COST-BASED ASSESSMENT OF DECOMMISSIONING ALTERNATIVES AND FINANCIAL STRATEGIES

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ABSTRACT

In this paper, we present a cost-based assessment of two decommissioning alternatives in the context of today’s changing environment: DECON–immediate decommissioning after shutdown, and Delayed DECON (SAFSTOR) -- delayed decommissioning after shutdown. Many factors can affect whether the choice of one, or the other alternative will be better in economic terms; i.e., the alternative of lower future cost. In our assessment, we assume that these factors can be viewed as stochastic variables whose future values may vary probabilistically. Accordingly, we constructed a Monte Carlo spreadsheet model to simulate, for a hypothetical reactor decommissioning scenario, the effects of 20,000 random draws for each of the eleven possible assumption factors that will likely affect: (1) the future (present values of) decommissioning costs under each alternative, respectively, and; (2) the measured adequacy of a utility’s decommissioning trust fund balance, and the measured adequacy of its recent yearly contributions, as of the current year (2004).

Our model forecasted results vary widely. They show that the “correct” (i.e., lower cost) decommissioning alternative, the two alternative costs, and the measured funding adequacies will depend greatly on the future values of the model’s assumptions. However, only two of these eleven assumption factors affected our forecast variables substantially – the after-tax rate-of-return on the decommissioning trust fund assets and the decommissioning cost escalation rate.

Our analysis presents a generic model and results for a hypothetical case. For an analysis such as this to be more useful and provide more definitive results for utility owners, regional planners, state Public Utilities Commissions (PUCs) or the Nuclear Regulatory Commission (NRC), further research and analysis would be necessary that is specific to a utility in terms of more realistic values, and reduced ranges for the *a priori* ranges assumed for our eleven assumption factors -- especially for the two sensitive factors identified in our analysis.

INTRODUCTION

The potential costs and sufficiency of funds for electric utilities in the United States to eventually decommission the nation’s nuclear power plants is an important issue for the nuclear industry. The process of decommissioning is necessary because, following the retirement of a nuclear power plant, a significant radiation hazard remains. Both the radioactive and non-radioactive materials (structures, components, equipment, etc.) must be decontaminated and safely removed, as well as the site itself remediated so that the land can be used again for some other economic purpose. In addition to the regulations, the costs and benefits of such “cleaning” will help determine the degree to which the land is decontaminated and, thereby, for what types of purpose the land can be subsequently used. Plant owners must also answer a related question at this time: “To delay, or not to delay,” decommissioning until sometime later (e.g., 20 years) after shutdown, if regulatory authorities will permit such delay. Given such freedom of choice, should the owner delay, or not? Unfortunately, as with many things in life, the answer is not definitive, rather it is: "It depends." This in turn leads to a question "On what"?

The short answer to the above question is that an owner should delay only if it is relatively cheaper to delay. While other non-economic issues (such as public safety and regulatory acceptance) will influence this decision, in this paper we focus only on the economic factors (e.g., returns on fund assets, decommissioning costs, and so on) affecting such a decision. To answer this question for a hypothetical plant/owner, we constructed a stochastic (Monte Carlo) simulation model – using Microsoft's Excel and Crystal Ball – to assess (1) whether delaying, or not delaying is less costly and (2) whether the decommissioning funding (i.e., current balance, and recent yearly contributions) is adequate. Our stochastic spreadsheet model yields (e.g., 20,000) results that vary, and will depend upon the random values chosen for our key assumptions. Under some sets of assumptions, not delaying is more costly, while for others, delaying for 20 years is more costly.

We focus on three main types of costs in performing our analysis. The first, and by far the largest cost element is the "initial" decommissioning cost estimate for the plant (as of the year of estimation). This cost element is composed of three parts: Nuclear Regulatory Commission (NRC-defined) costs -- radioactive plant machinery, structures and land; "clean costs" -- non-radioactive machinery and structures; and spent fuel storage costs. The second cost element is the additional monitoring/maintenance costs that arise if the plant decommissioning is delayed for 20 years. The third cost element is the opportunity cost in land value of the 20-year delay of an alternative economic use for the land upon which the plant resides. If decommissioning is not delayed, only the first cost element is relevant. If decommissioning is delayed for 20 years, all three cost elements are relevant. However, if decommissioning is delayed for a substantial period, these initial costs may be slightly lower due to radioactive decay and other factors.

Key Input Data for the Hypothetical Case

(1) A plant (Reactor), owned 100% by ABC Utility, was licensed to operate from 12/31/1984 until 12/31/2024. We assume a 50/50 chance for a further 20-year license extension.

(2) A decommissioning cost "initial" estimate ($600 million) [for each owner's plant "portion;" this can be assigned proportionally] -- in current dollars as of the current year December 31, 2004. [When available, a site-specific estimate of all decommissioning costs should be used. If a site-specific estimate is not available, then the cost estimates derived from NRC's generic formula for NRC-defined costs, assumed by NRC to be a "minimum" estimate, could be used, plus "initial" estimates for clean costs and spent fuel storage costs (as of 2004)].

(3) An "initial" monitoring/maintenance/safety cost estimate ($2.5 million/year) as of 12/31/04, to evaluate the additional 20-year monitoring costs that will arise because of the 20-year delay.

(4) The current value of the land ($10 million) upon which the plant is sited as of 12/31/04.

(5) Decommissioning fund current balance ($130 million), as of December 31, 2004, for the plant (or, plant portion) owner. Use that fund balance that the owner designates for meeting NRC-defined costs, clean costs, and spent fuel storage costs combined.

(6) Decommissioning fund recent-year contributions: as of 12/31/04 ($15 million); and as of 12/31/03 ($13 million) for the owner/plant. Use those fund contributions that the owner designates for meeting NRC-defined costs, clean costs, and spent fuel storage costs combined.

Key Assumptions

The eleven stochastic assumptions used in our analysis include: (1) future after-tax annual-average rate-of-return on decommissioning fund assets (i.e., discount rate), (2) future annual-average decommissioning cost escalation rate, (3) “initial” decommissioning cost estimate, (4) start of “instantaneous” decommissioning: years after permanent shutdown, (5) number of years for extension of operating license, (6) current market value of the decommissioning fund balance and contributions, (7) monitoring/maintenance/safety costs, (8) reduction fraction of “initial” decommissioning costs due to 20-year delay, (9) current land value, (10) inflation rate in land value if decommissioning is not delayed for 20 years, and (11) inflation rate in land value if decommissioning is delayed for 20 years.

