# APPENDIX C

# TREATMENT OF UNCERTAINTY

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## C.1 Introduction

Analyses contain uncertainties for a variety of reasons, examples of which include 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 is an important analysis component. 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 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. Appendix H covers other forms of uncertainty.

## C.2 Treatment Of Uncertainty

The U.S. Nuclear Regulatory Commission (NRC) and the U.S. Government Accountability Office (GAO) guidelines require that uncertainties be addressed in regulatory analyses both for radiological exposure and economic cost measures. In addition, NRC's policy statement on the use of probabilistic risk assessment (PRA) methods in nuclear regulatory activities 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 (Ref. C.1). Uncertainties in radiological exposure measures, especially those related to facility accidents, have traditionally not been estimated. With respect to 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 for reactor facilities.

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. Thus, to the extent applicable, the sources and magnitudes of uncertainties in cost-benefit estimates should be considered in the regulatory analysis, backfit analysis, and environmental analysis reviews.

Additionally, peer-reviewed studies, and data collected by accepted or best available methods, should be considered and used, as appropriate. 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 should, to the extent practicable, be reported in the regulatory analysis. Hypothetical best- and worst-case costs and benefits can also be estimated from sensitivity analyses. Sensitivity analysis can be used in addition to formal uncertainty analysis. This appendix will provide guidance on the appropriate treatment of uncertainty in cost-benefit analyses. Further discussions of uncertainties in probabilistic risk and severe accident assessments are addressed in Appendix H.

## C.3 Available Guidance

There is an extensive body of knowledge on the subject of uncertainty. For this appendix, the focus is on using current NRC documents supplemented by GAO guidance to perform uncertainty and sensitivity analyses in cost-benefit analyses. Specifically, NUREG-1855, "Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making," Revision 1, and GAO-09-3SP, "Cost Estimating and Assessment Guide—Best Practices for Developing and Managing Capital Program Costs," should be considered.

The GAO-09-3SP provides detailed guidance for best practices in developing cost estimations and also contains guidance on how to develop the sensitivity and uncertainty analyses in support of those estimations. Specifically, it provides details on developing 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 analyst is tasked with presenting the results to support a decision. Therefore, when developing the analysis, the analyst should understand the individual variables, as well as the cumulative impacts of those variables to the analysis. The former is supported by sensitivity analyses on each of the individual variables, while the latter 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

Using sensitivity analysis, the analyst can determine the importance of variables to the regulatory analysis. Variables that significantly affect the overall cost-benefit analysis need to 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. The results of a sensitivity analysis can be illustrated using a tornado diagram (see Figure C-2). 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. In order for a sensitivity analysis to reveal how the cost estimate is affected by a change in a single assumption, the analyst should examine the effect of changing one assumption or cost driver at a time, while holding all other variables constant. By doing so, this 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 be conducted to 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 risk or uncertainty analysis is that a sensitivity analysis tries to isolate the effects of changing one variable at a time, while a risk or uncertainty analysis examines the effects of many variables changing all at once.

