

A SIMULATION MODEL FOR RESOURCE  
POLICY EVALUATION

By

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## A SIMULATION MODEL FOR RESOURCE POLICY EVALUATION

Regardless of the resource being considered, private sector response to public resource policies will normally follow a similar logic. Assuming competitive markets and a profit maximization objective function for the private sector, discounted cash flow techniques (appropriately constrained for public rules and market rigidities) can be used to simulate these responses. This paper provides the detailed specification and description of a model, incorporating these techniques, which can be used to evaluate a number of policy questions pertaining to various resources located on the public domain.

This model has been developed over a four year period, and several versions have been employed for analytical efforts during this time. A brief history of the different versions may be useful for readers who have followed the model development. The first version was a discounted cash flow model which was used for OCS and oil shale leasing policy analysis (Kalter, Stevens and Bloom; Kalter, Tyner and Stevens; Stevens and Kalter). The model calculated installed capacity for all production time horizons between one year and the economic limit when marginal costs exceed marginal revenue. All exploration and development occurred in the first year. Point estimates were used for all variables with no Monte Carlo simulation. This model version consisted of ninety-seven computer source statements.

The next model version included new policy options and added Monte Carlo simulation for price and cost variables. This version was first used for an analysis of policy options which could be used to stimulate oil shale production (Kalter and Tyner, Shale Oil, 1975) and for OCS leasing policy. (Kalter and Tyner, Contingency Leasing Options, 1975). Price guarantee, purchase guarantee, and investment subsidy options were included. This model contained about six hundred source statements.

Over an eight month period, the model was developed into the GEN1 version of the generalized resource policy evaluation model which preceded the current version. This version performed Monte Carlo simulation with risked variables for the chance of no resource, reserves, prices, investment cost, and operating cost. Exploration and development were separated and development was not undertaken if the discovered reserves were uneconomic or no resources were found. Advance royalty options (Kalter and Tyner, Advanced Royalty, 1975) were included and a number of new policy options were added. Capital recovery profit share systems and variable rate structures for both royalty and profit share were added. The GEN1 version was about thirteen hundred source statements. It was used for an analysis of OCS oil leasing policy (Kalter, Tyner and Hughes) and for other analyses.

The description that follows explains the current GEN2 version in detail. New options have been added and the entire model has been reprogrammed using structured programming to facilitate understanding of the model and to increase efficiency. All calculations in this version are performed on an annual basis, and annual streams for output variables may be obtained. The GEN2 version contains about twenty-three hundred source statements.

This generalized leasing model incorporates a number of factors important for public policy decisions into a framework of private market behavior. Economic, geological and engineering considerations relevant to private producer decision making are included so that the model may be useful for quantitatively testing the effects of a wide range of public policy alternatives. For example, the model is designed to determine the impacts of a number of alternative federal policies aimed at reducing risk for private sector resource development. A wide range of leasing policy alternatives are also incorporated into the model so that it may be used to analyze the effects of alternative leasing strategies.

This paper is designed to provide readers with an in depth understanding of how the model works. It is not written with reference to a specific resource; rather, a generalized model description is retained which can be applicable to any resource. Both the theoretical and mechanical aspects are covered in great detail, in order that the reader will understand not only the rationale behind the relationships modeled but also will comprehend the means used to translate the theoretical structure into actual equations and solution procedures.<sup>1</sup>

#### Model logic and procedures

The model utilizes exogenously supplied estimates of reserves on an individual or group of leaseholds, along with estimates of the associated production costs (investment and operating) and market prices to determine the after tax net present value of the leasehold. In so doing, the model determines the productive capacity to be installed on the leasehold and the length of time that capacity is used. Uncertainty with respect to the key variables supplied exogenously (reserves, production costs and market prices) is incorporated via use of Monte Carlo simulation. Net present value calculations are carried out using discounted cash flow techniques with exogenously supplied rates of return as discount rates.

#### Installed capacity options

Given this basic model logic, several approaches to model solution can be used. The solution algorithm can be designed to handle installed capacity ( $q_0$ ) either endogenously (all possible values for installed capacity are evaluated) or exogenously (only prespecified capacities are permitted in the model solution). This distinction, in large part, leads to the different model algorithms. In the former situation, equations are specified which solve for and optimize installed capacity simultaneously

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<sup>1</sup>The Appendix contains operating instructions plus a complete list of input variables. The computer code is available from the authors.

with other model outputs. In the latter, the discrete installed capacities are entered into the model and the optimal capacity among these is determined. One advantage of this approach is that it permits economies of scale with respect to installed capacity to be considered in model solutions since unique cost relationships can be entered with each capacity examined.<sup>2</sup>

Figures 1 and 2 are flow diagrams for the two alternative solution algorithms. Both approaches have been programmed for model execution. The model description will follow these two flow diagrams and will separately describe the solution algorithm with endogenous and exogenous  $q_0$ . It may be helpful for the reader to refer back and forth between these two flow diagrams and the text. To make the description easier to follow, a list of all model input variables used in this description is provided in Table 1. All symbols in the text and future references to variable names will refer to the variable definitions in Table 1.

#### Time indices

The model relationships consist of both discrete and continuous time calculations. Both integral and summation forms are used in the calculations. Hence, it is necessary to define time variables in both discrete and continuous terms. Also, for some purposes, the lease life is divided into a development and a production period with separate time indices. For discounting purposes, only one time index is used which originates with the beginning of the lease.

To avoid confusion, the time variable definitions used in this discussion are provided in Table 2. The variable  $tt$  is used as a discrete time index for variables such as annual production,  $qq(tt)$ , and yearly initial prices,  $P_0(tt)$ . The variables  $t$  and  $u$  are time rate variables used in calculating changes in production and prices and in computing the discount factor.

#### Mean values case

After the variables are read in and stored if necessary, the first step in the model solution is to run completely through the model once using mean values for all input variables. This step determines the after tax net present value (ATNPV) if all mean values are used and converts that value into a bonus bid payment to be used in subsequent calculations.<sup>3</sup> This conversion is assumed to be linear according to equation (1):

$$(1) \quad \text{BONUS} = B_0 + B_1 \cdot \text{ATNPV}$$

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<sup>2</sup>However, economies of scale with respect to reserve size can be considered under both approaches.

<sup>3</sup>The amount of the bonus bid is necessary for tax calculations. The use of mean input values to calculate the bonus serves to approximate the actual value. This can then be used in subsequent calculations where uncertainty is considered. Optionally, the bonus may also be recalculated after any number of Monte Carlo iterations for use in subsequent iterations.

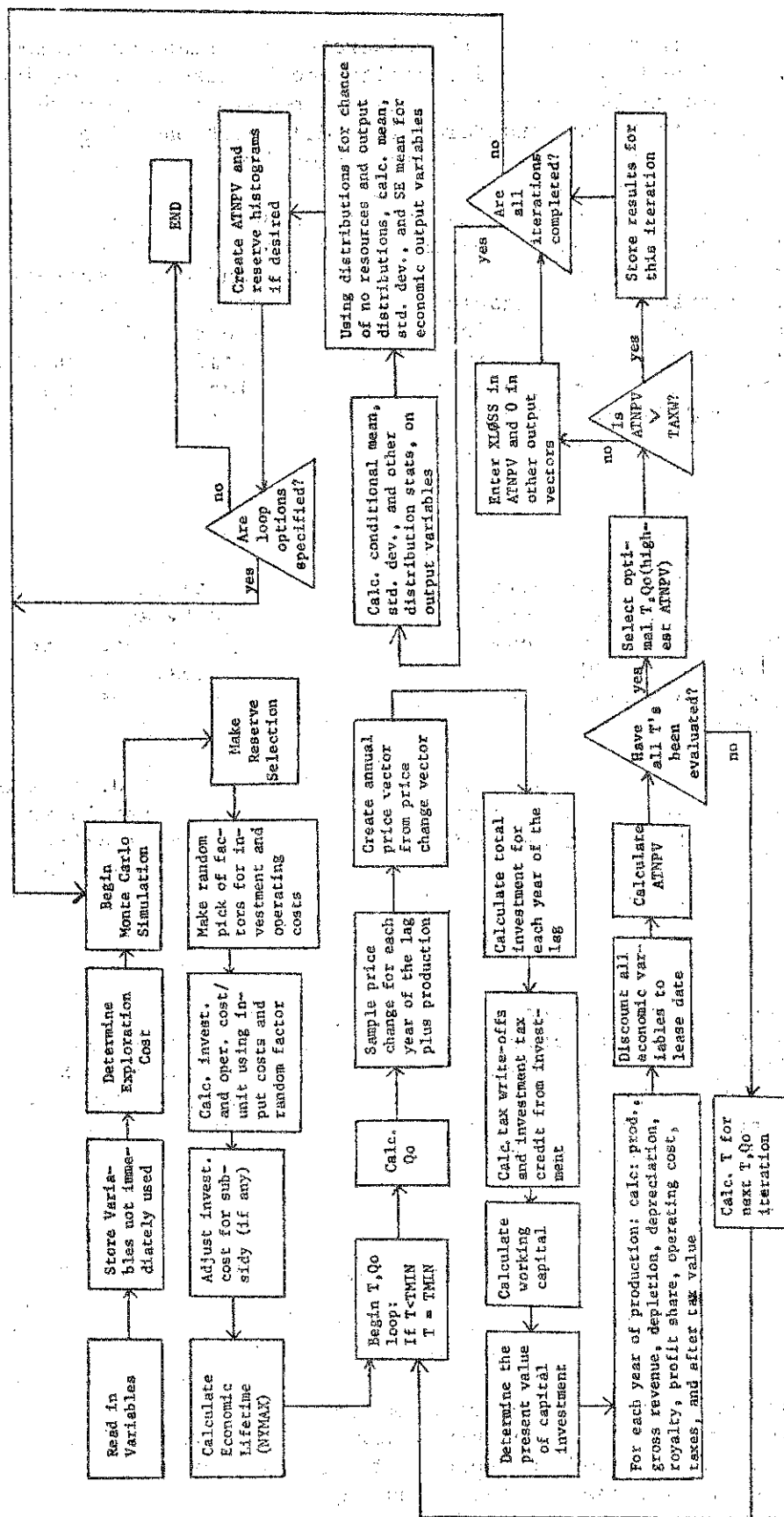


FIGURE 1.-FLOW DIAGRAM FOR SIMULATION MODEL WITH ENDOGENOUS  $Q_0$

$Q_0$  = installed annual capacity  
 ATNPV = after-tax net present value  
 TAXW = tax write-off available if lease is not developed after exploration  
 XLOSS = loss incurred from exploration if lease is not developed (exclusive of bonus)  
 TMIN = minimum production time period

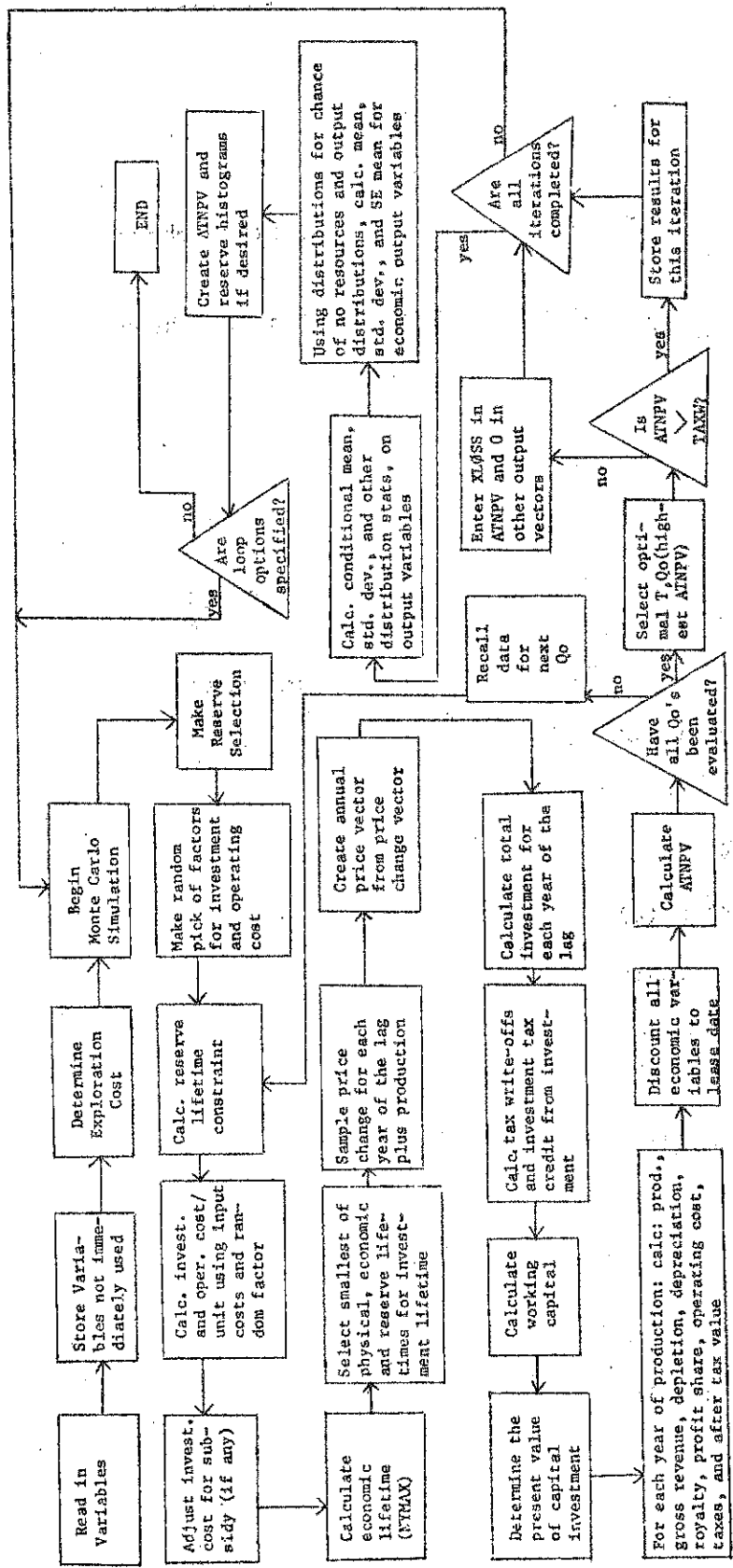


FIGURE 2.---FLOW DIAGRAM FOR SIMULATION MODEL WITH INPUT Qo

Qo = installed annual capacity  
 ATNPV = after-tax net present value  
 TAXW = tax write-off available if lease is not developed after exploration  
 XI/SS = loss incurred from exploration if lease is not developed (exclusive of bonus)

