Geothermal Resources Council, TRANSACTIONS, Vol. 13, October 1989

ECONOMIC ANALYSIS OF STEAM PRODUCTION AT THE GEYSERS GEOTHERMAL FIELD, CALIFORNIA

S. K. Sanyal, R. C. Henneberger and P. J. Brown

GeothermEx Inc., Richmond, CA

ABSTRACT

This paper investigates the economics of steam production at The Geysers from the point of view of a field developer. We present a cash-flow analysis and the calculation of several profitability criteria for steam supply to a hypothetical 55 MW (gross) power plant starting in 1989. This paper assesses in two parts the economics of developing the steam supply: (1) a deterministic economic analysis to establish the sensitivity of the profitability criteria to steam price where each parameter is given a unique value, and (2) a probabilistic analysis to estimate the profitability criteria, and their sensitivity to steam price, when uncertain parameters are allowed to vary. The results of the study indicate that no new commercial project is economically feasible at The Geysers unless the steam price exceeds 2 cents/kw·hour, because of long payout and extremely low profitability. Only a steam price exceeding 2.7 cents/kw·hour ensures a reasonably short payout time and the minimum profitability typically expected by field developers. Above a steam price of 3 cents/kw·hr, the economics of field development are attractive and risks are low. The accelerated decline in well productivity in recent years has increased risks and reduced profitability.

INTRODUCTION

The economics of steam production at The Geysers varies widely depending on a number of resource and economic parameters. Sanyal and Che (1982) reviewed the sensitivity of the economics of steam production at The Geysers to most of these parameters. However, the economics of steam production at The Geysers have changed significantly during the last few years because of 3 reasons: (1) the rate of decline in well productivity has accelerated, (2) the steam price offered by Pacific Gas & Electric Company, the utility that owns a major part of the generating capacity at The Geysers, has declined substantially, and (3) there exists a much wider variation in steam price offered under various contracts than ever before, from about 1.6 cents/kw·hour to over 4 cents/kw·hour. The purpose of this paper is to reassess the economics of steam production at The Geysers in the context of the above changes, and, in particular, to assess the sensitivity of profitability to the wide range of steam price. Another purpose of this paper is to investigate the combined impact of the uncertainties of drilling results, productivity decline rate and inflation on the economics, and particularly on the sensitivity of economics to steam price. The analysis is conducted in two stages. First, each resource and economic parameter (except for steam price) is assumed to have a unique value typical of the current conditions at The Geysers field and the sensitivity of a set of profitability criteria to steam price is evaluated. Next, a probabilistic economic analysis is conducted by assuming that several parameters (initial MW capacity per well, drilling cost per well, initial annual productivity decline rate, drilling success rate and inflation rate) are uncertain and can vary within a range, with or without a most likely value. The remaining parameters, except for steam price, were assumed to have the same values as in the deterministic analysis. The probabilistic analysis was conducted to estimate the mean, standard deviation and most likely value of several profitability criteria. The probabilistic analysis was repeated for a range of steam prices.

PROFITABILITY CRITERIA

We have considered the following four profitability criteria to allow a balanced evaluation of the profitability of developing geothermal steam supply:

1. <u>Cumulative Present Worth of Net Revenue (CPWNR) Before Taxes</u>: This is based on discounted cash-flow analysis, the principle being that in making an investment outlay one is actually buying a series of future annual incomes. Since no amortization pattern needs to be adopted, this method is particularly suited to property evaluation, because it involves only the discounting of projected cash flow to present value by means of the desired rate of interest.

2. Discounted cash flow rate of return (DCF-ROR): For a proposed venture DCF-ROR is the maximum interest rate which one could pay on the capital tied up over the life of the investment and still break even. It should be noted that DCF-ROR is different from the average annual rate-of-return; the latter is essentially the ratio of the present value of the future earnings after amortization to the present value of the undepreciated balance of the investment over the life of the property.

3. Payout Time: The estimation of the payout period usually consists in first estimating annual revenues, from which are subtracted all annual expenses, except for the depreciation expense. Thus, the amount available for depreciation is found by the difference. Dividing this available amount into the capital investment gives the payout period, or the number of years needed to complete the payback. The shorter this period, the more attractive is the project. Usually payout is defined as the time when CPWNR is zero for the first time in a project.

4. Discounted Profit-to-Investment Ratio (DPIR): DPIR is also called Investment Efficiency by some authors. DPIR is simply the dimensionless ratio obtained by dividing CPWNR by the present value of the investment. The ratio is interpreted as the amount of discounted net profit generated in excess of the average opportunity rate per unit investment.

