Effect on the Offsite Consequence of the MACCS Non-Site-Specific Best Modeling Practices Used in the US SOARCA Project

Dong-Sik Jin [a*], Sang-Koo, Han [a], Chul-Kyu, Lim [a], Kwang-Il Ahn [b]
[a]*Atomic Creative Technology Co., Ltd., #406, IT Venture town, 35, Techno 9 ro, Yuseong-gu, Daejeon, Korea*
[b]*Korea Atomic Energy Research Institute, 1045 Daeduck daero, Yusoeong-Gu, Daejeon, Korea*
[*] *Corresponding author: jds@actbest.com*

1. Introduction

The evaluation of accident phenomena and the offsite consequences of severe reactor accidents have been the subject of considerable research over the last several decades. By applying modern analysis tools and techniques, the US Nuclear Regulatory Commission (NRC) has developed a body of knowledge regarding the realistic outcomes of the selected severe reactor accident scenarios for the Peach Bottom and Surry Power Stations and as a result, published the related report, NUREG-1935, in 2012 [1]. The integrated modeling of accident progression and offsite consequences in this State-of-the-Art Reactor Consequence Analyses (SOARCA) project have created best modeling practices drawn from the collective wisdom of the severe accident analysis community. The term 'best modeling practices' describes the best available modeling approaches and parameter choices to date. To analyze the offsite consequences in US SOARCA, in terms of health effect risk, the MELCOR Accident Consequence Code System (MACCS) code [2] was used and the report that provides a description of how MACCS modeling capabilities were used to represent important aspects of radionuclide atmospheric transport, emergency response, and dose response to radiation exposure was published in 2014 [3].

The US SOARCA project provided sample inputs for the MACCS II 1.12 offsite consequence model of Surry Power Station using previous model parameter values. This paper studies the effects of the new best modeling practices compared to the previous offsite consequence model using the Surry sample inputs. However, we only considered the MACCS non-site-specific modeling practices in the Surry model input; site specific data such as the population distribution data and the meteorological data are excluded. In this manner, the results are applicable to domestic power plants and provide a preliminary assessment of offsite consequences for domestic power plants.

2. Methods and Results

2.1 Assumptions and Conditions for the Effect Evaluation

The dose conversion factors for external exposure to radioactive material in the plume, radioactive material on the ground, and inhalation and ingestion of radioactive material provided with MACCS II 1.12 were used in the present work. These dose conversion factors are dose coefficients based on ICRP 26 and ICRP30 [4, 5]. US SOARCA used the dose coefficients provided in FGR-13 [6] which was based on ICRP-72 published in 1996 [7]. The effect of these updated dose coefficients is not considered in this preliminary effect evaluation.

In the source term, the data described in reference 8 (Table I) were used for this effect evaluation [8].

Table I: Release Fraction for 9 radioisotope group (small LOCA)

Radioisotope Group	Release Fraction
Xe/Kr	1.00E+00
I	7.70E-01
Cs	8.50E-03
Te	5.20E-03
Sr	2.60E-04
Ru	1.20E-06
La	4.70E-06
Ce	2.50E-08
Ba	1.30E-04

Other assumptions and conditions considered in the effect evaluation are as follows.

1. The MACCS II code version : 1.12
2. The region and object considered for the effect evaluation
    - Evaluation region : within16 km and 80 km
    - Evaluation object :
        - early fatality (unit : person, mean value)
        - cancer fatality (unit : person, mean value)
3. Dry deposition velocity : the existing NRC recommendation value(0.01 m/s) was applied due to severe accident code (MAAP or ISAAC) limitation (updated in SOARCA)
4. Early Injury Data: the value of LD_{50} for early injury related to PNEUMONITIS (A-LUNGS) was updated in US SOARCA. Because the effect of early and cancer fatality is only calculated in this effect evaluation, the existing value was applied.

2.2 The MACCS Best Modeling Practices for the Effect Evaluation

The MACCS best modeling practices applied in the analysis of the offsite consequences in this effect evaluation are described in Table II. These best modeling practices are some of the non-site-specific parameters which were updated values in US SOARCA project. The site-specific parameters such as emergency response related parameters and non-site-specific parameters such as dose conversion factor and dry deposition velocity related parameters are not considered in this preliminary effect evaluation.

The wet deposition data (Case 1) of Table II is related to the washout model which predicts how much material is deposited on the ground by rainfall. The variation is described in Table III.

The dispersion parameter data (Case 2) is related to the Gaussian plume model and the variation is described in Table IV.

The variations of the early fatality data (Case 3) and the latent cancer induction model (Case 4) are described in Table V and Table VI, respectively.

The Long-Term Protective Action Data (Case 5) is related to the duration of the long-term exposure period and the variation is described in Table VII.

