Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

A Review of New NEI's EPZ Size Determination for Non-LWRs

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***Keywords :** *EPZ, Non-LWR, Emergency Planning Zone*

1. Introduction

Recently, the Nuclear Energy Institute (NEI) proposed a new method for determining EPZ (Emergency Planning Zone) distances for non-LWRs in NEI 24-05 [1] and requested endorsement [2] from the NRC. Since the method for establishing EPZ distances was first set forth in NUREG-0396 (1978) [3], several alternative approaches have been suggested and applied over the years, with RG 1.242 [4] currently in use. Nevertheless, even after 47 years, the philosophy and key elements of the NUREG-0396 methodology have largely been preserved without significant change. The NEI 24-05 proposal will likewise be reviewed by the NRC, which will either request revisions or decide on its endorsement.

Meanwhile, because Korea is also pursuing the development of site-boundary EPZs for non-LWRs, NEI's new EPZ proposal and the NRC's response are of considerable interest. Accordingly, this paper addresses the following:

- The main points of NEI 24-05,
- The philosophy of NUREG-0396 EPZ approach,
- NRC Questions and NEI's Responses
- A comparison between RG 1.242 and NEI 24-05.

2. Methods

2.1 EPZ Setup Methodology of NEI 24-05

2.1.1 Background

NEI 24-05 describes the determination of the EPZ distance assuming that the site boundary has already been established. (Of course, from a technical standpoint, selecting the site boundary as the EPZ distance and proceeding with the design appears reasonable, but since this is not the subject of this paper, it is omitted here.)

In the case of Non-LWRs under the Licensing Modernization Project (LMP), many LBEs (Licensing Basis Events) are identified. The frequencies of these LBEs are derived from PSA, while the consequences are calculated using source term analysis and Level-3 codes.

In NUREG-0396, the basis for establishing the EPZ distance of 10 miles for U.S. commercial nuclear power plants is explained using the graph from WASH-1400 (see Fig. 1). NEI 24-05 interprets this as follows: namely, in the event of a core melt accident, at a distance of 10 miles (the EPZ boundary), the probability of whole-body exposure exceeding 1 rem is 30%, while the probability of exceeding 200 rem is 3%. Therefore, if the frequency of a core melt accident is assumed to be 5E-5 per year;

1 rem dose exceedance frequency is,

(1) $5E\text{-}5 \times 0.3 = 1.5E\text{-}5 \rightarrow 1E\text{-}5$

where, the value of 1E-5 is conservatively used as the limit for the exceedance frequency of 1 rem dose.

200 rem dose exceedance frequency is,

(2) $5E\text{-}5 \times 0.03 = 1.5E\text{-}6 \rightarrow 1E\text{-}6$

where, the value of 1E-6 is conservatively used as the limit for the exceedance frequency of 200 rem dose.

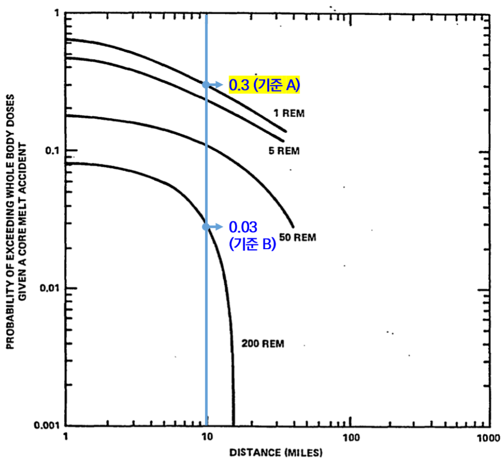

Fig. 1. Conditional Probability of Exceeding Whole Body Dose-versus-Distance

2.1.2 NEI 24-05 Approach for EPZ Distance Determination

NEI 24-05 determines the EPZ distance for non-LWRs as follows:

Step 1. Identify the dose exceedance frequency for all LBEs, distinguishing between the 1 rem and 200 rem criteria.

Step 2. Determine the cumulative dose exceedance frequency as a function of distance, again distinguishing between the 1 rem and 200 rem criteria.

Sep 3. The EPZ distance is defined as the larger of:

- the distance at which the cumulative dose exceedance frequency for 1 rem falls below 1E-5, or
- the distance at which the cumulative dose exceedance frequency for 200 rem falls below 1E-6.