DETERMINISTIC ECONOMIC ANALYSIS

Drilling of geothermal wells will be the principal capital expenditure over the lifetime of the field. This includes the costs of initial production and injection wells, workovers, replacement or make-up wells, and dry holes. In this report, for the base case, a 90% drilling success rate (that is, 10% dry holes, as typical at The Geysers field) is assumed for the deterministic economic analysis and a range of 80% to 95% for the probabilistic economic analysis. Drilling cost is assumed to be $1.5 million (1989 dollars) per well in the base case for the deterministic economic analysis and a range of $1.0 to $2.0 million, with a most likely value of $1.5 million, is assumed for the probabilistic economic analysis. Table 1 lists the values of the parameters used for the deterministic economic analysis. For simplicity, both production and injection wells were assumed to require the same drilling cost.

Since typical geothermal wells have a finite mechanical life, some of the wells need to be worked over from time to time. A "well loss" rate (of both active and standby production wells) of 10% per year, after the first year, has been assumed. The "lost" wells are assumed to be brought back to production by workover, costing $200,000 each (1989 dollars).

Operating costs (in 1989 dollars), for field operation and maintenance, have been estimated to be $1.0 million per year (1989 dollars). The operating costs include expenditures for staff and office operations and routine maintenance of the wells and the injection and gathering systems, but do not include make-up well drilling cost or workover cost.

The initial number of production wells required is calculated by dividing the MW capacity of the plant by the average MW capacity of the wells (assumed to be 5 MW in the base case, and 3 to 10 MW with a most likely value of 5 MW in the probabilistic study). During the first 25 years of operation, a 20% standby well requirement was assumed at all times; that is, the number of production wells at all times was assumed to be 120% of that required to supply the plant. The wells were assumed to decline continuously in productivity once production starts, and make-up wells were assumed to be drilled as needed to maintain plant capacity. After the first 25 years of plant operation, no new make-up wells were assumed to be drilled until the stand-by wells were used up as make-up wells.

The decline trend has been assumed to be exponential during the first year (Sanyal, et al, 1989), the decline trend being defined by

$$W = W_i e^{-D_i t}, \tag{1}$$

where W_i = initial production rate,
W = production rate at time t, and
D_i = initial annual productivity decline rate.

After the first year, the decline trend is assumed to be harmonic (Sanyal, et al, 1989); that is, the decline rate itself declines with time. The quantitative expression of harmonic decline is:

$$W = \frac{W_i}{1 + D_i t} \tag{2}$$

The initial productivity decline rate was assumed to be 20% in the base case and to vary between 10% to 35% in the probabilistic study; this has been typical for wells at The Geysers in recent years.

The ratio of producers to injectors was assumed to be 10. The number of injection wells was assumed to remain constant with time, as the total amount of condensate to be injected will not increase with time.

Based on the initial average well deliverability decline rate, the required number of active wells for each year after plant start-up was calculated. From this, the numbers of standby wells, injectors and workovers required were calculated. Based on this requirement and the success in drilling, the number of wells drilled each year was calculated. The total drilling cost (including workover cost) was then calculated for each year. All costs and expenses were escalated at an annual inflation rate from 1989, which was assumed to be 5% in the base case, and to vary between 4% to 7% (with a most likely value of 5%) in the probabilistic study.

Initial field development costs were assumed to be incurred at the plant start-up. The initial non-drilling costs (acquisition, road and drilling pad construction, gathering system construction, etc.) were assumed to total $15 million in 1989 dollars. Gross annual revenue was calculated based on the plant size, ratio of net to gross plant capacities (assumed to be 90%), plant capacity factor (assumed to be 90%), unit steam price (2 cents per kilowatt-hour in the base case, escalated at the inflation rate from the 1989 base price) and royalty rate (10%). The net annual revenue before income taxes is the difference between the gross annual revenue and total annual cost for the year. Present worth of the net annual revenue before income taxes was calculated assuming annual compounding, with 1989 as the base year. In the base case, the annual discount rate was assumed to be 10%. The cumulative present worth of net revenue (CPWNR) before income taxes was calculated by adding the present worth of net annual revenues from the future years of operation for a plant life of 30 years. The above cash flow analysis was repeated for a range of discount rates and steam prices. The other profitability criteria were calculated from the above-described cash-flow analyses.