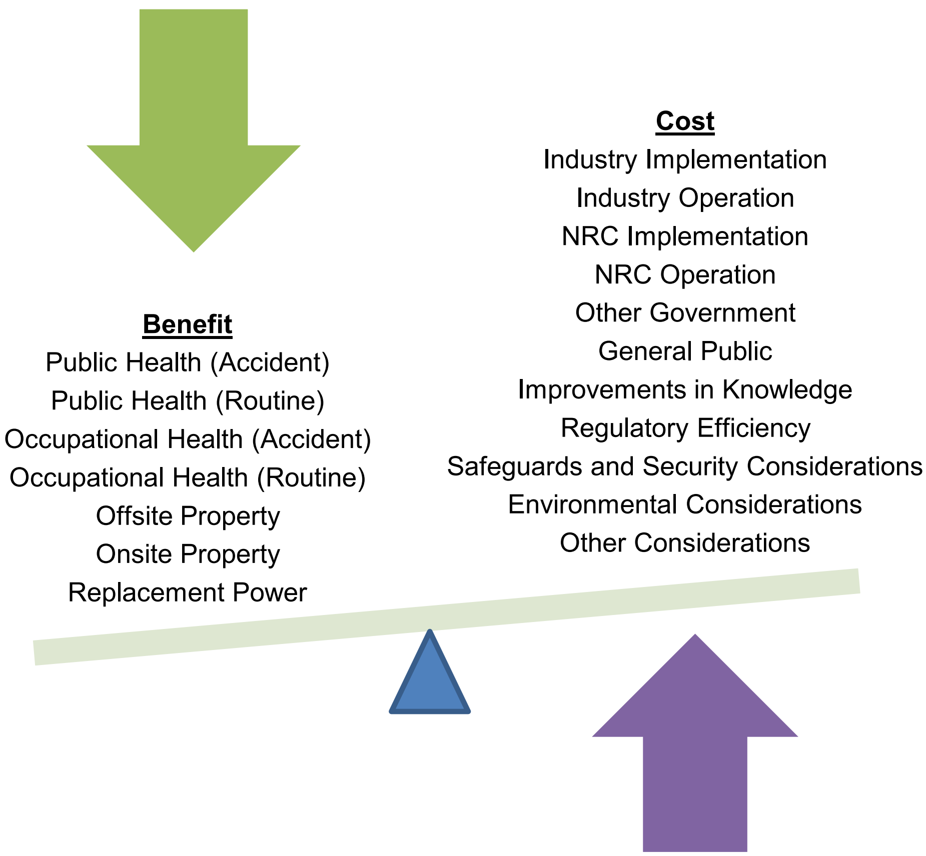


**Figure C-1 Examples of Affected Variables that Support the Weighing of Costs and Benefits in a Regulatory Analysis**

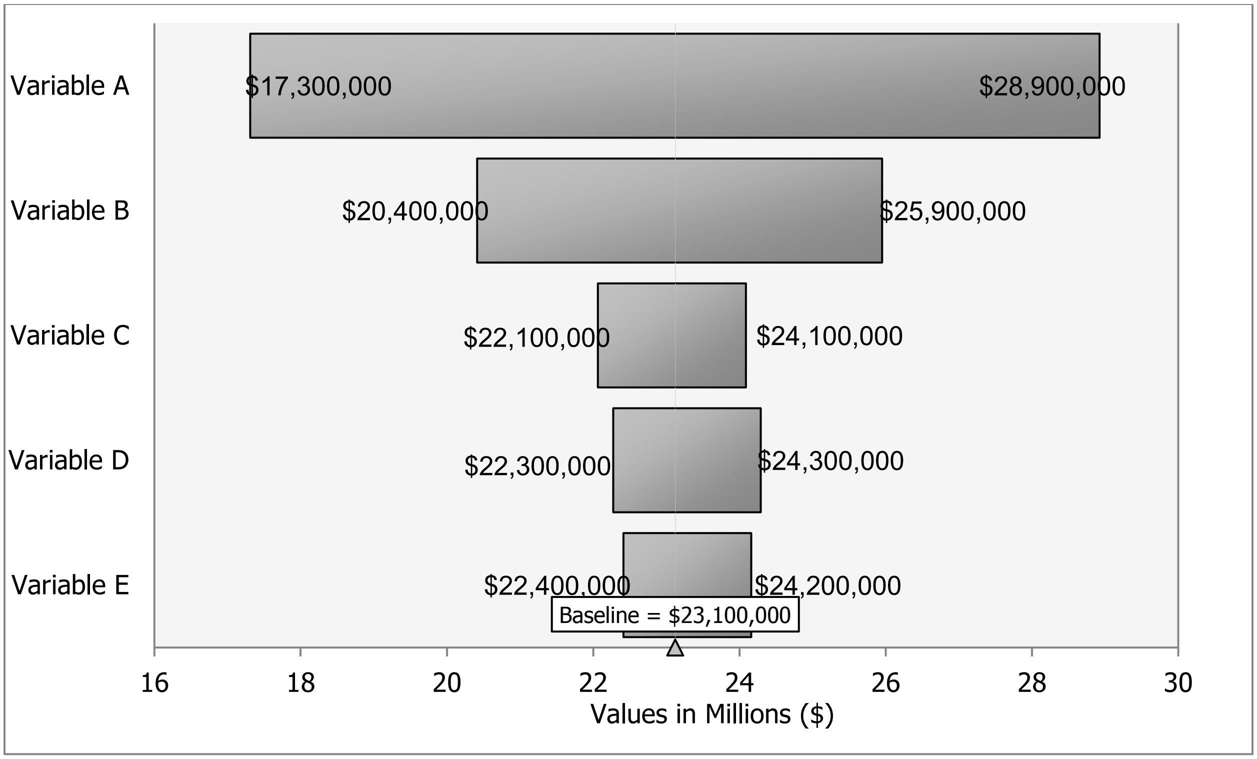


**Figure C-2 Example Tornado Diagram from an NRC Rulemaking Regulatory Analysis**

### C.3.3 Monte Carlo Simulation

A sensitivity analysis typically changes one variable at a time to determine its impact. The Monte Carlo simulation combines all the variables statistically to determine the overall uncertainty in the results of the analysis. The numerical calculation using Monte Carlo has been facilitated by the availability of high-performance computers. However, efficacy of the analysis depends on the data supporting the overall variables to determine the individual distributions for those elements. Since the NRC published the “Regulatory Analysis Technical Evaluation Handbook” in 1997, a number of regulatory analyses and severe accident mitigation alternatives (SAMA) analyses have been performed. These analyses provided 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 for probability distributions. Table C-1 illustrates nine of the distributions that could be used in support of the regulatory analysis and 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.

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 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 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 one 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. |
| Uniform | Has no peaks because all values, including highest and lowest possible values, are equally likely. | With engineering data or analogy estimates. |
| Weibull | Versatile, 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 its objective relationship to reliability modeling. |

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

### C.3.4 <u>Results</u>

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. It can illustrate 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. It is

also important to communicate any change in cost as the issue progresses from the conceptual stage to later stages in the development of regulatory requirements.
Figure 15 in GAO-09-3SP illustrates this concept and is shown here as Figure C-4. This further supports the NRC's position in issuing the implementation guidance with the proposed rule to ensure that the costs associated with the regulatory action accurately reflect the costs associated with implementing the change. It is also important to note that, as the issue progresses, the uncertainty band typically narrows, due to the availability of more accurate information and a better understanding of details of the requirement.