Step 4. However, LBEs that can be adequately addressed through protective measures are excluded from the cumulative dose exceedance frequency.

The followings are in detail explanation of each step;

<u>Step 1</u>

In the case of a non-LWR with an F-C curve as shown in Fig. 2, the probability of exceedance for 1 rem and 200 rem, as in Fig. 1, is determined for all LBEs. Then, by multiplying these probabilities by the corresponding frequency of each LBE, Fig. 3 and 4 are obtained. In Fig. 3, only seven significant LBEs were used, while in Fig. 4, only two LBEs were found to be meaningful.

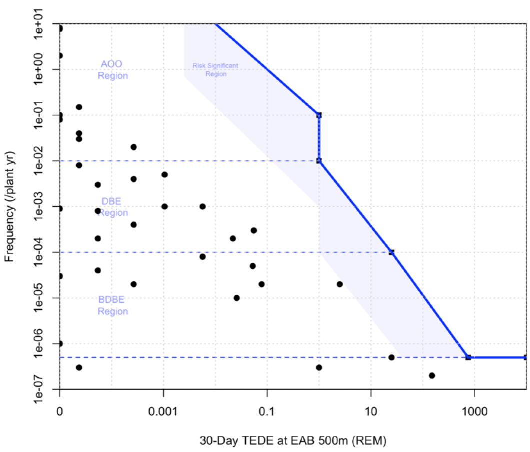

Fig. 2 Example Analysis – LBEs on Frequency versus Consequence Plot

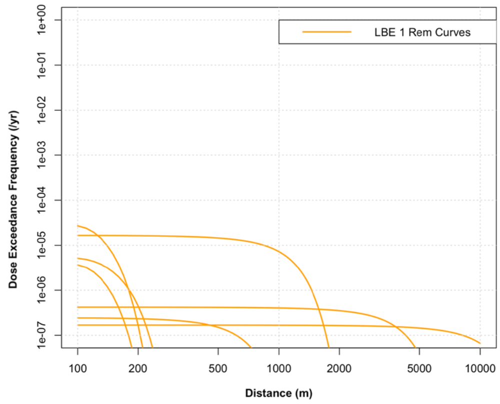

Fig. 3 Example Analysis – LBE 1 Rem Dose-versus-Distance Curves

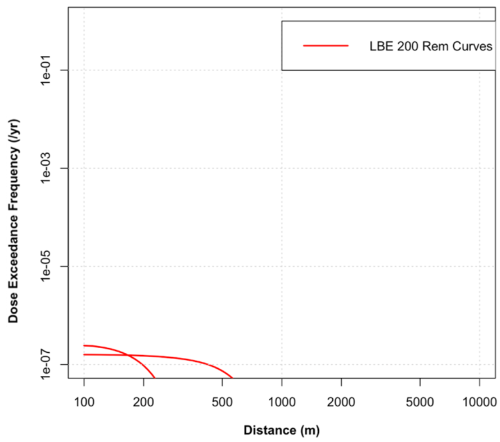

Fig. 4 Example Analysis – LBE 200 Rem Dose-versus-Distance Curves

<u>Step 2</u>

In Fig. 5, the curve representing the combined dose exceedance frequency of the seven LBEs from Fig. 3 (shown in yellow) and the curve representing the combined dose exceedance frequency of the two LBEs from Fig. 4 (shown in red) are presented.

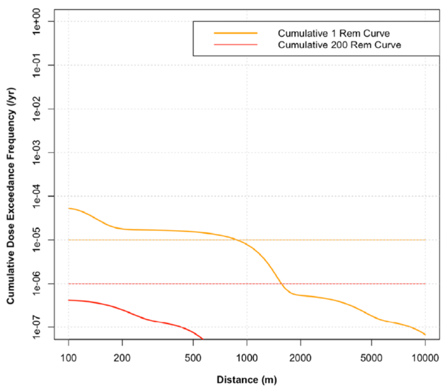

Fig. 5 Example Analysis – Cumulative Dose-versus-Distance Curves

In Fig. 5, the intersection with the 1E-5 line derived from equation (1) represents the EPZ distance based on 1 rem (approximately 800 m), while the intersection with the 1E-6 line derived from equation (2) represents the EPZ distance determined by 200 rem. However, since the cumulative curve of 200 rem dose exceedance frequencies lies below the limit line, the EPZ distance cannot be derived from the 200 rem exceedance frequencies.

