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A Study on Risk Assessments Using the MACCS Code for a Nuclear Power Plant

Moosung JAE*, Seok Won HWANG

Department of Nuclear Engineering Hanyang University

17 Haengdang, Sungdong, Seoul, Korea

A consequence analysis includes assessment of effects on health and environment caused by radioisotopes released from severe accidents of nuclear power plants. In this study the consequence analysis to assess effects on health and environment caused by released radioisotopes has been performed for a nuclear power plant, Ulchin 3 & 4 using ORIGEN, MELCOR, MACCS code and IPE results. The core inventory and release fraction, respectively, are calculated by both the ORIGEN and the MELCOR code to produce the magnitudes of source terms amount for each radionuclide. And the MACCS code is utilized to calculate the offsite consequence by the amount of an atmospheric release of radioactive nuclides. Three parameters, such as the release height, the heat content, and the duration time, are used as important factors to perform the best estimate analysis and sensitivity analysis with respect to the measure of early fatalities and latent cancer fatalities. The results of this study may contribute to identifying the relative importance of various parameters occurred in consequence analysis as well as to assessing risk reduction accident management strategies.

KEY WORDS: source terms, risk assessment, health effects, early fatalities, latent cancer fatalities

I. Introduction

A consequence analysis denotes an assessment of effects on health and environment caused by radioisotopes released from severe accidents of nuclear power plants[1-2]. The consequence analysis has been now partly performed for the nuclear power plants in Korea, which are APR (Advanced Power Reactor)-1400 and YGN 3&4. By applying the integrated methodology using ORIGEN, MELCOR, MACCS code as well as the IPE (Individual Plant Examination) results to a Korean nuclear power plant, Ulchin 3 & 4, the overall radiation risk assessment including the consequence analysis has been performed in this study. The IPE and plant specific data, such as weather and population data of the plant, are used as input for the MACCS (MELCOR Accident Consequence Code System) calculations[3]. **Fig. 1** shows the risk assessment flow used in this study.

The potential magnitude of radionuclide release amount under severe accident loadings and offsite consequences are calculated by multiplying accident occurrence frequencies and the consequences to result in the overall risk of the plant. The source term bins of an accident progression based on the STD (Source Term Diagrams are simulated by both the ORIGIN and the MELCOR code to produce the magnitudes of source terms for each radioactive nuclides in this study. The release fractions and corresponding core inventories for the source terms have been obtained from both the ORIGEN and the MELCOR calculations. And subsequently they are utilized as input data for the MACCS calculations.

This work includes both the preparation of an input file for the ATMOS, EARLY, and LATE modules in the MACCS code and of inputs of the ORIGEN and the MELCOR code. The dose conversion factor and actual yearly weather data for Ulchin 3 & 4 plant are used for the overall risk

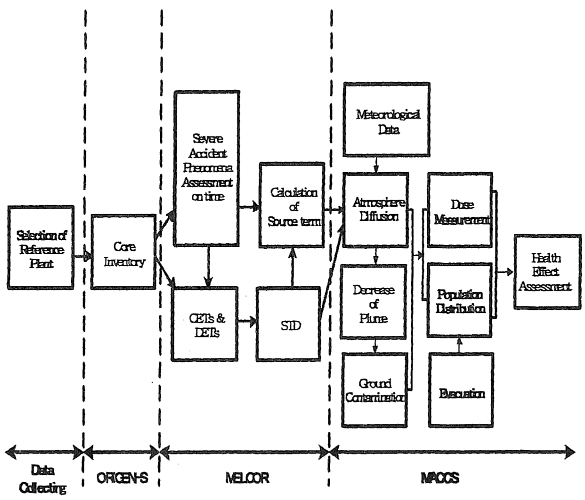

Fig 1. A procedure used for consequence analysis

* Corresponding author, Tel. +81-2-2290-1346, Fax. +81-2299-5729, E-mail; jae@ihanyang.ac.kr

calculations. Early fatalities, organ doses exposures, and latent cancer fatalities have been assessed using the integrated code packages and the IPE results associated with accident occurrence frequencies. In this study three variables, such as the release height, the heat content, and the duration time, are used as parameters to perform the sensitivity analysis for the 19 radiation source term categories.