RESULTS OF THE DETERMINISTIC ECONOMIC ANALYSIS

Figure 1 shows plots of CPWNR versus steam price for a range of discount rates. As expected, the sensitivity to steam price is linear for all discount rates and the lower the discount rate, the higher is the relative sensitivity to steam price. At a discount rate of 10%, CPWNR increases by about $6 million for each 0.1 cent/kw·hour increase in steam price.

Figure 2 shows plots of DPIR versus steam price for a range of discount rates. Again, the sensitivity of DPIR to steam price is linear and the relative sensitivity is higher for a lower discount rate.

Figure 3 shows plots of the payout time versus steam price for a range of discount rates. The sensitivity of the payout time to steam price is very high in the low steam price range. However, above a steam price of about 3.0 cents per kw·hour the sensitivity is low for the base case (10% discount rate).

Figure 4 shows a plot of the discounted cash-flow rate-of-return (DCF-ROR) as a function of the steam price. The plot is linear, and shows an increase in DCF-ROR of about 1.3% for every 0.1 cents/kw·hour increase in steam price; this is a strong sensitivity.

Certain general conclusions can be drawn from figures 1 through 4 as follows. Considering the long payout time and negative CPWNR and DPIR, a steam price of 2 cents per kw·hour or less is unrealistically low and no new commercial project can be developed. Assuming that a typical developer requires a DCF-ROR of at least 15% and a payout time of less than 15 years, a minimum required steam price for any new development is 2.7 cents/kw·hour.

PROBABILISTIC ECONOMIC ANALYSIS

The economic analysis described above assumes a unique value of each parameter, except for steam price and discount rate, which were varied systematically. In reality many resource and economic parameters are too uncertain to be given unique values; these parameters can be best defined as random variables. Economic analysis involving random variables requires probabilistic simulation. The use of probabilistic simulation is an accepted practice by which to estimate the probability distribution of any profitability criterion under such uncertainties (for example, refer to Hess and Quigley, 1963). The mean (or "expected") value and most-likely value of the present worth are two of the most important parameters that can be determined by such a simulation. The standard deviation of a profitability criterion is a valuable index of the uncertainty; the larger the standard deviation the greater is the inherent economic risk. Probabilistic economic analysis provides a defensible and quantitative basis for use in investment decisions and negotiations.

In probabilistic analysis, the outcome of a specific sequence of events may be defined as a function of several variables, each variable representing an event in the sequence. Application of any quantitative risk analysis method requires: (1) the estimation of probability distributions for each of the variables and (2) a technique for repeated sampling of these distributions. The Monte Carlo simulation technique is a sampling procedure whereby highly complex expressions involving one or more probability distributions may be evaluated. In essence, it consists of simulating a process, such as the development of a geothermal field, using a random sampling of the uncertain input parameters.

The basic method of Monte Carlo simulation can be best outlined as a series of steps as follows:

1. Estimate the range and distribution of possible values of each independent variable that will affect one or more chosen profitability criteria. This step may require the judgment of several experts: the geologist, drilling engineer, reservoir engineer, surface facilities engineer or economist. Each would describe the distribution of the variables of which he or she is most knowledgeable. Obviously, detailed distributions will not be available for most variables; triangular or uniform distributions will have to be used.

A triangular distribution is defined by the minimum, maximum and most likely values of the variables while a uniform distribution is defined by the minimum and maximum values only.

2. From the distribution of each variable, select at random one value. This is usually done on the computer by using a "random number generator". Compute a desired profitability criterion using this combination of values of the variables. This determines one point in the final distribution of the values of the chosen profitability criterion. Select at random a second value from the distribution of each of the variables. Again, compute the resulting value of the profitability criterion. This is the second point in the distribution of values of the chosen profitability criterion.

3. Repeat the process again and again, each time with the set of values selected at random from the distribution of each variable. Enough combinations of variables should be considered to describe adequately the shape and range of the distribution of the values of the chosen profitability criterion. Typically, several hundred of such simulation runs are necessary. Mathematical methods are used for judging the adequacy of the number of simulation runs and the statistical validity of the defined distribution.

4. The calculated values of the profitability criterion can be arranged in the form of a distribution to determine the probability of obtaining various ranges of values of the criterion. By rearranging the calculated values, on a cumulative frequency basis, the probability of obtaining at least a specific value of the criterion can be estimated.

