Determination of conversion factor from radionuclides release to latent cancer fatality

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1. Introduction

Probabilistic safety assessment (PSA) has been used as a method to estimate the risk of nuclear power plant. The process of the PSA has three steps, consisting of Level 1, 2, and 3. Generally used risk surrogates for each Level 1, 2, and 3 PSA are core damage frequency (CDF), large early release frequency (LERF), and early and late fatality, respectively. Health effects are normally achieved by computational codes for Level 3 PSA based on the consequence of Level 2 PSA. There have been efforts to define index to assess severe accident consequence using simulation results [1, 2]. Moreover, IAEA report tried to calculate radiological equivalence for health effects [3].

It would be helpful to predict the health effect directly from the consequences of severe accident. In this study, the effect of radioactive material release on late fatality is estimated through top-down approach using WinMACCS code.

2. Methods

In this study, the effect of the radionuclides' release to the latent cancel fatality (LCF) is calculated through the top-down approach based on the result of WinMACCS code. The WinMACCS generated exact solution of LCF from 19 different core damage accident scenarios. In the Table I, initiation of emission time, which is the first time when radioactive materials release from containment after accident occurs, varies from 1.92 to 61.55 hours. The delay to shelter and evacuation is assumed to be equal to 2.75 hours after accident initiation in every cases. Total release of radioactive materials consists of I, Cs, Te, Sr, Ru, La, Ce and Ba. For convenience of the calculation, the simulation roughly assumed that total amount of radioactive materials is released evenly from the containment in an hour after the initiation of emission time, which is very conservative.

Firstly, WinMACCS calculation and results from conversion factors introduced by ICRP-60ED are compared. These multiplication factors are used to calculate long-term fatality in MAACS2 code.

In addition, multiplication factors of each nuclide were calculated using Moore-Penrose Pseudoinverse of 19 cases matrix of inventory. The matrixes include squared (2^{nd} order) and cubed (3^{rd} order) terms to more accurately calculate the conversion factors. Time factor is added as well as multiplication factors for more precise fitting. In this study, it is assumed that Population Weighted Individual Risk (PWIR) of LCF is proportional to the reciprocal of time or the square of time. Therefore, each the reciprocal of time or the square of time is multiplied to the matrix before obtaining pseudoinverse.

Table I: Characteristics of various simulation cases

No.	Description of scenario	Initiation of emission after accident (hr)	Total release of radioactive materials (10^3TBq)
1	No CF (w/o RV rupture)	6.25	53
2	No CF (w/ RV rupture)	17.01	59
3	Early CF- Leak (w/ CS)	17.01	5,303
4	Early CF- Leak (w/o CS)	8.00	23,743
5	Early CF – Rupture (w/ CS)	17.01	8,516
6	Early CF – Rupture (w/o CS)	8.00	25,127
7	Late CF – Leak (cooled[1] w/o CS)	48.06	13,527
8	Late CF – Leak (not cooled[2] w/ CS)	61.55	9,082
9	Late CF – Leak (not cooled w/o CS)	48.00	13,397
10	Late CF – Rupture (cooled w/o CS)	48.06	14,858
11	Late CF – Rupture (not cooled w/ CS)	61.55	13,413
12	Late CF – Rupture (not cooled w/o CS)	48.00	15,001
13	BMT	34.02	15,901
14	Alpha-mode failure	11.67	23,849
15	CFBRB	82.00	15,062
16	Not isolate (w/ CS)	1.92	3,363
17	Not isolated (w/o CS)	17.17	22,070
18	ISLOCA	4.05	21,711
19	SGTR	45.25	9,280

where, CF is Containment Failure; RV is Reactor Vessel; CS is Containment Spray; BMT is Basement Melt-through; CFBRB is Containment Failure Before Reactor Vessel Breach

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[1] Cooled : Corium was in the basement and well cooled
[2] Not cooled: Corium was in the basement and not cooled. It makes molten corium core interaction.

3. Results and Discussion

2.1 Conversion Factor Regardless of the Emission Time

MACCS2 calculates long-term fatality based on ICRP-60ED conversion factors. The long-term fatality can be simply calculated by multiplying the conversion factor of each element to each inventory, and add them all. Fig. 1 shows the results of normalized PWIR using ICRP-60ED conversion factor and WinMACCS simulation in log scale. The ICRP-60ED conversion factor can similarly expect the WinMACCS simulation results, except the case of too early initiation of emission time (especially case 16). Since people are outside because of the evacuation, many of them are directly exposed to radiation after emission. Therefore, it shows unexpectedly high PWIR-LCF compared with its total release of radioactive materials. Much severe consequence is yielded due to the assumption that total amount of radionuclides is released in an hour.

