Appendix C

Treatment of Uncertainty

Contents

Abbreviations and Acronyms

GAO	Government Accountability Office
NRC	U.S. Nuclear Regulatory Commission
PRA	probabilistic risk assessment
SAMA	severe accident mitigation alternatives

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 world, variability in populations, and inability to predict the timing and magnitude of random events. Assessing and representing uncertainties is an important analysis component to present to decisionmakers. There are various tools that 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. Sensitivity analysis assesses how sensitive outcomes are to variations in inputs. Typically 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. Sensitivity analysis typically does not assess the relative likelihood of different outcomes. 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.

C.2 Treatment of Uncertainty

The U.S. Nuclear Regulatory Commission (NRC) and the 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 Final Policy Statement on the use of probabilistic risk assessment (PRA) in nuclear regulatory activities states that sensitivity studies, uncertainty analysis, and importance measures should be used, where practical, in regulatory matters (Ref. 1). Uncertainties in radiological exposure measures, especially those related to facility accidents, have traditionally been difficult to estimate. With respect to power reactor facilities, much has been written about uncertainty analysis in risk assessments. Risk assessments for non-reactor facilities often identify best estimates only. Some non-reactor assessments provide uncertainty ranges but their development has generally been less rigorous than that for reactor facilities. Conversely, accident scenarios for non-reactor facilities are much less complex than for power reactors, facilitating uncertainty estimation. On the other side of the equation the cost estimates also have associated uncertainties.

High and low estimates associated with costs can be developed. From these values, the analyst can generate distributions. Using a Monte Carlo simulation, a statistical summation can be used to characterize the overall uncertainty for the analysis. This can then be combined with the statistical results from the benefit evaluation to derive the overall uncertainty for the cost-benefit estimation.

Uncertainties are important to consider and should be presented in a regulatory analysis. However, reason should be applied in determining the level of effort applied to the consideration and discussion of uncertainty. In general, the detail and breadth of the uncertainty treatment should be commensurate with the overall policy significance, complexity, and level of controversy, as well as the perceived significance of the uncertainties to the conclusion. Thus, to the extent practical, the sources and magnitudes of uncertainties in cost-benefit estimates should be considered in regulatory analysis, backfit analysis, and NEPA reviews.

Additionally, best available peer-reviewed studies, and data collected by accepted or best available methods, should be considered and, as appropriate, utilized. 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 must, to the extent practical, 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[1].

C.3 Available Guidance

There is an extensive body of knowledge on the study of uncertainty. For this appendix, the focus is to use current NRC documents supplemented by GAO guidance to perform uncertainty and/or sensitivity analyses in cost-benefit analyses. Specifically, NUREG-1855, “Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making,” Rev. 1 (Ref. 2) and GAO-09-3SP, “Cost Estimating and Assessment Guide - Best Practices for Developing and Managing Capital Program Costs,” (Ref. 3) should be considered.

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 analysis 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, program management including cost estimating and scheduling);
- Accounting for 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; and
- 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, justifying a modification to a site, or other issues that require weighing the cost against the benefit of the change. To complicate matters, the analyst in most cases is not the decisionmaker. The analyst is tasked to present the results to support a decision. Therefore, when developing the analysis, the analyst must 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 treatment, such as that accomplished by Monte Carlo simulation. Further, the results of the analysis must evaluate the confidence interval for the cost-benefits that are presented to support an informed decision. References 4 and 5 provide useful discussions and potential approaches to treating uncertainty and informing decisions.

[1] Further discussion of uncertainties in probabilistic risk and severe accident assessments will be addresses in Appendix H.

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 must be identified. Figure C-1 lists the variables that should be evaluated. For each issue, significant cost or benefit drivers may be different. The sensitivity analysis is performed by changing each variable and evaluating the impact to the result. This is best illustrated in a tornado diagram (Figure C-2). The tornado diagram helps to graphically display the result and illustrates the impact of each cost variable to the overall analysis.

For a sensitivity analysis to be useful, the analyst must assess the underlying risks and supporting data. Additionally, the sources of the variation should be well documented. In order for sensitivity analysis to reveal how the cost estimate is affected by a change in a single assumption, the analyst must examine the effect of changing one assumption or cost driver at a time while holding all other variables constant. By doing so, it is easier to understand which variable most affects the cost estimate. In some cases, 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 sensitivity analysis and risk or uncertainty analysis is that sensitivity analysis tries to isolate the effects of changing one variable at a time, while risk or uncertainty analysis examines the effects of many variables changing all at once.