The results of Monte Carlo simulation can best be presented by selecting interval ranges of the profitability criterion and by calculating the percentage of computed values which fall within each range. From this, one can plot a probability distribution (or histogram) of the profitability criterion. Such a plot is a graphical expression of the underlying economic risks in a project. For example, if such a frequency distribution has a sharp mode (that is, a small standard deviation) the underlying risks are lower. Conversely, if the distribution is flat (that is, the standard deviation is large), risks are higher.

For probabilistic economic analysis the following parameters were considered uncertain for a project at The Geysers: parameters defining drilling results (initial MW capacity per well, drilling success rate, and drilling cost per well), well productivity decline rate, and inflation rate. Table 2 presents the probability distributions chosen for these variables. The other parameters were assumed to have the same unique values as in the base case.

RESULTS OF PROBABILISTIC ECONOMIC ANALYSIS

Figures 5 and 6 present the probability distribution (histogram) and the cumulative probability distribution, respectively, of the calculated CPWNR values for a base steam price of 2 cents/kw·hour and a range of discount rates. These figures indicate that the most likely CPWNR is negative for a discount rate of 10% or more. The standard deviation of CPWNR is small for discount rates of 10% and higher, implying a small uncertainty. However, at low discount rates, the standard deviation is large, implying a significant uncertainty. Figures 7 and 8 present the probability distribution and cumulative probability distribution, respectively, of the calculated DPIR values for a base steam price of 2 cents/kw·hour and a range of discount rates. These figures indicate that the most likely DPIR is negative for typical discount rates; the standard deviation is fairly high for all discount rates, reflecting significant uncertainty.

The probabilistic economic analysis was repeated for a range of steam prices and a fixed discount rate of 10%. Figure 9 shows the statistically most likely value of CPWNR, and the values within one standard deviation of the mean, versus steam price. The width of the band in figure 9, defined by the values within one standard deviation of the mean, is a direct reflection of the uncertainty; the wider the band at any steam price, the larger is the uncertainty. Figure 9 indicates that the uncertainty in the CPWNR value (about ± $40 million from the mean) is nearly independent of the steam price. This figure agrees in general with figure 1 derived from the deterministic analysis. Figure 9 indicates that CPWNR increases by about $6 million for each 0.1 cents/kw·hour increase in steam price, also as seen in figure 1.

Figure 10 shows the statistically most likely value of payout time, and the values within one standard deviation of the mean, versus steam price. The band in figure 10 shows that the uncertainty in payout time decreases substantially at high steam prices; for example, as steam price increases from 1.5 to 5 cents/kw·hour, the uncertainty in payout time declines from about ± 6 to ± 2 years from the mean. Figure 10 agrees in general with figure 3 derived from deterministic analysis.

Figures 9 and 10 further confirm the conclusion from the deterministic analysis that it is uneconomic to start a field development at The Geysers for a steam price of 2 cents/kw·hour or less. Beyond a steam price of 2.7 cents/kw·hour the CPWNR and DPIR are positive and payout time becomes acceptably low and relatively insensitive to the steam price, making it economic for new field development.

The width of the bands in figures 9 and 10 indicate the uncertainties in absolute terms. It is worthwhile to assess the uncertainties in relative terms; this is done in figure 11 where the standard deviations of CPWNR and payout time as percentages of their respective means are plotted as functions of steam price. This figure indicates that, in relative terms, the uncertainty in CPWNR is high for steam prices below 3 cents/kw·hour and the uncertainty in payout time increases gently as steam price increases up to 3 cents/kw·hour. Figure 11 indicates that uncertainties in CPWNR and payout time are low only above a steam price of 3 cents/kw·hour. Also, figure 10 shows that the payout time is insensitive to steam price when the price exceeds 3 cents/kw·hour. Therefore, at a steam price above 3 cents/kw·hour, a new development at The Geysers has a low risk and good profitability.

Finally, probabilistic analysis was used to investigate how the profitability at The Geysers has changed due to the accelerated decline of well productivity during the last few years. Until about 1986, the observed initial annual well productivity decline rate (D_i) at The Geysers was in the range of 3% to 15%. Since 1986 the rate has accelerated to 10% to 35%. Figures 12 and 13 compare the distributions of the CPWNR and payout time, respectively, for D_i ranges of 0.3 - 0.15 and 0.10 - 0.35. These figures correspond to the base case steam price of 2 cents/kw·hour and a discount rate of 10%. The other fixed and uncertain variables have the same values as in the other probabilistic simulations described before. These figures indicate that the recent acceleration in well productivity decline rate has reduced profitability (as shown by lower CPWNR and higher payout time values) and increased risks (as noted by an increase in the standard deviation).