(1) Future After-Tax Rate of Return on Decommissioning Fund Assets

We use an after-tax rate-of-return on fund assets to discount future values for trust fund contributions, plant decommissioning costs, and plant monitoring costs. We used the industry data reported by the U.S. Government Accountability Office (GAO). In a 2002 survey of plant owners, which was used in a 2003 GAO Report [1] that assessed the adequacy of decommissioning funding for 222 individual decommissioning funds, the GAO asked owners for information on the financial assets contained in their respective decommissioning funds. Most, but not all, owners responded. Using the variation in the annual-averages of the owners’ after-tax rate-of-return data over 1997-2001, and the “baseline” rate of return estimated in this GAO Report over the subsequent 25 years (using Global Insight’s 25-year forecasts) [2], we estimate here the annual-average forecast for the mean, and standard deviation of the rate of return variable. We divided these funds into 3 categories depending on the relative percentages of “bond-like” and “stock-like” assets in each fund. For our hypothetical utility fund, we assumed that it was of bond category 3, with 20% bonds and 80% stocks. Therefore, we assume our annual-average rate-of-return variable follows a “truncated” Logistic probability distribution, varying plus, or minus 1.5 standard deviations from its assumed mean; namely, from 0.68%, 5.48% (mean), to 10.28%. (The 90% confidence interval is 1.62 standard deviations; however, we used 1.5 standard deviations from the 1997-2001 industry financial data because we felt that, over the long run, this variation would be somewhat less than it was in this volatile 5-year period.)

(2) Future Decommissioning Cost Escalation Rate

We use a cost escalation rate that is not strictly an inflation rate although inflation is likely a major component. Rather, it combines the effects of inflation (which increases costs) with two other factors, one that increases, and one that decreases such costs. For example, if the scope of decommissioning is expanded over time, costs will increase regardless of any inflation; but if technological progress leads to a more efficient decommissioning process, costs will decrease -- even with a zero inflation rate. Using the biennial reports sent to NRC for year 2000, the GAO had received the cost escalation assumption data submitted by each fund owner, as mentioned in item (1). Using this same data here, we assume our annual-average cost escalation variable follows a “truncated” Logistic probability distribution, varying plus, or minus 1.5 standard deviations from its assumed mean; namely, from 2.91%, 4.55% (mean), to 6.19%.

A reasonable hypothesis may be that the nominal-dollar after-tax rate-of-return assumption is correlated with the nominal-dollar cost-escalation rate assumption to the extent that cost escalation reflects inflation. Further, the direction and degree of such correlation might depend on the percentages of bonds versus stocks in the decommissioning funds. Therefore, we performed a simple analysis, for our three bond categories, using various financial data (1969-2002) from the 2004 Economic Report of The President. [3] From such data, we calculated the correlations between a general measure of the yearly rate of inflation and an asset-weighted yearly nominal rate of return on bonds and stocks. For the bond category 3 (0.2

bonds; 0.8 stocks) assumed for our hypothetical fund, this correlation (Correll and Pearson) over 1969-2002 was -0.235. In other words, as the nominal-dollar cost escalation rate rises, the nominal-dollar after-tax rate-of-return on the fund assets falls modestly, and vice versa. Therefore, in our Crystal Ball stochastic simulation, we correlate these two random variables at this same rate.

(3) Alternative Initial Decommissioning Cost Estimates

The initial decommissioning costs may not be as estimated, even if they are site-specific. Because of a pervasive concern in the industry that the “initial” decommissioning costs may be underestimated, we believe that a skewed (to the right) probability distribution may be more appropriate. Specifically, we assume a “truncated” Triangle probability distribution for this assumption, varying from –5.0%, 0.0% (mode, most likely), 15.79% (mean), to 40.0%.

(4) Start of Instantaneous Decommissioning -- Years after Shutdown

For our assumption of the number of years until the start of “instantaneous” decommissioning after shutdown, we based this assumption on a combination of expert opinion and personal judgment. There was (and still is) an insufficient availability of actual decommissioning cost data for nuclear power plants. Moreover, such data would reflect the experiences of “early adopters” of decommissioning technology and procedures (i.e., early pioneers) who might be expected to take much longer to complete the decommissioning process compared to later adopters who could learn from and efficiently use this earlier experience. In short, the decommissioning process may still be just in the earlier stages of its “learning curve”, partially because of the continuing technological developments and partially because of the impending NRC rulemaking initiatives.

Nonetheless, we assume here that decommissioning activities will most likely span 5 to 10 years; i.e., for modeling simplicity and robustness, “instantaneous” decommissioning at 3.75 years (7.5 years/2) after shutdown. Because we also feel that such estimates may likely be under-estimated, we believe that a skewed (to the right) probability distribution may be appropriate. Specifically, we assume a “truncated” Weibull probability distribution for this assumption, varying from 2.5 years, 4.0 years (mode, most likely), 4.45 years (mean), to 7.75 years.

(5) Number of Years Extension of Operating License

The year of plant operating-license expiration (e.g., permanent shutdown) is assumed to vary in our stochastic simulation model to reflect that NRC has approved 20-year license renewals for 26 reactors to date, has 20 other reactors under application review, and an additional 22 reactors where the owners have expressed their interest to renew the licenses in the coming four years. The prospects for plant license extensions now seem very likely.

However, in the mid to late 1990s, the prevailing expectation was that, at best, no plants would be shut down early (e.g., before their 40-year operating life) and none would ask for a license extension. Obviously, the economics of nuclear power generation of electricity can be very changeable. As a compromise view with respect to these previous pessimistic, and current optimistic, industry viewpoints, we assume here for our hypothetical plant that there is a 50/50 likelihood that it may ask, and receive a 20-year extension from NRC. Specifically, we assume a Custom discrete probability distribution for this assumption, with a 0.5 probability that the plant will receive a 20-year extension, and a 0.5 probability that it will not (i.e., 0 years). The mean (or expected value) is a 10-year extension; however, such a result cannot actually occur because this is a discrete distribution with only two possible values (20, or 0).

(Because the model was designed to subtract an assumed reduction in plant lifespan, these two assumption values are actually “-20 years” for a 20-year extension, and “0 years” for no extension.)

