APPENDIX C
TREATMENT OF UNCERTAINTY

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ABBREVIATIONS AND ACRONYMS

ADAMS	Agencywide Documents Access and Management System
GAO	U.S. Government Accountability Office
NRC	U.S. Nuclear Regulatory Commission
PERT	program evaluation and review technique
PRA	probabilistic risk assessment

C.1 INTRODUCTION

Analyses contain uncertainties for a variety of reasons, including limitations in our state of knowledge and ability to model the issue to a certain level of precision, variability in populations, and inability to predict the timing and magnitude of random events. Assessing and representing uncertainties are important analysis components. Various tools can be used to assess uncertainty and its effects on the outcomes or results. In general, the tools fall into two broad categories: (1) sensitivity analysis and (2) uncertainty analysis.

A sensitivity analysis assesses how sensitive outcomes are to variations in inputs. Typically, a sensitivity analysis characterizes the effect of one input at a time, but the analysis can be used to characterize the effect of multiple inputs together on the outcomes. A sensitivity analysis typically does not assess the relative likelihood of different outcomes. The uncertainty analysis assesses the range of outcomes, and usually the relative probabilities of different outcomes within the range, produced from a combined propagation of uncertainty in model inputs. The purpose of this appendix is to describe cost estimating uncertainty and sensitivity.

This appendix is responsive to the U.S. Government Accountability Office (GAO) guidelines that require uncertainties to be addressed in regulatory analyses both for radiological exposure and economic cost measures. In addition, the NRC's "Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities; Final Policy Statement," issued August 16, 1995, states that sensitivity studies, uncertainty analyses, and importance measures should be used in regulatory matters, where practical within the bounds of the state of the art. Uncertainties in radiological exposure measures, especially those related to facility accidents, have traditionally not been estimated. For power reactor facilities, uncertainty analysis in risk assessments has been well vetted. Risk assessments for nonreactor facilities often identify best estimates only. Some nonreactor assessments provide uncertainty ranges, but their development has generally been less rigorous than that for reactor facilities.

C.2 TREATMENT OF UNCERTAINTY IN COST-BENEFIT ANALYSES

The NRC staff should determine the appropriate level of effort to apply to the determination and discussion of uncertainty. In general, the detail and breadth of the uncertainty treatment should be commensurate with the overall complexity, as well as the perceived significance of the uncertainties to the overall finding and conclusion. To the extent applicable, the regulatory analysis, backfit analysis, and environmental analysis reviews should consider the sources and magnitudes of uncertainties in cost-benefit estimates.

Additionally, peer-reviewed studies and data collected by accepted or best available methods should be considered and used, as appropriate. To the extent practicable, the cost-benefit analysis should report expected values; expressions of uncertainty that can be presented in terms of upper and lower bounds; and studies, data, and methodologies that support or fail to support the cost-benefit estimates. Hypothetical best and worst case costs and benefits can also be estimated from sensitivity analyses, which can be used in addition to formal uncertainty analysis. This appendix will provide guidance on the appropriate treatment of uncertainty in cost-benefit analyses.

C.3 AVAILABLE GUIDANCE

Knowledge on the subject of uncertainty is extensive. This appendix focuses on the use of current NRC documents, supplemented by GAO guidance, to perform uncertainty and sensitivity analyses in cost-benefit analyses. Specifically, analysts should consider NUREG-1855, "Guidance on the Treatment of Uncertainties Associated with PRAs [probabilistic risk assessments] in Risk-Informed Decision Making," Revision 1, and GAO-09-3SP, "GAO Cost Estimating and Assessment Guide—Best Practices for Developing and Managing Capital Program Costs," issued March 2009.

