A Study on a Korean SMR EPZ Determination with NEI and NRC Approaches

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1. Introduction

Recently, in U.S., small modular reactors (SMRs) can have a site boundary emergency planning zone (EPZ), and thus, a new plume exposure pathway EPZ of NuScale SMR, which is near site boundary size, is submitted to NRC as a topical report [1]. The EPZ setup methodology adopted in the NuScale is the methodology suggested in the NEI guidance [2], and it was also reflected in the DG 1350 [3].

After receiving many comments about DG 1350, NRC issued RG. 1.242 [4] in 2021 which is different from NEI (NuScale) approach in the treatment of 'less' severe and 'more' severe accidents in the NUREG-0396 [5].

In this paper, the different EPZ determination approaches between NEI (NuScale) and RG. 1.242 are compared with each other, by applying each approach to a Korean SMR EPZ Determination.

2. Methods

In USA, NUREG-0396 [5], which was issued in 1978 before TMI accident, is still backbone in the current EPZ regulation. However, for a long time, it has been unclear to interpret the 'less' severe accident and 'more' severe accident used in the regulation. Several years ago, the NEI approach [2] practically and clearly interpret the 'less' and 'more' severe accidents. Finally, NRC smartly and formally interpret the ambiguous words in RG 1.242.

2.1 EPZ Setup Methodology of NEI

The NEI EPZ setup methodology [2] adopted by NuScale has the following assumption;

- The EPZ is determined by the criteria of NUREG-0396. However, the determination between less and more severe accidents is depend on whether the containment is intact or not. (Assumption 1)

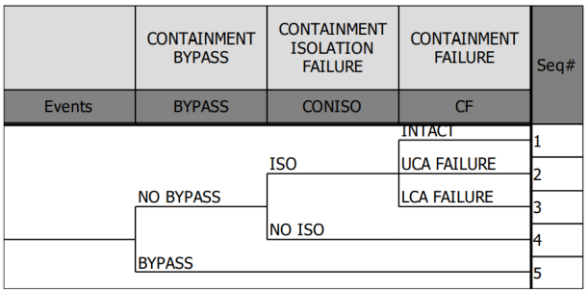
2.2 EPZ Setup Methodology of RG 1.242

In RG. 1.242, the EPZ determination criteria of NUREG-0396 are interpreted as the followings;

> *Criterion a: Projected doses from the design-basis accidents would not exceed 10 mSv (1 rem) TEDE over 96 hours outside the EPZ.*
>
> *Criterion b: Projected doses from most sequences that result in a radiological release would not exceed 10 mSv (1 rem) TEDE over 96 hours outside the EPZ.*
>
> *Criterion c: For the worst sequences that result in exceeding 10 mSv (1 rem) over 96 hours off site from a radiological release, immediate life-threatening doses would generally not occur outside the EPZ.*

2.3 EPZ for a Korean SMR with NEI Approach

After the level 2 PSA of a Korean SMR, source terms are calculated according to five source terms categories (STC) shown in Fig. 1.



UCA: Upper Containment Area
LCA: Lower Containment Area

Fig. 1. Source Term Category Logic Diagram

In Fig. 1, source term category 1 (STC 1) means 'no containment failure'. STC 2, STC 3, STC 4, and STC 5 indicate 'UCA failure', 'LCA failure,

'containment isolation failure' and 'containment bypass', respectively.

By the *Assumption 1* of Section 2.1, STC 1 is treated as a less severe accident sequence since the containment is intact. STC 2, STC 3, STC 4, and SCT 5 are treated as more severe accident sequences.

Containment failure frequency for each STC was calculated. However, in Table 1, the containment failure frequency is not shown, but only its fraction is given since frequency fraction is enough for this paper.

Table 1. Containment failure freq. of the Korean SMR

STC	Containment Failure Mode	Freq. Fraction	Remark
1	NO CF		Less Severe
2	CF: UCA Failure	10 %	More Severe
3	CF: LCA Failure	52 %	
4	CF: Isolation Failure	0 %	
5	CF: Bypass Failure	38 %	

2.4 EPZ for a Korean SMR with RG. 1.242 Approach

In RG. 1.242 approach, *Criterion b* of Section 2.2 is applied to STC 1, 2, 3, 5. Then, the accident sequences which are less than 1 rem for 4 days are aggregated according to their frequency fraction to derive EPZ distance.

For the accident sequences which are more than 1 rem for 4 days, the conditional probability of the dose exceeding 200 rem summed over all sequences at a given distance, and the distance at which probability drops below 1E-3 is determined, as an EPZ distance.

3. Results

3.1 EPZ Distance by NEI Approach

As mentioned in Section 2.3, STC 1 accident sequence is less severe accident and STC 2, 3, 5 are more severe accidents. As discussed in Ref. [6], 300 m EPZ distance was derived from Criteria a and b, and 800 m EPZ distance was derived from Criterion c.

3.2 EPZ Distance by RG. 1.242 Approach

The *Criterion a* of NUREG-0396 is not different between NEI approach and RG. 1.242. There are differences in *Criterion b* and *c*.

EPZ Distance by Criterion b

At first, the EPZ distances are derived by *Criterion b* of Section 2.2 for all accident sequences. The *Criterion b* was applied with mean weather condition. Thus, in Fig. 2, the EPZ distance would be roughly determined as 150 m for the STC 1 accident sequence.

