

Mortality-Based Reference Values for the NRC QHOs and Implications for Applying NEI 18-04 in the Republic of Korea

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1. Introduction

As interest in licensing non-light water reactors (non-LWRs) grows in Korea, the technology-inclusive, risk-informed, and performance-based (TI-RIPB) methodology developed through the Licensing Modernization Project (LMP) provides a framework for consideration. NEI 18-04 describes this methodology and specifies plant-level cumulative risk targets for evaluating the combined risks of Licensing Basis Events (LBEs), including targets associated with the NRC Quantitative Health Objectives (QHOs) [1].

The NRC QHOs express nuclear-related mortality risk objectives relative to other accidental and cancer mortality risks [2]. NEI 18-04 uses numerical cumulative risk targets associated with these objectives. Although mortality statistics provide context for their numerical basis, differences in national mortality rates do not, by themselves, establish whether these targets are appropriate for regulatory use in Korea.

This study applies a consistent cause-of-death classification based on NUREG-0880 [3] to Korean mortality statistics for 1983–2024 and U.S. mortality statistics for 1977–2024. Values corresponding to 0.1% of the annual mortality rates are calculated and compared with the NEI 18-04 cumulative risk targets. The purpose is to characterize differences between countries and changes over time in mortality-based reference values and to identify considerations for domestic implementation, without treating the calculated values as proposed Korean performance goals.

2. Methods and Results

2.1 Basis of the NEI 18-04 Cumulative Risk Targets

In NUREG-0880, the NRC applied the U.S. accidental death rate and cancer death rate as reference risks to derive the risk values corresponding to the 0.1% design objective [3]. For early fatality, the reference risk is about 5×10^{-4} /yr, which corresponds to the 1977 U.S. accidental death rate of 48 per 100,000 population (4.8×10^{-4} /yr) [4]. For cancer death, a rate of 19 per 10,000 population (1.9×10^{-3} /yr) given in a 1981

publication of the American Cancer Society was applied. Applying 0.1% to each rate yielded an early fatality risk (termed “prompt fatality” in NUREG-0880) of 5×10^{-7} /yr for the average individual in the vicinity of the site and a cancer fatality risk of 1.9×10^{-6} /yr for the population near the site.

The 1986 NRC Safety Goal Policy Statement subsequently adopted the 0.1% criterion applied in NUREG-0880 as its Quantitative Health Objectives, but did not specify absolute annual fatality-risk values risk targets. The NRC has since used 5×10^{-7} /yr for early fatality and 2×10^{-6} /yr for latent cancer fatality as the quantitative risks corresponding to this criterion.

NEI 18-04 adopted these values previously used by the NRC — an early fatality risk of 5×10^{-7} per plant-year and a latent cancer fatality risk of 2×10^{-6} per plant-year — as the plant-level cumulative risk targets corresponding to the QHOs [1].

The historical use of mortality statistics to establish the numerical basis of these targets should be distinguished from recalculating reference values using statistics for a different country or year. In this study, the NEI 18-04 values are treated as established numerical targets within the LMP methodology, whereas values calculated from annual mortality statistics are used as analytical references. Their comparison does not, by itself, determine whether a regulatory target should be adopted or revised.

2.2 Relevant Domestic Regulation

In Korea, Article 9(2)1 of the Regulations on Scope of Accident Management and Detailed Criteria for Evaluation of Accident Management Capabilities (NSSC Notice No. 2026-1) requires that the early fatality risk and the cancer fatality risk each “be not more than 0.1% of the corresponding total risk, or satisfy an equivalent performance goal” [5].

This criterion uses a relative-risk formulation conceptually similar to that of the NRC QHOs. This similarity alone does not establish that the NEI 18-04 numerical targets constitute equivalent performance goals under the domestic Notice.

Table I. Cause-of-death classification applied to the mortality-based reference value and the estimation scope of the Korean and U.S. statistics^I

Estimation scope based on NUREG-0880 (U.S. statistics) ^I		Corresponding item in the Korean cause-of-death statistics	Correspondence
Latent cancer fatality	Malignant neoplasms (C00-C97)	Malignant neoplasms (C00-C97)	Identical
Early fatality	Accidents (V01-X59)	Ten accident items (V01-X59)	Identical
	Sequelae of transport accidents (Y85)	Sequelae of transport accidents (Y85)	Identical
	Sequelae of other accidents (Y86) and sequelae of complications of medical and surgical care (Y88)	Sequelae of other external causes (Y86-Y89) (Y86 and Y88, which fall within the NUREG-0880 scope, cannot be separated)	Partial (sensitivity analysis ²)
	Complications of medical and surgical care (Y40-Y84)	Residual external causes of morbidity and mortality (Re. V01-Y89, U12) (Y40-Y84, which falls within the NUREG-0880 scope, cannot be separated)	Partial (sensitivity analysis)

1. The 1977 U.S. accidental death statistics cited in NUREG-0880 are based on the ICDA-8 classification; they are mapped to ICD-10 codes here for comparison with the Korean statistics.