The results of this study may contribute to identifying the relative importance of various parameters occurred in consequence analysis as well as to assessing risk reduction accident management strategies.

II. Methods

Both the core inventories and the radioisotopes release fractions have been calculated through the ORIGEN and the MELCOR code, respectively in this study. Using the ORIGEN and the MELCOR code, the plant specific source term for each accident scenario has been evaluated for the accident sequences, which are shown in the release categories[4]. The source term categories are shown in figure 2[3]. Defining the source term categories, all possible branches are considered, and then some branches are neglected due to their relatively low frequencies. Among the remaining release categories, however, some categories are defined to have the same characteristics, even if they have different representative accident scenarios. Eliminating any scenarios with quotient zero from the early effects evaluation, dominant groups of accident sequences, such as STC 15 and STC 4, are surveyed. **Table 1** represents some of characteristics for STC 15 and STC 4 sequences. Three variables, such as release height, heat content, duration time, are utilized as important parameters for analyzing sensitivity for the 19 groups of radiation source terms in this study.

MACCS[2] code consists of three modules, such as ATMO S, EARLY, and CHRONC. The ATMOS module treats the a tmospheric dispersion, the transport of material, and its dep

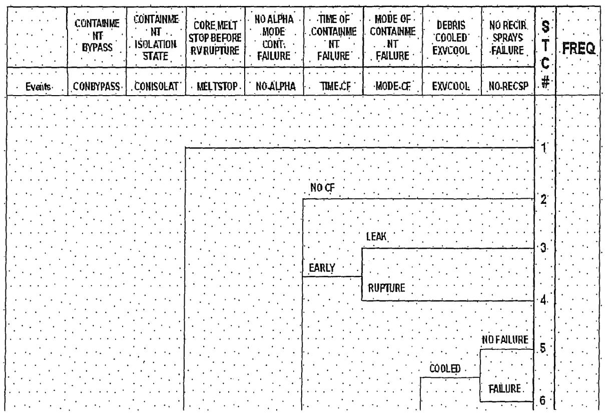

Fig 2. Source term diagrams used in this study

osition onto the ground. Meanwhile the EARLY module eva luates the direct exposure pathways, dosimetry, mitigative a ctions and health effects during the emergency phase. On th e other hand, the CHRONC module is used to produce the d irect and indirect exposure pathways, dosimetry, mitigative actions, and health effects during the period that follows the emergency phase. It also calculates the economic costs wit h the mitigative actions during the emergency, intermediate, and the long-term phases.

Since risk involves uncertainty and some kind of damage that might be received[4], the risk can be expressed a product of "Uncertainty" and "Damage". The risk analysis, therefore, consists of answers to the following questions. "What can go wrong? How likely will it happen? And "If it does happen, what are the consequences? These questions are three factors of risk triplets. Therefore the occurrence probability of the accident occurrence frequency obtained from the IPE has been multiplied by the consequence results to result in risk of the plant.

In addition, a quantitative analysis has been performed to evaluate the whole body dose and the organ dose, such as bone, lung, thyroid and stomach, exposed during severe accidents. They are presented in Section III with respect to the distance from the radiation source. Aforementioned high-frequency STC 15 and STC 4 are used for calculations

Table 1. Characteristics and Frequencies of STC 15 & STC 4

Type of Source Term	Containment Failure Mode	Initial Event	Frequency
STC 15	Early Containment failure: SIT Injection Success HPSIS Injection Success Recirculation Cooling Using CSS Success Without CTMNT Heat Removal System	Large LOCA	4.92×10^{-7}
STC 4	Early Containment Failure (Rupture): Reactor Trip Success AFW Fail Bleed RCS Fail LPSIS Injection Fail LPSIS Recirculation Success CTMNT Spray Injection Success Recirculation Cooling Using CSS Success	Loss of Feed Water	1.80×10^{-8}

varying 0 km to 64 km. In this study the evacuation speed is assumed to be a value of 1.8 m/s and 95 % of inhabitants are also assumed to evacuate from contaminated area during the severe accident.