GAO-09-3SP provides detailed guidance on best practices in developing cost estimates and also explains how to develop the sensitivity and uncertainty analyses in support of those estimates. Specifically, it provides details on the following:

- determining the program cost drivers and associated risks
- developing probability distributions to model various types of uncertainty (e.g., program, technical, external, organizational, and program management, including cost estimating and scheduling)
- accounting for the correlation between cost elements to properly capture risk
- performing the uncertainty analysis using a Monte Carlo simulation model
- identifying the probability level associated with the point estimate
- recommending sufficient contingency reserves to achieve levels of confidence acceptable to the organization
- allocating, phasing, and converting a risk-adjusted cost estimate to then-year dollars and identifying high-risk elements to help in risk mitigation efforts

C.3.1 Methodology

Uncertainty analysis is a process, not a result. The analyst is using many variables, each with statistical distributions, to determine the merits of implementing a regulatory requirement in rulemaking, to justify a modification to a site, or to analyze other issues that require weighing the cost against the benefit of the change. To complicate matters, the analyst is not the decisionmaker. The task of the analyst is to present the results to support decisionmaking. Therefore, when developing the study, the analyst should understand the individual variables as well as the cumulative impacts of those variables on the analysis. Individual variables require sensitivity analyses of each variable, and cumulative impacts requires a combined analysis, such as that accomplished by a Monte Carlo simulation. Further, the results of the analysis should evaluate the confidence interval for the cost-benefits that are presented to support an informed decision.

C.3.2 Sensitivity Analysis

Credibible cost estimates clearly identify limitations because of uncertainty or bias surrounding the data or assumptions. Major assumptions should be varied and other outcomes recomputed to determine how sensitive outcomes are to changes in the assumptions. In addition, an uncertainty analysis should be performed to determine the level of risk (i.e., cost estimate uncertainty) associated with the estimate.

Using sensitivity analysis, the analyst can determine the importance of variables to the regulatory analysis. Variables that significantly affect the overall cost-benefit analysis should be identified. Figure C-1 lists the variables that should be evaluated. For each issue, the significant cost or benefit drivers may be different. The sensitivity analysis is performed by changing each variable and evaluating the impact on the result. A tornado diagram (Figure C-2) can illustrate the results of a sensitivity analysis. The tornado diagram helps to graphically display the results and illustrates the impact of each cost variable on the overall analysis.

For a sensitivity analysis to be useful, the analyst should assess the underlying risks and supporting data. Additionally, the sources of the variation should be well documented. For a sensitivity analysis to reveal how a change in a single assumption can affect the cost estimate, the analyst should examine the effect of changing one assumption or cost driver at a time, while holding all other variables constant. This method facilitates a better understanding of which variable most affects the cost estimate. In some cases, such as for discount rates or for the dollar per person-rem conversion factor, a sensitivity analysis can examine the effect of multiple assumptions changing in relation to a specific scenario. Regardless of whether the analysis is performed on only one cost driver or several within a single scenario, the difference between the sensitivity analysis and uncertainty analysis is that a sensitivity analysis tries to isolate the effects of changing one variable at a time, while an uncertainty analysis examines the effects of many variables changing all at once to determine the level of risk associated with the estimate. By examining the effects of varying the estimate's elements, a degree of uncertainty about the estimate can be expressed with a range of potential costs and benefits that are qualified by a factor of confidence.