Table 1.--Selected Input Variables for the Generalized Resource Policy Model

| Symbol                    | Definition                                                                   |
|---------------------------|------------------------------------------------------------------------------|
| Price related:            |                                                                              |
| $P_0$                     | Initial price for the primary resource                                       |
| $GP_0$                    | Initial price for the secondary resource                                     |
| $P_1$                     | Mean of the normal distribution for annual price change (primary resource)   |
| $GP_1$                    | Mean of the normal distribution for annual price change (secondary resource) |
| Geologic:                 |                                                                              |
| $R$                       | Mean of reserve distribution                                                 |
| $\beta$                   | Geologic parameter                                                           |
| AGFAC                     | Factor for calculating the amount of associated gas or other resource        |
| $F$                       | Length of the initial flat production period (years)                         |
| $a$                       | Production decline rate (%)                                                  |
| Economic and tax related: |                                                                              |
| $\lambda$                 | Royalty rate (%)                                                             |
| $s$                       | Severance tax rate (%)                                                       |
| $\alpha$                  | Investment salvageable (%)                                                   |
| $\Omega$                  | Investment tax credit rate (%)                                               |
| $z$                       | Depletion rate (revenue) (%)                                                 |
| $\phi$                    | Federal tax rate (%)                                                         |
| $N$                       | Depreciation period (years)                                                  |
| $r$                       | Discount rate (%)                                                            |
| $B_0$                     | Constant used to calculate BONUS                                             |
| $B_1$                     | Factor used to calculate BONUS                                               |

Table 1.--Continued

| Symbol                       | Definition                                                       |
|------------------------------|------------------------------------------------------------------|
| $T_p$                        | Maximum physical lifetime (years)                                |
| Production and cost related: |                                                                  |
| $q_0$                        | Installed capacity (annual)                                      |
| $c$                          | Cost per unit of installed capacity                              |
| $k_0$                        | Operating cost per unit                                          |
| $\theta$                     | Annual change in operating cost (%)                              |
| $L$                          | Length of the development period (years)                         |
| $f$                          | Proportion of investment expended in each year                   |
| $y$                          | Proportion of yearly investment which is tangible                |
| RENT                         | Annual rent per acre                                             |
| $h_j$                        | Factor used to determine production during build-up period (IBP) |

Table 2.--Time Variable Definitions

| Variable | Definition                                      | Range     |
|----------|-------------------------------------------------|-----------|
| $t$      | Continuous time index for the production period | 0 to $T$  |
| $tt$     | Discrete time index for the production period   | 1 to $TT$ |
| $T$      | End of production <sup>a</sup>                  |           |
| $TT$     | Last year of production <sup>a</sup>            |           |
| $v$      | Continuous time index for lease life            | 0 to $T$  |
| $T$      | End of the lease                                |           |
| $L$      | Length of development period                    |           |

<sup>a</sup>Numerically,  $T$  always equals  $TT$  because production time in years is set equal to an integer.



where  $B_0$  and  $B_1$  are input values.<sup>4</sup> If Monte Carlo simulation is not being used, the mean values produce the model results. In this case, the model description that follows is only relevant to the use of this single set of values.

The exploration phase of resource development

The next step in the model solution is to determine the exploration cost for the lease tract or area in question. For example, gross exploration costs (EC) are a function of the number of wells to be drilled per acre, the number of acres in the tract, and the cost per well as illustrated in equation (2):

$$(2) \quad EC = \text{Wells/acre} \times \text{acres} \times \text{dollars/well}$$

A portion (exogenously specified) of exploration expenses (intangible investment) can be expensed immediately. Since no revenues are produced during exploration and development, expensed investment and other tax losses are written off and entered into the tax vector as negative taxes. Exploration expenses each year minus the savings from tax write-offs are entered into the after tax value vector as negative values. These vectors contain the time stream of taxes, after tax value, and other economic output variables.

In addition to calculating the total net expenses of exploration, the potential tax write-off available to the company if the lease is not developed is also calculated at this time. This potential tax write-off is the bonus payment and the remaining depreciable base of exploration expenses multiplied by the tax rate. This value is compared later in the program with the potential present value of the lease if developed to decide whether or not it is advantageous to develop the lease.

Exploration is the last aspect of the model solved outside the Monte Carlo simulation. At this point, the analysis of uncertain input variables begins (see Figures 1 and 2). A description of this type of simulation and of the procedures used for this model follow.

#### Uncertainty and the Monte Carlo analysis

Once exploration cost is determined, the Monte Carlo simulation begins. A number of the variables used in this model are considered uncertain and are subject to Monte Carlo simulation analysis. Any or all of the following variables may be selected randomly in the Monte Carlo simulation: annual change in price, contingency factor for investment cost, contingency factor for operating cost, and the amount of resources actually present. In addition, the presence or absence of resources is an independently risked variable.

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<sup>4</sup>If  $B_0$  and  $B_1$  are set equal to 0 and 1, respectively, the bonus will equal ATNPV. The values of  $B_0$  and  $B_1$  depend on the bidder's risk preference function.

For policy analysis, it is important to determine the potential effects on private decisions of uncertainty with respect to future prices, production costs, and reserves. Using the mean (average) values of probability distributions is inadequate because only outputs resulting from these mean values are produced. No measure of the spread (variance) of potential outcomes is obtained. In other words, in the absence of some type of simulation, no measure of the potential riskiness of the final outcome is derived. For policy purposes, it is desirable to learn not only how the mean output values are affected by various policy options but also how the variance or range of the outcomes is changed.

For example, suppose two policy options have identical effects on the means of relevant policy objectives (model outputs), have identical costs (in whatever terms cost is measured), but have differential effects on the expected outcome variances. Naturally, the policy maker would want to consider the difference in variance in his policy decision. Also, because of non-linear transformations in some of the model operations, the simulation results may differ from the analysis using mean input values. For example, revenue depletion is constrained not to exceed 50 percent of net income before taxes. This constraint is one type of non-linear transformation which can cause the simulation means to differ from outputs using mean input values. Trade-offs between changes in means, differences in relative cost, and variances must be weighed by the decision makers.

Monte Carlo simulation is one technique for handling the problem of uncertainty in input values and estimating the variance in potential outcomes. Rather than using point estimates of uncertain input variables an assumed probability distribution is provided from which samples are taken to be used as inputs for the analysis. The process of sampling each variable from its unique probability distribution and performing the model calculations is repeated many times to produce a range of model output values. A frequency distribution of these output values can be derived and the mean and variance of the expected outcomes determined. In performing this type of simulation, we replace the unknown actual population of future prices, costs and reserves by an assumed probability distribution from which samples are drawn. By sampling many times it is possible to generate many possible combinations of prices, costs, and reserves that together produce outcomes, each in the appropriate proportion (King).

Any type of probability distribution may theoretically be specified for the uncertain variables. For this analysis we have used the normal, triangular, and lognormal distributions which are depicted in Figures 3, 4, and 5, respectively. The uncertain variables used in this model and the type of distribution which is used for each variable are listed in Table 3.

#### Future Resource Prices

Uncertainty in future resource prices is handled by randomly selecting the annual change in price each year from a normal distribution with a specified mean and variance. This vector of sample annual price changes together with the resource price at the beginning of the lease,  $P_0(1)$ , is

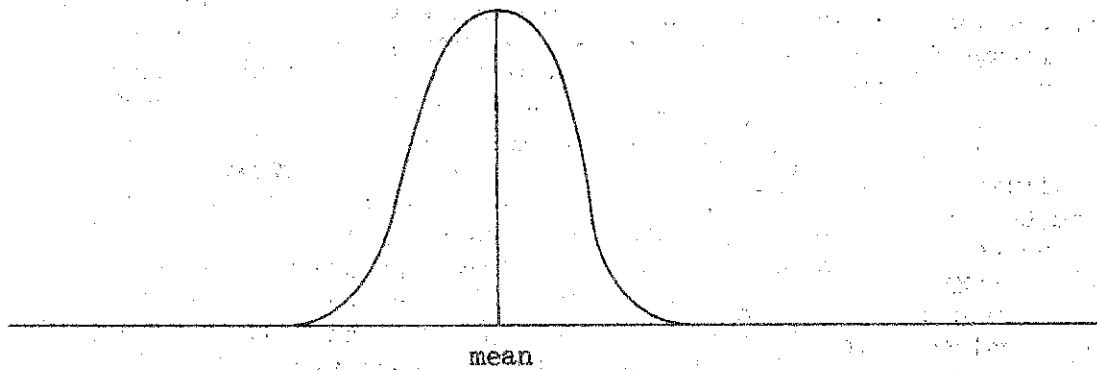


Figure 3.--Normal Distribution Used for Annual Price Change and Reserves

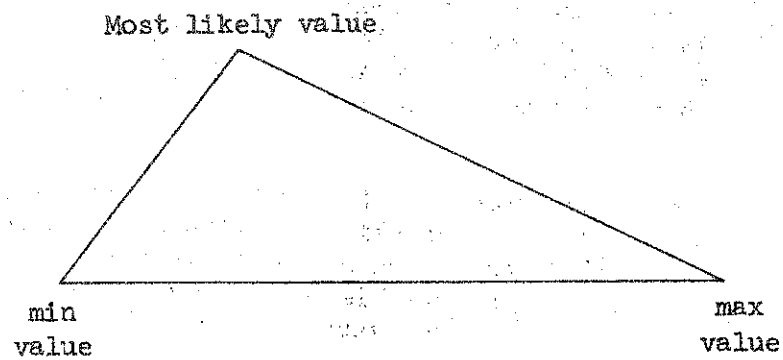


Figure 4.--Triangular Distribution

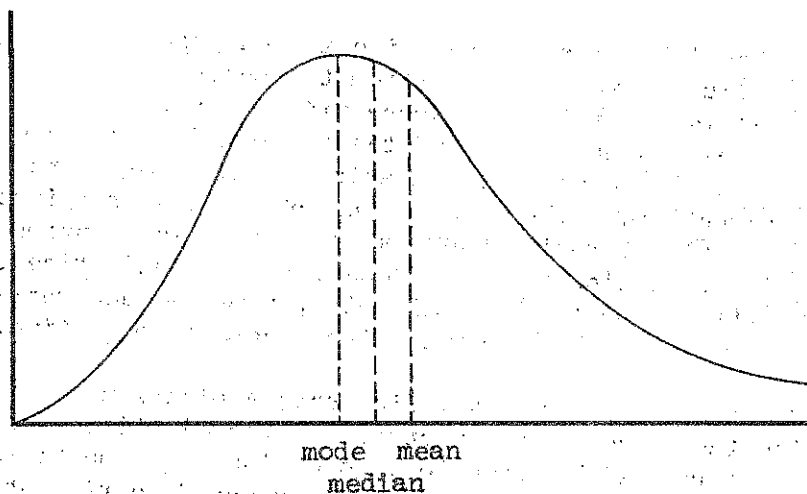


Figure 5.--Lognormal Distribution

Table 3.--Distributions Used For Uncertain Variables

| Variable                           | Distribution               |
|------------------------------------|----------------------------|
| Annual price change                | Normal or truncated normal |
| Investment cost contingency factor | Triangular                 |
| Operating cost contingency factor  | Triangular                 |
| Amount of reserves                 | Lognormal or normal        |

used to create a vector of initial prices for each year of potential lease duration. Equation (3) illustrates this process:

$$(3) \quad P_0(tt + 1) = P_0(tt)e^{P_1(tt)}$$

$P_0(tt)$  is the initial resource price in year  $tt$ ,  $P_1(tt)$  is the rate of change in price during year  $tt$  (from the vector of price change samples), and  $P_0(tt+1)$  is the initial resource price in year  $(tt+1)$ . This vector of initial prices for each year and the vector of price changes during each year are used in the model computations to determine gross revenue for each year of production. Since this procedure is repeated independently for each Monte Carlo iteration, a separate price distribution emerges for each year of the production period. Because the annual price change has a compound effect upon the initial price, the mean and variance of these annual price distributions would also change through time.