(6) Current Market Value for Decommissioning Fund Balance and Contributions

Because any data may be inaccurate to some degree, we vary the fund balance and contribution(s) values by 5 percent, down and up. (Note: the rationale here is not to simulate the market effects of bond and stock prices.) Assuming such errors to be somewhat random, we assume a “truncated” Normal probability distribution (2.5% standard deviation) for this assumption, varying from –5.0%, 0.0% (mean, mode), to 5.0%.

(7) Monitoring/Maintenance/Safety Costs

For the scenario of the 20-year delay in decommissioning, we must add the additional 20 years of monitoring costs to the “initial” decommissioning cost estimate for the plant. To estimate these maintenance costs, we multiplied an industry representative value of 3.13 percent (the estimated “security services” percentage for the Maine Yankee reactor, already in decommissioning) times the $600 million “initial” cost estimate, divided by 7.5 years, to yield a current (2004) cost of about $2.5 million per year. We assume a Triangle probability distribution for this assumption, varying from $1.5 million, $2.5 million (mean, mode), to $3.5 million. For our hypothetical case, when there is no 20-year license extension, this “initial” monitoring cost value is “cost escalated” for 40 years from 2004, to 2025 (the year after shutdown), and then through each year thereafter, respectively, until 2044. The model then “present values” this 20-year stream of cost-escalated monitoring costs, from the years 2025 through 2044, back to the current year 2004. After a 20-year delay, following the plant’s shutdown in 2024, decommissioning is assumed to commence in 2045. (For those stochastic simulations in which there is a 20-year license extension, 20 years is added to each of these future dates.)

(8) Reduction Fraction of “Initial” Decommissioning Costs due to 20-Year Delay

If decommissioning is delayed for a substantial period (e.g., 20 years), the “initial” decommissioning costs may be slightly lower due to such cost factors as radioactive decay that may result in slightly less costly decommissioning operations. For example, for radioactive decay, one must estimate what would have been the “initial” cost estimate (in 2004) if such decay could occur “at once.” The model then cost-escalates these lower costs to the future year in which the plant is “instantaneously” decommissioned. As a rough approximation, we estimated that these “initial” costs would by lowered by perhaps 5 percent. We assume a Triangle probability distribution for this assumption, varying from -10.0%, -5.0% (mean, mode), to 0.0%.

(9) Current Land Value

If decommissioning is delayed for 20 years, the land upon which the plant resides will likely have a lower value than it would have had if decommissioning had occurred with no such delay. In other words, there is an opportunity cost reflected in the reduction in the present value of the land (as of 2004). This loss results from the 20-year delay of an alternate economic use for the land. The economic or market value of any land reflects the stream of future profits, income, or non-economic asset leverage “income” that the land can generate. (Note: the land generates no such income during this 20-year delay.) The current value of the land is obviously also determined greatly by where the plant is located. As realtors say, “location, location, location.” We assumed that the plant is located somewhere in the Midwest and would have a current (2004) land value of roughly $10 million. We assume a Triangle probability distribution for this assumption, varying from $6.0 million, $10 million (mean, mode), to $14 million.

(10) Inflation Rate in Land Value if Decommissioning is Not Delayed 20 Years

As a general rule in recent decades, inflation in land values has much exceeded the overall inflation rate, however measured. We assume here, as well, that it may often exceed our assumed decommissioning cost escalation rate. Also, the inflation rate in the underlying land value of the plant is likely to be larger if decommissioning is not (expected to be) delayed for 20 years. Therefore, from 12/31/2004 until year 2031.5 (= year 2024, at plant shutdown, plus 7.5 years (=2*3.75 years), at decommissioning completion) the model assumes an increase in the market value of the land. We assume a Triangle probability distribution for this assumption, varying from 5.0%, 6.0% (mean, mode), to 7.0%. The model then “present values” this inflation-escalated land value in year 2031.5 (i.e., June 30th) back to the current year 2004. (For stochastic simulations with a 20-year license extension, 20 years are added to each of these future dates.)

(11) Inflation Rate in Land Value if Decommissioning is Delayed 20 Years

The inflation rate in the underlying land value of the plant is likely to be lower if decommissioning is (expected to be) delayed for 20 years. Therefore, from 12/31/2004 until year 2051.5 (= year 2024, at plant shutdown, plus 20 years delay, plus 7.5 years (=2*3.75 years), at decommissioning completion) the model assumes an increase in the market value of the land. We assume a Triangle probability distribution for this assumption, varying from 3.0%, 4.0% (mean, mode), to 5.0%. The model then “present values” this inflation-escalated land value in year 2051.5 (i.e., June 30th) back to the current year 2004. (For stochastic simulations with a 20-year license extension, 20 years are added to each of these future dates.)

Model Results

Figures 1a-4a, respectively, present our 20,000 stochastically simulated results for four of our five forecast variables. Figures 1b-4b, respectively, present the contribution to variance, and direction of results, for these same four forecast variables.

Fig. 1a.
Excess of Present Value of Initial Decommissioning Costs with No Decommissioning Delay over Present Value of Total Decommissioning Costs with 20-Year Delay

In Present Value Million 2004 Dollars

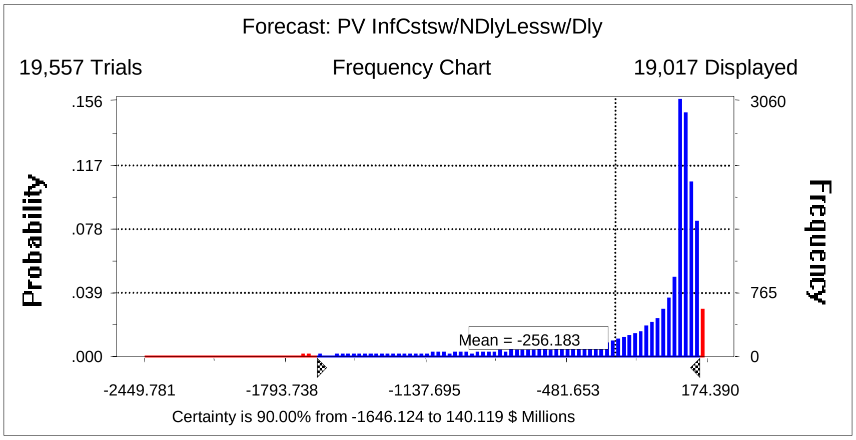

Fig. 1b.
Assumption’s Percentage Contribution to Variance of Target Forecast Variable

