A Study for Establishment of SMART EPZ Reflecting the Frequency of Source Terms

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1. Introduction

The SMART reactor is a small size reactor (365 MWt) which will be installed in Korea or in Saudi Arabia. Since the SMART reactor is much smaller than commercial nuclear reactors, it is necessary to set up a reduced emergency planning zone (EPZ).

Recently, since a new EPZ regulation rule for small modular reactors (SMR) is almost set up in USA [1], the methodology to establish the EPZ for SMR accepted in the rule [1] will be used in setting up the SMART EPZ. One of the accepted methodology for SMR is to use the frequencies of source terms which has not been accepted for the large reactors' EPZ.

The effectiveness of the use of source terms frequency in the determination of SMART EPZ is discussed in this paper.

After Fukushima Accident, since the EPZ requirement in Korea was changed, roughly, from USA to IAEA requirement, the IAEA dosimetric criteria for the EPZ is used in the decision of SMART EPZ size.

2. Methods

First of all, the current EPZ of USA and IAEA are discussed. Then, a new method accepted in the SMR EPZ requirement in USA is introduced, and then the result of applying the new method to the SMART EPZ decision is described.

2.1 EPZ of USA

In USA, NUREG-0396 [2], which was issued in 1978 before TMI accident, is still backbone in the current EPZ regulation.

The following basic criteria suggested in NUREG-0396 are used for the current commercial large reactors as well as for the future reactors such as SMR.

Criterion 1: The EPZ should encompass those areas where the projected dose from design-basis accidents could exceed the EPA PAGs [3].

Criterion 2: The EPZ should encompass those areas where consequences of less-severe Class 9 (core-melt) accidents could exceed EPA PAGs.

Criterion 3: The EPZ should be of sufficient size to provide for substantial reduction in early severe health effects in the event of the more severe Class 9 accidents.

In 1980's, after NUREG-0396 decided that EPZ should be about 10 miles by the plume exposure pathways, the 10 miles requirement on the commercial reactors above 250 MWt has not been changed for more than 30 years in U.S.A.

2.2 EPZ of IAEA

The EPZ of IAEA can be summarized in Table 1, and the PAZ, UPZ, etc., are defined in Ref. [4].

Table 1. IAEA EPZ

Emergency zones and distances	Suggested max radius (km)	
	1000 MW(th)	100~1000 MW(th)
PAZ[a]	3 to 5	
UPZ[b]	15 to 30	
EPD[c]	100	50
ICPD[d]	300	100

[a]PAZ (precautionary action zone)
[b]UPZ (urgent protective action planning zone)
[c]EPD (Extended planning distance)
[d]ICPD (Ingestion and commodities planning distance)

2.3 EPZ for SMR

The NRC position papers [5-6] about scalable EPZ for SMR, and NEI report [7] for the reduced EPZ for SMR are all based on the criteria of NUREG-0396 [2].

However, the problem in using the criteria of NUREG-0396 for SMR EPZ is that it is difficult to select adequate Class-9 accidents. For example, if we select a severe accident whose frequency is 10^{-9} as the most severe accident, then EPZ size would be huge. Thus, in China, they consider only the severe accidents whose frequencies are larger than 10^{-7} or 10^{-8} by the Chinese regulation [8] as a frequency-threshold approach, which results in small EPZ size.

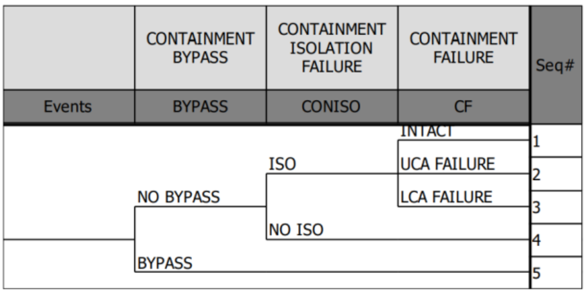
Again, the current EPZ requirement using NUREG-0396 is that the analyses with BDBA source terms simply presented dose-distance curves without consideration of frequency. However, in the recent regulation [1, 9-10] of NRC, for severe accidents

(BDBA), dose-distance results are aggregated using frequency information, and scalable EPZ is admitted.

IAEA also studied EPZ for SMR, and the scalable EPZ, and the use of frequencies for accidents scenarios were discussed in 2009 [11].