III. Results

1. Doses for Organs

The doses for various organs, such as bone, lung, thyroid, stomach, and whole body dose are assessed for the centerline in the radius of 60 km from the plant[6]. As shown in **Table 2**, the release fractions for Iodine, which is significantly affects the thyroid, is shown to be the largest value. **Fig. 6** and **Fig. 7** represents the calculation results of the organ doses for STC 15 and STC 4 respectively. Radiological dose of the thyroid gland is shown to be the highest value with respect to the distance. Noticeable is the lowest dose that is recorded in the stomach in both STC scenarios. It is because the stomach is located in the farthest in the radiological bombing course. Each organ dose has a correlation with both the release fractions to the exterior of containment and the dose conversion factors for 12 units of organs and 60 units of radioactive-nuclides.

Table 2. Release Fractions for STC 15 and STC 4

	STC 15	STC 4
Xe/ Kr	1.04E-01	9.99E-01
I	1.03E-01	9.99E-01
Cs	2.96E-03	4.59E-01
Te	3.35E-03	3.16E-01
Sr	2.79E-03	2.16E-01
Ru	1.28E-03	3.94E-01
La	1.18E-03	1.50E-01
Ce	1.06E-03	1.23E-01
Ba	2.79E-03	2.16E-01

2. Fatalities

This study performs a best estimate calculation and a sensitivity analysis for both early fatalities and cancer fatalities regarding STC 15, which have the largest frequency in 6 representative source term scenarios. **Fig. 3** shows the results with respect to early fatalities and cancer fatalities for release height ranging from 0 m to 60 m. As shown in **Fig. 3**, the release height has no significant effects on latent cancer fatalities. For the measure of early fatalities, the release height is shown to be effective and sensitive. In case the exact release height is unknown, it needs to be assumed conservatively.

Fig 4 shows the variations of early fatalities and latent cancer fatalities depending on latent heat contents ranging from 0 MW to 60 MW. As the latent heat content increases, the value of latent cancer fatalities decreases smoothly as shown in **Fig. 4**. In the mean time the value of early fatalities shows a significant decrease ranging from 0 MW to 20 MW for the same cases. With this reasons, as the heat content increases, the area of the low concentration in radioactive materials is characterized by the plume rise progression up to the distance of about 16 km. Eventually, the plume stops rising and radioactive material is expected to move onto the ground due to a warm atmosphere.

Fig. 5 shows the variation trends for the measures of early fatalities and latent cancer fatalities with respect to the duration time. As the duration time increases, the value of early fatalities decreases generally as shown.

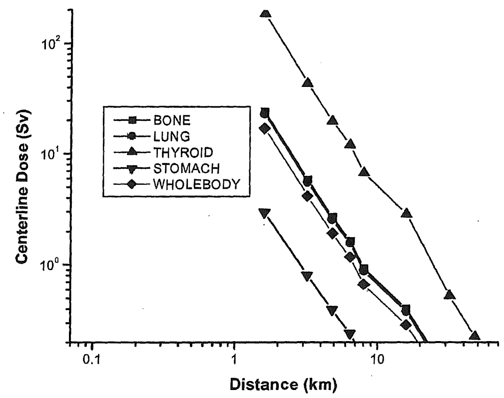

Fig 6. Organ doses with respect to the distance

(STC 15: Large LOCA)

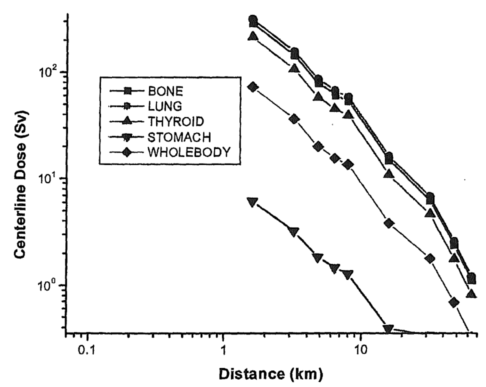

Fig 7. Organ doses with respect to the distance

(STC 4: Loss of Feed water)

