Proceedings of the Korean Nuclear Society Autumn Meeting
Taejon, Korea, October 1996

A Study on the Estimation of Economic Consequence of Severe Accident

Dae Seok Hong and Kun Jai Lee
Korea Advanced Institute of Science and Technology

Jong Tae Jeong
Korea Atomic Energy Research Institute

Abstract

A model to estimate economic consequence of severe accident provides some measure of the impact on the accident and enables to know the different effects of the accident described as same terms of cost and combined as necessary. Techniques to assess the consequences of accidents in terms of cost have many applications, for instance in examining countermeasure options, as part of either emergency planning or decision making after an accident. In this study, a model to estimate the accident economic consequence is developed appropriate to our country focused on PWR accident costs from a societal viewpoint. Societal costs are estimated by accounting for losses that directly affect the plant licensee, the public, the nuclear industry, or the electric utility industry after PWR accident.

1. Introduction

A nuclear power plant accident have onsite and/or offsite consequences. The effect of an accident may range from onsite impact such as health effects and damage of plant itself, to offsite impact such as numbers of people being evacuated or relocated, areas of land contaminated and quantities of food being considered unfit for consumption. A common framework into which many of the consequences of an accident may be translated is their economic cost. This provides some measure of the impact of an accident and enables to know the different effects of the accident described as same terms of cost and combined as necessary.

Several models for predicting the economic impact of accidents have been developed in several countries. However, these models have been either incomplete in the economic aspects considered or inappropriate for application in our country because of differences of national economic structures. In addition to the inappropriateness, these models treat only offsite consequence. So, it is necessary to treat onsite economic consequence for estimation of entire economic consequence.

2. Model Description

Based on the location of occurrence of resulting losses and the directly damaged organizations, PWR accident costs in this study is divided into two groups such as onsite costs group and offsite costs group.

Onsite costs group includes those cost components that most directly affect the plant licensee, electric utilities, the nuclear power industry, or occur at onsite locations. On the other hand, offsite costs group includes costs associated with the countermeasures taken to reduce population radiation exposure, the offsite property damage or losses which occur as a result of an accident, the costs of radiation-induced health effects and health care costs incurred by the population.

2. 1. Replacement Power Cost

This cost is incurred because power produced by nuclear plants is cheaper than that of available sources used for replacement power. The net cost resulting from the need to replace previously operating plant can be substantial. The simplified method for estimating reactor outage cost is intended to provide rough estimates of the production cost increases for a plant outage as:

$$C_{rep} = PC \int_{t_2}^{t_1} F(t)\exp(-rt)dt, \qquad [1\text{-}a]$$

Where,

C_{rep} = Present discounted value of production cost increases over the outage period,
F(t) = Unit production cost increases of outage versus time,
P = Power generation rating of reactor during outage,
C = Assumed capacity factor of plant had outage not occurred,
r = Real discount rate,
t_1,t_2 = Start, end time of reactor plant outage, respectively.

If a constant F(t) is assumed, the model is reduced as:

$$C_{rep} = \frac{PCF}{r}\left[\exp(-rt_1) - \exp(-rt_2)\right]. \qquad [1\text{-}b]$$

2. 2. Capital Investment Loss After Severe Accidents

For some PWR accidents, plant damage may be so severe that shortens the productive lifetime of the reactor plant. In these cases, the entire capital investment in the plant may not be recovered, so some part of the capital cost of the plant represents investment loss. The normal method for accounting for this loss would be to calculate the depreciated value of the reactor plant at the time of these accident.

There are two common methods for estimation depreciation accounting. Using these depreciation accounting, the capital investment loss can be estimated.

a. Straight-Line Depreciation Accounting

$$D_r = P_{cost}/l, \qquad [2\text{-}a]$$
$$C_{ear} = P_{cost} - nD_r, \qquad [2\text{-}b]$$

Where,

P_{cost} = Initial cost of the plant,
l = Lifetime of the plant,
n = The year when an accident occurs, compared to the lifetime of the plant.

b. Sum-Of-Years-Digits Depreciation Accounting

$$SOYD_l = l(l+1)/2, \qquad [2\text{-}c]$$
$$C = P_{cost}/SOYD_l, \qquad [2\text{-}d]$$
$$C_{ear} = P_{cost} - C\left[SOYD_n - SOYD_{n-1}\right], \qquad [2\text{-}e]$$

Where,

P_{cost} = Initial cost of the plant,
l = Lifetime of the plant,
n = The year when an accident occurs, compared to the lifetime of the plant.