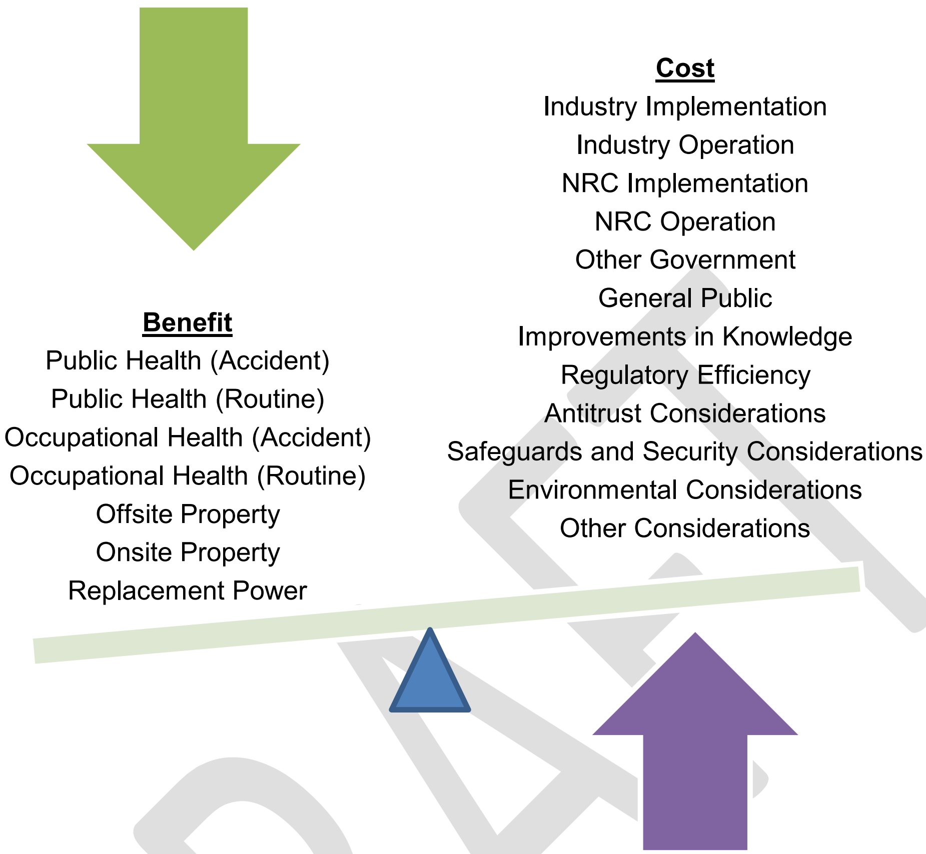


Figure C-1 Examples of Affected Variables that Support the Weighing of Costs and Benefits in a Regulatory Analysis