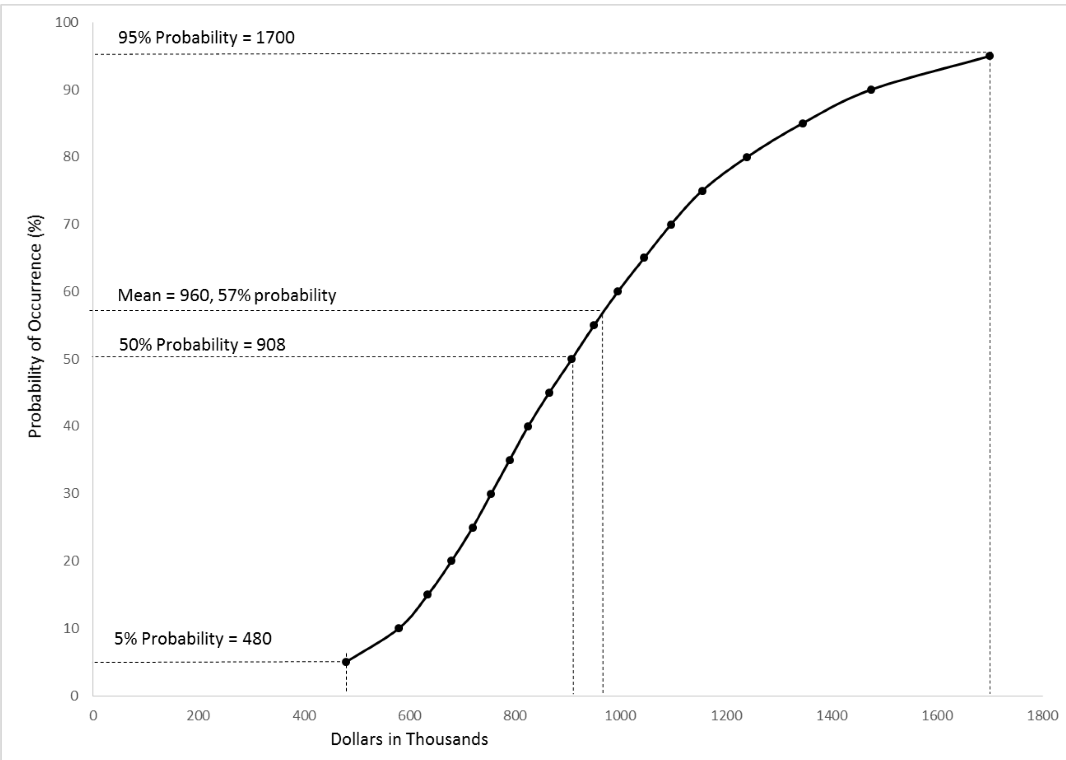


**Figure C-3 Example of a Cumulative Distribution Function**

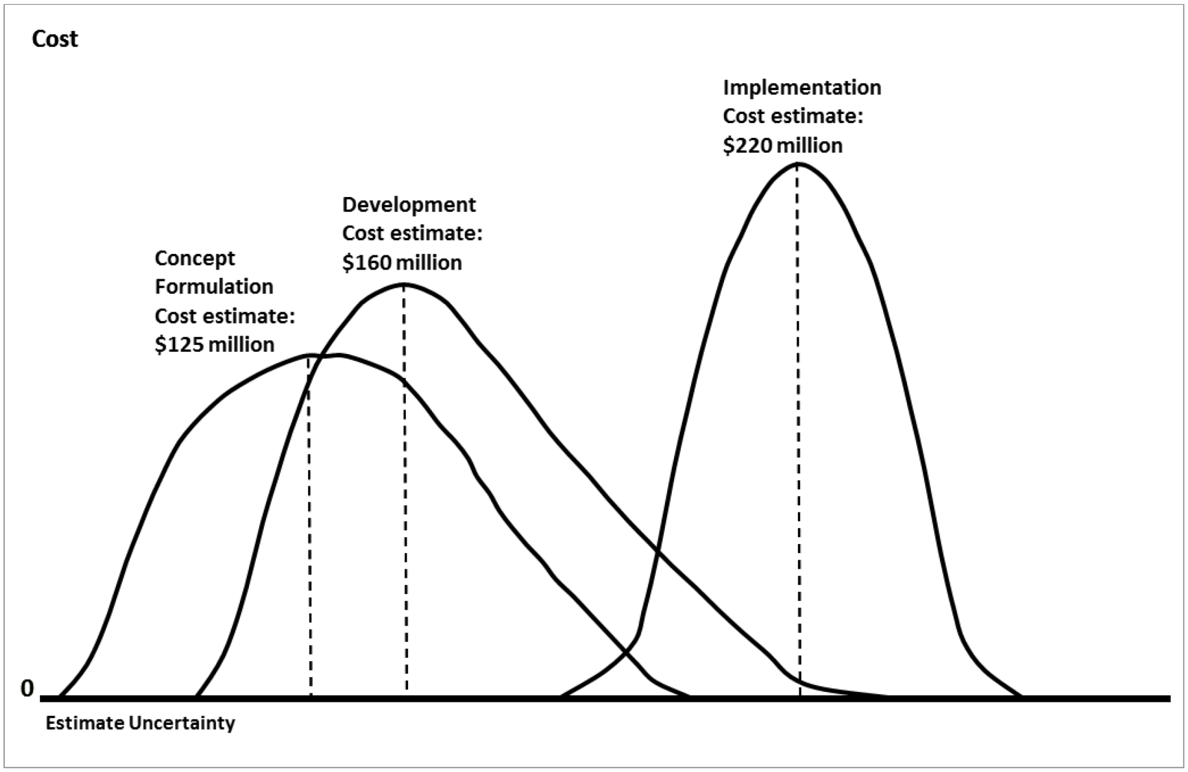


**Figure C-4 Example of Change in Cost-Estimate Uncertainty**

## C.4 References

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C.2 U.S. Nuclear Regulatory Commission (NRC). 2013. "Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making. Draft Report for Comment." NUREG-1855, Revision 1, Washington, D.C. ADAMS Accession No. ML13093A346. Accessed at http://pbadupws.nrc.gov/docs/ML1309/ML13093A346.pdf.

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C.4 U.S. Nuclear Regulatory Commission (NRC). 1997. "Regulatory Analysis Technical Evaluation Handbook." NUREG/BR-0184, ADAMS Accession No. ML050190193. Accessed at http://pbadupws.nrc.gov/docs/ML0501/ML050190193.pdf.