2. Because the codes falling within the estimation scope cannot be separated in the Korean statistics, the value excluding these items is taken as the lower bound and the value including them as the upper bound, and the range is shown as a band in Fig. 1.

2.3 Statistical Data Used

The estimation scope of the reference risk and its correspondence to the Korean and U.S. statistics are summarized in Table I. The reference mortality category for comparison with the latent cancer fatality target was malignant neoplasms (C00–C97). For comparison with the early fatality target, the reference mortality category comprised the “all accidental causes” used as the reference risk in NUREG-0880. In NUREG/CR-1916, the source of that value, this scope is presented in Table 14 as comprising transport accidents, poisoning, falls, fires and flames, natural and environmental factors, other accidents, surgical and medical complications, and sequelae of accidents [4]; intentional self-harm, assault, legal intervention, and events of undetermined intent are not included.

For Korea, the 237-item classification of the cause-of-death statistics of the Ministry of Data and Statistics was used [6]. The items corresponding exactly to the estimation scope are the ten accident items and sequelae of transport accidents (Y85), which were summed. In contrast, “residual external causes of morbidity and mortality (Re. V01-Y89, U12)” and “sequelae of other external causes (Y86-Y89)” each combine causes within the estimation scope (Y40-Y84, Y86, Y88) with causes outside it (legal intervention and operations of war, sequelae of intentional self-harm and assault, and others), and cannot be separated within the limits of the data available. A sensitivity analysis was therefore performed taking the value excluding these two items as the lower bound and the value including them as the upper bound, and the range is shown as a band in Fig. 1.

For the United States, the data were extracted from WONDER (Wide-ranging Online Data for Epidemiologic Research), the online statistical database of the U.S. Centers for Disease Control and Prevention

(CDC) [7]. Data based on the International Classification of Diseases, Eighth Revision, Adapted for Use in the United States (ICDA-8) for 1977-1978, the Ninth Revision (ICD-9) for 1979-1998, and the Tenth Revision (ICD-10) for 1999-2024 were linked and mapped to the same scope as in Table I. The 2024 figures are provisional.

2.4 Estimated Mortality-Based Reference Values for Korea and the United States

The mortality-based reference values were calculated by applying the 0.1% criterion to the selected mortality statistics. These calculated values are used for numerical comparison and do not constitute adopted or proposed regulatory performance goals. For Korean early fatality, the lower and upper bounds reflect the exclusion and inclusion, respectively, of the inseparable cause-of-death categories described in Section 2.3. The resulting range is shown as a band in Fig. 1.

On an upper-bound basis, the Korean early-fatality mortality-based reference value was numerically higher than the NEI 18-04 early fatality cumulative risk target from 1987 to 1997. It reached a maximum of $6.36 \times 10^{-7}/\text{yr}$ in 1992 and subsequently declined to a minimum of $2.10 \times 10^{-7}/\text{yr}$ in 2021 (Table II). The 2024 value of $2.28 \times 10^{-7}/\text{yr}$ corresponds to approximately 46% of the NEI 18-04 target.

The U.S. early-fatality mortality-based reference value, calculated using the same method, increased from a minimum of $3.38 \times 10^{-7}/\text{yr}$ in 1992 and was numerically higher than the NEI 18-04 target from 2016 onward. It reached a maximum of $6.96 \times 10^{-7}/\text{yr}$ in 2021 and was $5.90 \times 10^{-7}/\text{yr}$ in 2024, corresponding to approximately 118% of the target (Fig. 1).

The Korean latent-cancer mortality-based reference value increased from $7.21 \times 10^{-7}/\text{yr}$ in 1983 to a

maximum of $1.74 \times 10^{-6}/\text{yr}$ in 2024, corresponding to approximately 87% of the NEI 18-04 latent cancer fatality cumulative risk target. The corresponding U.S. reference value ranged from 1.75×10^{-6} to $2.04 \times 10^{-6}/\text{yr}$, was numerically higher than the NEI 18-04 target from 1989 to 1996 and has recently been approximately $1.82 \times 10^{-6}/\text{yr}$ (Fig. 2).