If desired, more than one price change distribution may be used in generating the price change vector. The model allows for as many as four unique price change distributions to be input for up to four specified time periods. For example, price could be expected to rise at an annual rate of 8 percent for three years, fall at a rate of 3 percent for six years, remain relatively constant for eight years, and then rise at a rate of 4 percent through the end of production. Each of the expected price change values could have a unique variance, so that the variance as well as the expected value of annual price change can vary through time. The price change vector is created by utilizing the distribution appropriate for each year in the vector.

It is important to understand that the price change used in this analysis is the expected price change in excess of general inflation. It is not the total expected change in price of the resource; rather, it is the difference between the expected change in price of the resource and the expected general rate of inflation in the economy. This same principle applies to investment and operating cost factors. Thus, the relative inflation rate between revenues expected from the resource and cost to obtain the resource is a derivative of the inputs to the model. Because both cost and revenue inflation factors are keyed to general inflation, relative inflation between costs and revenues for a particular investment is automatically accounted for using this procedure (given the subjective distributions pertaining to the input variables).

#### Investment cost contingency factor

Investment costs are uncertain for at least three reasons, and a cost contingency factor is used to handle this uncertainty. The contingency factor is a percentage of the estimated investment cost and is selected from a triangular distribution with an input minimum, maximum, and most likely value.

One of the most important reasons for a contingency factor in investment cost is that inflation in construction costs in recent years has taken place at a rate higher than the rate of general inflation. Although this experience

will not necessarily continue, it is uncertain what the rate will be in the future. Since the construction and start-up period may be five years or more, the rate of inflation can have a significant effect on total construction costs. Second, investment costs may be uncertain because technology for extracting and refining some resources is relatively new. For example, coal gasification technology and costs are highly uncertain. Unforeseen engineering and technical problems could raise investment costs substantially. A third reason for an investment cost contingency factor is that if facilities of the type and scale required have not been constructed previously, the length of the development and construction period required cannot be known with certainty. Changes in the assumed period will have a significant impact on the present value of investment costs.

As is evident from the discussion of these factors, the distribution of investment cost uncertainty tends to be one sided. In other words, the risk is mainly on the high side, so the distribution would be expected to be skewed in that direction.

#### Operating cost contingency factor

The two factors affecting annual operating costs in the model are  $\theta$ , the annual increase in cost per unit, and  $K_0$ , the initial operating cost per unit. For purposes of analysis,  $\theta$  was assumed to be known and constant throughout the production period, and a triangular distribution of  $K_0$  values was utilized. Uncertainty in initial operating cost arises from the same sources as investment cost (future relative inflation and unforeseen technological difficulties) plus uncertainty in the future cost of environmental protection. Since future government regulations are unknown or are subject to modification, it is difficult to forecast the environmental control costs which must be borne by the private sector. However, once production has begun with technological problems solved and environmental control equipment in place, future changes in operating cost should be subject to less uncertainty. Therefore, the initial operating cost,  $K_0$ , was assumed to be uncertain with risk mainly on the high side.

In addition to the factors  $K_0$  and  $\theta$ , unit operating costs are also affected by the rate of decline in production (especially for resources like oil). Since total operating costs are determined by the factors described above, unit operating costs may rise as production falls. This point is discussed further at a later point in the text.

#### Presence or absence of resources

This variable is particularly relevant for oil and natural gas or other resources for which there is a significant chance that no resource will be discovered on the lease. Almost any distribution may be used for the chance of no resources being present. The distribution mean and standard deviation are model inputs. Table 4 displays the mean, variance, and characteristics of a number of distributions which could be used for the chance of no resource being present. Using the formulae in Table 4, the mean and variance can be calculated from the distribution parameters and input into the model. For example, if a triangular distribution is selected, the mean is the average of the minimum value (a), most likely value (b), and maximum value

Table 4.--Selected Distributions

| Distribution      | Symbol              | Domain                           | Restriction               | Mean                                            | Variance                                                                                                     |
|-------------------|---------------------|----------------------------------|---------------------------|-------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| Beta              | $\beta e(a,b)$      | $0 \leq x \leq 1$                | $a, b > 0$                | $\frac{a}{a+b}$                                 | $\frac{ab}{(a+b+1)(a+b)^2}$                                                                                  |
| Binomial          | $\beta(n,p)$        | $0 < p < 1$<br>$n = 1, 2, \dots$ | $x = 0, 1, \dots, n$      | $np$                                            | $np(1-p)$                                                                                                    |
| Chi-square        | $\chi^2(n)$         | $0 \leq x < \infty$              | $n = 1, 2, \dots$         | $n$                                             | $2n$                                                                                                         |
| Exponential       | $E(\beta)$          | $0 < x < \infty$                 | $\beta > 0$               | $\beta$                                         | $\beta^2$                                                                                                    |
| Gamma             | $G(\alpha, \beta)$  | $0 \leq x < \infty$              | $\alpha, \beta > 0$       | $\alpha\beta$                                   | $\alpha\beta^2$                                                                                              |
| Lognormal         | $LN(\mu, \sigma^2)$ | $0 \leq x < \infty$              | $\sigma^2 > 0$            | $\mu$                                           | $\sigma^2$                                                                                                   |
| Negative Binomial | $NB(r, p)$          | $0 < p < 1$<br>$r > 0$           | $x = 0, 1, \dots, \infty$ | $\frac{rp}{1-p}$                                | $\frac{rp}{(1-p)^2}$                                                                                         |
| Normal            | $N(\mu, \sigma^2)$  | $-\infty < x < \infty$           | $\sigma^2 > 0$            | $\mu$                                           | $\sigma^2$                                                                                                   |
| Poisson           | $P(\beta)$          | $\beta > 0$                      | $x = 0, \dots, \infty$    | $\beta$                                         | $\beta$                                                                                                      |
| Triangular        | $T(a, b, c)$        | $a \leq x \leq c$                | $c > b > a$               | $\frac{a+b+c}{3}$                               | $\frac{a(a-b) + c(c-a) + b(b-c)}{18}$                                                                        |
| Uniform           | $U(a, b)$           | $a \leq x \leq b$                | $b > a$                   | $\frac{a+b}{2}$                                 | $\frac{(b-a)^2}{12}$                                                                                         |
| Weibull           | $W(\alpha, \beta)$  | $0 \leq x < \infty$              | $\alpha, \beta > 0$       | $\beta \Gamma\left(\frac{1}{\alpha} + 1\right)$ | $\beta^2 \left[ \Gamma\left(\frac{1}{\alpha} + 2\right) - \Gamma^2\left(\frac{1}{\alpha} + 1\right) \right]$ |

SOURCE: Fishman, George S. Concepts and Methods in Discrete Event Digital Simulation, pp. 201, 218.

(c) as shown in Table 4. The standard deviation is the square root of the triangular distribution variance as calculated using the formulae in Table 4.

Rather than directly sampling from the distribution as for the other Monte Carlo variables, the risk that no resource is present is handled by combining the distributions of value with resources present and value (loss) with no resources being found. This step requires the linear combination of the product of random variables as shown in equation (4):

$$(4) \quad V = N \cdot X + (1 - N) \cdot R$$

where  $N$  is the random variable representing the chance that no resource will be found,  $X$  is the loss from exploration,  $(1 - N)$  is the variable representing the chance that resources will be found, and  $R$  is the variable representing the value of the lease given that resources are present. The expected value of the value distribution ( $V$ ) is the sum of the products of expected values as shown in equation (5):

$$(5) \quad E(V) = E(N) \cdot E(X) + E(1 - N) \cdot E(R)$$

where  $E(N)$  is the input mean of the chance of no resources being found distribution,  $E(X)$  is the exploration loss calculated in the exploration subroutine,  $E(1 - N)$  is the probability that resources will be found, and  $E(R)$  is the mean of the sample distribution of value calculated from the Monte Carlo simulation. In other words, the expected value of a lease is the probability of no resource being found multiplied by the value if no resources are found plus the probability that resources are found multiplied by the expected value if resources are present.

The variance of the total expected value distribution is somewhat more complicated. The random variable sets  $N$  and  $X$  and  $N$  and  $R$  are each independent, but clearly the two products are not independent because both contain  $N$ . Hence, the products can be taken assuming independence, but the linear combination must include the covariance term. The resulting variance of total expected value is given in equation (6):<sup>5</sup>

$$(6) \quad \sigma_V^2 = (E(N))^2 \cdot \sigma_X^2 + (1-E(N))^2 \sigma_R^2 + (E(R)-E(X))^2 \sigma_N^2 + (\sigma_X^2 + \sigma_R^2) \sigma_N^2$$

This term can be further simplified for this analysis because the variance of  $X$  is zero. None of the variables in the exploration calculations are risked, so a point estimate is calculated (with no variance). Therefore equation (6) can be reduced to the form shown in equation (7):

$$(7) \quad \sigma_V^2 = (1-E(N))^2 \cdot \sigma_R^2 + (E(R)-E(X))^2 \cdot \sigma_N^2 + \sigma_R^2 \cdot \sigma_N^2$$

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<sup>5</sup>The authors are indebted to Don Bieniewicz and Mike LeBlanc for their assistance in calculating the variance.



Since all the terms on the right side of equation (7) are either inputs or are calculated in the simulation, the variance of total expected value can be calculated directly. By using this process, uncertainty regarding the presence or absence of resources can be handled outside the Monte Carlo simulation yet allowing for maximum flexibility in the input distribution.

If resources are certain to be found, the mean and variance of the chance of no resources distribution can be specified as zero. In that event equation (7) reduces to the variance when resources are present ( $\sigma_R^2$ ) which is the appropriate value for total variance.

#### Amount of reserves

For some resources, such as oil and natural gas, a major source of uncertainty is the amount of reserves present. For almost all resources some degree of uncertainty about the total quantity of resources in place exists.

Relating to petroleum exploration, a number of researchers have found that the lognormal distribution provides a good fit for experimental data on the size of petroleum deposits. (Uhler and Bradley; U.S. Geological Survey, 1975; Kaufman, 1962). Therefore, the lognormal distribution is used for the size distribution of petroleum resources and in other situations where deemed appropriate.

For resources which are not distributed lognormally (such as coal), the normal distribution also may be used in the simulation program. In either case, the mean, standard deviation and distribution selection are model inputs.

#### Model description with Monte Carlo simulation

Once the Monte Carlo simulation begins, each of the procedures is repeated for each iteration of the simulation. The results of each iteration are stored and used to calculate the mean and other statistics on output variables.

The number of Monte Carlo iterations,  $NL\phi\phi P$  represents only the number of iterations for which resources are found. The effective number of iterations is equal to  $NL\phi\phi P$  divided by one minus the mean of the no resource risk distribution. For example, if  $NL\phi\phi P$  is two hundred and the mean of the no resource risk distribution is .5, the effective number of iterations is four hundred.

Once the amount of resources on the tract is determined, the next step in the process is to make a random selection of factors to be used in determining total investment and operating costs. A choice of four methods is allowed in making this selection of factors. First, the investment and operating cost input values may be used without any random component added. In this case, random selection is bypassed. Second, a cost adjustment factor may be randomly selected from the triangular cost distributions supplied for both investment and operating costs. For both investment and operating cost the minimum adjustment factor, the most likely adjustment

factor and the maximum adjustment factor are inputs determining the shape of the triangular density function. Third, the mode (most likely value) of the triangular distribution may be used directly. Fourth, the mean of the triangular distribution (the average of the three vertices) may be selected.

The cost adjustment factor is then multiplied by the base cost, and the result added to the base cost. In essence, the random cost component which results from the cost adjustment factor is a contingency. The actual amount of the contingency may be zero (if the base value is used), equal to the mean or mode of the triangular distribution, or randomly selected from the distribution. Normally, the random selection method is used because contingency is considered a random component of total cost. Hence, the random selection method is considered to better reflect actual operating conditions.

The next two steps in the model simulation vary depending upon whether installed capacity is input or determined within the model. If installed capacity is internally determined, the random factors for investment and operating costs are immediately used to determine the investment and operating cost values that will be used for each installed capacity. If installed capacity is an input, associated investment and operating cost values are also inputs unique to each installed capacity. The same random factor is applied to each of the investment and operating cost values for each installed capacity to determine a unique investment and operating cost.

If installed capacity is an input to the model, that capacity, together with reserves and other input variables, is used to determine the maximum production time horizon which can be used given the installed capacity and the amount of reserves. On the other hand, if installed capacity is solved within the model, a time horizon is determined internally and the corresponding (maximum) installed capacity is calculated within the model. Since each of these procedures represent a different solution to the same basic structural relationship, we will develop that relationship carefully and explain the correlation between the two procedures.