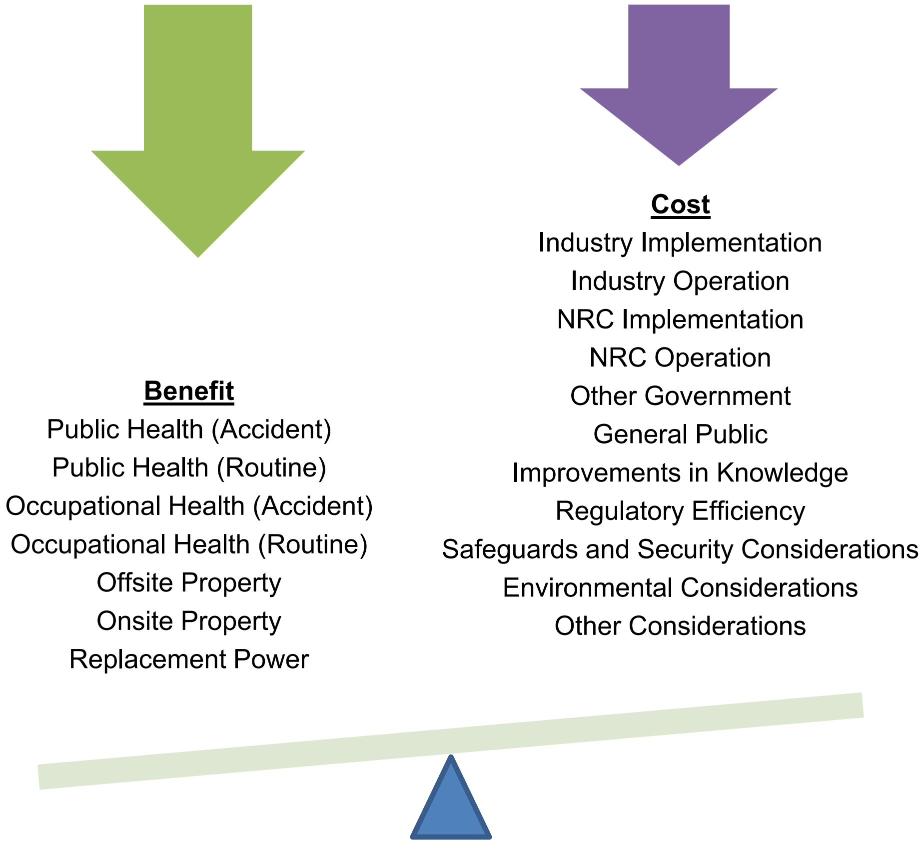

Figure C-1 Examples of Affected Variables that Support the Weighing of Costs and Benefits in a Regulatory Analysis