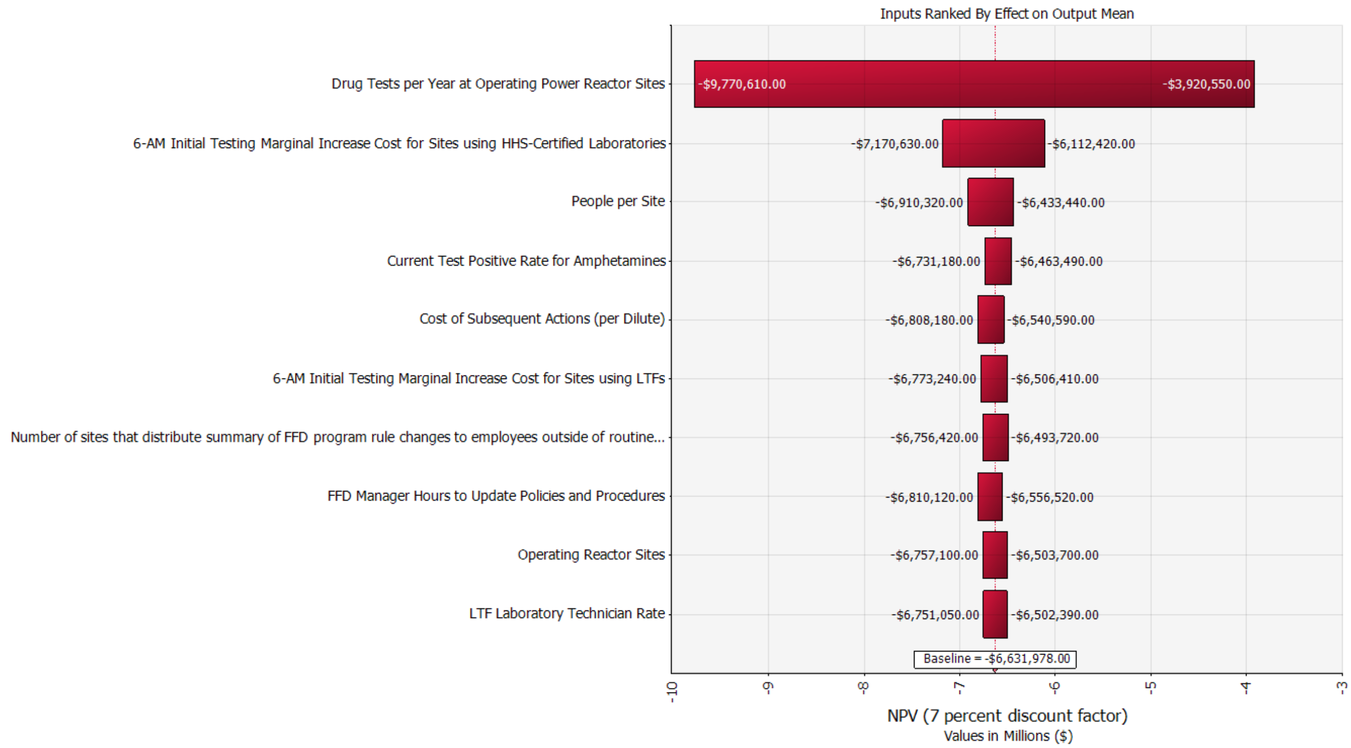


Figure C-2 Example Tornado Diagram from an NRC Proposed Rulemaking Regulatory Analysis Tornado Diagram

C.3.3 Monte Carlo Simulation

A sensitivity analysis changes one variable at 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, the limitations and robustness of the analysis depend on the data supporting the overall variables to determine the individual distributions for those elements. Since the original Regulatory Analysis Technical Evaluation Handbook was published in 1997 (Ref. 6), 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.

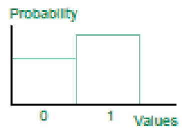
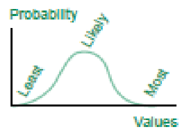
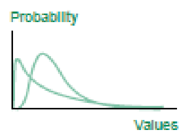
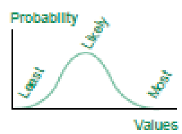
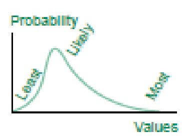
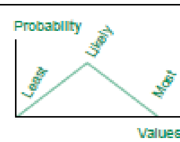
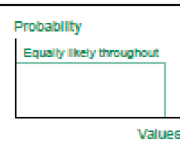
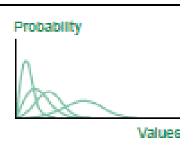
If data is available, then the analyst should attempt to fit the data using a regression analysis to the appropriate distribution. Table C-1 illustrates eight of the distributions that could be used in support of the regulatory analysis. As was discussed earlier, additional work should be done to evaluate the data for the benefits. For cost parameters, the PERT[2] or beta distribution is commonly used which consists of low, best and high estimates to evaluate the uncertainty.

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

[2] Program Evaluation and Review Technique (PERT) distribution – 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. The PERT distribution is similar to a Triangular distribution, in that it has the same set of three parameters.

simulation on that limited set. The analyst can also choose to run the simulation on all the variables by either looking at the cost and benefit separately and then statistically combining the results or by running a holistic simulation of both the benefit and the cost.

Table C-1 Eight Common Probability Distributions

Distribution	Description	Shape	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. Since data must be symmetrical, it is not as useful for defining risk, which is usually asymmetrical, but can be useful for scaling estimating error
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 since 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

(Ref. 3)

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. 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 position in issuing the implementation guidance with the proposed rule to ensure 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 narrows due to the availability of more accurate information and a better understanding of details of the requirement.