CONCLUSIONS

1. CPWNR, DPIR and DCF-ROR are linear functions of steam price; for the base case, a 0.1 cent/kw·hour increase in steam price increases CPWNR by about $6 million and DCF-ROR by about 1.3%.

2. Payout time is a hyperbolic function of steam price; at low steam prices it is very sensitive. For steam prices greater than 3 cents/kw·hour it is relatively insensitive in the base case.

3. Even if one considers the entire possible range of drilling results, productivity decline rate and inflation rate, the above conclusions remain essentially unchanged.

4. Whether one considers the base case or the entire range of uncertainties referred to above, the following conclusions are apparent:

(a) No new field development at The Geysers is economic at a steam price of 2 cents/kw·hour or less.

(b) The minimum profitability conditions expected by field developers are only achieved at a steam price of 2.7 cents/kw·hour or higher.

(c) A new development at The Geysers is economically attractive and has a low risk if the steam price exceeds 3 cents/kw·hour.

5. The calculated payout time from probabilistic analysis shows an uncertainty range of ± 6 years from the mean at the lowest steam price (1.6 cents/kw·hr) and decreases to about ± 2 years at the highest steam price (5 cents/kw·hr) considered. As a percentage of the mean, the uncertainty increases gently with increasing steam price.

6. The CPWNR value calculated by probabilistic analysis has an uncertainty of about ± $40 million from the mean at all steam prices. As a percentage of the mean, the uncertainty decreases significantly with increasing steam price.

7. The recent acceleration in well productivity decline rate at The Geysers has reduced profitability and increased risks of field development.

REFERENCES

Hess, S. W. and H. A. Quigley, 1963, Analysis of Risk in Investment Using Monte Carlo Techniques, Chem. Eng. Symposium Series 42, AIChE, New York (1963) 55.

Sanyal, S. K. and M. Che, 1982, A Sensitivity Study of The Economic Parameters for The Geysers Geothermal Field, California, Trans. Geothermal Resources Council, San Diego, 1982.

Sanyal, S. K., A. J. Menzies, P. J. Brown, K. L. Enedy and S. Enedy, in press, A Systematic Approach to Decline Curve Analysis for The Geysers Steam Field, California, Trans. Geothermal Resources Council, Santa Rosa, 1989.

TABLE 1. ECONOMIC PARAMETERS USED FOR DETERMINISTIC ECONOMIC ANALYSIS

Base Year = 1989
No existing production wells
No existing injection wells
Ratio of Producers to Injectors = 10.0
Ratio of Net to Gross Plant Capacity = .90
Plant Capacity Factor = 90%
Stand-by Well Requirement = 20%
Annual Workover Requirement = 10%
Steam Price per Net kilowatt-hour = 2 cents (base case)
Acquisition, Access and Gathering Systems Cost = $15,000,000*
Revenue Interest = 90%
Annual Discount Rate = 10% (base case)
Workover Cost per Well = $200,000*
Initial Capacity/Well = 5.0 MW (gross) (base case)
Drilling Cost/Well = $1,500,000* (base case)
Initial Annual Productivity Decline Rate = 20% (base case)
Drilling Success Rate = 90%
Annual Inflation Rate = 5%

* in 1989 dollars

TABLE 2. PROBABILITY DISTRIBUTION OF UNCERTAIN VARIABLES

Variable	Type of Probability	Minimum Value	Maximum Value	Most Likely Value
Initial MW capacity per well	Triangular	3	10	5
Drilling cost per well (million $)	Triangular	1.0	2.0	1.5
Initial annual productivity decline rate (%)	Uniform	10	35	--
Drilling success rate (%)	Uniform	80	95	--
Annual inflation rate (%)	Triangular	4	7	5