2.4 EPZ for SMART

After the level 2 PSA of SMART, source terms are calculated according to five source terms categories (STC) shown in Fig. 1 [12].



UCA: Upper Containment Area
LCA: Lower Containment Area

Fig. 1. Source Term Category Logic Diagram

In Fig. 1, source term category 1 (STC1) means no containment failure, and STC2 means UCA failure, … and STC5 indicates containment bypass.

Containment failure frequency for each STC was calculated. In Table 2, the containment failure frequency is not shown, but only its fraction is given since frequency fraction is enough for this paper. In Table 2, among severe accidents, most (89.5%) of severe accidents are the ones with no containment failure.

Table 2. Containment Failure Freq. for Internal Event

Containment Failure Mode	Containment Failure Freq. Fraction	Freq. Fraction without NO CF
NO CF	89.50%	
CF: UCA Failure	2.80%	26.60%
CF: LCA Failure	3.10%	29.52%
CF: Isolation Failure	0.00%	
CF: Bypass Failure	4.60%	43.88%

With MACCS code [13], the doses received after accidents are calculated with different distances from SMART reactor, and with different meteorological conditions. One example of dose-distance curve is shown in Fig. 2. In Fig. 2, effective doses from external and internal exposure due to STC2 are depicted with the protective action criteria line (0.1 Sv). Nine (9) protective action criteria posed on the different human organs to set up PAZ and UPZ are mentioned in Ref. [14-15] as shown in Table 3. In Table 3, the dose criteria for the effective dose (ED) is 0.1 Sv. Thus, in Fig. 2, if mean value is used, UPZ size should be decided as one larger than 1.1 km to satisfy the effective dose criteria in SCT2 case. For STC2, all nine (9) criteria of Table 3 should be satisfied, and it should be repeated for the other STCs. With this work, PAZ and UPZ can be set up.

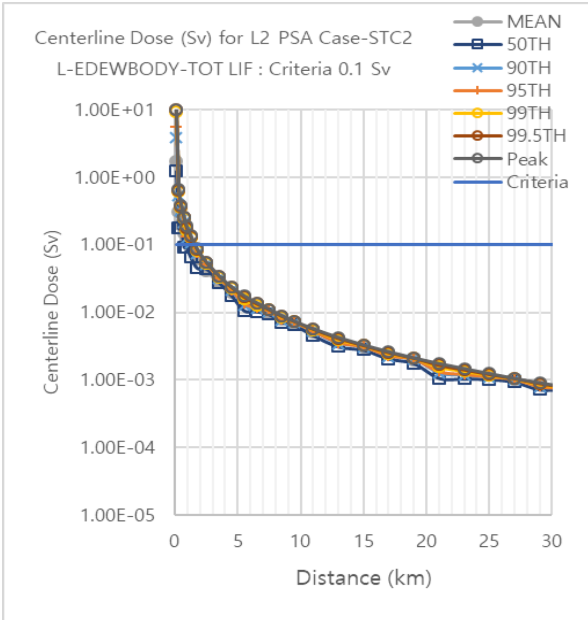


Fig. 2. Effective Dose from External and Internal Exposure in STC2 Case

Table 3. Generic Criteria for Doses Received within a Short Period of Time for which Protective Actions Are Expected to be taken.

	Target-organ	Pathway	Duration		Criterion		Remark
			MACCS	IAEA			
1	Red Marrow	Cloud	Simulation	10hr	1.0	Gy-Eq	
2	Red Marrow	Ground	Simulation	10hr	1.0	Gy-Eq	
3	Skin	Surface Contamination	Simulation	10hr	10.0	Gy-Eq	
4	Red Marrow	Acute, Inhalation	50 years	30d	2.0	Gy-Eq	
5	ThyroidH	Acute, Inhalation	50 years	30d	2.0	Gy-Eq	For ITB
6	Lung	Acute, Inhalation	50 years	30d	30.0	Gy-Eq	
7	Low LI	Acute, Inhalation	50 years	30d	20.0	Gy-Eq	
8	ThyroidH	Total (internal + external)	Simulation	7d	50	mSv	UPZ
9	ED	Total (internal + external)	Simulation	7d	100	mSv	UPZ

The effective dose-distance curves for SCT3 and SCT5 are shown in Fig. 3 and Fig. 4, respectively.