#### Economic, engineering and geologic relationships

We begin with the relationship between reserves and production. Reserve estimates enter the calculus of profitability both as a basis for the investment and as a constraint on the production from an investment. The production constraint is represented in equation (8):

$$(8) \quad xR \geq \sum_{tt=1}^{TT} qq(tt)$$

where R represents the amount of the resources in place, x the recoverable fraction with a given technology, qq(tt) the amount of annual production, and TT, the production time horizon. This equation merely states that the sum of production through time can be no greater than the recoverable portion of the resource in place (with a given technology). Given this constraint, the producer attempts to select an initial plant capacity which

will maximize his return through time. In other words, the producer attempts to select the investment which maximizes his after tax net present value of revenue subject to the production constraint.

Assume for the moment that production declines exponentially through time. Annual production may then be expressed as a function of initial installed capacity as in equation (9):

$$(9) \quad qq(tt)_i = \int_{t-1}^t q(o)_i e^{-at} dt$$

where  $q(o)_i$  represents initial installed capacity of the  $i$ th plant which is one of a group of possible initial capacities. While this simple relationship between installed capacity and annual production may be adequate for resources such as oil after a period of time, it is not adequate for other resources or for oil resources during the early production phase. A typical resource production pattern includes a production build-up period during which production is increasing each year as installed capacity is coming on stream followed by a flat production period which continues indefinitely (as for coal) or is followed by a declining production period as shown in Figure 6. Under this scenario, total production during the lease life is given by equation (10):

$$(10) \quad \text{PROD} = q_o \left[ \sum_{j=1}^B h_j + (F-B) \right] + \int_0^{T-F} q_o e^{-at} dt$$

where the build-up period is the period between year one and year B, the flat production period is between year B and year F, and the declining production period (perhaps at a zero rate) is the period from F to T; T being the production life of the lease as determined below.<sup>6</sup> Equation (10) gives the sum of production during each of the three phases of production.<sup>7</sup> Production during the build-up period is equal to the sum over the build-up period of the annual factors,  $h_j$ , times installed capacity; production during the flat period is simply the number of years in which production is constant times installed capacity; and production during the decline period is equal to the integral over the number of years production is declining. Recalling from equation (8) that total production must be less than or equal to recoverable reserves we may now combine equations (8) and (10) to yield

<sup>6</sup>The integral for the decline period goes from zero to T-F rather than F to T because this integral properly measures the sum of production over the decline period.

<sup>7</sup>The notation,  $q(o)_i$ , is here changed to  $q_o$  representing one potential investment, but the reader should be aware that the optimization process covers all available investment opportunities.

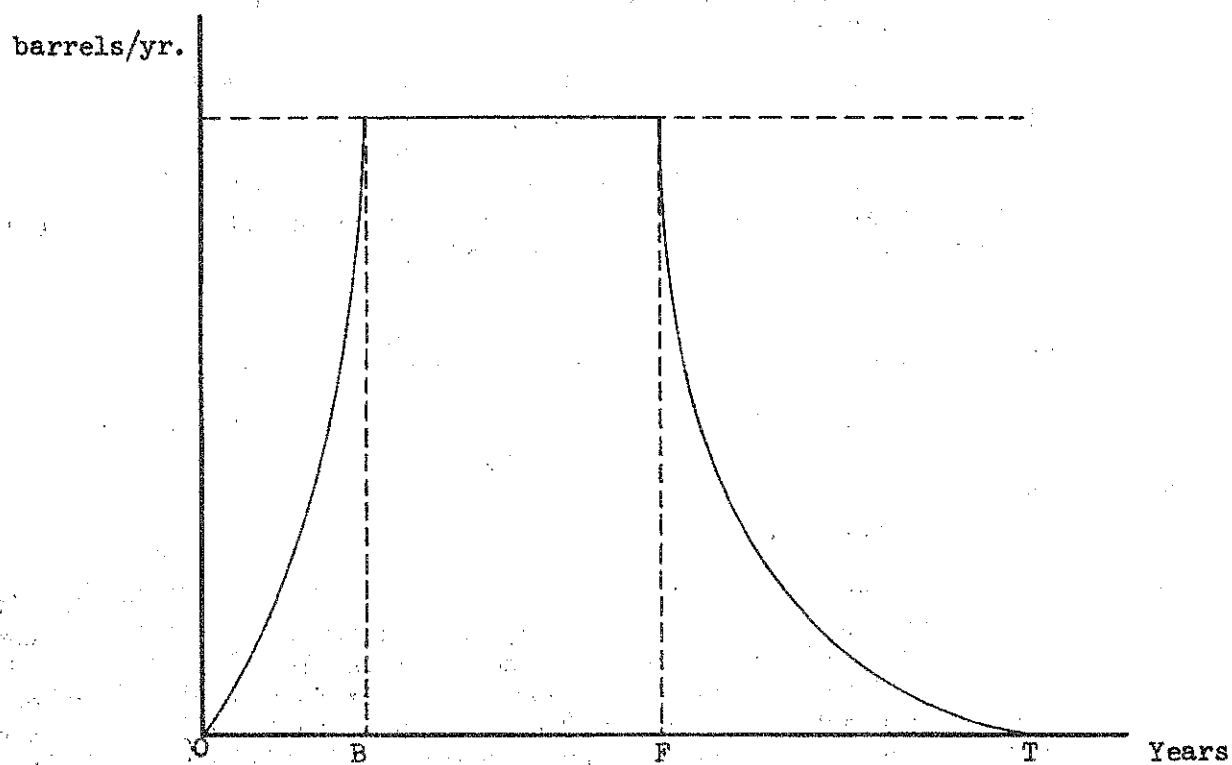


Figure 6.--Production Profile Through Time

the relationship between recoverable resources and installed capacity as in equation (11):<sup>8</sup>

$$(11) \quad xR - Bq_0 e^{-a} \geq q_0 \left[ \sum_{j=1}^B h_j + (F-B) \right] + \int_0^{T-F} q_0 e^{-at} dt$$

By assuming that recoverable reserves are exhausted, we may change equation (11) from an inequality to an equality and solve for either  $q_0$  or  $T$ . Equation (12) represents the solution for equation (11) for  $T$  which is used in the case of input  $q_0$ :

$$(12) \quad T = \left[ \ln \left[ 1 + a(-xR/q_0 + \beta e^{-a} + \sum_{j=1}^B h_j + F - B) \right] \right] / -a + F$$

Equation (13) represents the solution to equation (11) when installed capacity,  $q_0$ , is solved within the model:

$$(13) \quad q_0 = \frac{axR}{\left[ 1 + a(\beta e^{-a} + \sum_{j=1}^B h_j + F - B) - e^{-a(T-F)} \right]}$$

#### Production period constraints

Given that  $q_0$  and  $T$  have been determined either by input or within the model, the production time horizon,  $T$ , must be subjected to two constraints before it can be employed. These constraints are the physical and economic lifetimes of the proposed investment. The production time horizon for a given investment can be no greater than the actual physical lifetime of the initial plant.<sup>9</sup> Nor can the production time horizon exceed the time at which the variable unit cost of producing the product exceeds the revenues per unit obtained from marketing it. In other words, when the steadily increasing unit costs of production (assuming a rising MC curve) exceed the revenues per unit of production, production would cease.

The first constraint is simply expressed as an exogenously determined constraint  $T \leq T_p$ , where  $T_p$  equals the maximum physical lifetime of the

<sup>8</sup> $\beta$  is a geologic variable applicable to resources like oil which relates total recovery to the rate of recovery. (The faster the oil is produced, the lower is total recovery.) If  $\beta$  equals zero, recoverable reserves,  $xR$ , are greater than or equal to production as defined in equation (10).

<sup>9</sup>If substantial resources still remained on the leasehold beyond the lifetime of the initial plant, a new plant investment could be initiated. This situation could be handled by resimulating the leasehold using the remaining resources and production conditions. An example of this type of situation is enhanced recovery of oil using tertiary production techniques.

investment. The second constraint is the limit obtained when marginal cost equals marginal revenue. Equation (14) states that the economic limit occurs when operating costs plus taxes exceed or equal revenue minus royalties and severance taxes:<sup>10</sup>

$$(14) \quad (1 - \lambda - s)P_0 e^{P_1(t+L)} \leq K_0 e^{[(\theta+a)t-aF]} + \phi \left\{ (1-\lambda-s)P_0 e^{P_1(t+L)} - z(1-\lambda-s)P_0 e^{P_1(t+L)} - K_0 e^{[(\theta+a)t-aF]} \right\}$$

Solving equation (14) for the time constraint yields:

$$(15) \quad T_e \leq \left[ \ln \left[ \frac{(1-\phi)K_0}{(1-\phi+\phi z)(1-\lambda-s)P_0} \right] - aF - P_1 L \right] / (P_1 - \theta - a)$$

Note that this equation may be negative or undefined when the rate of change in price is greater than or equal to the decline rate plus the rate of change in unit operating cost ( $P_1 \geq \theta + a$ ). The negative sign occurs because the marginal revenue-marginal cost curve intersection is in the negative quadrant to the left of the origin as shown in Figure 7. The correct interpretation for this negative sign is that the economic time constraint is infinite.

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<sup>10</sup>The form of the economic time constraint shown in equation (14) corresponds to the operating cost option which makes total operating cost in each period a function of peak production:

$$q_0 K_0 e^{\theta t}$$

Thus, unit costs become:

$$q_0 K_0 e^{\theta t} / q_0 e^{-a(t-F)} = K_0 e^{[(\theta+a)t-aF]}$$

The denominator of this equation represents the production rate at point  $t$ . This form for operating cost is appropriate when most of the operating cost is determined by the fixed installed equipment such as for offshore oil operations where the pumps, separators, platforms and other equipment must be operated regardless of the rate of production.

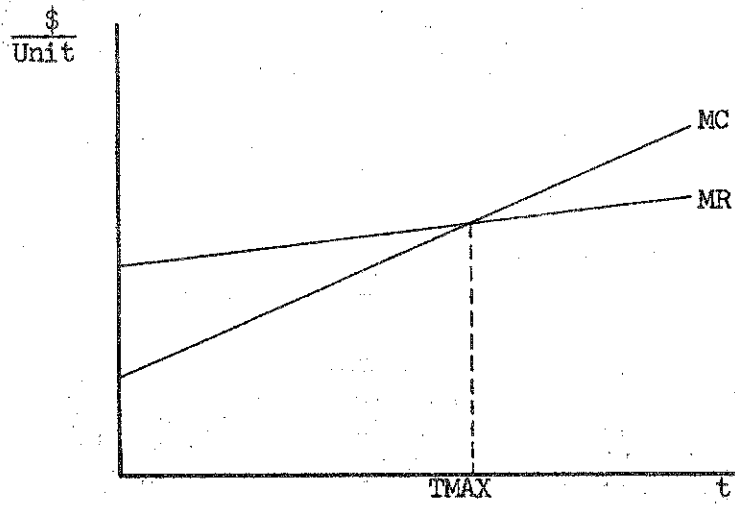
For other resources or in other production situations, total operating cost may be assumed to be a function of actual production:

$$q_0 e^{-a(t-F)} K_0 e^{\theta t} / q_0 e^{-a(t-F)}$$

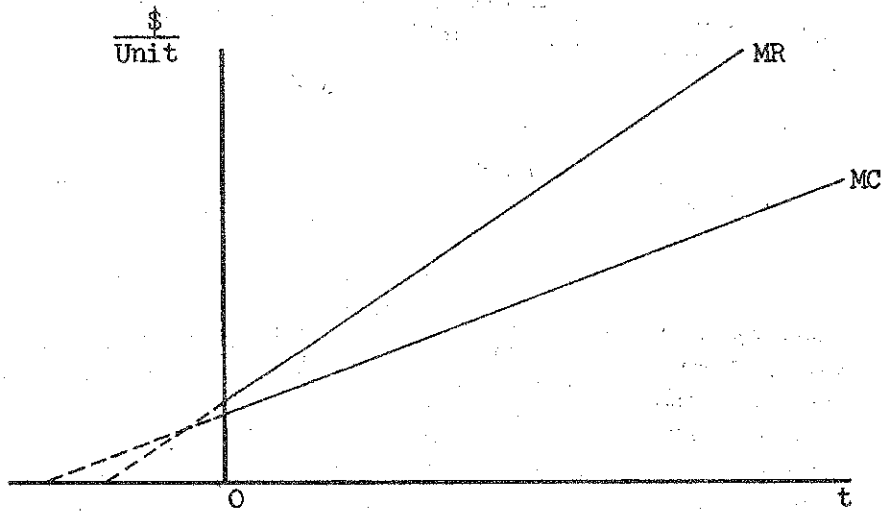
Unit operating costs in this case become  $K_0 e^{\theta t}$ .