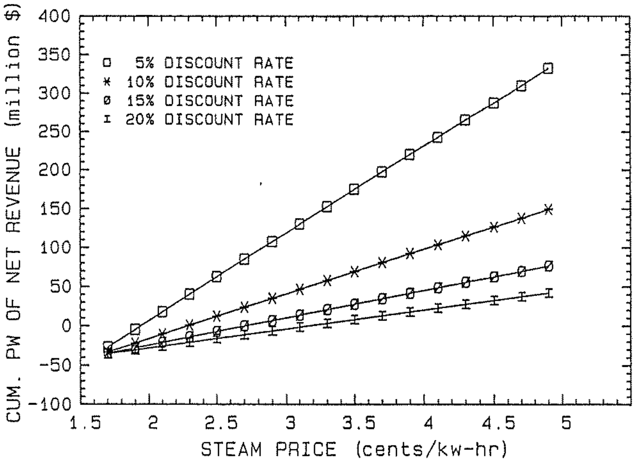

Figure 1: CPWNR vs. steam price from deterministic analysis

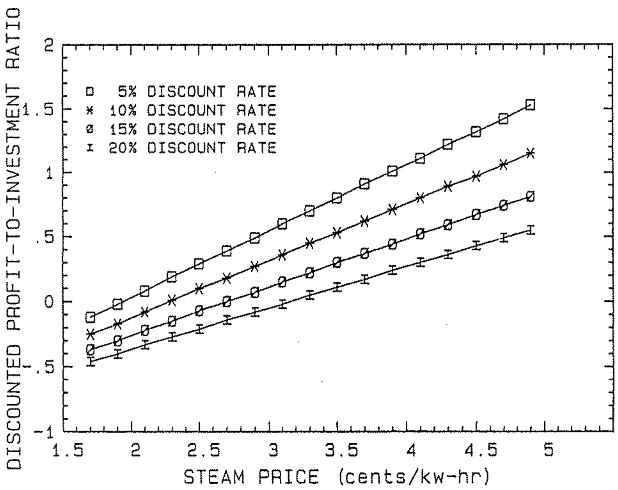

Figure 2: DPIR vs. steam price from deterministic analysis

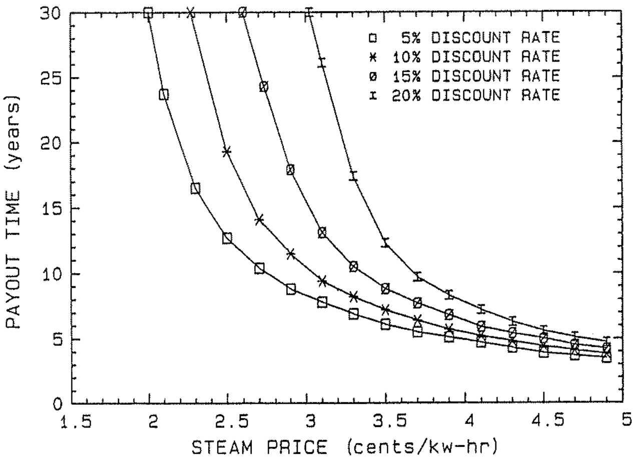

Figure 3: Payout time vs. steam price from deterministic analysis

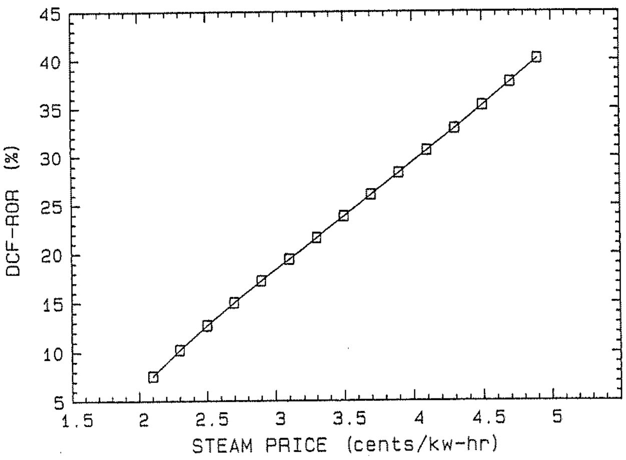

Figure 4: DCF-ROR vs. steam price from deterministic analysis