<u>Step 3</u>

Fig. 6 shows that the EPZ is determined to be 800 m based on 1 rem. However, since the site boundary is 500 m, setting the EPZ at 500 m would help avoid unnecessary administrative resource expenditures.

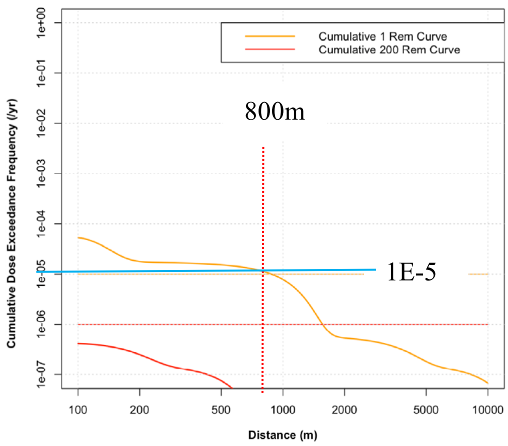

Fig. 6 EPZ distance determination through the intersection of limit lines

<u>Step 4</u>

Fig. 7 shows that by implementing protective measures for LBE-32, the EPZ can be set at 500 m, the same as the site boundary, instead of 800 m.

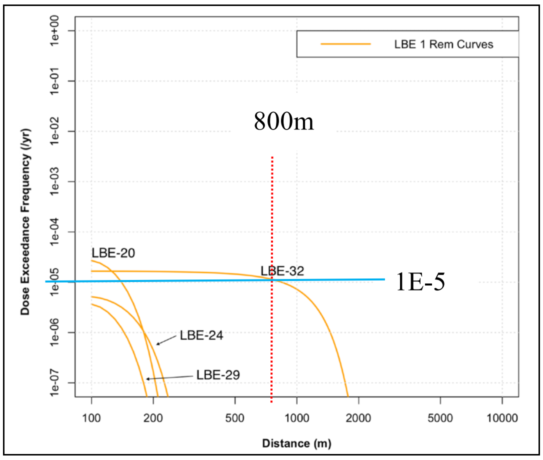

Fig. 7 Example Analysis – LBE Breakdown

2.2 The philosophy of NUREG-0396 EPZ approach

The following basic criteria suggested in NUREG-0396 [3] is still backbone in the current EPZ regulation, and in the EPZ for future reactors such as SMR.

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 the NUREG-0396 methodology for EPZ determination, a long-standing controversy has been how to classify less severe Class-9 accidents versus more severe Class-9 accidents.

The EPZ determination method applied to the NuScale SMR, which was licensed in 2023 [4], followed the 2013 NEI methodology [5]. This approach considered a *severe accident with intact containment* as a less severe Class-9 accident, while a *severe accident with failed containment* was regarded as a more severe Class-9 accident**.**

Subsequently, in RG 1.242 [6], which is now used for EPZ determination of SMRs and non-LWRs in the United States, this distinction was clarified as follows.

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.

In other words, an LBE that does not exceed 1 rem at EPZ is treated as the **most sequence**, to which Criterion b is applied, whereas an LBE that exceeds 1 rem is regarded as the **worst sequence**, for which Criterion c is applied in determining the EPZ distance.

Meanwhile, traditionally, Criterion b is associated with the provision in the U.S. Safety Goal related to cancer fatality, ensuring that beyond the EPZ distance, radiation exposure does not exceed 1 rem so that long-term cancer risks are avoided. Criterion c, on the other hand, is linked to the Safety Goal provision concerning prompt fatality, designating the EPZ at the point where radiation doses high enough to cause early deaths have been completely eliminated. Conventionally, the EPZ under Criterion c has been defined as the distance at which the radiation dose of 200 rem abruptly decreases and the exceedance probability (i.e., the Complementary Cumulative Distribution Function, CCDF) reaches 1E-3.

2.3 NRC Questions and NEI's Responses

In July 2024, NEI requested for NRC endorsement of NEI 24-05 revision 0 [2]. After reviewing NEI 24-05, NRC asked many questions [7]. One of important question is:

"What is the technical basis for applying the proposed frequency metrics which are representative of older large light water reactor data, to new reactor designs, instead of identifying the distance at which the likelihood of exceeding the dose level of interest dropped substantially directly from the cumulative dose-versus-distance curves?"

