An Evaluation of Long-term Protective Actions using the MACCS Code

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1. Introduction

Radioactive materials released to the environment by a severe accident that may occur in a nuclear power plant(NPP) can affect the surrounding area for a relatively long period of time. As a result, the residents of the area will be exposed for a long time through the external exposure from the contaminated ground and the internal exposure from the inhalation of resuspended radionuclide and the ingestion of the contaminated food. The Fukushima accident occurred on March 11, 2011 has been affecting the vicinage. It reminds that the rational intermediate and long-term mitigation strategies and the criteria of protective actions for severe accidents are necessary.

The basic concept of the long-term protective actions is to protect people from radiation-induced health effects while keeping the individual life style close to normal. For this purpose, not only the justification and the optimization but also the social, economic and political issues must be taken into consideration in the establishment of the criteria on the long-term protective actions.

To review and evaluate the Korean criteria of the long-term protective actions, it is necessary to reflect actual accident scenarios as much as possible. In this study, MELCOR accident consequence code system(MACCS), a computational code for the level 3(L3) probabilistic risk analysis(PRA), was used to predict the accident consequences by applying the domestic criteria of the long-term protective actions concerning the habitability to the accident scenarios that may occur in a reference NPP. And the results were analyzed and compared with those from the criteria in other countries and organizations.

2. Methods and Results

2.1 Code and Reference model

In L3 PRA, the effects on health and economics from the radionuclide released to the atmosphere are assessed quantitatively. In the MACCS, a L3 PRA computation code, the intermediate phase can be set after the early phase generally considered 7 days after the release. During the intermediate phase, the exposure pathways are the ground-shine and inhalation of the resuspended radioactive materials. The only protective action applied in the intermediate phase is temporary relocation based on the user specified time and dose during the whole intermediate phase. The long-term phase is after the intermediate phase. The ingestion of contaminated food and water is considered as an additional exposure pathway. The mitigation actions related to the habitability in the long-term phase include decontamination, temporary interdiction, and condemnation. If the dose during the time specified for the long-term phase is not satisfied, the residents of the area will be relocated and decontamination and temporary interdiction will be performed according to the degree of contamination. If the area is anticipated not to meet criteria even after the 30-year temporary interdiction or to cost too much, it will be permanently condemned [1].

In this study, The reference plant is the OPR1000 reactor type in the Kori site. Also, the situation in Korea was reflected as much as possible to assign the other MACCS parameters and if the data were scarce or underdeveloped, the values of the US SOARCA project were used [2,3].

2.2 Evaluation of Domestic Criteria

The standard for the intermediate and long term protective actions related to the habitability in the present Korean regulation system is for the temporary relocation and the permanent settlement [4]. Normally, the temporary relocation should not exceed over 6 months. It is shown in Table I.

Table I: Standard for the protective actions related to the habitability in Korea

Protective action	Determination Standard (Effective Dose)
Temporary Relocation	30mSv/first one month, 10mSv/next one month (One month represents 30 days)
Permanent Settlement	1Sv/lifetime (lifetime represents 70 years)

The calculation structure for the habitability in MACCS and the standard of the protective actions in Korea are inconsistent fully, which leads to the following discussions. First, the results may differ depending on the way to connect each criterion for the intermediate and long-term phase in MACCS and total three items for the temporary relocation and the permanent settlement in the Korean standard. And the starting time point of the domestic standard is not clearly defined. Also, the exposure from ingestion of food or water and other protective actions such as decontamination are not included during the

intermediate phase in MACCS. It may affect the received dose estimation. Lastly, return from the temporary relocation can start immediately in the domestic standard if it is satisfied, whereas the relocation of the intermediate phase in MACSS is maintained during whole intermediate phase.

Therefore, a base case and sensitivity cases in Table II were decided with consideration for these points especially to look into the effects of differences in return time from relocation and the exclusion of ingestion and decontamination from the intermediate phase.