(*NOTE: As the assumption value increases, target forecast increases if “bar” is to the right, decreases if to the left*)

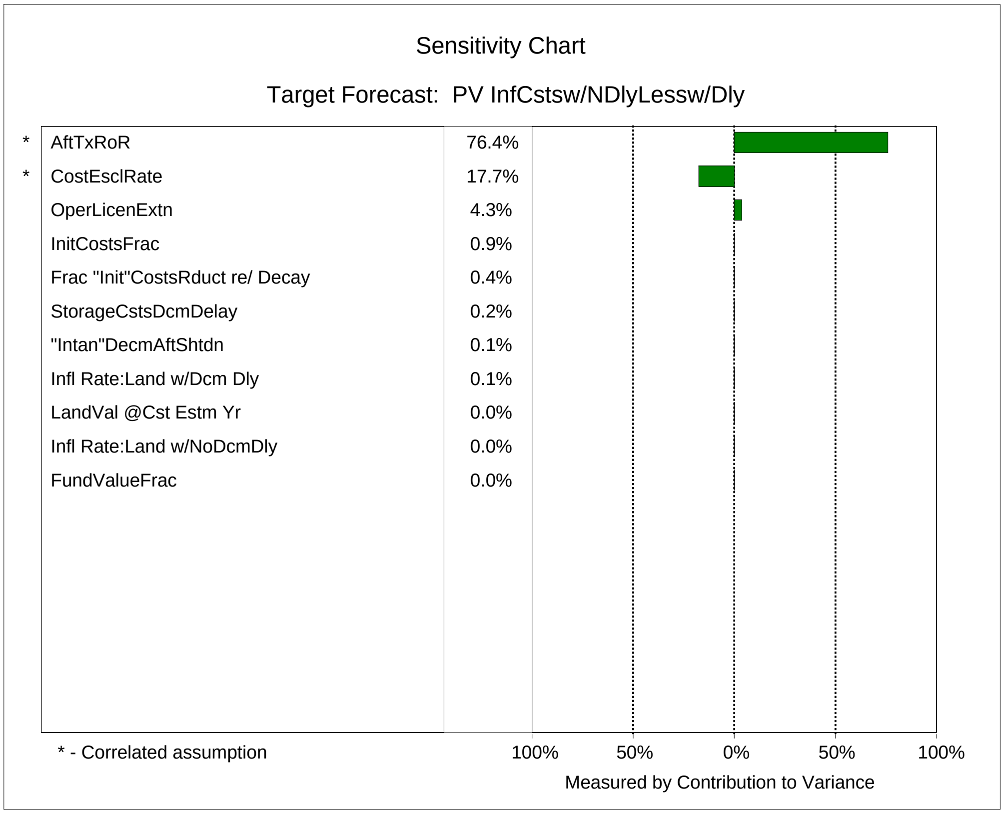

Fig. 2a.
Present Value of Initial Decommissioning Costs with No 20-Year Decommissioning Delay

In Present Value Million 2004 Dollars

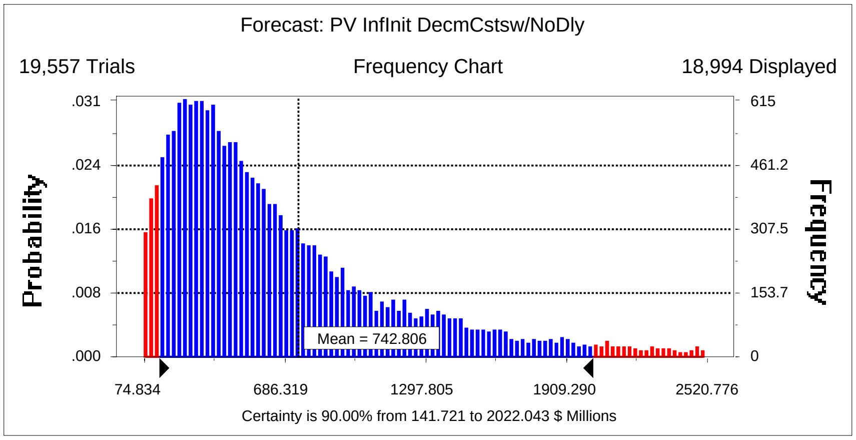

Fig. 2b.
Assumption’s Percentage Contribution to Variance of Target Forecast Variable

(*NOTE: As the assumption value increases, target forecast increases if “bar” is to the right, decreases if to the left*)