Table II: The MACCS best modeling practices used for the effect evaluation

Case No.	Description
Case 1	Wet Deposition Data (Table III)
Case 2	Dispersion Parameter Data (Table IV)
Case 3	Early Fatality Data (Table V)
Case 4	Latent Cancer Induction Model (Table VI)
Case 5	Long Term Protective Action Data (Table VII)
Case 6	All of the best modeling practices are considered (Cases 1 ~ 5)

Table III: Wet deposition data variation between the previous parameters and the updated ones

Description	Previous	Updated
Linear Coefficient for Washout	9.50×10^{-5}	1.89×10^{-5}
Exponential Term for Washout	0.80	0.664

Table IV: Dispersion parameter data variation between the previous parameters and the updated ones

Description	Previous	Updated
Linear Coefficient for sigma-y (Stability Class A/B/C/D/E/F)	0.3658 0.2751 0.2089 0.1474 0.1046 0.0722	0.7507 0.7507 0.4063 0.2779 0.2158 0.2158
Exponential Term for sigma-y (Stability Class A/B/C/D/E/F)	0.9031 0.9031 0.9031 0.9031 0.9031 0.9031	0.8660 0.8660 0.8650 0.8810 0.8660 0.8660
Linear Coefficient for sigma-z (Stability Class A/B/C/D/E/F)	2.5E-4 1.9E-3 2.0E-1 3.0E-1 4.0E-1 2.0E-1	0.0361 0.0361 0.2036 0.2636 0.2463 0.2463
Exponential Term for sigma-z (Stability Class A/B/C/D/E/F)	2.1250 1.6021 0.8543 0.6532 0.6021 0.6020	1.277 1.277 0.859 0.751 0.619 0.619

Table V: Early fatality data variation between the previous parameters and the updated ones

Description	Previous	Updated
LD_{50} for Early Fatality Types (A-RED MARR/ A-LUNGS)	3.8 10.0	5.6 23.5
Shape Factor for EA Types (A-RED MARR/ A-LUNGS)	5.0 7.0	6.1 9.6
Threshold Dose to Target (A-RED MARR/ A-LUNGS)	1.5 5.0	2.32 13.6

Table VI: Latent cancer induction model variation between the previous parameters and the updated ones

Description	Previous	Updated
Lifetime Cancer Fatality Risk Factors(L-RED MARR/ L-BONE SUR/L-BREAST/ L-LUNGS/L-THYROIDH/ L-LOWER LI/ L-EDEWBODY)	9.70E-3 9.00E-4 5.40E-3 1.55E-2 7.20E-4 3.36E-2 2.76E-2	1.11E-02 1.90E-04 5.06E-03 1.98E-02 6.48E-04 2.08E-02 5.23E-02
Lifetime Cancer Injury Risk Factors(L-RED MARR/ L-BONE SUR/L-BREAST/ L-LUNGS/L-THYROIDH/ L-LOWER LI/ L-EDEWBODY)	0.0 0.0 1.7E-2 0.0 7.2E-3 0.0 0.0	1.13E-02 2.71E-04 1.01E-02 2.08E-02 6.48E-03 3.78E-02 1.72E-01
Dose-Dependent Reduction Factor(L-RED MARR/ L-BONE SUR/L-BREAST/ L-LUNGS/L-THYROIDH/ L-LOWER LI/ L-EDEWBODY)	2.0 2.0 1.0 2.0 1.0 2.0 2.0	2.0 2.0 1.0 2.0 2.0 2.0 2.0

Table VII: Long term protective action data variation between the previous parameters and the updated ones

Description	Previous	Updated
the duration of the long-term exposure period	1.E10 (317 years)	1.58E+09 (50 years)

2.3 Results

The results of the effect evaluation for early fatality during emergency phase are shown in Fig. 1. As shown in Fig. 1, in all of the cases excluding cases 4 and 5 which don't affect early fatality, the numbers of early fatality are decreased and the early fatality beyond 16 km doesn't occur. In case of the consideration of the all best modeling practices (Case 6), the number of early fatality is reduced to about 75%.

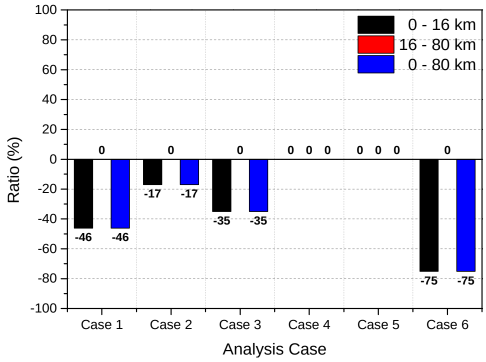

Fig. 1. The changes of early fatality-emergency phase calculation

The results of the effect evaluation for cancer fatality during emergency phase are shown in Fig. 2. There are some different effects between early fatality and cancer fatality during emergency phase. The numbers of cancer fatality of Case 1 in only 16 km and Case 2 in both 16 km and 80 km are decreased. But the numbers of cancer fatality of Case 1 in 80 km and Case 3 and Case 4 in all regions are increased. In case of the consideration of the all best modeling practices (Case 6), the number of cancer fatality in 16 km is reduced to about 13% and in 80 km is increased to about 41%. The Case 5, that is "Long-Term Protective Action Data", doesn't affect cancer fatality during emergency phase. Fig. 3 shows the regional distribution for each case