Table II. Mortality-based reference values for early fatality and latent cancer fatality in Korea (per year)II¹

Item	Early fatality	Latent cancer fatality
Maximum (year)	6.36×10^{-7} (1992)	1.74×10^{-6} (2024)
Minimum (year)	2.10×10^{-7} (2021)	7.21×10^{-7} (1983)
Mean (1983-2024)	3.89×10^{-7}	1.25×10^{-6}

1. Early fatality values are given on an upper-bound basis of the estimation scope.

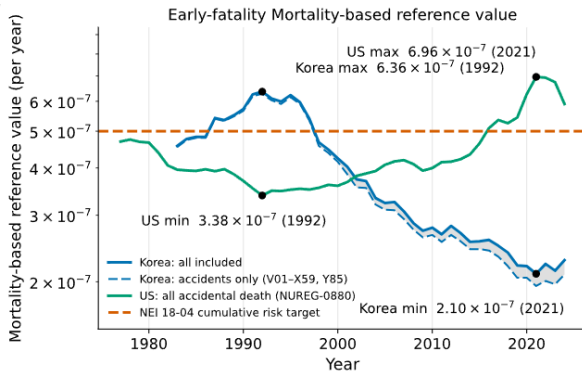


Fig. 1. Trends in the early-fatality mortality-based reference value for Korea and the U.S.1

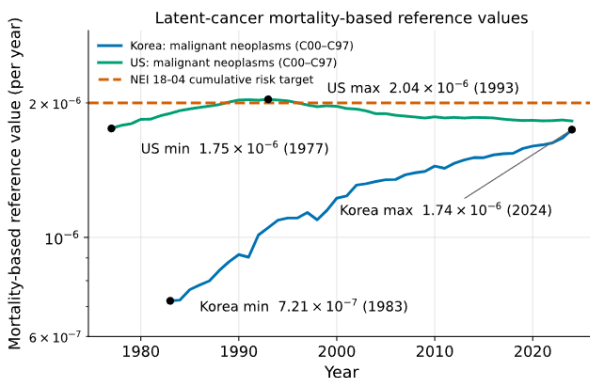


Fig. 2. Trends in the latent-cancer mortality-based reference value for Korea and the U.S.2

3. Discussion and Conclusions

This study compared mortality-based reference values calculated as 0.1% of selected annual mortality rates in Korea and the United States. Using a consistent cause-of-death classification, the analysis identified differences between countries and changes over time.

The Korean reference value associated with early fatality declined overall after 1992, whereas the value associated with latent cancer fatality increased over the study period. These results demonstrate that the numerical values obtained from the same relative-risk formulation depend on the country and reference period selected.

For 2024, the Korean reference values were $2.09 - 2.28 \times 10^{-7}/\text{yr}$ for early fatality and $1.74 \times 10^{-6}/\text{yr}$ for latent cancer fatality, numerically below the corresponding NEI 18-04 cumulative risk targets. These calculated values are analytical references, not adopted or proposed Korean performance goals. Consequently, the observed differences alone establish neither that the NEI 18-04 targets are inappropriate for Korea nor that their adoption would satisfy the domestic regulatory criterion.

The temporal variation also illustrates a consequence of automatically linking numerical targets to updated mortality statistics: the resulting targets would change with background mortality even if the nuclear facility and its assessed risk remained unchanged. A reduction in accidental or cancer mortality would lower the calculated reference value, while an increase would raise it. These arithmetic changes do not, by themselves, justify corresponding changes in acceptable nuclear risk. Statistical accuracy remains important for a transparent comparison, but it cannot determine the regulatory judgment required to establish or revise a numerical benchmark.

For domestic implementation of the LMP methodology, the basis for selecting cumulative risk targets should therefore be made explicit, including their relationship to the safety objective and the applicable domestic criterion. Relevant considerations include the reference population and risk metrics, the treatment of uncertainty, the justification for the selected level of protection, and the stability and predictability of its implementation. Any review of the targets in light of updated mortality data should proceed through an explicit regulatory process rather than automatic recalculation. This study provides quantitative context for that discussion by characterizing the variation in mortality-based reference values; it does not determine the numerical performance goals to be adopted in Korea.

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