Table II: Sensitivity Cases for Evaluation of Domestic Standard

Case	Intermediate Phase		Long-term Phase	
	Duration [sec]	Dose [Sv]	Duration [sec]	Dose [Sv]
1 (Base)	1.56E+07	0.08	2.21E+09	1
2	7.78E+06	0.05		
3	~~0~~	~~1E+05~~		

The values of parameters for the long-term phase were fixed to 2.21E+09 seconds and 1 Sv in the all cases, using the standard of the permanent settlement intactly. In this study, the first case that the standard of the relocation during 6 months was applied to the intermediate phase was consider as a base case. In the second case, the intermediate phase was set to 3 months and the sum of the domestic determination standard of the temporary relocation would be the value of dose. The temporary relocation and intermediate phase were not considered in the third case. The results of the sensitivity study are shown in the Fig. 1, 2, and 3.

There was no change in the results related to the emergency phase such as the early fatality risk. In all cases, the cancer effects risk to 17 km and 30 km sufficiently satisfied the quantitative health objectives(QHO) of US which are under 2E-06/ry [5]. Also, as the level of the protective actions increased, the population and the maximum distance affected by each protective action decreased sharply. The population affected level 2 decontamination and interdiction resulted in zero because they were not conducted in the calculations due to higher costs than the condemnation.

In the base case, the intermediate phase costs accounted for 74.4% of the total economic costs. In the second case, the cancer effects risk increased by 6.7% at ~17 km and 11.8% at ~30km. And the affected population of the intermediate phase relocation, the level 1 decontamination, and the condemnation increased by about 1.2, 1.7, and 1.6 times each. The total economic costs decreased to 78.4%. For the last case, the cancer effects risk increased by 12.1% at ~17 km and 54.0% at ~30km. Whereas the intermediate phase relocation was not implemented, the affected population of the level 1 decontamination and condemnation greatly increased by 4.5 and 2.4 times each. The total economic costs were 77.4% of the base case, which were not much different from the second case.

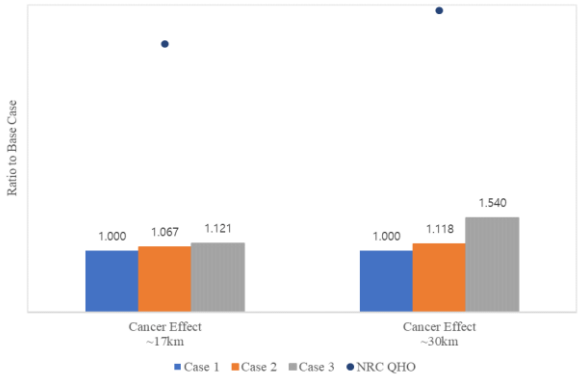

Fig. 1. Change of the cancer fatality risk by sensitivity cases.

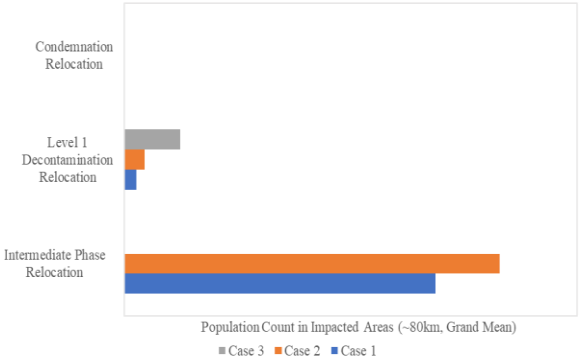

Fig. 2. Populataion affected by each protective action for sensitivity cases.

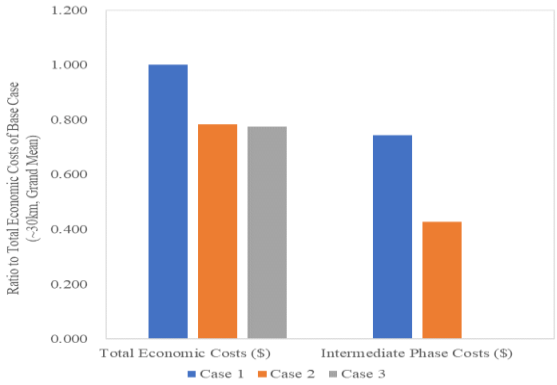

Fig. 3. Change of the economic costs by sensitivity cases.