In response to this, NEI provided a rather inadequate answer [7].

"Dose versus distance curves do not always have clear drop-offs, which could cause subjective results (see 1 rem curve of Fig. 1)"

In the traditional approach, the EPZ distance is defined at the drop-off point only in the case of 200 rem. However, NEI explains that since no such drop-off occurs for 1 rem, the traditional method was not applied.

2.4 A comparison between RG 1.242 and NEI 24-05

In RG. 1.242, The following probabilistic dose aggregation is mentioned:

Analyses with design-basis accident source terms may simply present dose-distance curves conditional upon the occurrence of the source term without consideration of frequency.

For beyond-design-basis events, dose-distance results may be aggregated using frequency information developed as described in Appendix B to evaluate the likelihood of exceeding a TEDE of 10 mSv (1 rem) as a function of distance.

Using the example data provided in NEI 24-05, the EPZ distance was calculated according to the RG 1.242 methodology. Specifically, the frequency and distance-dependent dose values used to generate Fig. 3 and 4 were tabulated in Tables 1, 2, and 3 (highlighted in yellow in Tables). In Table 1, each LBE falls within the frequency range corresponding to a Design Basis Event, i.e., greater than or equal to 1E-4. The distances at which the dose reaches 1 rem were determined through interpolation or extrapolation, and these values are not weighted by frequency.

Table 1. EPZ Distance by design basis events

LBE	freq	100m	300m	500m	1 rem 거리	EPZ Dist. (m)
20	3E-04	4.44E+0	1.48E+0	1.38E-1	372	
22	2E-04	1.76E+0	5.86E-1	5.45E-2	229	
						372

The LBEs in Table 2 fall into the Beyond-DBE category and were subjected to probabilistic dose aggregation, resulting in an EPZ of 364 m. In Table 2, the rightmost column shows the EPZ distance of each LBE corresponding to its frequency fraction. Accordingly, the aggregation of the frequency fractions yields an EPZ distance of 364 m, as determined by Criterion b of RG 1.242.

Table 2. Probabilistic dose aggregation of the most beyond design basis events

LBE	100m	300m	500m	1 rem 거리	EPZ Dist. (m)
24	4.24E+0	1.41E+0	1.32E-1	364	227
29	6.30E+0	2.10E+0	1.95E-1	415	103
31	2.08E+0	6.94E-1	6.45E-2	256	32
37	8.06E+1	2.69E+1	2.50E+0	520	2
	8.03E-5				364

Similarly, Table 3 (highlighted in yellow) presents the distance-dependent 200 rem exposure values for the LBEs in the NEI 24-05 example data that release higher levels of radioactive material. According to Criterion c of RG 1.242, the EPZ is determined by identifying the point at which the exceedance probability for 200 rem rapidly decreases to 1E-3. By performing probabilistic dose aggregation on these distances, the EPZ distance based on the sharp decline of 200 rem for the prevention of early fatalities is calculated to be 280 m.

Table 3. Probabilistic dose aggregation of the worst beyond design basis events

LBE	freq	100m	300m	500m	200 rem Ex. Prob $<10^{-3}$	EPZ Dist. (m)
32	2E-05	2.02E+2	6.72E+1	6.25E+0	250	242
35	5E-07	2.02E+3	6.72E+2	6.25E+1	803	19.4
38	2E-07	1.21E+4	4.03E+3	3.75E+2	1990	19.2
	2.07E-5					280

Therefore, the EPZ distance established to prevent latent cancer fatality and early fatality is 372 m, which is the larger value among 372 m, 364 m, and 280 m.

3. Conclusions

As a leverage for LMP, NEI proposed an approach for EPZ distance determination in NEI 24-05. The approach appears logical and convenient. However, under the current regulation, RG 1.242, a shorter EPZ distance can be derived using probabilistic dose aggregation—an element not included in NEI 24-05. Therefore, NEI 24-05 appears to require modification before it can be applied.

In addition, NEI 24-05 does not use the traditional method under Criterion (c), which relies on exceedance probabilities below 1E-3 as substantial drop-offs for 200 rem. This omission presents another challenge for obtaining NRC endorsement.

The advantage of NEI 24-05 is that it allows dose exceedance frequencies to be easily identified by distance, making it straightforward to evaluate whether protective measures can be applied to reduce the dose for LBEs with unusually long dose exceedance frequencies.

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