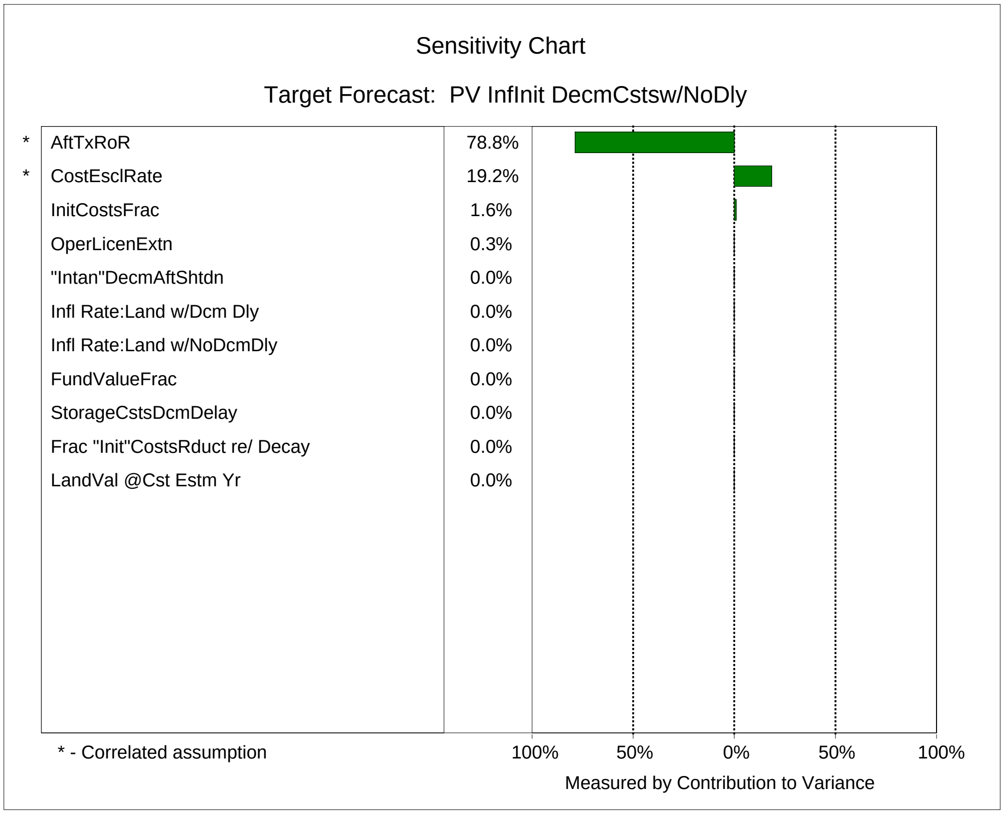

Fig. 3a.
Present Value of Total Decommissioning Costs with 20-Year Decommissioning Delay

In Present Value Million 2004 Dollars

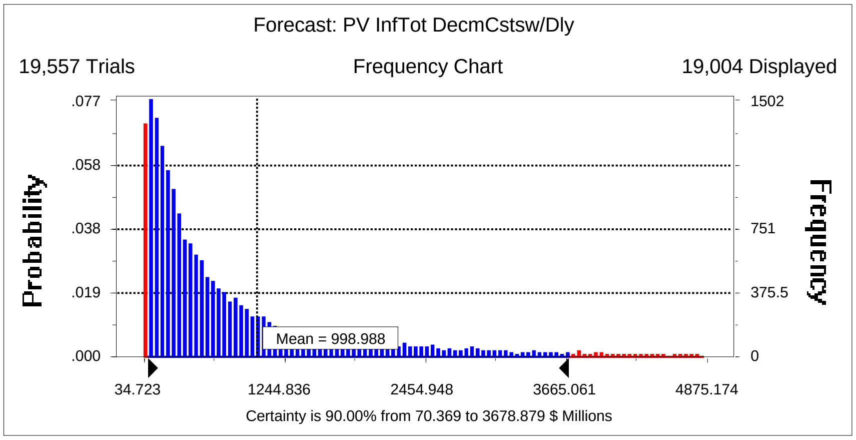

Fig. 3b.
Assumption’s Percentage Contribution to Variance of Target Forecast Variable

(*NOTE: As the assumption value increases, target forecast increases if “bar” is to the right decreases if to the left*)

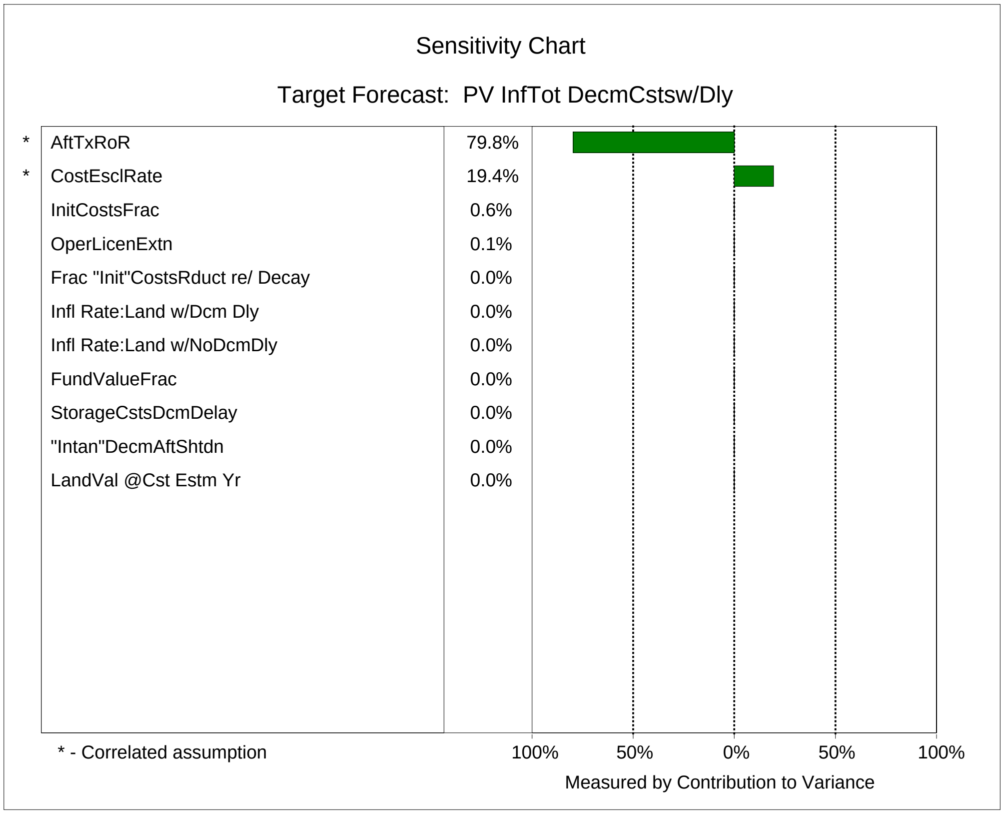

Fig. 4a.
Adequacy of Current-Year (2004) Balance of Decommissioning Trust Fund

In Fractions (times 100 = balance adequacy in percentages

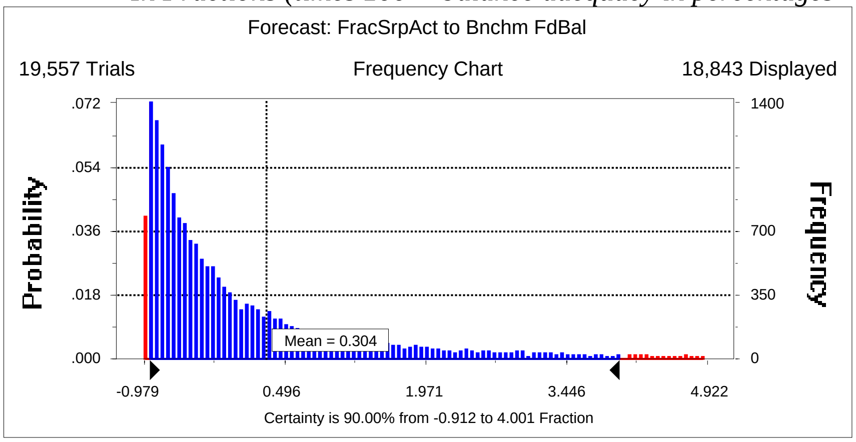

Fig. 4b.
Assumption’s Percentage Contribution to Variance of Target Forecast Variable