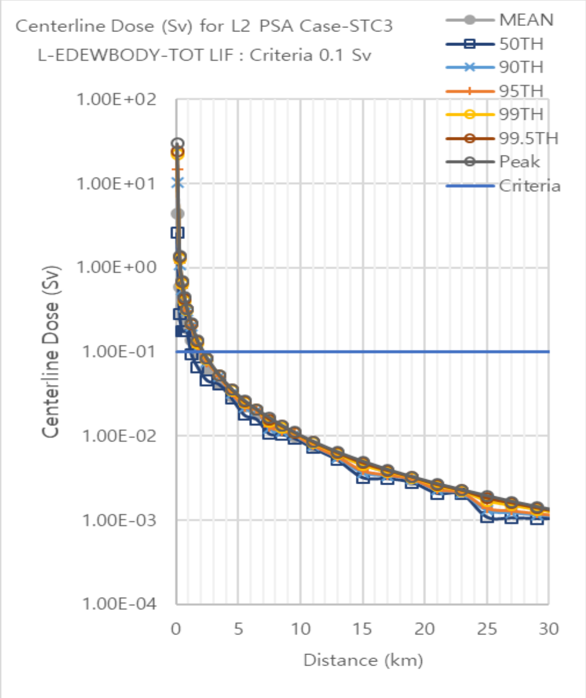


Fig. 3. Effective Dose from External and Internal Exposure in STC3 Case

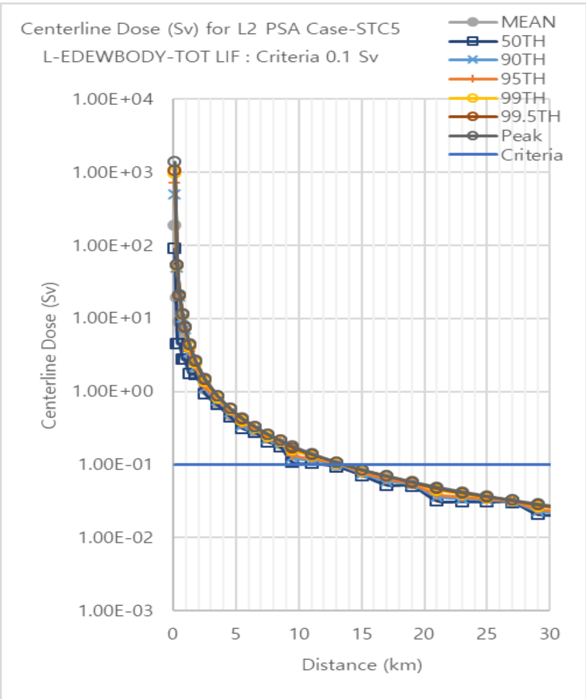


Fig. 4. Effective Dose from External and Internal Exposure in STC5 Case

Thus, from the curves of Fig. 2-4, we can find the possible UPZ distances at which the dose criteria are satisfied in each STC as shown in Table 4.

Table 4. Possible UPZ Satisfying Effective Dose in Each STC

	STC2	STC3	SCT5	Remark
Freq. Fraction[a] (%)	26.60	29.52	43.88	STC4 Fraction is Zero
UPZ distance (km)	1.1	1.5	12	

[a]derived in Table 2

In Table 4, by aggregating the frequency fraction, we can get 6 km as UPZ, from the point of view of effective dose, which is reduced by 50 % from 12 km.

3. Conclusions

The result of MACCS calculation shows that the largest PAZ and UPZ size for SMART comes from STC5 since STC5 is the most severe accident. However, as discussed in Section 2.3, 'EPZ for SMR', if the frequency information shown in Table 2 is reflected in PAZ and UPZ decision, the size of PAZ and UPZ can be reduced roughly by 55% and 50%, respectively. For example, the 3.9 km of PAZ can be reduced to 1.77 km.

In Table 2, if we consider the frequency of STC1 (no containment failure), the reduction of PAZ and UPZ size would be enormous. However, since the idea of the 2nd and the 3rd criterion in NUREG-0396 is to check the consequences after a containment failure, the frequency fraction of STC1 is not reflected in the aggregation of frequency information.

For SMART EPZ, the scalable EPZ and the use of frequencies for accident scenarios was described, and although, at this time, IAEA dosimetric criteria were used, US dosimetric criteria will be used in the next time.

Acknowledgement

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