A third option programmed into the model is the average of these two assumptions:

$$\text{Unit cost} = \left[ K_0 e^{\theta t} + K_0 e^{[(\theta+a)t-aF]} \right] / 2$$



Finite Solution



Infinite Time Horizon

Figure 7.--Solution to the Economic Time Horizon

We now have each of the equations and relationships necessary to determine the production time horizon. The production time horizon is that  $T$  determined in the model either by equation (12) or through the  $q_0, T$  optimization procedure, subject to the maximum physical lifetime and the economic lifetime constraint given by equation (15). Hence, the production time horizon is the minimum of the resource exhaustion time period, maximum physical life of the plant, or the economic production time constraint.<sup>11</sup> Mechanically, these equations are determined slightly differently depending on whether installed capacity is input or determined by the model as explained above and as outlined in Figures 1 and 2.

### Prices

For the first  $q_0-T$  set to be evaluated in each Monte Carlo iteration, the next step is to create a vector of prices covering each year in the production period. The first step in this process is to generate a vector of annual price change. Price change values are generated for sixty years which is the maximum lease life allowed in the model. This vector may be created by randomly sampling from a normal distribution of price change with an input mean and standard deviation as explained above. Alternatively the mean annual price change may be used for each year in the vector.

The next step is to create a vector of prices from the lease time until the end of production using the initial input price  $P_0$  along with the vector of price changes. As described above, the vector is created by multiplying the price at the beginning of each year by the exponential price change during that year to get the price at the beginning of the next year.

### Investment costs

Investment for each year of the construction and development period and the discounted value of total capital investment is calculated next. Total capital investment is determined by multiplying installed capacity,  $q_0$ , by the investment cost per unit of installed capacity,  $C$ , as determined in the cost subroutine for each resource. To determine the discounted value of total investment, the total investment figure must be multiplied by the percentage of total investment occurring in each year of the development period, and the investment value for each year discounted back to the beginning of the lease. Both development costs and exploration costs for each year are summed together and discounted to the beginning of the lease. In functional form this relationship is expressed in equation (16):

$$(16) \quad PVI = \sum_{i=1}^L (q_0 \cdot b \cdot f_i + EX_i) / (1+r)^{i-.5}$$

where PVI represents the present value of investment,  $f_i$  the factor used to determine the proportion of investment in each year of the lag ( $L$ ), and

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<sup>11</sup>Clearly, the form chosen for operating cost affects the economic lifetime calculation. Separate economic time constraint solutions are provided for each of operating cost assumptions.



EX<sub>1</sub> the exploration expense during each year of the lag. The values for total annual investment are then used to calculate depreciation streams for the production period and to calculate expensed investment and investment tax credit.

#### Deferred investment

In some situations, a substantial amount of capital investment takes place during the production period to replace equipment which has worn out. This investment normally takes place in regular cycles. For example, trucks used to haul coal may be replaced at regular intervals over the life of the mine. For this model up to three categories of deferred investment are permitted. For each category, the physical lifetime, depreciation lifetime, amount of deferred capital investment for each cycle, and salvage value are model inputs. Separate depreciation streams and salvage values are maintained for each category of deferred investment as well as for that portion of original investment which is not replaced during the mine life. The present value of the stream of deferred investment is added to the initial investment cost (and subtracted from after tax net present value). Investment tax credit is calculated for each year of deferred investment.

#### Depreciation and taxes

The model allows any of the following forms of depreciation to be used:

1. No depreciation
2. Sum of years' digits (SYD) depreciation with input depreciation lifetime (N)
3. Double declining balance (DDB) with automatic conversion to straight line (SL) at the appropriate time--using input depreciation lifetime
4. Straight line using input depreciation lifetime
5. Unit of production depreciation--at the same rate as the resource is depleted (annual production/total production) using the production horizon (T) as depreciation lifetime
6. SYD with the production horizon as depreciation lifetime
7. SL with the production horizon as depreciation lifetime
8. DDB with the production horizon as depreciation lifetime

According to IRS regulation, capital investment cannot be depreciated until it is placed in service. Therefore, all tangible investment during the development period is depreciated beginning with the first year of production.

Tax savings during the exploration and development periods result from expensed (intangible) investment, rental payments during exploration (RENT), and the investment tax credit (at the beginning of production). Tax savings during development are entered as negative values in the tax vector (and consequently as positive values in the after tax value vector).

## Production period calculations

Working capital is calculated as a fraction of total operating cost during a year of peak production. Once this calculation is complete, calculations for the production period begin. Annual and total production, gross revenue, operating cost, royalty, severance tax, depletion, profit share or production share, and taxes are calculated. Because many of the equations are in integral form, yet many of the values are needed on an annual basis, integral solutions are obtained over each year of production and then summed over the production period. For example, production is obtained from point zero to the end of year one and then from the beginning of year one to the end of year two and so on through the beginning of the last year of production to the end of the last year of production. These values are then summed to determine total production. In this way both annual and total values can be obtained for variables such as production, profit share, and royalty. A form of continuous discounting is utilized for variables such as gross revenue and operating cost.

The methods used to determine annual production in each year of the production period are described in detail above. In addition to calculating production for the basic resource, production is also calculated for any associated resource such as associated gas with petroleum production. The ratio of production between the major resource and the secondary resource is assumed to be a constant factor. In other words, to determine the production of associated natural gas in each period, the production of oil is multiplied by the factor (AGFAC) to determine the production of natural gas. In the equations that follow, the annual production of the major resource will be denoted by  $qq(tt)$  and production of the secondary resource will be denoted by  $gg(tt)$ .

A number of equations are used in calculating the economic variables for each year of the production period. So that this process may be clearly understood, the equation for gross revenue is presented below in two forms:

1. The integral form divided into annual periods
2. The computational form actually used in the model

For simplicity of exposition, the values of  $F$  and  $B$  are assumed equal to zero. Hence, equations (17) and (18) represent the two forms of the gross revenue equation during the period of production decline:<sup>12</sup>

$$(17) \quad GR = qq(tt)P_o(tt) \int_0^1 e^{P_1 t} dt + gg(tt)GP_o(tt) \int_0^1 e^{GP_1 t} dt$$

<sup>12</sup>Actually  $P_1$  and  $GP_1$  are also time indexed variables as explained above, but they are written here in unindexed form for clarity of exposition.  $P_o(tt)$  and  $GP_o(tt)$  represent prices at the beginning of year  $tt$ , and  $qq(tt)$  and  $gg(tt)$  represent production during year  $tt$ .

$$(18) \quad GR = qq(tt)P_o(tt) \left( \frac{e^{P_1 t} - 1}{P_1} \right) + gg(tt)GP_o(tt) \left( \frac{e^{GP_1 t} - 1}{GP_1} \right)$$

Calculation of annual operating cost (OC) proceeds in the same manner as shown in equation (19):

$$(19) \quad OC = qq_c K_o \int_{t-1}^t e^{\theta t} dt = qq_c K_o \left[ \frac{e^{\theta t} - e^{\theta(t-1)}}{\theta} \right]$$

where  $q_c$  may be set equal to production in year  $tt$ , peak production ( $q_o$ ), or the average of the two. The marginal cost of extracting the second resource is assumed to be zero, or included in the cost of extracting the primary resource.

The model contains three annual revenue calculations in addition to the gross revenue calculation in equation (18). The first net revenue value (NTREV1) is calculated by subtracting royalty, operating cost, depreciation, severance tax, and rent from gross revenue. In the next step the depletion allowance is calculated. Currently, in the United States only cost depletion is allowed for oil but for other resources such as coal, revenue depletion, cost depletion, or the maximum of the two may be selected. Cost depletion is allowed on the bonus payment and other lease acquisition costs in proportion to the depletion of reserves. The second revenue value is the annual profit share base (NTREV2). To obtain this value, depletion is subtracted from NTREV1. The third annual revenue value is taxable income (NTREV3) which is the profit share base minus profit share payments.

After tax income in each year is simply taxable income minus state and federal taxes. After tax value and other output variables in each year are discounted using the continuous discounting factor shown in equation (20):

$$(20) \quad DSC = \int_{v-1}^v e^{-rv} dv = \frac{e^{-rv} - e^{-r(v-1)}}{-r}$$

where  $v$  is the index beginning with the lease date.

After tax net present value (ATNPV) is calculated by subtracting the present value of investment and lease acquisition cost from the discounted stream of annual after tax values and adding the discounted value of salvage and working capital. The after tax net present value represents the net worth of the lease and the residual economic rent to the resource.

Once the after tax net present value is determined for a particular  $q_o$ , other output variables associated with that ATNPV are stored. The model then

checks to determine if all  $q_0$  or  $T$  values have been evaluated. If not, the model returns to the beginning of the  $q_0$ - $T$  loop and repeats the procedure outlined above. If all possible  $T$  values or all input  $q$  values have been evaluated, the model then selects the optimal  $q_0$ - $T$  combination for each Monte Carlo iteration; the optimal set being the one with the highest ATNPV.

This optimal ATNPV is then compared with the potential tax write-off calculated earlier during the exploration phase. If the ATNPV is greater than the potential tax write-off, the optimal ATNPV value is stored as the result for this iteration. If the potential tax write-off from not developing the lease is greater than the potential gain from developing the lease (ATNPV), the decision is made not to develop the lease and the exploration loss is entered into the after tax net present value register. A zero is entered into the register for other output variables such as production, production time horizon, profit share, royalty, and tax. This result corresponds to the real world situation in which some quantity of resource is discovered during the exploration phase, but the economics dictate that the quantity is so small that it is not commercial and the lease is not developed.

#### Monte Carlo results and model outputs

With the final values of all output variables determined for this Monte Carlo iteration, the model then checks to see if all Monte Carlo iterations specified have been completed. If not, the model returns to the beginning of the Monte Carlo simulation and repeats the entire process. If all the Monte Carlo iterations have been completed, then the mean, standard deviation, and other statistics on each output variable are calculated. If desired, histograms can be constructed for after tax net present value (ATNPV) and reserves. The histograms illustrate the distribution of output for these two variables. The distribution of after tax net present value provides the range of potential outcomes and the frequency with which each outcome occurs.

In the above described model, economic rent is composed of royalty and profit share payments, tax payments, and the after tax net present value (ATNPV). These rent components can be manipulated to determine expected bidding behavior and associated impacts for various leasing policy alternatives. For example, in a bonus bidding system with a fixed royalty rate, the expected bonus bid is a function of after tax net present value.<sup>13</sup> The sum of the bonus bid, royalty income, and taxes is equal to total government revenue.

#### Policy options

A number of policy options are available for use with the generalized policy evaluation model. This section describes the major options and how they are utilized within the model.

The first set of options are called loop options in that each requires the model to be run iteratively to solve for the desired output variable. The first of these options is termed the delayed development (lag) loop and determines the optimum development time in situations where rising prices

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<sup>13</sup> Actual bonus bids are a result of bidding strategies formulated from game theoretic approaches combined with bidders estimates of lease values.

provide an incentive to delay development. The other three loop options involve determining the price, profit share, or royalty rate which would equate after tax net present value to zero. In addition to the loop options, a number of profit share, royalty, and variable rate options are available. Also, several advance royalty, depletion, and deferred bonus options may be used. These and other options are described below.

#### Delayed development loop

The delayed development loop option is most often used in conjunction with evaluation of advance royalty policy options. The effectiveness of advance royalty policies in deterring premature purchasing of leases can be evaluated by simulating lease development with expectations of rising prices and advance royalty policies in place. The development delay can be as long as eighteen years; hence, the model would be run iteratively with delays ranging from zero through the maximum delay to determine the year in which after tax net present value is highest--which is the year the lease would be developed. Lease delays can also be evaluated without utilizing the loop option by specifying a fixed length of delay before development of the lease begins.

#### Other loop options

The price loop is used to determine that price which is just sufficient to produce the resource at a specified rate of return (discount rate). This option can be utilized to determine the minimum price to produce given a set of cost inputs and expected production. One potential leasing policy which can be evaluated using this process is price bid leasing. In this approach, the government would lease resources to the private sector based on sealed bids of price to produce a specified amount of the resource. This option could be particularly useful in stimulating development of resources which have not been produced on a large scale in the past such as gas production from coal because price uncertainty may be a major factor inhibiting resource development.

The royalty and profit share loops determine the royalty or profit share rate at which after tax net present value is approximately equal to zero. These options can be used to determine the royalty or profit share bid for leasing systems in which the bid variable is the contingency rate. The profit share bid options can be used with any of the profit share systems which are included in the model.

#### Profit share options

Three different profit share systems have been included in the model. These are termed the taxable income profit share system, the annuity capital recovery profit share system, and the fixed capital recovery profit share system. In the taxable income profit share system, the profit share base is specified as taxable income as defined by the United States Internal Revenue Service. The other two profit share systems allow a return to capital to be subtracted from the taxable income base to calculate a revised profit share base. For the annuity capital recovery system, the initial investment plus interest during construction is converted to an annuity with a prespecified interest rate and length of recovery period. The value of this annuity is subtracted from the profit share base in each of the capital recovery years before a

government profit share is taken. For the fixed capital recovery system, the initial capital investment is multiplied by some prespecified factor and this capital recovery amount is subtracted from the taxable income base before any profit share is taken. In other words, the capital recovery amount is credited against taxable income in the early years of production until the capital recovery amount is exhausted. At that point, the full government profit share is taken until the lease is terminated.