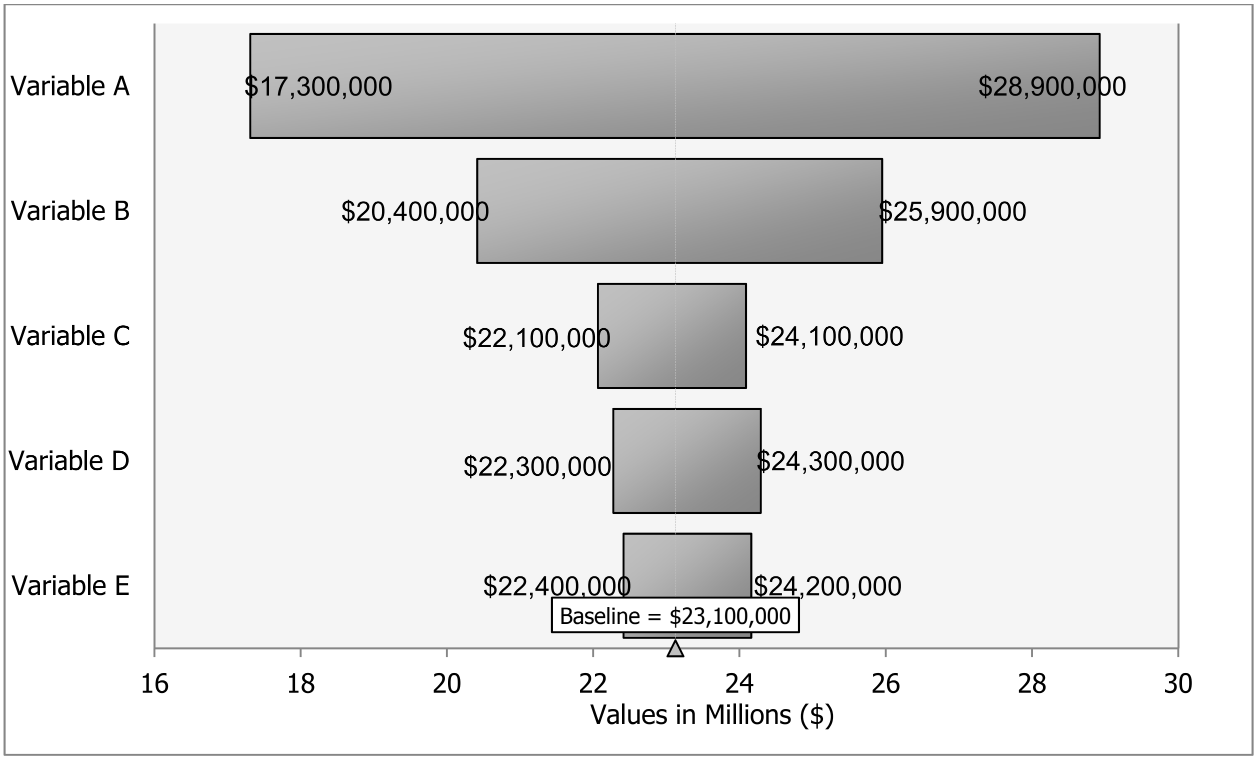

Figure C-2 Example Tornado Diagram from an NRC Rulemaking Regulatory Analysis

C.3.3 Monte Carlo Simulation

A sensitivity analysis typically changes one variable at a time to determine its impact. The Monte Carlo[1] simulation combines all the variables statistically to determine the overall uncertainty in the results of the analysis. The availability of high-performance computers has facilitated numerical calculation using Monte Carlo simulation. However, the efficacy of the analysis depends on the data supporting the overall variables to determine the individual distributions for those elements. Since the NRC issued NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook," in January 1997, a number of regulatory analyses and severe accident mitigation alternative analyses have been performed. These analyses provide data to help inform the overall benefit distributions for the regulatory analysis.

If data are available, then the analyst should attempt to fit them into the appropriate distribution using a goodness-of-fit technique[2] for probability distributions. Table C-1 illustrates nine of the distributions that could be used in support of the regulatory analysis and shows when they would typically be used. For cost parameters, the program evaluation and review technique (PERT), represented as a beta distribution, is commonly used, which consists of low, best, and high estimates to evaluate the uncertainty. The PERT distribution is a special form of the beta distribution with a minimum and maximum value specified. The shape parameter is calculated from the defined most likely value.

[1] A Monte Carlo simulation is a computer-based method of analysis that uses statistical sampling techniques to obtain a probabilistic approximation to the solution of a mathematical equation or model.

[2] Goodness-of-fit techniques include formal statistical tests as well as graphical methods to measure how well predicted values match a set of observations.

Once the distribution is obtained for each variable, the analyst can use a sensitivity analysis to determine which variables are more important to the analysis and then run the Monte Carlo simulation on that limited set. The analyst can run the simulation on all the variables by running a holistic simulation of both the benefit and the cost.

Table C-1 Nine Common Probability Distributions

Distribution	Description	Typical Application
Bernoulli	Assigns probabilities of “p” for success and “1 – p” for failure; mean = “p”; variance = “1 – p”.	With likelihood and consequence risk cube models; good for representing the probability of a risk occurring but not for showing the impact on the program.
Beta	Similar to normal distribution but does not allow for negative cost or duration; this continuous distribution can be symmetric or skewed.	To capture outcomes biased toward the tail ends of a range; often used with engineering data or analogy estimates; the shape parameters usually cannot be collected from interviewees.
Lognormal	A continuous distribution positively skewed with a limitless upper bound and known lower bound; skewed to the right to reflect the tendency toward higher cost.	To characterize uncertainty in nonlinear cost estimating relationships; it is important to know how to scale the standard deviation, which is needed for this distribution.
Normal	Used for outcomes likely to occur on either side of the average value; symmetric and continuous, allowing for negative costs and durations. In a normal distribution, about 68% of the values fall within 1 standard deviation of the mean.	To assess uncertainty with cost estimating methods; standard deviation or standard error of the estimate is used to determine dispersion. Because data should be symmetrical, it is not as useful for defining risk, which is usually asymmetrical, but can be useful for scaling estimating error.
Program Evaluation and Review Technique (PERT)	The PERT distribution is similar to a triangular distribution, in that it has the same set of three parameters. Technically, it is a special case of a scaled beta distribution.	To express technical uncertainty, because it works for any system architecture or design; also used to determine schedule uncertainty. It is considered superior to the triangular distribution when the parameters result in a skewed distribution, as the smooth shape places less emphasis in the direction of the skew.
Poisson	Peaks early and has a long tail compared to other distributions.	To predict all kinds of outcomes, like the number of software defects or test failures.
Triangular	Characterized by three points (most likely, pessimistic, and optimistic values); can be skewed or symmetric and is easy to understand because it is intuitive. One drawback is the absoluteness of the end points, although this is not a limitation in practice because it is used in a simulation.	To express technical uncertainty, because it works for any system architecture or design; also used to determine schedule uncertainty.

