Benefit-Cost Assessment for Long Term Asset Management Strategy in Nuclear Power Plants

Kyung-Hwan Na [*], Hansang Kim, Eunsub Yun
Nuclear Engineering & Technology Institute, Korea Hydro & Nuclear Power Co. Ltd., 25-1 Jang-Dong, Yuseong-Gu, Daejeon, KOREA, 305-343
[*]*Corresponding author: cylomon@khnp.co.kr*

1. Introduction

Thirty years have already passed since the first Korean nuclear power plant commenced commercial operation. As the operation time of nuclear power plants increases, their structures, systems, and components (SSCs) become degraded and, accordingly, long-term asset management (LTAM) is required [1]. The goal of a LTAM is to maximize the values of the SCCs from an economic point of view, while ensuring an acceptable level of nuclear safety.

In the LTAM strategy, several alternatives, such as improvement of maintenance activities, repair, and replacement/refurbishment, can be derived. In order to find an optimum alternative in the LTAM strategy, the economic aspect should be considered under the assumption that the suggested alternatives guarantee the minimum nuclear safety requirement level.

In this regard, it is worthwhile to note that the United States Nuclear Regulatory Commission (USNRC) has conducted regulatory analyses according to its guidelines to ensure that its decisions that impose regulatory burdens on licensees are based on adequate information regarding values and impacts [2].

In the present work, we estimate the benefit and cost for a certain action that reduces core damage frequency (CDF). This estimation can be useful in the economic evaluation of alternatives in the LTAM strategy.

2. Benefit-Cost Assessment

Modifications to an operating power plant by assessing alternatives in the LTAM strategy can exert measurable economic effects. However, on the other hand, the resources, both financial and personnel, required for the implementation of these alternatives are limited. Thus, all potential benefits and effects of a proposed alternative must be thoroughly investigated to judge whether the alternative is beneficial. In addition, the results obtained from benefit-cost assessments can be used to prioritize the implementation of the alternatives in the LTAM strategy.

2.1 Positive Attributes

2.1.1 Public Health

This attribute is a value that measures expected change in radiation exposure to the public due to changes in CDF associated with alternatives. The monetary value of public health risk avoided per facility-year can be described as follows:

$$Z_{ph} = R \times \Delta CDF \times D_{pop} \qquad (1)$$

where R is the monetary equivalent of a unit dose (₩/person-rem), ΔCDF is the change in CDF, and D_{pop} is the population dose factor (person-rem/event).

R was conservatively estimated to be $2000/person-rem by USNRC [3]. However, in Korea, ₩10,000,000/preson-rem has been widely accepted in various reports. The population dose factor, D_{pop}, meanwhile, directly depends on the population within 50 miles (roughly 80 km). USNRC calculated the population dose factor for the representative five power reactors and concluded that the average value is about 1.99×10^5. However, considering the difference in population density (US: 31 persons/km^2, Korea: 483 person/km^2 in 2005) and the circumstances around nuclear facilities, it is reasonable to estimate the population dose factor in Korea as 1.99×10^7. In Korea, it was revealed that most of the total benefit yielded by reduction in CDF originated from this attribute.

2.1.2 Occupational Health

This attribute is a value that measures health effects, both immediate and long-term, associated with site workers as a result of changes in CDF. The monetary value of occupational health risk avoided per facility-year is given as follows:

$$Z_{work} = R \times \Delta CDF \times (D_{IO} + D_{LTO}) \qquad (2)$$

where R is the monetary equivalent of a unit dose (₩10,000,000/preson-rem) and ΔCDF is the change in CDF. In addition, D_{IO} and D_{LTO} are the immediate and long-term occupational dose, respectively.

D_{IO} and D_{LTO} were estimated from the TMI and Chernobyl experience by USNRC [3]. Taking into account the conservatism included in the estimation of D_{IO} and D_{LTO}, highly estimated values of 14,000 person-rem and 30,000 person-rem can be acceptable.

2.1.3 Offsite Property

This attribute is a value that measures the expected total monetary effects on offsite property resulting from the implementation of alternatives. The monetary value of avoided offsite property damage is given by:

$$Z_{FP} = \Delta CDF \times D \quad (3)$$

where ΔCDF is the change in CDF and D is the monetary value of property damage occurring with CDF.

USNRC considered only property damage within 50 miles, and the average value of the representative five power reactors was estimated to be $\$2.46{\times}10^{8}$. Similarly to the case of public health, a factor of 100 can also be considered for this value in Korea, resulting in $\$2.46{\times}10^{10}$.

2.1.4 Onsite Property

This attribute is an impact that measures the expected monetary effects on onsite property, including replacement power and decontamination costs. The monetary value of avoided offsite property damage can be estimated from the following relation:

$$Z_{op} = \Delta CDF \times (Z_{decon} + Z_{replacement}) \quad (4)$$

where ΔCDF is the change in CDF, Z_{decon} is the decontamination cost, and $Z_{replacement}$ is the long-term replacement power cost.

Based on the TMI experience, USNRC evaluated the decontamination cost as follows:

$$Z_{decon} = [1.5 \times 10^{8} / mr][1 - \exp(-rm)] \quad (5)$$

where m is the years required to return the site to a pre-accident state and r is the real discount rate. The above equation includes the assumption that $\$1.5{\times}10^{8}$/year is needed for ten years to return the site to a pre-accident state by decontamination.

On the other hand, long-term replacement power cost can be expressed as:

$$Z_{replacement} = [1.2 \times 10^{8} / r][1 - \exp(-rt_{f})]^{2} \quad (6)$$

where r is the real discount rate and t_f is the years remaining until the end of the facility life.

2.2 Negative Attributes

2.2.1 Licensee Investment Cost

Licensee investment cost is the required expense to a licensee for the implementation of alternatives. Investment cost can be calculated according to the following procedure:

Step 1: Calculation of working expense and cost for equipment, piece parts, and materials
Step 2: Calculation of total investment cost
Step 3: Calculation of power replacement cost
Step 4: Conversion of total cost into net present value (NPV)

2.2.2 Operating Cost

Operating cost includes maintenance cost and operating cost after modifying an operating power plant by alternatives in the LTAM strategy.

3. Conclusions

For all safety-related actions modifying operating power plants, there may be a benefit that results from a reduction in core damage frequency (CDF). Improvement in public health and occupational health as well as reduction in offsite and onsite property damage belongs to this category. It was revealed that most of the total yielded safety-related benefit originated from improvement in public health for the case of Korea. On the other hand, there are also expenses related to investment cost and operating cost.

The economic evaluation in the long-term asset management (LTAM) strategy involves a comparison of the benefit to the cost for the alternatives under the assumption that the alternatives can maintain an acceptable level of nuclear safety. If the benefit exceeds the cost, the alternative is worthy of implementation and the optimum alternative may be that which exhibits the maximum benefit compared to the cost.

KHNP has just started to develop a LTAM strategy. In the case of evaluating an alternative related to the repair or the replacement of safety-related components, the benefit originating from the reduction in CDF may be taken into consideration in addition to the benefit from a decrease in loss of power generation due to lower failure rate of the repaired or replaced components. The estimation method suggested in the present work can be useful in more objective economic evaluation of alternatives in the LTAM strategy.

REFERENCES

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[3] USNRC, Regulatory Analysis Technical Evaluation Handbook, NUREG/BR-0184, January 1997.