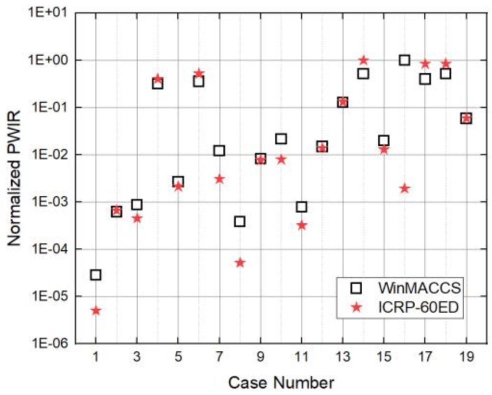

Fig. 1. Prediction of PWIR of Latent Cancer Fatality using existing conversion factor

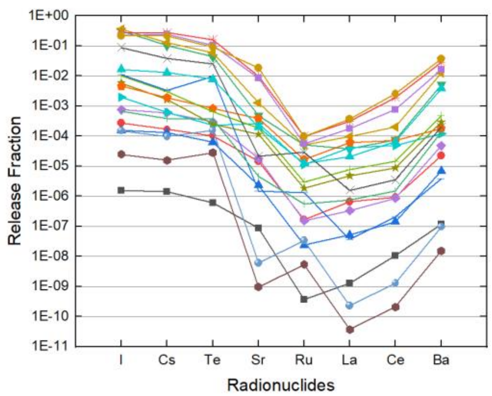

Fig. 2. Radionuclides release fraction of all scenarios

Since the trends of release fractions are similar in every case as in Fig. 2, each conversion factor does not have a big impact on the normalized PWIR-LCF, but are relatively proportional to the total amount of release as long as the time of emission is late enough and release time is 1 hour. Thus conversion factor should include time factor together with risk weighting of each radionuclide.

2.2 Conversion Factor Considering of the Emission Time

In case the initiation of the emission is early, people who evacuate their home are directly exposed to radiation, so late fatality could be much higher than expected. Therefore, initiation of emission time is taken into account in this analysis. Four sets of conversion factors are calculated using the method described in section 2. Two normalized PWIR are proportional to 1/t, while the other two are proportional to $1/t^2$. Calculated PWIR-LCF using Pseudoinverse matrix predicts the results of WinMACCS simulation very accurately as shown in the Fig. 3. However, some of conversion factors show negative value, and the difference between them are several orders, which are considered to have no physical meaning. Though conversion factors including time factor can predict the late fatality rather precisely, conversion factors are unreliable as data are limited. It is expected that large numbers of accurate WinMAACS database can improve the reliability of the calculation.

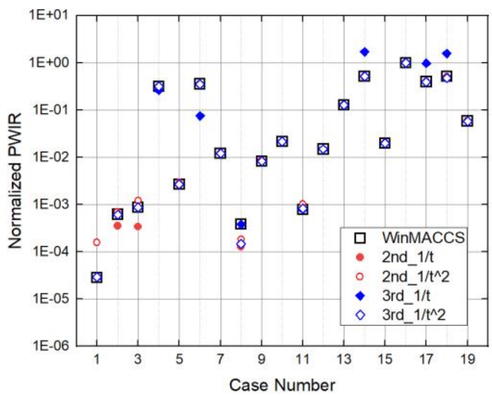

Fig. 3. Prediction of PWIR of Latent Cancer Fatality using various conversion factor

4. Conclusions

In this study, PWIR of LCF was calculated based on various conversion factors. This study clearly shows that release time should be considered to accurately predict late fatality. In the limited simulation results, PWIR-LCF can be well predicted employing conversion factor with time consideration. However, this method fails to generate meaningful multiplication factors of each nuclide. To overcome this limitation, the followings are required to improve this research.

1. Large number of highly reliable simulation results are required to construct numerous database. Database should be made based on the well-structured parameters such as release/evacuation time and duration, or more specified inventory of isotopes.
2. Methodology using not only Moore-Penrose pseudoinverse matrix, but also parameter optimization to minimize standard deviation based on the big data can be used to accurately calculate conversion factor.

REFERENCES

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