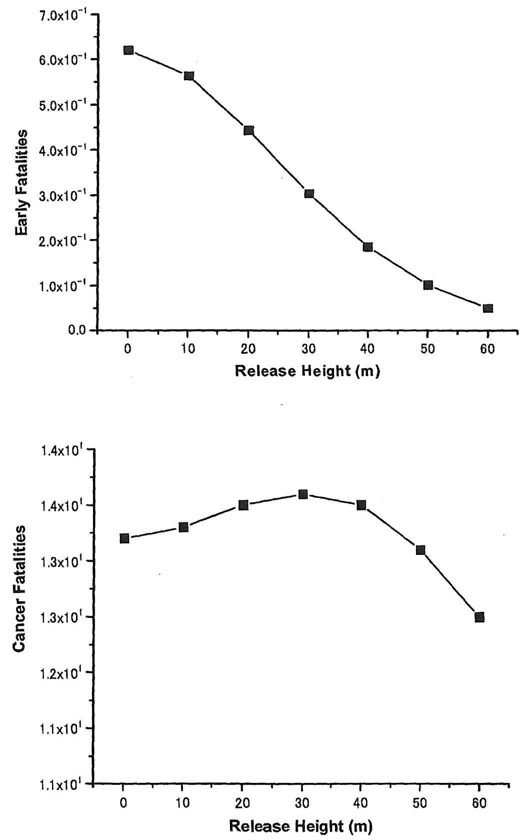

Fig. 3. Early and latent cancer fatalities with respect to the release height (0~32 km)

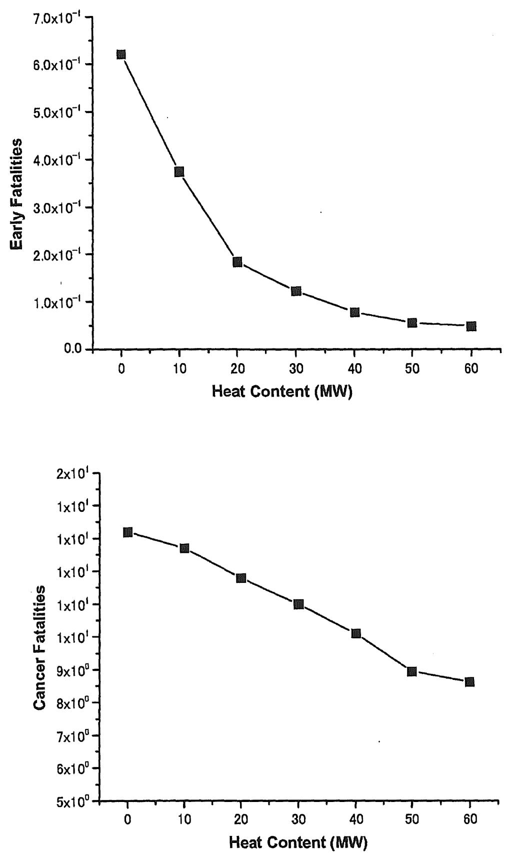

Fig. 4. Early and latent cancer fatalities with respect to the latent heat content (0~32 km)

3. Risk Assessments

Risk assessment is the process of assigning the probability of an adverse effect to a plant, a situation, or an action. The risk has been calculated for Ulchin 3 & 4 plant[3)]. The risk quantification is based on the concept of risk triplets, which are accident scenarios, probability of the scenarios, and consequence of the scenarios[5)]. The plant specific design data, the yearly plant specific site weather data and population data around Ulchin 3 & 4 plant are used as inputs for producing the plant specific risk curve. The occurrence probability of the 19 STC source term categories obtained from the IPE (individual plant examinations) has been multiplied by the consequence results[8)], which are 'early fatality' and 'latent cancer fatality' to determine the risk curves as shown in **Fig. 8**. This study includes the sequential use of computer codes, such as ORIGEN, MELCOR, and MACCS for assessing the risk of a specific nuclear power plant. The calculation procedure shown in **Fig. 1** is applied for assessing the plant accidental risk as well as identifying the dominant accident sequences and vulnerable systems during severe accidents. The calculation results in **Fig. 8** include the fatality risk with the average values as well as the 95 percentiles for the ranges of 32km and 80km, respectively.

