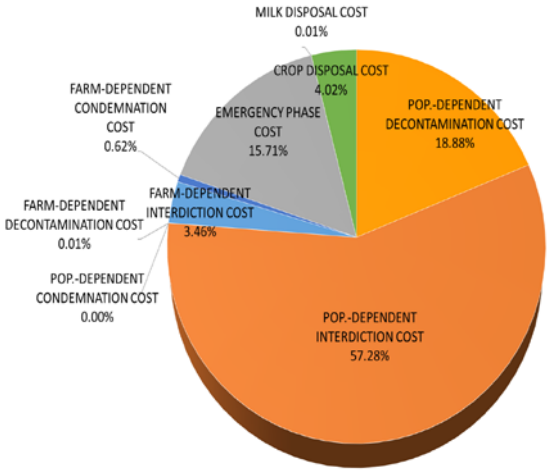


Fig. 3. Economic risk contribution of cost category

The relative magnitude of each STC is figured in Table III, using the ratio of the total economic costs resulted from each STC simulation to the simple average of those from all. The ratio is significantly high in the cases of ISLOCA (Inter-System Loss of Coolant Accident), SGTR (Steam Generator Tube Rupture), and CFBRB (Containment Failure Before Reactor vessel Breach), whose amount of released radioactive materials is relatively large.

Fig. 3 represents the contribution of each cost category to the total economic costs risk. More than 3/4 were population-dependent costs which are taken to meet the habitability criteria. Especially, the population-dependent interdiction cost holds more than half share.

On the other hand, the condemnation cost shows very low contribution regardless of population or farmland. It is implied that the radioactive contamination from hypothetical accidents of the reference plant can be reduced sufficiently after the implementation of decontamination or/and interdiction. In addition, it also means that the introduction of these two long-term protective actions is reasonable in terms of cost-benefit when Korea-specific economic factors are used in MACCS model.

## 3. Conclusions

In this study, the value of variables regarding economic factors in the MACCS code was derived and analyzed, reflecting a domestic situation. To derive Korea-specific inputs, various methods suggested in the previous studies were reviewed and used. And the valid data from the authorities (e.g. Statistics Korea) were referred. In addition, the function to facilitate to create a site file with regional economic information was developed and added in MSPAR-SITE code, a preprocessor of MACCS.

The derived values were applied to a full-power L3 PSA model of the reference plant and a preliminary evaluation of the health and economic effects risk were conducted. The results of the health effects risk are found to be significantly lower than the QHO suggestion. The results of the total costs tend to be proportional to the amount of the released inventory. While the cost of interdiction contributes a lot to the economic risk, that of the condemnation is rarely incurred in any STC case.

Several issues and improvement needs have been derived in the course of carrying out this study. The decontamination plan data were excluded in the range of this study. For future work, it is necessary to collect the data of decontamination experiences in other countries and to apply it to the Korean environment for future work. The need for additional updating MSPAR-SITE code raises to reflect the inland water system and to assign the regional index in the cases that a spatial sector includes more than 2 administrative districts. The derived variable values have a wide variance depending on the methodologies and data sources so that sensitivity analysis should be conducted.

The results of this study are expected to reduce the uncertainty in the evaluation of the severe accident risks and to contribute to the future studies of the level 3 PSA in Korea as the basic data.

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