2. 3. Plant Decontamination Cost

After an accident at a PWR facility, it may be necessary to decontaminate areas within the power plant which have become contaminated with radioactive material released from the reactor core. Accident decontamination activities would be similar whether the reactor is refurbished for restart or decommissioned.

$$C_{dec} = \sum_{n=0}^{m} C_n \left[\frac{(1+g)}{(1+r)} \right], \quad [3]$$

Where,

C_{dec} = The net present value of decontamination cost at the time of the accident occurrence,
n = The year measured from the year of accident occurrence,
m = The year of the completion of the cleanup programs,
C_n = Unescalated, undiscounted program cost estimate for year n after accident occurrence,
g = Real escalation rate for program cost (assumed constant and uniform for all costs),
r = Real discount rate for program cost..

2. 4. Plant Repair Cost

The magnitude of plant repair cost is difficult to quantify for the majority of PWR forced outages or accidents. The major reason for this is the difficulty in distinguishing between normal maintenance of plant equipment and repairs which are forced by an accident. In many cases repairs after an accident can be performed by the normal plant operation crew and outside contractors are not employed.

2. 5. Early Decommissioning Cost for Severe Accidents

Because of present value discounting, incurring decommissioning cost sooner results in real cost. It is assumed that the decommissioning cost incurred after plant decontamination would be roughly the same as that which is anticipated at the normal end of plant life.

The real cost incurred due to accelerated decommissioning of a reactor facility is dependent upon the time during the life of the reactor at which decommissioning occurs. The real cost due to accelerated decommissioning is calculated using :

$$C_{ear} = S(1.0 - e^{-(l-t_d)r}), \quad [4]$$

Where,

C_{ear} = Real cost incurred due to acceleration of decommissioning activities,
S = Cost of decommissioning at end of plant life,
r = Real discount rate,
l = Plant service life ,
t_d = Time at which decommissioning starts, measured from the start of plant commercial operation.

2. 6. Worker Health Effect and Medical Care Cost

Any event at an PWR facility has the potential for causing plant worker health impacts. These impacts may have costs ranging from minimal health care costs to costs for worker fatalities caused by an events. Plant worker health effects resulting from routine PWR forced outage events are extremely rare. On the other hand, the most serious core-melt accidents at PWR facilities may result in significant injuries or fatalities among workers at the facility. The costs of radiation-induced health effects are estimated by multiplying the expected number of health effects by average societal costs for each type of health effect :

$$C_{hj} = N_{hj} \bullet HC_j, \quad [5]$$

Where,

C_{hj} = Total medical care and human capital cost of radiation-induced health effects of type j,
N_{hj}= Average medical care and human capital cost of specific health effect j,
HC_j = Total number of health effects of type j predicted to occur in area.

2. 7. Population Evacuation Cost

Two important protective measures which may be implemented during a serious reactor accident are evacuation or sheltering of the population in the immediate vicinity of the plant. The term "evacuation" means the immediate movement of individuals out of an area at the time of an accident. The costs of sheltering individuals are assumed to be negligible. The costs of immediate evacuation are estimated using :

$$C_{ev} = P_{ev} \bullet t_{ev} \bullet (E + I), \qquad [6]$$

Where,

C_{ev} =The cost of the evacuation,
P_{ev} = Population in the user specified area to be evacuated,
t_{ev} = Duration of evacuation, measured in the number of days for individuals to return to unaffected areas,
E = Cost of food, lodging, and transportation for each evacuee,
I = Average per-capita personal and corporate income.