Distribution	Description	Typical Application
Uniform	Has no peaks because all values, including highest and lowest possible values, are equally likely.	With engineering data or analogy estimates.
Weibull	Versatile as it can take on the characteristics of other distributions, based on the value of the shape parameter "b"—e.g., Rayleigh and exponential distributions can be derived from it.*	In life data and reliability analysis because it can mimic other distributions and has an objective relationship to reliability modeling.

* The Rayleigh and exponential distributions are a class of continuous probability distribution.

C.3.4 Results

Using the results from the Monte Carlo analysis, the analyst can then develop the cumulative distribution function illustrated in Figure C-3. This is an important tool to support the decisionmaking process. The distribution illustrates the confidence interval for the analysis and the cost associated with achieving a higher confidence interval. In this case, decisionmakers can evaluate the benefit of approving the change and also understand that the cost can vary considerably.

Any change in cost as the issue progresses from the conceptual stage to later stages in the development of regulatory requirements is important to communicate. Figure 15 in GAO-09-3SP illustrates this concept (shown here as Figure C-4). Issuing the implementation guidance with the proposed rule ensures that the costs associated with the regulatory action accurately reflect the costs associated with implementing the change. As additional cost information is gained, the uncertainty band typically narrows, because of the availability of more accurate information and a better understanding of details of the requirement.