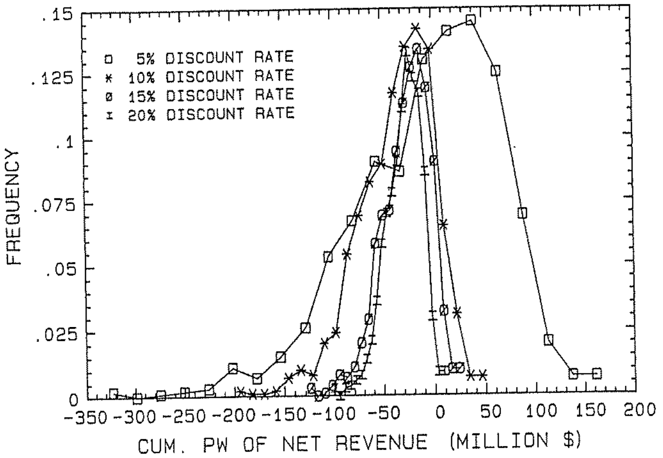

Figure 5: Histogram of CPWNR

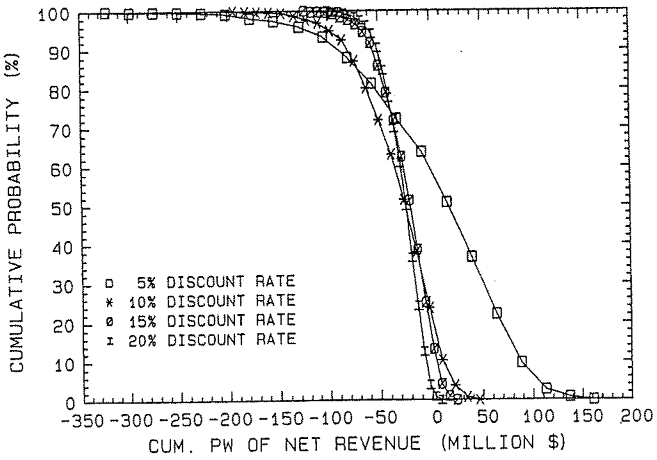

Figure 6: Cumulative probability distribution of CPWNR

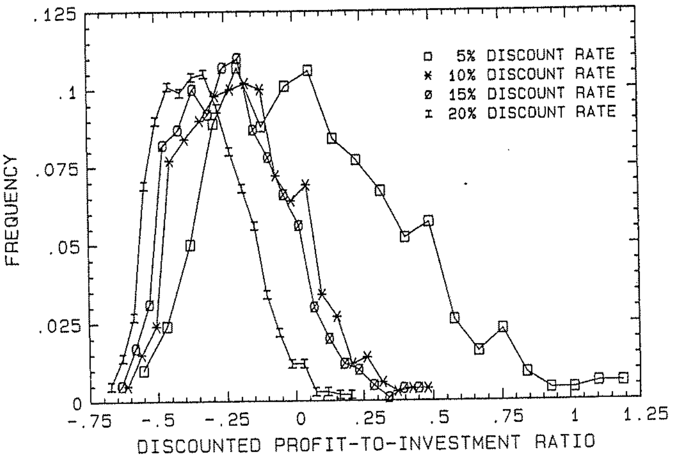

Figure 7: Histogram of DPIR

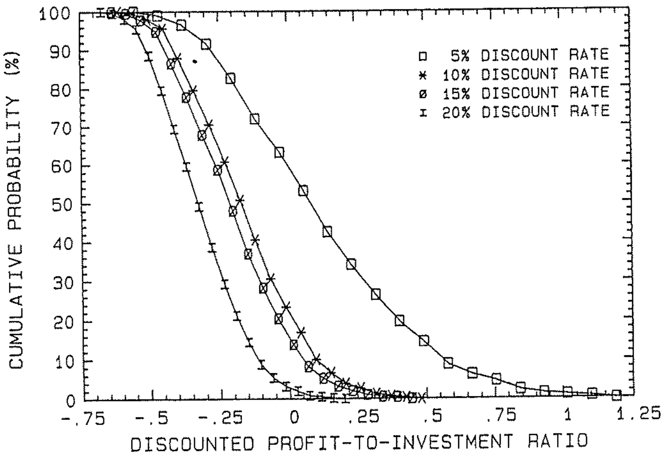

Figure 8: Cumulative probability distribution of DPIR

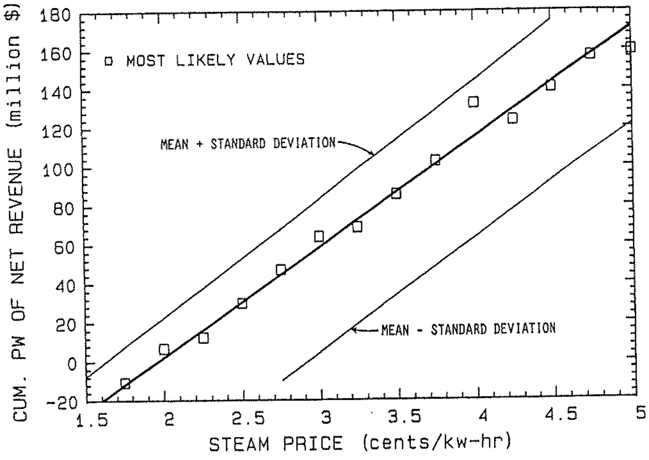

Figure 9: CPWNR vs. steam price from probabilistic analysis