(*NOTE: As the assumption value increases, target forecast increases if “bar” is to the right, decreases if to the left*)

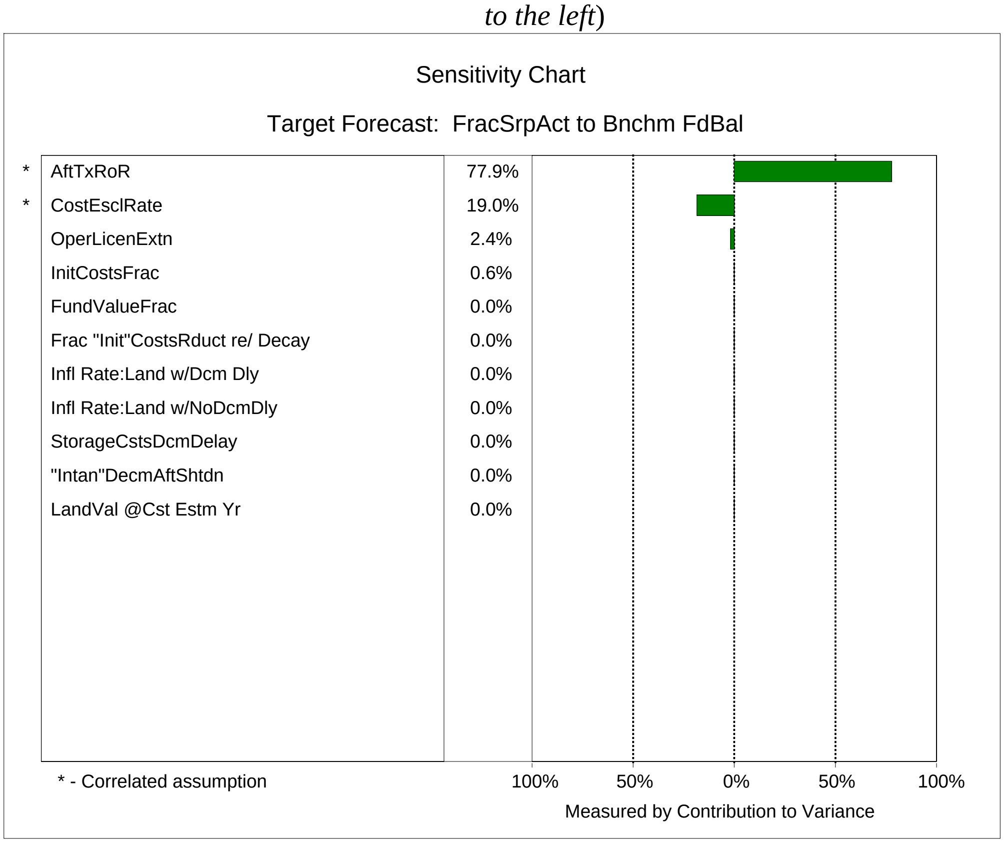

Figure 1a presents the probability (histogram) results for the forecast variable that attempts to answer the main question that we posed earlier: After a nuclear power plant is shut down, should the plant owner(s) delay its decommissioning for 20 years, or begin its decommissioning process almost immediately? That is, whether an owner should choose the “to delay” scenario, or the “not to delay” scenario. The forecast variable in Figure 1a calculates (as of December, 31, 2004) the present value of the cost-escalated “initial” decommissioning costs with no decommissioning delay minus the present value of the cost-escalated total decommissioning costs (i.e., slightly-reduced “initial” costs, plus monitoring costs, plus reduction in land value opportunity costs) with a 20-year decommissioning delay.

If the owner’s criterion is merely to choose the less costly of these two scenarios (in present value terms), a positive valued result means that to not delay decommissioning for 20 years is more costly; therefore, the owner should choose to delay decommissioning for 20 years. Conversely, a negative valued result means that to delay for 20 years is more costly; therefore, the owner should choose to decommission immediately after shutdown. The absolute value of this variable quantifies how much one scenario’s cost exceeds the other; a value of zero means that both the not delay and delay scenario costs are equal.

In Figure 1a, the 90% confidence interval results for this (present value) cost-difference forecast variable run from -$1,646 million to $140 million, as of 2004. These 20,000 stochastic results are extremely skewed to the left, as can be seen by a mean result at -$256 million, and a median result at $50 million. How much help are these results to a plant owner deciding whether to delay decommissioning, or not to delay? Our percentile results for this forecast variable can help provide some assistance. The “sign” of this variable’s results changes from minus, to plus, between the 40^{th} and 50^{th} percentiles of our 20,000 random outcomes. Therefore, about 45% of our outcomes are negative and, therefore, show that delaying decommissioning for 20 years is more costly; and about 55% of our outcomes are positive and, therefore, show that not delaying decommissioning is more costly. So, with roughly 55/45 odds in the plant owner’s/planner’s favor, he/she might choose to delay decommissioning for 20 years in order to reduce the present value costs of decommissioning. But, 45 out of 100 times such a choice would be wrong!

Because of the large skewing to the left, the absolute value of the above “cost increase” of such a (delay) decision would be higher in these 45 times than would be the absolute value of the “cost reduction” of such (delay) decision in the 55 times. [In statistics, a situation such as this might be handled by defining a statistical “loss function;” however, we did not perform this more sophisticated analysis here.] Hence, our results suggest that it would be useful for a plant owner to undertake an analysis such as ours**,** but to re-evaluate such decisions regularly, over the lifetime of the reactor, as assumptions and other circumstances change.