#### Royalty options

Two different royalty options may be used. First, a fixed rate royalty system such as that currently being used by the United States may be specified. Second, a constrained royalty system such as that in use in India and Indonesia may be selected. This system is more commonly (and accurately) called a production sharing system. It allows cost to be recovered from a portion of the oil produced (which is termed cost oil) with the remainder of the oil (termed profit oil) divided between the government and the private contractor. When this option is specified, input variables needed to define the system are determined exogenously, including production sharing rates and cost recovery schedules.

#### Variable rate options

For both royalty and profit share systems, variable rates (rather than fixed rates) may be specified. In particular, a variable profit share rate may be specified with any of the three profit share systems. Variable royalty rates based on both production and value may be specified. In each case a minimum rate, maximum rate and rate adjustment factor are input. In addition the value of production, production level, or net income level for which the minimum rate applies is also input. The minimum rate applies to production or income levels up to the prespecified amount, and the rate is adjusted according to the adjustment factor up to the maximum rate for levels above this amount.

#### Advance royalty

Another royalty option which may be specified is advance royalty. Advance royalty may be calculated in one of three forms: (1) a specific advance royalty calculated using a rate per unit of resource produced, (2) a specific advance royalty calculated using the initial resource price and the advance royalty rate throughout the life of the lease, and (3) an ad valorem advance royalty using the resource price for each year of the lease. The advance royalty rate may be the same as or different from the basic royalty rate. The advance royalty option involves a complex set of sums of advance royalty payments and basic royalty payments which are checked against each other in the royalty calculation for each year of the lease. Advance royalty is payable only through the prespecified lease life. The production for advance royalty payments is calculated from the prespecified lease life and reserves found on the tract.

#### Depletion

Another policy option relates to the method used for depletion. Three options are allowed for depletion: (1) cost depletion, (2) revenue depletion,

and (3) the highest of cost or revenue depletion in each year. In addition, no depletion may be selected. Revenue depletion is currently not allowed for oil and natural gas for major producers but is allowed for coal and other resources. Cost depletion is calculated for the lease acquisition cost and the lease bonus. Revenue depletion is calculated as a percentage of gross revenue not to exceed 50 percent of net income in each year.

#### Deferred bonus

Another policy option allows for deferred payment of the bonus. This option changes the absolute value of the bonus because the payments are spread out into the future. For example, suppose the normal initial bonus is estimated to be \$1000. The absolute value of that bonus paid in five equal installments (one at the beginning of the lease and four annual installments) is \$1199.08 with five installments of \$239.82. This conversion of the bonus amount is made and adjustments are also provided in the depletion calculations to compensate for the deferred payment schedule. The length of the bonus deferral period is an input.

#### Other policy options

Another possible use of the model is to evaluate public and private sector revenues with different discount rates. The model may be run with the same rate used for all calculations or with one rate used for private sector calculation of after tax net present value and another rate used in calculating the present value of royalty, profit share, and taxes which are components of government revenue.

Another option which may be of interest is the price guarantee. With this option, the market price is simulated independently and if the price falls below a prespecified rate, the government guarantees the price at this prespecified rate. In other words, the government guarantees to purchase all production at the prespecified price or to subsidize production to achieve at least that price for all sales. Both the effects on development of resources and the cost to the government of this option can be calculated.

Similarly, an investment subsidy option is provided. With this option the government guarantees to pay a certain percentage of the investment cost. Again, both the effects on development and the cost to the public of this option can be calculated.

For all the policy options and for the normal tax policies not discussed above any rates desired may be specified. Additional policy options which involve changes in rates of existing or proposed policies can be evaluated. For example, the effects of changing the investment tax credit from 10 to 15 percent could be easily evaluated. Similarly, the effects of changing the royalty rate from .1667 to .3333 could be simulated.

In addition to the above options, a number of options for determining investment cost, operating cost, installed capacity and the form in which output and input variables are to be specified are provided. For example, operating costs may be calculated as a function of installed capacity, annual production, or the average of the two.

### Output options

With respect to outputs, histograms may be specified for after tax net present value and reserves. A number of print options are allowed with varying degrees of detail. Annual output values are printed with the results for the mean values case. The model may be run with or without Monte Carlo simulation.

### Internal rate of return

Instead of using an input discount rate to calculate present values, the internal rate of return (IRR) may be calculated. Internal rate of return is that interest rate which equates the stream of revenues and costs to zero as shown in equation (21):

$$(21) \quad 0 = \sum_{u=1}^T \frac{ATV_u}{(1+r)^{(u-.5)}}$$

where ATV is after tax value in year  $u$  and  $r$  is the internal rate of return.<sup>14</sup> For the mean values case, one IRR is calculated, and for the Monte Carlo simulation, the distribution of IRR is determined and a histogram produced.

### Annual value distributions

Another output option which may be selected is annual distributions of gross revenue, taxable income, taxes, royalty, profit (or production) share, and production. For this option, the annual outputs for the optimal installed capacity are saved for each Monte Carlo iteration. After the simulation is completed, distributions of the above output variables are obtained for each year of development and production.

### Model summary

Clearly a wide range of leasing policy options including bonus bidding systems, royalty systems, profit share systems, the Indian production sharing system and a number of combinations of these systems and their many variants may be analyzed with the generalized leasing model. In addition to the wide range of leasing policy options, a number of other policy options such as tax policies, price subsidies, purchase guarantees, price supports, investment subsidies and other policy options designed to increase certainty for private investors are included in the model. Furthermore, other tax policy, general policy, or leasing policy options can easily be incorporated in the model framework.<sup>15</sup> Hence, the model is ideally suited for analysis of a wide range

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<sup>14</sup> For some ATV streams, more than one interest rate may solve equation (21). The model selects the first solution as the IRR. For a more complete discussion of the internal rate of return see Mishan, pp. 215-57.

<sup>15</sup> Since the model is well structured with numerous subroutines, additional policy options beyond those described above can be added.



of government alternatives dealing with the disposition of publicly owned natural resources.

Outputs of the basic model include statistics on the following variables: production time horizon, installed capacity, present value of royalty payments, present value of depletion, present value of taxes and taxable income, present value of profit share or production share payments, production, reserves, present value of investment and operating cost, after tax net present value, and the present value of gross revenue. Additional outputs are provided for specialized leasing or other policy options such as the royalty bidding system.

The use of Monte Carlo simulation with uncertain variables provides an additional dimension to government policy analysis. Not only can the change in expected value of model outputs be determined when a policy variable is changed, but also the change in variance of the model outputs can be determined. The simulation process more closely approximates the decision making procedure used in the private sector when evaluating potential resource investments.

## APPENDIX

This appendix contains operating instructions for the Generalized Resource Policy Evaluation Model. It is designed to provide the basic information needed to successfully utilize the model for resource policy analysis.

The computer program was developed at Cornell University on an IBM 370 series computer. It is written in Fortran and employs the EBCDIC key punch mode. The program may be compiled on both Fortran G and H compilers. The basic program runs with about 100K of core when compiled in Fortran H and 110K when compiled in Fortran G. In addition to using less core, the Fortran H compile runs more efficiently.

### Control variables

The control variables determine the options which are used in analyzing the data and calculating and printing the results. Although the definitions of the control variables are provided in the program input sequence (see below), it may be helpful to review the meanings of some of them in more detail. The first card contains the number of cases to be evaluated--up to 99 cases per run are allowed. A complete set of data cards including the control card must be included for each case.

### Print options

The first control variable determines what output will be printed. When Monte Carlo simulation is not being used, this variable is automatically set at four, the highest (most extensive) print level. Of course, no output distribution statistics are calculated in this case; the detailed output for the mean values case is printed. The print option may also be set at four with Monte Carlo simulation if detailed results are desired for each iteration. However, if a high number of iterations are specified, this option involves a large amount of printing. The next level of printing (three) omits the results of each Monte Carlo iteration, but prints all output statistics for each output variable. Level two of printing produces the mean and standard deviation only of all output variables, and level one produces the mean and standard deviation of ATNPV only. Details of the output which is printed under each of these options is provided below.

### Internal rate of return

IDISC, the discount control variable may be used to specify the internal rate of return calculation. When internal rate of return is calculated, a discount rate must still be provided for the installed capacity ( $Q_0$ ) optimization procedures. In other words, the optimal installed capacity is determined using the input discount rate ( $R$ ), and the undiscounted stream of values for after tax value are fed into the internal rate of return calculation. If desired, this process could be repeated with the internal rate of return from the first trial used as

a discount rate to determine if any significant difference results in the optimization procedure.

#### Annual output statistics

The IVEC control variable when set equal to one stores annual outputs for each iteration and calculates statistics on output variables for each year of the lease. Because this procedure requires a large amount of core, two versions of the GEN2 model are used. The basic version contains a dummy subroutine for the vector statistics and can be used only when IVEC equals zero. GEN2 Extended contains the complete IVEC subroutine and should be used only when IVEC equals one to minimize cost. The extended version may be used for both values, however, if computer cost is not a concern.

#### Deferred investment with production change

The INVC equal two option for deferred investment is inoperative in this model version. It has been provided for future changes which will allow deferred investment to change the rate of resource recovery and level of operating cost.

#### Number of iterations

The GEN2 model allows a maximum of two hundred Monte Carlo iterations. These iterations determine the value of a lease given that resources are found. The number of effective iterations is  $NL\phi\phi / (1 - DTRSK)$ . If DTRSK equals zero, the number of iterations is  $NL\phi\phi$ . If DTRSK equals .5, the effective number of iterations is  $2 * NL\phi\phi$ . If a greater number of iterations are desired, the STAT common areas and the dimension statements for R, A, and LQ in SETAR, STATIC, and STDMN subroutines would have to be changed to increase the vector sizes.

#### Potential problem areas

As with any complex computer program, there are a number of possible problems that may be encountered by program users. Three such potential problem areas are untested options, illegal variable values or combinations, and the random number generators.

#### Untested options

First of all, it should be stressed that, as of this writing, all possible options have not been thoroughly tested. The most commonly used options such as the royalty and profit share system options have been tested, but others such as the royalty and profit share bid (loop) options have not been thoroughly evaluated.

#### Illegal variable values

Also, there may be variable values or combinations of values that will cause the program not to work. Some of these values have been determined and corrections included in the program. For example, the

program will not accept a discount rate of minus one. The program changes any minus one input for discount rate to zero. Similarly, if depreciation is specified ( $NDEPR > 0$ ), the depreciation lifetime must be greater than zero. If depreciation lifetime is input as zero, the model sets depreciation method ( $NDEPR$ ) to zero also.

The input variables for chance of no resource being present should be set carefully. This variable represents a probability so it must take a value between zero and one. Hence, the mean of the chance of no resources distribution must have a value between zero and one. The standard deviation should be calculated directly from the parameters of the assumed input distribution. For example, the mean and standard deviation of an assumed triangular distribution should be calculated from the distribution parameters (min, mode, and max values). If the triangular distribution has a min of 0, mode of .1 and max of .5, the mean is .2 and the standard deviation is .11. The triangular distribution is often chosen because it is easily bounded. Other distributions (especially those for which the variable can take on negative values) could be more of a problem. For example, if the normal distribution were used, the standard deviation should be small enough that the mean plus or minus three times the standard deviation falls within the range zero to one. For example, if the mean is .5, the standard deviation should be no larger than .16. For any distribution chosen, the input values should provide a high probability that any value selected from the distribution would fall within the range zero to one. Otherwise, the distribution is conceptually inappropriate.

#### Random number generators

Another problem that could arise on non-IBM systems is in the random number generators. Significant differences can result when the random number generators used in this program ( $RANDK$  and  $RANNM$ ) are installed on non-IBM systems. If this problem arises, users should substitute their own generators for those contained in the program. The alternate generators should be thoroughly tested. Also, the random number generators produced biased distributions when used with some seeds. Seeds which have produced good results in the past are contained in the program input sequence.

#### Inputs

The inputs consist of a case card (number of cases), control card, plus eight or nine data cards depending on the options being used. Variables are arranged by general topic. The first data card is the case description which is printed at the top of the output heading. Card 2 contains price variables, and card 3 contains geologic inputs. Tax and economic variables are contained on card 4. Card 5 contains the seeds for random number generation. Cost data is included on card 6, and policy variables on card 7. Card 7a contains input parameters for the Indian system and is used in place of card 7 when this system is being analyzed ( $MRQYL=2$ ). Card 8 contains the data for each installed capacity ( $Q_0$ ), and card 8a contains data on deferred investment (used only when that option is selected). If installed capacity is determined endogenously,

only one  $Q_0$  set is used (card 8 plus 8a if deferred investment is used). If installed capacity is input, a  $Q_0$  set must be provided for each capacity (up to 10).

For all data and control variables, a blank is read as a zero. Therefore, variables which are not used need not be punched. For example, when only one price change distribution is used, columns 56-80 of card 2 may be left blank.