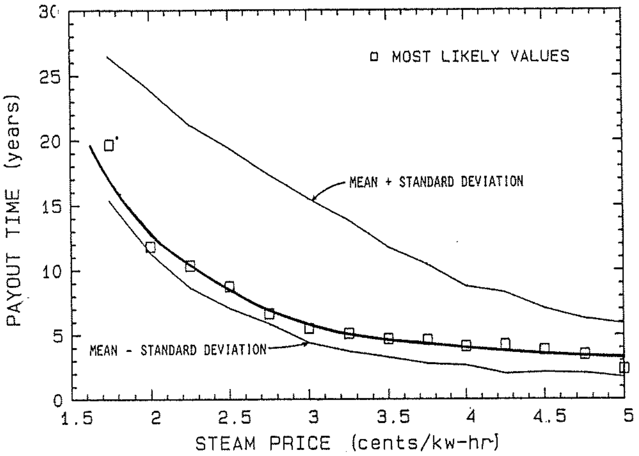

Figure 10: Payout time vs. steam price from probabilistic analysis

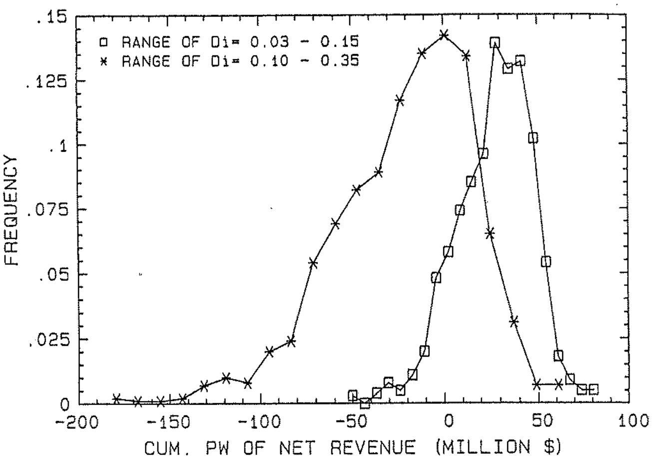

Figure 12: Histogram of CPWNR for 2 different D_i ranges

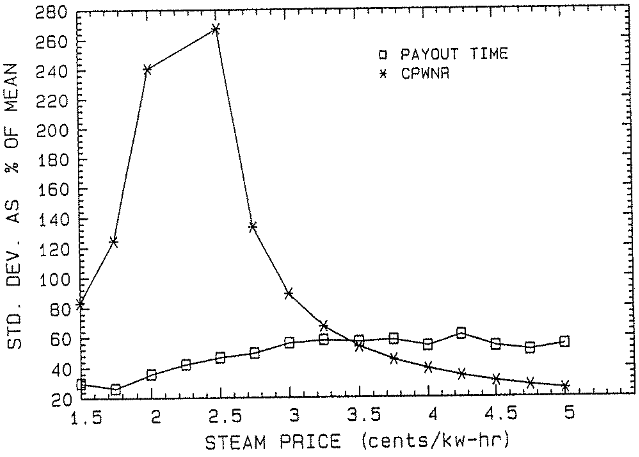

Figure 11: Standard deviation of CPWNR and payout time as percentage of mean vs. steam price

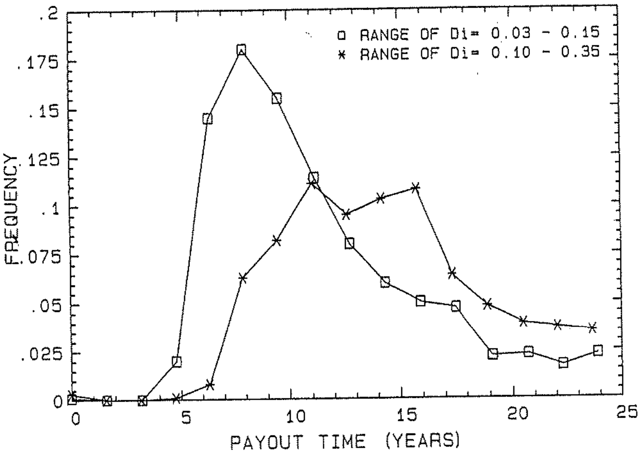

Figure 13: Histogram of payout time for 2 different D_i values