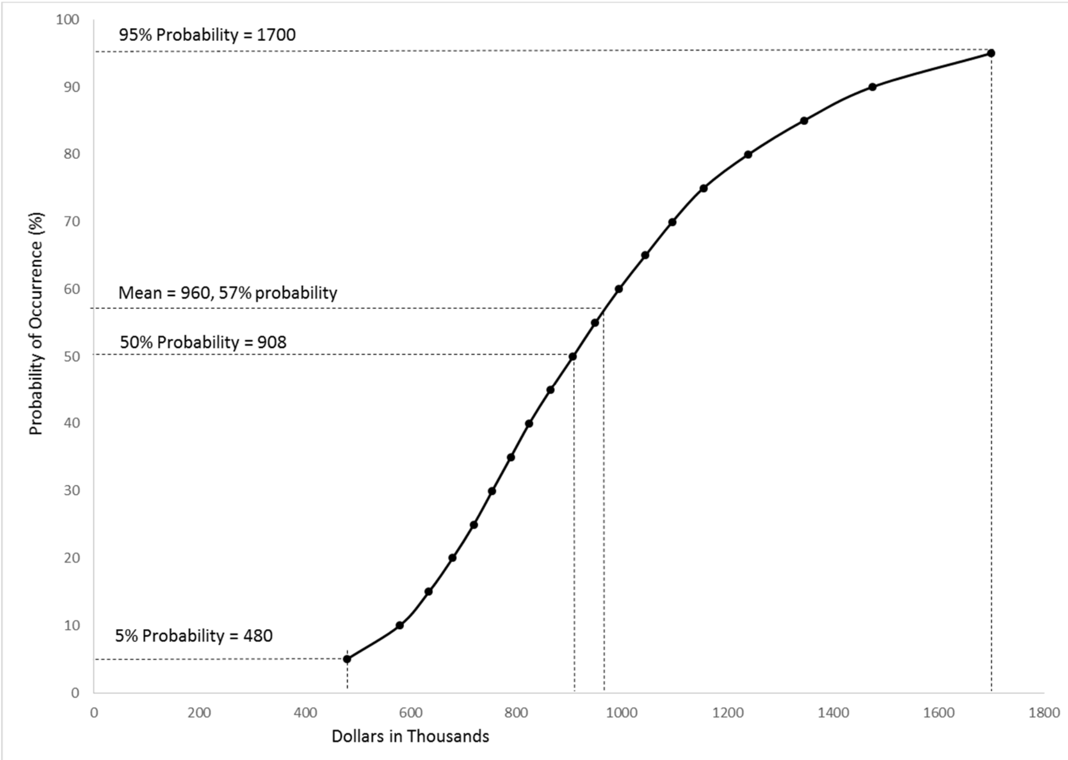

Figure C-3 Example of a Cumulative Distribution Function

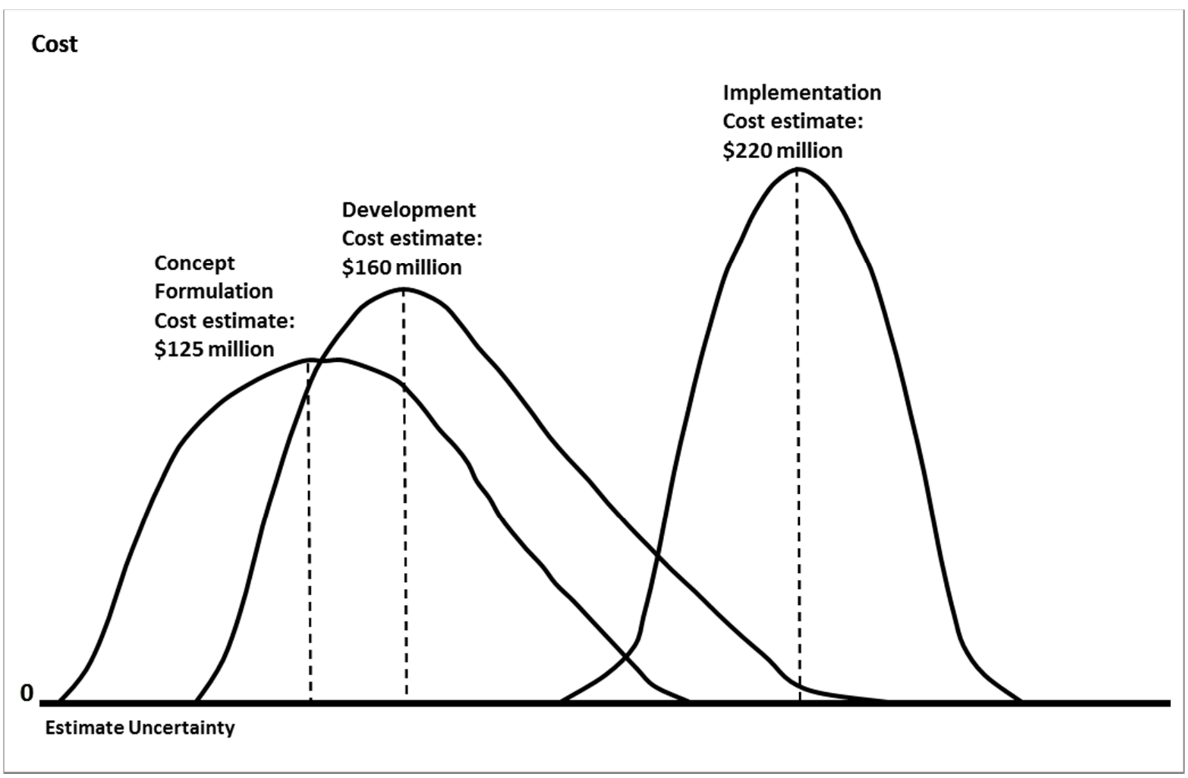

Figure C-4 Example of Change in Cost-Estimate Uncertainty

C.4 REFERENCES

U.S. Government Accountability Office (GAO), "GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs," GAO-09-3SP, March 2009. Available at http://www.gao.gov/assets/80/77175.pdf.

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