The results showed that the shorter the intermediate phase is, the greater the cancer risk and the affected population and distance, and the smaller the economic costs. It is caused by the reduction in amount of the radioactive materials over time after the accident due to their decay and other reasons. Thus, when applying the

same Sv/month criteria in the intermediate phase, the shorter duration makes satisfaction of the habitability more difficult and more population and areas affected in the intermediate phase. Also, the level of the contamination at the time to start the long-term phase becomes higher, which increases long-term population dose, affected population and distance of protective actions in the long-term phase. The decrease of costs can be explained by the decrease of the intermediate phase costs which has the large portion of the total costs. Despite the increase of affected population, the intermediate phase costs decreased due to shortening th duration and it overcame the increase of the long-term phase costs.

In practice, the duration of the temporary relocation assumed to be one value will vary area by area depending on the contamination level. Moreover, it should be noted that decontamination and ingestion in the intermediate phase are not considered in MACCS. Therefore, the realistic results will be in some range among sensitivity cases. For the conservative approach, a consideration of the intermediate phase depends on whether the focus of evaluation is on the health effects or on the economic effects.

2.3 Comparison with Overseas Criteria

US Environmental Protective Agency(EPA) states that relocation will be implemented when the expected annual dose exceeds 20 mSv in the first year of the accident or 5 mSv in a next and continuous year [6]. Based on this guide, the sum of the dose limits during first five years was used as the value for the long-term phase without the intermediate phase for the Surry NPP in the State-of-the-Art Reactor Consequence Analyses(SOARCA) project of NRC. But, 20mSv/yr for the intermediate phase and 5mSv/yr for the long-term phase were applied for the Sequoyah NPP [3,7].

After the Fukushima accident in Japan, a government announced on 11 April 2011 that the relocation of residents would be implemented in areas expected to exceed 20 mSv in one year from the accident. Though the designation of the relocated areas was reorganized later, the criteria of the restricted residence zone and the evacuation order cancellation preparation zone remain at 20mSv/yr [8].

In IAEA Safety Standards updated after the Fukushima accident, 100mSv in the first year and 20mSv/yr in the next years, 1/5 of the first year, are proposed to the generic criteria for relocation [9].

Therefore, the cases for the comparison with overseas criteria are shown in Table III. In the Fig. 4, 5, and 6, The results applying these values to the base model were compared with the base case 1 using the domestic standards.

In the all cases using the overseas criteria, the cancer risk decreased by 20~40% from the base case. Also, costs, affected maximum distance, and affected

Table III: Cases for Comparison with Overseas Criteria

Case	Intermediate Phase		Long-term Phase	
	Duration [sec]	Dose [Sv]	Duration [sec]	Dose [Sv]
EPA PAG 1 (Surry)	~~0~~	~~1E+05~~	1.58E+08	0.04
EPA PAG 2 (Sequoyah)	3.15E+07	0.02	3.15E+07	0.005
Japan	~~0~~	~~1E+05~~	3.15E+07	0.02
IAEA	3.16E+07	0.1	3.15E+07	0.02

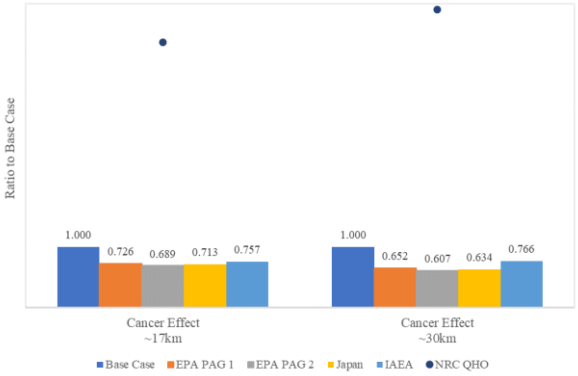

Fig. 4. Change of the cancer fatality risk by application of the overseas criteria.