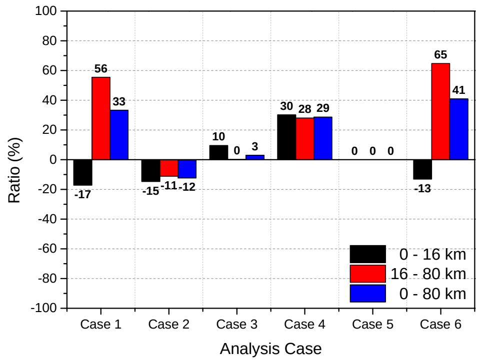

Fig. 2. The changes of cancer fatality-emergency phase calculation

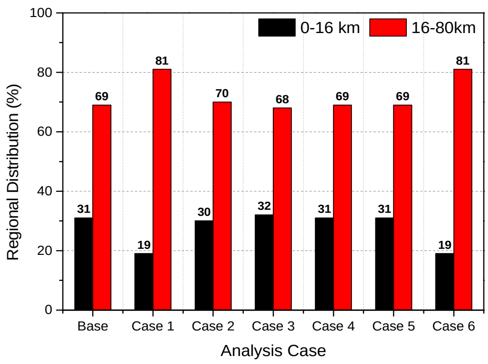

Fig. 3. The regional distribution of cancer fatality-emergency phase calculation

The results of the effect evaluation for cancer fatality during emergency and long term phase are shown in Fig. 4. The effect of cancer fatality during emergency and long term phase is similar with that of cancer fatality during emergency excluding the Case 5. The number of cancer fatality of the Case 5 in all regions is slightly decreased. Fig. 5 shows the regional distribution for each case.

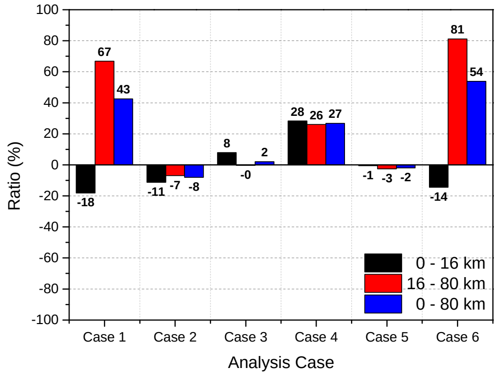

Fig. 4. The changes of cancer fatality-emergency and long term phase calculation

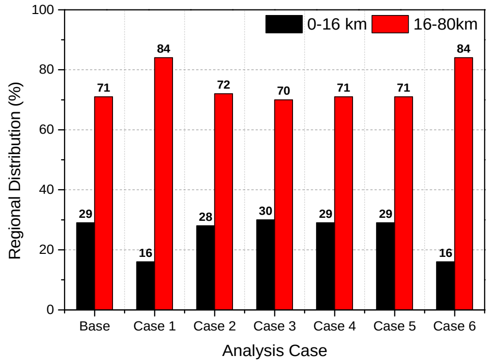

Fig. 5. The regional distribution of cancer fatality-emergency and long term phase calculation

3. Conclusions

In terms of a preliminary analysis applicable to domestic nuclear power plants, the effect evaluation on offsite consequences was performed by applying some of the non-site specific parameters used in the offsite consequence analysis of Surry Power Station in the US SOARCA project to the previous offsite consequence model and sample MACCS II 1.12 inputs for Surry Power Station. The results reflect offsite consequences for domestic nuclear power plants excluding the site specific data such as population data and the meteorological data.

The results show that there are some differences between early fatality and cancer fatality. For early fatality, in all of the cases excluding cases 4 and 5 which don't affect early fatality, the numbers of early fatality are decreased. But for cancer fatality, the effects are varied. The numbers of cancer fatality of Case 1 in only 16 km and Case 2 in both 16 km and 80 km are decreased. The numbers of cancer fatality of Case 1 in 80 km and Case 3 and Case 4 in all regions are increased. When all of the best modeling practices are considered (Case 6), the number of cancer fatality in 16 km is reduced and in 80 km is increased. Therefore, in view of non-site-specific parameters considered in this effect evaluation, these updated best modeling practices may cause the results of some parts of the offsite consequences to be worse such as cancer fatality beyond emergency planning zone and to be better such as early fatality than the previous non-site-specific parameters.

The present preliminary effect evaluation applied some of non-site-specific parameters and did not consider the site-specific parameters such as emergency response related parameters and non-site-specific parameters such as dose conversion factor and dry deposition velocity related parameters. Therefore, the offsite consequence analysis applying the best modeling practices related to all site-specific and non-site-specific parameters need to be performed for the more realistic results.

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