### Outputs

As described above, four different print levels may be specified. Three of these pertain to the amount of simulation output statistics which are calculated and printed, and the fourth specifies printing results of each M.C. iteration. This section describes the print for each iteration and the highest level of print for simulation statistics.

#### Heading

The heading contains input variables for each case. The case title is printed first followed by the resource name. Control options and policy options in use for the case are printed next. Input variables are printed in the same groupings that were used for card inputs. If the Indian system is used, input data for this system is printed next. Finally, the input data for each installed capacity is printed including deferred investment input variable if that option is exercised.

#### Iteration print

The first item printed for each iteration is the iteration number (or mean run heading). Next, initial year prices for the primary and secondary resource (if SP% is greater than zero) are printed. The remainder of the iteration print is repeated for each installed capacity (whether input or determined endogenously).

The actual print differs for the Indian system and other systems. In both cases, a series of annual values are printed followed by a summary of present value results. For the Indian system the following annual outputs are printed: gross revenue, cost oil, profit oil, foreign tax, government share, private share, income tax, and after tax value. For other systems, the following annual outputs are printed: gross revenue, depletion, depreciation, state severance and income tax, royalty or profit share payments, net revenue (taxable income), federal tax, and after tax value.

The same summary results are printed for all systems as follows:

RC = investment cost per unit  
 RK1 = operating cost per unit  
 TAXW = amount of the potential tax write-off if the lease is not developed  
 EXX = exploration expenses (PV)  
 RIVTC = investment tax credit

RNTLS = rent payments during exploration (PV)  
 XLØSS = exploration loss (PV)  
 RCAP = reserves found  
 NYMAX = maximum economic lifetime  
 A = production decline rate  
 YEAR = lease life for this installed capacity (lag plus production period)  
 Q = installed capacity  
 RNPVLM = royalty payments (PV)  
 PFSRAT = profit share rate (for variable profit share systems, the rate in the last year)  
 PVDEP = depletion (PV)  
 TAXINC = taxable income (PV)  
 TØTAX = total state and federal tax payments (PV)  
 ATNPV = after tax net present value  
 PRØD = total production  
 TRANIV = investment cost (PV)  
 TCØST = total investment plus operating cost (PV)  
 TDEPPD = total depreciation (PV)  
 SALVG = salvage value  
 PRFSHR = profit share payments (PV)  
 ØPCØ = total operating cost (PV)  
 ØPC = operating cost in the last year of production  
 VALUE = gross revenue (PV)  
 IT = production time for input installed capacity  
 FCAP = annuity value for the annuity capital recovery profit share system

#### Simulation output

Output distribution statistics are calculated for total expected value and for value given that resources are found. For total expected value, the mean, standard deviation, and standard error of the mean are calculated and printed (if desired). For value given that resources are found, these statistics plus the coefficient of skewness and coefficient of kurtosis may be calculated. Total expected value is calculated for after tax net present value (ATNPV), taxes (PV), royalty (PV), depletion (PV), profit or production share (PV), reserves, and gross value (PV). Value if resources are found for these variables includes both cases in which the resource is developed and situations in which resources are found but no development occurs (for economic reasons).

Statistics are also calculated on a number of output variables for the cases (iterations) in which development occurs. Development statistics are calculated on reserves, production, installed capacity ( $Q_0$ ), investment cost per unit of installed capacity ( $B$ ), operating cost per unit ( $K_1$ ), production time horizon ( $T$ ), production of the second resource (such as associated gas), and the present value of operating cost, investment cost, and taxable income. If no development occurs, these statistics are deleted.

Following the above output statistics, the exploration loss is printed. ATNPV and reserve histograms are the last output.

### Conclusion

With these operating instructions, users of the generalized resource policy model should encounter little difficulty. However, the model is not simple; users should thoroughly review the model description before attempting to utilize it. The authors are available for consultation should any problem arise.

The table that follows provides the program input sequence for the generalized resource policy model. It contains the card spaces, format, variable name, and brief definition for each variable used in the program.

Generalized Resource Policy Model--Program  
Input Sequence  
(version GEN2)

| <u>Card<br/>Spaces</u> | <u>Format</u> | <u>Variable<br/>Name</u> | <u>Data Element</u>                                                                                                                                                                                       |
|------------------------|---------------|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case card:             |               |                          |                                                                                                                                                                                                           |
| 1-2                    | I2            | NCASE                    | Number of cases                                                                                                                                                                                           |
| Control card:          |               |                          |                                                                                                                                                                                                           |
| 1-2                    | I2            | NPRINT                   | Print and statistics options--<br>1=ATNPV mean and S.D. only<br>2=mean and S.D. of all output<br>3=all statistics on all output<br>4=all statistics on all output plus<br>results for each M.C. iteration |
| 3-4                    | I2            | LP/VER                   | Royalty, price, profit share, or lag<br>loop options--<br>0=no loops<br>1=l原因 loop<br>2=price bid loop<br>3=royalty bid loop<br>4=profit share bid loop                                                   |
| 5-6                    | I2            | NRRES                    | Resource code--<br>1=offshore oil<br>2=offshore natural gas<br>3=oil shale<br>4=coal<br>5=uranium<br>6=geothermal<br>7=onshore oil<br>8=onshore gas                                                       |
| 7-8                    | I2            | NHIST                    | Histogram options--<br>0=none<br>1=ATNPV distribution only<br>2=ATNPV and reserve distributions<br>3=cumulative and the standard ATNPV<br>4=cumulative and standard for ATNPV and<br>reserves             |
| 9-10                   | I2            | NPMETH                   | Price generation method--<br>0=mean price change used<br>1=random selection of annual price change                                                                                                        |



| <u>Card<br/>Spaces</u> | <u>Format</u> | <u>Variable<br/>Name</u> | <u>Data Element</u>                                                                                                                                                                                                                                                |
|------------------------|---------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 11-12                  | I2            | NCM                      | Investment cost (contingency) method--<br>0=mean of contingency distribution<br>1=random selection<br>2=most likely investment cost (mode)<br>3=base investment cost (contingency=0)                                                                               |
| 13-14                  | I2            | NKM                      | Operating cost contingency method--<br>same as for NCM                                                                                                                                                                                                             |
| 15-16                  | I2            | KRS                      | Reserve distribution--<br>0=lognormal<br>1=normal                                                                                                                                                                                                                  |
| 17-18                  | I2            | NOØ                      | No. of installed capacities to be evaluated--<br>0=variable installed capacity ( $Q_0$ )<br>1-10=no. of $Q_0$ cards                                                                                                                                                |
| 19-20                  | I2            | MDEPL                    | Depletion method--<br>0=no depletion<br>1=cost depletion<br>2=revenue depletion<br>3=select best depletion method each year                                                                                                                                        |
| 21-22                  | I2            | MRØYL                    | Royalty method--<br>0=no royalty<br>1=basic royalty<br>2=Indian-Indonesian type constrained<br>royalty                                                                                                                                                             |
| 23-24                  | I2            | KPFS                     | Profit share method--<br>0=no profit share<br>1=IRS profit share<br>2=annuity capital recovery profit share<br>3=fixed capital recovery profit share                                                                                                               |
| 25-26                  | I2            | KVAR                     | Variable rate control--<br>0=no variable royalty or profit share<br>1=variable profit share<br>2=variable royalty-production<br>3=variable royalty-value                                                                                                           |
| 27-28                  | I2            | MADROY                   | Advance royalty method--<br>0=no advance royalty<br>1=specific advance royalty calculated<br>using CNT<br>2=specific advance royalty calculated<br>using the <u>initial</u> resource price and<br>the advance royalty rate<br>3= <u>ad valorem</u> advance royalty |

| <u>Card Spaces</u> | <u>Format</u> | <u>Variable Name</u> | <u>Data Element</u>                                                                                                                                                      |
|--------------------|---------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 29-30              | I2            | MB/M                 | Bonus method--<br>0=normal bonus calculations<br>other=deferred bonus years                                                                                              |
| 31-32              | I2            | KCRL                 | Operating cost control<br>0=cost times $Q_0$<br>1=cost times $PROD$<br>2=cost times $(Q_0 + PROD)/2$                                                                     |
| 33-34              | I2            | INVC                 | Investment cost control--<br>0=inoperative<br>1=deferred investment<br>2=deferred investment with change in<br>operating cost and production rate<br>(enhanced recovery) |
| 35-36              | I2            | IDISC                | Discount control variable--<br>0=one private discount rate used<br>1=private and public rates used<br>2=IRR calculated                                                   |
| 37-38              | I2            | IVEC                 | Vector storage control--<br>0=no output vectors<br>1=annual output vectors                                                                                               |
| 39-42              | I4            | NL/P                 | Number of Monte Carlo iterations                                                                                                                                         |
| 43-46              | I4            | MCR                  | Number of M.C. iterations used for further<br>bonus approximation if desired (if MCR=0,<br>bonus after mean run is used)                                                 |

Data cards:

Card 1 - title card

|     |      |      |                                           |
|-----|------|------|-------------------------------------------|
| 1-8 | 20A4 | TITL | Case description (blank card may be used) |
|-----|------|------|-------------------------------------------|

Card 2 - price card

|       |      |        |                                                         |
|-------|------|--------|---------------------------------------------------------|
| 1-5   | F5.2 | PPO    | Initial primary resource price                          |
| 6-10  | F5.2 | SPO    | Initial secondary resource price                        |
| 11-12 | F2.2 | PlM(1) | Primary resource-price change mean                      |
| 13-14 | F2.2 | PSD(1) | Primary resource-price change std. dev.                 |
| 15-16 | F2.2 | SlM(1) | Secondary resource-price change mean                    |
| 17-18 | F2.2 | SSD(1) | Secondary resource-price change std. dev.               |
| 19    | I1   | NPP    | Number of primary resource price change distributions   |
| 20    | I1   | NPS    | Number of secondary resource price change distributions |
| 21-22 | I2   | NP(1)  | End of period for 1st PlM distribution                  |
| 23-24 | I2   | NP(2)  | End of period for 2nd PlM distribution                  |

| <u>Card<br/>Spaces</u> | <u>Format</u> | <u>Variable<br/>Name</u> | <u>Data Element</u>                                                 |
|------------------------|---------------|--------------------------|---------------------------------------------------------------------|
| 25-26                  | I2            | NP(3)                    | End of period for 3rd P1M distribution                              |
| 27-28                  | I2            | NP(4)                    | End of period for 4th P1M distribution                              |
| 29-30                  | I2            | NS(1)                    | End of period for 1st S1M distribution                              |
| 31-32                  | I2            | NS(2)                    | End of period for 2nd S1M distribution                              |
| 33-34                  | I2            | NS(3)                    | End of period for 3rd S1M distribution                              |
| 35-36                  | I2            | NS(4)                    | End of period for 4th S1M distribution                              |
| 37-38                  | I2            | LPMIN                    | Length of time primary resource minimum<br>price is valid           |
| 39-40                  | I2            | LSMIN                    | Length of time secondary resource minimum<br>price is valid         |
| 41-45                  | F5.2          | PMIN                     | Minimum price for primary resource                                  |
| 46-50                  | F5.2          | SMIN                     | Minimum price for secondary resource                                |
| 51-55                  | F5.2          | PSUB                     | Price subsidy for primary resource                                  |
| 56-57                  | F2.2          | P1M(2)                   | Mean of second primary resource price change<br>distribution        |
| 58-59                  | F2.2          | PSD(2)                   | Std. dev. of second primary resource price<br>change distribution   |
| 60-61                  | F2.2          | P1M(3)                   | Mean of third primary resource price change<br>distribution         |
| 62-63                  | F2.2          | PSD(3)                   | Std. dev. of third primary resource price<br>change distribution    |
| 64-65                  | F2.2          | P1M(4)                   | Mean of fourth primary resource price change<br>distribution        |
| 66-67                  | F2.2          | PSD(4)                   | Std. dev. of fourth primary resource price<br>change distribution   |
| 68-69                  | F2.2          | S1M(2)                   | Mean of second secondary resource price change<br>distribution      |
| 70-71                  | F2.2          | SSD(2)                   | Std. dev. of second secondary resource price<br>change distribution |
| 72-73                  | F2.2          | S1M(3)                   | Mean of third secondary resource price change<br>distribution       |
| 74-75                  | F2.2          | SSD(3)                   | Std. dev. of third secondary resource price<br>change distribution  |
| 76-77                  | F2.2          | S1M(4)                   | Mean of fourth secondary resource price change<br>distribution      |
| 78-79                  | F2.2          | SSD(4)                   | Std. dev. of fourth secondary resource price<br>change distribution |