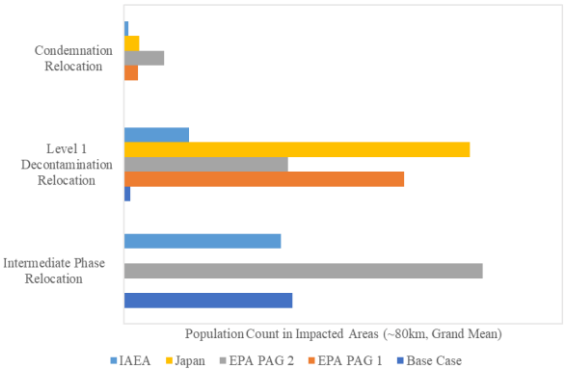

Fig. 5. Populataion affected by each protective action for overseas criteria cases.

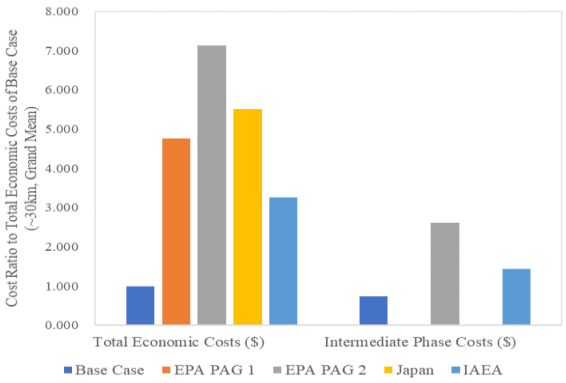

Fig. 6. Change of the economic costs by application of the overseas criteria

population except the intermediate phase relocation greatly increased. It implies that the domestic criteria will be easier to achieve than overseas ones and residents will receive more dose. The reason is considered to be related to the duraion of the long-term phase. The contamination of the surrouding area by the radionuclide and corresponding dose will decrease with time. Therefore, even if some areas meet the domestic criteria for 70 years, they may be impossible to satisfy the overseas criteria regarding the annual dose when the time is not far after the accident.

The results of two cases based on the US EPA PAG showed some differences according to the parameter values. EPA PAG 2 case using the values of the evaluation of Sequoyah NPP leaded less cancer risk and population affected by the decontamination and more costs and population affected by the condemnation. It may be due to the differences in the exclusion of the decontamination and ingestion in the intermediate phase, the calculation structures of the economic effects in the two phases, and the duration of the long-term phase. the actual result of the EPA PAG will be in the range between two cases. The Japanese criteria based on the Fukushima accident response showed the relatively large population and distance affected by the decontamination. It should be noted that this result cannot be compared with the actual situation because 30 days to take the criteria after accidents in the Fukushima were not modeled. In the results of IAEA safety standard, the decrease of the population affected by the intermediate phase relocation is noticeable. It means that the 100mSv for the first one year of IAEA standard is not stricter than the temporary relocation standard in Korea.

3. Conclusions

The purpose of this study is to review the domestic criteria of the long-term protective actions in case of the severe accidents. So, they were evaluated by applying to MACCS code and compared with overseas criteria.

In this study, it was figured out that setting the temporary relocation standard for the intermediate phase influenced the cancer risk, impacted areas, population, and economic costs. And the consideration of the intermediate phase should be changed by the focus of the evaluation. In addition, the result of health effects using the domestic criteria is relatively lower than QHO of US though they leaded larger health effect than overseas criteria. And the economic and social effects applying the domestic criteria were estimated lower than those of the overseas criteria.

Therefore, it is necessary for the domestic criteria to be reviewed, considering that the goal of the long-term protective actions is to protect the residents from the radiation induced health effects while keeping the individual's life close to the normal state.

The result of this study will contribute to establish rational intermediate and long-term mitigation strategies and the criteria of protective actions for severe accidents. Furthermore, it is expected to be used for data to enhance the completeness of the domestic L3 PRA model.

Acknowledgements

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