2. 8. Temporary Relocation Cost

The term "temporary relocation" means the movement of a population from an area based on monitored levels of radioactive contamination and distinguished from "evacuation". It may be necessary to relocate individuals away from areas in which radionuclides have deposited after a severe PWR accident. As improved information is gathered concerning the dose rates from deposited radioactive material, individuals may be permitted to reenter those areas in which projected doses do not exceed unacceptable levels.

$$C_{ep} = P_{ep} \bullet t_{ep} \bullet (E + I), \qquad [7]$$

Where,

C_{ep} = Cost of population relocation from area,
P_{ep} = Population affected in area,
t_{ep} = Duration of relocation.

2. 9. Agricultural Product Disposal

a. Food(Crop) Product Disposal

Direct deposition of radionuclides on crops from releases which occur during the growing season can result in the need to dispose of the agricultural harvest which is affected.

$$C_c = FF \bullet A \bullet FP \bullet S, \qquad [8]$$

Where,

C_c = Cost of crop disposal,
FF = Fraction of region which is farmland,
A = Area where doses from ingestion of foods would be unacceptable,
FP = Average annual farm production (sales) in area,
S = Season factor [1.0 in growing season, = 0.0 outside of growing season].

b. Milk and Dairy product Disposal

Population dose levels from ingestion of milk could exceed protective action criteria after a release of radionuclides because dairy cows are extremely efficient collectors of radionuclides deposited on pastureland.

$$C_c = FF \bullet A \bullet DY \bullet S \bullet t_m, \qquad [9]$$

Where,

C_m = Cost of milk disposal,
FF = Fraction of region which is farmland,

A = Area where doses from ingestion of foods would be unacceptable,
DY = Fraction of farm sales from dairy products,
S = Season factor = 1.0 in growing season, = 0.0 outside of growing season,
t_m = Time for radioactivity levels in milk to reach acceptable levels for ingestion.

2. 10. Decontamination of Land And Property

Decontamination is one of less disruptive measures than long-term interdiction of areas because after the cleanup process is completed normal activities can resume in the affected areas. Decontamination can restore much of the initial wealth and economic activity in an area without the need for permanently moving the population to new locations.

The total cost of the necessary decontamination program in an area is estimated using land usage in an area and decontamination cost for each land usage.

$$C_{de} = \sum A_j \bullet DC_j , \quad [10]$$

Where,

C_{de} = Cost of decontamination program in an area,
A_j = Area of land usage j in an area,
DC_j= Decontamination cost for land usage j.

2. 11. Population Health Effects Cost

One method to estimate health effect cost is evaluation of the in human capital (or human wealth) induced by health effect occurrence. This approach values the loss in productivity of an individual caused by the incidence of a health effect. The loss in productivity can be estimated by discounting an individual's expected lifetime loss of earnings due to the incidence of a particular health effect. The advantage of this approach is that estimation of costs is straightforward. However, the estimated health effect cost from this approach includes only purely economic costs, and in no way reflects individual preferences for avoidance of pain, suffering, or anguish.

$$C_{hj} = N_{hj} \bullet HC_j , \quad [11]$$

Where,

C_{hj} = Total medical care and human capital cost of radiation-induced health effects of type j,
N_{hj} = Average medical care and human capital cost of specific health effect j,
HC_j = Total number of health effects of type j predicted to occur in area.

3. Result

It is assumed that a severe accident occurred at 1000MW plant having capacity factor of 0.8. From 6year to 10years of plant construction duration, the replacement power cost will be 213.8 billion Won to 306.4 billion Won. Theses costs correspond to 13.8% and 19.7% of total plant construction cost, respectively. As the discount rate reduces the cost is decreased.

If the occurred accident is so severe that about 50% of fuel is melted, and the remaining lifetime of the plant is 20 years, then the early decommissioning cost will be about 40 to 50 billion Won. And these will be 2.6% and 3.2% of the construction cost, respectively.

When the offsite decontamination is performed to 8km boundary from the plant, the cost will be about 26.9 billion Won to 491.4 billion Won(in case of YONG-GWANG site) per operation.