The contribution to variance results in Figure 1b can also help provide an answer. Of the eleven assumption variables that we constructed, only two of them substantially affect this forecast result. The after-tax rate-of-return assumption explains most (76.4 percent) of the statistical variance of this forecast variable and the cost-escalation assumption explains (17.7 percent), nearly all the rest. (The percent contribution to variance of an assumption is calculated here, as *ceteris paribus*; that is, statistically holding the values of all other assumptions unchanged.) It should be noted that this Crystal Ball calculation is not precisely a decomposition of variance and, therefore, represents an approximation. The directions (i.e., bar right, or left) of the effects for these two assumptions also make “economic” sense. As the rate of return increases, *ceteris paribus*, this forecast variable (i.e., present value cost difference) becomes more positive. This is because the delay in decommissioning scenario becomes less costly at a faster rate than does the not delay scenario become less costly; courtesy of the power of compound interest. (See Figures 2b and 3b to see the direction of this effect – both present value costs decrease as the rate of return increases.) For the cost escalation assumption, the effects are reversed; as the cost escalation rate increases, the present value cost difference becomes more negative. In short, for a plant owner to get a smaller, perhaps more useful, range for this result for planning purposes, he/she must focus on estimating the rate of return assumption (and to a lesser extent, the cost escalation assumption) more precisely, i.e., with a smaller assumed probabilistic range.

In Figure 2a, this forecast variable calculates (as of December 31, 2004) the present value of the cost-escalated “initial” decommissioning costs with no decommissioning delay. The 90% confidence interval results for this (present value) cost run from $142 million to $2,022 million, as of 2004. These 20,000 stochastic results are somewhat skewed to the right, as can be seen by a mean result at $743 million, and a median result at $534 million. In Figure 2b, as the rate of return assumption increases, *ceteris paribus*, the present value of “initial” decommissioning costs with no delay decreases. A larger discount rate reduces the present value of future costs. Conversely, as the cost escalation rate assumption increases, the present value of “initial” decommissioning costs with no delay, increases. A larger cost rate increases the present value of future costs.

In Figure 3a, this forecast variable calculates (as of December 31, 2004) the present value of the cost-escalated total decommissioning costs (i.e., slightly-reduced “initial” costs, monitoring costs, plus land value opportunity costs) with 20-year decommissioning delay. The 90% confidence interval results for this (present value) cost run from $70 million to $3,679 million, as of 2004. These 20,000 stochastic results are extremely skewed to the right, as can be seen by a mean result at $999 million, and a median result at $472 million. As would be expected, because decommissioning is delayed for 20 years (note the power of compound interest again), the range of these forecast cost results is much larger than the range when there is no delay in decommissioning. Also, these decommissioning costs comprise three types of costs rather than only one type - the “initial” costs - shown in Figures 2a and 2b. In Figure 3b, as the rate of return assumption increases, *ceteris paribus*, the present value of total decommissioning costs, with 20-year delay, decreases. Again, a larger discount rate reduces the present value of future costs. Conversely, as the cost escalation rate assumption increases, the present value of total decommissioning costs, with 20-year delay, increases. A larger cost rate increases the present value of future costs.

Figure 4a addresses an additional question that a plant owner might have: Is the level of my decommissioning fund balance ($130 million) adequate, as of this date (e.g., 12/31/04), relative to some reasonably, and equitably defined standard? Figure 4a presents the probability results for the forecast variable that measures the adequacy of the plant owner’s decommissioning trust fund balance relative to a benchmark balance. Figure 4a shows the results for which decommissioning is delayed for 20 years. (Note: We do not present, in this paper, these results when decommissioning is not delayed; however, the results are similar.) Because this concept of a “benchmark” balance has been explained previously [4], we will explain the concept here only briefly to conserve space. [Obviously, there are an infinite number of funding streams that, mathematically, could accumulate sufficient funds over the 40-year (or 60-year) operating life of a plant. We define a benchmark stream that we believe is transparent, economically efficient, and fair. It requires that the decommissioning funding financial burden (in present value) be equally shared among all users of electricity from this plant, whether past, present, or future.]

Among other factors, this adequacy will depend upon the (present value of) future decommissioning costs, which, in turn, are affected by whether the owner delays decommissioning for 20 years, or not. For an owner’s individual trust fund, the balance adequacy model algorithm, for a “current” year (2004), computes the surplus (or shortage) of the actual fund balance over the benchmark balance. It divides this surplus (or shortage) by the benchmark balance to yield the percentage excess (or shortage) of the fund balance relative to its benchmark balance. A positive percentage represents over-benchmark balance, a negative percentage represents under-benchmark, and a zero percentage represents a balance that is exactly “on track” with respect to the benchmark. Mathematically, these balance percentages can be no more than 100 percent below benchmark, but can be more than 100 percent above benchmark.

The level of the benchmark balance will depend, of course, upon the values of our eleven key assumptions. Therefore, our 20,000 stochastic simulations can conceivably yield 20,000 different levels of the benchmark balance for the fund and, thereby, a different measured balance adequacy percentage for a given (i.e., actual) balance level. In Figure 4a, the 90% confidence interval results for this fund balance forecast variable run from –91 percent (i.e., below benchmark) to 400 percent (i.e., above benchmark), as of 2004. These 20,000 stochastic results are extremely skewed to the right, as can be seen by a mean result at 30.4 percent, and a median result at -34 percent. Our percentile results for this forecast variable can be demonstrative. The "sign" of this variable's results changes from minus to plus, between the 60th and 70th percentiles of our 20,000 random outcomes. Therefore, about 65% of our outcomes show that this utility's fund balance level is below benchmark, and about 35% of our outcomes show that this utility's fund balance level is above benchmark. Therefore, with roughly 65/35 odds, one can say that this owner's balance is *not* currently adequate, with respect to benchmark, for eventual decommissioning.

The contribution to variance results in Figure 4b can also be useful. Of the eleven assumption variables that we constructed, only two of them substantially affect this forecast result – the same two assumptions as for our above three decommissioning cost forecast variables. The after-tax rate-of-return assumption explains most (77.9 percent) of the statistical variance of this forecast variable and the cost-escalation assumption explains (19.0 percent) nearly all the rest. The directions (i.e., bar right, or left) of the effects for these two assumptions also make "economic" sense. As the return rate increases, *ceteris paribus,* the measured adequacy of fund balances increases. For the cost escalation assumption, the effects are reversed; as the cost escalation rate increases, the balance adequacy decreases.