IV. Conclusion

The consequence analysis to assess effects on health and environment caused by released radioisotopes has been performed for the reference plant of Ulchin 3 & 4 using ORIGEN, MELCOR, MACCS code and IPE results. The core inventory and release fraction, respectively, are calculated by both the ORIGEN and the MELCOR codes to produce the magnitudes of source terms amount for each radionuclide in the plant. And the MACCS (MELCOR Accident Consequence Code System), is utilized to calculate the offsite consequence by the amount of an atmospheric release of radioactive nuclides. Three parameters, such as the release height, the heat content, and the duration time, are used as important factors to perform the best estimate analysis and sensitivity analysis with respect to the measure of early fatalities and latent cancer

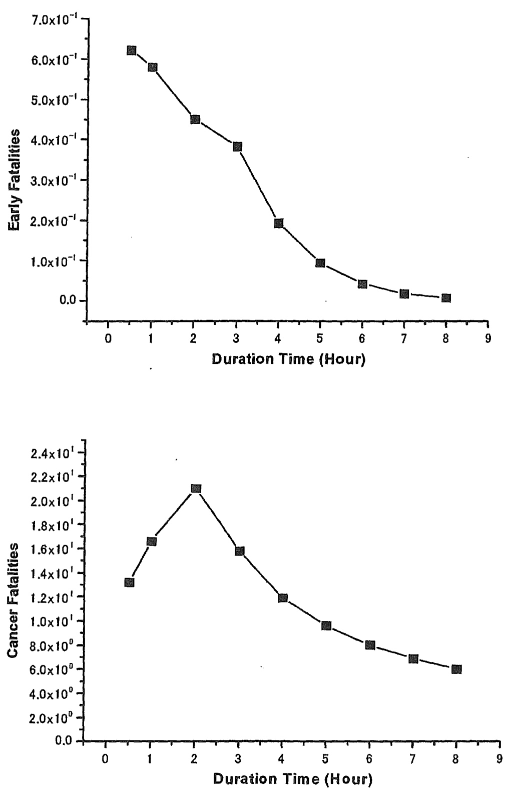

Fig 5. Early and latent cancer fatalities with respect to the duration time (0~32 km)

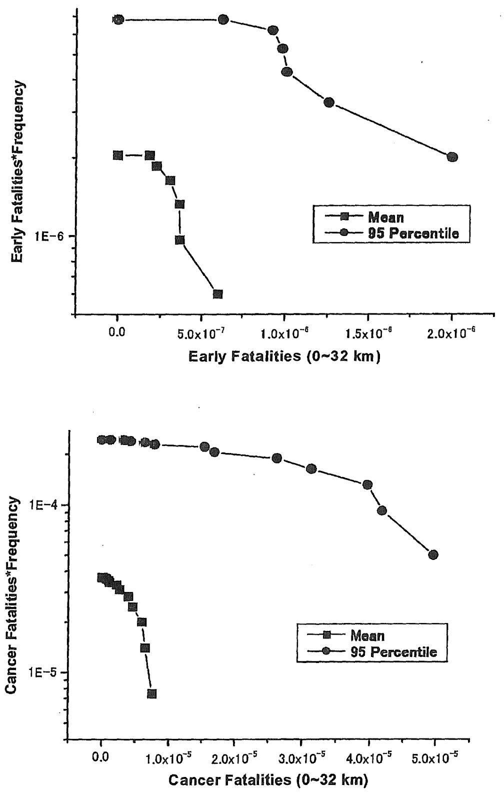

Fig 8. Risk curves for early and latent cancer fatalities (0~32 km)

fatalities. The results of this study may contribute to identifying the relative importance of various parameters occurred in consequence analysis as well as to assessing risk reduction accident management strategies.

The risk assessment results obtained for a specific nuclear power plant can be applied to establish the accident management plans (AMP) as well as to prepare periodic safety reviews (PSR).

Acknowledgement

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