Table. Power Production and Sources[7](1990)

	Nuclear	Coal	Oil	LNG	Hydro
Power Generation(GWh) (%)	52,887 (49.1)	22,445 (20.9)	14,202 (13.2)	11,775 (10.9)	6,361 (5.9)
Generation Cost(Won/kWh)	23.75	30.95	37.88	40.89	23.06

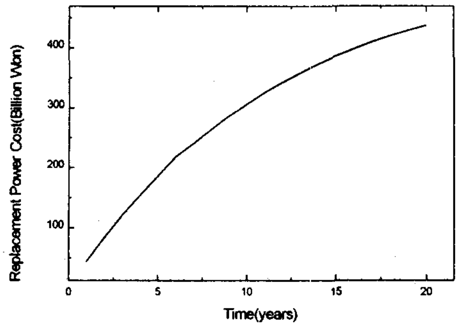

Figure 1.Replacement Power Cost
(for constant discount rate=8.5%)

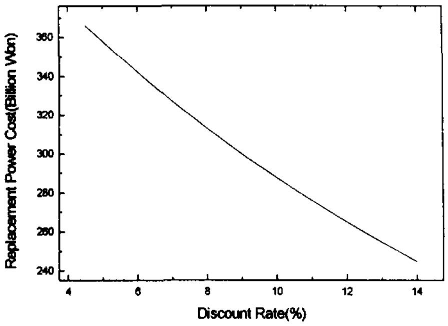

Figure 2. Replacement Power Cost
(for constant period=10years)

4. Conclusion

The economic consequence estimation model of an accident can be useful, as it can be applied in emergency planning, or in decision making after an accident. The estimation model of an accident is data intensive work to estimate a number of onsite and offsite cost terms. When compared other countries, our country is short of experience of estimating economic consequence of an accident. Because of data-insufficiency and short of experience, the estimation performed in this study is very rough and have many uncertainties.

On estimation of replacement power cost, model used in this study can not consider any characteristic of the plant such as fuel concentration rate, plant type, site characteristic or the time when the accident occurs compared to plant lifetime.

In this study, the offsite decontamination cost is estimated that depending on applied methods the cost varies about 1000times. The decontamination methods are so variable that it is not always good to take low cost. In comparison of some methods, the decontamination operation time is differed more than in factor of 10. So, to choose a reasonable method, some criteria must be applied first.

For the development of more exact estimation model for the purpose of real application, there need to get more data related to the economics and emergency planning. Also, there will need to perform a more exact study in estimation on onsite cost estimation and offsite estimation, respectively. When compared other countries, our country is short of experience of estimating accident consequence.

5. References

[1] Richard P. Burke, David C. Aldrich, "*Economic Risks of Nuclear Power Reactor Accidents*", **NUREG/CR-3673**(SAND84-0178), Sandia National Lab., 1984.

[2] S. M. Haywood, C. A. Robinson and C Heady, "*COCO-1: Model for Assessing the Cost of Offsite Consequences of Accidental Releases of Radioactivity*", **NRPB-R243**, National Radiological Protection Board, 1991.

[3] OECD/NEA and CEC, "*Probabilistic Accident Consequence Assessment Codes-Second International Comparison, Overview Report*", OECD, 1994.

[4] H-N Jow, L. J. Sprung, J. A. Rollstin and L. T. Ritchie, "*MELOCR Accident Consequence Code System(MACCS)* ", **NUREG/CR-4691**(SAND86-1562), Vol. 1, 2, and 3, Sandia National Lab., 1990.

[5] E.S. Murphy, G. M. Holter, "*Technology, Safety and Costs of Decommissioning Reference Light Water Reactors Following Postulated Accidents*", **NUREG/CR-2601**, Vol. 1 and 2, PNL, 1982.

[6] J. J. Tawil, et al., "*Off-site Consequences of Radiological Accidents : Methods, Costs and Schedules for Decontamination* ", **NUREG/CR-3413**, Battelle Pacific Northwest Lab., 1985.

[7] Eugene L. Grant, W. Grant Ireson and Richard S. Leavenworth, "*Principles of Engineering Economy*", John & Sons.

[8] "도표로 본 원자력발전 ", 원 자 력 산업회의, 1991.