We address a similar question that a plant owner might have: Are the levels of my recent-year decommissioning fund contributions ($13 million in 2003, and $15 million in 2004) adequate, as of this date (e.g., 12/31/04), relative to some reasonably, and equitably defined standard? Although the figures are not shown for this fifth forecast variable (due to page limitations), we have looked at the probability results for the forecast variable that measures the adequacy of the plant owner's decommissioning trust fund recent-year contributions relative to a benchmark, annual-average recent contribution. The results for the case when decommissioning is delayed for 20 years are similar to the results when decommissioning is not delayed. Again, among other factors, this adequacy will depend upon the (present value of) future decommissioning costs, which, in turn, are affected by whether the owner delays decommissioning for 20 years, or not.

For an owner's individual trust fund, the contributions adequacy model algorithm, for a "current" year (2004), computes the surplus (or shortage) of the actual fund contribution (2-year, cost-adjusted average, 2003 & 2004) over the benchmark contribution. It divides this surplus (or shortage) by the benchmark contribution to yield the percentage excess (or shortage) of the fund contribution relative to its benchmark contribution. A positive percentage represents an over-benchmark contribution, a negative percentage represents under-benchmark, and a zero percentage represents a contribution that is exactly "on track" with respect to the benchmark. Mathematically, these contribution percentages can be no more than 100 percent below benchmark, but can be above benchmark – infinitely above, if the owner needs to contribute no additional funds, given the values of the eleven assumptions.

As with balances, the level of the benchmark contribution will depend, of course, upon the values of our eleven key assumptions. Although not shown, the 90% confidence interval results for this contributions forecast variable run from –89 percent (i.e., below benchmark) to +infinity percent (i.e., above benchmark), as of 2004. (Note: No value of +infinity was calculated; in such cases, the model inserts the large value of +999,999,999.) These 20,000 stochastic results show a median result of 13.8 percent. (The results for the mean obviously have no useful meaning.) Our percentile results for this forecast variable are demonstrative. The "sign" of this variable's results changes from minus, to plus, between the 40th and 50th percentiles of our 20,000 random outcomes. Therefore, about 45% of our outcomes show that this utility's, recent-year contributions are below benchmark, and about 55% of our outcomes show that this utility's, recent-year contributions are above benchmark. Additionally, about 15% of the outcomes show a contributions adequacy that is infinitely above benchmark. Therefore, with roughly 55/45 odds, one can say that this owner's recent-year contributions are currently adequate, with respect to benchmark, for eventual decommissioning.

The contribution to variance results can be useful for the adequacy assessment of fund contributions. Of the eleven assumption variables that we constructed, only two of them substantially affect this forecast result – the same two assumptions as for all four of our above forecast variables. The after-tax rate-of-return assumption explains most (77.7 percent) of the statistical variance of this forecast variable and the cost-escalation assumption explains (18.9 percent) nearly all the rest. The directions (i.e., bar right, or left in our contribution to variance figure, not shown here) of the effects for these two assumptions also make "economic" sense. As the return rate increases, *ceteris paribus*, the measured adequacy of fund contributions increases. For the cost escalation assumption, the effects are reversed; as the cost escalation rate increases, the contributions adequacy decreases.

Our hypothetical case provides the reader with a useful and informative example: ABC Utility's 2004 actual decommissioning fund balance ($130 million), and its recent yearly contributions of $13 million and $15 million in 2003 and 2004, respectively. Note that the NRC did not have specific funding assurance and adequacy rules in place until 1990, long after most reactors had commenced operations. Thus, many owners may not have contributed to their funds at sufficient rates in the past, but recently may have greatly increased their contribution rates to begin to reduce their funding shortfall. Our ABC Utility represents such a case. It has a median adequacy of 34 percent below benchmark fund balance through the end of 2004, but recently (in 2003 & 2004) had contributed to its fund at a much higher rate than it had, on average, in the past. In fact, ABC Utility's recent 2-year cost-adjusted average contribution has a median adequacy of 13.8 percent above its benchmark contribution.

CONCLUSIONS

Our assessment results show that it is not simple to obtain a definitive answer to the question of whether a nuclear plant owner should delay decommissioning for 20 years, or not. This holds even if, as we did in this paper, one simplifies and confines the analysis to choosing as preferable one of the two scenarios that has lower decommissioning costs (in present value terms). Which is the less costly scenario depends greatly upon the values chosen for the assumptions. However, our results do show that only two of the eleven key assumption variables affect the choice greatly: (1) the assumed nominal-dollar after-tax rate-of-return on the decommissioning fund financial assets and (2) the nominal-dollar cost-escalation rate assumed to cost escalate the "initial" decommissioning cost estimate and the yearly decommissioning monitoring costs over the 20 years of decommissioning delay. In other words, the most important single assumption that an owner can make is the assumption value (and range) for the real (i.e., cost-adjusted) after-tax rate of return.

The analysis in this hypothetical case suggests that an owner must carefully estimate the future values of the two variables identified above and reduce the, *a priori*, assumed stochastic ranges for each, especially for the rate of return assumption variable. Such reduction would accomplish two things. First, the forecasted ranges for all five of the forecast variables would be reduced and, therefore, would certainly make the forecasts more useful to an owner. In particular, this would yield more definitive forecasts for the cost difference variable (i.e., costs with no decommissioning delay, minus with delay), and for the two individual cost forecast variables (decommissioning costs with no decommissioning delay, and those with a 20-year delay). Second, with an *a priori* reduction in the assumed ranges of the rate of return and cost escalation variables, the other nine assumption variables would likely become more "important" in that they would likely account for more of the "contribution to variance" of the five forecast variables. In turn, plant owners could further refine and reduce their assumption value ranges for the most important of these remaining nine assumption variables to arrive at a more realistic case -- with more useful results for an owner -- relevant to their specific situation.

We can, however, offer some examples of heavily qualified, probabilistic statements relative to the hypothetical case that we modeled here: (1) with roughly 55/45 odds in the plant owner's favor, he/she should choose to delay decommissioning for 20 years in order to reduce the present value costs of decommissioning and (2), with roughly 65/35 odds, one can say that this owner's decommissioning fund balance is not currently adequate, with respect to benchmark, for eventual decommissioning.

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3. Council of Economic Advisors, *Economic Report of the President*, *February 2004*, Table B-7 (chain-type gross domestic product price indexes 1969-2002, p. 294); Table B-73 (bond yields and interest rates, 1969-2002, p. 370); and Table B-95 (common stock prices and yields, 1969-2002, p. 394).

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