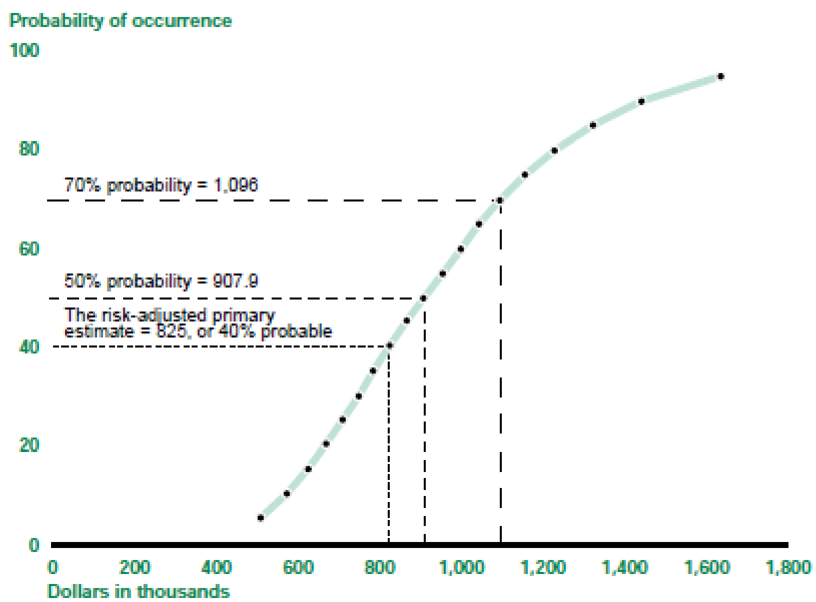


Figure C-3 Example of a Cumulative Distribution Function (Ref. 3)

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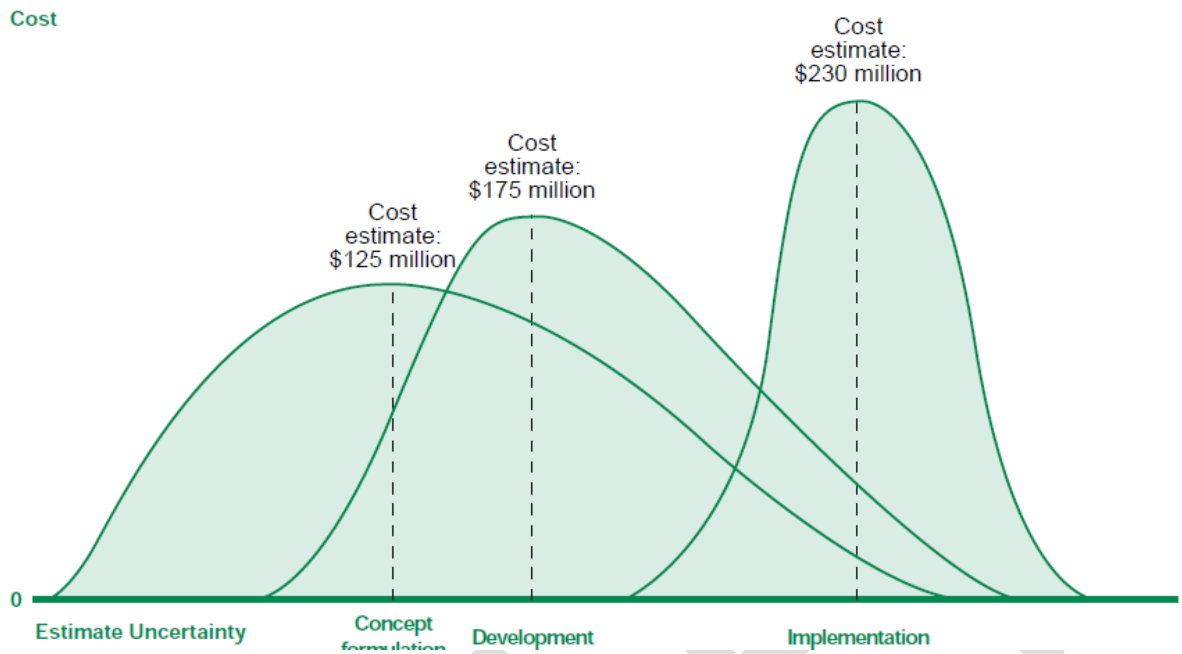

Figure C-4 Example of Change in Cost Estimate Uncertainty (Ref. 3)

C.4 References

1. U.S. Nuclear Regulatory Commission (NRC). 1995. 60 FR 42622 (August 16, 1995) "Final Policy Statement on the Use of Probabilistic Risk Assessment in Nuclear Regulatory Activities." *Federal Register*, U.S. Nuclear Regulatory Commission, Washington D.C. Accessed at http://www.gpo.gov/fdsys/pkg/FR-1995-08-16/pdf/95-20237.pdf

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

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6. U.S. Nuclear Regulatory Commission (NRC). 1997. "Regulatory Analysis Technical Evaluation Handbook." NUREG/BR-0184, ADAMS Accession Number ML050190193. Accessed at http://pbadupws.nrc.gov/docs/ML0501/ML050190193.pdf