Card 3 - geologic

|       |       |        |                                          |
|-------|-------|--------|------------------------------------------|
| 1-2   | F2.2  | A      | Production decline rate                  |
| 3-6   | F4.2  | BETA   | Geologic parameter (oil only)            |
| 7-10  | F4.3  | AGFAC  | Associated gas factor                    |
| 11-20 | E10.2 | RMEAN  | Mean of reserve distribution             |
| 21-30 | E10.2 | RSTD   | Std. dev. of reserve distribution        |
| 31-32 | I2    | IFLATP | Length of flat production period         |
| 33-34 | I2    | ITMIN  | Minimum production period                |
| 35-36 | I2    | ITMAX  | Maximum production period                |
| 37    | I1    | LEXLOR | Exploration time period                  |
| 38-40 | F3.3  | DTRSK  | Mean chance of no resource being present |

| Card Spaces | Format | Variable Name | Data Element                            |
|-------------|--------|---------------|-----------------------------------------|
| 41-43       | F3.3   | DTSD          | Std. dev. for no resources distribution |
| 44-53       | E10.2  | ACRES         | Number of acres in lease area           |
| 54-57       | F4.3   | WELLS         | Number of exploratory wells/1000 acres  |
| 58-60       | F3.0   | COHT          | Height of coal (coal seam thickness)    |
| 61-63       | F3.0   | OBHT          | Height of overburden                    |
| 64-68       | F5.0   | BTU           | BTU content (BTU/pound)                 |
| 69-70       | F2.1   | SULF          | Sulfur content (%)                      |
| 71-73       | F3.1   | H2O           | Water content (%)                       |
| 74-76       | F3.1   | ASH           | Ash content (%)                         |

Card 4 - tax and economic related

|       |       |        |                                                                                   |
|-------|-------|--------|-----------------------------------------------------------------------------------|
| 1-2   | I2    | N      | Depreciation lifetime                                                             |
| 3     | I1    | NDEPR  | Depreciation method--                                                             |
|       |       |        | 0=no depreciation                                                                 |
|       |       |        | 1=sum of year's digits (SYD)                                                      |
|       |       |        | 2=double declining balance with switch over to straight line (DDB)                |
|       |       |        | 3=straight line (SL)                                                              |
|       |       |        | 4=depreciation based on the rate of resource depletion (annual prod./total prod.) |
|       |       |        | 5=SYD with N=production lifetime                                                  |
|       |       |        | 6=DDR with N=production lifetime                                                  |
|       |       |        | 7=SL with N=production lifetime                                                   |
| 4-6   | F3.2  | SLVGPC | % investment salvagable                                                           |
| 7-9   | F3.2  | MEGA   | Investment tax credit rate                                                        |
| 10-12 | F3.2  | R      | Discount rate                                                                     |
| 13-15 | F3.2  | Z      | Depletion rate for gross depletion                                                |
| 16-18 | F3.2  | PHI    | U.S. tax rate                                                                     |
| 19-21 | F3.2  | TAXF   | Foreign tax rate                                                                  |
| 22-24 | F3.2  | STR    | Severance tax rate                                                                |
| 25-27 | F3.2  | STAXR  | State tax rate                                                                    |
| 28-30 | F3.2  | RR     | Public sector discount rate                                                       |
| 31-34 | F4.2  | BFAC   | Bonus factor for ATNPV                                                            |
| 35-44 | E10.2 | BONUS  | Initial bonus                                                                     |
| 45-54 | E10.2 | BCON   | Bonus calculation constant                                                        |

Card 5 - seeds

|       |    |        |                                                                   |
|-------|----|--------|-------------------------------------------------------------------|
| 1-5   | I5 | NPSEED | Seed for primary resource price change generation such as 15849   |
| 6-10  | I5 | NSSEED | Seed for secondary resource price change generation such as 34579 |
| 11-15 | I5 | NCSEED | Investment cost seed such as 41687                                |
| 16-20 | I5 | NKSEED | Operating cost seed such as 27341                                 |
| 21-25 | I5 | NRSEED | Seed for reserve value generation such as 21851                   |

| <u>Card Spaces</u>           | <u>Format</u> | <u>Variable Name</u> | <u>Data Element</u>                                                                                               |
|------------------------------|---------------|----------------------|-------------------------------------------------------------------------------------------------------------------|
| <u>Card 6 - cost related</u> |               |                      |                                                                                                                   |
| 1-3                          | F3.2          | CMIN                 | Minimum value for investment cost contingency distribution                                                        |
| 4-6                          | F3.2          | CMAx                 | Maximum value for investment cost contingency distribution                                                        |
| 7-9                          | F3.2          | CMQDE                | Most likely value for investment cost contingency distribution                                                    |
| 10-12                        | F3.2          | KMIN                 | Minimum value for operating cost contingency distribution                                                         |
| 13-15                        | F3.2          | KMAx                 | Maximum value for operating cost contingency distribution                                                         |
| 16-18                        | F3.2          | KMQDE                | Most likely value for operating cost contingency distribution                                                     |
| 19-21                        | F3.2          | THETA                | Rate of change in operating cost                                                                                  |
| 22-24                        | F3.2          | WCF                  | Working capital factor--multiplied by first year's operating cost to determine working capital value              |
| 25-27                        | F3.2          | SUBINV               | Investment subsidy--% of investment is subtracted from investment                                                 |
| 28-30                        | F3.2          | BYPRCD               | By-product credit--value of production of additional resources is credited as a percent of primary resource price |
| 31-40                        | E10.2         | EXPWLL               | Cost per exploratory well                                                                                         |
| 41-45                        | F5.2          | RENT                 | Annual rent per acre                                                                                              |
| 46-48                        | F3.2          | FX(1)                | Proportion of exploration expense occurring each year                                                             |
| 49-50                        | F2.2          | FX(2)                | Proportion of exploration expense occurring each year                                                             |
| 51-52                        | F2.2          | FX(3)                | Proportion of exploration expense occurring each year                                                             |
| 53-55                        | F3.2          | TX(1)                | Proportion of exploration expense occurring each year which is tangible                                           |
| 56-58                        | F3.2          | TX(2)                | Proportion of exploration expense occurring each year which is tangible                                           |
| 59-61                        | F3.2          | TX(3)                | Proportion of exploration expense occurring each year which is tangible                                           |
| 62                           | I1            | LCLM                 | Investment cost control variable (climatic region for OCS costs)                                                  |
| 63-70                        | F8.0          | AQCST                | Lease acquisition cost (excluding the bonus)                                                                      |

Card 7 - policy (not used if card 7a is used)

|       |      |        |                                                                                              |
|-------|------|--------|----------------------------------------------------------------------------------------------|
| 1-4   | F4.4 | RQYRT  | Royalty rate (or minimum royalty rate for variable royalty)                                  |
| 5-10  | F6.6 | RQYFAC | Factor used to change royalty rate with annual production or value levels (variable royalty) |
| 11-12 | F2.2 | RRTMAX | Maximum royalty rate (variable royalty)                                                      |

| <u>Card Spaces</u> | <u>Format</u> | <u>Variable Name</u> | <u>Data Element</u>                                                                                 |
|--------------------|---------------|----------------------|-----------------------------------------------------------------------------------------------------|
| 13-22              | E10.2         | PR/DF                | Production (or value) allowable for minimum royalty rate (variable royalty)                         |
| 23-24              | F2.2          | PFSHRT               | Profit share rate (or minimum profit share rate for variable profit share)                          |
| 25-26              | F2.2          | PRTMAX               | Maximum profit share rate (variable profit share)                                                   |
| 27-36              | E10.2         | PRTFAC               | Factor used to change profit share rate with the level of net annual income (variable profit share) |
| 37-46              | E10.2         | PSBASE               | Allowable net income level for the minimum profit share rate (variable profit share)                |
| 47-48              | F2.2          | RI                   | Interest rate used for annuity capital recovery                                                     |
| 49-51              | F3.2          | BPF                  | Capital recovery factor used when a British type profit share system is employed                    |
| 52                 | I1            | NCAP                 | Capital recovery payback period used with annuity capital recovery                                  |
| 53                 | I1            | LAGR                 | Allowable development period (used for advance royalty)                                             |
| 54-55              | I2            | LAGD                 | Maximum development delay                                                                           |
| 56-57              | I2            | LLIFE                | Lease life--used to calculate required production level for advance royalty                         |
| 58-60              | F3.2          | FR                   | Fraction of total reserves used in calculating production requirement for advance royalty           |
| 61-63              | F3.2          | CNT                  | Rate for specific advance royalty (\$/ton)                                                          |
| 64-66              | F3.2          | ALAMB                | Advance royalty rate                                                                                |
| 67-69              | F3.2          | CHALMB               | Change in advance royalty rate for each year production is delayed (LAGR+1)                         |

Card 70 - Indian-Indonesian system (card is used only when MRØYL equals 2)

|       |      |        |                                                                          |
|-------|------|--------|--------------------------------------------------------------------------|
| 1     | I1   | NYCT   | Minimum time for cost recovery (years)                                   |
| 2-4   | F3.2 | CSTFAC | Maximum proportion of cost which may be recovered each year              |
| 5-7   | F3.2 | DØMRQ  | Domestic requirement of profit oil                                       |
| 8-10  | F3.3 | PI(1)  | Profit share rates (for private contractor) for each level of production |
| 11-13 | F3.3 | PI(2)  | Profit share rates (for private contractor) for each level of production |
| 14-16 | F3.3 | PI(3)  | Profit share rates (for private contractor) for each level of production |
| 17-19 | F3.3 | PI(4)  | Profit share rates (for private contractor) for each level of production |
| 20-22 | F3.3 | PI(5)  | Profit share rates (for private contractor) for each level of production |
| 23-25 | F3.3 | PI(6)  | Profit share rates (for private contractor) for each level of production |
| 26-31 | F6.0 | PIL(2) | Production level for each rate step                                      |
| 32-37 | F6.0 | PIL(3) | Production level for each rate step                                      |

| <u>Card Spaces</u> | <u>Format</u> | <u>Variable Name</u> | <u>Data Element</u>                 |
|--------------------|---------------|----------------------|-------------------------------------|
| 38-43              | F6.0          | PIL(4)               | Production level for each rate step |
| 44-49              | F6.0          | PIL(5)               | Production level for each rate step |
| 50-55              | F6.0          | PIL(6)               | Production level for each rate step |

Card 8 -  $Q_0$  card (repeated for each input  $Q_0$ ; if  $NQ_0=0$ , one card only)

|       |       |      |                                                                           |
|-------|-------|------|---------------------------------------------------------------------------|
| 1-10  | E10.2 | Q    | Installed capacity                                                        |
| 11-16 | F6.2  | C    | Cost per unit of installed capacity                                       |
| 17-21 | F5.3  | K    | Initial operating cost                                                    |
| 22-23 | I2    | LDEV | Length of the development period                                          |
| 24-26 | F3.2  | FD   | Fraction of development cost incurred each year                           |
| 27-28 | F2.2  | FD   | Fraction of development cost incurred each year                           |
| 29-30 | F2.2  | FD   | Fraction of development cost incurred each year                           |
| 31-32 | F2.2  | FD   | Fraction of development cost incurred each year                           |
| 33-34 | F2.2  | FD   | Fraction of development cost incurred each year                           |
| 35-36 | F2.2  | FD   | Fraction of development cost incurred each year                           |
| 37-38 | F2.2  | FD   | Fraction of development cost incurred each year                           |
| 39-40 | F2.2  | FD   | Fraction of development cost incurred each year                           |
| 41-43 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 44-46 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 47-49 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 50-52 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 53-55 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 56-58 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 59-61 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 62-64 | F3.2  | TD   | Fraction of development cost each year which is tangible                  |
| 65    | I1    | LBP  | Length of production build-up period                                      |
| 66-67 | F2.2  | BP   | Fraction of initial (peak) production during each year of build-up period |
| 68-69 | F2.2  | BP   | Fraction of initial (peak) production during each year of build-up period |
| 70-71 | F2.2  | BP   | Fraction of initial (peak) production during each year of build-up period |
| 72-73 | F2.2  | BP   | Fraction of initial (peak) production during each year of build-up period |

| <u>Card</u><br><u>Spaces</u>                          | <u>Format</u> | <u>Variable</u><br><u>Name</u> | <u>Data Element</u>                |
|-------------------------------------------------------|---------------|--------------------------------|------------------------------------|
| Card 8a - deferred investment (used only when INVC=1) |               |                                |                                    |
| 1-2                                                   | I2            | NL(1)                          | Physical life-category 1           |
| 3-4                                                   | F2.0          | ND(1)                          | Depreciation life-category 1       |
| 5-14                                                  | E10.2         | DB(1)                          | Amount of deferred inv.-category 1 |
| 15-16                                                 | F2.2          | SV(1)                          | Salvage value(%)-category 1        |
| 17-18                                                 | I2            | NL(2)                          | same as above-category 2           |
| 19-20                                                 | F2.0          | ND(2)                          |                                    |
| 21-30                                                 | E10.2         | DB(2)                          |                                    |
| 31-32                                                 | F2.2          | SV(2)                          |                                    |
| 33-34                                                 | I2            | NL(3)                          | same as above-category 3           |
| 35-36                                                 | F2.0          | ND(3)                          |                                    |
| 37-46                                                 | E10.2         | DB(3)                          |                                    |
| 47-48                                                 | F2.2          | SV(3)                          |                                    |