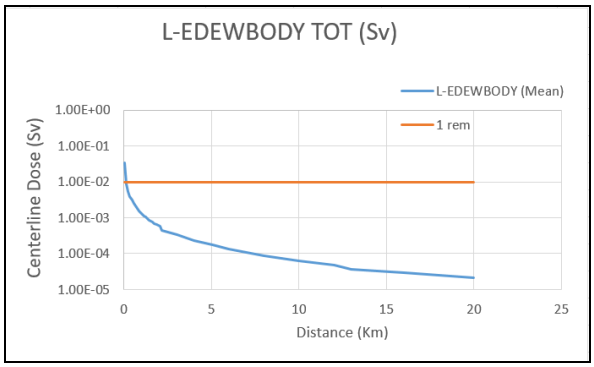


Fig. 2. EPZ distance for STC 1 accident sequence by *Criterion b*

The result of the *Criterion b* for the STC 2 accident sequence is shown in Fig. 3. The EPZ distance derived from STC 2 accident sequence could be much larger than 1 km.

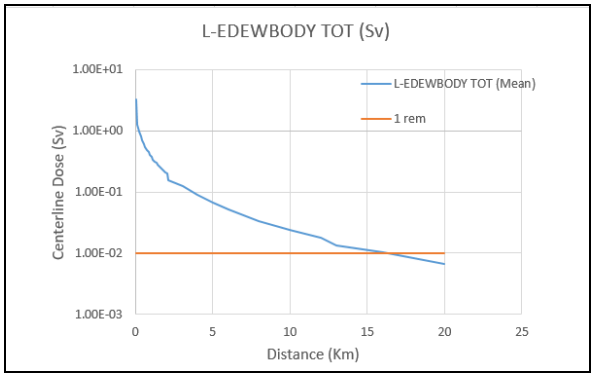


Fig. 3. EPZ distance for STC 2 accident sequence by *Criterion b*

Similarly, the EPZ distances derived from STC 3 and STC 5 accident sequences could be much larger than 1 km. Thus, according to the RG. 1.242, STC 1 is less severe accident, and STC 2, STC 3, and STC 5 are more severe accidents.

As a result, the accident sequences are identically classified as the less severe accident and the more severe accidents both in the NEI and RG. 1.242 approaches. Thus, *Criterion c* of Section 2.2 is applied to STC2, STC3,

and STC5. In addition, the EPZ distance results are the same in the both approaches.

3.3 EPZ Distance by Criterion c

If we repeat the results discussed in Ref. [6] in this section, more severe accident sequences are STC2, STC3, and STC5, and the probability of 200 rem dose exceedance vs distance is shown in Table 2.

Table 2. Calculation of probability of dose exceedance

		Sequences			
		STC2	STC3	STC5	Total CDF
	CDF	10%	52%	38%	1.00E+00
	Distance (km)	Cond. Prob. of exceeding 200 rem for sequence i at distance j			Total Cond. Prob. of exceeding 200 rem at distance j
1	0.025	5.03E-01	5.56E-01	1.00E+00	7.17E-01
2	0.1	2.81E-03	2.81E-03	1.00E+00	3.77E-01
3	0.2	0.00E+00	0.00E+00	1.00E+00	3.75E-01
4	0.3	0.00E+00	0.00E+00	1.00E+00	3.75E-01
5	0.4	0.00E+00	0.00E+00	4.30E-01	1.61E-01
6	0.5	0.00E+00	0.00E+00	4.30E-01	1.61E-01
7	0.6	0.00E+00	0.00E+00	4.08E-01	1.53E-01
8	0.7	0.00E+00	0.00E+00	1.64E-01	6.16E-02
9	0.8	0.00E+00	0.00E+00	2.81E-03	1.05E-03
10	0.9	0.00E+00	0.00E+00	1.14E-04	4.28E-05

In Table 2, the conditional probabilities (given more severe accidents) of dose exceeding 200 rem whole body acute for each of the three sequences (STC4 is neglected since its frequency fraction is zero.) are given for ten distances from the reactor, 25 m to 900 m. The conditional probability of the dose exceeding 200 rem summed over all sequences at a given distance is in the right-hand column. From these values for the 10 distances in Table 2, a curve is plotted as shown in Fig. 4 and the distance at which probability drops below 1E-3 is determined, as an EPZ distance. In Fig. 4, the EPZ distance would be 800 m by aggregating the frequency fraction.

3. Conclusions

The NEI approach adopted in NuScale topical report for EPZ makes the Criteria c of NUREG-0396 clear in a practical way. However, it has a little bit informal flavor in determination of ‘less’ and ‘more’ severe accidents. Instead, NRC formally classified the ‘less’ and ‘more’ severe accidents with RG. 1.242 without changing the EPZ distance result derived from NEI approach. Since the number of accident sequences is too small (~ 5) in this Korean SMR example, the result is the same in the classification of less and more severe accidents with both approaches. However, if there are many accident sequences, the result could be slightly different in the classification of less and more severe accidents.

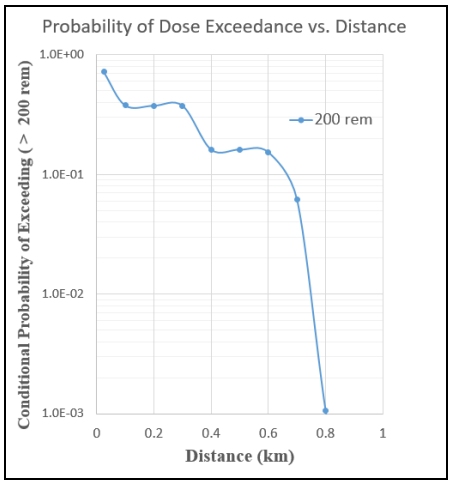


Fig. 4. Probability of 200 rem exceedance vs distance curve in more severe accident sequences case

Acknowledgement

This work was supported by joint project funded by KAERI and K.A. CARE.

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